AMERICAN AVALANCHE ASSOCIATION

SNOW, WEATHER, AND AVALANCHES:

Observation Guidelines for Avalanche Programs in the United States

SNOW, WEATHER, AND AVALANCHES:
Observation Guidelines for Avalanche Programs in the United States
3rd Edition

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PREFACE

It has now been 12 years since the American Avalanche Association, in cooperation with the USDA Forest Service National Avalanche Center, published the inaugural edition of *Snow, Weather and Avalanches: Observational Guidelines for Avalanche Programs* in the United States. As those of us involved in that first edition grow greyer and more wrinkled, a whole new generation of avalanche professionals is growing up not ever realizing that there was a time when no such guidelines existed. Of course, back then the group was smaller and the reference of the day was the 1978 edition of Perla and Martinelli's *Avalanche Handbook*.

Upon their initial release, these guidelines — more commonly known as SWAG — gained immediate acceptance by the U.S. avalanche community, as well as by avalanche workers in many other countries. SWAG is now integrated into operations, handed out in avalanche classes, and can be found in most patrol rooms and on most forecaster's desks around the country. The development and use of this document has helped develop our professional industry over the past decade.

Like past editions, this version of SWAG aims to capture the techniques and tools currently being used by U.S. avalanche programs. Since these tools are constantly evolving and being updated, so too must this document. Originally, we aimed to update SWAG every 5 to 10 years. Our first update came after five years, with a few minor updates added a year later. This update follows six years later. These updates demonstrate the dynamic nature of our profession and emphasizes the importance of continuing education. From this edition gone is the venerable Stuffblock Test, which now sees limited use. We made changes to the pencil hardness standard and also to the recording standards for the ECT and PST tests. There are other odds and ends that have been updated or edited throughout the document. In the future, we look forward to developing an electronic version of SWAG that will facilitate timely updates.

SWAG's goals remain the same: to be a professional reference that establishes common methods. Clearly, this benefits everyone by making communication between operations easier and by facilitating the development of good long term datasets. Throughout the editions we aimed to maintain the tone of the original SWAG. As the late Ed LaChapelle pointed out nearly thirty years ago, there is no one correct path to an accurate avalanche forecast. Similarly, there is not one set of tools or one set methodology that must be used for avalanche operations. This document recognizes the unique nature of many avalanche programs and their special needs and strives to provide the flexibility necessary for them to operate effectively while still providing a common language for all of us. Finally, this edition – like the first edition – is not meant to inhibit creativity or innovation. We encourage experimentation and the development of new tests and methods by practitioners. In this document you will find that many developments in our field have come out of M.S. and Ph.D. theses, while others started with discussions in a ski patrol shack.

SWAG is meant to be a valuable and useful reference for your avalanche work. Ron Perla provided extensive comments on the first edition of SWAG, and when he received his copy he wrote to us that "I believe it's much more than just 'Guidelines for Observations'. It's a valuable reference for a wide variety of avalanche studies. I'll keep it close to my desk together with my very limited collection of references which I expect to consult often." We hope that this edition and future editions continue to merit such high praise.

Karl Birkeland

USDA Forest Service National Avalanche Center

Bozeman, Montana

August, 2016

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Sections marked with ❄ describe parameters included in a standard observation.

Sections marked with ❄ describe parameters included in a standard observation.

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ACKNOWLEDGMENTS

This document is a collection of protocols and common practices developed during more than 60 years of avalanche work in the United States. Common practice in the United States, in turn, developed through fruitful collaborations with scientists and practitioners in Canada, Europe, Scandinavia, Asia, and other parts of the world. Although the people that contributed to what is now common practice are too numerous to mention here, their contribution to our field and the methods described within this document is significant.

The first version of this document started with a publication of the Canadian Avalanche Association (CAA) entitled *Observational Guidelines and Recording Standards for Weather, Snowpack, and Avalanches (OGRS*). The CAA has devoted a tremendous amount of time and money towards creating and maintaining that document, which has become a symbol of professional practice in North America. The CAA periodically revises OGRS, and we have tried to include some of the changes they instituted during the 2007 revision. I sincerely appreciate the CAA's past and present efforts to promote common practice among avalanche programs, and for allowing the U.S. community to benefit from their effort. Within the CAA, Clair Israelson (former CAA Executive Director) and Ian Tomm (CAA, Former Executive Director) both provided us with support and encouragement. The CAA's Technical Committee continues to help us coordinate with their efforts and promote common field practice when ever possible. Bruce Jamieson provided both material and insight from the work of the Applied Snow and Avalanche Research group at the University of Calgary.

The American Avalanche Association (AAA) and the USDA Forest Service National Avalanche Center (NAC) provided the majority of the funds and infrastructure to develop this document and complete the first revision. Janet Kellam (AAA, President), Mark Mueller (AAA, Executive Director), and Doug Abromeit (NAC, Director) all contributed to this effort.

A public and technical review process dramatically improved the content of the first version. Although we did not seek assistance from as large a group during the revision, their contribution remains a part of this document. They include: Pat Ahern, Jon Andrews, Don Bachman, Hal Boyne, Doug Chabot, Steve Conger, Nolan Doesken, Dave Hamre, Bill Glude, Liam Fitzgerald, Ron Johnson, Chris Joosen, Art Judson, Janet Kellam, Tom Kimbrough, Mark Kozak, Bill Lerch, Chris Lundy, Tom McKee, Art Mears, Peter Martinelli Jr., Rod Newcomb, Ron Perla, and Nancy Pfeiffer. I apologize to anyone that I forgot.

There are some individual contributions that are worthy of mention. Ian McCammon provided the field book figures, snow profile reporting forms, and density nomogram. Dale Atkins was very helpful in creating the incident forms in Appendix H and the metadata fields in Appendix C. Joyce VanDeWater drew the illustrations in Chapter 2. Charles Fierz allowed us to include the new snow classification (Appendix F) and snow symbol fonts. Ron Simenhois contributed most of the material in the Extended Column Test and Propagation Saw Test sections. Many photographers provided images for this publication, and they are listed with their contribution.

I would like to thank the group that worked on the 3rd Edition of this document. Jaime Musnicki and the Governing Board of the American Avalanche Association for supporting this work. Doug Krause put in long hours collecting information, opinions and making updates to the material. McKenzie Long designed a new look for, and increased the utility of, this publication. Blase Reardon helped polish and put the finishing touches on the manuscript. Lastly the other members of the Observation Standards Committee for their continued work to support and maintain this document.

Ethan Greene

American Avalanche Association, Observation Standards Committee, September 2016

INTRODUCTION

This document contains a set of guidelines for observing and recording snow, weather, and avalanche phenomena. These guidelines were prepared for avalanche forecasting operations, but can be applied to other programs as well. The guidelines are presented as a resource of common methods and are intended to promote efficient and fruitful communication among professional operations and between research and operational communities.

The observations presented in this manual were selected to support active avalanche forecasting programs. Observing these parameters will help avalanche forecasters make informed and consistent decisions, provide current and accurate information, and document methods and rationale for operational decisions. Recording these parameters will assist program managers to document and analyze unusual events, apply pattern recognition and statistical forecasting methods, and assist research into snow and avalanche phenomena. In addition, there is often little snow and weather data collected in mountainous areas and data collected by avalanche forecasting programs can be used in climatological and mountain systems research. Our hope is that this manual will help forecasters carefully choose the observations that support their programs, and that those observations will generate high quality and consistent data sets.

It is unlikely that any one operation will make all of the observations outlined within this document. Individual program managers should select a set of parameters that their staff can observe routinely. Programs with specialized needs may have to look elsewhere for information on additional observations. A set of references is listed in Appendix A as a starting point.

STRUCTURE OF THIS MANUAL

This manual is divided into three chapters and nine appendices. Within each chapter, methods for composing an observational scheme are presented first. A standard observation is presented next, and the remainder of each chapter is devoted to describing detailed methods for observing and recording a particular phenomenon. The appendices provide additional information without distracting from the main topics within the manual.

UNITS

The avalanche community within the United States typically uses a combination of English and International (SI) unit systems. In this document we have attempted to adhere to the SI system whenever possible. In the United States, personnel of avalanche operations and users of their products may not be familiar with all SI units. Individual programs should choose a unit system that suits their particular application. A recommended system of units, an alternative system of English units, and methods for converting values between the two systems are presented in Appendix B. The most noticeable deviation from the SI system is the unit for elevation. In North America most topographic maps use feet as the unit for elevation. Therefore the recommended unit for elevation remains the foot. Throughout the document the recommended unit appears in the text with the common alternative unit adjacent in parentheses. Long-term data records should be stored in the recommended system of units in Appendix B. Data records submitted to a central database are assumed to be in the recommended system unless otherwise stated in the accompanying metadata file (see Appendix C).

DATA CODES AND SYMBOLS

Symbols and data codes for many of the observations in this document appear in tables within each section. The use of these codes will save space in field books and on log sheets. Many of the codes in Chapter 1 follow conventions from the meteorological community. The codes in Chapters 2 and 3 were chosen to conform to common methods in the avalanche community and to promote efficient communication.

MANUAL SNOW AND WEATHER OBSERVATIONS

1.1 INTRODUCTION

Manual observations of snow and weather conditions are an important part of an avalanche forecasting operation. This chapter describes methods for making and recording these observations. Section 1.2 describes observation objectives. Section 1.3 outlines the recommended standard morning snow and weather observation. Sections 1.4 through 1.6 give important background information for planning and implementing observational schemes, Sections 1.7 and 1.8 discuss field observations, and Sections 1.9 through 1.27 describe how to observe and record individual parameters.

1.2 OBJECTIVES

Snow and weather observations represent a series of meteorological and snow surface measurements taken at a properly instrumented study plot or in the field (refer to Appendix D – Observation Sites for Meteorological Measurements). Observational data taken at regular intervals provide the basis for recognizing changes in stability of the snow cover and for reporting weather conditions to a meteorological office or regional avalanche center.

Sustained long-term data sets of snow and weather observations can be used to improve avalanche hazard forecasts by statistical and numerical techniques. They also serve to increase climatic knowledge of the area. Observations should be complete, accurate, recorded in a uniform manner, and made routinely. Following an established protocol increases the consistency in the data record, reduces error, and increases the potential for useful interpretation of the data.

FIGURE 1.1 Alpine weather station in the Colorado Rocky Mountains. (P: Kelly Elder)

1.3 STANDARD MORNING SNOW AND WEATHER OBSERVATION

Operations that include an avalanche forecasting program typically observe and record a set of weather and snow parameters daily. These observations should be made at about the same time each day and between 4 am and 10 am local standard time. Many operations will need to observe these parameters more than once per day. Listed below are a set of suggested fields to observe and record, and a brief explanation. Detailed information on each of these parameters is available in the sections that follow. Sections that are marked with a ❄ contain information on the parameters listed below. An example record sheet appears in Figure 1.2.

1. **Observation Location**– record the location of the observation site or nearest prominent topographic landmark (mountain, pass, drainage, avalanche path, etc.), political landmark (town, road mile, etc.), or geographic coordinates (latitude/longitude or UTM). If the measurements are made at an established study site, record the site name or number.
2. **Elevation (ASL)**– record the elevation of the observation site in feet (meters) above sea level.
3. **Date** – record the date on which the observation is being made (YYYYMMDD).
4. **Time** – record the local time on the 24-hour clock (0000 – 2359) at which the observation began.
5. **Observer** – record the name or names of the personnel that made the observation.
6. **Sky Condition**s– record the sky conditions as Clear, Few, Scattered, Broken, Overcast, or Obscured (Section 1.12).
7. **Current Precipitation** – record the precipitation type and rate using the scale and data codes in Section 1.13.
8. **Air Temperature** – record the 24-hour maximum, minimum, and current air temperature to the nearest 0.5 °C (or whole °F) (Section 1.14).
9. **Snow Temperature 20 cm (or 8 in)** – record the snow temperature 20 cm (or 8 in) below the snow surface (Section 1.17).
10. **Surface Penetration** – record the surface penetration to the nearest whole centimeter (or 0.5 inch) as described in Section 1.18.
11. **Total Snow Depth** – record the total depth of snow on the ground to the nearest whole centimeter (or 0.5 inch) (Section 1.20).
12. **24-hour New Snow Depth** – record the depth of the snow that accumulated during the previous 24-hours to the nearest whole centimeter (or 0.5 inch) (Section 1.21).
13. **24-hour New Snow Water Equivalent** – record the water equivalent of the snow that accumulated during the previous 24-hours to the nearest 0.1 mm (or 0.01 inch) (Section 1.22).
14. **24-hour Liquid Precipitation**– record the depth of the liquid precipitation that accumulated during the previous 24 hours to the nearest 0.1 mm (or 0.01 inch) (Section 1.24).
15. **Wind Direction** – observe the wind for at least two minutes and record the average wind direction or use an automated measurement. Record wind direction as N, NE, E, SE, S, SW, W, or NW. If an automated measurement is used, record to the nearest 10 degrees (Section 1.26).

16. **Wind Speed** – observe the wind for at least two minutes and record the average wind speed using the indicators in Section 1.26, or use an automated measurement.
17. **Maximum Wind Gust**- observe the wind for at least two minutes and record the speed of the strongest wind gust, or use an automated measurement. For an automated measurement record the time that the wind gust occurred (Section 1.26).

1.4 MANUAL VS. AUTOMATED OBSERVATIONS

Observation networks for avalanche forecasting programs usually involve at least one set of manual observations and one or more automated weather stations (Figure 1.1). Manual observations can be used to maintain a long-term record and observe and record data not amenable to sensing by automated systems. Automated observations provide unattended continuous weather (and some snowpack) information about a certain region or regions within a forecast or ski area. Automated weather stations can be co-located at study sites where manual weather observations and/or snowpack observations are collected. Programs that maintain a study plot should use data from automated weather stations to augment and not replace manual observations. The following chapter discusses how to make and record manual observations. Details regarding automated snow and weather observations appear in Appendix E.

1.5 TIME PERIODS FOR MANUAL SNOW AND WEATHER OBSERVATIONS

Observations taken at regular daily times are called standard observations. Manual observations are typically carried out in 24-hour, 12-hour, or 6-hour intervals. Data collected at 6-hour intervals beginning at 0000 hours Greenwich Mean Time (also termed Coordinated Universal Time (UTC) or Zulu time (Z)) will conform to climatic data sets. Avalanche forecasting operations typically make two standard observations each day at 0700 and 1600 hours local time, when a 12-hour interval is not possible. The type of operation and availability of observers may necessitate different frequencies and times. In regions that observe Daylight Savings Time, schedules should be adjusted so that the observation time does not change (i.e. use local standard time when recording observations). If observations are made on a 24-hour interval, it is best to make that observation in the morning.

Observations taken between the standard times are referred to as interval observations. They are taken when the snow stability is changing rapidly, such as during a heavy snowfall. Interval observations may contain a few selected observations or a complete set of observations.

Observations taken at irregular times are referred to as intermittent observations. They are appropriate for sites that are visited infrequently; visits will typically be more than 24 hours apart and need not be regular (i.e. in a heli-ski operation). Intermittent observations may contain a few selected observations or a complete set of observations. In highway operations, intermittent observations often include shoot or storm observations to coincide with the timing of avalanche mitigation or the start and end of particular storm cycles (see Figure 1.2 for sample of field book entry).

It is common for avalanche forecasting operations to collect information for an individual storm event. Observations of snowfall, temperature changes, wind direction and speed, and avalanche activity can be observed for a particular storm unit. A storm unit is typically a qualitative increment based on precipitation rates or meteorological events. Operations that choose to use a storm unit may also find it useful to develop a quantitative storm unit definition.

1.6 EQUIPMENT FOR MANUAL STANDARD OBSERVATIONS

A snow and weather study plot usually contains the following equipment:

- Stevenson screen for housing thermometers (height adjustable)
- Maximum thermometer
- Minimum thermometer
- One or more snow boards with 1 m (~3 ft) rods and base plate with minimum dimensions of 40 cm x 40 cm (~15 in) and appropriate labels (Figure 1.3)
- Snow stake, depth marker (graduated in cm (in))
- Ruler (graduated in cm (in))
- Snow sampling tube and weighing scale (graduated in grams or water equivalent), or precipitation gauge
- Large putty knife or plate for cutting snow samples
- Field book and pencil (water resistant paper)

The following additional equipment is useful:

- Hygrothermograph located in a Stevenson screen
- Recording precipitation gauge or rain gauge (Figure 1.4)
- Additional snow boards
- First section of a Ram penetrometer
- Barograph (in the office) or barometer/altimeter
- Anemometer at a separate wind station with radio or cable link to a recording instrument (Figure D.4)
- Box (shelter) for the equipment
- Small broom
- Snow shovel

In some cases the weather sensors listed above have been linked to data loggers where, in most instances, comparable data may be obtained (see Appendix E). However, a broken wire or power outage may render automated data useless, so manual observations are still preferred as a baseline.

1.7 FIELD BOOK NOTES

There are many good and different methods for taking field notes. Following these general practices will ensure that quality data are collected.

- Do not leave blanks. If a value was not observed, record N/O for not observed.
- Only write "0" when the reading is zero, for example, when no new snow has accumulated on the new snow board.
- Only record values that are actually observed.

1.8 FIELD WEATHER OBSERVATIONS

Heli-ski guiding, ski touring and similar operations often observe general weather conditions in the field. These observations may serve as an interval measurement, accompany a snow profile, or serve to document conditions across a portion of their operational area. The records should describe some of the parameters listed in this section, but field reports should be made as a series of comments so as not to be confused with observations taken at a fixed weather station. Maximum and minimum temperatures cannot be observed, but a range in present temperatures can be reported. Field observations should specify the elevation range and the time, or time range, from where the observations were taken. Common field observations typically include: time, location, elevation, sky cover, wind speed and direction, air temperature and precipitation type and rate. Field weather observations that are estimates and not measurements should be recorded with a tilde (~) to denote that the value is approximate.

1.9 LOCATION ❄

Record the location and elevation, or study plot name, at the top of the record book page.

1.10 DATE ❄

Record the year, month and day. Avoid spaces, commas etc., i.e. December 5, 2001, is noted as 20011205 (YYYYMMDD). This representation of the date is conducive to automated sorting routines.

1.11 TIME ❄

Record the time of observation using a 24-hour clock (avoid spaces, colons etc.) (i.e. 5:10 p.m. is noted as 1710). Use local standard time (i.e. Pacific, Mountain, etc. as appropriate). Operations that overlap time zones should standardize to one time.

1.12 SKY CONDITION ❄

Classify the amount of cloud cover and record it using the definitions in Table 1.1. Observers may select a separate data code for each cloud layer or one code for the total cloud cover.

Valley Fog/Cloud

Where valley fog or valley cloud exists below the observation site, estimate the elevation of the top and bottom of the fog layer in feet (meters) above sea level. Give the elevation to the nearest 100 ft (or 50 m). Data code: VF.

Example: Clear sky with valley fog from 7,500 to 9,000 ft is coded as CLR VF 7500-9000.

Thin Cloud

The amount of cloud, not the opacity, is the primary classification criterion. Thin cloud has minimal opacity, such that the disk of the sun would still be clearly visible through the clouds if they were between the observer and the sun, and shadows would still be cast on the ground. When the sky condition features a thin scattered, broken or overcast cloud layer then precede the symbol with a dash.

Example: A sky completely covered with thin clouds is coded as -OVC.

1.13 PRECIPITATION TYPE, RATE, AND INTENSITY ❄

The amount of snow, rain, or water equivalent that accumulates during a time period will help forecasters determine the rate and magnitude of the load increase on the snowpack. In this document, Precipitation Rate refers to an estimate of the snow or rain rate. Precipitation Intensity is a measurement of water equivalent per hour.

TABLE 1.1 Sky Condition

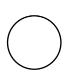
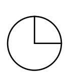
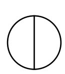
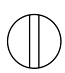
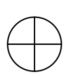
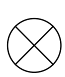
CLASS	SYMBOL	DATA CODE	DEFINITION
Clear		CLR	No clouds
Few		FEW	Few clouds: up to 2/8 of the sky is covered with clouds
Scattered		SCT	Partially cloudy: 3/8 to 4/8 of the sky is covered with clouds
Broken		BKN	Cloudy: more than half but not all of the sky is covered with clouds (more than 4/8 but less than 8/8 cover)
Overcast		OVC	Overcast: the sky is completely covered (8/8 cover)
Obscured		X	A surface based layer (i.e. fog) or a non-cloud layer prevents observer from seeing the sky

TABLE 1.2 Precipitation Type

DATA CODE	DESCRIPTION
NO	No Precipitation
RA	Rain
SN	Snow
RS	Mixed Rain and Snow
GR	Graupel and Hail
ZR	Freezing Rain

Procedure

Precipitation Type

Note the type of precipitation at the time of observation and record using the codes in Table 1.2.

Precipitation Rate

Use the descriptors listed in Table 1.3 to assess the precipitation rate at the time of observation. Record the estimated rate with the appropriate data code in Table 1.3.

Precipitation Intensity

Use measurements of rain or the water equivalent of snow to calculate the precipitation intensity with the following equation:

Record the results with the data code PI and the measured value in millimeters (inches) of water.

$$PI\left(\frac{\text{mm}}{\text{hr}}\right) = \frac{\text{water equivalent of precipitation (mm)}}{\text{duration of measurement period (hr)}}$$

PI values are assumed to be in millimeters. Use the symbol " to signify when inches are used

Example: A precipitation intensity of one half inch per hour would be coded as PI0.5".

1.14 AIR TEMPERATURE ❄

Temperature is measured in degrees Celsius (abbreviated °C) or degrees Fahrenheit (°F). The standard air temperature should be observed in a shaded location with the thermometer 1.5 m above the ground or snow surface. At a study site, thermometers should be housed in a Stevenson screen and the lower edge of the screen should be 1.2 to 1.4 meters above the ground or snow surface (Figure 1.4).

Procedure

1. Read the maximum thermometer immediately after opening the Stevenson screen.
2. Read the present temperature from the minimum thermometer, and read the minimum temperature from the minimum thermometer last.
3. Read temperature trend and temperature from the thermograph.

TABLE 1.3 Precipitation Rate

DATA CODE	DESCRIPTION	RATE
Snowfall Rate (this table provides examples; any appropriate rate may be specified)		
S-1	Very light snowfall	Snow accumulates at a rate of a trace to about 0.5 cm (~ 0.25 in) per hour
S1	Light snowfall	Snow accumulates at a rate of about 1 cm (~ 0.5 in) per hour
S2	Moderate snowfall	Snow accumulates at a rate of about 2 cm (a little less than 1 in) per hour
S5	Heavy snowfall	Snow accumulates at a rate of about 5 cm (~ 2 in) per hour
S10	Very heavy snowfall	Snow accumulates at a rate of about 10 cm (~ 4 in) per hour
Rainfall Rate		
RV	Very light rain	Rain produces no accumulation, regardless of duration
RL	Light rain	Rain accumulates at a rate up to 2.5 mm (0.1 in) of water per hour
RM	Moderate rain	Rain accumulates at a rate between 2.6 to 7.5 mm (0.1 to 0.3 in) of water per hour
RH	Heavy rain	Rain accumulates at a rate of 7.5 mm (0.3 in) of water per hour or more

At the end of the temperature observation:

4. Remove any snow that might have drifted into or accumulated on top of the screen.
5. Reset the thermometers after the standard observations (refer to Appendix D).
6. If the Stevenson screen is fitted with a height adjustment mechanism ensure that the screen base is in the range of 1.2 to 1.4 m above the snow surface. In heavy snow climates where daily access of the site is not always possible, the Stevenson screen may be mounted on top of a tower to prevent burial. However the height of the screen should be noted in the metadata.
7. Check that the screen door still faces north if any adjustments are made.

Read all air temperatures from thermometers to the nearest 0.5 °C (or whole °F).If there is snow on the thermometer it should be brushed off prior to reading the instrument and noted in the comment section.

1.14.1 AIR TEMPERATURE TREND

If available, read the air temperature from the thermograph and record to the nearest whole degree. Use an arrow symbol to record the temperature trend shown on the thermograph trace over the preceding three hours.

Location	**South Fork Cement Creek Site #2 11,300'**					
Observer	DK	JC	NG	DK	JC	NG
Date	20101215	20101215	20101216	20101216	20101217	20101218
Time, Type (Std, Int)	0530, S	1600, I	0530, S	1600, I	0530, S	0530, S
Sky	OVC	OVC	OVC	OVC	-BRK	CLR
Precip Type/Rate	S2	S4	S3	S2	S1	NO
Max Temp (°C)	-2.5	-3.0	-3.0	-1.5	-1	0.0
Min Temp (°C)	-7.0	-6.0	-6.0	-5.0	-5.0	-9
Present Temp (°C)	-6.0	-4.0	-5.5	-2.5	-5.0	-8
Thermograph	-6.5	-4	-5	-2	-5	-8
Thermograph Trend	R	S	R	F	S	R
20cm Snow Temp (°C)	-8	-7	-7	-7	-6	-7
Relative Humidity (%)	92	98	97	96	92	65
Interval (cm) HIN	0	37	0	24	N/O	N/O
New (cm) HN24	42	N/O	55	N/O	25	8
Storm (cm) HST c=cleared	42	63c	32	39c	25c	8c
Snow Depth (cm) HS	164	219	224	240	258	258
New Water (g)	N/O	N/O	N/O	N/O	N/O	N/O
New Water (mm)	33	N/O	49	N/O	15	4
Density (kg/m^3)	N/O	N/O	N/O	N/O	N/O	45
Rain Gauge (mm)	N/O	N/O	N/O	N/O	N/O	N/O
Precip Gauge (mm)	N/O	N/O	N/O	N/O	N/O	N/O
Foot Pen (cm)	25	N/O	35	N/O	30	25
Ram Pen (cm)	30	N/O	39	N/O	33	28
Surface Form/Size (mm)	PP	PP/5	pp	pp	PP/3	PP
Wind Speed/Direction	L, SW	M, SW	M, SW	L, SW	L, W	C
Blowing Snow/Direction	L, SW	M, SW	I, SW	M, SW	L, W	Prev, W
Barometric Pressure (mb)	852	817	825	847	860	870
Pressure Trend	F	S	S	R	S	S
Comments	Heavy precip fcst	Dumping	All passes closed	Wdsprd SS-N	Precip decreasing	Blower country

FIGURE 1.2 An example standard observation record sheet.

TABLE 1.4 Temperature Trend

SYMBOL	DATA CODE	DESCRIPTION
↑	RR	Temperature rising rapidly (> 5 degree increase in past 3 hours)
↗	R	Temperature rising (1 to 5 degree increase in past 3 hours)
→	S	Temperature steady (< 1 degree change in past 3 hours)
↘	F	Temperature falling (1 to 5 degree decrease in past 3 hours)
↓	FR	Temperature falling rapidly (> 5 degree decrease in past 3 hours)

Note: Table 1.4 assumes the use of the Celsius temperature scale. Operations that use the Fahrenheit temperature scale should use a threshold of 10-degrees (rather than 5-degrees) for rapid temperature changes.

1.15 RELATIVE HUMIDITY (*RH*)

Read the relative humidity to the nearest one percent (1%) from the hygrograph or weather station output.

The accuracy of relative humidity measurements decreases at low temperatures. Furthermore, the accuracy of any mechanical hygrograph is unlikely to be better than five percent (5%) but trends may be important especially at high RH values. Refer to Appendix D for information on exposure issues and relative humidity measurements.

Depending on location, humidity measurements may be more relevant from mid-slope or upper- elevation sites than from valley-bottom sites.

Hygrographs should be calibrated at the beginning of each season, mid season, and after every time the instrument is moved. Calibration is most important when data from multiple instruments are compared with each other. The simplest calibration method is to make a relative humidity measurement near the Stevenson screen with a psychrometer (aspirated or sling). Calibration should be done midday or at a time when the air temperature is relatively stable. Psychrometer measurements are easier to perform when the air temperature is near or above freezing.

1.16 BAROMETRIC PRESSURE AT STATION

The SI unit for pressure is the pascal (Pa). For reporting weather observations, barometric pressure should be recorded in millibars (1 mb = 1 hPa = 100 Pa, see Appendix B). The recommended English unit for barometric pressure is inches of mercury (inHg). Conversions from other commonly used pressure units to millibars and inches of mercury are listed in Appendix B.

TABLE 1.5 Pressure Trend

SYMBOL	DATA CODE	DESCRIPTION
↑	RR	Pressure rising rapidly (>2 mb rise per hour)
↗	R	Pressure rising (<2 mb rise per hour)
→	S	Pressure steady (<1 mb change in 3 hours)
↘	F	Pressure falling (<2 mb fall per hour)
↓	FR	Pressure falling rapidly (>2 mb fall per hour)

1.16.1 PRESSURE TREND

Use an arrow symbol to record the pressure trend as indicated by the change of pressure in the three hours preceding the observation. Record the change in barometric pressure in the past three hours.

1.17 20 CM SNOW TEMPERATURE (*T20*) ❄

Dig into the snow deep enough to allow access to an area 20 cm (or 8 in) below the surface. Cut a shaded wall of the pit smooth and vertical. Shade the snow surface above the area where the sensor will rest in the snow. Cool the thermometer in the snow at the same height, but a different location than where the measurement will be taken. Insert the thermometer horizontally 20 cm (or 8 in) below the snow surface and allow it to adjust to the temperature of the snowpack. Once the sensor has reached equilibrium, read the thermometer while the sensor is still in the snow.

Record snow temperature to the nearest degree or fraction of a degree based on the accuracy and precision of the thermometer.

1.18 SURFACE PENETRABILITY (*P*) ❄

An indication of the snowpack's ability to support a given load and a relative measure of snow available for wind transport can be gained from surface penetrability measurements. There are several common methods for examining surface penetration. Ram penetration is the preferred method of observation because it produces more consistent results than ski or foot penetration. When performing foot or ski penetration on an incline, average the uphill and downhill depths of the track.

Procedure

Ram Penetration (*PR*)

Let the first section of a standard ram penetrometer (cone diameter 40 mm, apex angle 60° and mass 1 kg) penetrate the snow slowly under its own weight by holding it vertically with the tip touching the snow surface and dropping it. Read the depth of penetration in centimeters.

Foot Penetration (*PF*)
Step into undisturbed snow and gently put full body weight on one foot. Measure the depth of the footprint to the nearest centimeter (or whole inch) from 0 to 5 cm and thereafter, to the nearest increment of 5 cm (or 2 in).

The footprint depth varies between observers. It is recommended that all observers working on the same program compare their foot penetration. Observers who consistently produce penetrations more than 10 cm (or 4 in) above or below the average should not record foot penetrations.

Ski Penetration (*PS*)
Step into undisturbed snow and gently put full body weight on one ski. Measure the depth of the ski track from its centerline to the nearest centimeter (or whole inch) from 0 to 5 cm and thereafter, to the nearest increment of 5 cm (or 2 in).

Ski penetration is sensitive to the weight of the observer and the surface area of the ski.

1.19 FORM (*F*) AND SIZE (*E*) OF SURFACE SNOW

Record the form and size in millimeters of snow grains at the surface using the International Classification for Seasonal Snow on the Ground, (Fierz and others, 2009) basic classification (Table 1.6).

Experienced observers may use the subclasses (Table 1.7) to discriminate between various types of surface deposits and crusts (refer to Appendix F for more detailed information about grain forms).

TABLE 1.6 Basic Classification of Snow on the Ground

SYMBOL	DESCRIPTION	DATA CODE
+	Precipitation Particles (New Snow)	PP
◎	Machine Made Snow	MM
/	Decomposing and Fragmented Particles	DF
●	Rounded Grains (monocrystalline)	RG
□	Faceted Crystals	FC
ʌ	Depth Hoar	DH
V	Surface Hoar	SH
○	Melt Forms	MF
▬	Ice Formations	IF

Note for Table 1.6: Modifications to Fierz and others, 2009: A subscript "r" modifier is used to denote rimed grains in the Decomposing and Fragmented Particles (DF) major class and the Precipitation Particles (PP) major class and its subclasses except for gp, hl, ip, rm (Example: PP-r). Subclasses for surface hoar are listed in Appendix F.

TABLE 1.7 Surface Deposits and Crusts Subclasses

SYMBOL	CLASSIFICATION	DATA CODE
∀	Rime	PPrm
=	Rain crust	IFrc
−	Sun crust, Firnspiegel	IFsc
⌀	Wind packed	RGwp
◎◎	Melt freeze crust	MFcr

1.20 HEIGHT OF SNOWPACK (*HS*) ❄

The height of the snowpack should be measured at a geographically representative site, preferably within 100 meters (or 300 ft) of the weather study plot. A white stake graduated in centimeters (inches) should be placed at the site. It is best to preserve an area with a radius of about 3 m (or 10 ft) around the snow stake for measurements. Ideally the snow in this area is not disturbed during the winter. Leave naturally forming settlement cones and depressions in place and try not to walk through the area.

Procedure

From a distance of about 3 m (or 10 ft) look across the snow surface at the snow stake. Observe the average snow depth between your position and the stake to the nearest centimeter (or 0.5 inch). Try not to disturb the snow around the stake during the course of a winter season. HS values are measured vertically (i.e. line of plumb).

1.21 HEIGHT OF NEW SNOW (*HN24*) ❄

The new snow measurement in the standard morning observation uses a 24-hour interval. Many operations will find it useful to observe snow fall on more than one interval. However, the 24-hour interval snow board should only be used for 24-hour observations. Additional snow boards should be added for additional observations as necessary. It is highly recommended that both 24-hour and Storm intervals be observed by operations that maintain a study plot. Other commonly used intervals appear in the Snow Board Naming Convention Section 1.21.1.

New snow measurements should be made on a snow board (Figure 1.3). The base plate should have minimum dimensions of 40 cm x 40 cm (or 15 in x 15 in), with an attached rod of 1 m (or 3 ft) in length. Larger boards (60 cm x 60 cm) provide more room to make measurements. The base plate and rod should be painted white to reduce the effects of solar heating.

Procedure

Use a ruler graduated in centimeters (or inches) to measure the depth of snow accumulated on the snow board. Take measurements in several spots on the board. Calculate the average of the measurements and record to the nearest cm (in). Record "T" (signifying a trace) when the depth is less than 1 cm (or 0.5 in), or when snow fell but did not accumulate. If there is no new snow, record zero. Do not consider surface hoar on the boards as snowfall; clear off hoar layer after observation. If both rain and snow fell, it should be noted in the remarks.

The sample on the snow board can also be used to measure the water equivalent of new snow (Section 1.22). Once the observations are complete, redeposit the snow in the depression left by the snow board, adding additional snow if necessary to reposition the board level with the surrounding snow surface.

If the snow board was not level, the measurement should be made normal to the surface of the board.

1.21.1 SNOW BOARD NAMING CONVENTIONS

The following convention can be used to identify snow boards used for different interval measurements.

HN24 – 24-hour Board: The HN24 board is used to measure snow that has been deposited over a 24-hour period. It is cleared at the end of the morning standard observation.

HST – Storm Board: Storm snowfall is the depth of snow that has accumulated since the beginning of a storm period. The storm board is cleared at the end of a standard observation prior to the next storm and after useful settlement observations have been obtained. The symbol "c" is appended to the recorded data when the storm board is cleared.

H2D – Twice-a-Day Board: An H2D board is used when standard observations are made twice a day. In this case both the HN24 and H2D boards should be cleared in the morning and then the H2D board is cleared again in the afternoon.

HSB – Shoot Board: The shoot board holds the snow accumulated since the last time avalanches were shot with explosives. The symbol "c" is appended to the recorded data when the shoot board is cleared.

HIN – Interval Board: An interval board is used to measure the accumulated snow in periods shorter than the time between standard observations. The interval board is cleared at the end of every observation.

HIT – Intermittent Board: Snow boards may be used at sites that are visited on an occasional basis. Snow that accumulates on the board may result from more than one storm. The intermittent snow board is cleared at the end of each observation.

1.22 WATER EQUIVALENT OF NEW SNOW (*HN24W*) ❄

The water equivalent is the depth of the layer of water that would form if the snow on the board melted. It is equal to the amount of liquid precipitation. The standard morning observation includes the water equivalent of the new snow on a 24-hour interval. The same snow board used for a 24-hour or other interval measurement should be used to calculate the water equivalent. There are several suitable methods for making this measurement. Three different methods are described in the following section.

