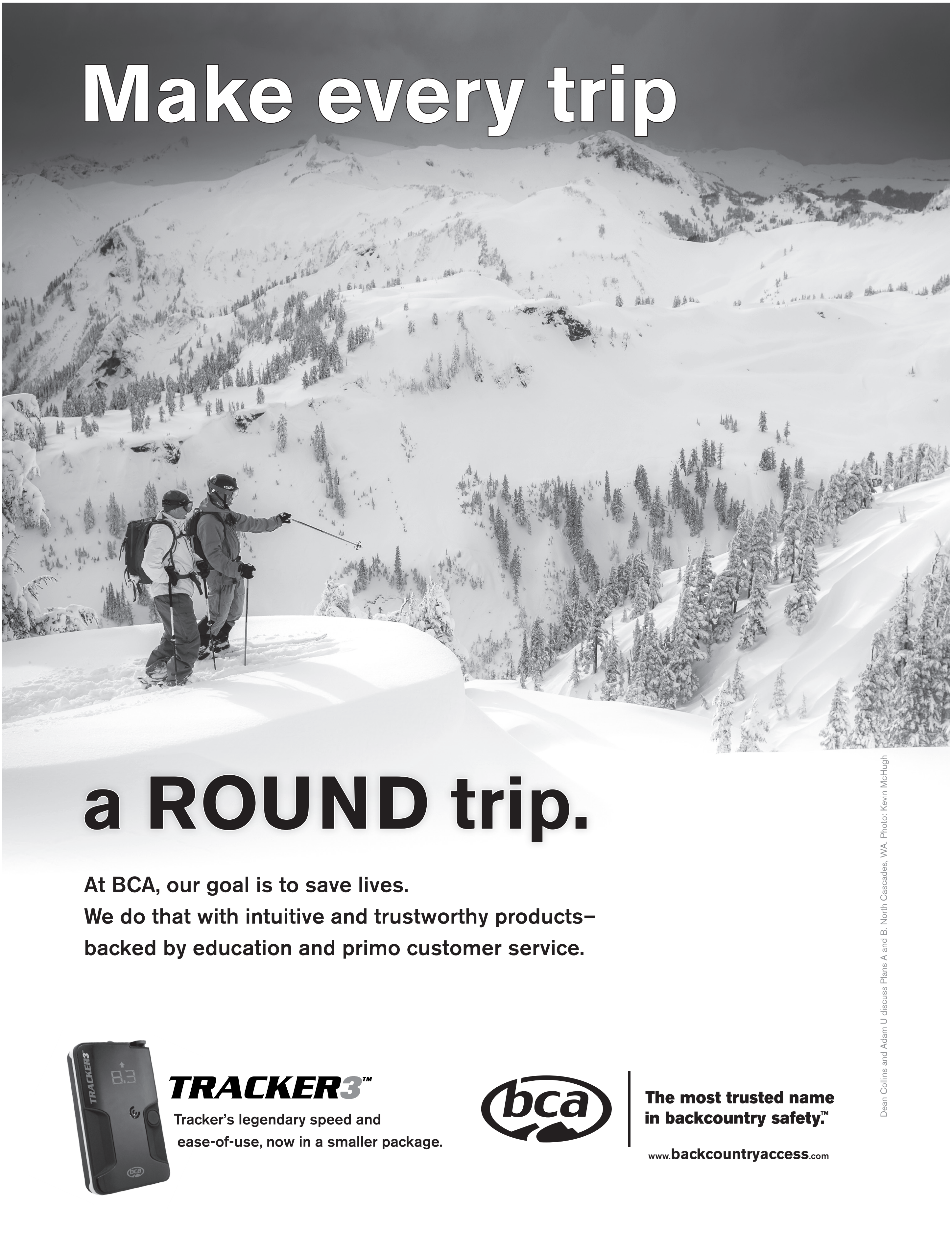
The American Institute for
AIARE
Avalanche Research and Education

AIARE 2 Avalanche Course:
Evaluating Snow Instability and Avalanche Hazard

Workbook 2017-18



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AIARE 2 Student Workbook November 2017 Edition

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Important Message for AIARE Course Participants

After completion of your course you will receive an email from the AIARE office directing you to the AIARE web site where you can log in and print your certificate of completion for this course.

The American Institute for Avalanche Research and Education (AIARE) is a nonprofit educational organization that develops and provides avalanche safety curriculum to organizations and individuals endeavoring to promote avalanche awareness and education.

AIARE (and its officers, directors and subcontractors) does not teach, oversee or conduct AIARE 1 or AIARE 2 avalanche courses. It does provide course curriculum and materials to avalanche course providers and qualified instructors to teach AIARE 1 and AIARE 2 courses. All organizations and individuals conducting AIARE courses act independently of AIARE and are solely responsible for conducting the courses.

Importantly, in choosing to voluntarily engage in avalanche courses or programs that operate in the backcountry and/or wilderness settings, individuals must understand that they accept and assume the inherent risks of these activities. No course can fully guarantee your safety, either during the course or after you leave. During the course, the instructors will manage risk and involve you in discussions about what is appropriate and what is not. They will inform you of any unusual or exceptional hazards or risks involved in carrying out lessons and exercises. Whether you will be “safer” after the course or not depends entirely on how you apply your new skills and knowledge when in the mountains.

Most of the understanding and techniques addressed during this course require extensive practice before you can expect to be proficient. No course, this one included, can provide all that experience. To establish and maintain proficiency in the knowledge and techniques covered in this course, you will have to practice extensively and regularly after leaving the program. Additionally, avalanche education continues to evolve as new research becomes available. To remain current, you will need to seek out opportunities for continued education.

The American Institute for
AIARE
Avalanche Research and Education

MISSION

“Save lives through avalanche education”

GOALS

AIARE strives to:

- Increase public awareness of avalanches and avalanche safety.
- Provide high-quality avalanche education and thereby enhance public safety.
- Provide avalanche instructors with the curriculum, training and tools with which to educate students about the knowledge, methods, and decision making skills necessary to travel in avalanche terrain.
- Develop an international network of professional avalanche educators, and provide continued professional development in the form of instructor training and education.
- Fund projects that develop avalanche course support materials for educators and students.

ABOUT AIARE

AIARE is a registered 501(c)(3) nonprofit educational organization, which serves as a focal point for the gathering, development, and dissemination of materials, ideas, and curriculum for avalanche educators in the U.S. There are currently over 100 course providers and 450 instructors nationwide representing AIARE. This student manual was created by input from this community. AIARE is comprised of an Executive Committee charged with assimilating ideas, materials and concepts from AIARE members to develop teaching tools and materials such as this workbook. AIARE’s Advisory Board of industry professionals provides guidance and comments in their respective fields of expertise.

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Introduction

0.1 Using the AIARE 2 workbook – *Evaluating Snow Instability and Avalanche Hazard*

The AIARE 2 Workbook is a study guide written to complement the information gained from class and field sessions during the *AIARE 2 Avalanche Course: Evaluating Snow Instability and Avalanche Hazard*. The AIARE 2 course workbook is divided into three chapters. The chapters are organized to reflect the cornerstone learning outcomes of the AIARE 2 course.

Chapter 1 describes how the terrain and mountain weather interact to create the changing mountain snowpack. In this chapter students learn how strong and weak layers form, how these layers vary over terrain, and why weak layers persist or gain strength over time. This chapter also reviews how avalanches form and release and identifies factors that are potential avalanche triggers. The Avalanche Handbook (3rd edition, David McClung and Peter Shaerer) is a key resource for during course study and post course reference, and it is referred to as the AHB.

Chapter 2 introduces the important daily task of observing and recording weather, snow, and avalanches. So much of our knowledge of how avalanches form and release is based on comprehensive observations. The ability to assess avalanche hazard and to accurately determine the avalanche risk is dependent upon quality observations, quality record keeping, and the ability to determine trends from records. The participants are introduced the publication, Snow, Weather and Avalanches: Observation Guidelines for Avalanche Programs in the United States (published the AAA, 2010 edition, referred in this document as SWAG). This document is the daily reference used on this course to ensure all field observations are observed, recorded and communicated using a common method.

Chapter 3 reviews the tools and techniques used when applying weather, snow, and avalanche observations to the daily process of hazard evaluation and avalanche risk assessment. The participant is asked to form an opinion. Specifically: “where is unstable snow?”; “where could avalanches occur?”; “if an avalanche occurs, what is the potential consequence?”; “what is the best terrain choice given our conditions?”; and “how can we limit our exposure, vulnerability and reduce the likelihood of having an avalanche involvement?”. The participant is asked to make decisions with regards to snow stability, avalanche hazard, and avalanche risk, and integrates daily checklists, group discussions, and documentation to complete the evaluation process.

AIARE 2 Learning Outcomes – Learn the skills and craftsmanship required of a “snow avalanche observer”

- Facilitate and participate in group discussions focused on evaluating snow stability and creating terrain options to reduce the avalanche risk.
- Form and communicate a personal opinion regarding the primary avalanche concern. Compare this to the public bulletin and/or the expert estimation of the avalanche problem.
- Use pre-trip and post-trip checklists as tools to evaluate the avalanche hazard, to target field observations, and to assess terrain options.
- Observe and record daily field weather, snow, and avalanche observations using SWAG guidelines. Observe and record a test snow profile and column tests to SWAG standards.
- Observe how the mountain snowpack varies significantly over terrain. Importantly, participants will recognize the challenges and risks associated with extrapolating from limited field observations. Specifically, participants will recognize that accurate site selection, personal craftsmanship, and thorough verification processes are integral to relevant observations.
- Participant will improve their snowpack skills and knowledge, but recognize that their decision-making in avalanche terrain may not improve until experience gives them the ability to recognize trends and patterns and accurately assess the quality of a data set.
- Practice and perform advanced companion rescue skills include multiple burial recovery, triage methods, deep burial recovery, and leadership during an avalanche rescue response (this learning outcome may be met during a pre-course workshop).

0.2 Making the Most of Your Avalanche Course

Pre-course reading. On the AIARE web site at www.avtraining.org you will find the AIARE 2 pre-course exercise. Complete the exercise prior to your course. Should you have any questions, write them down and bring to the course. Please complete this quiz prior to the course start date and bring it with you to the course.

Asking questions. Snow is complicated. Make the most out of your course by asking group members and your instructor questions. Record the responses in your notebook.

Taking notes. The workbook provides room to follow along with the classroom sessions and make relevant notes.

Complete each day's questions. Class and field sessions have several follow-up questions to test your understanding of each day's topic. Complete the questions at each day's end and bring those you find difficult to the next morning's discussion.