Procedure

Use one of the following methods to calculate the water equivalent of the new snow. Record the value to the nearest 0.1 mm (or 0.01 in). Make several measurements and report the average value. Record "T" (signifying a trace) when the snow depth is less than 1 cm (or 0.5 in). If there is no new snow, record a zero. Do not consider surface hoar on the boards as snowfall; clear off hoar layer after observation.

Snow Board Tube and Weighing Scale

1. Cool the measurement tube in the shade prior to making the measurement
2. Hold the tube vertically above the surface of the snow on the snow board
3. Press the tube into the snow at a slow and constant rate until it hits the base plate of the snow board
4. Record the height of the snow sample in the tube
5. Remove the snow next to one side of the tube with a large putty knife or scraper
6. Slide putty knife under the tube and remove the sample from the board

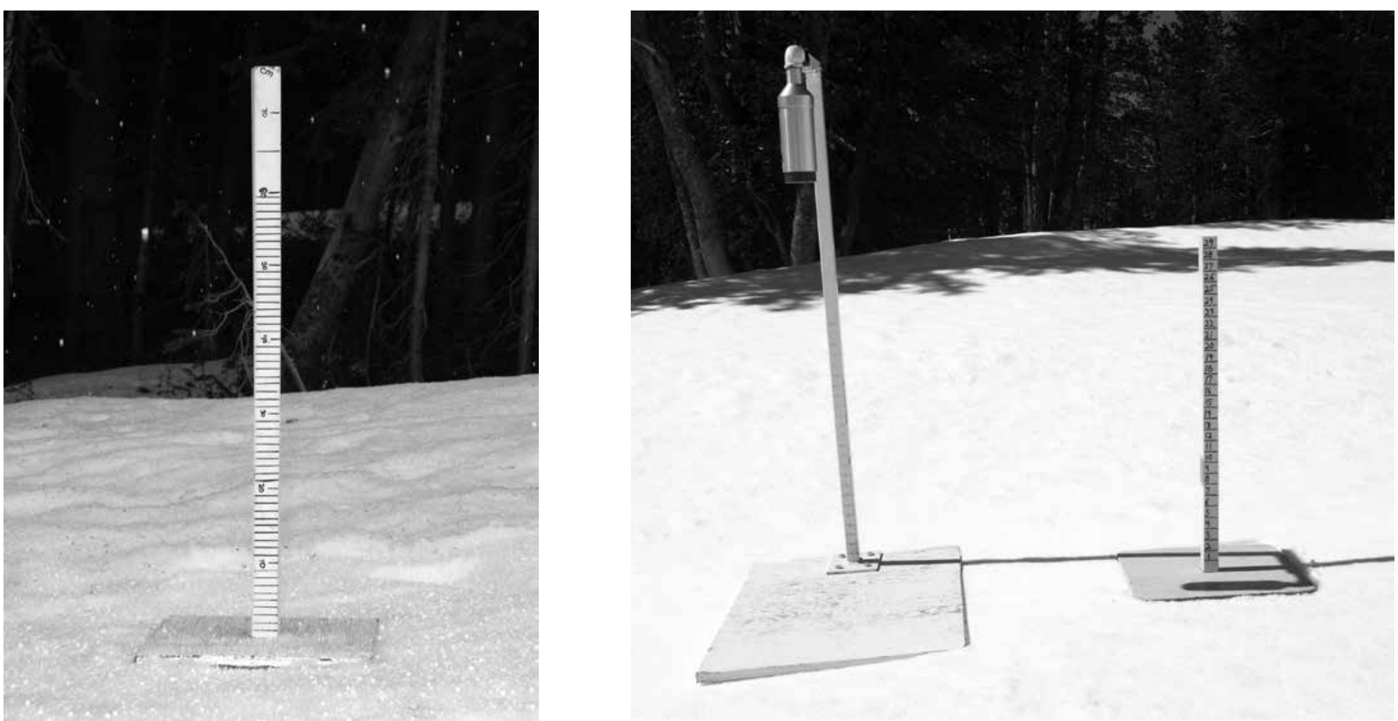


FIGURE 1.3 Left: Snow board graduated in centimeters. Right: Automated snow board and snow board graduated in inches. (P: Tom Leonard)

7. Weigh the sample and read the water content from the scale, or use the equation listed below, or the SWE nomogram in Appendix I
8. Repeat and record the average of several measurements to the nearest 0.1 mm (or 0.01 in)

Melting the Snow Sample
The water equivalent of the new snow can be obtained by melting a sample of snow and measuring the resulting amount of melt water. The height of the melt water in mm (in) is the water equivalent of the sample. When using this method, the base area of the snow sample and the melted sample must remain the same.

Indirect Method
The water equivalent of snow can also be obtained by weighing a snow sample of known cross-sectional area. Water equivalent is calculated by using the following equation:

$$H2DW \text{ mm} = \frac{\text{mass of snow sample (g)}}{\text{area of sample tube (cm}^2\text{)}} \times 10$$

This method is commonly used by avalanche operations because of its ease (Note: 1 cm^3 of water has a mass of 1 g). The expanded equation is in Appendix B, Section B.5.

1.23 DENSITY OF NEW SNOW (ρ)
Density is a measure of mass per unit volume; density is expressed in SI units of kg/m3. It is also common for avalanche operations to discuss snow density in percent water content per volume. Calculations of both quantities are described below. Data records of snow density should be recorded in units of kg/m^3. The Greek symbol ρ (rho) is used to represent density.

Calculating Density
Divide the mass (g) of new snow by the sample volume (cm^3) and multiply by 1000 to express the result in kilograms per cubic meter (kg/m^3). Record as a whole number (i.e. 120 kg/m^3).

$$\rho\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{\text{mass of snow sample (g)}}{\text{sample volume (cm}^3\text{)}} \times 1000$$

For measurements from standard observations:

$$\rho\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{H2DW \text{ (mm)}}{H2D \text{ (cm)}} \times 100$$

The density of a snow sample is often communicated as a dimensionless ratio or percent. Calculate this ratio by dividing the height of the water in a snow layer by the height of the snow layer and then multiply by 100 (e.g. 10 cm of snow that contains 1 cm of water has a water content of 10%). This ratio can also be calculated by dividing the density of the snow (kg/m^3) by the density of water (1000 kg/m^3) and multiplying by one hundred. Using the density of water allows for an easy calculation by moving the decimal one space to the left (i.e. 80 kg/m^3 = 8%).

$$\%\text{ water} = \frac{\text{water equivalent of snow sample (mm)}}{\text{height of snow sample (mm)}} \times 100$$

$$\%\text{ water} = \frac{\text{water equivalent of snow sample (mm)}}{\text{height of snow sample (cm)}} \times 10$$

$$\%\text{ water} = \frac{\text{water equivalent of snow sample (in)}}{\text{height of snow sample (in)}} \times 100$$

1.24 RAIN ❄
There are a variety of commercial rain gauges available. The standard rain gauge is made of metal and has an 8-inch (~20 cm) orifice (Figure 1.4). However, good results can be obtained with commercially manufactured 4-inch (~10 cm) diameter plastic gauges. The gauge should be mounted at the study site (see Appendix D for site guidelines). If a mounted gauge is not available, an 8-inch (~20 cm) gauge may be placed on the snow board prior to a rain event.

Procedure
Measure the amount of rain that has accumulated in the rain gauge with the length scale on the gauge or a ruler. Record the amount to the nearest 0.1 mm (or 0.01 in). Empty the gauge at each standard observation.

1.25 ACCUMULATED PRECIPITATION
Accumulated precipitation gauges collect snowfall, rainfall and other forms of precipitation and continuously record their water equivalent. There are a variety of commercial gauges (both manual and automated) available.

Procedure
Record the amount of precipitation accumulated in the recording precipitation gauge to the nearest tenth of a millimeter (0.1 mm) or 0.01 of an inch. The amount of precipitation that fell during a single event can be obtained by taking the difference between the present reading and the previous reading.

1.26 WIND ❄
Both estimates and measurements of wind speed and direction are useful to observe and record. However, it is important to distinguish between the two types of observations. Measurements are made with an instrument located at a fixed point. Estimates are made without instruments or with hand-held instruments, and typically represent wind in a local area rather than at a fixed point.

Procedure
Measured Wind Speed
The SI unit for wind speed is meters per second (miles per hour). Refer to Appendix B for unit conversions.

Measured Maximum Wind Gust
Record the speed and time of occurrence of the maximum wind gust.

FIGURE 1.4 Precipitation gauge with Alter shield. (P: Tom Leonard)

FIGURE 1.5 Evidence of previous blowing snow. (P: Ben White)

Measured Wind Direction
Measured wind direction for standard observations should be rounded to the nearest 10 degrees (i.e. 184 degrees (just beyond south) is coded as 180). Forty-five degrees (northeast) is coded as 050. Archived wind direction data from an automatic weather station can be stored as a three digit number.

Estimated Wind Speed
For the standard morning observation, an estimate of the wind speed can be obtained by observing for two minutes. Use the indicators in Table 1.8 to determine the categorical wind speed and the data codes to record average conditions during the observation period.

The indicators used to estimate the wind speed are established by rule of thumb. Observers should develop their own relationships specific to their area. Wind estimates (speed and direction) should be averaged over a two-minute period prior to the observation. Since wind speed classes are determined by an estimate, mi/h categories can be rounded to the nearest 5 mi/h.

Estimated Maximum Wind Gust
Estimate the maximum wind speed during the observation period. Record the estimated speed to the nearest 2 m/s (or 5 mi/hr).

TABLE 1.8 Wind Speed Estimation

CLASS	DATA CODE	KM/H	M/S	MI/HR	TYPICAL INDICATOR
Calm	C	0	0	0	No air motion. Smoke rises vertically.
Light	L	1-25	1-7	1-16	Light to gentle breeze, flags and twigs in motion.
Moderate	M	26-40	8-11	17-25	Fresh breeze. Small trees sway. Flags stretched. Snow begins to drift.
Strong	S	41-60	12-17	26-38	Strong breeze. Whole trees in motion.
Extreme	X	>60	>17	>38	Gale force or higher.

FIGURE 1.6 Evidence of current blowing snow. (P: Ethan Greene)

Estimated Wind Direction
During a two-minute period, note the direction from which the wind blows. The wind direction can be recorded using the compass directions listed in Table 1.10. Do not record a direction when the wind speed is zero (Calm). If no definitive wind direction can be established, record direction as Variable (VAR).

1.27 BLOWING SNOW

Estimate the extent of snow transport (Table 1.9) and note the direction from which the wind blows to the closest octant of the compass (Table 1.10). The observer should also note the location and/or elevation of the wind transport (e.g. valley bottom, study site, ridgetop, peaks, 11,000 ft, 3000 m, etc.). Record wind direction as indicated by blowing snow (Figures 1.5 and 1.6).

TABLE 1.9 Extent of Blowing Snow

DATA CODE	DESCRIPTION
None	No snow transport observed.
Prev	Snow transport has occurred since the last observation, but there is no blowing snow at the time of observation.
L	Light snow transport.
M	Moderate snow transport.
I	Intense snow transport.
U	Unknown as observation is impossible because of darkness, cloud, or fog.

TABLE 1.10 Direction of Wind

DIRECTION	N	NE	E	SE	S	SW	W	NW
DEGREES	0	45	90	135	180	225	270	315

SNOWPACK OBSERVATION

2.1 INTRODUCTION

Information on the structure and stability of the snowpack within an area is essential to assessing current and future avalanche conditions. In certain applications, starting zones may be inaccessible and snowpack properties can be estimated with careful analysis of past and present weather and avalanche events. Snowpack parameters vary in time and space, and observation schemes should address these variations. Snowpack information is generally observed and recorded separately from the snow and weather observations outlined in Chapter 1. However, some basic weather observations are typically made in conjunction with snowpack observations (Figure 2.1).

Broad objectives are outlined in Section 2.2. A set of standard parameters to be collected with any snowpack observation follows in Section 2.3. Snow profiles and snowpack measurements are described in Sections 2.4 and 2.5. In Section 2.6 methods for observing and recording shear quality are discussed. Section 2.7 presents column and block stability tests; slope cuts are described in Section 2.8; non-standardized tests are described in Section 2.9 and instrumented measures are listed in Section 2.10.

2.2 OBJECTIVES

The primary objective of any observer working in avalanche terrain is safety. Secondary objectives may include observing and recording the current structure and stability of the snowpack. Other objectives will depend on the type of operation.

Specific measurements and observations will be dependent on the type of operation, but in general the objective is to observe and record the current structure and stability of the snowpack. More specific objectives are listed in the sections that follow.

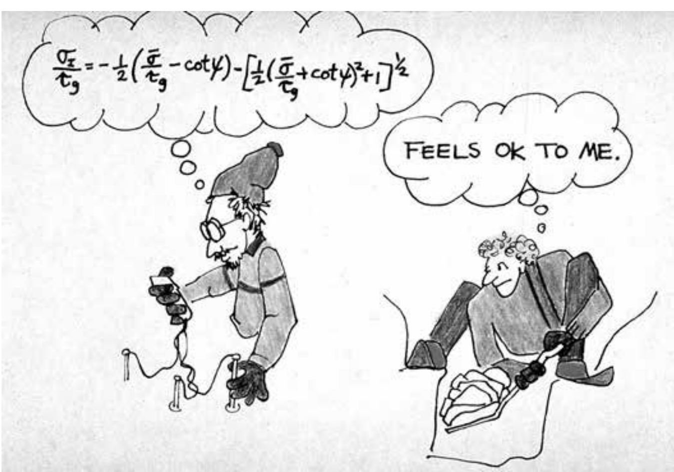


FIGURE 2.1 There are many different approaches to observing snowpack properties. (Illustration by Sue Ferguson)

2.3 STANDARD SNOWPACK OBSERVATION

The snowpack parameters observed and the detail of those observations will depend on the particular forecasting problem. This section presents an outline for daily snowpack observations. Parameters one through five and parameter seven will be useful for most avalanche forecasting programs. Individual programs and field workers should select snowpack properties (parameter six) from those listed in this chapter to supply the information needed for their specific application.

1. **Date** – record the date on which the observation was made (YYYYMMDD).
2. **Time** – record the local time at which the observation was begun (24-hour clock).
3. **Observer** – record the name or names of the personnel that made the observation.
4. **Site Characteristics**
   - *Observation Location* - Record the nearest prominent topographic landmark (mountain, pass, drainage, avalanche path, etc.), political landmark (town, road mile, etc.), or geographic coordinates (latitude/longitude or UTM and datum). If observing a fracture line profile, note the location within the avalanche path.
   - *Aspect* – Record the direction that the slope faces where the observation was made (i.e. N, NE, E, SE, S, SW, W, NW, or degrees azimuth).
   - *Elevation* – Record the elevation of the observation site (feet or meters).
   - *Slope Angle* – Record the incline of the slope where the observation was made (degrees).
5. **Current Weather**
   - *Sky Conditions* - Record the sky conditions as Clear, Few, Scattered, Broken, Overcast, or Obscured (Section 1.12).
   - *Air temperature* – Record the current air temperature to the nearest 0.5 °C (or whole °F).
   - *Precipitation Type and Rate* – Record the precipitation type and rate (Section 1.13).
   - *Wind* – Record the wind speed and direction (Section 1.26).
   - *Surface Penetration* – Record the surface penetration (Section 1.18).
6. **Snowpack Properties** – observe and record the necessary snowpack properties as described in this chapter.
7. **Avalanche Potential** – record one or more of the parameters as applicable to the operation (see Appendix G). Avalanche conditions can be grouped by region, aspect, slope angle range (i.e. 35°-40°), or obvious snow properties (such as recently wind loaded or amount of new snow). In this case a separate stability, danger, or hazard rating should be given for each group (Appendix G).
   - *A) Snow Stability*
     Forecast – record the snow stability stated in the morning meeting or current forecast.
     Observed – record the snow stability observed at this location.
   - *B) Avalanche Danger*
     Forecast – record the avalanche danger stated in the current avalanche advisory.
     Observed – record the avalanche danger assessed at this location.

- *C) Avalanche Hazard*
  Forecast – record the avalanche hazard currently stated by the program
  Observed – record the avalanche hazard assessed at this location.

2.4 SNOW PROFILES

Snow profiles are observed at study plots, study slopes, fracture lines and targeted sites. This section outlines two types of snow profiles: full profiles and test profiles. A full profile is a complete record of snow-cover stratigraphy and characteristics of individual layers. A test profile is a record of selected observations.

Full Profiles

Full snow profiles (Figure 2.2) are frequently observed at study plots or study slopes in time series to track changes in the snowpack. They require that all, or most, snowpack variables be measured (Section 2.5). Full profiles are time consuming and not always possible at targeted sites.

Test Profiles

Test profiles (Figure 2.2) are the most common type of snow profile. There is no fixed rule about the type and amount of information collected in a test profile. Each observer must select, observe, and record the parameters needed by their operation. These parameters may change in both time and space. Test profiles are commonly observed at targeted sites and fracture lines.

The objectives of observing *full profiles* are:

1. Identify the layers of the snowpack
2. Identify the hardness and/or density of the layers in the snowpack
3. Identify weak interfaces between layers and to approximate their stability
4. Observe snow temperatures
5. Monitor and confirm changes in snowpack stability
6. Determine the thickness of a potential slab avalanche
7. Determine the state of metamorphism in different snow layers
8. Observe and record temporal and spatial changes in snow properties

A test profile addresses one or more of the above objectives. In addition, this information can be used for climatological studies, forecasts of snow-melt runoff, engineering applications, and studies of the effect of snow on vegetation and wildlife.

FIGURE 2.2 Different types of snow profiles clockwise from left: Full Profile, Test Profile, Fracture Line Profile. Snow profiles will vary depending on the information needed to support a particular application. (P: Karl Birkeland, Bruce Tremper, and Ben Pritchett)

Typical Full Profile
A typical full profile may include the following observations:
- Total Depth
- Temperature by depth (Section 2.5.1)
- Identification of layer boundaries (Section 2.5.2)
- Hand hardness of each layer
- Grain type and size of each layer (Sections 2.5.3 and 2.5.4)
- Water content of each layer (Section 2.5.5)
- Density of each layer (Section 2.5.6)
- Stability tests (Sections 2.6, 2.7, 2.9, and 2.10)
- Comments

2.4.1 LOCATION
Snow profiles can be observed at a variety of locations depending on the type of information desired. Typical locations include study plots, study slopes, fracture lines, or targeted sites. Full profiles are usually conducted at study plots, study slopes, and fracture lines; however, full profiles and test profiles can be completed at any location.

Study Plot
Study plots are used to observe and record parameters for a long-term record. They are fixed locations that are carefully chosen to minimize contamination of the observations by external forces such as wind, solar radiation, slope angle, and human activity (See Appendix D). Study plots are typically flat sites and can be co-located with a meteorological observing station.

Observations are carried out at a study plot by excavating each snow pit progressively in a line marked with two poles. Subsequent observation pits should be at a distance about equal to the total snow depth, but at least 1 m from the previous one. After each observation, the extreme edge of the pit is marked with a pole to indicate where to dig the next pit (i.e. at least 1 m from that point). When the observations are complete, the snowpit should be refilled with snow to minimize atmospheric influences on lower snowpack layers.

Study plots and study slopes should be selected and marked before the winter and the ground between the marker poles cleared of brush and large rocks. Some operations will require multiple study plots to adequately track snowpack conditions.

Study Slope
The best snow stability information is obtained from snow profiles observed in avalanche starting zones. Since starting zones are not always safely accessible, other slopes can be selected that are reasonably representative of individual or a series of starting zones. Choosing a safe location for a study slope is critical. The study slope should be relatively uniform in aspect and slope angle, and with the exception of the observations, should remain undisturbed during the winter. The study slope may be pre-selected and marked in the same manner as study plots; however, marker poles on slopes will be tilted by snow creep and may have to be periodically reset. Some operations may find it advantageous to collect their time series observations on a study slope in addition to, or in place of, a study plot. Multiple study slopes may be useful.

Fracture Line
Observing snow profiles (Figure 2.2) near an avalanche fracture line can provide valuable information about the cause of the slide. Safety considerations are paramount when selecting a site for a profile. Before approaching a site, observers must evaluate the potential for and consequences of further releases. Snow profiles can be observed on a crown face or flank as well as areas where the weak layer did not fracture (Figure 2.3). When possible, profiles should be observed at a fracture line and at least 1.5 m away from the crown face or flank in undisturbed snow.

Fracture line profiles should be observed at as many locations as possible (Figure 2.3), including thick and thin sections of the fracture line. In addition, use a sketch or camera to document the location of prominent features and location of fracture line profiles. Carefully note terrain, vegetation, solar, and wind effects on the snowpack. Note any evidence of past avalanche activity which may have influenced the structure of the snowpack.

The snow that remains following an avalanche can be either stronger than what slid or dangerously weak. Care should also be taken to choose a location where average crown depth is not exceeded. It is preferable to examine the snow along a fracture line at as many places as possible as time allows.

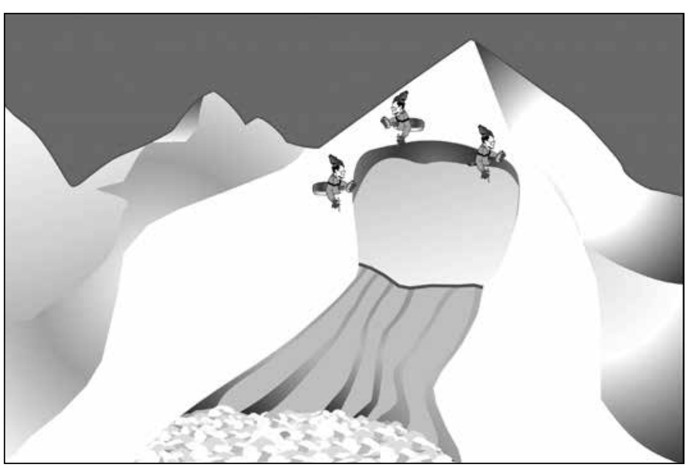


FIGURE 2.3 Possible locations for a fracture line profile. From left to right: undisturbed snow in the flank, undisturbed snow in the crown, on the crown face.

FIGURE 2.4 A targeted site for a snow profile. (P: Doug Richmond)

Targeted Site

A targeted site (Figure 2.4) is selected to satisfy a particular observer's objectives. The site should be selected to target parameters of interest. Keep in mind that exposure to wind, solar radiation, elevation, and other factors produce variations in snowpack characteristics.

General rules for choosing a targeted site include:

- Always evaluate the safety of a location prior to performing a snow profile.
- To minimize the effects of trees, dig the snow pit no closer to trees than the height of the nearest tree (draw an imaginary line from the top of the tree at a 45 degree angle to the snow surface). In high traffic areas, or when evaluating forested slopes this criterion may not be practical.
- Avoid depressions such as gullies or other terrain traps.
- Avoid heavily compacted areas such as tree wells, canopy sluffs, and tracks made by humans or other animals.

2.4.2 FREQUENCY OF OBSERVATIONS

No firm rules can be set on how frequently snow profiles should be observed. Frequency is dependent on climate, terrain, access to starting zones, recent weather, current snow stability, type of avalanche operation, and other considerations. Full profiles should be conducted at regular intervals at study plots and study slopes. Profiles at fracture lines and targeted sites can be completed on an as-needed basis.

2.4.3 EQUIPMENT

The following equipment can be useful when observing snow profiles:

1. Probe
2. Snow shovel (flat bladed shovels are preferred)
3. Snow thermometer (calibrated regularly)
4. Ruler or probe graduated in centimeters
5. Magnifying glass (5x or greater)
6. Crystal card
7. Field book
8. Two pencils
9. Gloves
10. Snow saw
11. 2 meter pre-knotted cord
12. Inclinometer
13. Compass (adjusted for declination)
14. Density kit
15. Brush
16. Altimeter (calibrated regularly)
17. Topographic map
18. Global positioning system (GPS) unit
19. Camera

The thermometers should be calibrated periodically in a slush mixture after the free water has been drained. Glass thermometers must be checked for breaks in the mercury or alcohol columns before every use.

2.4.4 FIELD PROCEDURE

Equipment

Equipment used to measure or observe snow properties should be kept in the shade and/or cooled in the snow prior to use. Observers should wear gloves to reduce thermal contamination of measurements.

Checking Snow Depth

Check the snow depth with a probe before digging the observation pit and make sure the pit is not on top of a boulder, bush or in a depression. Careful probing can also be used to obtain a first indication of snow layering. Probing prior to digging is not necessary in a study plot, or when the snow is much deeper than your probe.

Digging the Snow Pit

Make the hole wide enough to facilitate all necessary observations and to allow shoveling at the bottom. Remember to examine the snow as you dig the pit as valuable information can be obtained during this process. In snow deeper than 2 m it may be advantageous to dig first to a depth of about 1.5 m, make the observations (such as stability tests) and then complete excavation and observations to the necessary depth. The pit face on which the snow is to be observed should be in the shade. Cut the observation face in an adjacent sidewall vertical and smooth. On inclined terrain it is advantageous to make the observations on a shaded sidewall that is parallel to the fall line

Recording

If there are two observers, the first observer can prepare the pit, while the second observer begins the observations (see Figures 2.7 and 2.9 for examples of field notes):

1. Record date, time, names of observers, location, elevation, aspect, slope angle, sky condition, precipitation, wind, surface penetrability (foot and ski penetration), and total snow depth.
2. Observe the air temperature to the nearest 0.5 degree in the shade about 1.5 m above the snow surface. Use a dry thermometer, wait several minutes, and then make several readings about a minute apart to see if the thermometer has stabilized. Record the temperature if there is no change between the two or more readings.
3. Convention for seasonal snow covers is to locate the zero point on the height scale at the ground. However, when the snow cover is deeper than about 3 m it is convenient to locate the zero point at the snow surface. Setting 0 at the snow surface, for test pits, eases comparisons with other snowpack observations made throughout the period. Observers should use whichever protocol fits their needs. In either case the total depth of the snowpack should be recorded when possible.

2.5 SNOWPACK OBSERVATIONS

2.5.1 SNOWPACK TEMPERATURE (*T*)

Observe snow temperature to the nearest fraction of a degree based on the accuracy and precision of the thermometers. Most field thermometers can measure snow temperature within 0.5 °C. Measure the snow surface temperature by placing the thermometer on the snow surface; shade the thermometer. The temperature profile should be observed as soon as practical after the pit has been excavated.

Push the thermometer horizontally to its full length parallel to the surface into the snow (use the shaded side-wall of the pit on a slope). Wait at least one minute, re-insert close by and then read the temperature while the thermometer is still in the snow. Shade the thermometer in order to reduce influence of radiation. One method is to push the handle of a shovel into the snow surface so that the blade casts a shadow on the snow surface above the thermometer. Shading the snow above your thermometer is important when you are making temperature measurements in the upper 30 cm of the snowpack.

Measure the first sub-surface snow temperature 10 cm below the surface. The second temperature is observed at the next multiple of 10 cm from the previous measurement and from there in intervals of 10 cm to a depth of 1.4 m below the surface, and at 20-cm intervals below 1.4 m. Measure the snow temperatures at closer intervals when needed, as may be the case when the temperature gradients are strong, significant density variations exist, or when the temperatures are near to 0 °C. When measuring relatively small temperature variations, as is common around a crust or density discontinuity, greater accuracy and reliability in measurements may be possible by using a single thermometer/temperature probe.

Begin the next observation while snow temperatures are being measured.

Compare thermometers first when two or more are used simultaneously. Place side-by- side in a homogeneous snow layer and compare the measurements. If they do not agree, only one of the thermometers should be used. Punch a hole in the snowpack with the metal case or a knife before inserting the thermometer into very hard snow and at ground surface. It is important to regularly check the accuracy of all thermometers by immersing them in a slush mixture after the free water has been drained; each should read 0°C. Prepare this mixture in a thermos and recalibrate or note variation from 0°C on the thermometer.

2.5.2 LAYER BOUNDARIES

Determine the location of each major layer boundary (Figure 2.5). Brushing the pit wall with a crystal card or a soft bristle paint brush will help to bring out the natural layering of the snowpack. Identify weak layers or interfaces of layers where a failure might occur. Record the distance from the layer boundary to the ground or snow surface depending on the convention being used.

Many operations find it useful to track specific features within the snowpack. Persistent weak layers or layers that are likely to produce significant avalanche activity (such as crusts, surface hoar, or near- surface facets) can be named with the date that they were buried. Some operations also find it useful to number each significant precipitation event and reference potential weak layers with these numbers or as interfaces between two numbered events.

Snow Hardness *(R)*

Observe the hardness of each layer with the hand hardness test. Record under "*R*" (resistance) the object that can be pushed into the snow with moderate effort parallel to the layer boundaries (Table 2.1).

TABLE 2.1 Hand Hardness Index

SYMBOL	HAND TEST	TERM	GRAPHIC SYMBOL
F	Fist in glove	Very low	
4F	Four fingers in glove	Low	/
1F	One finger in glove	Medium	X
P	Blunt end of pencil	High	//
K	Knife blade	Very High	⋇
I	Too hard to insert knife	Ice	▬
N/O	Not observed		N/A

Fierz and others (2009) suggests a maximum force of 10 to 15 newtons (1 to 1.5 kg force or about 2 or 3 pounds) to push the described object into the snow. Wear gloves when conducting hand hardness observations.

Slight variations in hand hardness can be recorded using + and - qualifiers (i.e. P+, P, P-). A value of 4F+ is less hard than 1F-. Individual layers may contain a gradual change in hand hardness value. These variations can be recorded in a graphical format (Figures 2.8 and 2.9), or by using an arrow to point from

FIGURE 2.5 The layered nature of a seasonal snow cover. (P: Bruce Tremper)

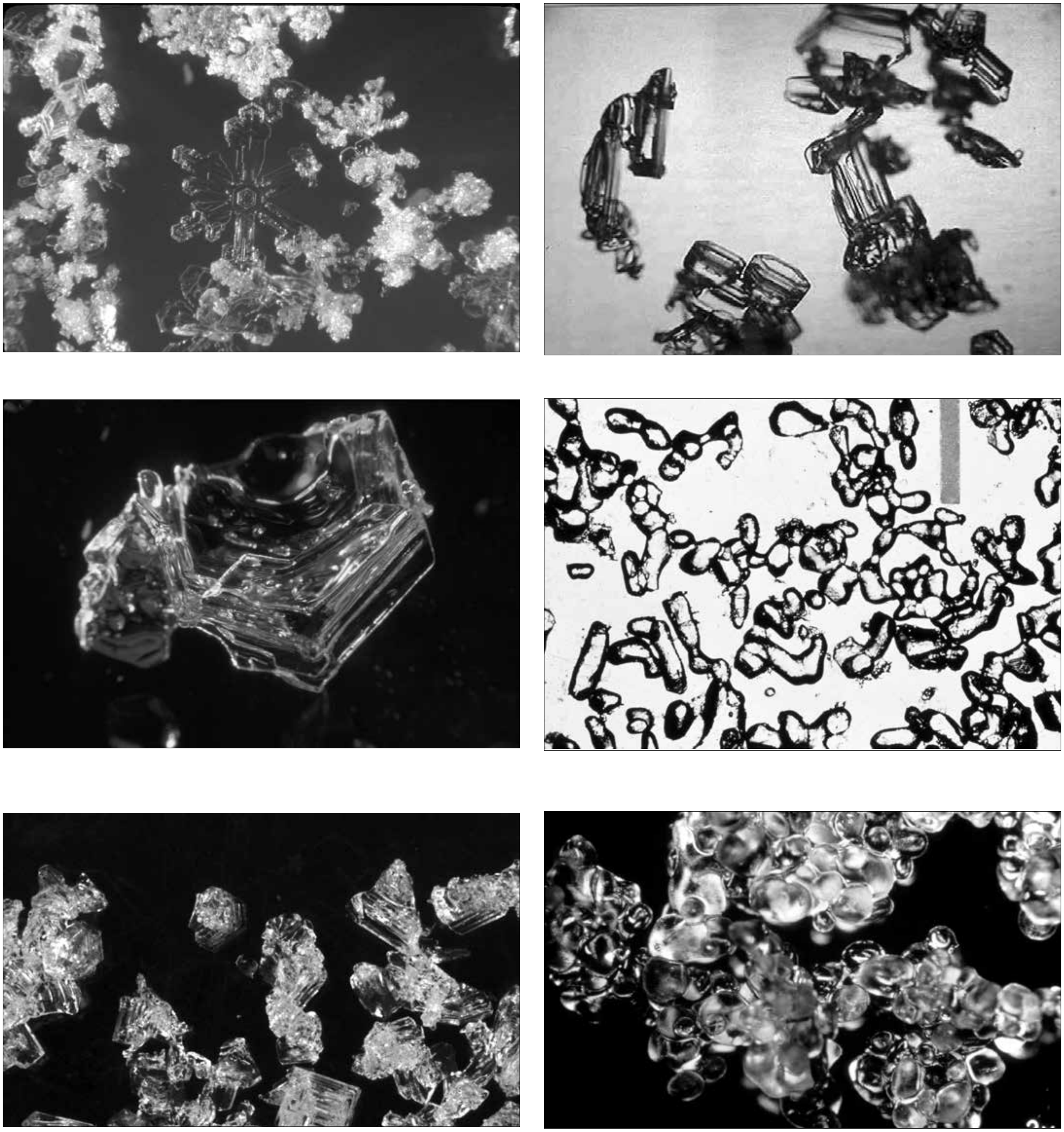


FIGURE 2.6 Snow crystal formations found in seasonal snow cover. Clockwise from top-left: Partially rimed new snow (+); Faceted grains formed near the snow surface (⧄); Rounded snow grains (●) ; Clustered melt forms (⚭); Faceted snow grains (□); Depth hoar (∧). (P: Kelly Elder, Joe Stock, courtesy of John Montagne, Ethan Greene, and Sam Colbeck)

the upper value to the lower value (i.e. a layer that is soft on top and gets harder as you move down would read 4F+ → 1F).

2.5.3 GRAIN FORM (*F*)

The International Classification for Seasonal Snow on the Ground (Fierz and others, 2009) presents a classification scheme composed of major and minor classes based on grain morphology and formation process. This scheme is used throughout this document. Primary classes are listed in Tables 2.2 and 2.3. Subclasses are listed in Appendix F.

The major class of Precipitation Particles can be divided into minor classes that represent different forms of solid precipitation according to the International Classification for Seasonal Snow on the Ground. Commonly, the Precipitation Particles class (graphic symbol "+") may be replaced by one of the classes in Table 2.2. Snow layers often contain crystals from more than

TABLE 2.2 Basic Classification of Snow on the Ground

SYMBOL	DESCRIPTION	DATA CODE
+	Precipitation Particles (New Snow)	PP
⊚	Machine Made Snow	MM
/	Decomposing and Fragmented Particles	DF
●	Rounded Grains (monocrystalline)	RG
□	Faceted Crystals	FC
Λ	Depth Hoar	DH
V	Surface Hoar	SH
○	Melt Forms	MF
▬	Ice Formations	IF

TABLE 2.3 Basic Classification of Snow in the Atmosphere

SYMBOL	DESCRIPTION	DATA CODE
▭	Columns	cl
↔	Needles	nd
⊙	Plates	pl
∗	Stellars and dendrites	sd
↱	Irregular crystals	ir
⩚	Graupel	gp
▲	Hail	hl
⚠	Ice pellets	ip

Notes for Tables 2.2 and 2.3: Modifications to Fierz and others, 2009: The use of a subscript "r" modifier is retained to denote rimed grains in the Precipitation Particles (PP) class and its subclasses except for gp, hl, ip, rm (Example: PP-r). The Decomposing and Fragmented Particles (DF) major class may be modified with "r". Subclasses for surface hoar are listed in Appendix F.

one class or that are in transition between classes. In this case the observer can select primary and secondary classes for a single layer and place the secondary class in parentheses (e.g. a new snow layer composed of mostly plates with some needles could be listed as ⊙ (↔)).

In warm weather the crystals may melt and their shape may change rapidly on the crystal card. In this case, a quick decision must be made and repeated samples taken from various depths of the same layer.

Snow layers often contain crystals in different stages of metamorphism (Figure 2.6). The classification should refer to the predominant type, but may be mixed when different types are present in relatively equal numbers. A maximum of two grain forms may be displayed for any single layer. The sub-classification in Fierz, and others, 2009 has "mixed forms" classes that can be used by experienced observers who recognize grains that are in a transition stage between classes.

Illustrations of the various types of crystal shapes may be found in the following publications: LaChapelle, 1992; Perla, 1978; Colbeck and others, 1990; McClung and Schaerer, 2006, and Fierz and others, 2009.