Group participation. Both field and class sessions have opportunities for discussion and group interaction. Have an opinion, have a voice! Take on a leadership role when you feel comfortable.

A Special Note to Students:

Most of the understanding and techniques addressed during this course require extensive practice before you can expect to be proficient. No course, this one included, can provide all that experience.

To establish and maintain proficiency in the knowledge and techniques covered in this course, you will have to practice extensively and regularly on your own after leaving the program. Additionally, avalanche education continues to evolve as new research becomes available. To remain current, you will need to seek out opportunities for continued education.

No course can fully guarantee your safety, either during the course or after you leave. During the course, the instructors will manage risk and involve you in discussions about what is appropriate and what is not. They will inform you of any unusual or exceptional hazards or risks involved in carrying out lessons and exercises. Whether you will be "safer" after the course or not depends entirely on how you apply your new skills and knowledge when in the mountains.

0.3 AIARE 2 Pre-course Exercise

This exercise encourages the AIARE 2 participant to take time prior to the course start date and review the AIARE 1 student manual, field book and key learning concepts. The intent of the exercise is to review the AIARE 1 learning outcomes and to provide context for how the AIARE 2 course builds upon the AIARE 1. Importantly, this exercise also begins to "put the student in the learning mindset" and gain familiarity with the topics of the mountain snowpack, avalanche terrain, and avalanche risk.

Learning Outcomes

- Re-engage in the learning process, prior to your AIARE 2 course.
- Review and define the AIARE 1 key concepts.
- Review AIARE's Decision Making Framework (DMF) and Communication Checklist.
- Discuss why small teams often make better decisions than experienced backcountry travelers in avalanche terrain.
- Refresh your memory on how layers form in the mountain snowpack and how strong over weak layers interact to create different avalanche problems.

Task: Review and Define The AIARE 1 Key Concepts

On a separate piece of paper, write out a definition or description for each term.

- **Teamwork**: Decision-making framework, teamwork, communication checklist, public avalanche bulletin, trip plan, AIARE fieldbook, review the day.
- **Avalanche type and characteristics**: loose snow avalanche, slab avalanche, glide avalanche, cornice, avalanche problem
- **Avalanche motion**: Gliding motion, flowing motion, destructive potential and avalanche size
- **Avalanche path terminology**: Defined avalanche path, poorly defined avalanche path, start zone, track, run out, deposit, flanks, bed surface, crown fracture, stauchwall,
- **Terrain characteristics**: Elevation of the slope, aspect to wind and sun, lee slope, windward slope, cross loaded slope, drifting snow, slope angle, convex rolls, trigger point, terrain trap,
- **Snow climates**: continental climate, intermountain climate, and maritime climate.
- **Layered mountain snowpack** snowpack, rounding, sintering, faceting, melt-freeze layer, persistent weak layer.
- **Danger scale**: low danger, moderate danger, considerable danger, high danger, likelihood of avalanches, distribution and size of avalanches.
- **Avalanche rescue response**: Companion rescue checklist, transceiver, avalanche balloon pack, search for a signal and clues, search mode, send or transmit mode, point last seen, single searcher pattern, multiple searcher pattern, probing the target, effective shoveling technique.
- **Snowpack observations**: Snow profile, compression test, Rutschblock test,
- Weather observations: red flags
- **Decision-making**: Human factor traps, bias, error, uncertainty, unfamiliarity

Task: Complete the AIARE 1 Review

The questionnaire is designed to encourage participant review and self-assessment. Please bring this filled out questionnaire to class on day 1. You will not receive grade marks on this quiz, nor is it pass/fail. In addition to a review for the participant, the exercise gives the instructor feedback for what concepts to revisit during the AIARE 2 course.

This is an 'open book' exercise. Participants are encouraged to use both the AIARE 1 manual and AIARE fieldbook to help solve any unanswered questions.

Exercise #1

On the AIARE 1, course instructors describe *human factors,* such as bias and poor communication, as conditions that commonly compromise the group's ability to make good decisions in avalanche terrain. Specifically, "human factors within the group have the potential to affect trip preparation (*Plan*), our ability to recognize clues in the field (*Observe*), and to make safe *Terrain Choices*". The antidote described to manage the situation is *Teamwork*.

Describe in a paragraph why each antidote listed below is integral to ensuring that small groups make better decisions than individuals:

Discuss Goals, Experience, and Abilities—

Share Tasks and Responsibilities—

Travel together, Decide Together, Build Consensus—

Exercise #2

The Trip Plan functions as a pre-trip decision-making checklist. It also encourages backcountry travelers to take both the public bulletin and the group's pre trip discussion into the field. The Trip Plan is one of the most important "check and balances" in the decision making process as it promotes terrain choices based on information and planning, as opposed to impulse and desire when at the top of an untracked slope. It requires the group to distill key information from the bulletin including the primary avalanche concern. It also helps the group to anticipate what field observations they will expect to see to verify the expert's determination of the avalanche risk. Read through the following bulletin description, and answer the questions using the terms in the AIARE 1 manual and the Avalanches and Observations Reference (AIARE fieldbook p.4):

January 13th, 2013. Tuesday, 0600AM
"20 - 70 cm of new snow fell over the weekend burying an old layer of surface hoar/facets that kicked off an avalanche cycle of sluffs that were running far and fast. While a few loose snow avalanches continue to be reported, the character of the weekend snow is changing; it's now settling into a soft slab with just enough cohesion to be triggered naturally and by backcountry users.

Slab avalanches with crown depths of 40 - 60 cm have been reported yesterday. Most of these slabs have been immediately lee of ridgetop, there hasn't been a whole lot of action midslope, yet. The situation will change rapidly with any sustained winds. The big thing here is how the snow feels under your skis or machine. Stiffer feeling snow indicates that the snow is taking on slab properties and if you can feel this change, you've already gone too far. The loose snow avalanches were pretty easy to deal with using proper sluff management techniques, but this new slab avalanche problem is a different beast & it demands respect.

Use terrain to your advantage to avoid wind affected snow. Last week rain fell up to about 1400 m creating a stout crust below treeline. A surface hoar layer buried around the Christmas holiday still produces clean fast fractures results in compression tests, but, avalanche activity as of late has been confined to layers closer to the surface.

The region remains under the influence of a cold and mostly dry Arctic Air mass. The moderate southerly winds that were prevalent during the storm and Monday should back off leaving quite pleasant, albeit cool weather and light north winds today. Skies will be clear. A daytime high of -19C is expected at 1500m with an overnight low of -32C.

What is the primary avalanche problem today? Describe the trend?

What *was* the avalanche problem during this past weekend?

What field observations and quick field tests would you observe and perform to verify the bulletin writer's (the expert's) statement?

Describe the terrain you would avoid; and describe safer choices. Describe the elevation and aspect and terrain features in your description.

Exercise #3

Why are Persistent Slab problems so challenging to anticipate and avoid as a backcountry traveler?

Exercise #4

Describe two techniques for managing a cornice hazard? Why is a relatively small cornice fall still a threat to a rider on the slope below?

a)

b)

c)

Exercise #5

The public avalanche bulletin rates the danger over a large area of terrain (for example a range or drainage). To keep yourself safe it is important to anticipate where avalanches are likely to occur on the scale of a mountain slope or terrain feature. Describe why loose or slab avalanches often initiate at or near the terrain features listed below:

Convex roll –

Lateral moraine slope –

Shallowly covered or exposed rocks or vegetation –

Exercise #6

Why is *rounding* associated with the process of snowpack *settlement* and *creep*? And, why does faceting resist snowpack settlement?

Exercise #7

If slab avalanches are identified as a strong layer over a weak layer, describe three observations of the weak layer that require no special tools other than a shovel (and exposed snowpack wall revealing the layers), a gloved hand, and the naked eye (with prescription glasses if necessary!).

a)

b)

c)

Exercise #8

Match the following field observations to specific problems (A-I). If the observations indicate there is a likelihood of no problem, record that observation (J). The same letter can be used twice if required.

<table>
<tr><th>Observation</th><th>Answer</th><th>Avalanche Problem</th></tr>
<tr><td>3cm/hr snowfall for 6 hrs below treeline with no wind.</td><td></td><td rowspan="7">A. Loose Dry Snow
B. Loose Wet Snow
C. Storm Slab
D. Wind Slab
E. Wet Slab
F. Persistent Slab
G. Deep Slab
H. Glide Slab
I. Cornices
J. No Problem</td></tr>
<tr><td>30cm new snow plus 25kph winds at ridge top.</td><td></td></tr>
<tr><td>Wide, and deep crevasse like cracks across the snow slope. Rock slab ground cover is recognizable where the fracture line is deepest.</td><td></td></tr>
<tr><td>No snow for 5 days, decreased foot penetration and snow cones around small trees.</td><td></td></tr>
<tr><td>Pinwheels on sunny slopes.</td><td></td></tr>
<tr><td>Avalanche debris has ribs and channels. The start zone shows exposed dirt and rocks.</td><td></td></tr>
<tr><td>Whumping and shooting cracks occur under a skier's weight on a 20 degree slope.</td><td></td></tr>
</table>

Exercise #9

When it is important to dig a snow profile to complement field or bulletin observations? Why is it often not necessary? Describe the potential hazards of gathering snow profile information.

Exercise #10

Avalanche occurrences are an obvious indication of unstable snow. What dangerous avalanche problems may be associated with rider-triggered avalanches, but *with no or few natural avalanches observed*?

Exercise #11

List four field observations that indicate that a wind slab problem may be lurking in alpine terrain:

a)

b)

c)

d)

Exercise #12

Give four reasons why it may be challenging to accurately determine slope angle on a slope that you intend to ski:

a)

b)

c)

d)

Exercise #13

An avalanche has occurred. You are performing a single searcher pattern with a transceiver and are closing in on the signal and buried victim. Your transceiver now reads 10m distance from the burial. Describe your actions as a rescuer how to *target* and *recover* the burial from the 10m distance, as indicated by a transceiver. You have one helper to probe and dig.

Exercise #14

In the column adjacent to each statement, regarding human triggered FATAL avalanches, describe the statement as either "rumor" or "research". Hint, use this link to Canadian fatal accident statistics: http://www.avalanche.ca/cac/library/patterns-in-avalanche-accidents/overview and http://www.wsl.ch/info/mitarbeitende//schweizj/publications/Schweizer_SkierTriggeredAvalanches_Stryn2002.pdf. While not exactly the same trends exist in the US, Europe, and other areas, the trends are close enough to be worthy of comparison.

Rumor or Research?	
A. The majority of fatal avalanches were triggered by the first skier/rider on the slope.	
B. Most fatalities involved only one rider on the slope. Most backcountry travelers use the "one at a time on the slope" rule.	

C. The majority of avalanche fatalities involved persons who were NOT carrying avalanche transceivers.	
D. Signs of unstable snow were present in 60 percent of avalanche fatalities.	
E. 96% of the fatal accidents occurred in areas where the steepest sections of the slope or adjacent terrain, were steeper than 30 degrees.	

Exercise #15

When caught in an avalanche your actions, especially in the first few seconds, may significantly increase your chances of survival. Select the statement that *best* describes your response:

Action	Circle One Answer
A. Immediately diagonal to the side attempting to escape the avalanche, pulling your avalanche balloon pack en-route.	1. A. 2. A and C. 3. A, B, C, D, and E. 4. B. 5. For at least one reason in each paragraph, none are correct
B. You are coming out of a high mark on your snowmobile when the entire slope fractures. Point your sled downhill, hit the throttle and straight line for the bottom of the avalanche path aiming for high ground.	
C. You are near the top of the slope. The snow breaks into blocks and has just started to move. You grab a nearby tree and hang on for dear life.	
D. You traverse slowly out onto upper part of the slope. The entire slope fractures into blocks. You sink through the blocks, unable to ski away. You punch through the broken moving snow with your hands/poles and dig into the bed surface attempting to self-arrest—permitting the bulk of the snow to move downhill without you.	
E. You are caught, and there is no hope of getting to the side of the avalanche. You release your skis and poles, curl into a ball and hope for the best. As the avalanche slows, and comes to a stop you fight to keep your hands around your face and mouth and your arms in close to your chest, making a breathing space and room for your chest to expand.	

Exercise #16

Since your last AIARE 1 course you have (circle True or False):

- Completed a Trip Plan diligently prior to every backcountry excursion. TRUE/FALSE
- Used elements of the communication checklist to encourage and value each group member's opinion in field discussions, regardless of his or her experience. TRUE/FALSE
- Have not been caught in an avalanche nor known any friend or co-worker who has been caught in an avalanche. TRUE/FALSE
- Completed this quiz with a refreshing read of your AIARE field book and AIARE 1 manual, and reviewed the answers with your friends. TRUE/FALSE

0.4 Accident Case Study

Case studies provide practical examples of scenarios where all did not go as planned. The goals with this case study are to illustrate:

- the importance of good observation skills in the decision-making process
- that when a backcountry traveler makes a decision that is based on his *interpretation of snowpack properties,* it requires experience verifying the accuracy of information, and experience applying the observation to actual avalanche slopes

Implicitly, any case history analysis asks observers to summarize how the incident or accident occurred. What were the mistakes made? Can we learn from the mistakes that others made? What would I have done in the same situation given my experience?

Please recognize that examples used for this end often involve real human suffering and loss. The goal of the exercise is not to illustrate fault. All the case details are not available for us. We can only review the situation in the context of the exercise.

The intent is to learn and improve our skills through vicarious experience.

Learning Outcomes

- Gain vicarious experience of the real-life consequences of an avalanche involvement.
- Reinforce the importance of excellent observation skills, verifying the observations with additional tests, and making decisions that are relevant to one's experience.
- Identify human elements that can alter decision-making.
- Describe the importance of developing and implementing terrain alternatives.

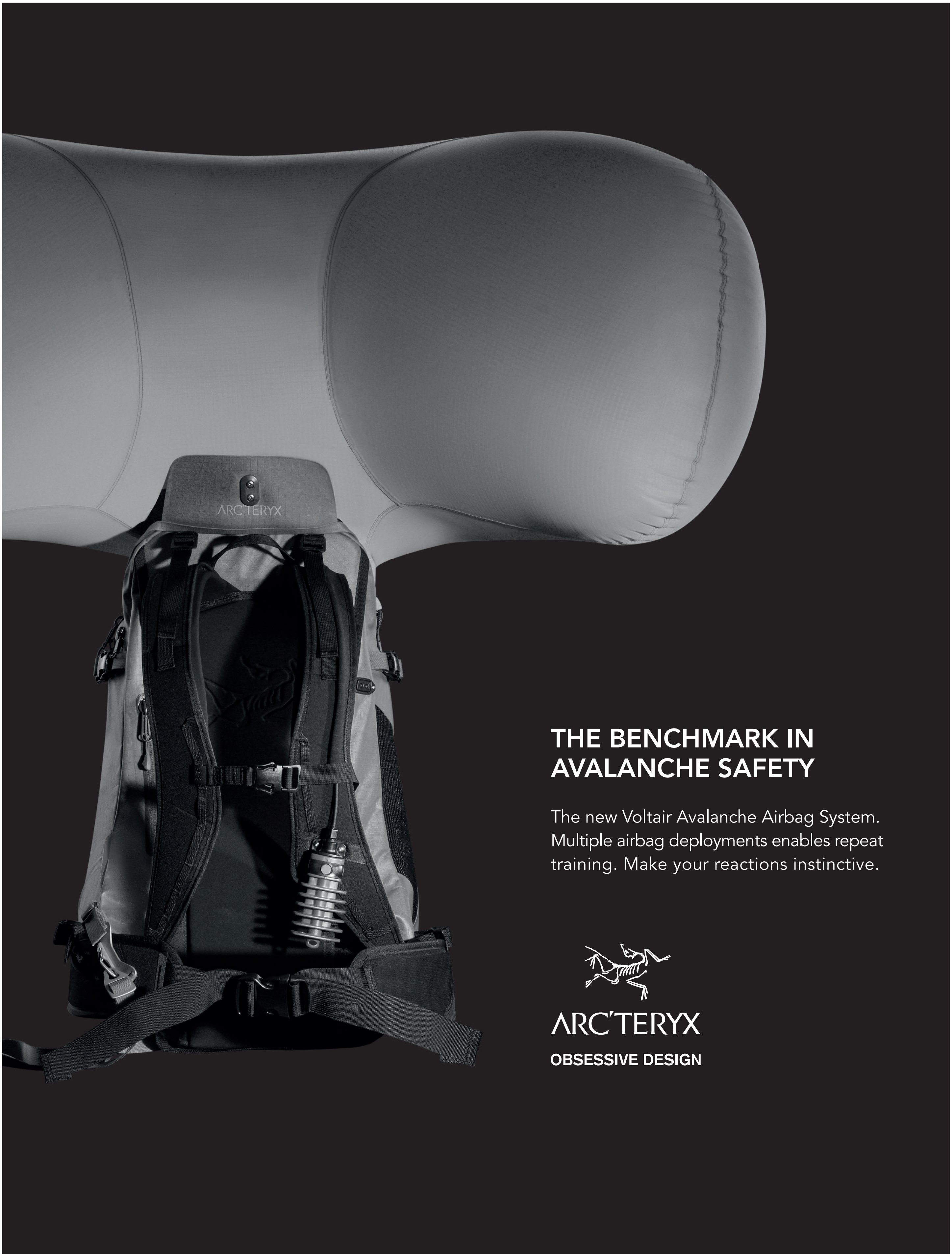
Notes

Task: Group debrief of an accident case study

As a group, discuss the event. Make a list of the three key weather, snowpack, avalanche and terrain factors that contributed to the event.

Answer the following questions:

- How do the concepts of verifying observations and applying experience relate to this event?
- What were the most important terrain factors that contributed to the incident?
- What would a less-experienced person have done? Would they have made the same human errors?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OBSESSIVE DESIGN

PRESENTATION NOTES:

Chapter 1: The Changing Mountain Snowpack

1.1 Mountain Weather Resources

Mountain weather and terrain combine to form the layered mountain snowpack. To forecast where and when avalanches are likely to occur, the backcountry traveler must have basic understanding of mountain weather—and experience with *how the weather interacts with* the local terrain. For avalanche forecasters, reading and interpreting current weather data and weather forecasts and projecting how the weather interacts with the local mountains becomes a daily routine. This is not a meteorology lesson. The session provides an introduction to local weather resources and tools and provides motivation to learn more about the important relationship between mountain weather and avalanches.

Learning Outcomes

Access the following resources:

- Local weather station information.
- Web-accessed local weather and snow stations.
- Local or Web sources' ridge top winds and temperatures.
- Weather forecasts for mountain regions.
- Local interpretations that include a description of how weather interacts with mountain terrain (avalanche bulletin or other sources).
- Be introduced to the weather information useful in daily hazard evaluation and forecast.

Key Concepts

- air masses
- high pressure
- low pressure
- fronts
- orographic lift
- upper level winds
- ridge top winds
- lapse rate
- precipitation type, rate, and duration
- forecasts
- weather resources

During the lesson presented in class, each student is introduced to various online resources for monitoring and anticipating weather conditions. The instructors recommend that participants establish a daily routine of monitoring these websites to develop skill at acquiring weather observations in a systematic way. This concept, along with the notion of manual weather observations, will be discussed further in Chapter 2.

It is important that the backcountry traveler understands the distinction between weather data and weather forecasts. It is also important to note the difference between a weather forecast for mountain towns (example: evening TV forecast) and a forecast for how the weather will affect the avalanche conditions (example: weather forecasts in the avalanche bulletin).

Observations and recordings of recent weather history are combined with current data to observe *trends*. The better an avalanche observer understands the local trends and patterns in each geographic region, the better is their understanding of why the mountain snowpack varies so dramatically over terrain.

AIARE encourages enrollment in a course on mountain weather to improve knowledge of this phenomenon.

Notes

Online Weather Resources

Each of these sites is a home page for a site that has a vast number of specific products. To explore these sites thoroughly will take a long time. It is helpful to choose a few weather products, stick with them and watch them daily to learn to recognize trends. The list below represents a few of many websites available.

National Weather Service: http://www.weather.gov/

Colorado Avalanche Info Center weather model forecasts (Western US domain): https://avalanche.state.co.us/pub_model_wx.php

Unisys Weather: http://weather.unisys.com/

San Francisco State University: http://squall.sfsu.edu/

University of Washington: http://www.atmos.washington.edu/weather.html

Colorado State University GOES satellite imagery: http://rammb.cira.colostate.edu/ramsdis/online/goes-west_goes-east.asp

National Center for Atmospheric Research real-time weather data: http://weather.rap.ucar.edu/

Snotel Data from NRCS: http://www.wcc.nrcs.usda.gov/partnerships/links_wsfs.html

Mesowest Wx Stations: http://mesowest.utah.edu/index.html

MetEd Comet Mountain Weather Distance Learning Course (estimate learning time 9-12 hrs) http://www.meted.ucar.edu/dl_courses/mtnwx/index.htm

Recommended Reading

The Avalanche Handbook – Selections from Chapter 2

Mountain Weather and Snow-Climate Types & Mountain Wind and Precipitation, p.21-26
Convergence: Upward Motion around a Low-Pressure Area; Frontal Lifting; Orographic Lifting & Convection, p.26-28
Quantitative Precipitation Forecasts & Orographic Precipitation Forecasts, p.28-29
Local Wind Flow Over Mountain Terrain & Blowing and Drifting Snow, p.29-34

Questions

Describe the general upper level weather pattern (example: SW flow) that provides the most precipitation for the local region?