Refer to the *International Classification for Seasonal Snow on the Ground* (Fierz and others, 2009) for complete descriptions of the grain forms listed here. (http://www.cryosphericsciences.org/snowClassification.html)

2.5.4 GRAIN SIZE (*E*)

Determine the grain size in each layer with the aid of a crystal card. In doing so, disregard the small particles and determine the average greatest extension of the grains that make up the bulk of the snow. Record the size or the range of sizes in millimeters in column "*E*". Record size to the nearest 0.5 mm, except for fine and very fine grains which may be recorded as 0.1, 0.3 or 0.5mm.

Where a range in sizes exists for any single grain form, specify the average and maximum size with a hyphen. **Example:** 0.5-1.5

2.5.5 LIQUID WATER CONTENT (*Θ*)

Classify liquid water content by volume of each snow layer that has a temperature of 0°C. Gently squeeze a sample of snow with a gloved hand and observe the reaction (Table 2.4); record in the column headed "θ" (theta).

2.5.6 DENSITY (ρ)

Measure density of the snow in layers that are thick enough to allow insertion of the snow sampling device. Small samplers are more suitable for measuring the density of thin layers and larger samplers are better suited for depth hoar.

Insert the sample cutter into the pit wall, compacting the sample as little as possible. On angled slopes, sampling on the pit sidewall will make it easier to sample a single layer. Samples used for bulk density calculations can contain more than one snow layer, otherwise be sure to sample one layer if possible. Trim the excess snow off the cutter and weigh. Either write down the mass under comments and calculate density later, or calculate density on site and note it in the column headed "ρ" (rho).

Calculate density as follows: Divide the mass (g) of the snow sample by the sample volume (cm^3) and multiply by 1000 to express the result in kg/m^3.

$$\rho\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{\text{mass of snow sample (g)}}{\text{sample volume (cm}^3\text{)}} \times 1000$$

The nomogram included on the final page (Section I.5) automates this calculation. Record as a whole number.

Practical methods for calculating snow density can be established based on the snow volume sampled. For example, when using a 500 cm^3 snow sampling tube multiply the mass of snow sample in the tube by 2, with a 250 cm^3 sampler, multiply the snow sample mass by 4, etc.

TABLE 2.4 Liquid Water Content of Snow (adapted from Fierz and others, 2009)

CLASS	DEFINITION	WATER CONTENT (BY VOLUME)	SYMBOL	DATA CODE
Dry	Usually the snow temperature (*T*) is below 0 °C but dry snow can occur at any temperature up to 0 °C. Disaggregated snow grains have little tendency to adhere to each other when pressed together. Difficult to make a snowball.	0%		D
Moist	*T* = 0 °C. Water is not visible even at 10x magnification. When lightly crushed, the snow has a distinct tendency to stick together. Snowballs are easily made.	<3%	I	M
Wet	*T* = 0 °C. Water can be recognized at 10x magnification by its meniscus between adjacent snow grains, but water cannot be pressed out by moderately squeezing the snow in the hands (Pendular regime).	3-8%	II	W
Very Wet	*T* = 0 °C. Water can be pressed out by moderately squeezing the snow by hand, but there is some air confined within the pores (Funicular regime)	8-15%	III	V
Slush	*T* = 0 °C. The snow is flooded with water and contains a relatively small amount of air.	>15%	IIII	S

2.5.7 STRENGTH AND STABILITY TESTS

Perform tests of strength and stability as appropriate (see Sections 2.6, 2.7, 2.9, and 2.10 for details on individual tests). It may be advantageous to perform multiple tests or iterations of a test.

2.5.8 MARKING THE SITE

If additional observations are to be made at this site, fill the pit and place a marker pole at the extreme edge. Pits dug in areas open to the public should be filled back in with snow.

2.5.9 GRAPHICAL SNOW PROFILE REPRESENTATION

Snow profiles can be represented graphically in a standard format for quick reference and permanent record (Figures 2.8 and 2.9).

1. Plot the snow temperatures as a curve; mark the air temperature above the snow surface and use a dashed line to connect the two.
2. Plot the height of the snow layers to scale.
3. Use graphic symbols for the shape of grains and liquid water content. Record N/O when the hardness or liquid water content can not be determined (a blank implies fist hardness or dry snow respectively). Use of graphic symbols for hardness is optional.
4. Tabulate grain size and density with the values observed in the field.
5. Include written comments where appropriate. If possible, label important layers by their date of burial.
6. Include the results of appropriate strength and stability tests in the comments column.

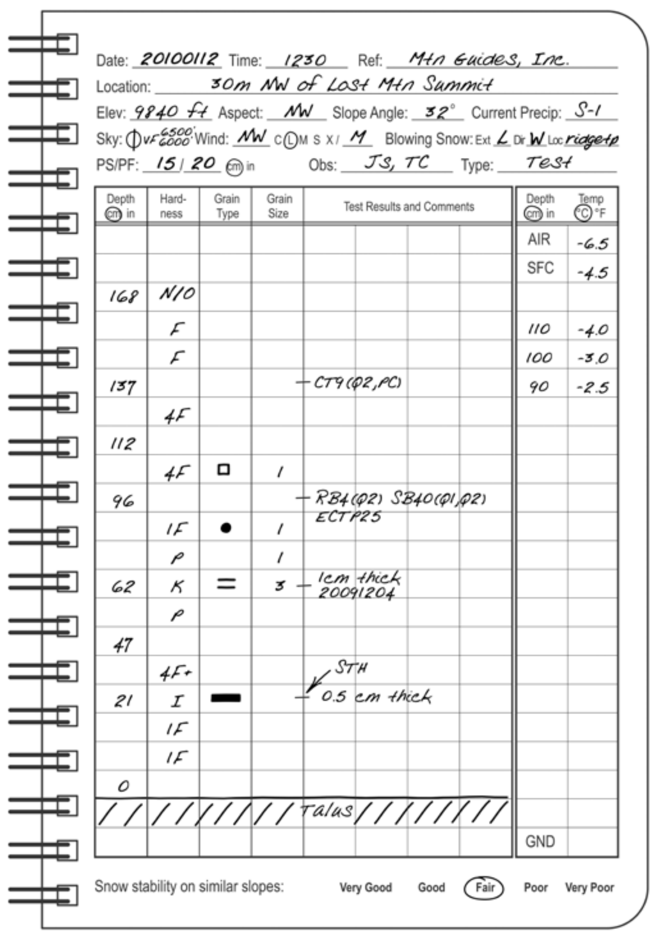


FIGURE 2.7 Example of field notes from a test profile.

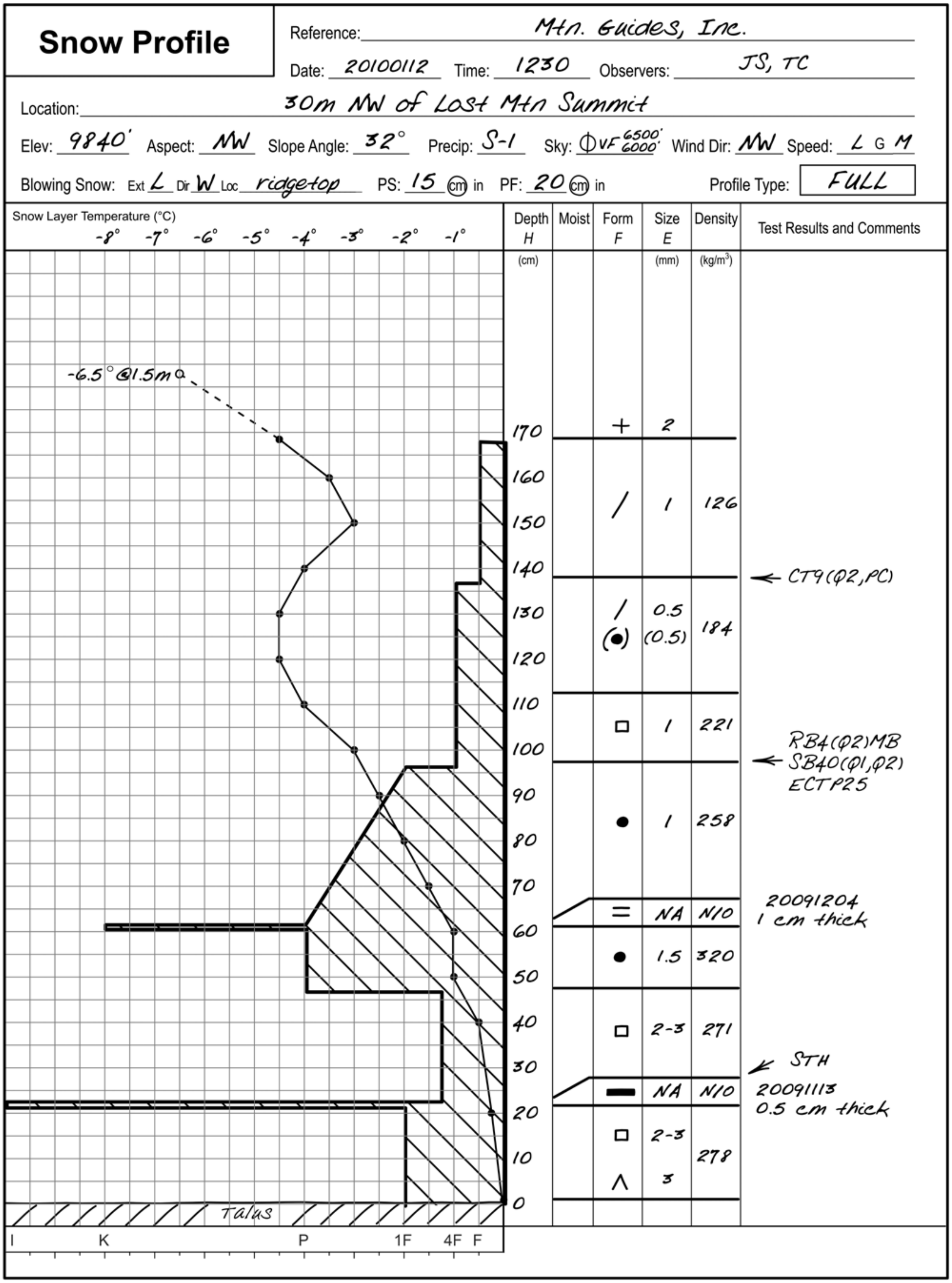


FIGURE 2.8 Hand drawn full snow profile. Snow profile forms are provided in Appendix I.

7. Document grain form and size of the failure layer. Draw an arrow at the height of each observed failure and use a shorthand notation to describe the test. When multiple tests are performed the results of every test should be included.

   Examples:
   - STE (Q1) SH 2.5 (shovel shear test, easy shear, quality 1, on 2.5 mm surface hoar)
   - RB6 (Q2) FC 1.5 (rutschblock score six, quality 2, on 1.5 mm faceted crystals)
   - CT8 (Q1) DH 2.0 (compression test, on 8th tap, quality 1, on 2.0 mm depth hoar)
   - CT12 (Q1x2) △ (two compression tests on 12th tap, quality 1, on graupel)

8. Plot the hand hardness test results as a horizontal bar graph (Figures 2.8 and 2.9). If a snowpack layer has variable hand hardness, the length of the upper or lower ends of the bar can be shortened or lengthened and the connecting line angled or curved to reflect the variation (Figures 2.8 and 2.9). Changes in hardness category can be emphasized by using the bar lengths in Table 2.5. In regions where both weak layers and slabs are composed of very soft snow (1F or softer), it may be beneficial to plot the hard hardness index using the same distance to represent each category.

TABLE 2.5 Graphical Representation of Hand Hardness Index

HAND TEST	LENGTH OF BAR
Fist in glove	Base Length
Four fingers in glove	2X Base Length
One finger in glove	4X Base Length
Blunt end of pencil	8X Base Length
Knife blade	16X Base Length
Ice	20X Base Length

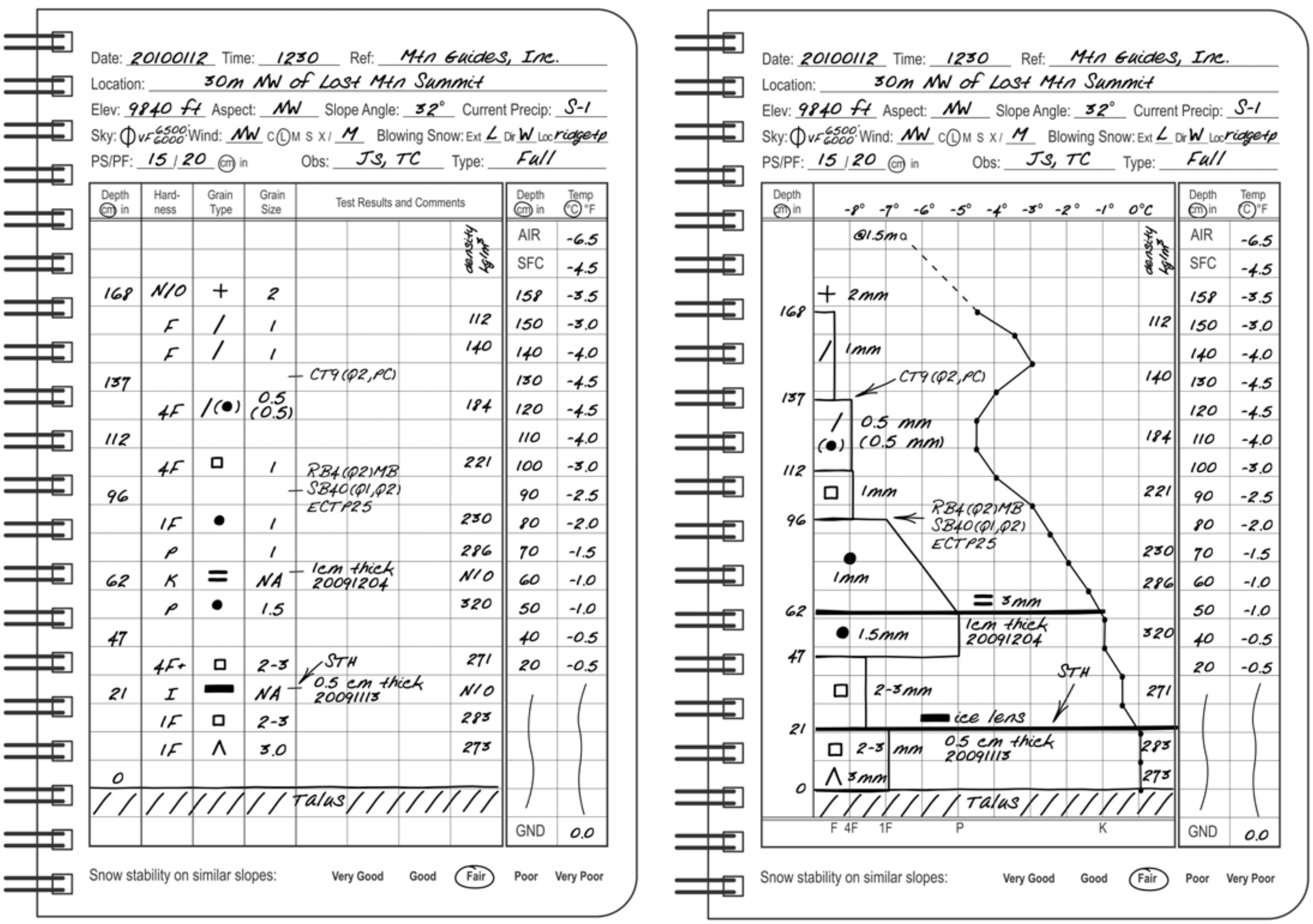


FIGURE 2.9 Two different methods for recording field notes from a full profile.

TABLE 2.6 A comparison of the categories in the Fracture Character and Shear Quality scales. (after van Herwijnen and Jamieson, 2003 and Birkeland, 2004)

FRACTURE CHARACTER CATEGORY	SUBCLASS	MAJOR CLASS	TYPICAL SHEAR QUALITY
	FRACTURE CHARACTER DATA CODE		
Sudden Planar	SP	SDN	Q1
Sudden Collapse	SC	SDN	Q1
Progressive Compression	PC	RES	Q2 or Q3
Resistant Planar	RP	RES	Q2
Break	BRK	BRK	Q3

2.6 CHARACTERIZING FRACTURES IN COLUMN AND BLOCK TESTS

Many of the stability tests described in the following sections yield some indication of the load required to produce a fracture. Fracture is the process of crack propagation. In addition to the magnitude of the load, observing the nature of the fracture can improve estimations of snow stability and can, in particular, reduce false-stable results (Johnson and Birkeland, 1998; Birkeland and Johnson, 1999; Johnson and Birkeland 2002; Birkeland and Johnson 2003; van Herwijnen and Jamieson, 2002; van Herwijnen, 2003). Both methods described below may be included with the results of a column or block test (see Section 2.7) and provide additional information about the stability of the snow slope. All the research with these methods has been conducted using compression-type tests such as the compression, stuffblock, and rutschblock tests.

The methods described in this section provide a qualitative assessment of the fracture (crack propagation) potential. Although the definitions and approach differ, the phenomena they describe are essentially identical (Table 2.6). Both methods require experienced observers to make somewhat subjective assessments, especially when trying to determine whether a planar fracture is sudden (SP/Q1) or resistant (RP/Q2). Members of an operational program should select the method that works best for their application and periodically compare their ratings to ensure consistency.

2.6.1 SHEAR QUALITY

Shear Quality was developed by avalanche workers at the Gallatin National Forest Avalanche Center (Southwest Montana) to assess fracture (crack propagation) potential. It can be used with many of the stability tests in this chapter, but is not recommended for use with the Extended Column Test and Propagation Saw Test, which were developed specifically to assess crack propagation potential.

Procedure

1. Conduct any of the stability tests described in this chapter.
2. Carefully observe how the fracture occurs and examine the nature of the fracture plane.
3. Record the results in accordance with the shear quality definitions (Table 2.7).

Recording

The results can be included at the end of a shear test result. Example: A rutschblock score of 2 with a shear quality of 1 would

TABLE 2.7 Shear Quality Ratings

DESCRIPTION	DATA CODE
Unusually clean, planar, smooth and fast shear surface; weak layer may collapse during fracture. The slab typically slides easily into the snow pit after weak layer fracture on slopes steeper than 35 degrees and sometimes on slopes as gentle as 25 degrees. Tests with thick, collapsible weak layers may exhibit a rougher shear surface due to erosion of basal layers as the upper block slides off, but the initial fracture was still fast and mostly planar.	Q1
"Average" shear; shear surface appears mostly smooth, but slab does not slide as readily as Q1. Shear surface may have some small irregularities, but not as irregular as Q3. Shear fracture occurs throughout the whole slab/weak layer interface being tested. The entire slab typically does not slide into the snow pit.	Q2
Shear surface is non-planar, uneven, irregular and rough. Shear fracture typically does not occur through the whole slab/weak layer interface being tested. After the weak layer fractures the slab moves little, or may not move at all, even on slopes steeper than 35 degrees.	Q3

TABLE 2.8 Fracture Character Ratings

FRACTURE CHARACTER CATEGORY	SUBCLASS	DATA CODE	MAJOR CLASS	DATA CODE
A thin planar* crack suddenly crosses column in one loading step AND the block slides easily** on the weak layer	Sudden planar	SP	Sudden	SDN
Crack crosses the column with a single loading step and is associated with a noticeable collapse of the weak layer.	Sudden collapse	SC	Sudden	SDN
A crack of noticeable thickness (non-planar fractures often greater than 1cm), which usually crosses the column with a single loading step, followed by step-by-step compression of the layer with subsequent loading steps.	Progressive compression	PC	Resistant	RES
Planar or mostly planar shear surface that requires more than one loading step to cross column and/or the block does NOT slide easily** on the weak layer.	Resistant planar	RP	Resistant	RES
Non-planar; irregular fracture.	Non-planar break	BRK	Break	BRK

Note: * *"Planar" based on straight fracture lines on front and side walls of column.*
*** Block slides off column on steep slopes. On low-angle slopes, hold sides of the block and note resistance to sliding.*

be recorded as RB2(Q1). A compression test that fractured with 5 taps from the elbow producing a rough shear plane would be recorded as CT15(Q3).

2.6.2 FRACTURE CHARACTER

Fracture Character was developed by the Applied Snow and Avalanche Research Group at the University of Calgary to assess fracture (crack propagation) potential. It can be used with many of the stability tests in this chapter and other tests that load a small column of snow until a fracture appears, but is not recommended for use with the Extended Column Test and Propagation Saw Test.

Fracture character is best observed in tests performed on a small isolated column of snow where the objective is to load the column until it fractures, or fails to fracture. The front face and side walls of the test column should be as smooth as possible. The observer should be positioned in such a way that one side wall and the entire front face of the test column can be observed. Attention should be focused on weak layers or interfaces identified in a profile or previous snowpack.

Procedure

1. Conduct a stability test.
2. Carefully observe how the fracture occurs in the target weak layer. For tests on low-angled terrain that produced planar fractures, it may be useful to slide the two shear surfaces across one another by carefully grasping the two sides of the block and pulling while noting the resistance.
3. Record the results in accordance with the definitions in Table 2.8.

Recording

The results can be included at the end of a stability test result.

Example:

A sudden fracture in a rutschblock test with a score of 2 would be recorded as RB2(SDN). A compression test that fractured with 5 taps from the elbow producing a resistant planar fracture would be recorded as CT15(RP).

2.7 COLUMN AND BLOCK TESTS

2.7.1 SITE SELECTION

Test sites should be safe, geographically representative of the avalanche terrain under consideration, and undisturbed. For example, to gain information about a wind-loaded slope, find a safe part of a similarly loaded slope for the test. The site should not contain buried ski tracks or avalanche deposits. In general, the site should be further than about one tree length from trees where buried layers might be disturbed by wind action or by clumps of snow which have fallen from nearby trees (imagine a line drawn between a tree top and the snow surface, the acute angle between that line and the horizontal should be at most 45°). Föhn (1987a) recommends slope angles of at least 30° for rutschblock tests, but stability tests done on 25°-30° slopes can yield useful information. Be aware that near the top of a slope snowpack layering and hence test scores may differ from the slope below.

Recently, interest in understanding and documenting spatial variations in the physical properties of snow has increased in both the research and applied communities (Schweizer et al., 2008). The general guidelines outlined in the paragraph above remain part of good field practice. However, there is increasing evidence that making more observations is an effective strategy for avalanche operations and can help minimize the frequency of false-stable situations (Birkeland and Chabot, 2006). Both scientists and field workers should maintain a high level of curiosity and continue to search for signs and areas of instability, even during periods when the snow appears to be stable.

2.7.2 SHOVEL SHEAR TEST

Objective

Identification of the location of weak layers is the primary objective of the Shovel Shear Test. The test provides:

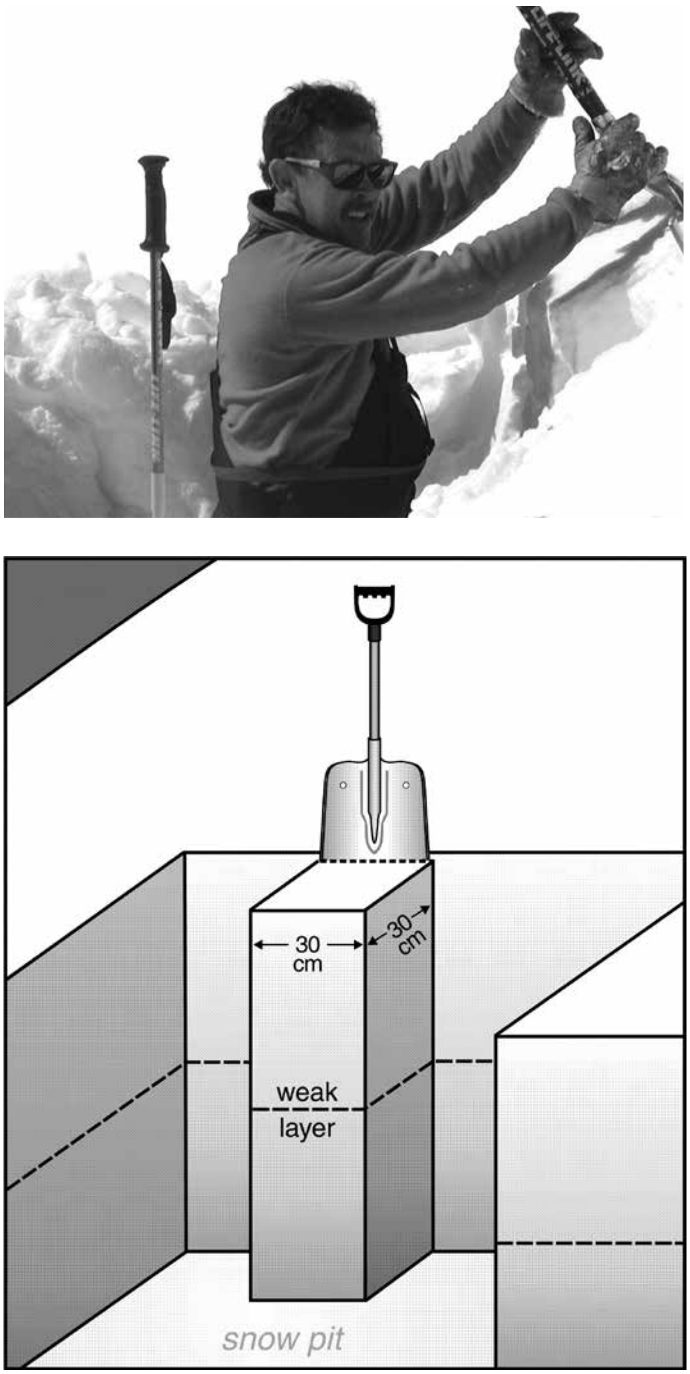


FIGURE 2.10 Photograph and schematic of the Shovel Shear Test. (P: Kelly Elder)

1. Information about the location where the snow could fail in a shear
2. A qualitative assessment of weak layer strength. It is best applied to identify buried weak layers, and it does not usually produce useful results in layers close to the snow surface.

Procedure

A shovel is the only equipment required for the Shovel Shear Test. However, a snow saw will make cutting the snow column easier and more precise.

1. Select a safe site that has undisturbed snow and is geographically representative of slopes of interest
2. Expose a fresh pit wall by cutting back about 0.2 m from the wall of a full snow profile or test profile.
3. Observers can remove very soft snow (fist hardness) from the surface of the area where the test is to be carried out if necessary.
4. On the snow surface mark a cross section of the column to be cut, measuring 30 cm wide and 30 cm in the upslope direction (approximately the width of the shovel blade to be used).
5. Cut a chimney wide enough to allow the insertion of the saw on one side of the column and a narrow cut on the other side.
6. Make a vertical cut at the back of the column and leave the cutting tool (saw) at the bottom for depth identification. The back-cut should be 0.7 m deep maximum and end in medium hard to hard snow if possible.
7. Carefully insert the shovel into the back-cut no farther than the heel of the shovel. Hold the shovel handle with both hands and apply an even force in the down-slope (slope parallel) direction (Figure 2.10). Be careful not to pry the column away from the snow pit wall.
8. When the column breaks in a smooth shear plane above the low end of the back-cut, mark the level of the shear plane on the rear (standing) wall of the back-cut.
9. After a failure in a smooth shear layer or an irregular surface at the low end of the back-cut, or when no failure occurs, remove the column above the bottom of the back-cut and repeat steps 6 to 8 on the remaining column below.
10. Repeat the test on a second column with the edge of the shovel 0.1 m to 0.2 m above the suspected weak layer.
11. Measure and record the depth of the shear planes if they were equal in both tests. Repeat steps 4 to 9 if the shear planes were not at the same depth in both tests.
12. If no break occurs, tilt the column and tap (see Section 2.9.4).
13. Use Table 2.9 to classify the results of the test.
14. Observe and classify the crystal form and size at the shear planes. (Often a sample of the crystals is best obtained from the underside of the sheared block.)
15. Record the results of the test with the appropriate data code from Table 2.9 along with the height, and grain type and size of the weak layer (i.e. "STE@125cm↑ □ 1mm" would be an easy shear on a layer of 1 mm faceted grains 125 cm above the ground).

Results

The ratings of effort are subjective and depend on the strength and stiffness of the slab, dimensions of the shovel blade and handle, and the force applied by the tester. Observers are cautioned

TABLE 2.9 Loading Steps and Shovel Shear Test Scores

TERM	DESCRIPTION	EQUIVALENT SHEAR STRENGTH (PA)	DATA CODE
Collapse	Block collapses when cut		STC
Very Easy	Fails during cutting or insertion	<100	STV
Easy	Fails with minimum pressure	100-1000	STE
Moderate	Fails with moderate pressure	1000-2500	STM
Hard	Fails with firm sustained pressure	2500-4000	STH
No Shear	No shear failure observed		STN

FIGURE 2.11 Stepping onto the block during a Rutschblock Test. (P: Kelly Elder)

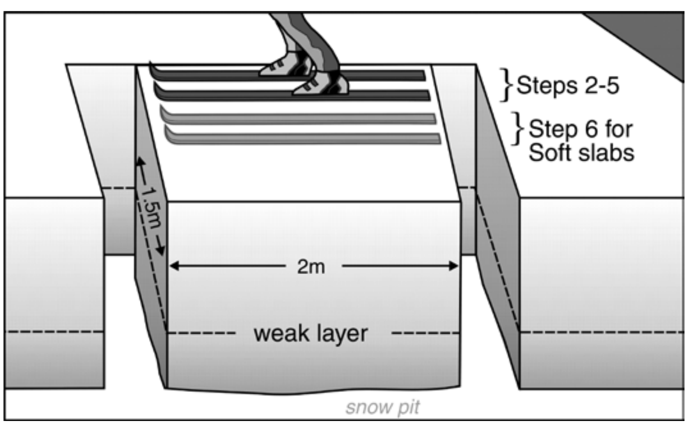


FIGURE 2.12 Schematic of the Rutschblock Test. (after Jamieson and Johnston, 1993a)

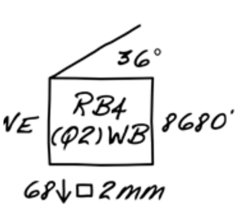


FIGURE 2.13 A field notebook method for recording a rutschblock score, release type, shear quality (center of box) along with the slope angle, elevation, crystal form and size, depth of weak layer, and aspect (clockwise from top). Arrows can be used to indicate whether the depth of the weak layer was measured from the snow surface or the ground (i.e. 68 cm below the snow surface).

that identification of the location of weak layers is the primary objective of the shovel shear test.

2.7.3 RUTSCHBLOCK TEST

The Rutschblock (or glide-block) test was developed in Switzerland in the 1960s. This section is based on analysis of rutschblock tests in Switzerland (Föhn, 1987a; Schweizer, 2002) and Canada (Jamieson and Johnston, 1993a and 1993b).

Objective

The Rutschblock is a good slope test for layers up to 1 m deeper than ski penetration. The test does not eliminate the need for snow profiles or careful field observations, nor does it, in general, replace other slope tests such as slope cutting and explosive tests.

Procedure

A shovel is required. Ski pole mounted saws or rutschblock cutting cords (8 meters of 3-4 mm cord with knots every 20-30 cm) save time isolating the block in soft or medium hard snowpacks. However, extra care is required to ensure the block has straight edges. Large rutschblock saws are useful to cut knife-hard crusts. The Rutschblock Test can be performed with either skis or a snowboard.

1. Select a safe site that has undisturbed snow and is geographically representative of the slopes of interest.
2. Observe a snow profile and identify weak layers and potential slabs.
3. Excavate a pit wall, perpendicular to the fall line, that is wider than the length of the tester's skis (2 m minimum)
4. Mark the width of the block (2 m) and the length of the side cuts (1.5 m) on the surface of the snow with a ski, ruler, etc. The block should be 2 m wide throughout if the sides of the block are to be dug with a shovel. However, if the side walls are to be cut with a ski, pole, or saw, the lower wall should be about 2.1 m across and the top of the side cuts should be about 1.9 m apart.
5. This flaring of the block ensures it is free to slide without binding at the sides
6. Dig out the sides of the block, or make vertical cuts down the sides using the lines marked on the snow surface.
7. Cut the downhill face of the block smooth with a shovel.
8. Using a ski or snow saw make a vertical cut along the uphill side of the block so that the block is now isolated on four sides (Figure 2.12).

TABLE 2.10 Rutschblock Loading Steps and Scores

FIELD SCORE	LOADING STEP THAT PRODUCES A CLEAN FRACTURE SURFACE	DATA CODE
1	The block slides during digging or cutting.	RB1
2	The skier approaches the block from above and gently steps down onto the upper part of the block within 35 cm of the upper wall (Figure 2.11).	RB2
3	Without lifting the heels, the skier drops once from straight leg to bent knee position (feet together), pushing downwards and compacting surface layers.	RB3
4	The skier jumps up and lands in the same compacted spot.	RB4
5	The skier jumps again onto the same compacted spot.	RB5
6	For hard or deep slabs, remove skis and jump on the same spot. For soft slabs or thin slabs where jumping without skis might penetrate through the slab, keep skis on, step down another 35 cm (almost to mid-block) and push once then jump three times.	RB6
7	None of the loading steps produced a smooth slope-parallel failure.	RB7

9. Rate any fractures that occur while isolating the block as RB1.
10. Conduct loading steps as described in Table 2.10, and record the results with the appropriate rutschblock score as well as the release type that occurred during the test (Table 2.11). A field book notation for recording rutschblock results is shown in Figure 2.13.
11. Rate any identified weak layers that did not fracture as no failure (RB7).
12. Record rutschblock results in a field book along with pertinent site information using the method shown in Figure 2.13 or the data codes in Tables 2.10 and 2.11.

Results

The rutschblock only tests layers deeper than ski penetration. For example, a weak layer 20 cm below the surface is not tested by skis that penetrate 20 cm or more. Higher and more variable rutschblock scores are sometimes observed near the top of a slope where the layering may differ from the middle and lower part of the slope (Jamieson & Johnston, 1993). Higher scores may contribute to an incorrect decision. The rutschblock may not effectively test weak layers deeper than about 1 m below ski penetration.

Research in the Canadian Rocky Mountains has shown that:
Field score of 1, 2, or 3: The block fails before the first jump. The slope is unstable. It is likely that slopes with similar snow conditions can be released by a skier.

Field score of 4 or 5: The block fails on first or second jump. The stability of the slope is suspect. It is possible for a skier to release slab avalanches on slopes with similar snow conditions. Other observations or tests must be used to assess the slab stability.

Field score of 6 or 7: The block does not fail on the first or second jump. There is a low (but not negligible) risk of skiers triggering avalanches on slopes with similar snow conditions. Other field observations and tests, and safety measures remain appropriate.

TABLE 2.11 Release Type Ratings for the Rutschblock Test

TERM	DESCRIPTION	DATA CODE
Whole block	90 – 100% of the block	WB
Most of block	50 – 80% of the block	MB
Edge of block	10 – 40% of the block	EB

Schweizer, McCammon and Jamieson (2008) found that rutschblock scores combined with release type correlated well with observed avalanche occurrence. Johnson and Birkeland (2002) found that combining rutschblock scores with shear quality ratings reduced the number of false-stable results.

2.7.4 COMPRESSION TEST

The Compression Test was first used by Parks Canada wardens working in the Canadian Rockies in the 1970s. The following procedure was developed by the University of Calgary avalanche research project in the late 1990s. Similar tests have been developed elsewhere.

Objective

The Compression Test attempts to locate weak layers in the upper snowpack (~ 1m) and provide an indication of the triggering likelihood on nearby slopes with similar snowpack conditions. The tester places a shovel blade on top of an isolated snow column and taps the blade (Figure 2.14), causing weak layers within the column to fracture. These fractures can be seen on the smooth walls of the column. Compression tests are typically performed on sloping terrain. Tests of distinct, collapsible weak layers can be performed on level study plots.

Procedure

A shovel is the only piece of equipment required for the Compression Test. However, a snow saw will make cutting the column of snow easier and more precise.