Why are ridge top or valley winds often different from the prevailing upper level winds?

List local online weather resources where you can observe ridge-top wind speed, direction, and temperature. List an online snow resource where one can find local precipitation amounts.

Describe the Web weather forecast that describes and interprets how the weather is forecast to affect local avalanche terrain.

1.2 The Layered Snowpack

This lesson is an initial discussion of processes that combine to form layers in the snowpack and change the characteristics of those layers over time. It begins with the formation of snow in the atmosphere and introduces changes that begin to affect the shape of the snow grain and the surface layers. The mechanisms of heat exchange are covered, which lays the framework for discussing the processes that are responsible for snowpack metamorphism, including the creation of weak layers.

1.2.1 Formation and Classification of New Snow and Rimed Snow

The knowledge of how snow crystals form and change in the atmosphere is an important building block toward understanding the effects that crystal form can ultimately have on new snow instability and how well new snow will bond to the old snow surface.

Learning Outcomes

- Identify new snow types including dendrites, plates, riming, graupel.
- Explain how variations in precipitation type, rate, and intensity create different snow layers.

Key Concepts

- Condensation deposition
- super-saturated air
- water droplet
- water vapor
- snow crystal/snow grain: snowflake, new snow, precipitation particle, riming, graupel, snowpack

The Formation of New Snow

When the environment is right, *snow crystals* form in the atmosphere. These crystals are created when water vapor *condenses (deposits)* as ice on a crystalline *nucleus* (or dust molecule). Depending on the temperature and humidity in the regions where snow is forming, new snow crystals take a variety of shapes and fall to earth in a variety of sizes.

The classic six-sided “Dendrite or Stellar” crystal is what most people visualize when we talk about a new snow crystal. In reality, atmospheric (new) snow comes in a variety of shapes and sizes. We recognize a number of sub-classes that reflect the main types of new snow. Large irregular snow grains including plates, needles, or columns may form weak layers if covered by storm snow.

Each of the sub-classes in turn has numerous variations. More than one sub-class and/or variation can form in a single storm as the temperature and humidity regimes change. It is not uncommon to see several different types of new snow during a single storm, sometimes changing back and forth over relatively short periods of time (a few minutes or hours).

When a new snow crystal gains enough mass to overcome gravity and escape any updrafts that might exist in the air mass, the crystal falls from the atmosphere and eventually lands on the ground. The build-up of snow crystals on the ground from successive snowfalls creates what we refer to as the *snowpack,* which is really just the total accumulation of snow that has fallen to the ground to date in a given winter.

Recording New Snow

In avalanche work, we refer to most atmospheric snow simply as *new snow (also precipitation particles)* and often use one symbol (+) as the basic grain classification for all types when making field notes. Notable exceptions include plates, needles, or graupel. Advanced practitioners often identify sub-classes when they are able to clearly identify the grain type and when a sub-class is significant in terms of stability.

Observers are interested in observing and recording precipitation type, rate, and intensity. Even when the snowpack is stable avalanches can result when precipitation rates exceed 2cm/hr and deposit 30cm or more on the mountain slope. Varying types of snow falling during a storm cycle can result in a buried weak layer (example: large, well-shaped dendrites forming a thin layer under 30cm of small, more densely packed precipitation particles).

Additional specialized symbols for new snow sub-classes are in the SWAG, Table 2.3, and pg. 30.

Riming, Graupel, and Hail

Under some conditions, tiny water droplets form in the atmosphere and remain in a liquid state at temperatures below 0º C due to a lack of a freezing nucleus. These water droplets are described as *super-cooled*. When a super-cooled water droplet comes into contact with any surface or object, it immediately adheres to the surface or object and freezes, forming a small spherical piece of ice. This process is called *riming*. The tiny ice spheres are referred to as *rime*.

The most visible form of rime is when super-cooled water is driven against a surface by wind. Under these conditions, rime accretes on the windward side of the surface and creates a kind of icy stalactite formation that grows larger as additional rime is added. These rime formations are often seen on rocks, trees, communication towers, etc., in wind-exposed areas, especially in maritime climates.

If a snow crystal comes into contact with super-cooled water droplets, riming occurs and the rime accretes on the crystal. When this happens, we refer to the new snow crystal as being *rimed*. When only a few of these ice spheres exist, they are almost invisible to the naked eye; however, they can usually be observed using a simple hand lens magnifier. As the amount of riming increases, rime becomes visible to the naked eye.

Under heavy riming, new snow crystals can accumulate so much rime that their original form becomes completely obscured, eventually forming a roughly spherical (seldom a perfect ball) pellet. Sometimes referred to as “pellet snow,” this is what we call *graupel*. Graupel particles that ride atmospheric updrafts and accrete multiple layers of rime can eventually form *hail.*

Riming may occur to individual snow crystals, or it can be deposited directly onto the snowpack if conditions are right. For example, if super-cooled water is present and the wind blows directly onto a slope where rime can be deposited and accumulate, a *rime crust* may form on the surface of the snowpack. While not a new snow crystal, rime added to the snowpack in this way becomes a layer that is part of the *snowpack*. Rime crusts are generally white and opaque, rough, and feel crunchy underfoot or to the touch.

Conclusion

This section presents a simplified discussion of how new snow forms and riming takes place. The actual processes are complex meteorological subjects. The previous paragraphs have limited the discussion to observable characteristics relevant to snowpack stability.

Since different sub-classes and variations of new snow often fall during a storm and since each of these may have significantly different characteristics, it is not unusual to see a number of layers form in the snow that accumulates during a storm (the *storm snow*).

Even if the storm snow is homogeneous, in most cases it differs from the surface of the snowpack it falls onto. This often forms the first of what may be many layers in the mountain snowpack, with the interface between the storm snow and the old snowpack surface being the boundary. In addition, riming may occur to individual snow crystals or on the snowpack itself.

The snow climate has an influence on the type of snow that forms, weather conditions under which it is deposited, and the likelihood that surface hoar will form (discussed in 1.2.5).

Due to all these factors (and more to be discussed later), it is unusual to see a snowpack composed of a single homogeneous layer with consistent characteristics throughout its height. Successive storm snow deposits, the weather conditions present during and between storms, riming, surface hoar deposits (discussed later), and the snow climate combine to create a succession of layers in the snowpack as it develops over the winter. These layers are often significantly different from one another. Even if they are initially similar, they may become different over time due to snow metamorphism processes. Since there are layers in the snowpack, and if they are different from one another, the layers may not bond to each other. It is this layering that is the basis for the formation and release of avalanches.

It is important to have this foundation prior to understanding the processes that drive snow metamorphism over time. Observers of the mountain snowpack require a solid grasp of the metamorphic processes. This knowledge provides essential clues to know where and what to look for when making field observations, recording findings, and eventually analyzing and forecasting snow stability.

Recommended Reading

The Avalanche Handbook - Selections from Chapters 2 & 3

Mountain Weather and Snow Climate Types, p.21

Snow Formation and Growth in the Atmosphere & Classification of Newly Fallen Snow Crystals, p.43-50

Snow, Weather, and Avalanches - Selections from Chapter 2

Table 2.3, p.30

Questions

List three factors that affect the shape and character of snow crystals as they form in the atmosphere.

Describe the differences between rimed snow, graupel, and hail.

Briefly explain how a layered snowpack develops.

1.2.2 Snowpack Structure

To understand how snow deposited from the atmosphere changes over time, it is helpful to begin with a mental framework of the physical structure of the snowpack and forces acting upon it.

Learning Outcomes

- Describe the physical makeup of a snowpack.
- Compare and contrast layers and interfaces.
- Explain how the various forces constantly exerted upon the snowpack by gravity change the snow through time.

Key Concepts

- ice lattice
- grain to grain contact
- pore space
- layers
- interfaces
- settlement
- snowpack creep
- snow gliding
- glide cracks

The Ice Lattice

The snowpack is a structure comprised of two basic components, the *grains* and the *pore space*. These parts may be apparent even to the casual observer. It is important to understand the physical nature of each component and its respective role in the transfer of heat and the movement of vapor (discussed in section 1.2.3).

The snow grains are ice particles comprised mostly of solid water and a smaller proportion of water vapor. The mass contained in these particles is not constant, and neither is their shape. Instead, the surface of these solid particles actually gives off water vapor to the air immediately surrounding the grains within the snowpack, also known as the pore space. Additionally, water vapor in the pore space migrates back onto the surface of the snow grains. The interplay of this movement of water vapor will determine the shapes that these snow grains will take in the near future. We call this process *metamorphism*. The actual process of snow metamorphism will be discussed more in section 1.2.4.

To the observer, it is important to understand that in low-density snow, where the grains are widely spaced, water vapor can move more readily. In contrast, with high-density snow, water vapor movement through the pore space is inhibited.

The transfer of heat is also determined by the structure of the snow grains and pore space. Solid ice conducts heat better than air, so dense snow or ice layers will transmit heat better than less dense snow. This concept will come into play in the upcoming section on heat exchange (section 1.2.3).

Layers and Interfaces

Each time snow falls from the sky, the snowpack gains a new layer. In some cases, where the nature of the storm changes, a single storm may produce multiple layers. As snow changes over time, multiple adjacent snowpack layers may become quite similar in their grain size and form. In practice these layers may be considered a single layer. Other times a single buried layer may be exposed to different conditions at various heights within that layer, becoming multiple layers over time. In short, avalanche practitioners consider a snowpack layer to be a band of snow grains with similar characteristics.

The boundary between two adjacent layers is referred to as the *interface*. This distinction between layers and interfaces will play an important role for the snowpack observer.

Settlement, Creep, & Glide

Over time, individual snow grains will move under the influence of gravity. This movement can be categorized in three basic categories—settlement, creep, and glide (see Avalanche Handbook p. 75 & 78). Ultimately, the impact of these processes causes snow grains to move both down slope and to settle into place closer to the ground. All of these processes tend to happen more quickly and play a more significant role in analyzing snowpack instability at warmer temperatures—particularly in relation to a dry snowpack.

Settlement involves the snow grains fitting together tighter like pieces of a puzzle. This process results from snow grains rearranging as they change shape over time and settling under the weight of overlying layers. Settlement tends to happen on the order of hours to days and can play a role in both weak layers stabilizing as well as slabs forming.