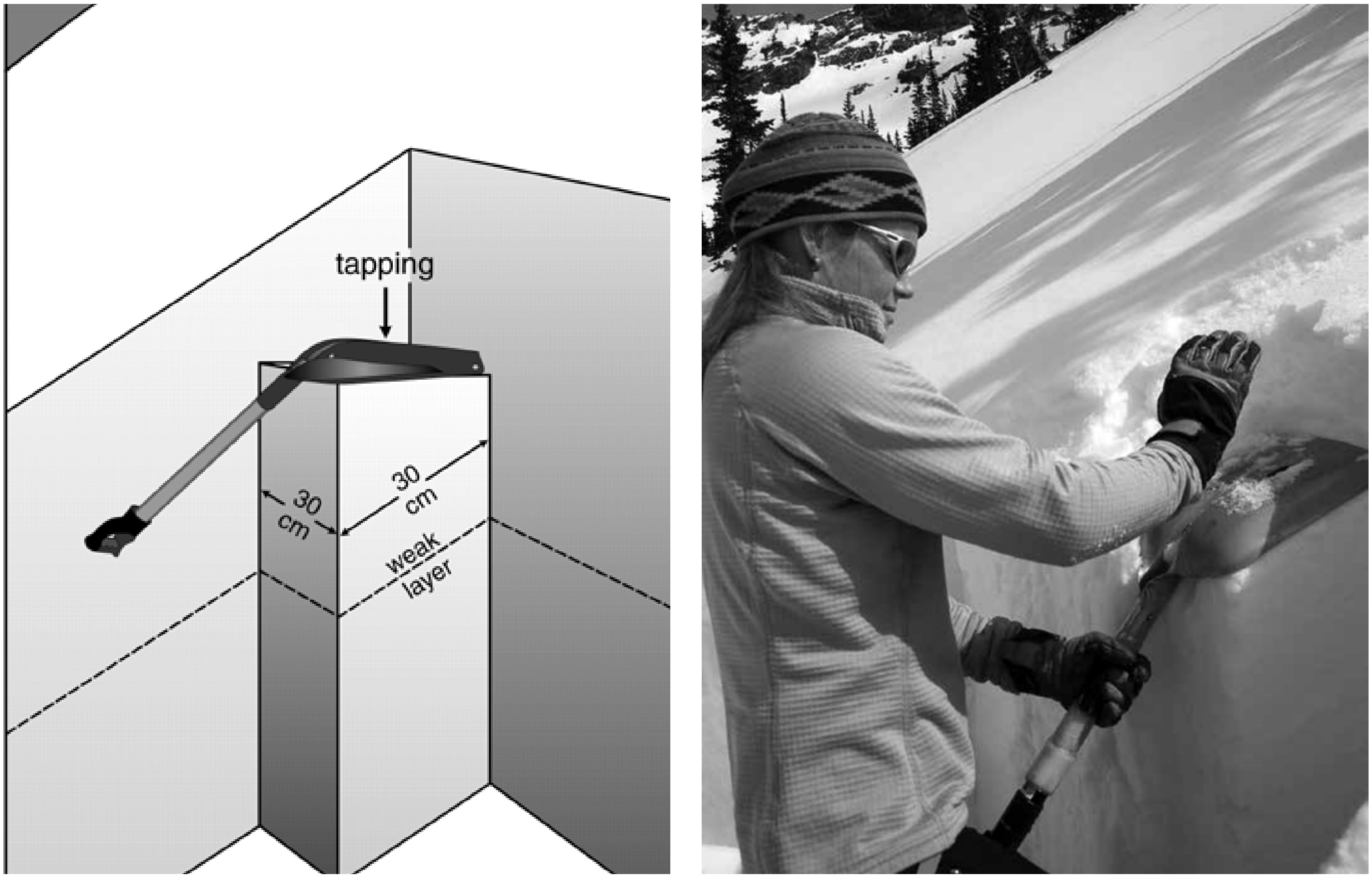


FIGURE 2.14 Schematic and photograph of the Compression Test. (P: Bruce Tremper)

1. Select a safe site that has undisturbed snow and is geographically representative of the slopes of interest.
2. Isolate a column of snow 30 cm wide with a 30 cm upslope dimension that is deep enough to expose potential weak layers on the smooth walls of the column (Figure 2.14). Field tests have indicated that the size of the shovel blade used has minimal impact on test outcome (Jamieson, 1996). A depth of 100-120 cm is usually sufficient since the compression test rarely produces fractures in deeper weak layers. Taller columns tend to wobble during tapping, potentially producing misleading results for deep weak layers (Jamieson, 1996).
3. Rate any fractures that occur while isolating the column as Very Easy (CTV).
4. If the snow surface slopes, you may remove a wedge of snow to level the top of the column.
5. Place a shovel blade on top of the column. Tap 10 times with fingertips, moving hand from wrist and note the number of taps required to fracture the column (1 to 10).
6. If during tapping the column fails, leave the failed portion on top of the column, provided it does not compromise other observations. If the upper part of the column slides off or no longer "evenly" supports further tapping on the column, remove the damaged part of the column and continue tapping.
7. Tap 10 times with the fingertips or knuckles moving forearm from the elbow, and note the total number of taps required to fracture the column (11 to 20). While moderate taps should be harder than easy taps, they should not be as hard as one can reasonably tap with the knuckles.
8. Finally, hit the shovel blade moving the arm from the shoulder 10 times with open hand or fist and note the total number of taps required to fracture the column (21 to 30). If the moderate taps were too hard, the operator will often try to hit the shovel with even more force for the hard taps and may hurt his or her hand.
9. Record the results as described in Table 2.12. Rate any identified weak layers that did not fracture as No Fracture (CTN).
10. Record the depth of the snowpack that was tested. For example, if the top 110 cm of a 200 cm snowpack was tested (30 taps on a column, 110 cm tall) and the only result was a failure on the 15th tap, 25 cm below the surface, then record "CT15 @ 25 cm; Test depth 110 cm, or TD 110". This clearly indicates that no fracture occurred from 25-110 cm below the surface and that the snowpack between 110 cm and 200 cm was not tested with the Compression Test. Operations that always test the same depth of the snowpack, (e.g. top 120 cm) may omit the test depth.

Results

Limitations of the compression test include sampling a relatively small area of the snowpack and the variability in force applied by different observers. A greater understanding of these limitations is gained by conducting more than one compression test

TABLE 2.12 Loading Steps and Compression Test Scores

TERM	DESCRIPTION	DATA CODE
Very Easy	Fractures during cutting	CTV
Easy	Fractures within 10 light taps using finger tips only	CT1 to CT10
Moderate	Fractures within 10 moderate taps from the elbow using finger tips	CT11 to CT20
Hard	Fractures within 10 firm taps from whole arm using palm or fist	CT21 to CT30
No Fracture	Does not fracture	CTN

in a snow profile and performing side by side tests with other observers.

Deeper weak layers are generally less sensitive to taps on the shovel, resulting in higher ratings. Similarly, deeper weak layers are less sensitive to human triggering.

Experience and research in the Rocky and Columbia Mountains of Western Canada indicates that human-triggered avalanches are more often associated with "Easy" (1-9 taps) fractures than with "Hard" (20-30 taps) fractures or with layers that do not fracture (Jamieson, 1996). Sudden fractures (SC, SP, Q1) that show up on the column walls as straight lines identify the failure layers of nearby slab avalanches more often than non-planar or indistinct failure surfaces (BRK, Q3)(vanHerwijnen and Jamieson, 2003).

The results of any stability test should be interpreted in conjunction with snowpack and weather histories, fracture type, and other snowpack and avalanche information.

2.7.5 DEEP TAP TEST

The Deep Tap Test was developed by the Applied Snow and Avalanche Research group at the University of Calgary. The test was developed to address very deep weak layers that are difficult to assess with other column and block tests.

Objective

The primary objective of the Deep Tap Test is to determine the type of fracture that occurs in a weak layer that is too deep to fracture consistently in the Compression Test. In addition, one may observe the tapping force required for fracture to occur.

Procedure

A shovel is the only piece of equipment required for the Deep Tap Test. However, a snow saw will make cutting the column of snow easier and more precise.

1. Using a profile or other means, identify a weak snowpack layer, which is overlaid by 1F or harder snow and which is too deep to fracture consistently in the Compression Test.
2. Prepare a 30 cm x 30 cm column as for a Compression Test (note that the same column can be used after a Compression Test of the upper layers, provided the Compression Test did not disturb the target weak layer). To reduce the likelihood of fractures in weak layer below the target layer, such as depth hoar at the base of the snowpack, it may be advantageous not to cut the back wall more than a few centimeters below the target weak layer.
3. Remove all but 15 cm of snow above the weak layer, measured at the back of the sidewall. This distance should be constant, regardless of the slope angle.
4. Place the shovel blade (facing up or facing down) on top of the column. Tap 10 times with fingertips, moving hand from wrist and note the number of taps required to fracture the column (1 to 10).
5. Tap 10 times with the fingertips or knuckles moving your forearm from the elbow, and note the total number of taps required to fracture the column (11 to 20). While moderate taps should be harder than easy taps, they should not be as hard as one can reasonably tap with the knuckles.
6. Finally, hit the shovel blade moving arm from the shoulder 10 times with open hand or fist and note the total number of taps required to fracture the column (21 to 30). If the moderate taps were too hard, the operator will often try to hit the shovel with even more force for the hard taps – and may hurt his or her hand.
7. Record the results as described in Table 2.13. Observers may also include the total depth of the weak layer below the snow surface at the location of the test.
8. Use one of the methods in Section 2.6 to describe the type of fracture observed during the test. This information is important for deep persistent weak layers.

TABLE 2.13 Loading Steps and Deep Tap Test Scores

TERM	DESCRIPTION	DATA CODE
Very Easy	Fractures during cutting	DTV
Easy	Fractures within 10 light taps using finger tips only	DT1 to DT10
Moderate	Fractures within 10 moderate taps from the elbow using finger tips	DT11 to DT20
Hard	Fractures within 10 firm taps from whole arm using palm or fist	DT21 to DT30
No Fracture	Does not fracture	DTN

Results

While very effective for testing deeper weak layers, the number of taps required to initiate a fracture in the Deep Tap Test has not been correlated with human-triggered avalanches or avalanches on adjacent slopes.

2.7.6 EXTENDED COLUMN TEST

The Extended Column Test (ECT) was developed in Colorado and New Zealand in 2005 and 2006. The ECT was tested in the continental and intermountain snow climates of the U.S. (Simenhois and Birkeland 2007; Hendrikx and Birkeland, 2008;Birkeland and Simenhois 2008), the Swiss Alps (Winkler and Schweizer 2009), the Spanish Pyrenees (Moner et al. 2008) and New Zealand's Southern Alps (Simenhois and Birkeland 2006, Hendrikx and Birkeland 2008).

Objective

The ECT tests the fracture propensity of slab/weak layer combinations in the upper portion (<1m) of the snowpack. The tester tries to initiate fracture by applying dynamic load to a shovel blade placed at the end of an isolated column. (Figure 2.16) Once initiated, the key observation in the test is whether or not the fracture immediately propagates across the entire column. The ECT identifies fracture initiation during the loading steps and describes how those fractures propagate across the column.

FIGURE 2.15a Cutting an ECT (P: courtesy Don Sharaf)

Procedure

A shovel is required, and a snow saw will make cutting the column easier and more precise. Also required are 1-2 snow probes or ski poles and 2 m of 3-4 mm cord knotted every 20-30 cm, or a snow saw with extension (Figure 2.15).

1. Select a safe site that has undisturbed snow and is geographically representative of the slope of interest.
2. Isolate a column of snow 90 cm wide in the cross slope dimension and 30 cm deep in the upslope dimension that is deep enough to expose potential weak layers. Depth should not exceed 120 cm since the loading steps rarely affect deeper layers .
3. Rate any fractures that cross the entire column while isolating it as ECTPV.
4. If the snow surface slopes and the surface snow is hard, remove a wedge of snow to level the top of the column at one edge.
5. Place the shovel blade on one side of the column. Tap 10 times moving hand from the wrist and note the number of taps it takes to initiate a fracture and whether or not the crack immediately propagates across the entire column (1 to 10) (See Table 2.14).
6. Tap 10 times with the fingertips or knuckles moving forearm from the elbow and note the number of taps it takes to initiate a fracture and whether or not the crack immediately propagates across the entire column (11 to 20).
7. Finally, hit the shovel blade moving arm from the shoulder 10 times with open hand or fist. Note the number of taps it takes to initiate a fracture and whether or not the crack immediately propagates across the entire column (21 to 30).
8. If a fracture occurs and you wish to keep testing, remove the failed portion of the block and continue with the next loading step.
9. If no fractures occurred within all loading steps, rate the test as ECTX.
10. If a crack initiated on a weak layer on the ## tap but did not propagate across the entire column rate that layer as ECTN##.
11. If a crack initiated and propagated across the entire column on the ## tap rate that layer as ECTP##.

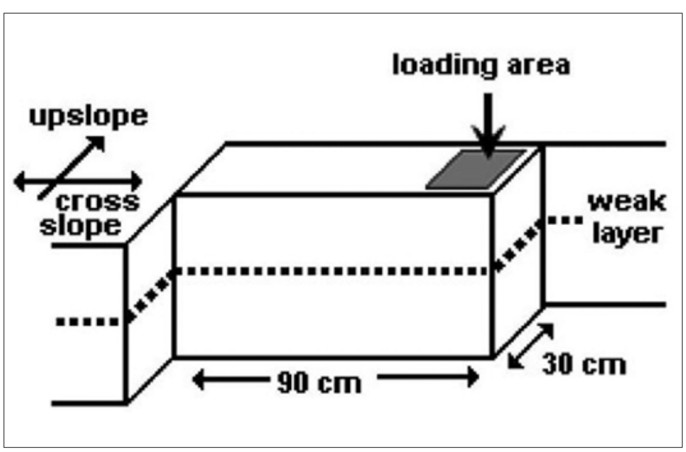


FIGURE 2.15b and c Schematic and photograph of the Extended Column Test. (P: courtesy of Ron Simenhois)

TABLE 2.14 Loading Steps and Extended Column Test Scores

DESCRIPTION	DATA CODE
Fracture propagates across the entire column during isolation	ECTPV
Fracture initiates and propagates across the entire column on the ## tap	ECTP##
Fracture initiates on the ## tap, but does not propagate across the entire column. It either fractures across only part of the column (observed commonly), or it initiates but takes additional loading to propagate across the entire column (observed relatively rarely).	ECTN##
No fracture occurs during the test	ECTX

Results

The ECT has a generally lower false-stability ratio than other similar tests. It is not a good tool for assessing weaknesses in very soft (F+) upper layers of the snowpack or in mid-storm shear layers. The ECT is also not a good tool for assessing fracture propagation potential on a weak layer deeper than 100-120 cms. In cases where a fracture is not initiated, snowpits in different locations or other stability tests are recommended.

2.7.7 PROPAGATION SAW TEST

The Propagation Saw Test (PST) was simultaneously developed in Canada (Gauthier and Jamieson, 2007) and in Switzerland (Sigrist, 2006). The PST has been tested in Canada since 2005 – mostly in the Columbia Mountains, in the Swiss Alps, and in Colorado's continental snowpack (Birkeland and Simenhois, 2008). The PST describes propagation propensity in persistent weak layers (PWL) buried 30 cm to over 100 cm and occasionally up to 250 cm deep.

Objective

The PST tests the propensity of a pre-identified slab/weak-layer combination to propagate a crack. The tester uses an isolated column and initiates a fracture by dragging a snow saw along the weak layer in the uphill direction (Figures 2.16 and 2.17).

Procedure

A shovel and a snow saw with a blade at least 30 cm long and 2 mm thick are required for the PST. For layers deeper than 30 cm, 1-2 snow probes and 3-5 m of 3-4 mm cord knotted every 20-30 cm are recommended.

The PST procedure involves three main steps (after Gauthier and Jamieson, 2007): identifying the weak layer of interest, isolating and preparing the test column, and performing and recording the results (Figures 2.16 and 2.17).

1. Select a safe site that has undisturbed snow and is geographically representative of the slope of interest.
2. Isolate a column 30 cm wide across the slope and 100 cm long upslope when the weak layer is less than 100 cm deep. (For layers deeper than the saw is long, two adjacent walls can be cut with a cord between probes.) When the weak layer is >100 cm deep the column length is equal to the weak layer depth in the upslope direction. The column should be isolated to a depth greater than the tested layer's depth.
3. To identify the weak layer clearly, mark it with a glove, a brush or a crystal card along the exposed column wall.
4. Drag the blunt edge of the saw upslope through the weak layer at 10-20 cm/s until the layer fractures (jumps) ahead of the saw, at which point the tester stops dragging the saw and marks the spot along the layer where propagation began.
5. After observations are complete, remove the column and check that the saw scored the weak layer in the wall behind the test column. If the saw deviated from the weak layer, the test should be repeated.

TABLE 2.15 Propagation Saw Test Description and Data Codes

OBSERVED RESULT	DESCRIPTION	DATA CODE
Propagation to end	The fracture propagates in the weak layer in front of the saw uninterrupted to end of column.	End
Slab fracture	The fracture propagates in the weak layer in front of the saw and stops where it meets a fracture through the overlying slab	SF
Self-arrest	The fracture propagates in front of the saw but self-arrests somewhere along the weak layer before reaching the end of the column.	Arr

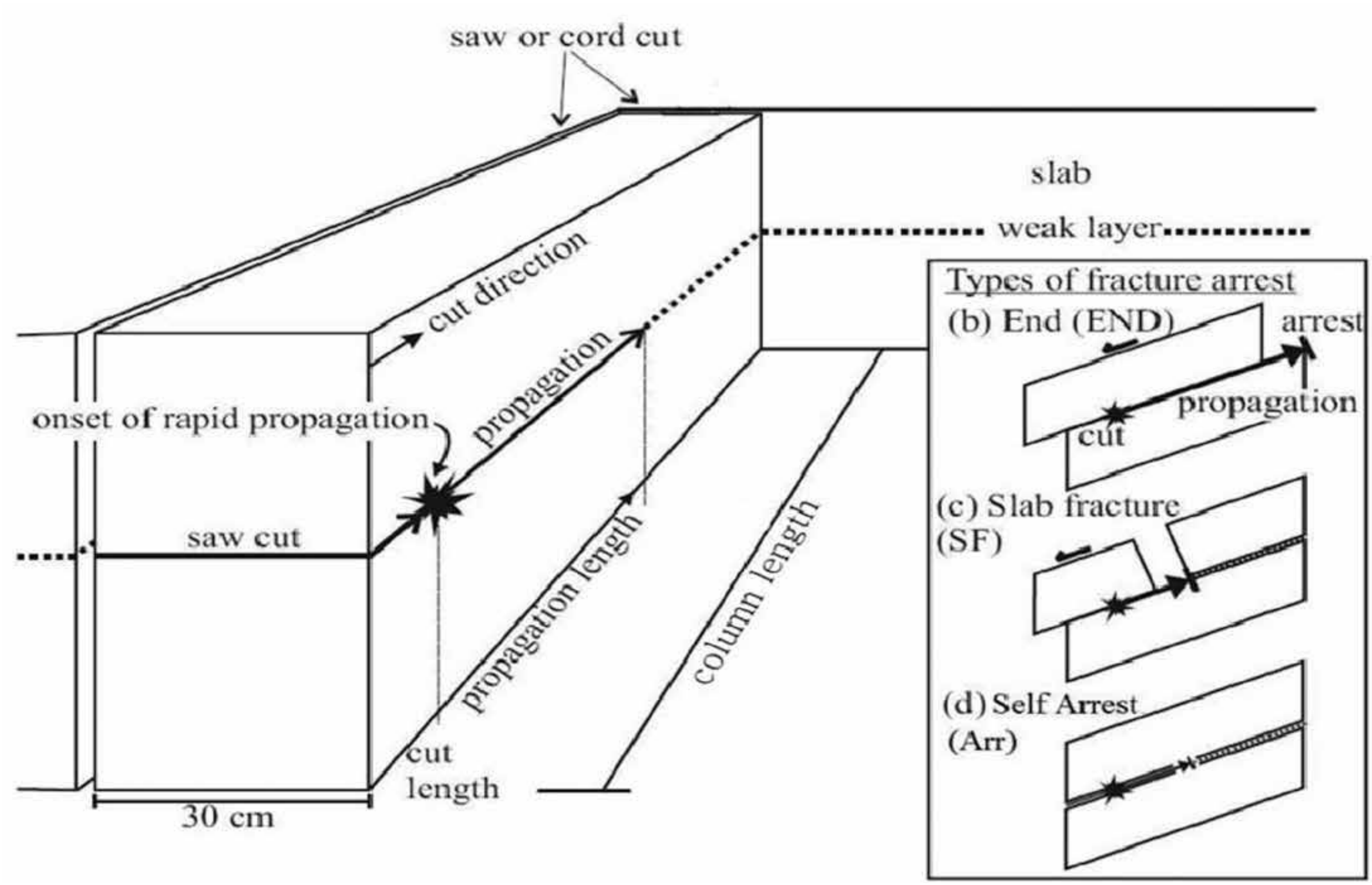


FIGURE 2.16 Schematic showing the PST column (a) and the observable results of propagation to end (b), slab fracture (c), and self arrest (d). (after Gauthier and Jamieson, 2007)

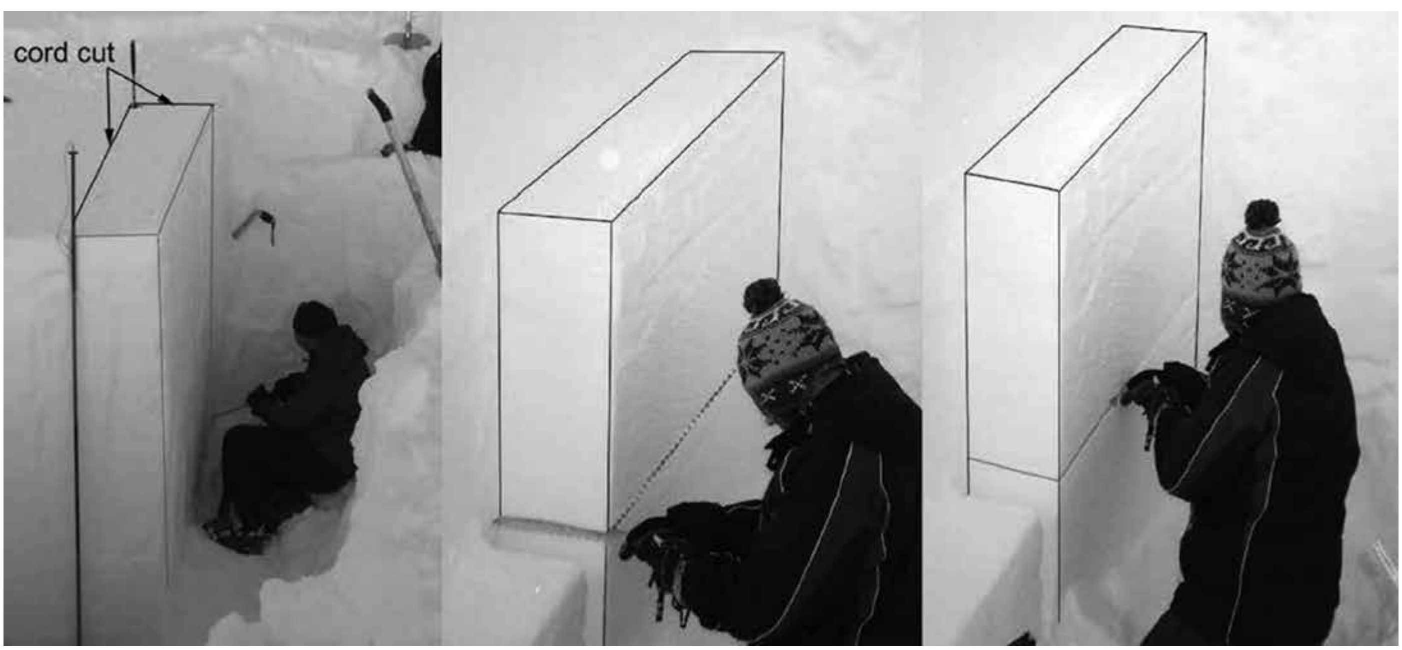


FIGURE 2.17 The PST process (left to right): isolating the column with probes and cord; identifying the weak layer and preparing to cut; dragging the saw along the weak layer until the onset of propagation. Lightly brushing the weak layer with a glove or brush before cutting helps the operator follow the layer along the column. (P: ASARC)

Results

When a fracture propagates ahead of the saw, one of the three results described in Table 2.15 can be observed. PSTs are then recorded as follows: **'PST x/y (Arr, SF, or End) down z on yymmdd'** where x is the length of the saw cut when propagation starts, y is the length of the isolated column, z is the depth of the tested weak layer, and yymmdd is the date if burial of the weak layer. Units are recorded in centimeters. It is recommended to record slope angle at the test site if it is not done on a 30-40 degree slope. Propagation to End occurs on flat as well as inclined slopes.

Fracture propagation is considered to be likely only if the fracture propagates to the end of the column along the same layer and initiates when the length of the saw cut is less than 50% of the length of the column (Gauthier and Jamieson, 2008). Otherwise fracture propagation is considered unlikely. An example of a result that indicates high propagation propensity is **'PST 34/100 (End) down 56 cm on 160223'**.

The PST assesses the propagation propensity of deeply buried weak layer and slab combinations (deep instability). However, the PST indicates a higher number of false-stable results than other common snowpack tests (~30% for PSTs versus ~10% for CTs, RBs, and SBs), particularly for soft shallow slabs and weak layers that are too hard to cut with the saws blunt edge (Birkeland and Simenhois, 2008; Gauthier and Jamieson, 2008).

FIGURE 2.18 Slope cut producing a small slab avalanche. (P: Bruce Tremper)

2.8 SLOPE CUT TESTING

Slope cutting can provide valuable snowpack information. Safety is the primary concern when attempting slope cuts; inexperienced observers should not perform this type of testing. There are many approaches and tricks of the trade that can be applied to slope cutting. All of them are beyond the scope of this manual. Slope cutting techniques should only be taught in the field or as on the job training. More information on slope cuts can be found in Tremper (2008), McClung and Schaerer (2006) and Perla and Martinelli (1976).

Objective

Slope cutting can provide valuable information on snowpack stability. A tester attempts to initiate failure on a given slope by quickly applying a dynamic force (with skis, snowboard, snowmobile, etc.) to a test slope and then escaping to a safe location (Figure 2.18).

Procedure

1. Choose a relatively small slope that is representative of the starting zones you wish to learn about.
2. Place one or more people in zones of safety that allow them to observe the entire cut and avalanche path, if possible.
3. Begin from a zone of safety.
4. Examine the starting zone and choose a line that crosses relatively high on the slope and ends in a zone of safety.
5. Travel along the line maintaining enough speed to cross the slope in one fast motion. The tester can bounce or jump during the cut to increase the load on the slope.
6. Exit the slope to a zone of safety.

Results

Record the results of the test using the data codes listed in Table 2.16 along with the aspect and angle of the slope. When a slope cut produces a slab avalanche the avalanche size (Relative and/ or Destructive) can be included in the data code. Additional information about the terrain and resulting avalanche can be recorded in comments as needed.

TABLE 2.16 Slope Cut Test Description and Data Codes

TERM	DESCRIPTION	DATA CODE
No release	No result	SCN
Whumpfing	Slope cut produces a collapse in the snowpack	SCW
Cracking	Slope cut produces shooting cracks	SCC
Avalanche Slab	Slope cut produces a slab avalanche	SCS
Avalanche Loose	Slope cut produces a loose snow or sluff avalanche	SCL

Example:

SCW35NE – Test produced a collapse (whumpf) on a 35° northeast facing slope.
SCL40S – Test produced a sluff on a 40° south facing slope.
SCN30N – Test produced no result on a 30° north facing slope.
SCS45NWR3D2 – Test produced a slab avalanche on a 45° NW facing slope. The avalanche was medium size for the path but large enough to injure or kill a person.

2.9 NON-STANDARDIZED SNOW TESTS

All of the stability tests described in Chapter Two were developed from many years of work by many observers. Each test went through several iterations before a standard procedure was established. Field practitioners and researchers eventually wrote protocols and conducted research on these tests to provide information on their response and suitability.

In addition to the standardized tests, there are many other tests that do not have specific field protocols. In this section, some of the more common non-standardized snow tests and suggested methods for communicating their results are presented. Field workers who are not satisfied with the standardized tests are encouraged to use additional methods for determining physical properties of the snowpack. As new methods evolve and we learn more about their responses and limitations, those methods may become standard practice.

2.9.1 COMMUNICATING THE RESULTS OF NON-STANDARDIZED SNOW TESTS

There is no standard method for communicating the results of non-standardized tests. A common method is to rate the amount of force required to produce a fracture using the descriptors Easy, Moderate, or Hard (with easy being the smallest amount), and note the height of the resulting fracture. Suggestions for communicating specific tests are presented below.

2.9.2 CANTILEVER BEAM TEST

Most of the standardized snow tests examine a weak snow layer or interface between snow layers. This type of information is critical for determining the snow stability. However, the weak layer is only one component of a slab avalanche and knowing more about the mechanical properties of the slab is also useful.

Several investigators have used cantilever beam tests to examine mechanical properties of snow beams and snow slabs (Johnson and others, 2000; Mears, 1998; Sterbenz, 1998; Perla, 1969). Sterbenz (1998) describes a cantilever beam test developed for avalanche forecasting in the San Juan Mountains of Colorado.

Procedure

1. Select a geographically representative site and dig a test profile.
2. Collect snowpack data as needed and conduct stability tests as desired.
3. Identify weak layer or interface and potential snow slab.
4. Above a smooth pit wall, mark a horizontal section of the slab 1 m (or 40") in length on the snow surface.

TABLE 2.17 Cantilever Beam Test from Sterbenz (1998)

LOADING STEP	BLOCK BREAKS WHEN
CB0	Removing snow from below the block.
CB1	0.5 m cut along one side.
CB2	0.5 m cut along the second side.
CB3	1 m cut along the first side.
CB4	1 m cut along the second side.
CB5	Loading the block that is isolated on three sides.

5. Mark 1 m (or 40") lengths perpendicular to the pit wall so a 1 m x 1 m square block is outlined on the snow surface.
6. At the identified weak layer, remove the supporting snow from below the slab to be tested (1 m x 1 m square block).
7. Using a snow saw, make a vertical cut 0.5 m (or 20") along one side of the block.
8. Using a snow saw, make a vertical cut 0.5 m (or 20") along the other side of the block.
9. Using a snow saw, extend the first cut an additional 0.5 m (or 20") so that one side of the 1 m x 1 m square block is isolated.
10. Using a snow saw, extend the second cut an additional 0.5 m (or 20") so that the other side of the 1 m x 1 m square block is isolated.
11. At this point the block should be suspended, with its only connection point along the uphill edge of the block. Place a shovel along the downhill side of the block and strike it with successive blows until the beam breaks.
12. Record with the data codes in Table 2.17.

Cantilever Beam Test References

Johnson, B.C., J.B. Jamieson, and C.D. Johnston. 2000: Field studies of the cantilever beam test. *The Avalanche Review*, 18, 8-9.

Mears, A., 1998: Tensile strength and strength changes in new snow layers. *Proceedings of the International Snow Science Workshop*, Sunriver, Oregon, 574-576.

Perla, R.I., 1969: Strength tests on newly fallen snow. *Journal of Glaciology*, 8, 427-440.

Sterbenz, C., 1998: The cantilever beam or "Bridgeblock" snow strength test. *Proceedings of the International Snow Science Workshop*, Sunriver, Oregon, p. 566-573.

2.9.3 LOADED COLUMN TEST

The loaded column test allows an observer to estimate how much additional mass a weak layer might support before it will fracture. Although this test describes a finite mass that will produce fracture, the results of this test should be regarded only as a general indicator of the additional load that the snowpack can sustain. As stated previously, operational decisions should not be made on a single number or test.

Procedure

1. Select a geographically representative site and dig a test profile.
2. Collect snowpack data as needed and conduct stability tests as desired.
3. Identify weak layer or interface and potential snow slab
4. Using a snow saw isolate a column 30 cm wide and 30 cm in the upslope direction.
5. Excavate blocks of snow and stack them on the column until the column fractures.
6. Note the level of the fracture, shear quality, and amount of load that caused the test column to fail.
7. The mass of each block can be measured and a total load calculated.

2.9.4 BURP-THE-BABY

This test is generally used to identify shear layers missed by the shovel shear test. Buried thin weak layers (often surface hoar) gain strength over time and their presence may be obscured or missed by the shovel shear test.

Procedure

When an isolated column remains intact after it breaks on a deeply buried layer, pick it up and cradle it in your arms. Burp the reclining column across your knee or with a hand. Clean shear planes can often be located above the original shovel shear plane.

2.9.5 HAND SHEAR TESTS

These tests can be used to quickly gain information about snow structure. They should not be used to replace stability tests, but can be used to estimate the spatial extent of a relatively shallow weak layer (Figure 2.19).

Procedure

1. With your hand or a ski pole make a hole in the snow deeper than the layer you wish to test.
2. Carve out an isolated column of snow.
3. Tap on the surface or pull on the column of snow in the down slope direction.
4. Record your results with the name of the test, weak layer depth, and rate the result as Easy, Moderate, or Hard (example: Hand Easy or Hand-E). Also include pertinent terrain parameters such as slope angle, aspect, and elevation.
5. Use other methods to investigate the weak layer or interface as needed.

2.9.6 SKI POLE PENETROMETER

The ski pole can be used like a penetrometer to look for or estimate the spatial extent of distinct weak layers or significant changes in layer hardness (Figure 2.20). In harder snow, an avalanche probe can be used.

Procedure

1. Place the ski pole perpendicular to the snow surface and push it into the snow (Basket end down for soft snow, handle down for harder snow).
2. Feel for changes in resistance as the ski pole moves through the snowpack.
3. Feel for more subtle layers as the pole is removed from the snowpack by tilting it slightly to the side.
4. Record the depth, thickness and spatial extent of buried layers.
5. Use other methods to investigate the snowpack as needed.

2.9.7 TILT BOARD TEST

This description follows material published in McClung and Schaerer (2006). The Tilt Board Test is typically used to identify weaknesses in new snow or storm snow layers. The test is generally conducted at an established study plot. It can be used to identify weak layers that will be tested with a shear frame.

Equipment

1. Thin metal plate 30 cm x 30 cm
2. Tilt Board – a board painted white and mounted on a frame. The frame is mounted to a joint that allows it to rotate in the vertical plane. The Tilt Board can be locked in the horizontal position or tilted about 15 degrees. This allows the test block to fracture in shear without sliding off the lower portion of the block.

FIGURE 2.19 A hand shear test. (P: Bruce Tremper)

FIGURE 2.20 The ski pole poke, aka Ski Pole Penetrometer. (P: Bruce Tremper)

Procedure

1. Cut a block of snow that is deeper than the suspected weak layer or that contains all of the new or storm snow. McClung and Schaerer (2006) recommend using a block no deeper than 0.4 m.
2. Using a thin metal plate, lift the block on to the Tilt Board.
3. Tap the bottom of the board until the snow fractures.
4. Record your results with the name of the test and rate the result as Easy, Moderate, or Hard (example: Tilt Board Easy or Tilt Board-E).
5. Use other methods to investigate the weak layer or interface as needed.

2.9.8 SHOVEL TILT TEST

The shovel tilt test is the field worker's version of the Tilt Board Test but requires no additional equipment be taken into the field. This test can be especially helpful for finding shears within storm snow (Figure 2.21).

Procedure

1. Isolate a column of snow of similar dimensions to your shovel blade.
2. Insert the shovel blade horizontally into the side of the column below the layers you wish to test (limited to about 0.4 m from the surface).
3. Lift the shovel and snow sample into the air and hold the shovel handle and bottom of the snow column in one hand,
4. Tilt the shovel blade about 5 to 15 degrees steeper than the slope angle of the sample.
5. Tap the bottom of the shovel blade with increasing force until fracture is observed.
6. Record the force required to produce the fracture as Easy, Moderate, or Hard.
7. Shovel tilt may be increased and angle recorded if no fracture occurs at 15 degrees.
8. Use other methods to investigate the weak layer or interface as needed.

FIGURE 2.21 The Shovel Tilt Test. (P: Howie Garber)

2.10 INSTRUMENTED METHODS

2.10.1 RAM PENETROMETER

Objectives

The ram penetrometer is used to obtain a quantifiable measure of the relative hardness or resistance of the snow layers. It can be applied on its own as an index of snow strength, but it is not recommended as the sole tool for determining snow stability. When used in combination with a snow profile, a ram profile should be taken about 0.5 m from the pit wall after observation of the snow profile, but before any shovel shear tests are performed. It is a valuable tool for tracking changes in relative hardness over time at study plots and slopes, or for measuring many hardness profiles over an area without digging pits.