Snowpack creep is settlement occurring on a slope, where gravity acts to pull snow grains slowly downhill. On an incline the grains in the snowpack rearrange and move down slope at a faster rate near the snow surface than near the ground.

Snow gliding involves the entire snowpack slipping down slope. When the snowpack is dry, glide is small or negligible. Glide in late spring can occur on certain slopes at a fast enough rate to produce a full-depth avalanche, called a glide avalanche. In this case the snowpack glides along a warm, (0°C), smooth, lubricated surface such as a smooth grassy slope, a smooth rock slab, or occasionally an ice layer. Glide cracks in the snowpack are often visible.

Snowpack creep is a continuous process and glide features can often be observed over multiple days.

Conclusion

A basic understanding of the physical structure of the snowpack is essential to understanding snowpack processes. In general terms, the snow grains interconnect to form a solid lattice of ice. In a dry snow layer, every pore space not filled with ice is filled with varying amounts of water vapor. The mountain snowpack is not a complete solid but a porous material that changes structure, deforms, and very slowly creeps downhill under the influence of gravity. The knowledge of how layers form, how grains change shape, and how the snowpack deforms as it lies over terrain is the foundation for anticipating and observing where and why avalanches occur.

Recommended Reading

The Avalanche Handbook - Selections from Chapter 4
Snowpack Creep & Snow Gliding, p.75-79

1.2.3 Snowpack Interaction with the Environment

Now that snow crystal and snowpack formation have been introduced (section 1.2.1), and the basic conceptual model of snowpack structure has been reviewed (section 1.2.2), the next step is to review how the snowpack interacts with the environment. This lesson introduces how energy (heat) is transferred to, from, and within the snowpack. It addresses the mechanisms for heat transfer, the importance of energy exchanges at the snow surface, and how air temperatures and precipitation can influence these heat exchanges to, from, and within the snowpack. This lesson illustrates the importance and usefulness of quality weather and snowpack observations in assessing how the snowpack changes over time.

Learning Outcomes

- Relate why energy exchange at the snow surface and within the snowpack is important to the snow observer.
- List the mechanisms for energy (heat) exchange.
- Describe the components of radiation balance at/near the surface (short-wave radiation and long-wave radiation).

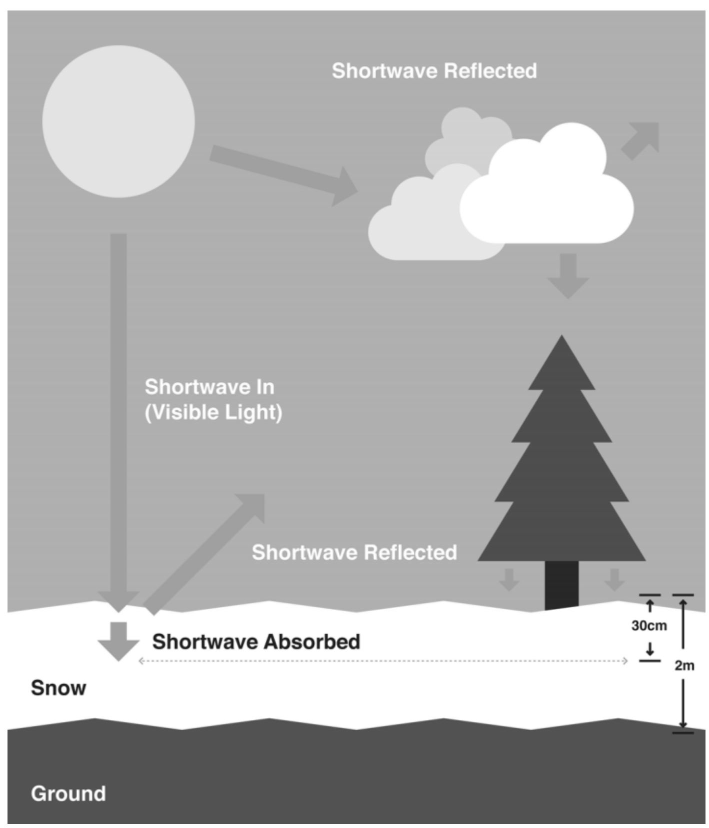
Key Concepts

Methods for Heat to Enter, Leave, and Transfer within the Snowpack

- Heat transfer: warm to cold, grain to grain, through pore space, rain and melt water
- Heat source: sun, earth, precipitation
- Terms: long-wave radiation, short-wave radiation, surface reflectivity

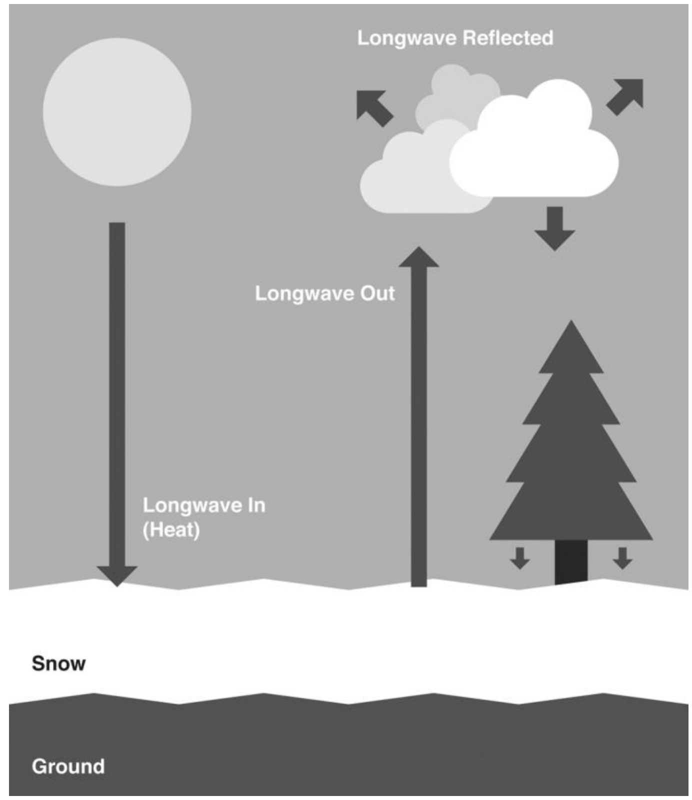
Solar Components: short-wave radiation, penetration into alpine snow, reflecting, warming of the snow surface

Energy (heat) exchanges at the snow surface play a major role in determining many properties of snow on the ground, including: snowpack stratigraphy, temperature, grain size and type, and snow density and depth. By examining energy exchanges at the snow surface, we can interpret and estimate metamorphism, and thereby make our weather observations more useful. This section describes how short-wave (sunlight) radiation factors into this overall energy balance at and near the surface.



Terrestrial Components: radiation into space, from clouds, heat flux through snow cover, conduction grain-to-grain

Long-wave radiation (heat) exiting or entering the snowpack is a primary component in estimating the overall energy balance at the snow surface and within the snowpack. This section describes how heat exchanges between the snowpack and the overlying atmosphere, between the snowpack and the ground, and within the snowpack factor into metamorphic processes.



Near-Surface Temperature Inversions

Temperature inversions are common occurrences in the mountains. Inversions can result in wind patterns that may transport snow and can influence spatial variability in temperature gradients and surface hoar formation. In addition, inversions affect the heat exchange between the snowpack and the overlying atmosphere.

Precipitation, Melting, and Freezing

Sensible heat (the heat you can feel) is exchanged if new precipitation is a different temperature than the temperature of the snow surface on which it falls. Rain contains more heat energy than snowfall. The warmer the rain, the more heat energy it has, and vice versa. If rain percolates into the snowpack and freezes*, latent heat* (heat released or absorbed from water changing phases) is released. Similarly, latent heat is also exchanged through melting, refreezing, sublimation, and condensation of snow grains. *Latent heat exchange* is a process that can warm or cool certain areas of the snowpack and alter temperature gradients. This can have an effect on metamorphic processes

There is heat exchange between the three distinct layers of the atmosphere (air), the snowpack, and the ground. Heat is also transferred within the snowpack itself. The ground releases stored heat into the atmosphere, and the snowpack acts like an insulating layer that "slows down" the transfer of heat from the ground to the overlying atmosphere. It may be easiest to think of the snowpack as insulating the ground from cold winter air like a down jacket. Conditions at the ground-snow interface remain fairly constant, while conditions at the snow-atmosphere interface can vary considerably throughout the course of the day.

Heat exchanges are responsible for many of the changes snow goes through, from the time it crystallizes in the atmosphere, to how it changes while exposed to atmospheric weather conditions, to how it changes once within the snowpack and, ultimately, to how and when snow melts.

By examining heat exchange at the surface and within the snowpack, the observer can interpret and estimate metamorphism, and thereby make weather observations more relevant.

This is a simplified discussion of energy (heat) exchange at and near the snow surface and within the snowpack. Energy exchange drives the metamorphic processes we consider relevant to avalanche analysis (covered in section 1.2.4). The actual processes are complex physical processes beyond the scope of this course.

Notes

Recommended Reading

The Avalanche Handbook - Selections from Chapter 2

Heat Exchange at the Snow Surface; Penetration of Heat into Alpine Snow; Interaction of Radiation with the Snow Cover & Temperature Inversions, p.36-41

Questions

What are the primary components of radiation balance at/near the snow surface and how do they “add up”?

Why is energy (heat) exchange important?

How does precipitation onto the snow surface impact the snowpack?

1.2.4 Metamorphism: Rounding, Faceting, and Sintering

This lesson discusses the processes that drive snowpack metamorphism. It begins with a review of snow grain decomposition and fragmentation. It covers how heat exchange (section 1.2.3) drives metamorphic processes and the importance of the relationship between temperature and vapor pressure. The concepts of temperature gradients and regimes, conditions that promote rounding and faceting, and snow grain sintering are covered. The topics covered in this lesson further emphasize how quality field observations are instrumental in assessing how the snowpack changes over time.

Learning Outcomes

- Explain why we measure snow temperatures.
- Relate temperature observations to vapor movement in the snowpack.
- Observe temperature gradients and their influence on metamorphism.
- Describe melt-freeze metamorphism and its effect on the snowpack.
- Observe faceting, rounding, and sintering and relate this observation to snowpack layering.

Key Concepts

- Decomposition
- Fragmentation
- Temperature gradient
- Temperature regime
- Rounding
- Faceting
- Sintering
- Melt-freeze

Decomposition and Fragmentation

Snow crystals are constantly trying to achieve a state of equilibrium and are undergoing constant change through vapor transport within the snowpack. In addition, as wind redistributes the snow, it mechanically changes the crystals; they tend to break up into smaller fragments and pack together more tightly. This forms a harder, denser layer (a wind slab or wind crust) on the surface of the snowpack. Snow grains that have been broken into small pieces and packed by wind are properly referred to as "broken" grains, but field practitioners tend to refer to them simply as wind-affected, wind crust, or wind slab depending on the extent of the effect.

Changing wind speeds and/or duration of wind transport of snow from the "fetch," or windward, slope to the lee slope results in stiffer and less stiff layers being formed on the leeward (deposition) slope. Strong layers (slabs) over weak layers on steep lee slopes may be conducive to avalanching. Temperature and humidity play a role in drifting snow and slab formation. Drier, colder snow favors more drifting and redistribution. Higher humidity favors bonding and sintering that may inhibit wind redistribution, but may favor slab formation.

Observing Temperature Gradients in the Snowpack

In this context, a temperature gradient is simply a change in snowpack temperature over height. Temperature gradients and vapor pressure gradients are related in a predictable way, and vapor pressure gradients drive the movement of water vapor in the snowpack.

Water vapor pressure is not practical to measure for most field practitioners and backcountry travelers, so we estimate vapor pressure by measuring snow temperatures. Because relative humidity in the snowpack pore space is always near 100%, as temperature increases in the pore space, so does vapor pressure. This is because warm air can "hold" more water vapor than cold air, so warmer pore spaces in the snowpack will have higher vapor pressures than similarly sized cooler pore spaces. This relationship between temperature and vapor pressure is non-linear, implying that a small change in temperature can cause a large change in vapor pressure.

Heat transfers from warmer areas of the snowpack to cooler areas by conduction of heat through the ice skeleton (or through liquid water if present) and convection of water vapor across the pore space. The rate of the vapor movement across the pore spaces dictates what type of metamorphic process likely will dominate. By measuring or estimating snowpack temperature gradients, it is possible to estimate where, and at what rate, vapor is diffusing through the pore spaces. The observer can therefore infer from careful field observations how the snowpack is changing (for example, estimating the dominant metamorphic process that is changing the grain shape).

Conditions that Promote Rounding and Faceting

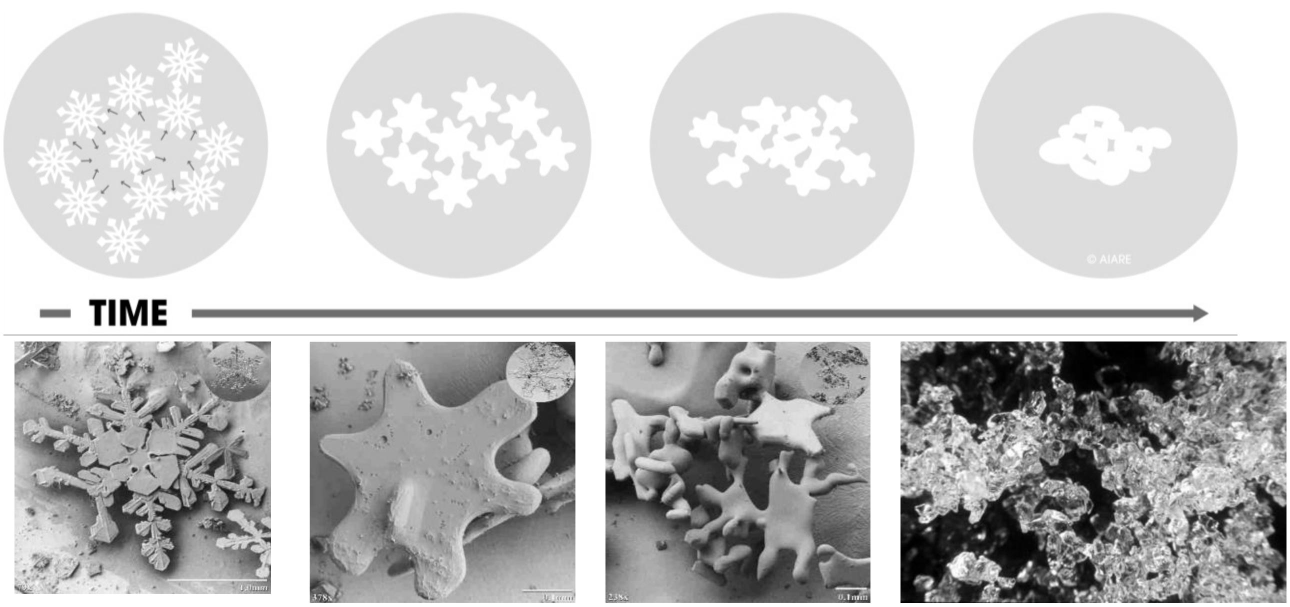
In avalanche work, temperature gradients are measured in degrees centigrade per 10 centimeters. This can be done for the layers of concern or for the entire depth of the snowpack. Taking temperatures throughout the entire depth of the snowpack is, of course, a time consuming and tedious process and often not practical. It may be worthwhile, however, to have a general idea of what the gradient is; this allows us to infer what metamorphic processes might be occurring in the snowpack so we can assess what the effect of those processes might be. Then we can decide whether it might be worthwhile for us to take a closer look at certain places to make a more detailed assessment.

Temperature gradients are described in this avalanche course as being either “low” or “high.” A low temperature gradient is less than a 1ºC changing over 10cm of snowpack height, and promotes rounding in the snowpack. Rounding is also promoted by high-density snow and warm temperature regimes. A high gradient is more than a 1ºC change over 10cm of snowpack height, and promotes faceting in the snowpack. Faceting is further promoted by low-density snow and warm temperature regimes. Note that warm temperature regimes promote enhanced rates of metamorphism for both rounding and faceting.

The characterizations of general snowpack temperatures are often referred to as temperature regimes. Simply put, “things happen” more quickly when the snowpack temperature is closer to 0°C (i.e., at -20° given a “high” gradient and a cold snowpack temperature regime, faceting would occur more slowly than at -5°C given a high gradient and warm temperature regime).

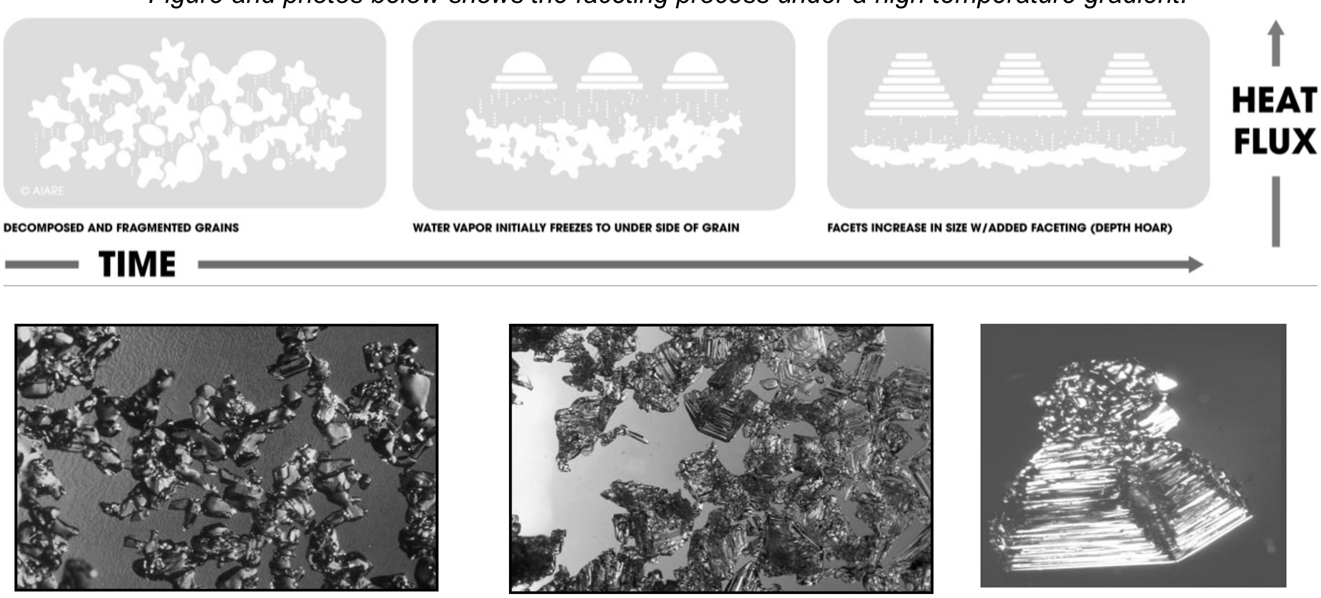
Rounding

Figure and photos below shows rounding process under a low temperature gradient.



Faceting

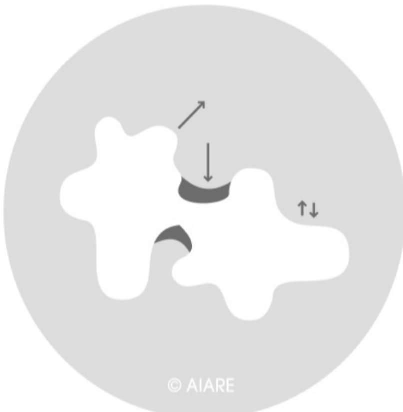
Figure and photos below shows the faceting process under a high temperature gradient.

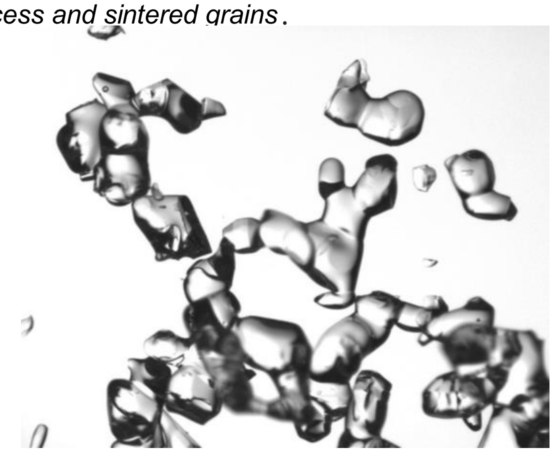


Sintering

Ultimately, it is the degree to which snow grains bond to one another that determines the strength of any given layer in the snowpack, and how well each layer bonds to the layers above and below it. The strength of bonds within and between layers plays a critical role in assessing overall snowpack stability. Understanding conditions that promote sintering/bonding in the snowpack, and being able to recognize these factors with quality field observations, is a key element in developing stability evaluations.

Figure and photo below shows sintering process and sintered grains.