The ram profile describes the hardness of layers in the snowpack. However, it often fails to identify thin weak layers in the snowpack, surface hoar layers or other weak layers that are one centimeter or less are difficult to detect. Its sensitivity is dependent on the hammer weight, particularly when used in soft or very soft snow. The magnitude of this problem may be reduced by using a lightweight hammer (500 g or less), or by using a powder or "Alta" ram (Perla, 1969).

Refer to Chapter 7 of *The Avalanche Handbook* (McClung and Schaerer, 2006) for a complete discussion on ram profiles.

Equipment

The standard ram penetrometer (Figure 2.22), also called ramsonde, consists of:

- 1 m lead section tube with 40 mm diameter cone and an apex angle of 60°.
- Guide rod and anvil.
- Hammer of mass 2 kg, 1 kg, 0.5 kg, 0.2 kg or 0.1 kg.
- One or two (1.0 m each) extension tubes.

The powder ram, also called an Alta Ram (Perla, 1969), consists of:

- 0.50 m to 1.0 m lead section and guide rod and anvil weighing 100 g
- A hammer of mass 0.1 kg
- Lead section cone has the same dimensions as a standard ram

The mass of hammer chosen depends on the expected hardness of the snow and desired sensitivity.

Unit of Measure

A ram profile depicts the force required to penetrate the snow with a ram penetrometer. The mass of the tubes, the mass of the hammer, and the dynamic load of the falling hammer all

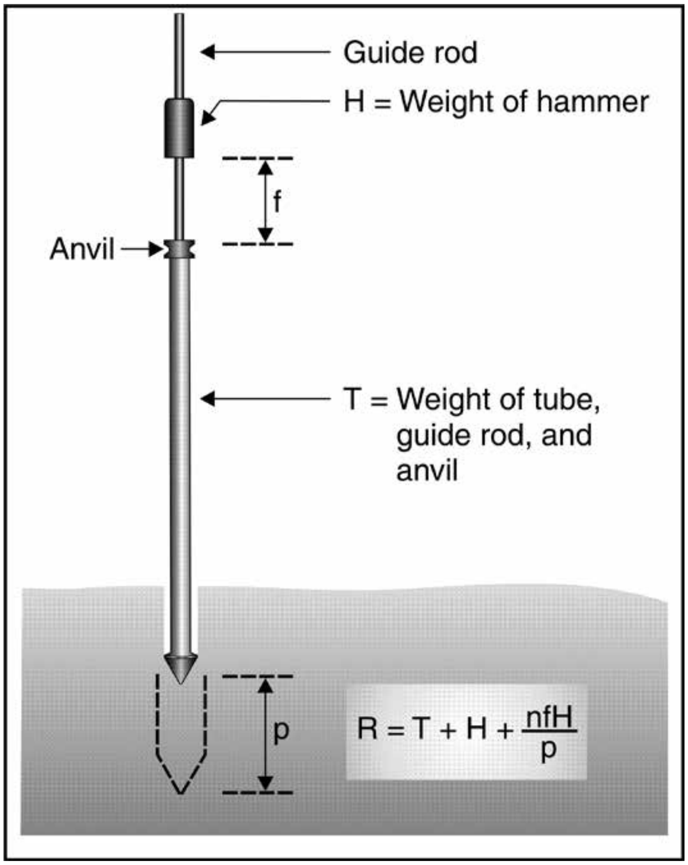


FIGURE 2.22 Schematic of the ram penetrometer. (after Perla and Martinelli, 1976)

contribute to the applied force. Ram profiles can display two different quantities: ram number (*RN*), which is a mass (kg), and ram resistance (*RR*), which is a force (N).

Weight is a gravity force that is calculated by multiplying mass by the acceleration due to gravity (9.81 m/s^2). Although not strictly correct, most practitioners multiply by 10 to simplify the calculations. Since the ram number is an index of hardness, there is little danger in rounding this value. Force, and consequently the ram resistance, are measured in newtons. A mass of 1 kg has a gravity force (weight) of 1 kg x acceleration which is approximately 10 N (1kg x 10m/s^2 =10N).

Procedure

Record the location, date, time, observers, slope angle, aspect, and ram type at the head of the data sheet. Also record any notes that will be pertinent to data analysis after leaving the field (Figures 2.23 and 2.24).

Work in pairs if possible. One person holds the ram penetrometer in a vertical (plumb) position with the guide rod attached. This person drops the hammer, counts the number of blows, and observes the depth of penetration. The other person records the information. The person holding the ram and dropping the hammer calls three numbers to the recorder: the drop number, drop height and penetration. For example, "5 from 20 is 143", means 5 drops from a drop height of 20 cm penetrated to 143 cm (Figure 2.24).

1. Hold the first sectional tube with the guide rod attached directly above the snow surface with the point touching the snow. Let the instrument drop and penetrate the snow under its own weight without slowing it down with your hand. You will need to guide it in many cases so it does not fall over. Record its mass in column *T + H*. Read the penetration (cm) and record in column p (see Figure 2.24 for field data sheet example). Since the tube weight *T* is 1.0 kg with the guide rod, it should be attached before the surface measurement is taken. Sometimes a greater sensitivity of the surface layer is desired. Dropping only the lead section without the guide rod will reduce the weight and may cause less of an initial plunge through the surface layers since the total mass will be lighter. If this method is used, then the weight of the lead section alone should be recorded for the *T* value, not the combined lead section and guide rod value of 1.0 kg.
2. Carefully add the hammer, or guide rod and hammer if using the lead section only for the surface measurement. Record the mass of the tube + hammer under *T + H*. Read the new penetration and record under *p*. If the ram does not penetrate further, as is often the case in this step, record the previous *p* value again.
3. Drop the hammer from a height between 1 cm and 5 cm; record the penetration. The low drop height (1-5 cm) is appropriate for near-surface layers. Larger drop heights (20-60 cm) and increased hammer weights may be desired as depth, and therefore, resistance increases. Continue dropping the hammer from the same height until the rate of penetration changes. Record fall height *f*, number of blows *n*, and penetration *p* up to the point. Some experience will allow the user to anticipate changes in the structure of the snow and record measurements before the rate of penetration changes. Continue with another series of blows; choose a fall height that produces a penetration of about 1 cm per blow. Do not change fall height or hammer weight within a series of measurements. Record the series then adjust fall height or change hammer weight if desired before beginning another series. Resolution of the profile depends on the frequency of recorded measurements and the snowpack structure. Many recorded measurements in a homogeneous layer will provide no more resolution than fewer measurements since the calculated *RN* will be the same for both. However, resolution will be lost in varied layers if too many drops are made between recordings as the layer will receive a single *RN* over the entire range of *p* for that layer.
4. Add another section of tube when necessary and record the new *T + H*.
5. Repeat the measurements (b and c) until the ground surface is reached.

Calculation

1. Calculate the increment of penetration p for each series of blows by subtracting the previous p value from the present p value (Figure 2.25).
2. Calculate ram number (RN) or ram resistance (RR) with the following equations:

$$RN = T + H + \frac{nfH}{p}$$

$$RR = RN \times 10$$

where:

RN = ram number (kg)
RR = ram resistance (N)
n = number of blows of the hammer
f = fall height of the hammer (cm)
p = increment of penetration for n blows (cm)
T = mass of tubes including guide rod (kg)
H = mass of hammer (kg)

3. Plot on graph paper the ram number or resistance vs. depth of snow (see Figure 2.25).

RAM DATA SHEET				
Location: Glory Bowl, Teton Pass, Wilson, WY.				
Date: 19930312			Time: 0750 MST	
Observer: Newcomb/Elder				
Total Depth: 239cm			Equipment: Standard Ram	
Slope: 28°	Aspect: 80°			
Notes: 30m south of GAZEX 1, S3, Wind SW 10m/s				
Tube and Hammer Weight T+H (kg)	Number of falls n	Fall height f (cm)	Location of point L (cm)	Comments
1 + 0	0	0	23	Tube and guide rod only, new snow deposited last 18 hr
1 + 0.5	0	0	25	add 0.5kg hammer - no drop
	6	1	32	
1 + 1	0	0	32	change to 1kg hammer
	4	5	37	
	11	10	49	
	7	20	52	crust
	5	10	64	
	15	10	87	
2 + 1	0	0	87	add 2nd tube section
	10	20	108	
	13	30	141	
	6	30	148	
3 + 1	0	0	148	add 3rd tube section
	25	30	181	
	22	30	209	
	1	30	215	
	3	10	239	

FIGURE 2.23 Sample field book page for Ram profiles.

RAM CALCULATION SHEET								
Location: Glory Bowl, Teton Pass, Wilson, WY.								
Date: 19930312			Time: 0750 MST					
Observer: Newcomb/Elder								
Total Depth: 239cm			Equipment: Standard Ram					
Slope: 28°	Aspect: 80°							
Notes: 30m south of GAZEX 1, S3, Wind SW 10m/s			$RN = T + H + (nfH)/p$ (kg) $RR = RN$ x 10 (N)					
Tube and Hammer Weight T+H (kg)	Number of falls n	Fall height f (cm)	Location of point L (cm)	Penetration p (cm)	$(nfH)/p$ (kg)	RN (kg)	RR (N)	Height above ground (cm)
								239
1 + 0	0	0	23	23	0.0	1.0	10	216
1 + 0.5	0	0	25	2	0.0	1.5	15	214
	6	1	32	7	0.4	1.9	19	207
1 + 1	0	0	32	0				207
	4	5	37	5	4.0	6.0	60	202
	11	10	49	12	9.2	11.2	112	190
	7	20	52	3	46.7	48.7	487	187
	5	10	64	12	4.2	6.2	62	175
	15	10	87	23	6.5	8.5	85	152
2 + 1	0	0	87	0				152
	10	20	108	21	9.5	12.5	125	131
	13	30	141	33	11.8	14.8	148	98
	6	30	148	7	25.7	28.7	287	91
3 + 1	0	0	148	0				91
	25	30	181	33	22.7	26.6	266	58
	22	30	209	28	23.6	27.6	276	30
	1	30	215	6	5.0	9.0	90	24
	3	10	239	24	1.3	5.3	53	0

FIGURE 2.24 Sample worksheet page for calculating RAM profiles.

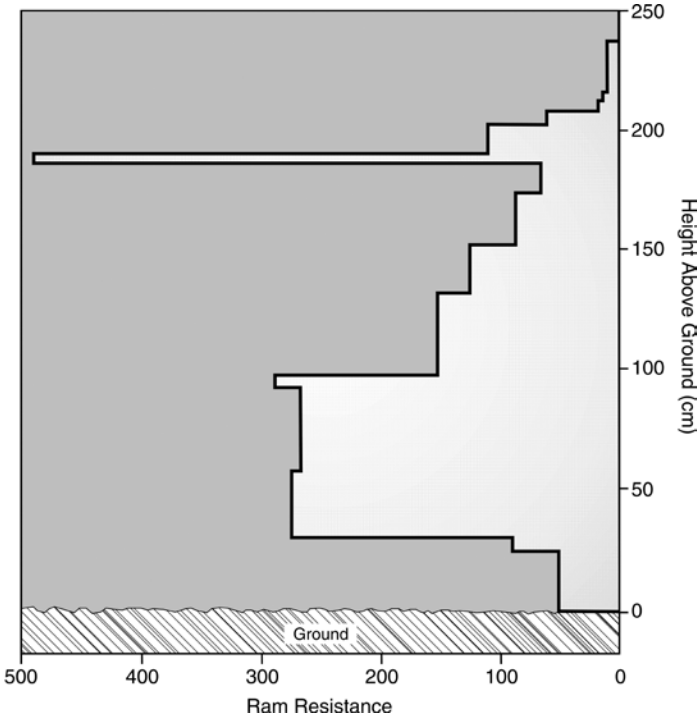


FIGURE 2.25 Graphical representation of a ram profile from data listed in Figures 2.23 and 2.24.

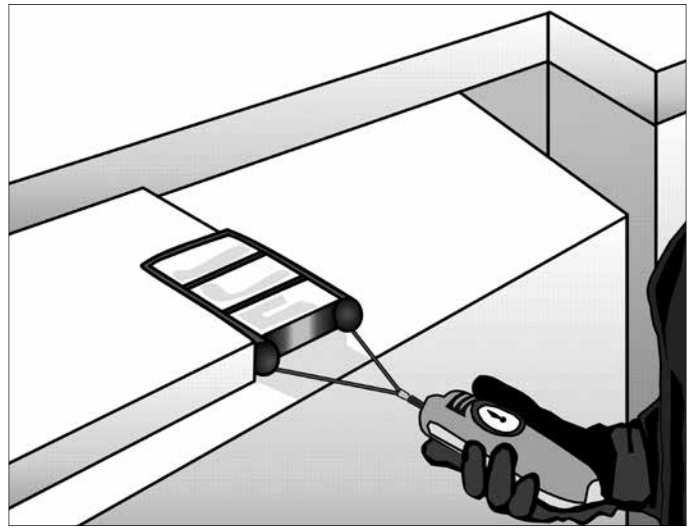


FIGURE 2.26 Measuring shear strength with a shear frame.

2.10.2 SHEAR FRAME TEST

The shear frame test is used to measure the shear strength of snow layers and interfaces between snow layers (Figure 2.26). The shear frame test requires experience but provides useful information when done correctly and consistently. The test combined with a stability ratio is a useful tool for assessing the strength of snow layers. Discussions of shear frame methods can be found in Jamieson, 2001; Jamieson, 1995; Fohn, 1987b, Perla and Beck, 1983, and Roch, 1966.

Equipment

The shear frame test requires the following equipment:

1. Putty knife
2. Metal cutting plate about 30 cm x 30 cm
3. Shear frame, usually 100 cm^2 or 250 cm^2
4. Force gauge, maximum capacity 10 to 250 N (1 to 25 kg).

If you are calculating the stability ratio, you will also need the following equipment:

5. Sampling tube, 50 to 80 cm
6. Weighing scale

Procedure

The shear frame test can be performed on storm snow layers and persistent weak layers. Typically 100 cm^2 frames are used for storm snow layers and 250 cm^2 are used for persistent weak layers.

Observers generally perform 7 to 12 consecutive tests and average the results. Once a series of measurements is started it is important to not switch frame sizes.

1. Identify weak layer using tilt board or other method.
2. Remove the overlying snow to within 4 or 5 cm of the layer or interface being measured.
3. Carefully insert the shear frame into the snow so the bottom of the frame is 2 to 5 mm above the layer.
4. Pass a thin blade (putty knife) around the shear frame to remove snow that was in contact with the frame.
5. Attach an appropriate force gauge and pull so that fracture occurs within 1 second. This method ensures brittle fracture. It is essential that the operator loads the force gauge at a constant rate and is consistent between all measurements.

Shear Strength Calculation

Once you have obtained the average shear force for the weak layer or interface, calculate the shear strength from the formula:

$$T_{frame} = \frac{F_{average}}{A_{average}}$$

where $F_{average}$ is the average shear force in newtons (N), A_{frame} is the area of the shear frame in m^2, and T_{frame} is the shear strength of the layer in pascals (Pa). This calculation produces a shear strength that is dependent on the shear frame size ($T_{frame} = T_{250}$ or T_{100}). For a value of shear strength that is independent of frame size use the following equations (Föhn, 1987b; Jamieson, 1995):

$$T_{\infty} = 0.65 T_{250}$$
$$T_{\infty} = 0.56\ T_{100}$$

where T_{∞} is the shear strength independent of shear frame size and T_{250} and T_{100} are the shear strengths measured with a 250 cm^2 and 100 cm^2 shear frame respectively.

Stability Ratios

The stability ratio is the shear strength of a layer divided by the overlying slab's weight per unit area. The stability ratio has a complex relationship with avalanche occurrence, but in general the lower the ratio the greater the likelihood of avalanches.

$$\textit{Stability Ratio (SR)} = \frac{\textit{shear strength}}{\textit{weight per unit area}}$$

To determine the slab's weight per unit area, slide a small plate such as a putty knife or crystal card horizontally into the pit wall at a depth equal to the sampling tube length. Now slide the sampling tube vertically down through the surface until it strikes the plate. Excavate the sampling tube, taking care not to lose any snow out of the end of the tube. Transfer the contents of the sampling tube to a plastic bag for weighing. Divide the sample weight by the cross sectional area of the tube to calculate the slab weight per unit area. For weak layers deeper than the sampling tube length, use a stepped sampling method.

Results

The shear frame works best for thin weak layers or storm snow interfaces. Thick weak layers (i.e. depth hoar) tend not to produce consistent fracture planes. The shear frame works poorly in situations where very hard layers (i.e. wind slabs and crusts) are directly above weak layers. The problem is inserting the shear frame into the hard layer without fracturing the weak layer below. In addition, there is little operational experience and literature on the use of shear frames with wet snow. The shear frame is sensitive to user variability.

Shear Frame References

Föhn, P.M.B., 1987: The stability index and various triggering mechanisms. Avalanche Formation, Movement, and Effects, In: B. Salm and H. Gubler, (eds.), *IAHS-AISH Publication No. 162*, 195-211.

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Jamieson, J.B., and C.D. Johnston, 2001: Evaluation of the shear frame test for weak snowpack layers. *Annals of Glaciology,* 32, 59 - 66.

Perla, R.I., and T.M.K. Beck, 1983: Experience with shear frames. *Journal of Glaciology,* 29, 485-491.

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AVALANCHE OBSERVATIONS

3.1 INTRODUCTION
Observations of past and present avalanche activity are of the utmost importance for any avalanche forecasting operation. These data should be recorded and organized in a manner that allows personnel to visualize temporal and spatial patterns in recent avalanche activity. Objectives for observing avalanches are presented in Section 3.2. A standard avalanche observation is presented in Section 3.4. The remainder of this chapter provides methods for observing a wide variety of avalanche related phenomena. Parameters are divided into avalanche path characteristics and avalanche event characteristics. Parameters in the standard avalanche observation are marked with a ❄ symbol.

Individual operations can chose to observe and record parameters beyond those included in the standard observation. The parameters collected will depend on the type of operation and the snow climate of the forecast area.

3.2 OBJECTIVES
Observations and records of avalanche occurrences have the following applications:

- Information about avalanche occurrences and non-occurrences is used in association with other observations in evaluating snow stability.
- Observations identify areas where avalanches released earlier in the winter or storm/avalanche cycle. Snow stability may vary between these sites and nearby undisturbed slopes.
- Avalanche observation data are essential when protective works and facilities are planned, when the effectiveness of mitigation measures is assessed, and when forecasting models are developed by correlating past weather and snow conditions with avalanche occurrences.
- Understanding the avalanche phenomenon through research.

All avalanches that are significant to an operation should be recorded. Noting the non-occurrence of avalanches is also important for snow stability evaluation and during hazard reduction missions.

FIGURE 3.1 Explosive triggered slab avalanche. (P: Matt Steen)

3.3 IDENTIFICATION OF AVALANCHE PATHS
Avalanche paths should be identified by a key name, number, aspect, or a similar identifier which should be referred to on lists, maps, or photographs. For roads, railway lines, and power lines it is convenient to refer to avalanche paths by the running mile or kilometer. Every effort should be made to retain historical names. Changing historical names creates confusing records and decreases the usefulness of past data records. Historical paths that have multiple starting zones can be reclassified with subcategories of the original name. Any reclassification should be clearly explained in the metadata (see Appendix C).

Avalanche paths with multiple starting zones are often divided into sub zones. Separate targets for explosive placement may be identified within each starting zone.

3.4 STANDARD AVALANCHE OBSERVATION
This section outlines a standard avalanche observation for single avalanche events. Suggestions for summarizing multiple avalanche events are discussed in Section 3.7. Storm cycles and access to starting zones may make it difficult to observe every parameter for every avalanche that occurs within a forecast area. In this case the avalanche size characteristics should be estimated, and some of the snow specific parameters can be marked N/O for not observed.

The parameters have been separated into avalanche path characteristics and avalanche event characteristics. Operations that deal with a "fixed" number of paths documented in an avalanche atlas replace the path specific parameters with path name or number.

1. *Date* – record the date on which the avalanche occurred (YYYYMMDD).
2. *Time* – record the local time at which the avalanche occurred to the hour or minute if possible. Time codes of 2405 and 2417 can be used for avalanches that released at an unknown time during the AM and PM respectively. Time ranges or start and end times of mitigation missions can also be used.
3. *Observer* – record the name or names of the personnel that made the observation.
4. *Path Characteristics* (Section 3.5)
   a. *Observation Location* – record the name or number of the path where the avalanche occurred, the latitude and longitude, or the nearest prominent topographic landmark (mountain, pass, drainage, etc.) or political landmark (town, road mile, etc.).
   b. *Aspect* – record the direction the slope faces where the avalanche occurred (N, NE, E, SE, S, SW, W, NW).
   c. *Slope Angle in Starting Zone* – record the average slope angle in the starting zone where the avalanche released. When possible, a number of locations in the starting zone should be measured so that a maximum, minimum, and average value can be reported.
   d. *Elevation* – record the elevation of the crown face in feet (meters).

5. *Event Characteristics* (Section 3.6)
   a. *Type* – record the avalanche type.
   b. *Trigger* – record the event that triggered the avalanche.
   c. *Size* – record the size of the avalanche.
   d. *Snow Properties*
      i. *Bed Surface* – record the location of the bed surface as in new snow (S), at the new/old interface (I), in old snow (O), or at the ground (G). If the site was visited, record the hand hardness, grain type, and grain size.
      ii. *Weak Layer* – record the grain type and date of burial if known. If the site was visited record the hand hardness, grain type, and grain size.
      iii. *Slab* – record the hand hardness, grain type, and grain size.
   e. *Dimensions*
      i. *Slab Thickness* – record the average and maximum thickness or height of the crown face to the nearest 0.25 m (or whole foot).
      ii. *Width* – record the width (horizontal distance) of the avalanche to the nearest 10 m (or 25 feet).
      iii. *Vertical Fall* – record the vertical fall of the avalanche to the nearest 50 m (or 100 ft).
   f. *Location of Start Zone* – record the location of the crown face, as viewed from below, within the starting zone as top (T), middle (M), or bottom (B).
   g. *Terminus* – record the location of the debris within the avalanche path.

3.5 AVALANCHE PATH CHARACTERISTICS

3.5.1 AREA AND PATH ❄

Enter the name of the operation or avalanche area where the avalanche path is located. Enter the identifier (name or number) of the avalanche path. Some road operations may name their paths by the running mile or kilometer. In this case two decimal places may be used to identify paths within a whole mile or kilometer.

It is not necessary to note the area in every entry of a field notebook if that book is not taken from area to area.

3.5.2 ASPECT ❄

Use the eight points of the compass to specify the avalanche's central aspect in the starting zone. Compass degrees or the sixteen major points (i.e. NNE, ENE, etc.) may be used to convey greater detail. A range in aspect can be specified for large or highly curved starting zones.

TABLE 3.1 Slope Aspect

DIRECTION	N	NE	E	SE	S	SW	W	NW
DEGREES	0	45	90	135	180	225	270	315

3.5.3 SLOPE ANGLE ❄

Record the average slope angle (to the nearest whole degree) in the starting zone where the avalanche released. When possible, a number of locations in the starting zone should be measured so that a maximum, minimum and average value can be reported (Figure 3.2).

FIGURE 3.2 Measuring the slope angle of a slab avalanche. (P: Bruce Tremper)

3.5.4 ELEVATION ❄

Record the elevation of the starting zone or crown face in feet (or meters) above sea level (ASL).

3.6 AVALANCHE EVENT CHARACTERISTICS

3.6.1 DATE ❄

Record year, month and day of the avalanche occurrence (avoid spaces, commas, etc.) i.e. December 15, 2016, is noted as 20161215 (YYYYMMDD).

3.6.2 TIME ❄

Estimate the time of occurrence and record it by hour and minute in local standard time.

Record the time of occurrence on the 24-hour clock (avoid spaces, colons etc.) i.e. 5:10 p.m. is noted as 1710.

Use local standard time (i.e. Pacific, Mountain, etc.). Operations that overlap time zones should standardize to one time.

TABLE 3.2 Avalanche Type

DATA CODE	TYPE
L	Loose-snow avalanche
WL	Wet loose-snow avalanche
SS	Soft slab avalanche
HS	Hard slab avalanche
WS	Wet slab avalanche
I	Ice fall or avalanche
SF	Slush flow
C	Cornice fall (w/o additional avalanche)
R	Roof avalanche
U	Unknown

FIGURE 3.3 Avalanche types clockwise from top-left: soft slab avalanche; wet debris; debris from a hard slab avalanche; point release avalanche or sluff. (P: Karl Birkeland, Doug Krause, and Bruce Tremper)

When the precise time of occurrence is unknown, use 2405 and 2417 for avalanches that released during the AM and PM respectively. Time ranges or start and end times of mitigation missions can also be used.

3.6.3 AVALANCHE TYPE ❄

Record the type of avalanche as described in Table 3.2.

A hard slab has an average density equal to or greater than 300 kg/m3. Informal distinctions can be made between hard and soft slab avalanches based on the form of the deposit and the hand hardness of the slab. Hard slab avalanches generally have a slab hardness of one finger or greater. Debris piles from hard slab avalanches are typically composed of angular blocks of snow.

3.6.4 TRIGGER ❄

Indicate the mechanism that caused avalanche release with a primary code, secondary code when possible, and modifier when appropriate. The secondary codes have been separated into two categories with separate modifiers for each. Operations may devise other trigger sub-classes that apply to their specific conditions in consultation with the American Avalanche Association. Guidelines for reporting avalanche involvements are listed in Appendix H. Examples of coding structure are given in Section 3.6.12.

TABLE 3.3 Avalanche Trigger Codes - Primary

DATA CODE	CAUSE OF AVALANCHE RELEASE
N	Natural or Spontaneous
A	Artificial
U	Unknown

TABLE 3.4 Avalanche Trigger Codes - Secondary - Human, Vehicle,and Miscellaneous Artificially Triggered Releases

DATA CODE	CAUSE OF AVALANCHE RELEASE
ARTIFICIAL TRIGGERS: VEHICLE	
AM	Snowmobile
AK	Snowcat
AV	Vehicle (specify in comments)
ARTIFICIAL TRIGGERS: HUMAN	
AS	Skier
AR	Snowboarder
AI	Snowshoer
AF	Foot penetration
AC	Cornice fall produced by human or explosive action
ARTIFICIAL TRIGGERS: MISCELLANEOUS	
AU	Unknown artificial trigger
AO	Unclassified artificial trigger (specify in comments)

TABLE 3.5 Avalanche Trigger Code Modifiers for Human, Vehicle, and Miscellaneous Artificially Triggered Releases

DATA CODE	CAUSE OF AVALANCHE RELEASE
c	An intentional release by the indicated trigger (i.e. slope cut, intentional cornice drop, etc.).
u	An unintentional release.
r	A remote avalanche released by the indicated trigger (Figure 3.5)
y	An avalanche released in sympathy with another avalanche

Note: For remote and sympathetic avalanches the distance between the trigger and the avalanche should be recorded in the comments. Avalanches that start when a helicopter or other aircraft flies overhead should be considered natural if the aircraft is a significant distance above the ground. Avalanches triggered by helicopters when in "ground effect" should be considered artificially triggered. Ground effect can be observed when significant rotor wash (blowing snow) is noticed on the snow surface below the helicopter. Use your best judgment.

TABLE 3.6 Avalanche Trigger Codes - Secondary - Natural and Explosively Triggered Releases

DATA CODE	CAUSE OF AVALANCHE RELEASE
NATURAL OR SPONTANEOUS	
N	Natural trigger
NC	Cornice fall
NE	Earthquake
NI	Ice fall
NL	Avalanche triggered by loose snow avalanche (Figure 3.4)
NS	Avalanche triggered by slab avalanche
NR	Rock fall
NO	Unclassified natural trigger (specify in comments)
ARTIFICIAL TRIGGERS: EXPLOSIVE	
AA	Artillery
AE	An explosive thrown or placed on or under the snow surface by hand
AL	Avalauncher
AB	An explosive detonated above the snow surface (air blast)
AC	Cornice fall triggered by human or explosive action
AX	Gas exploder
AH	Explosives placed via helicopter
AP	Pre-placed, remotely detonated explosive charge
ARTIFICIAL TRIGGERS: MISCELLANEOUS	
AW	Wildlife
AU	Unknown artificial trigger
AO	Unclassified artificial trigger (specify in comments)

TABLE 3.7 Avalanche Trigger Code Modifiers for Natural and Explosively Triggered Releases

DATA CODE	CAUSE OF AVALANCHE RELEASE
r	A remote avalanche released by the indicated trigger
y	An avalanche released in sympathy with another avalanche

3.6.5 SIZE ❄

The two commonly used avalanche size classification schemes are 1) Relative to Path and 2) Destructive Force. Both systems use a scale that varies from 1 to 5. These guidelines recommend observing and recording avalanche size in both systems. Using both systems will maintain long-term data sets and provide the most useful information to active forecasting programs. However, forecasting program managers should decide whether to use one or both schemes. Each system provides different and useful information, but the numerical categories of each scale are often not comparable.

3.6.5.1 SIZE – DESTRUCTIVE FORCE

Estimate the destructive potential of the avalanche from the mass of deposited snow, and assign a size number. Imagine that the objects described in Table 3.8 (people, cars, trees, etc.) were located in the track or at the beginning of the runout zone and estimate the harm the avalanche would have caused.

3.6.5.2 SIZE – RELATIVE TO PATH

The size relative to path classification is a general measure and takes into account many factors, including the horizontal extent and vertical depth of the fracture, the volume and mass of the debris, and the runout distance of the avalanche. The observer estimates the size of the avalanche relative to the terrain feature or avalanche path where it occurred. A "small" avalanche is one that is relatively small compared to what that particular avalanche path could produce, while a "large" avalanche is, or is close to, the largest avalanche that the particular avalanche path could produce.

FIGURE 3.4 Slab avalanche triggered by a loose-snow avalanche. (P: Andy Gleason)

TABLE 3.8 Avalanche Size – Destructive Force (after CAA, 2007; Perla, 1980)

DATA CODE	AVALANCHE DESTRUCTIVE POTENTIAL	TYPICAL MASS	TYPICAL PATH LENGTH
D1	Relatively harmless to people.	<10 t	10 m
D2	Could bury, injure, or kill a person.	10^2 t	100 m
D3	Could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees.	10^3 t	1000 m
D4	Could destroy a railway car, large truck, several buildings, or substantial amount of forest.	10^4 t	2000 m
D5	Could gouge the landscape. Largest snow avalanche known.	10^5 t	3000 m

Note for Table 3.8: The use of half-sizes may be used to signify an avalanche that is on the high end of a single class.

The destructive potential of avalanches is a function of their mass, speed and density as well as the length and cross-section of the avalanche path. Typical impact pressures for each size number are given in McClung and Schaerer (1981).

The number "0" may be used to indicate no release of an avalanche following the application of mitigation measures.

TABLE 3.9 Avalanche Size – Relative to Path

DATA CODE	AVALANCHE SIZE
R1	Very small, relative to the path.
R2	Small, relative to the path
R3	Medium, relative to the path
R4	Large, relative to the path
R5	Major or maximum, relative to the path

Note for Table 3.9: Half-sizes should not be used for the Size-Relative to Path scale.

The number "0" may be used to indicate no release of an avalanche following the application of mitigation measures.

The size classification pertains to both the horizontal extent and the vertical depth of the fracture, as well as the volume and runout distance of the avalanche.

3.6.6 SNOW PROPERTIES

3.6.6.1 BED SURFACE ❄

Level of Bed Surface

Record the level of the bed surface (the upper surface of the layer over which a slab slid) in the snowpack per Table 3.10. If the avalanche involved more than one bed surface, all applicable codes should be included.

Form and Age of Fracture Plane

Record the predominant grain form observed in the layer below the fracture plane using the International Classification for Seasonal Snow on the Ground (refer to Appendix F). Where possible identify the failure plane by its probable date of burial. Use the comments section to note the occurrence of a fracture that steps down to other layers.

TABLE 3.10 Avalanche Bed Surface

DATA CODE	BED SURFACE
S	The avalanche released within a layer of recent storm snow.
I	The avalanche released at the new snow/old snow interface.
O	The avalanche released within the old snow.
G	The avalanche released at the ground, glacial ice or firn.
U	Unknown

Note for Table 3.10: Storm snow is defined here as all snow deposited during a recent storm.

3.6.6.2 WEAK LAYER ❄

Record the grain type using the International Classification for Seasonal Snow on the Ground (see Appendix F), grain size (mm), and hand hardness of the weak layer.

3.6.6.3 SLAB ❄

Record the grain type using the International Classification for Seasonal Snow on the Ground (see Appendix F), grain size (mm), and hand hardness of the slab directly above the weak layer.

3.6.6.4 LIQUID WATER CONTENT IN STARTING ZONE AND DEPOSIT

Determine the liquid water content of the avalanche snow in the starting zone and deposit at the time of failure and deposition. The liquid water content can be different in the starting zone and deposit.

Although these observations use the same data code, they can be recorded as two separate items to include more information.

TABLE 3.11 Liquid Water Content of Snow in Avalanche Starting Zone

DATA CODE	LIQUID WATER CONTENT
D	Dry snow
M	Moist snow
W	Wet snow
U	Unknown

Note: See Table 2.4 for water content definitions.

3.6.7 AVALANCHE DIMENSIONS

3.6.7.1 SLAB THICKNESS ❄

If practical, estimate or measure the average and maximum thickness of the slab (normal to the slope to the nearest 25 centimeters or whole foot) and the average thickness of the slab at the fracture line. If only one value is reported it should be the average dimension. Add "M" when the slab is actually measured.

3.6.7.2 SLAB WIDTH ❄

In a slab avalanche, record the width (horizontal distance) in meters (feet) of the slab between the flanks near the fracture line. Add "M" when width is actually measured.

3.6.7.3 VERTICAL FALL ❄

Using an altimeter or contour map, calculate the elevation difference in feet (meters) between the fracture line and the toe of the debris.

3.6.7.4 LENGTH OF PATH RUN

Some operations may wish to record the estimated distance an avalanche ran along a slope. Record the distance between the fracture line and the toe of the debris. Up to a distance of 300 m (~ 1000 ft) estimate the distance traveled to nearest 25 m (~ 100 ft). Beyond a distance of 300 m estimate the distance run to nearest 100 m (~ 300 ft). All dimensions are assumed to be estimates

FIGURE 3.5 Slab avalanches remotely triggered by foot penetration. (P: John Sykes)

unless the values are followed with the letter M (measured). Dimensions are assumed to be in meters. Measurements or estimates in feet should be indicated with a ' after the number (i.e. 3').

3.6.8 LOCATION OF AVALANCHE START ❄

Position in Starting Zone

Describe the location of the avalanche fracture with one of the following code letters, physical features or elevation and, when applicable, add the data code for the starting sub-zone or the target.

Note: For this code (Table 3.12) gunner's left and right should be used. Gunner's perspective is looking up at the starting zone (opposite of skier's perspective).

TABLE 3.12 Location of Avalanche Start

DATA CODE	VERTICAL LOCATION WITHIN STARTING ZONE FROM GUNNER'S PERSPECTIVE
T (L, R, C)	At the top of the starting zone (left, right, or center)
M (L, R, C)	In the middle of the starting zone (left, right, or center)
B (L, R, C)	At the bottom of the starting zone (left, right, or center)
U	Unknown

Note for Tables 3.12 and 3.13: The codes TP, MP and BP are applicable for short paths where the starting zone, track and runout zone cannot be easily separated.

3.6.9 TERMINUS ❄

Describe the location of the tip of the avalanche deposit with a data code. See Table 3.13.

3.6.10 TOTAL DEPOSIT DIMENSIONS

Record the average width and length of the deposited avalanche snow in meters (feet).

Record the average deposit depth in meters and tenths of a meter. Add an "M" after each value if measured by tape or probe.

3.6.11 AVALANCHE RUNOUT

The angle between the horizontal and a line drawn from the highest portion of the crown face and the toe of the debris can be used as a relative measure of avalanche runout. This angle, known as the alpha angle (α), has been used by landslide investigators since the late 1800's and has been applied to avalanche studies to describe extreme (~100 year) events. Although in avalanche research α has generally been reserved for very large events, guide services, engineers, scientists, and forecasters may find the subcategories defined in Table 3.15 useful.