Melt-Freeze Metamorphism

The effect of melt-freeze metamorphism is obvious and relatively easy to assess, as it is due to weather effects (primarily sun and warm temperatures) and occurs at or near the surface. It creates very strong snow in the frozen phase. When melted, the snow is very weak. One needs little in the way of experience, skills, or tools to assess the effects of melt-freeze metamorphism.

Despite the ease of observing melt-freeze, it's important to recognize melting and refreezing can happen in different parts of the snowpack due to differences in slope aspect and angle, vegetative cover, elevation, snowpack characteristics, and spatial differences in air temperature and cloud cover. Melting does not only occur in the spring, and occurs in mid-winter to varying degrees in different climates. The surface may melt and refreeze as crust and then become buried by snowfall. Alternatively, the surface may melt, become buried as a wet layer, and *then* slowly refreeze into a buried crust. Either of these successive events can create a melt-freeze crust that is a distinct layer in the snowpack. The presence of crusts within the snowpack has implications for snow metamorphism and snowpack stability (discussed in section 1.2.4).

There are various degrees to which melting can occur, which is observable by the liquid water content of the snowpack. Melting may be confined to near the surface layers, or the entire snowpack may be experiencing some degree of melt. Similarly, the entire snowpack may refreeze if melting has occurred throughout, or only a portion of the snowpack may refreeze. If temperatures at night do not become cold enough, or stay cold enough for long enough, or if cloud or vegetative cover cause long-wave radiation inputs to the snowpack, only the surface of the snowpack may refreeze. Observers may notice a wet snowpack with only a thin melt-freeze crust at surface. This frequently occurs in spring conditions. It is not an uncommon occurrence to ski out early in the morning on a spring day, and have the surface freeze provide support in most places. Once the surface warms, the melt-freeze softens and one begins to "punch through" the surface crust to the wet snow layer below.

The melting and refreezing usually occurs many times in a cycle driven by the diurnal temperature and radiation fluctuations. This is what avalanche practitioners refer to as the melt-freeze cycle.

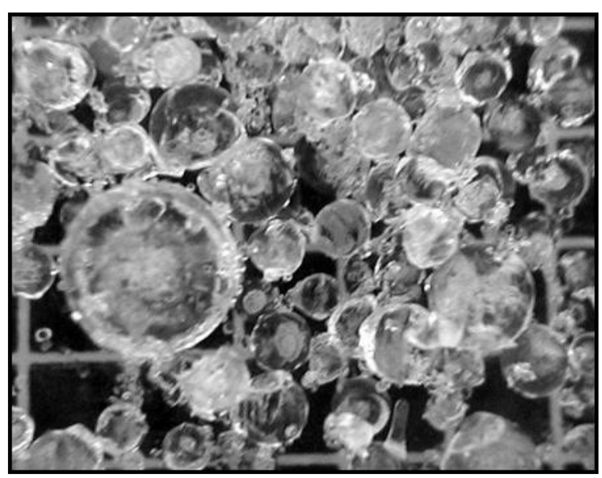


Photo shows melt freeze grains.

Conclusion

Snow crystals constantly change as they grow, fragment, and metamorphose. The precipitation particles seen on the snow surface are recorded as a form identified "at the time of observation." Snow has already undergone substantial change before it hits the ground. When snow is on the ground, it continues to undergo change. This change is driven by heat exchanges, and the influence of atmospheric weather conditions such as air temperature, solar radiation, and wind. Once snow is buried, the changes are driven by heat exchange within the snowpack, pressure from overlying layers of snow, and/or the addition of liquid water through rain-on-snow events.

While a calculated temperature gradient may be useful (to determine the "direction" of faceting or rounding), determining what the temperature gradient might be and what processes are dominant quickly becomes intuitive and practical: if one is in a continental climate and it is early season, it's usually a no-brainer to figure out that the temperature gradient is probably high much of the time, and it's easy to tell that the snowpack is largely faceted when your skis are penetrating to the ground and the entire snowpack has a sugary texture. To the contrary, in maritime climates in the late winter where there are several meters of settled snow, you are skiing in a t-shirt, and ski penetrations are zero, you have a pretty good idea of what is going on in the metamorphic picture.

Despite this, it is valuable—one might say essential—to go through the exercise and a few examples to provide a thorough grounding in what temperature gradient is and how we measure it. Many people who have taken courses in the past will be stuck with the assumption that a high temperature gradient is "bad" because it creates "TG" snow. The instructors want to correct this "misperception." While facets are often associated with weak snow layers, and persistent grain types, old facets may be well sintered and relatively strong.

The important point is that snow metamorphism occurs as a result of vapor moving within the snowpack. How vapor moves around, and hence, what metamorphic process(es) is observable, can be estimated by considering several primary drivers:

- Snow temperatures
- Radiation balance near and at the surface
- Effects of precipitation and melting/refreezing
- The heat exchanges between the ground and snowpack, between the snowpack and the overlying atmosphere, and within the snowpack itself

In addition to these discussed drivers, physical preconditions such as grain size, type, and available pore space (or porosity of the grain lattice) affect the rounding and faceting process. Wind-blown snow has small equal-sized particles that settle close together, providing low porosity and high grain contact. In this case, rounding and sintering is often the dominant process even given a relatively high temperature gradient. Stiffer wind slabs may result from rapidly sintering grains. Loose new snow recently exposed to clearing skies can rapidly facet even in conditions where the snow surface is relatively warm and a high gradient isn't measurable (though radiation cooling can produce high gradients over a few millimeters or centimeters).

The discussion of rounding and faceting is not intended to delve into engineering or physics. The actual processes that cause rounding and faceting are complex and not fully understood. A good understanding of the factors that promote and influence the processes makes it easier to recognize which processes are likely dominating. The bottom line is: in stability analysis the observer needs to be able to recognize the difference between a rounded grain and a faceted grain and needs to know when rounding is likely occurring and when the factors favor faceting. *A look at the bonds between the grains as well as the grains themselves is encouraged.*

During faceting and rounding (or any other process), the resulting grains, and strong/strengthening or weak/weakening snow in and of themselves are not necessarily good or bad. Snow stability analysis requires us to take into account a much larger picture and look at not only individual factors but also combinations of factors. Yes, generally speaking, in the long term, weak or weakening snow is not desirable—but in certain combinations and over certain time spans, it may not be bad and, in fact, it may have a positive effect on stability (in the short term anyway). Conversely, strong/strengthening snow is usually preferred in the long run but it may not necessarily be good for stability in the short term. These concepts will be discussed further below.

Recommended Reading

The Avalanche Handbook – Selections from chapters 2 & 3

Snowpack Temperatures and Temperature Gradients, p.52
Disappearance of Branches: Initial Changes in Dry, Newly Fallen Snow, p.53
Dry Snow Metamorphism in the Seasonal Snow Cover & Crystal Forms in Dry, Seasonal Alpine Snow, p.55-63
Growth of Crystals Around Crusts in Dry Snow & Bond Formation in Dry Alpine Snow, p.63-67
Metamorphism of Wet Snow, p.68
Snow with High Water Content & Snow with Low Water Content, p.68-70
Bond Melting and Formation in Wet Snow, p.71

Questions

Why do we measure snow temperatures?

Define low and high temperature gradients.

Low

High

Which conditions promote rounding and which promote faceting?

Which conditions are conducive to sintering in the snowpack?

What influence does melt-freeze metamorphism have on the snowpack?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1.2.5 Facets: Near-Surface Facets, Near-Crust Facets and Depth Hoar

We know that faceting can occur when there is a *high* temperature gradient observed in the layered snowpack. While it is common for facets to occur at or near the bottom of a shallow snowpack, especially early in the season, facets can and do develop in other parts of the snowpack—sometimes in very localized regions of the snowpack.

In this lesson we will discuss two specialized circumstances in which facets might occur where they may not be suspected: 1) on or near the surface of the snowpack, and 2) near buried crusts in the snowpack where the surrounding temperature gradients are observed to be *low*. The facetted crystals produced in these circumstances are examples of persistent weak layers (persistence discussed in section 1.2.7) that are responsible for a large percentage of avalanches. Being able to recognize the existence of the problematic weak layers, and the conditions in which they are likely to form, is very important in assessing overall snowpack stability.

Learning Outcomes

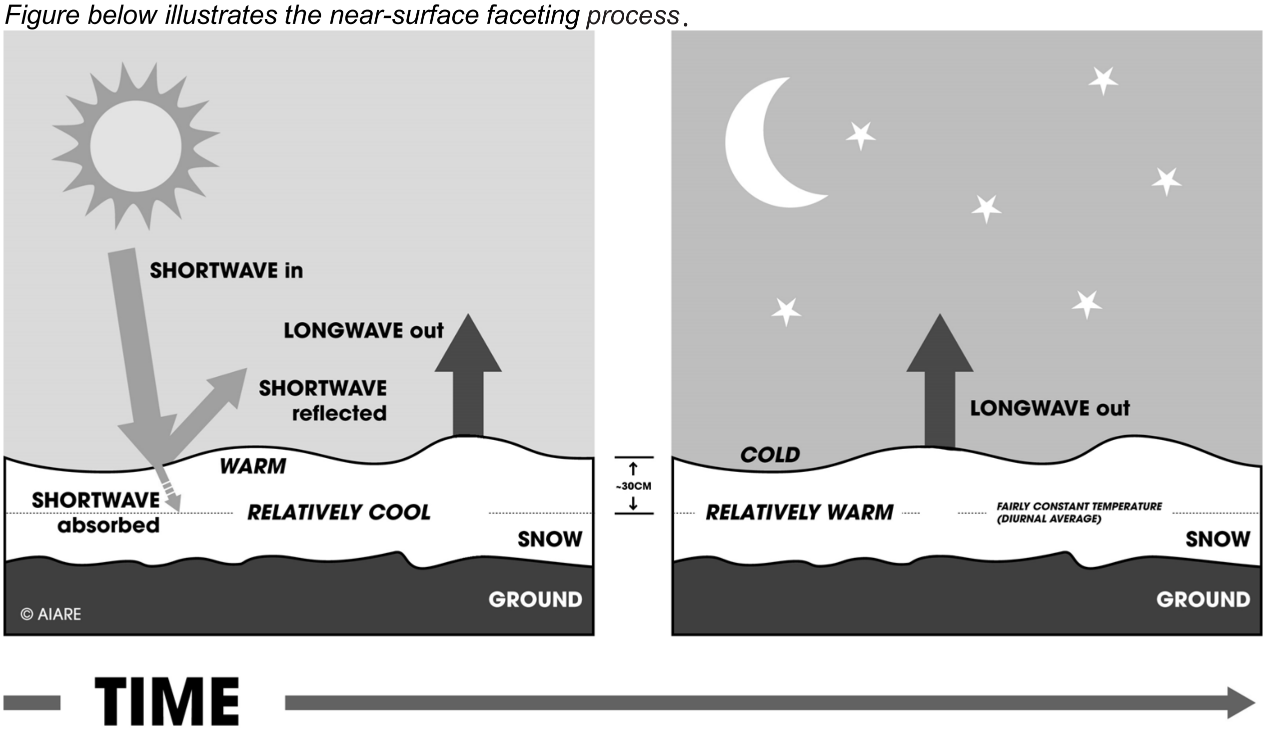
- Anticipate the weather and snow conditions that commonly lead to the formation of persistent facet layers.
- Describe why facets form around crusts in various places in the snowpack: near-surface faceting; dry snow over wet layer faceting, under-crust faceting.
- Observe how depth hoar forms and varies with terrain configuration and ground cover.