Statistical studies suggest that alpha angles in a specific mountain range can cluster around a characteristic value. This value

TABLE 3.13 Terminus of Avalanche Debris

DATA CODE	TERMINUS FOR LONG PATHS
SZ	The avalanche stopped in the starting zone
TK	The avalanche stopped in the track
TR	The avalanche stopped at the top part of the runout zone
MR	The avalanche stopped in the middle part of the runout zone
BR	The avalanche stopped in the bottom part of the runout zone
U	Unknown

DATA CODE	TERMINUS FOR SHORT PATHS
TP	The avalanche stopped near the top of the path
MP	The avalanche stopped near the middle part of the path
BP	The avalanche stopped near the bottom part of the path

Note: Operations that have large avalanche paths with well-defined features may apply additional codes (See Table 3.14).

TABLE 3.14 Detailed Terminus Codes

DATA CODE	TERMINUS
1F	Stopped on top ¼ of the fan
2F	Stopped halfway down the fan
3F	Stopped ¾ of way down the fan

may be governed by terrain and snowpack conditions characteristic of the range (McClung and Schaerer, 2006; Mears, 1992; McClung and others, 1989; Lied and Bakkehøi, 1980).

3.6.12 CODING AVALANCHE OBSERVATIONS

Avalanche observations can be recorded in tabular format with a separate column for each data code. Common data codes can also be recorded in one string.

Example:

HS-AA-R2-D2: a hard slab avalanche triggered artificially by artillery
SS-AE-R4-D3: a soft slab avalanche triggered artificially by a hand charge
L-N-R1-D1: a small loose snow avalanche that released naturally
HS-ASr-R3-D3-O: a hard slab avalanche triggered remotely by a skier that broke into old snow layers (see Section 3.6.4)

TABLE 3.15 Alpha Angle Subcategories

DATA CODE	DESCRIPTION
α	The measured alpha angle for any individual avalanche.
α_e	The alpha angle of an extreme event. The smallest alpha angle (furthest avalanche runout) observed in a specific avalanche path, determined by historical records, tree ring analysis, or direct observation.
α_{number}	A calculated value of the smallest alpha angle (furthest avalanche runout) in a specific avalanche path during a defined time period. Where the designated time period (return period) in years is listed in the subscript (α_{10}, α_{50}, α_{100}).

HS-ACu-R4-D3: a hard slab avalanche triggered by an unintentional artificial cornice fall
HS-ACc-R2-D3: a hard slab avalanche triggered by an intentional artificial cornice fall
HS-AC-R2-D3: a hard slab avalanche triggered by a cornice drop produced by explosives
WS-NS-R4-D3: a wet slab triggered by a natural slab avalanche.
AC-0: An intentionally triggered cornice that did not produce an avalanche

3.6.13 COMMENTS

Enter information about damage and accidents caused by the avalanche and any other significant information. Note when the avalanche was triggered artificially. Use as much space as required.

3.7 MULTIPLE AVALANCHE EVENTS

An operation may wish to group large numbers of similar avalanche events (avalanche cycle) into one record or report, especially if that information is to be sent to a central information exchange. Grouping is achieved by allowing certain fields to hold a range of values (i.e. by specifying lower and upper bounds, separated by a dash). The report should be repeated for different types of activity (i.e. natural versus artificially released avalanches).

Significant avalanches (larger than size D3 or R3), and events involving incident, damage or injury should be described individually.

3.8 ADDITIONAL OBSERVATIONS

Additional observations may be selected as applicable from those listed in this section. Certain additional observations are valuable in areas where avalanches are either mitigated or affect traffic and/or communication lines.

TABLE 3.16 Multiple Avalanche Events – Recording Example

PARAMETER	CRITERIA	EXAMPLES
Date or date range	Record beginning of cycle and end of cycle when possible.	20010212 or 20010212 – 20010214
Time range	Digits	0000 – 1000
Area (location)	Text (80 characters max.)	Mt. Timpanogos
Size	Attempt to limit the size range to 2 classes. Significant or very large avalanches should be recorded as individual events.	D1.5 – D2.0 R2-R3
Trigger	Trigger Data code (do not mix natural and artificial triggers in this report)	AE, U
Type	Data code (group slab and loose avalanches separately)	HS, SS, U, or WL, U
Aspect (of starting zone)	A single, range, or a combination of compass directions.	All, W, SW-NW
Elevation (at fracture)	Group events by elevation range. Use separate reports for significant elevation ranges as applicable to forecast area.	5000-6500 and 8000-10,000 ft.
Slope Angle (at fracture)	Record range in average starting zone angle and max and min	32-42, 30, 45
Level of bed surface	Key letter (do not mix storm snow, old snow, and ground)	S, O, G, or U
Hardness of bed surface	Hand hardness scale	1F
Weak layer grain form	Grain abbreviation (Fierz et al., 2009)	SH
Hardness of weak layer	Hand hardness scale	4F
Age of failure plane	Probable date of burial	20011204
Slab width	Range (in meters)	60-110 m
Slab thickness	Range (in centimeters)	10-30 cm
Hardness of slab	Hand hardness scale	P
Vertical fall	Range (in meters)	500-1500 m
Comments	Max. of 5 lines by 80 characters per line	

3.8.1 AVALANCHE HAZARD MITIGATION MISSIONS

3.8.1.1 NUMBER OF EXPLOSIVE CHARGES / NUMBER OF DETONATIONS

Record the number of projectiles or explosive charges applied to a target. Record the number of confirmed detonations. The difference in the two values gives a dud count.

3.8.1.2 SIZE OF EXPLOSIVE CHARGE

Note the mass (kg) of the explosive charge used at each shot location.

3.8.2 ROAD AND RAILWAY OPERATIONS

3.8.2.1 DEPOSIT ON ROAD OR RAILWAY

Record in meters (feet) the length of road, railway line, ski run, power line, or other facility buried in avalanche snow.

Record average depth at center line and maximum depth of avalanche snow on the road, etc., in meters and tenths of a meter (feet/inches). Add "M" when length and depth are measured.

FIGURE 3.6 An avalanche triggered by glide of the snowpack. (P: Heather Thamm)

3.8.2.2 DISTANCE TO TOE OF DEPOSITED MASS

Measure or estimate the distance between the uphill edge of the road, or other development, and the farthest point reached by the mass of avalanche. Negative values are used when the deposited mass failed to reach the road or facility. Some operations may also wish to document the occurrence of snow dust on the road. Dust results from the fallout of an avalanche's powder cloud. Its main impact is on driver visibility.

3.8.2.3 ROAD / LINE STATUS

Transportation operations should record the status (open or closed) and danger rating (Appendix G) in effect for any roads or railway lines at the time when the avalanche occurred. During closures due to mitigation missions or avalanche activity, the start and end time of the closure should be recorded.

FIGURE 3.7 Trees damaged in the runout zone of a large avalanche path. (P: Doug Krause)

Accuracy — The difference between the measured value and the actual or true value. A property of a measurement method and instruments used. Also see precision.

Alpha Angle —The angle between the horizontal and a line drawn from the highest point of the crown face to the toe of the debris. Alpha can be measured for an individual avalanche (α_i). Extreme values of alpha (α_e) can be determined from historical records, tree ring data, or direct observation. Minimum values of alpha (longest runout length) can also be calculated for a specific return period (α_{10}, α_{50}, α_{100}). Also termed the angle of reach.

Anemometer — An instrument that measures the pressure exerted by, or the speed of wind.

Aspect — The exposure of the terrain as indicated by compass direction of the fall line (relative to true north). A slope that faces north has a north aspect.

Atmospheric Pressure — The pressure due to the weight of air on the surface of the earth or at a given level in the atmosphere. Also called barometric pressure.

Avalanche, Snow — A mass of snow sliding, tumbling, or flowing down an inclined surface that may contain rocks, soil, vegetation, or ice.

Avalanche Danger Scale — A categorical estimation of the avalanche danger. In the U.S., a five level scale is used for backcountry recreational users. See Appendix G.

Avalanche Path — A terrain feature where an avalanche occurs. An avalanche path is composed of a starting zone, track, and runout zone.

Avalauncher — A compressed gas delivery system for explosives. Designed for avalanche hazard mitigation.

Barometer — An instrument that measures atmospheric pressure. Barometers typically express this measure in millibars (mb) or inches of mercury (inHg).

Barometric Pressure — The pressure exerted by a column of air on the surface of the earth or at a given level in the atmosphere. Also called atmospheric pressure.

Bed Surface — The surface over which fracture and subsequent avalanche release occurs. The bed surface is often different than the running surface over which the avalanche flows through the track. A bed surface can be either the ground or a snow/ice surface.

Calibrate — To ascertain the error in the output of a measurement method by checking it against an accepted standard.

Caught — A category of the avalanche toll for an accident. A person is caught if they are touched and adversely affected by the avalanche. People performing slope cuts are generally not considered caught in the resulting avalanche unless they are carried downhill.

Collapse — When fracture of a lower layer causes an upper layer to fall, producing a displacement at the snow surface. The displacement may not always be detectable with the human eye. A collapse in the snowpack often produces a whumpfing sound.

Completely Buried — A category of the avalanche toll for an accident. A person is completely buried if they are completely beneath the snow surface when the avalanche stops. Clothing or attached equipment is not visible on the surface.

Concave Slope — A terrain feature that is rounded inward like the inside of a bowl (i.e. goes from more steep to less steep).

Condensation — The process of a gas being converted to a liquid due to changes in temperature and/or pressure. Also see definition of evaporation.

Convex Slope — A terrain feature that is curved or rounded like the exterior of a sphere or circle (i.e. goes from less steep to more steep).

Cornice — A mass of snow that is deposited by the wind, often overhanging, and usually near a sharp terrain break such as a ridge.

Creep — The time-dependent permanent deformation (strain) that occurs under stress. In the snow cover this includes deformation due to settlement and internal shear.

Crown — The snow that remains on the slope above the crown face of an avalanche.

Crown Face — The top fracture surface of a slab avalanche. Usually smooth, clean cut, and angled 90 degrees to the bed surface. Also see fracture line.

Crystal — A physically homogeneous solid in which the internal elements are arranged in a repetitive three-dimensional pattern. Within an ice lattice the internal elements are individual water molecules held together by hydrogen bonds. Usually synonymous with grain in snow applications (see definition for grain), although the term grain can be used to describe multi- crystal formation.

Danger, Avalanche — The potential for an avalanche(s) to cause damage to something of value. It is a combination of the likelihood of triggering and the destructive size of the avalanche(s). It implies the potential to affect people, facilities or things of value, but does not incorporate vulnerability or exposure to avalanches. Avalanche danger and hazard are synonymous and are commonly expressed using relative terms such as high, moderate and low.

Debris, Avalanche — The mass of snow and other material that accumulate as a result of an avalanche.

Deformation, Solid — A change in size or shape of a solid body.

Density — A mass of substance per unit volume. The International System of Units (SI) uses kg/m^3 for density.

Deposition, Vapor — The process of a gas being converted directly to a solid due to changes in temperature and/or pressure. Also see definition for sublimation.

Deposition, Wind — The accumulation of snow that has been transported by wind.

Dew Point — The temperature at which water vapor begins to condense and deposit as a liquid while the pressure is held constant.

Equilibrium Vapor Pressure — The partial pressure at which evaporation and condensation are occurring at the same rate. Also see saturation vapor pressure.

Error — The difference between the output of a measurement method and the output of a measurement standard.

Evaporation — Strictly defined as the conversion of mass between liquid and gas phases due to changes in temperature and/or pressure. Commonly used to describe mass conversion from liquid to gas, with condensation describing a phase change in the opposite direction.

Exposure — An element or resource (person, vehicle, structure, etc…) that is subject to the impact of a specific natural hazard.

Failure — A state of stress or deformation that meets a specific criterion. Many criteria for failure exist, but the most commonly used criteria for snow are: 1) the point at which shear stress in a weak layer equals the shear strength, 2) the point at which shear deformation increases while the strength of the weak layer decreases, 3) sudden excessive plastic deformation, 4) during a stability test, the loading step at which the test column fractures. Failure is a precursor to fracture, but fracture (and slab release) may or may not occur after failure. To avoid confusion, the criterion should always be specified when discussing failure.

Fall line — The natural downhill course between two points on a slope.

Flank — The snow to the sides of a slab avalanche, which remains after the release.

Force — An agent that causes acceleration or deformation of a particular mass. Often expressed by Newton's Second Law, $F = ma$, where the force acting on a given object is the product of its mass and its acceleration.

Fracture — The process of separating a solid body into two or more parts under the action of stress. The result of the fracture process is variously described depending on stress mode(s), scale, material type, and other variables. Nomenclature includes cracks, breaks, slip regions, dislocations, and ruptures. Occasionally, the word fracture is also used to denote the result of the fracture process (e.g. fracture line profile, fracture character, etc.)

Fracture Line — The remaining boundary of a slab after an avalanche has occurred. Also see definitions for crown face, flank and stauchwall.

Fracture Mechanics — A branch of materials physics that is concerned with the initiation and propagation of cracks. The field generally utilizes three variables: applied stress, flaw size, and fracture toughness (a material property), to characterize crack energetics or crack stresses.

Full Profile — A complete snow profile observation where grain size, grain type, interval temperature, layer density and layer hardness are measured and recorded in addition to stability information.

Funicular, Wet Snow Regime — When discontinuous air spaces and continuous volumes of water exist in a snow cover. In a funicular snow cover only water-ice and air-liquid connections exist. It is generally assumed that snow with a liquid water content (by volume) of 8 - 15 % is in the funicular regime. Also see the definition for the pendular regime.

Glide — Downhill slip of the entire snowpack along the ground or firm interface.

Grain — The smallest distinguishable ice component in a disaggregated snow cover. Usually synonymous with crystal in snow applications. The term grain can be used to describe polycrystal formations when the crystal boundaries are not easily distinguishable with a field microscope.

Hang Fire — Snow adjacent to an existing fracture line that remains after avalanche release. Hang fire typically has a similar aspect and incline to the initial avalanche.

Hard Slab — A snow slab having a density equal to, or greater than 300 kg/m^3 prior to avalanching.

Hazard, Avalanche — The potential for an avalanche(s) to cause damage to something of value. It is a combination of the likelihood of triggering and the destructive size of the avalanche(s). It implies the potential to affect people, facilities or things of value, but does not incorporate vulnerability or exposure to avalanches. Avalanche danger and hazard are synonymous and are commonly expressed using relative terms such as high, moderate and low.

Heat — A form of energy associated with the motion of atoms or molecules that is capable of being transmitted through a solid by conduction, through fluid media by conduction and/or convection and through empty space by radiation.

Humidity — The amount of water vapor contained in air. Also see relative humidity.

Hysteresis — 1) The history dependence of physical systems. When the outcome of a physical process depends on the history of the element or the direction of the process. 2) The properties of an instrument that depend on approaching a point on the scale during a full-scale traverse in both directions.

Hysteretic Error — The difference between the upscale reading and downscale reading at any point on the scale obtained during a full-scale traverse. Also see hysteresis.

Incline — The steepness of a slope. The acute angle measured from the horizontal to the plane of a slope. Also termed slope angle.

Induced Errors — Errors that stem from equipment quality or deviation from a standard measurement technique.

Inherent Errors — Errors due to natural variations in the process of measurement and will vary in sign (+/-) and magnitude each time they occur.

Injured — A category of the avalanche toll for an accident. A person is considered injured if they require medical treatment after being caught, partially buried-not critical, partially buried-critical, or completely buried in an avalanche.

Isothermal — The state of equal temperature. In an isothermal snow cover there is no temperature gradient. Seasonal snow covers that are isothermal are typically 0°C.

Latent Heat — The quantity of heat absorbed or released by a substance undergoing a change of state, such as ice changing to water or water to steam, at constant temperature and pressure.

Layer, Snow — An element of a snow cover created by a weather, metamorphic, or other event.

Loose-Snow Avalanche — An avalanche that releases from a point and spreads downhill entraining snow. Also termed a point-release avalanche or a sluff.

Mitigation, Avalanche Hazard — To moderate the frequency, timing, force, or destructive effect of avalanches on people, property, or the environment through active or passive methods.

Mixing Ratio — The ratio of the mass of water vapor to the mass of dry air in a volume of air. The mixing ratio is dimensionless, but usually expressed as g/kg.

Partially Buried—Critical — A category of the avalanche toll for an accident. A person is partially buried–critical if their head is below the snow surface when the avalanche stops but equipment, clothing and/or portions of their body are visible.

Partially Buried—Not Critical — A category of the avalanche toll for an accident. A person is partially buried–not critical if their head was above the snow surface when the avalanche stops.

Partial Pressure — The pressure a component of a gaseous mixture would exert if it alone occupied the volume the entire mixture occupies.

Pendular, Wet Snow Regime — When continuous air spaces and discontinuous volumes of water exist in a snow cover. In a pendular snow cover: air-ice, water-ice and air-liquid connections exist simultaneously. It is generally assumed that snow with a liquid water content (by volume) of 3 – 8% is in the pendular regime. Also see the definition for the funicular regime.

Point-Release Avalanche — See loose snow avalanche or sluff.

Precipitation Intensity — A measurement of the water equivalent that accumulated during a defined time period (usually 1 hour).

Precipitation Rate — An estimate of the amount of snow and/or rain that accumulated during a defined time period (usually 1 hour).

Precision — The level of detail that a measurement method can produce under identical conditions. Precision is a property of a measurement method and a measure of repeatability. The precision of a measurement method dictates the degree of discrimination with which a quantity is stated (i.e. a three digit numeral discriminates among 1,000 possibilities). Also see accuracy.

Pressure — The force applied to or distributed perpendicular to a surface, measured as force per unit area. The International System of Units (SI) uses N/m^2 or a pascal (Pa) for pressure.

Relative Humidity — A dimensionless ratio of the vapor pressure to the saturation vapor pressure, or the mixing ratio to the saturation mixing ratio. Relative humidity is reported as percent (i.e. vapor pressure/ saturation vapor pressure x 100 = % relative humidity).

Remote Trigger — When an avalanche releases some distance away from the trigger point.

Repeatability — The difference between consecutive measurements obtained by the same measurement method under the same conditions.

Resolution — The smallest interval between two adjacent, discrete measured values that can be distinguished from each other under specified conditions.

Return Period — The average time interval between occurrences of an event of given or greater magnitude. Usually expressed in years.

Risk — The effect of uncertainty on objectives (ISO 31000: 2009). *Avalanche Risk* is the probability or chance of harm to a specific element at risk, determined by the element's exposure and vulnerability to the avalanche hazard (Statham, 2008). In common usage, risk is a broad construct that relates uncertainty to outcome, often mediated by decision making or a diagnostic tool.

Running Surface — The surface over which an avalanche flows below the stauchwall. This surface can extend from the stauchwall, through the track, and into the runout zone. The running surface can be composed of one or more snowpack layers.

Runout Zone — The portion of an avalanche path where the avalanche debris typically comes to rest due to a decrease in slope angle, a natural obstacle, or loss of momentum.

Saturation Mixing Ratio — The mixing ratio of a parcel of air that is at equilibrium. See definitions of vapor pressure, saturation vapor pressure and equilibrium vapor pressure.

Saturation Vapor Pressure — The partial pressure of a vapor when evaporation and condensation are occurring at the same rate over a flat surface of pure substance (i.e. water). The saturation vapor pressure is a special case of the equilibrium vapor pressure.

Sensitivity — The response of a measurement method to a change in the parameter being measured. The sensitivity of a measurement method is usually expressed as a ratio. Example: For a mercury thermometer the sensitivity equals the change in length of the column of mercury per degree of temperature (m/°C).

Settling, Settlement — The slow, internal deformation and densification of snow under the influence of gravity. A component of creep.

SI Units — Système International d´Unités. An international system of units. See Appendix B.

Slab — A cohesive snowpack element consisting of one or more snow layers.

Slab Avalanche — An avalanche that releases a cohesive slab of snow producing a fracture line. Slope Angle —The acute angle measured from the horizontal to the plane of a slope.

Sluff — A loose snow avalanche or point release avalanche.

Snow Profile — A pit dug vertically into the snowpack where observations of snow cover stratigraphy and characteristics of the individual layers are observed. Also used to describe data collected by this method at an individual site.

Soft Slab — A snow slab with a density less than 300 kg/m^3.

Spatial Variability — The variation of physical properties across the physical extent, or various spatial scales, of a material. Typical scales in snow avalanche research and practice include the continental scale (defining variations in snow and avalanche climates), the regional scale (such as regions covered by backcountry avalanche advisories), the scale of individual mountain ranges (of various sizes), and the scale of individual slopes. Physical properties investigated vary, but include weak layer shear strength, stability test scores, penetration resistance, microstructural parameters, layer continuity, snow water equivalent, snow depth, and other characteristics.

Stability — 1) A property of a system where the effects of an induced disturbance decrease in magnitude and the system returns to its original state. 2) For avalanche forecasting stability is the chance that avalanches do not initiate. Stability is analyzed in space and time relative to a given triggering level or load.

Starting Zone — The portion of an avalanche path from where the avalanche releases.

Stauchwall — The downslope fracture surface of a slab avalanche.

Strain — The deformation of a physical body under an external force represented by a dimensionless ratio (m/m).

Strength — 1) The ability of a material to resist strain or stress. 2) The maximum stress a snow layer can withstand without failing or fracturing.

Stress — The distribution of force over a particular area. Expressed in units of force per area (N/m^2).

Study Plot — A fixed location where atmospheric and snow properties are measured and recorded. Study plot locations are chosen to limit the effects of external influences (i.e. wind, sun, slope angle) and are typically close to level.

Study Slope — A fixed, normally inclined location where snow properties and snow stability are measured and recorded. Atmospheric fields can also be recorded at a study slope. Study slope locations are chosen in relatively uniform areas, so that snow properties can be monitored over time and extrapolated to starting zones.

Sublimation — Strictly defined as the conversion of mass between solid and gas phases due to changes in temperature and/or pressure. Commonly used to describe mass conversion from solid to gas, with deposition describing a phase change in the opposite direction.

Sympathetic Trigger — When an avalanche triggers another avalanche some distance away. The second avalanche releases due to the disturbance of the first.

Targeted Site — A location where a targeted observation is conducted. A targeted site is chosen to investigate parameters of interest to a particular observer at a particular location. Data from targeted sites complements data from study plots and study slopes.

Temperature — Often defined as the condition of a body that determines the transfer of heat to or from other bodies. Particularly, it is a manifestation of the average translational kinetic energy of the molecules of a substance due to heat agitation. Also, the degree of hotness or coldness measured on a definite scale.

Temperature Gradient — The change in temperature over a distance. Expressed in units of degrees per length (i.e. °C/m).

Test Profile — A snow profile where selected characteristics of the snowpack are observed and recorded. Stability tests are typically conducted in a test profile. Also see full profile.

Track — The portion of an avalanche path that lies below the starting zone and above the runout zone.

Trigger — The mechanism that increases the load on the snowpack, or changes its physical properties to the point that fracture and subsequent avalanching occurs.

Trigger Point — The area where a trigger is applied.

Vapor Pressure — The partial pressure of a vapor.

Vulnerability — The degree to which an exposed element (person, vehicle, structure, etc…) will suffer loss from the impact of a specific natural hazard.

Wind Sensor — An instrument that measures both wind speed and direction.

Wind Slab — A dense layer(s) of snow formed by wind deposition.

Whumpf — See collapse.

APPENDIX A: REFERENCES

A.1 REFERENCES CITED

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APPENDIX B: UNITS

B.1 UNITS

A unit is a particular physical quantity, defined and adopted by convention, to which other quantities of the same kind are compared to determine their relative value. The use of a common system of units aids in communication of quantities, qualities, and rules of thumb between people and programs. A recommended system of units for snow, weather, and avalanche observations is listed in Section B.2. It follows the International System of Units (SI) (Section B.3) with a few exceptions.

B.2 UNITS FOR SNOW, WEATHER AND AVALANCHE OBSERVATIONS

In the United States, personnel of avalanche operations and users of their products may not be familiar with all SI units. For this reason individual programs should choose a unit system that suits their particular application. Data records generated for regional and national databases should use the international units listed below (or clearly list units used in accompanying metadata files). Deviations from the international units should use the common U.S. units listed below. Conversions between the two systems are listed in Section B.4.

TABLE B.1 Recommended Units for Snow, Weather, and Avalanche Observations

	INTERNATIONAL UNIT		COMMON U.S. UNIT	
QUANTITY	**UNIT**	**SYMBOL**	**UNIT**	**SYMBOL**
temperature – air	degree Celsius	°C	degree Fahrenheit	°F
temperature – snow	degree Celsius	°C	degree Celsius	°F
wind speed	meter/second	m/s	mile/hour	mi/hr
aspect and wind direction	compass degree	°	compass direction	N,NE,E,SE, S, SW, W , NW
relative humidity	percent water	%	percent water	%
barometric pressure	millibar	mb (1 mb = 1 hPa)	inches of mercury	inHg
new snow depth	centimeter	cm	inch	in
total snow depth	centimeter or meter	cm or m	inch	in
water equivalent of precipitation or snowpack	millimeter	mm	inch	in
density	kilogram/cubic meter	kg/m^3	percent water	%
snow grain size	millimeter	mm	millimeter	mm
length	meter	m	foot	ft

Note: Most topographic maps in North America use feet as the unit for elevation. Thus it is more practical to use feet for the common elevation unit. Field observations can use feet to record elevations, however metadata for weather and snow study plots should list the elevation in meters.

B.3 SI UNITS

The Système International d´Unités (SI), or International System of Units, has been accepted by most of the nations of the world as a common language for science and industry. It defines a set of base units from which other quantities are derived. Details of the International System of Units can be found at http://physics.nist.gov/cuu/Units/. Common conversion factors are listed in Section B.4.

Some derived SI units have been given special names to make them easier to use.

For large or small quantities, a set of prefixes and associated decimal multiples can be used with SI units. These prefixes can be used with any base or derived SI unit with the exception of kilogram. Since the base unit kilogram already contains the prefix kilo, the set of prefixes are used with the unit name gram.

Example of prefix use:

1 m x 103 = 1 kilometer
1 m x 1000 = 1 kilometer
1 kilometer = 1000 m

TABLE B.2 SI Base Units

QUANTITY	UNIT NAME	UNIT SYMBOL
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
amount of substance	mole	mol
electric current	ampere	A
luminous intensity	candela	cd

TABLE B.3 Common Derived SI Units

QUANTITY	UNIT NAME	UNIT SYMBOL
area	square meter	m^2
volume	cubic meter	m^3
speed	meter per second	m/s
acceleration	meter per second squared	m/s^2
density	kilogram per cubic meter	kg/m^3

TABLE B.5 SI Unit Prefixes

FACTOR	NAME	SYMBOL
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

TABLE B.4 Derived SI Units with Special Names

QUANTITY	UNIT NAME	UNIT SYMBOL	DERIVED DEFINITION	BASE DEFINITION
force	newton	N		$kg{\times}m/s^2$
pressure or stress	pascal	Pa	N/m^2	$kg/(m{\times}s^2)$
energy or work	joule	J	$N{\times}m$	$kg{\times}m^2/s^2$
power	watt	W	J/s	$kg{\times}m^2/s^3$
Celsius temperature	degree Celsius	°C		K
plane angle	radian	rad		m/m

B.4 UNIT CONVERSIONS

B.4.1 UNIT ANALYSIS

Unit conversions can be accomplished by a method known as unit analysis. Each unit can be written as a combination of base units, such as length, time, or mass. Then conversion can be accomplished by multiplying by a unit ratio, canceling the unwanted units and thus leaving the desired value. This technique combined with the use of the SI unit prefixes can be used to accomplish most conversions.

Example:

$$5.0 \text{ m x } \frac{3.28 \text{ ft}}{1 \text{ m}} = 16.4 \text{ ft}$$

$$5.0 \frac{\text{mi}}{\text{hr}} \text{ x } \frac{5280 \text{ ft}}{1 \text{ mi}} \text{ x } \frac{1 \text{ hr}}{3600 \text{ s}} = 2.2 \frac{\text{mi}}{\text{s}}$$

$$20.67 \text{ inHg x } 3386.389^{\star} \frac{\text{Pa}}{\text{inHg}} \cong 70{,}000 \text{ Pa x } \frac{1 \text{ bar}}{100{,}000 \text{ Pa}} = 0.7 \text{ bar x } \frac{1000 \text{ mb}}{\text{bar}} = 700 \text{ mb}$$

**This is a conversion for inches of mercury at 0° C*

The appropriate ratios can be easily constructed if you know the proper proportions.

Example:

There are 5,280 feet in 1 mile: $\frac{5280 \text{ ft}}{1 \text{ mi}}$

There are 60 seconds in 1 minute: $\frac{60 \text{ s}}{1 \text{ min}}$

B.4.2 TIME

There are:

60 seconds in 1 minute
60 minutes in 1 hour
24 hours in 1 day
365 days in 1 year (366 days in one leap year)

B. 4.3 TEMPERATURE

For temperature conversions it is more appropriate to list conversion equations.

°C = K − 273.15 K = °C + 273.15
°C =(5/9)(°F –32) °F = (9/5)°C + 32

B.4.4 SPEED

1 mi/hr = 1.609344 km/hr
= 0.8689762 knots
= 0.44704 m/s

1 m/s = 3.6 km/hr
= 2.2369363 mi/hr
= 1.9438445 knots

1 km/hr = 0.6213712 mi/hr
= 0.2777778 m/s
= 0.5399568 knots

1 knot = 1.1507794 mi/hr
= 0.514444 m/s
= 1.852 km/hr

B.4.5 PRESSURE

1 Pa = 0.00001 bar
= 0.01 mb = 0.01 hPa
= 0.000295 inches of mercury at 0°C
= 0.007501 millimeters of mercury at 0°C
= 0.000009869 atm

B.4.6 LENGTH

1 in = 2.54 cm
1 ft = 0.3048 m
1 mi = 1609.344 m

B.4.7 DENSITY

The density of snow is usually calculated by weighing a sample of known volume.

Example:

If the mass of a 250 cm^3 snow sample is 70 g, then:

$$\frac{70\text{g}}{250 \text{ cm}^3} = 0.28 \frac{\text{g}}{\text{cm}^3} \text{ x } \frac{1\text{kg}}{1000\text{g}} \text{ x } \frac{1{,}000{,}000\text{cm}^3}{1\text{m}^3} = 280 \frac{\text{kg}}{\text{m}^3}$$

Simple relations can be determined for common calculations. For example if you typically use a 250 cm^3 cutter to take your snow sample then you can multiply the mass in grams by 4 to obtain the density in kg/m^3.

The percent water content of a snow sample is often communicated as a dimensionless ratio or percent. It is easily calculated by dividing the density of the snow by the density of water (1000 kg/m^3) and multiplying by one hundred. Using the density of water allows for an easy calculation by moving the decimal one space to the left (ie: 280 kg/m^3 = 28%).

The percent water content of a snow sample can also be obtained by dividing the height of its water equivalent by the height of the snow layer and then multiplying by 100.

Example:

If you have 10 cm of snow whose water equivalent is 1 cm of water.

$$\frac{1 \text{ (cm) water}}{10 \text{ (cm) snow}} = 0.1\text{x}100 = 10\% \text{ water content}$$

B.5 EXPANDED EQUATIONS

Several equations are presented in abbreviated form in the text. The expanded versions below are intended to explain how the abbreviated versions were derived.

Section 1.22

$$H2DW\,(mm) = \frac{mass\ of\ snow\ sample\ (g)}{area\ of\ snow\ sample\ (cm^2)} \times 10$$

Expanded Equation

$$H2DW\,(mm) = \frac{mass(g)}{area(cm^2)} \times \frac{1(cm^2)}{100(mm^2)} \times \frac{1(cm^3\ of\ water)}{1(g\ of\ water)} \times \frac{1000(mm^3)}{1(cm^3)}$$

Section 1.23

$$\rho\ \frac{kg}{m^3} = \frac{mass\ of\ snow\ sample(g)}{sample\ volume(cm^3)} \times 1000$$

Expanded Equation

$$\rho\ \frac{kg}{m^3} = \frac{mass\ of\ snow\ sample(g)}{sample\ volume(cm^3)} \times \frac{1{,}000{,}000(cm^3)}{1(m^3)} \times \frac{1(kg)}{1000(g)}$$

Section 1.23

$$\rho\ \frac{kg}{m^3} = \frac{H2DW(mm)}{H2D(cm)} \times 100$$

Expanded Equation

$$\rho\ \frac{kg}{m^3} = \frac{water\ equiv.of\ snow\ sample\ (mm)}{height\ of\ snow\ sample(cm)} \times \frac{1(cm)}{10(mm)} \times \frac{1(g water)}{1(cm^3\ water)} \times \frac{1(kg)}{1000(g)} \times \frac{1{,}000{,}000(cm^3)}{1(m^3)}$$

APPENDIX C: METADATA

C.1 INTRODUCTION

Metadata is information about data (data about data). It is an integral part of maintaining a long-term record. Metadata provides a chronology of methods used to obtain a dataset and can provide important information for observers and data users alike.

C.2 FILE FORMAT AND CONTENT

There is no clear method for collecting and recording metadata. What should be recorded and how to record it depends on the application. For avalanche operations we recommend maintaining a "field book" for each observation site. This field book could be an actual book stored at the site or an electronic or paper file stored in an office. An example of commonly recorded metadata fields for a meteorological site are listed in Section C.3

A metadata file should contain a basic description of the observation site. This includes, but is not limited to, location, aspect, elevation and exposure. A photographic record of the site and changes to the site may be useful. A description of each instrument should be included. Metadata files should also contain a record of site maintenance (e.g. new tower, growth/removal surrounding vegetation) and instrument calibration; and a list of measurements made at the site should be in the order that they are listed in the record or data file. Data is assumed to be in the recommended system of international units listed in Appendix B unless other units are specified in the metadata file. Metadata and data archives should be stored and formatted to facilitate efficient retrieval.

C.3 METADATA EXAMPLE FOR METEOROLOGICAL OBSERVATION SITES

1. Site
    - a Station/site name/site ID
    - b. Lock combination
    - c. Lat / Lon (map datum: NAD27 or NAD83/ WSG84) or UTM
    - d. Elevation
    - e. Aspect
    - f. Slope angle
    - g. Photographs from each aspect
    - h. Changes to site (date and type)
    - i. Comments
2. Operation Status
    - a. Year-round
    - b. Seasonal
    - c. Special
    - d. Start date
    - e. End date
3. Type
    - a. Study plot
    - b. Mountaintop
    - c. Ridgetop
4. Power
    - a. None
    - b. Solar/battery
    - c. AC
5. Sensors
    - a. Properties
        - i. Make
        - ii. Model
        - iii. Serial Number
        - iv. Type
    - b. Installation
        - i. Height above ground
        - ii. Distance from tower or obstacle
        - iii. Date installed
        - iv. Sampling rate
        - v. Average length and technique
        - vi. Service and calibration dates
        - vii. Units of stored values
        - viii. Comments
6. Data loggers
    - a. Brand
    - b. Model
    - c. Serial number
    - d Type
    - e Acquisition date
    - f. Service dates
    - g. Comments
7. Data Retrieval
    - a. Direct-manual
    - b. Radio telemetry
    - c. Cellular phone
    - d. Telephone
    - e. Short haul modem
    - f. Satellite
8. Software
    - a. Product name
    - b. Version number
    - c. Program name
    - d. Installation date
    - e. Upgrade date
    - f. Comments
9. Observer Contact Information
    - a. Name
    - b. Agency
    - c. Address
    - d Telephone
    - e. Email

D.1 INTRODUCTION

Measurements of precipitation, temperature, wind, and the characteristics of the snowpack are dependent on the observation site. The utmost care must be taken to select a site for weather and/or snowpack observations that is geographically representative of the forecast area or avalanche starting zones.

Measurements made at study sites often serve as baseline information from which conditions in starting zones can be extrapolated.

Site selection requires knowledge of the area and skill in meeting contradictory needs. Sometimes parallel observations may be recorded in several possible locations for one winter before a permanent site is chosen, or a site may have to be abandoned after yielding unsatisfactory correlations. The access should be convenient and safe under normal conditions.

Site characteristics differ depending on the parameter of interest and the application of the data. Avalanche forecasting operations typically require precipitation measurements from sheltered locations (Figures D.2 and D.3) and wind measurements in exposed areas (Figures D.1 and D.4). For this reason more than one observation site may be necessary for an individual program. Ideally each program would have at least one site where all of the basic meteorological parameters are observed, and one or more sites where at least wind speed, wind direction, and air temperature are measured.

The guidelines presented in this appendix represent the best-case scenario. Some of the guidelines will be difficult for all avalanche forecasting operations to achieve. These guidelines should be considered during the site selection process before a practical site is selected.

D.2 METEOROLOGICAL AND SNOWPACK STUDY SITE SELECTION

Observation sites should be selected so that measurements made at the site will be representative of the forecast area. The site should be as close as possible to avalanche starting zones and still permit regular observations. Exposure issues usually dictate separate sites for wind and precipitation measurements. When separate sites are deemed necessary, air temperature measurements should be collected from both sites.

A meteorological study site will ideally be located in a level, open area that is devoid of large vegetation. The World Meteorological Organization (WMO) recommends a site 10 meters by 7 meters (WMO, 1996). This recommendation should be treated as an ideal, as significantly smaller sites may be more appropriate for observations in exposed mountain areas. The surface should

FIGURE D.1 A remote weather station. (P: Doug Krause)

FIGURE D.2 The Utah Department of Transportation's study site in Alta, Utah. (P: Bruce Tremper)

be cleared so that the ground cover consists of short grass or the predominate ground cover in the area. Instruments should be placed in a measurement site (approximately two-meter by two-meter area) at the center of the opening. A visual barrier or signs should surround the area to prevent unwary travelers from disturbing the study site.

Snowpack observation sites can be co-located with meteorological sites if adequate space is available. Snowpack and precipitation measurement sites should be sheltered from the wind. Sites that minimize snow drifting should be selected if wind effects cannot be avoided. The main requirement for wind stations is a good correlation between measurements at observation locations and avalanche starting zones.

D.3 INSTRUMENT EXPOSURE

Precipitation

For sites where precipitation measurements are made, it is recommended that the instrument (snow board, rain gauge, snow depth sensor, etc.) be at least as far from the nearest obstacle (building, tree, fence post, etc.) as that obstacle is high. Precipitation sites should be devoid of sloping terrain if possible and away from depressions or hollows. Rooftop sites should be avoided. When practical or environmental constraints require deviating from these guidelines, the changes can be recorded in the metadata file (see Appendix C).

Precipitation gauges located at windy sites can seriously underestimate the actual precipitation amount. Gauge catch can be improved by the following methods listed in the order of effectiveness (WMO, 1996):

1. The vegetation height of the site can be maintained at the same height as the gauge orifice, thus maintaining a horizontal wind flow over the gauge.
2. The effect listed in point 1 can be simulated by an artificial structure (i.e. fence).
3. The use of a wind shield such as an Alter or Nipher shield, or a similar device around the gauge orifice.

Many avalanche operations use ultra-sonic distance instruments to remotely monitor snow height. These gauges can be used to record both total snow height (HN) or interval values (e.g. HN24). The response of these instruments is affected by both air temperature (which can be addressed in the datalogger program) and the concentration of airborne particles.

Temperature

Temperature instruments must be properly ventilated and sheltered from radiation sources. This can be accomplished by housing the instrument in a commercial radiation shield or Stevenson screen. Manual and automated instruments can be co-located in a Stevenson screen. The screen door should open to the north to prevent solar heating of the temperature sensors.

FIGURE D.3 A manual snow stake, precipitation can, and ultrasonic snow depth sensor. (P: Don Sharaf)

FIGURE D.4 A weather station coated in rime ice. (P: John Stimberis)

Temperature instruments should be located 1.25 m to 2 m above the surface (WMO, 1996). Ideally the instrument shelter is mounted on an adjustable post so that a constant distance above the surface can be maintained. The instrument should be exposed to wind and sun (although properly shielded).

Depressions or hollows that can trap cold air should be avoided. Temperature measurements should not be made near buildings or on rooftops.

Relative Humidity

Instrument exposure issues for relative humidity measurements will depend on the measurement method. Relative humidity measurements in below freezing environments can be difficult and instrument selection is critical (and beyond the scope of this discussion). In general, instruments should be sheltered from direct solar radiation, atmospheric contaminants, precipitation and wind (WMO, 1996). Materials such as wood and some synthetic products can absorb and desorb water according to atmospheric humidity (WMO, 1996). If the enclosure is made of wood it should be coated in white enamel paint (creating a vapor barrier). Relative humidity instruments can be co-located with temperature instruments provided that these issues are addressed.

Wind

Anemometers should ideally be located atop a vibration-free, 10-meter (~30 ft) tower. Wind measurements can be dramatically affected by the presence of upstream obstacles. Ideally, there should be no obstructions within a 100 m (~ 300 ft) radius of the anemometer (WMO, 1996). In mountainous terrain, where large obstacles are prevalent, anemometers at two or more locations can be used to gain adequate wind information in a variety of conditions. Local obstructions, such as the tower or other instruments, should be a distance away from the wind sensor that is four to five times the diameter of the obstruction. These effects can be addressed by placing the wind sensor at the top of the tower.

Several wind stations may be needed to obtain a reasonable estimate of wind effects within a forecast area. Considerable separation (vertical and horizontal) may be required to achieve a suitable representation of the actual wind field. It is essential that cup anemometers be horizontal to the underlying surface. All stations must be accessible in the winter either by foot, snowmobile or helicopter for occasional maintenance of equipment. Rime ice accretion is a common problem (Figure D.5) that can be addressed with heated sensors.

FIGURE D.5 Left: An exposed wind site to monitor general atmospheric flow. (P: Mark Moore) Right: A pyranometer for measuring incoming short wave solar radiation. (P: Don Sharaf)

Radiation

Radiation processes have a large effect on snowpack stability and avalanche release. Instrument exposure issues will depend on the type of radiation measured and the direction of the radiation (incoming or outgoing), but radiation can be measured at any study site. If only one radiation component can be measured, incoming shortwave radiation may be the most useful. However, both short and longwave components can benefit avalanche applications.

Incoming shortwave radiation can be measured in a flat open area. Sensors should be installed so that they are level and in locations that are not in the shadow of buildings, trees, and when possible mountains (Figure D.4). Shadowing should be evaluated throughout the day and season for instrument placement. The effects of the tower will be minimized if the instrument is placed a significant distance from (long arm) and on the south side (in the Northern Hemisphere) of the tower. It may also be beneficial to place incoming shortwave sensors above the vegetation canopy.

APPENDIX E: AUTOMATED WEATHER STATIONS

E.1 INTRODUCTION

Automated measurements of snow and weather phenomena are extremely useful components of an observational record. Automated sites provide an uninterrupted record and yield information about areas that are not commonly visited. Automated measurements allow observers to fill in the periods between manual observations, and may provide key information that would otherwise be missed. In many cases it may be more practical to maintain a weather record that is a combination of manual and automated measurements. When possible, automated measurements should be used to augment and not replace manual observations.

E.2 OBJECTIVES

The purpose of this appendix is to:

- Establish common methods for recording and reporting data collected by automated stations
- Encourage uniformity of measurements
- Provide methods for combining manual and automated data
- Encourage methods that produce data that is compatible with other long-term records.

E.3 COMBINING MANUAL AND AUTOMATED DATA

Maintaining a separate manual and automated data record is generally preferred. Replacing manual observations with automated measurements should only be employed when the operation headquarters are a significant distance from the avalanche terrain, or if access to a study site is unreliable.

Daily weather summaries that include a combination of manual observations and automated measurements are often useful for operations that make decisions based on these data. This practice is not a problem until the data set is transmitted to another user or central database. Manual and automated records can be co-located as long as a careful record of the source and type of measurement is present in the metadata file (see Appendix C). However, maintaining separate manual and automated data records is recommended.

The most common parameters obtained from automated weather stations are wind speed, wind direction, and temperature. Automated measurements of precipitation and total snow depth have become more common with improvements in sensors. Automated depth sensors can be used to record valuable interval measurements at stations that can not be visited regularly.

Values for wind speed and direction for daily observation sheets can be obtained by recording the hourly average from the period during which the manual observations were made. Maximum and minimum temperatures can also be obtained from an automated station provided that system explicitly records these values. The 24-hour maximum and minimum temperature should be averages of a period no longer than one minute (WMO, 1996).

E.4 SAMPLING RATES AND AVERAGING PERIODS

The time interval between measurements (sampling rate) is an important and complex issue. Avalanche forecasting operations typically use a sampling rate of 3 to 5 seconds for temperature, wind, relative humidity, and pressure measurements. However, longer execution intervals (up to 60 sec) may be necessary at remote stations where power is limited. Precipitation measurement rates will depend on the instrument. Snow depth sensors can be sampled at the same rate that data is stored (i.e. 10 minute, 1 hour, etc.). Other precipitation sensors may require the computation of a running total rather than an average. These are practical solutions that work for many applications. Operations that require more robust sampling schemes are referred to World Meteorological Organization Publication Number 8 (see Appendix A for full reference).

Power constraints may dictate sampling schemes in remote locations. If these issues prevent continuous sampling, measurements can be sampled for 5 minutes before the hour and data can be recorded and reported on the hour.

The period over which a parameter is averaged depends upon the application. Many avalanche forecasting operations find it useful to look at averages of 5, 10, or 15 minute periods. These short interval averages will be most useful during storm periods, while one-hour averages are more useful for daily operations. Parameters stored in six-hour averages will conform to other long-term records such as climatic datasets. It is recommended that one-hour averages be stored as the long-term record.

Most parameters measured at automated weather stations can be averaged with a simple arithmetic scheme. Wind direction is the most notable exception. Wind direction averages must be computed with a scheme that accounts for the circular nature of the values. Most data logger programming structures have a specific averaging scheme for these data (see programming example below for Campbell Scientific). Otherwise it is common practice to use a vector representation of wind and average its two horizontal components (Fisher, 1993: p. 31).

APPENDIX F: ICSI CLASSIFICATION FOR SEASONAL SNOW ON THE GROUND

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
PRECIPITATION PARTICLES			**PP**				
+	Columns ▭	Prismatic crystal, solid or hollow	PPco	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at –3 to –8 °C and below–30 °C		
	Needles ↔	Needle-like, approxi-mately cylindrical	PPnd	Cloud	Growth from water vapour at high super-saturation at –3 to –5 °C and below –60 °C		
	Plates ⎔	Plate-like, mostly hexagonal	PPpl	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at 0 to –3 °C and –8 to –70 °C		
	Stellars, Den-drites ∗	Six-fold star-like, planar or spatial	PPsd	Cloud; temperature inversion layer (clear sky)	Growth from water vapour at high super-saturation at 0 to –3 °C and at –12 to –16 °C		
	Irregular crystals ⌒	Clusters of very small crystals	PPir	Cloud	Polycrystals growing in varying environ-mental conditions		
	Graupel ⧗	Heavily rimed particles, spherical, conical, hexagonal, or irregular in shape	PPgp	Cloud	Heavy riming of particles by accretion of supercooled water droplets Size: ≤ 5 mm		
	Hail ▲	Laminar internal structure, translu-cent or milky glazed surface	PPhl	Cloud	Growth by accretion of supercooled water Size: > 5 mm		
	Ice Pellets ⚠	Transparent, mostly small spher-oids	PPip	Cloud	Freezing of raindrops or refreezing of largely melted snow crystals or snowflakes (sleet) Graupel or snow pellets encased in thin ice layer (small hail) Size: both ≤ 5 mm		
See Notes on next page	Rime ∀	Irregular deposits or longer cones and needles pointing into the wind	PPrm	Onto surface as well as on freely exposed objects	Accretion of small, supercooled fog droplets frozen in place. Thin breakable crust forms on snow surface if process continues long enough	Increase with fog density and exposure to wind	

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
MACHINE MADE SNOW			**MM**				
	Round polycrystalline particles	Small spherical particles, often showing protrusions, a result of the freezing process, may be partially hollow	MMrp	Atmosphere, near surface	Machined snow, i.e., freezing of very small water droplets from the surface inward	Liquid water content depends mainly on air temperature and humidity but also ons snow density and grain size	In dry conditions, quick sintering results in rapid strength increase
	Crushed ice particles	Ice plates, shard-like	MMci	Ice generators	Machined ice, i.e., production of flake ice, subsequent cruchins, and pneumatic distribution	All weather safe	

References: Fauve et al., 2002

Precipitation Particles Notes: A subscript "r" modifier is used to denote rimed grains in the Decomposing and Fragmented Particles (DF) major class and the Precipitation Particles (PP) major class and its subclasses except for gp, hl, ip, rm (Example: PP-r). Hard rime is more compact and amorphous than soft rime and may build out as glazed cones or ice feathers (AMS, 2000). The above subclasses do not cover all types of particles and crystals one may observe in the atmosphere. See the references below for a more comprehensive coverage.
References: Magono & Lee, 1966; Bailey & Hallett, 2004; Dovgaluk & Pershina. 2005; Libbrecht, 2005

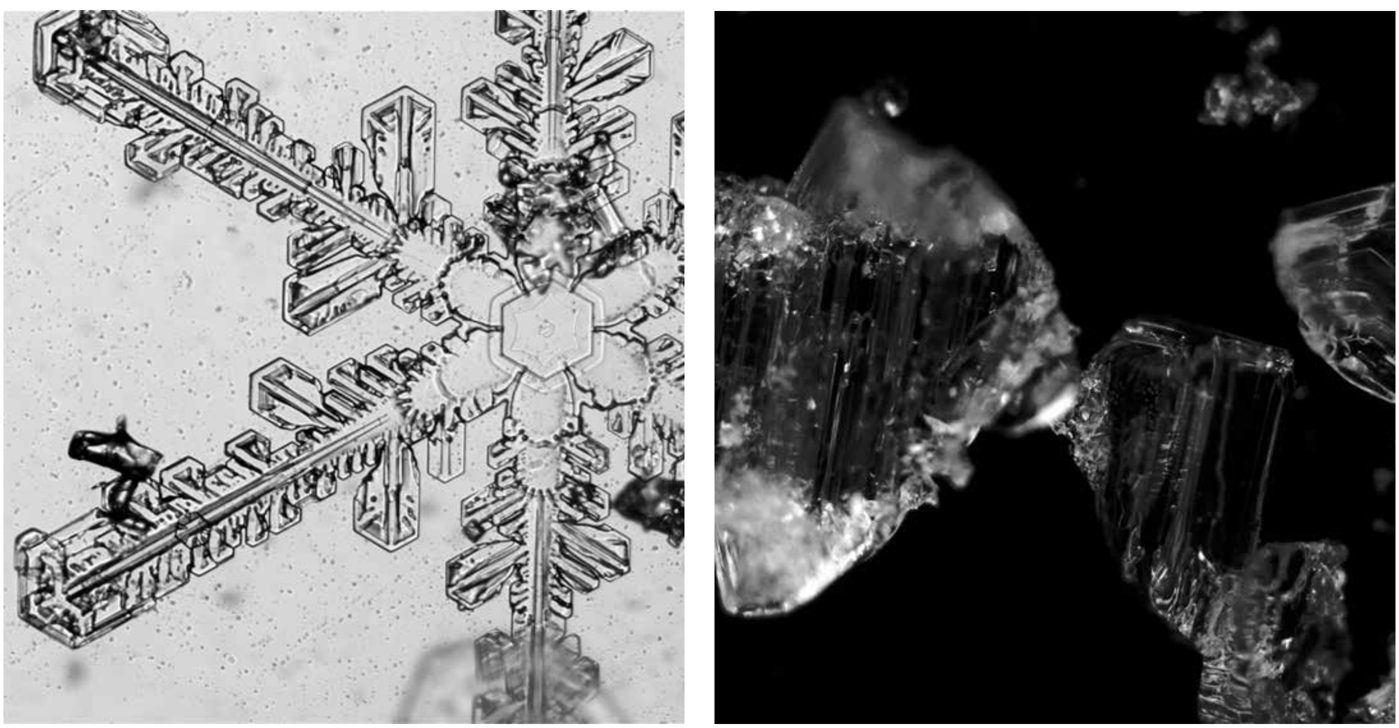


FIGURE F.1 Left: A stellar snow crystal (PPsd) in the Precipitation Particle class (PP) Right: A hollow, cupped, depth hoar crystal (DHcp) in the Depth Hoar class (DH)

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
			DF				
DECOMPOSING AND FRAGMENTED PRECIPITATION PARTICLES	Partly decomposed precipitation particles	Characteristic shapes of precipitation particles still recognizable; often partly rounded	DFdc	Within the snowpack; recently deposited snow near the surface, usually dry	Decrease of surface area to reduce surface free energy; also fragmentation due to light winds lead to initial break up	Speed of decomposition decreases with decreasing snow temperatures and decreasing temperature gradients	Regains cohesion by sintering after initial strength decreased due to decomposition process
	Wind-broken precipitation particles	Shards or fragments of precipitation particles	DFbk	Surface layer, mostly recently deposited snow	Saltation particles are fragmented and packed by wind, often closely; fragmentation often followed by rounding	Fragmentation and packing increase with wind speed	Quick sintering results in rapid strength increase

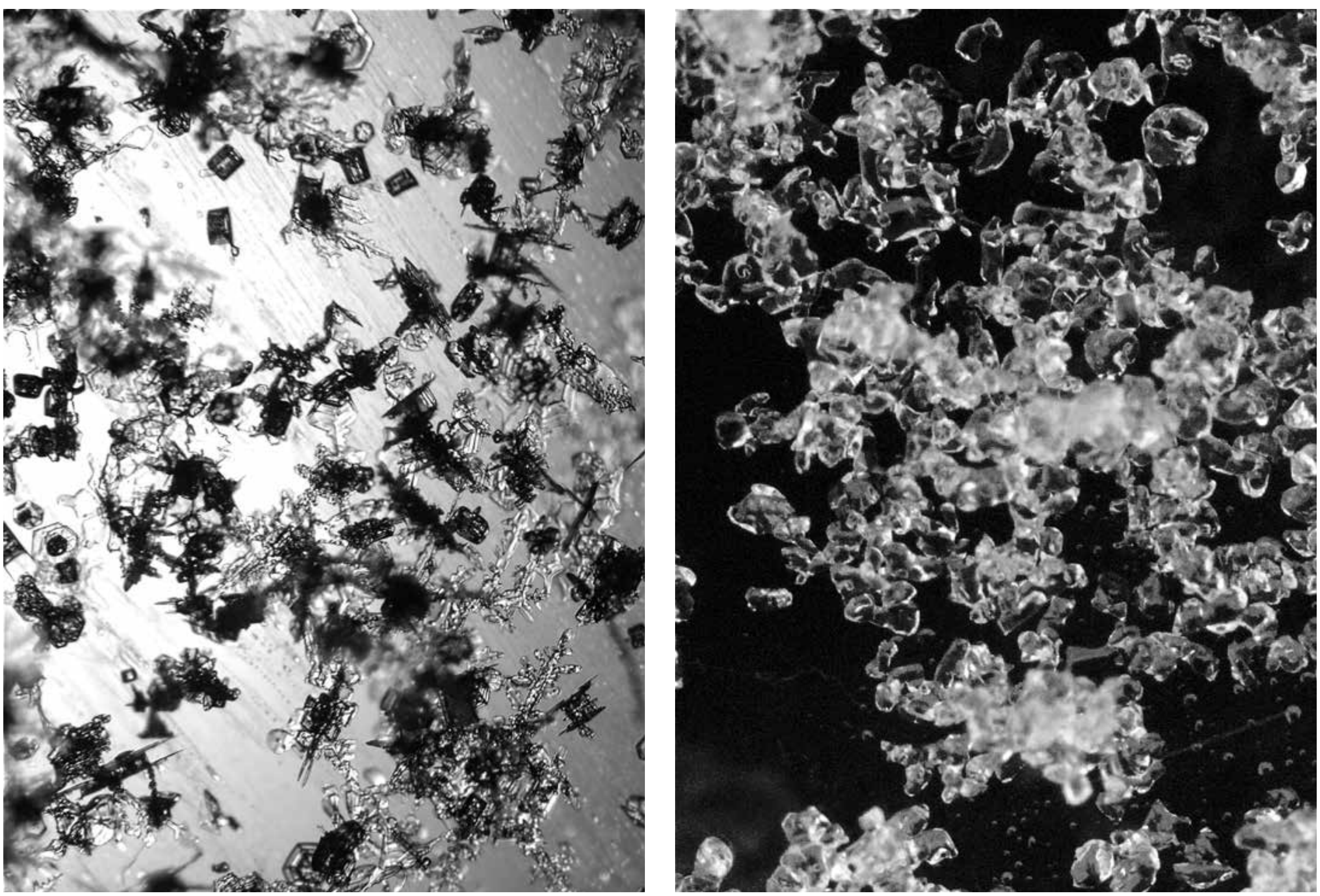


FIGURE F.2 Left: New snow that contains an array of precipitation particles including columns (PPco), plates (PPpl), and stellar crystals (PPsd) Right: Rounded snow grains (RR).

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
ROUNDED GRAINS			**RG**				
	Small rounded particles	Rounded, usually elongated particles of size <0.25 mm; highly sintered	RGsr	Within the snowpack, dry snow	Decrease of specific surface area by slow decrease of number of grains and increase of mean grain diameter. Small equilibrium growth form	Growth rate increases with increasing temperature; growth slower in high density snow with smaller pores	Strength due to sintering of the snow grains [1]. Strength increases with time, settlement and decreasing grain size
	Large rounded particles	Rounded, usually elongated particles of size > o.25 mm; well sintered	RGlr	Within the snowpack, dry snow	Grain-to-grain vapor diffusion due to low temperature gradients, i.e., mean excess vapor density remains below critical value for kinetic growth. Large equilibrium growth form	Same as above	Same as above
	Wind packed	Small, broken or abraded, closely packed particles; well sintered	RGwp	Surface layer, dry snow	Packing and fragmentation of wind transported snow particles that round off by interaction with each other in the saltation layer. Evolves into either a hard but usually breakable wind crust or a thicker wind slab.	Hardness increases with wind speed, decreasing particle size and moderate temperature	High number of contact points and small size causes rapid strength increase through sintering
	Faceted rounded particles	Rounded, usually elongated particles with developing facets	RGxf	Within the snowpack, dry snow	Growth regime changes if mean excess vapor density is larger than critical value for kinetic growth. Accordingly, this transitional form develops facets as temperature gradient increases	Grains are changing in response to an increasing temperature gradient	Reduction in number of bonds may decrease strength

Round Grains Notes: Both wind crusts and wind slabs are layers of small, broken or abraded, closely packed and well-sintered particles. The former are thin irregular layers whereas the latter are thicker, often dense layers, usually found on lee slopes. Both types of layers can be represented either as sub-class RGwp or as RGsr along with proper grain size, hardness and/or density. If the grains are smaller than about 1 mm, an observer will need to consider the process at work to differentiate RGxf from FCxr.

References: [1] Colbeck, 1997

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
FACETED CRYSTALS			**FC**				
	Solid faceted particles	Solid faceted crystals; usually hexagonal prisms	FCso	Within the snowpack; dry snow	Grain-to-grain vapour diffusion driven by large enough temperature gradient, i.e., excess vapour density is above critical value for kinetic growth Solid kinetic growth form, i.e., a solid crystal with sharp edges and corners as well as glassy, smooth faces	Growth rate increases with temperature, increasing temperature gradient, and decreasing density; may not grow to larger grains in high density snow because of small pores	Strength decreases with increasing growth rate and grain size
	Near surface faceted particles	Faceted crystals in surface layer	FCsf	Within the snowpack but right beneath the surface; dry snow	May develop directly from Precipitation Particles (PP) or Decomposing and Fragmented particles (DFdc) due to large, near-surface temperature gradients [1] Solid kinetic growth form (see FCso above) at early stage	Temperature gradient may periodically change sign but remains at a high absolute value	Low strength snow
	Rounding faceted particles	Rounded, usually elongated particles with developing facets	FCxr	Within the snowpack, dry snow	Trend to a transitional form reducing its specific surface area; corners and edges of the crystals are rounding off	Grains are rounding off in response to a decreasing temperature gradient	

Faceted Crystals Notes: Once buried, FCsf are hard to distinguish from FCso unless the observer is familiar with the evolution of the snowpack. FCxr can usually be clearly identified for crystals larger than about 1 mm. In case of smaller grains, however, an observer will need to consider the process at work to differentiate FCxr from RGxf.
References: [1] Birkeland, 1998

FIGURE F.3 Crown face of a fresh slab avalanche that released on basal facets. (P: Doug Krause)

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
DEPTH HOAR ∧			**DH**				
	Hollow cups ∧	Striated, hollow skeleton type crystals; usually cup-shaped	DHcp	Within the snowpack, dry snow	Grain-to-grain vapour diffusion driven by large temperature gradient, i.e., excess vapour density is well above critical value for kinetic growth. Formation of hollow or partly solid cup-shaped kinetic growth crystals [1]	See FCso.	Usually fragile but strength increases with density
	Hollow prisms ⊓	Prismatic, hollow skeleton type crystals with glassy faces but few striations	DHpr	Within the snowpack, dry snow	Snow has completely recrystallized; high temperature gradient in low density snow, most often prolonged [2]	High recrystallization rate for long period and low density snow facilitates formation	May be very poorly bonded
	Chains of depth hoar ⩚	Hollow skeleton type crystals arranged in chains	DHch	Within the snowpack, dry snow	Snow has completely recrystallized; intergranular arrangement in chains; most of the lateral bonds between columns have disappeared during crystal growth	High recrystallization rate for long period and low density snow facilitates formation	Very fragile snow
	Large striated crystals ⍲	Large, heavily striated crystals; either solid or skeleton type	DHla	Within the snowpack, dry snow	Evolves from earlier stages described above; some bonding occurs as new crystals are initiated [2]	Longer time required than for any other snow crystal; long periods of large temperature gradient in low density snow are needed	Regains strength
	Rounding depth hoar ∧	Hollow skeleton type crystals with rounding of sharp edges, corners, and striations	DHxr	Within the snowpack, dry snow	Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may lose their relief, i.e., striations and steps disappear slowly. This process affects all subclasses of depth hoar	Grains are rounding off in response to a decreasing temperature gradient	May regain strength

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

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
SURFACE HOAR ∨			**SH**				
	Surface hoar crystals ∨	Striated, usually flat crystals; sometimes needle-like	SHsu	Usually on cold snow surface relative to air temperature; sometimes on freely exposed objects above the surface (see notes)	Rapid kinetic growth of crystals at the snow surface by rapid transfer of water vapour from the atmosphere toward the snow surface; snow surface cooled to below ambient temperature by radiative cooling	Both increased cooling of the snow surface below air temperature as well as increasing relative humidity of the air cause growth rate to increase. In high water vapour gradient fields, e.g., near creeks, large feathery crystals may develop	Fragile, extremely low shear strength; strength may remain low for extended periods when buried in cold dry snow
	Cavity or crevasse hoar ∨	Striated, planar or hollow skeleton type crystals grown in cavities; orientation often random	SHcv	Cavity hoar is found in large voids in the snow, e.g., in the vicinity of tree trunks, buried bushes [1] Crevasse hoar is found in any large cooled space such as crevasses, cold storage rooms, boreholes, etc.	Kinetic growth of crystals forming anywhere where a cavity, i.e., a large cooled space, is formed or present in which water vapour can be deposited under calm, still conditions [2]		
	Rounding surface hoar ∨	Surface hoar crystal with rounding of sharp edges, corners and striations	SHxr	Within the snowpack; dry snow	Trend to a form reducing its specific surface area; corners and edges of the crystals are rounding off; faces may loose their relief, i.e., striations and steps disappear slowly	Grains are rounding off in response to a decreasing temperature gradient	May regain strength

Surface Hoar Notes: It may be of interest to note more precisely the shape of hoar crystals, namely plates, cups, scrolls, needles and columns, dendrites, or composite forms [3]. Multi-day growth may also be specified. Surface hoar may form by advection of nearly saturated air on both freely exposed objects and the snow surface at subfreezing temperatures. This type of hoarfrost deposit makes up a substantial part of accumulation in the inland of Antarctica. It has been termed 'air hoar' (see [2] and AMS, 2000). Crevasse hoar crystals are very similar to depth hoar.
References: [1] Akitaya, 1974; [2] Seligman, 1936; [3] Jamieson & Schweizer, 2000

FIGURE F.4 Unusual surface hoar formations. (P: Doug Krause)

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
MELT FORMS			**MF**				
	Clustered rounded grains	Clustered rounded crystals held by large ice-to-ice bonds; water in internal veins among three crystals or two grain boundaries	MFcl	At the surface or within the snowpack; wet snow	Wet snow at low water content (pendular regime), i.e., holding free liquid water; clusters form to minimize surface free energy	Meltwater can drain; too much water leads to MFsl; first freezing leads to MFpc	Ice-to-ice bonds give strength
	Rounded polycrys-tals	Individual crystals are frozen into a solid polycrystalline particle, either wet or refrozen	MFpc	At the surface or within the snowpack	Melt-freeze cycles form polycrystals when water in veins freezes; either wet at low water content (pendular regime) or refrozen	Particle size increases with number of melt-freeze cycles; radi-ation pene-tration may restore MFcl; excess water leads to MFsl	High strength in the frozen state; lower strength in the wet state; strength in-creases with number of melt-freeze cycles
	Slush	Separated rounded particles completely immersed in water	MFsl	Water saturated, soaked snow; found within the snowpack, on land or ice surfaces, but also as a viscous floating mass in water after heavy snowfall.	Wet snow at high liquid water content (funicular regime); poorly bonded, fully rounded single crys-tals – and polycrys-tals – form as ice and water are in thermo-dynamic equilibrium	Water drain-age blocked by capillary barrier, imperme-able layer or ground; high energy input to the snowpack by solar radia-tion, high air temperature or water input (rain)	Little strength due to decaying bonds
	Melt-freeze crust	Crust of recogniz-able melt-freeze polycrystals	MFcr	At the surface	Crust of melt-freeze polycrystals from a surface layer of wet snow that refroze after having been wetted by melt or rainfall; found either wet or refrozen	Particle size and density increases with number of melt-freeze cycles	Strength in-creases with number of melt-freeze cycles

Melt Form Notes: Melt-freeze crusts MFcr form at the surface as layers at most a few centimeters thick, usually on top of a subfreezing snowpack. Rounded polycrystals MFpc will rather form within the snowpack. MFcr usually contain more refrozen water than MFpc and will not return to MFcl. Both MFcr and MFpc may contain a recognizable minority of other shapes, particularly large kinetic growth form FC and DH. See the guidelines (Appendix C) for examples on the use of the MFcr symbol.

MORPHOLOGICAL CLASSIFICATION				ADDITIONAL INFORMATION ON PHYSICAL PROCESS AND STRENGTH			
BASIC CLASSIFICATION	**SUBCLASS**	**SHAPE**	**CODE**	**PLACE OF FORMATION**	**PHYSICAL PROCESS**	**DEPENDENCE ON MOST IMPORTANT PARAMETERS**	**COMMON EFFECT ON STRENGTH**
ICE FORMATIONS			**IF**				
	Ice layer	Horizontal ice layer	IFil	Within snowpack	Rain or meltwater from the surface percolates into cold snow where it refreezes along layer-parallel capillary barriers by heat conduction into surrounding subfreezing snow, i.e., snow at T < 0 °C; ice layers usually retain some degree of permeability	Depends on timing of percolating water and cycles of melting and refreezing; more likely to occur if a stratification of fine over coarse-grained layers exists	Ice layers are strong but strength decays once snow is completely wetted
	Ice column	Vertical ice body	IFic	Within snowpack layers	Draining water within flow fingers freezes by heat conduction into surrounding subfreezing snow, i.e., snow at T < 0 °C	Flow fingers more likely to occur if snow is highly stratified; freezing enhanced if snow is very cold	
	Basal ice	Basal ice layer	IFbi	Base of snowpack	Melt water ponds above substrate and freezes by heat conduction into cold substrate	Formation enhanced if substrate is impermeable and very cold, e.g., permafrost	Weak slush layer may form on top
	Rain crust	Thin, transparent glaze or clear film of ice on the surface	IFrc	At the surface	Results from freezing rain on snow; forms a thin surface glaze	Droplets have to be supercooled but coalesce before freezing	Thin breakable crust
	Sun crust, Firnspiegel	Thin, transparent and shiny glaze or clear film of ice on the surface	IFsc	At the surface	Melt water from a surface snow layer refreezes at the surface due to radiative cooling; decreasing shortwave absorption in the forming glaze enhances greenhouse effect in the underlying snow; additional water vapour may condense below the glaze [1]	Builds during clear weather, air temperatures below freezing and strong solar radiation; not to be confused with melt -freeze crust MFcr	Thin breakable crust

Ice Formation Notes: In ice formations, pores usually do not connect and no individual grains or particles are recognizable, contrary to highly porous snow. Nevertheless, some permeability remains, in particular when wetted, but to much a lesser degree than for porous melt forms. Most often, rain and solar radiation cause the formation of melt-freeze crusts MFcr. Discontinuous ice bodies such as ice lenses or refrozen flow fingers can be identified by appropriate remarks.

References: [1] Ozeki & Akitaya, 1998

ROUNDED POLYCRYSTALS, WIND CRUSTS, AND MELT-FREEZE CRUSTS

To distinguish between rounded polycrystals (MFpc) and a melt-freeze crust (MFcr), consider the structural units. If a crust layer is broken apart, the result is lumps of variable size since the crust (of indeterminate length and width) is the structural unit. If a portion of a layer of frozen rounded polycrystals is broken apart, the result is quite consistently sized particles (the individual polycrystals).

When formed by freezing rain, rain crusts (IRrc) are often thin, fragile transparent layers that form on the surface. Rain more commonly forms melt-freeze crust (MFcr), which can vary from thin (several mm to 1 cm) to thick (>5 cm) layers.

Sun crusts (IFsc) are thin, fragile transparent layers that form on the surface. More commonly, direct sun causes a melting of the snow that results in a melt-freeze crust (MFcr).

Wind crusts (RGwp) are thin irregular layers of small, broken or abraded, closely packed and well- sintered particles (usually found on windward slopes). The particles in these layers may be similar in appearance to those in wind slabs (usually found on lee slopes); however, some authors report that particle size is more variable in wind crusts than wind slabs.

SURFACE HOAR

Sub-classes listed in Table F.1 can be used to record different types of surface hoar (SH).

TABLE F.1 Sub-classes of surface hoar (based on Jamieson and Schweizer, 2000)

SUBCLASS	DESCRIPTION	FORMATION TEMPERATURE
i. Needle	Primarily one dimensional, sometimes spike- or sheath-like	Below -21°C
ii. Plate	Two-dimensional sector plate; usually wedge shaped and narrow at base. Usually striated when formed; however, the striations may disappear while buried in	-10°C to -21°C
iii. Dendrite	Two-dimensional form with numerous branches; often feather-like in appearance; narrow at base	-10°C to -21°C
iv. Cup or scrolls	Three-dimensional; these form with narrow base on surface of the snowpack; once separated from the snowpack, these forms can be indistinguishable from depth hoar-cup crystals	
v. Composite forms	Combinations of shapes associated with subclasses i to iv	

Refer to Fierz and others (2009) for further explanation of shapes, place of formation, classifications, physical processes and common effects on strength. The document is online at: http://www.cryosphericsciences.org/snow_class.html

FIGURE F.5 Large surface hoar formed in a valley bottom. (P: Doug Krause)

APPENDIX G: AVALANCHE DANGER, HAZARD, AND SNOW STABILITY SCALES

G.1 INTRODUCTION

There are many ways to communicate the current avalanche conditions. Categorical scales of avalanche danger, avalanche hazard, and snow stability can improve communication between forecasters and customers. Forecasting operation managers should select an appropriate scale based on the definitions that follow. The scales presented in this appendix are examples of commonly used communication methods.

G. 2 DEFINITIONS

Stability— The chance that avalanches do not initiate. Stability is analyzed in space and time relative to a given triggering level or load.

Exposure— An element or resource (person, vehicle, structure, etc…) that is subject to the impact of a specific natural hazard.

Hazard, Avalanche—The potential for an avalanche(s) to cause damage to something of value. It is a combination of the likelihood of triggering and the destructive size of the avalanche(s). It implies the potential to affect people, facilities or things of value, but does not incorporate vulnerability or exposure to avalanches. Avalanche danger and hazard are synonymous and are commonly expressed using relative terms such as high, moderate and low.

Risk— The chance of something happening that will have an impact on an element (person, vehicle, structure, etc.). A risk can often be specified in terms of an event or circumstance and the consequences that may follow. Risk is evaluated in terms of a combination of the consequences of an event and its likelihood. See the Glossary (Appendix A) for a standard definition of Risk.

Vulnerability— The degree to which an exposed element (person, vehicle, structure, etc.) is susceptible the impact of a specific natural hazard.

FIGURE G.1 Vegetation damage from a large avalanche. (P: John Stimberis)

G. 3 GENERAL GUIDELINES FOR THE USE OF AVALANCHE CONDITIONS SCALES

Avalanche conditions within a forecast area can be separated based on terrain or snowpack characteristics.

Specify the area based on:

1. Elevations
   a. Numerical range
   b. Geographic feature (i.e. Alpine, Treeline, Below Treeline)
2. Aspect
3. Slope angle
4. Specific conditions such as wind loaded slopes or depth of new snow
5. Spatial extent (localized or widespread)
6. Time of day

Timberline (treeline) describes a transition area between closed forest and the open treeless areas above.

Where practical give the expected stability trend for the next 12 to 24 hours. Use the terms: improving, steady, and decreasing stability to describe the trend.

Specify a confidence level in the ratings when appropriate; describe sources of uncertainty in forecast. Note the level of the unstable layer in the snowpack (i.e. near surface, mid level, deep).

Observers may qualify the rating based on:

- Topography (aspect, slope angle, etc.)
- Spatial extent (localized or widespread)
- Time of day

G.4 SNOW STABILITY SCALE

Stability refers to the chance that avalanches will not initiate, and does not predict the size or potential consequences of expected avalanches. Stability scales are sometimes used operationally in combination with variables such as slope aspect, elevation, and temporal effects. The Avalanche Danger Scale (Section G.5) is the preferred method for communicating avalanche conditions to the public.

Statements about avalanche activity take precedence over results of stability tests. For regional and larger forecast areas, isolated natural avalanches may occur even when stability for the area as a whole is good.

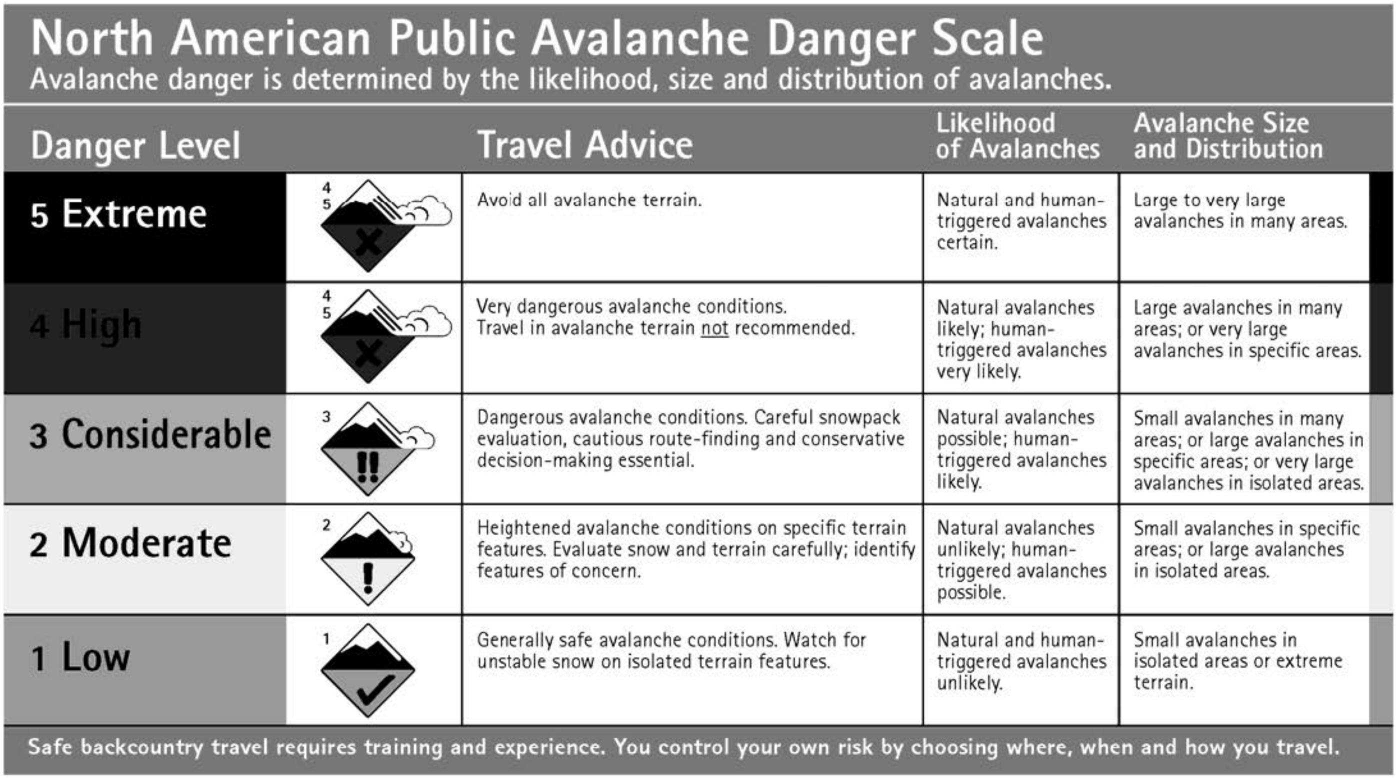
Definitions / Examples

- Natural avalanches: Avalanches triggered by weather events such as snowfall, rain, wind, temperature changes, etc.
- Heavy load: A cornice fall, a compact group of people, a snowmobile or explosives.
- Light load: A single person, or a small cornice fall.
- Isolated terrain features: Extreme terrain; steep convex rolls; localized dispersed areas (pockets) without readily specifiable characteristics.
- Specific terrain features: Lee slopes, sun-exposed aspects.
- Certain snowpack characteristics: Shallow snowpack with faceted grains, persistent weaknesses, identified weaknesses.

FIGURE G.2 Widespread avalanche activity within a single drainage. (P: Craig Sterbenz)

TABLE G.1 Snow Stability Rating System

STABILITY		EXPECTED AVALANCHE ACTIVITY		
STABILITY RATING	**COMMENT ON SNOW STABILITY**	**NATURAL AVALANCHES** (excluding avalanches triggered by icefall, cornice fall, or rock fall)	**TRIGGERED AVALANCHES** (including avalanches triggered by human action, icefall, cornice fall, rock fall or wildlife)	**EXPECTED RESULTS OF STABILITY TESTS**
Very Good (VG)	Snowpack is stable	No natural avalanches expected	Avalanches may be triggered by very heavy loads such as large cornice falls or loads in isolated terrain features	Generally little or no result
Good (G)	Snowpack is mostly stable	No natural avalanches expected	Avalanches may be triggered by heavy loads in isolated terrain features	Generally moderate to hard results
Fair (F)	Snowpack stability varies considerably with terrain, often resulting in locally unstable areas	Isolated natural avalanches on specific terrain features	Avalanches may be triggered by light loads in areas with specific terrain features or certain snowpack characteristics	Generally easy to moderate results
Poor (P)	Snowpack is mostly unstable	Natural avalanches in areas with specific terrain features or certain snowpack characteristics	Avalanches may be triggered by light loads in many areas with sufficiently steep slopes	Generally easy results
Very Poor (VP)	Snowpack is very unstable	Widespread natural avalanches	Widespread triggering of avalanches by light loads	Generally very easy to easy results



North American Public Avalanche Danger Scale

Avalanche danger is determined by the likelihood, size and distribution of avalanches.

Danger Level	Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	Very dangerous avalanche conditions. Travel in avalanche terrain not recommended.	Natural avalanches likely; human-triggered avalanches very likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.

FIGURE G.3 The North American Public Avalanche Danger Scale. (Statham et al., 2010)

G.5 AVALANCHE DANGER SCALE

The Avalanche Danger presented in this section is used by regional avalanche forecast centers in the United States. The scale was designed to facilitate communication between forecasters and the public. The categories represent the probability of avalanche activity and recommend travel precautions.

TABLE G.2 Color Standards for the North American Public Avalanche Danger Scale

DANGER LEVEL	CMYK	RGB	WEB
5 Extreme	(0, 64, 100, 100)	(35, 31, 32)	231F20
4 High	(0, 100, 100, 0)	(237, 28, 36)	ED1C24
3 Considerable	(0, 50, 100, 0)	(247, 148, 30)	F7941E
2 Moderate	(0, 0, 100, 0)	(255, 242, 0)	FFF200
1 Low	(70, 0, 100, 0)	(80, 184, 72)	50B848

FIGURE G.4 An explosive triggered avalanche strikes US 160 near Wolf Creek Pass, Colorado. (P: Mark Mueller)

G. 6 AVALANCHE HAZARD SCALE

Avalanche hazard scales can be used when forecasting the threat of avalanches to structures and transportation arteries. The scale should be tailored for each individual operation. Figure G.5 contains a scale used by the Colorado Avalanche Information Center/ Colorado Department of Transportation. This scale is presented as an example of an operational avalanche hazard scale. Figure G.5 includes the entire scale, but columns can be included or excluded for different applications.

LEVEL	DESCRIPTION: Avalanche Size	DESCRIPTION: Impact on Highway	OPERATIONAL PROCEDURES
NONE	Natural avalanches are very unlikely to reach the highway.	Insufficient snow for avalanches to reach the highway.	-No operational changes for avalanche hazard -Notify CAIC forecaster of any avalanche activity
NOTICE	Natural avalanches are unlikely to significantly affect highway operations.	Avalanches may run onto the highway, but will not require more than a snow plow to clear debris.	-Avalanche rescue equipment required (wear beacon; carry shovel and probe in vehicle) -Do not stop traffic in avalanche areas -Advise travelers to move out of avalanche areas -Notify supervisor before working outside of your vehicle in an avalanche area -Notify supervisor if a project will require more than one hour of work in an avalanche area
CAUTION	Natural avalanches, up to D2, may reach the highway (possible).	Avalanches that run onto the highway may require more than a snow plow to clear debris.	-Do not stop traffic in avalanche areas -Move stopped travelers out of avalanche areas -Do not work outside of a vehicle in avalanche areas -Notify supervisor and CAIC forecaster **before** performing any stationary work or removing debris in an avalanche area -Use a spotter when working in an avalanche area
WARNING	Natural avalanches, D2.5 or larger, are likely to affect highway operations.	Avalanches large enough to bury passenger vehicles and damage maintenance vehicles are likely.	-Maintenance work limited to non-avalanche areas -Consult senior supervisor and CAIC forecaster **before** entering avalanche areas

FIGURE G.5 Sample Avalanche Hazard Scale for transportation corridors.

APPENDIX H: REPORTING AVALANCHE INVOLVEMENTS

H.1 OBJECTIVE

The objective of reporting avalanche accidents and damage is to collect data about the extent of avalanche hazards in the United States. Summaries of the reports will draw attention to avalanche problems and assist in the development of risk reduction measures.

H.2 REPORTING FORMS

Two different reports are available for recording avalanche accidents and damage. Any person who wishes to report an avalanche incident or accident can use these reports.

The short form is a brief summary of an avalanche incident or accident. This form should be submitted every time people are involved in an avalanche, property is damaged or a significant natural event occurs.

The long form is a detailed report that can be used as a template for an accident investigation. This report should be completed when an avalanche causes a fatality, serious injury, or property damage in excess of $5,000, or when the incident has a high educational value. It may be useful as a checklist when operations wish to describe an accident and rescue work in greater detail.

H.3 FILING OF REPORTS

Completed short reports should be returned as quickly as possible to the nearest avalanche center. A copy should also be sent to the Colorado Avalanche Information Center, which serves as a central recording hub for avalanche accident information.

Colorado Avalanche Information Center 325 Broadway WS1 Boulder, CO 80305 caic@state.co.us Voice: (303) 499-9650 www.colorado.gov/avalanche

Reports will be used to identify trends in avalanche accidents, used for educational purposes, and to maintain long-term data sets. The reporter's and victim's names and contact information should be recorded. Requests for anonymity will be noted and respected whenever possible.

H.4 COMPLETING THE SHORT FORM

H.4.1 DATE AND TIME

Fill in the date and time of the avalanche occurrence.

H.4.2 LOCATION

Give the mountain range, valley and feature where the avalanche occurred. Include as much information as possible including county name, ski area name, highway name, avalanche path and GPS coordinates.

H.4.3 GROUP AND ACTIVITY DESCRIPTION

Record the primary purpose of the group when the avalanche occurred. Enter the number of people engaged in each listed activity. If the activity is not listed write it in (i.e. mountain climbing, snowshoeing, traveling on a road). Note if the group was ascending, descending, etc.

H.4.4 PEOPLE CAUGHT IN THE AVALANCHE

Enter the number of people that were involved in the avalanche and the number injured or killed. Of those involved, give the number that were not caught or buried; the number caught; the number that were partially buried–not critical; the number that were partially buried–critical; and the number completely buried using the definitions listed below.

The following definitions were composed for the purpose of reporting incidents and accidents with the intent of delineating between different rescue scenarios.

A person is caught if they are touched and adversely affected by the avalanche. People performing slope cuts are generally not considered caught in the resulting avalanche unless they are carried down the slope.

A person is partially buried–not critical if their head is above the snow surface when the avalanche stops.

A person is partially buried–critical if their head is below the snow surface when the avalanche stops but equipment, clothing and/or portions of their body are visible.

A person is completely buried if they are completely beneath the snow surface when the avalanche stops. Clothing and attached equipment are not visible on the surface.

For people that were completely buried or partially buried–critical, estimate the length of time they were buried, the burial depth measured from the snow surface to their face, position of person (face up, face down, or sitting), the distance between multiple persons and distance from vehicle if applicable. Include the method of rescue used to find the victim (i.e. transceiver, exposed equipment, exposed body part, spot probe, probe line, voice, etc.).

H.4.5 DIAGRAM

Provide a sketch, photograph, or digital image showing the outline of the avalanche, the deposit, and the locations of people, snowmobiles, and other equipment when the avalanche started and when it stopped. Include significant terrain features and avalanche path characteristics such as starting zones or terrain traps.

H.4.6 AVALANCHE DESCRIPTION

Fill in the appropriate fields as accurately as possible.

H.4.7 COMMENTS

Briefly describe: events leading to the avalanche involvement; how the rescue was conducted; the injuries sustained; level of avalanche training of group members; and other information that may be significant. A description of the events and decision-making process leading up to the accident should be recorded.

H.5 COMPLETING THE DETAILED REPORT

On the form enter the information in the spaces provided or tick off the multiple-choice statements.

Write "N/Av" if the information is not available or "N/App if not applicable. Online versions of these forms can be found at www.avalanche.org, www.fsavalanche.com, and www.colorado.gov/avalanche.

American Avalanche Association
Forest Service National Avalanche Center
Avalanche Incident Report: Short Form

Occurrence Date:(YYYYMMDD)____________________ **Time:**(HHMM) ________________

Reporting Party Name and Address: ____

Avalanche Characteristics:

Type:_______ Aspect:_____________
Trigger _____ Slope Angle:_________
Size: R__/D__ Elevation:____________ m / ft
Sliding Surface (check one):
In new New/old In old Ground

Location:

State:____ County:_________________ Forest:________________________
Peak, Mtn Pass, or Drainage:____
Site Name:____
Lat/Lon or UTM:____
Datum:____

Group	Number of People	Time Recovered	Duration of Burial	Depth to Face □□□ m □ ft
Caught				
Partially Buried—Not-critical				
Partially Buried—Critical				
Completely Buried				

Number of people injured:_____________ Number of people killed:_________

Dimensions □□ m □ ft	Average	Maximum
Height of Crown Face		
Width of Fracture		
Vertical fall		

Snow	Hardness	Grain Type	Grain Size
Slab			
Weak Layer			
Bed Surface			

Thickness of weak layer:_______________ mm / cm / in

Burial involved a terrain trap? □ no □ yes→type:________________________ Number of people that crossed start zone before the avalanche: _______
Location of group in relation to start zone during avalanche: □high □middle □low □ below □ all □ unknown Avalanche occurred during: □ ascent □

Subject	Name	Age	Gender	Address	Phone	Activity
1						
2						
3						
4						
5						

Equipment Carried 1 2 3 4 5	Experience at Activity 1 2 3 4 5	Avalanche Training 1 2 3 4 5	Signs of Instability Noted by Group	Injuries Sustained 1 2 3 4 5	Extent of Injuries or Cause of Death 1 2 3 4 5
□□□□□ transceiver	□□□□□ unknown	□□□□□ unknown	□ unknown	□□□□□ none	□□□□□ asphyxiation
□□□□□ shovel	□□□□□ novice	□□□□□ none	□ none	□□□□□ first aid	□□□□□ head trauma
□□□□□ probe pole	□□□□□ intermediate	□□□□□ some	□ recent avalanches	□□□□□ doctor's care	□□□□□ spinal injury
□□□□□ _________	□□□□□ advanced	□□□□□ advanced	□ shooting cracks	□□□□□ hospital stay	□□□□□ chest trauma
			□ collapse or whumphing		□□□□□ skeletal fractures

Damage Number of Vehicles Caught:___________ Number of Structures Damaged:___________ Estimated $ Loss:_______________________

Accident Summary Include: events leading to accident, group's familiarity with location, objectives, route, hazard evaluation, etc.

Rescue Summary Include: description of initial search, report of accident, organized rescue etc.

Rescue Method:
1 2 3 4 5
□□□□□ self rescue
□□□□□ transceiver
□□□□□ spot probe
□□□□□ probe line
□□□□□ rescue dog
□□□□□ voice
□□□□□ object
□□□□□ digging
□□□□□ other_____

Attach additional pages as needed. Include: weather history, snow profiles, reports from other agencies, diagram of site, and any other supporting information.

Please send to: CAIC; 325 Broadway WS1; Boulder, CO 80305; caic@state.co.us
Voice:(303) 499-9650 www.colorado.gov/avalanche

American Avalanche Association
Forest Service National Avalanche Center
Avalanche Accident Report: Long Form

Please send to:
Colorado Avalanche Information Center
325 Broadway WS1
Boulder, CO 80305
voice: (303) 499-9650, email: caic@state.co.us, web: www.colorado.gov/avalanche

Occurrence Date:________________________ **Time:**________________

Report Author(s):
Name:________________________________ Affiliation____
Address: ____
Phone:____________________________ Fax:________________ Email:____________________________

Location:
State:_______ County:__________________________ Region:__________ Forest:_____________________________
Geographic Area (mountain range, mountain pass, drainage, or feature):____
Site Name:____
Lat/Lon or UTM:____ Elevation: ☐ above treeline ☐ near treeline ☐ below treeline
Datum:____

Summary	Caught	Partially Buried Not-critical	Partially Buried Critical	Completely Buried	Injured	Killed	Vehicles Damaged	Structures Damaged
Number								

Weather Fill in the weather chart of the five days prior to the accident. Use 24 hr averages or trends for wind speed and direction.

Weather station(s): Location__________________________ Lat/Lon or UTM:_____________ Elevation:__________ m / ft

Date						Day of Accident
Tmax						
Tmin						
HN24						
HN24W						
Wind Speed						
Wind Dir						

Avalanche Conditions Attach most recent avalanche advisory

Closest Avalanche Center:	Avalanche Danger Rating	Recent Avalanche Activity
____________________ accident outside of forecast area Avalanche warning in effect? yes no	Low Moderate Considerable High Extreme	

Snowpack Describe the state of the snowpack. Include season history, snow profiles, and prominent features as necessary.

Section I: Group Information	
Fill in the following tables. Some of the fields can be checked yes or left blank. Attach additional pages and reports from other agencies as necessary.	

Subject	Name	Age	Gender	Address	Phone
1					
2					
3					
4					
5					

Skill Level	Activity	Years at Activity	Rank skill level as novice, intermediate, advanced, or expert.		Years Traveling in Avalanche Terrain	Avalanche Education Level
			Activity Skill Level	Accessed Local Avalanche Advisory		
1						
2						
3						
4						
5						

Rescue Equipment Carried	Transceiver Make and Model	Shovel	Probe Pole	Releasable Bindings	Other	Snowmobile: Rescue Equipment Carried on Person
1						
2						
3						
4						
5						

Injuries or Cause of Death	Unknown	None	First-Aid Necessary	Doctor's Care Needed	Hospital Stay Required	Asphyxia	Head Injury	Chest Injuries	Spinal Injury	Hypothermia	Skeletal Fracture	Other	Fatal
1													
2													
3													
4													
5													

Comments

Section II: Avalanche Path and Event Information

Fill in the following tables. Some of the fields can be checked yes or left blank. Attach additional pages, fracture line profiles, and reports as necessary.

Avalanche Characteristics

Type:_____________ Trigger:_______________ Size: R1 R2 R3 R4 R5 / D1 D2 D3 D4 D5

Sliding Surface (check one): Within new snow New/old interface Old snow layer Ground Avalanche stepped down into old snow layers.

Distance from trigger to crown face:________________________ m ft

Comments:

Dimensions □ m □ ft	Average	Maximum	Measured
Height of Crown Face			
Width			
Vertical fall			

Snow	Hardness	Grain Type	Grain Size	Thickness
Slab				
Weak Layer				
Bed Surface				

Start Zone

Elevation: ___________m / ft

Average Slope Angle (°) :________

Maximum Slope Angle (°) :_______

Aspect:_________

Ground Cover: Smooth, Rocky, Glacier, Dense Forest, Open Forest, Brush, Grass, Unknown

Location of Crown Face: Ridge, Cornice, Mid-slope, Convex Roll, Concave Slope, Rocks, Unknown

Snow Moisture: Dry, Moist, Wet

Vegetation:____

Track

Open Slope Average Slope Angle (°):___________

Confined Aspect:___________

Gully

Snow Moisture: Dry Moist Wet

Runout

Elevation: ___________m / ft

Average Incline (°) :________

Aspect:_________

Ground Cover: Smooth, Rocky, Glacier, Dense Forest, Open Forest, Brush, Grass, Unknown

Snow Moisture: Dry, Moist, Wet

Debris Type (check all that apply): Fine, Blocks, Hard, Soft, Rocks, Trees, ________, ________

α_i (°) :___________

□ α_e (°) :_________

Debris Density:_________ kg/m^3

Terrain Trap: no yes

Terrain Trap Type:__________________

Vegetation:____

Comments

Section III: Accident Description

Fill in the following sections with available information. Attach additional pages, statements, witness accounts, and other reports as necessary.

Events Leading Up to the Avalanche

Include objectives of party, departure point, route taken, familiarity with area, and encounters with other groups, location of party at time of avalanche, etc.

Location of group in relation to start zone at the time of avalanche release: high middle low below all unknown

Slope angle at approximate trigger site:________°

Avalanche Danger Evaluation

Number of snowpit observations :____

Signs of Instability Observed:

none unknown
some cracking shooting cracks
whumphing hollow sounds
recent avalanche activity

Stability Tests Performed:

yes
no
unknown

Location of observations:________________________________

Test Results

Comments

Witnesses	Name	Address	Phone
1			
2			

Accident Diagram

On a separate page or on a photograph, draw a diagram of the accident scene. Include avalanche boundaries, prominent rock and/or trees, the location of all party members before the avalanche, and the location of people, machines and equipment after the avalanche.

Section IV: Rescue

Fill in the following sections with available information. Attach additional pages, statements, witness accounts, and other reports as necessary.

Rescue Chronology

First Report	Response					
Reporting Party: ____________	Agency	Time Dispatched	Time on Scene	Method of Travel	Number of Rescuers	Equipment
Report Method: ____________						
Time Reported:___________						

Recovery

For Body Position use: Prone/Face Down, Supine/On Back, On Side, Sitting, Standing
For Head Position use: Up Hill, Down Hill, Sideways

Subject	Caught	Partially Buried - Non-critical	Partially Buried - Critical	Completely Buried	Depth to Face m ft	Time Recovered	Length of Burial	Body Position	Head Position
1									
2									
3									
4									
5									

Recovery Method

For a transceiver recovery, include make and model of transceiver used by searcher. If an object on the surface was used as a clue, list the object.

Subject	Self Rescue	Companion	Organized	Voice	Object	Transceiver	Spot Probe	Probe Line	Rescue Dog	Digging
1										
2										
3										
4										
5										

Rescue Description

List pertinent events that occurred during the rescue. Include additional pages of dispatch notes, statements, and agency reports as needed.

Section V: Damage

Fill in the following sections with available information. Attach additional pages, statements, witness accounts, and other reports as necessary.

Vehicles in Avalanche

Fill in the table below. Describe and/or estimate the cost of the damage to each vehicle caught in the avalanche.

Type	Partially Buried	Completely Buried	Damage	Replacement Cost

Structures Damaged

Fill in the table below. Describe and/or estimate the cost of the damage to each structure affected by the avalanche.

Type	Construction Type	Damage	Destroyed	Replacement Cost

Total Loss

Estimate the cost of the damage caused by the avalanche. $____________________

Rescue Cost

Estimate the cost of rescue. $____________________

Economic Effects

List economic effects not included in the above tables (road closed, ski area closed, mine closed, change in policy, etc.)

Additional Comments and Recommendations

APPENDIX I: MISCELLANEOUS

I.1 SYMBOLS AND ABBREVIATIONS

SYMBOL	TERM	UNITS
CT	Compression test	categorical
D#	Avalanche size – destructive force	categorical
DT	Deep Tap Test	categorical
E	Grain size	mm
ECT	Extended column test	categorical
F	Grain form	categorical
f	Fall height of the hammer, ram penetrometer	cm
H	Vertical coordinate (line of plumb)	cm, m
H	Mass of hammer, ram penetrometer	kg
H2D/H2DW	Twice per day snow accumulation/water equivalent	cm/mm
HIN/HNW	Interval snow height/water equivalent	cm/mm
HN24/HN24W	Height of 24-hour snow accumulation/water equivalent	cm/mm
HN/HNW	Height of new snow layer/water equivalent	cm/mm
HS/HSW	Height of snowpack/total water equivalent	cm/mm
HST/HSTW	Storm snow height/water equivalent	cm/mm
HW	Water equivalent of a layer	mm
L	Layer thickness (measured vertically)	mm, cm, m
n	Number of blows of the hammer, ram penetrometer	dimesnionless
N/O	Not observed	categorical
P	Penetrability	cm
p	Increment of penetration for n blows, ram penetrometer	cm
PF	Depth of foot penetration	cm
PR	Depth of penetration by standard ramsonde	cm
PS	Depth of ski penetration	cm
PST	Propagation saw test	categorical
Q	Shear quality	categorical
R	Hand hardness index	categorical

SYMBOL	TERM	UNITS
R#	Avalanche size – relative to path	categorical
RB	Rutschblock test	categorical
RH	Relative humidity	%
RN	Ram number	kg
RR	Ram resistance	N
SR	Stability ratio	dimesionless
ST	Shovel shear test	categorical
T	Temperature of snow	°C
T	Mass of tubes, ram penetrometer	kg
Ta	Air temperature	°C
Tg	Ground temperature	°C
Ts	Temperature of snow surface	°C
T20	Temperature of snow 20 cm below the surface	°C
α	Alpha angle	degree
α_i	Alpha angle of an individual avalanche	degree
α_e	Alpha angle of an extreme event. Smallest angle observed in a specific avalanche path	degree
Δ (Delta)	Change in penetration	cm
ε (epsilon)	Strain	dimensionless (m/m)
θ (theta)	Liquid water content	% (by volume)
ρ (rho)	Density	kg/m^3
σ (sigma)	Normal stress	Pa
Σ (Sigma)	Normal strength	Pa
τ (tau)	Shear stress	Pa
T (Tau)	Shear strength	Pa
T_∞	Frame independent shear strength	Pa
T_{100}	Shear strength measured with 100 cm^2 shear frame	Pa
T_{250}	Shear strength measured with 250 cm^2 shear frame	Pa
ψ (psi)	Slope angle	degree

I.2 SNOW PROFILE TEMPLATES

Snow Profile

Reference:____

Date: ____________ Time: __________ Observers: _____________________

Location:____

Elev: ________ Aspect: ______ Slope Angle: ______ Precip: _____ Sky: ________ Wind Dir: _____ Speed: ____G___

Wind Loading? Y N PREV Ski Pen: ____ cm in Boot Pen: ____ cm in Profile Type: [ ]

Snow Layer Temperature (°C)

-18° -16° -14° -12° -10° -8° -6° -4° -2°C

Depth H (cm)	Moist θ	Form F	Size E (mm)	Density ρ (kg/m^3)	Test Results and Comments
200					
190					
180					
170					
160					
150					
140					
130					
120					
110					
100					
90					
80					
70					
60					
50					
40					
30					
20					
10					
0					

I K P 1F 4F F

Snow Profile

Reference:______________________________

Date: ____________ Time: ___________ Observers: ______________________

Location:____

Elev: ________ Aspect: ______ Slope Angle: ______ Precip: _____ Sky: ________ Wind Dir: _____ Speed: _____G___

Wind Loading? Y N PREV Ski Pen: _____ cm in Boot Pen: _____ cm in Profile Type: [ ]

Snow Layer Temperature (°C)	Depth *H* (cm)	Moist θ	Form *F*	Size *E* (mm)	Density ρ (kg/m³)	Test Results and Comments
I K P 1F 4F F						

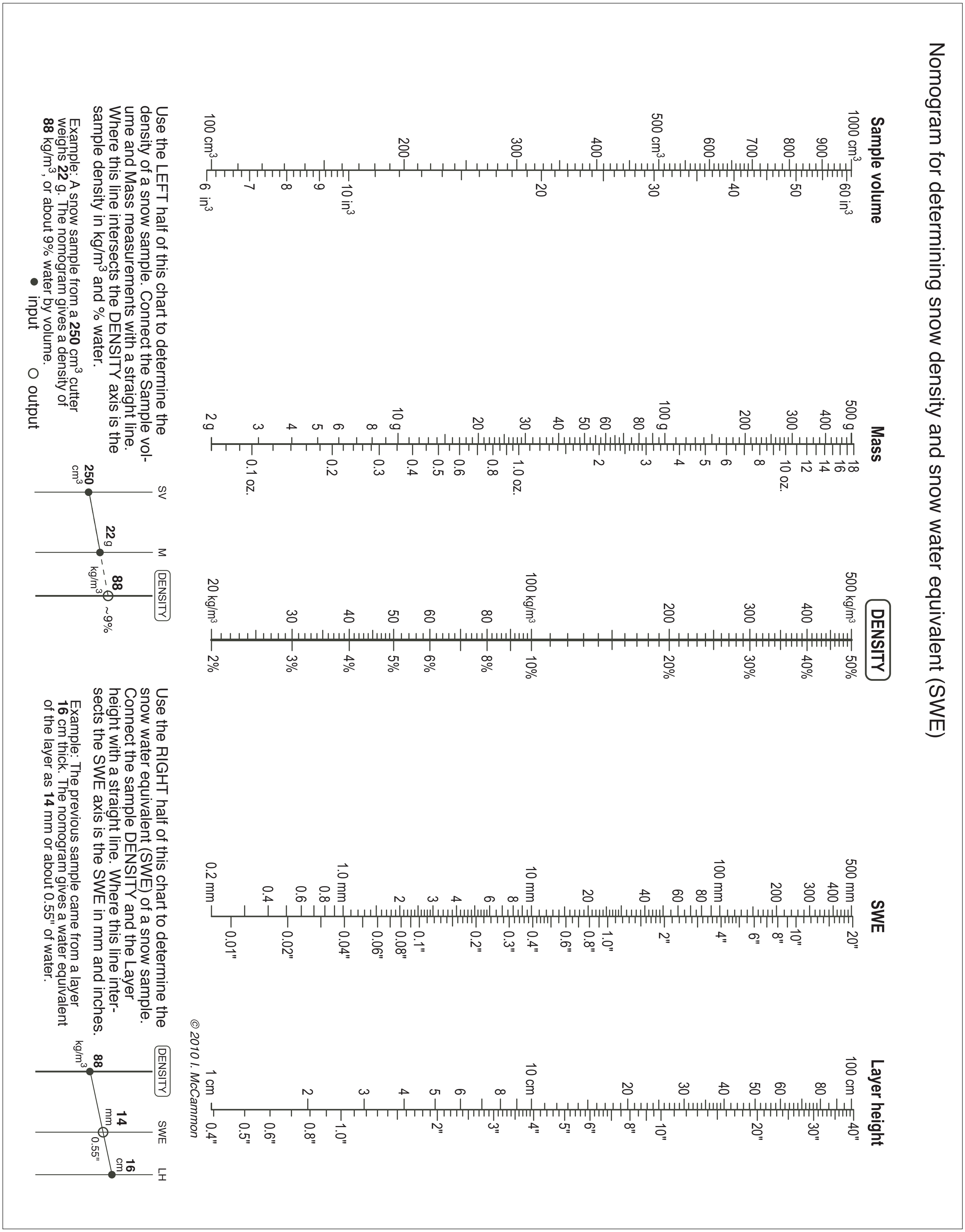
I.3 TEMPERATURE CONVERSION CHART

°C	°F	°C	°F
-40	-40	0	32
-39	-38.2	1	33.8
-38	-36.4	2	35.6
-37	-34.6	3	37.4
-36	-32.8	4	39.2
-35	-31	5	41
-34	-29.2	6	42.8
-33	-27.4	7	44.6
-32	-25.6	8	46.4
-31	-23.8	9	48.2
-30	-22	10	50
-29	-20.2	11	51.8
-28	-18.4	12	53.6
-27	-16.6	13	55.4
-26	-14.8	14	57.2
-25	-13	15	59
-24	-11.2	16	60.8
-23	-9.4	17	62.6
-22	-7.6	18	64.4
-21	-5.8	19	66.2
-20	-4	20	68
-19	-2.2	21	69.8
-18	-0.4	22	71.6
-17	1.4	23	73.4
-16	3.2	24	75.2
-15	5	25	77
-14	6.8	26	78.8
-13	8.6	27	80.6
-12	10.4	28	82.4
-11	12.2	29	84.2
-10	14	30	86
-9	15.8	31	87.8
-8	17.6	32	89.6
-7	19.4	33	91.4
-6	21.2	34	93.2
-5	23	35	95
-4	24.8	36	96.8
-3	26.6	37	98.6
-2	28.4	38	100.4
-1	30.2	39	102.2
0	32	40	104

I.4 WIND SPEED CONVERSION CHART

mi/hr	m/s	kT	km/hr
1	0.4	0.9	1.6
2	0.9	1.7	3.2
3	1.3	2.6	4.8
4	1.8	3.5	6.4
5	2.2	4.3	8.0
10	4.5	8.7	16.1
15	6.7	13.0	24.1
20	8.9	17.4	32.2
25	11.2	21.7	40.2
30	13.4	26.1	48.3
35	15.6	30.4	56.3
40	17.9	34.8	64.4
45	20.1	39.1	72.4
50	22.4	43.4	80.5
55	24.6	47.8	88.5
60	26.8	52.1	96.6
65	29.1	56.5	104.6
70	31.3	60.8	112.7
75	33.5	65.2	120.7
80	35.8	69.5	128.7
85	38.0	73.9	136.8
90	40.2	78.2	144.8
95	42.5	82.6	152.9
100	44.7	86.9	160.9
105	46.9	91.2	169.0
110	49.2	95.6	177.0
115	51.4	99.9	185.1
120	53.6	104.3	193.1
125	55.9	108.6	201.2
130	58.1	113.0	209.2
135	60.4	117.3	217.3
140	62.6	121.7	225.3
145	64.8	126.0	233.4
150	67.1	130.3	241.4

I.5 NOMOGRAM


Nomogram for determining snow density and snow water equivalent (SWE)
Sample volume
Mass
DENSITY
SWE
Layer height
Use the LEFT half of this chart to determine the density of a snow sample. Connect the Sample volume and Mass measurements with a straight line. Where this line intersects the DENSITY axis is the sample density in kg/m3 and % water.
Example: A snow sample from a 250 cm3 cutter weighs 22 g. The nomogram gives a density of 88 kg/m3, or about 9% water by volume.
● input ○ output
Use the RIGHT half of this chart to determine the snow water equivalent (SWE) of a snow sample. Connect the sample DENSITY and the Layer height with a straight line. Where this line intersects the SWE axis is the SWE in mm and inches.
Example: The previous sample came from a layer 16 cm thick. The nomogram gives a water equivalent of the layer as 14 mm or about 0.55" of water.
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