Key Concepts

- Near-surface energy balance
- Conditions that promote faceting
- Conditions that promote persistence
- Crust-facet interfaces

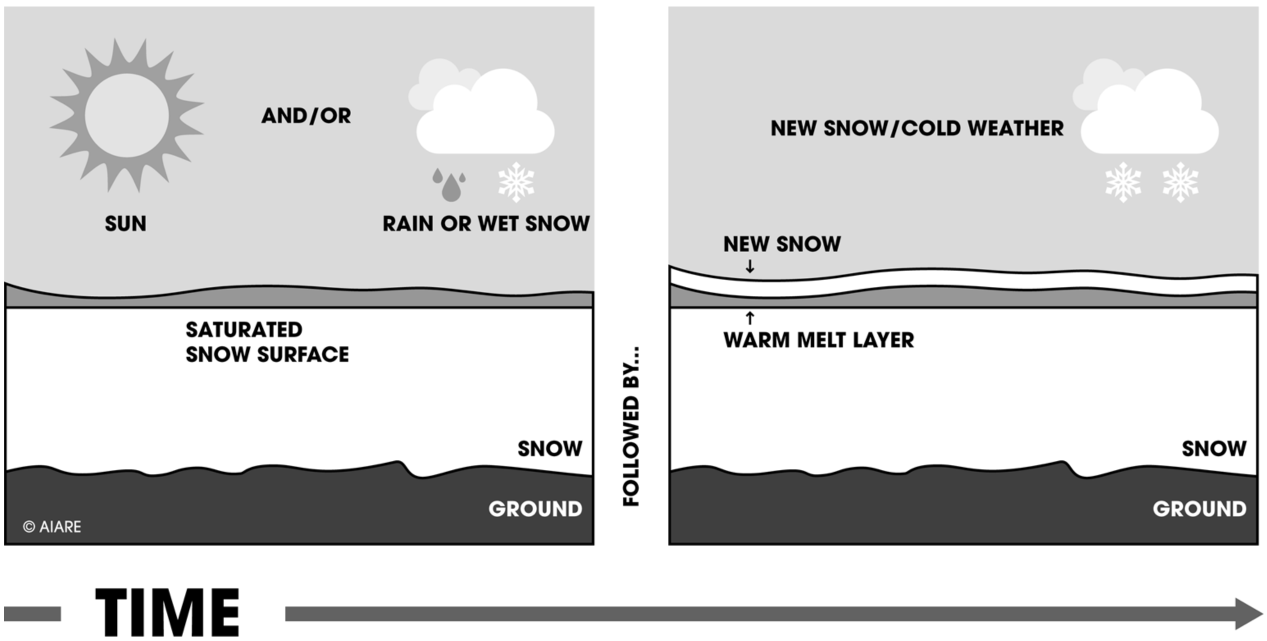
When surface or near-surface faceting is occurring, the surface of the snowpack will commonly change texture and appearance. Skiers often say the snow is “drying out” and skiing quality sometimes improves as moist or even wet snow which was sticky and well bonded loosens due to the breakdown in bonds with the development of faceted grains. Surface crusts and even soft slabs can soften or disappear altogether if surface faceting persists. Surface and near-surface facets often play a major role in skier-triggered avalanches. Understanding and recognizing when these layers are present, and when the conditions that promote the formation of these facets are present, is crucial in assessing stability.

Figure below illustrates the near-surface faceting process.



Field practitioners have noted near-crust faceting for years. Yet, new theories and recent published research are cautioning practitioners to look more carefully at crusts. We are now better aware of how problems can develop over time regardless of the crust's initial characteristics, associated temperature gradients, and whether there was a bonding problem of some sort when the crust originally formed. Crust formation can also occur in conjunction with near-surface faceting. When dry snow over wet-layer faceting occurs, the wet layer that provides the heat and moisture source to drive the faceting process will end up refreezing as a crust, with the newly formed facets above (and likely below) it.

Figure below illustrates the dry-snow over wet-layer faceting process.



With more careful observations, near-crust faceting has been noted in a variety of scenarios. For example, in Crested Butte, Colorado, near-crust faceting was observed in a fracture line profile where the snowpack was completely faceted over its entire depth. An old, weak sun crust that was almost completely eroded had notably larger facets just above and below it. Another notable case occurred in conjunction with the famous "ice storm" of January 1998 that occurred in eastern Canada and New England. When the snowpack at Pinkham Notch in the White Mountains of New Hampshire was observed in March, the entire snowpack was moist or wet. Facets were observed on the bottom of a very strong, 10cm thick freezing rain crust. Near- crust faceting created a very persistent problem in the Columbia Mountains of Western Canada during the '96/97 season when facets that formed in conjunction with a November rain crust caused large avalanches for several months.

These examples, while extreme, indicate that near-crust faceting can be a significant factor in the metamorphism of the snowpack and that practitioners should be aware of its potential and know what to look for.

Both surface/near-surface and near-crust faceting are important processes to recognize, since they can create problematic and persistent weak layers relevant to snowpack stability. The good news is the conditions that promote these processes are easy to observe in the field. Conditions that promote surface/near-surface faceting can be ascertained by considering the radiation balance at the surface, the amplitude of diurnal temperature swings, and the presence of wet layers. Conditions that promote near-crust faceting can be ascertained by looking for crusts in the snowpack, and when dry snow is falling on a crust or wet snow surface.

Recommended Reading

The Avalanche Handbook – Covered in reading list for section 1.2.4

Questions

Describe the conditions that promote near-surface facets.

Describe how and why facets form both above and below crusts in the snowpack.

1.2.6 Surface Hoar

Learning Outcomes

- Describe how surface hoar forms and under what weather conditions.
- Apply the process of surface hoar formation to terrain features where it is and is not likely to grow.
- Explain why surface hoar can be persistent and difficult to observe.

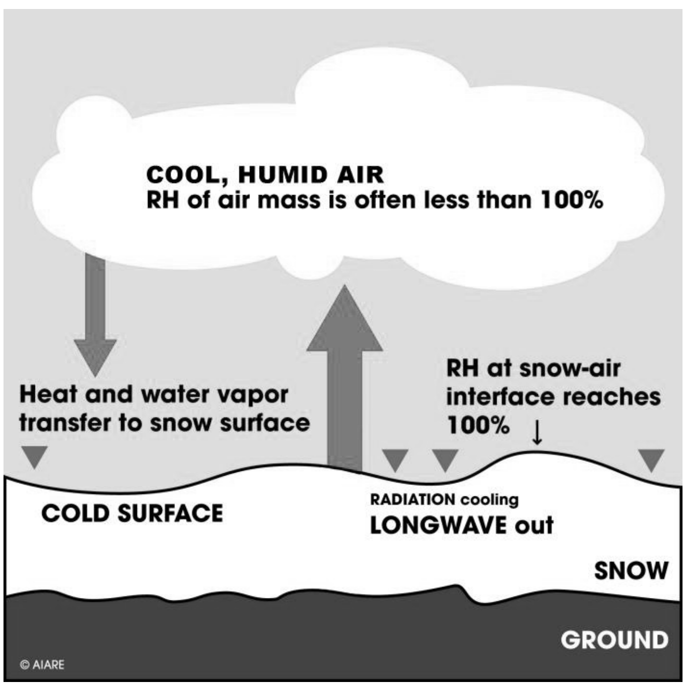
Surface hoar is the winter equivalent of dew.

Under certain conditions, the surface of the snow cools a thin layer of air at the snow/air interface to the dew point. The surface hoar visible on the snowpack in winter comes from the air that was in contact with the snowpack. Surface hoar crystals grow when the moisture in the air condenses on the snow surface. This process is analogous to the moisture in the air condensing on a beer mug removed from the freezer. Surface hoar is not limited to forming on snow; it is often seen on trees, bushes, rocks, etc., and sometimes referred to as "hoar frost" in non-technical circles.

Surface hoar crystals have a characteristic "icy" looking "V" shape, but they can also form as needle, plate, and hollow six-sided cuplike varieties. Generally, striations are visible on the crystals. The number of ice crystals formed on the snow surface and the size and shape of the crystals depends primarily on how much water vapor was in the air, what the air temperatures were, and the temperature of snowpack surface while the surface hoar was forming.

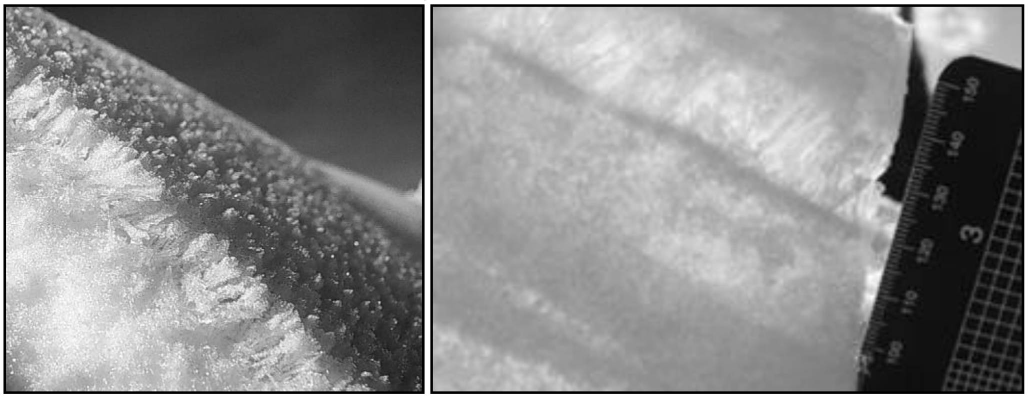
Surface hoar is an example of *a persistent weak layer* that is a major factor in many avalanches, especially in inter-mountain and continental climates.

Figure below illustrates the process by which surface hoar forms.



Surface hoar is quick to form (hours to overnight), hard to find once it is buried, and slow to decompose. Surface hoar can be easy to see when on the surface of the snow, but is often more difficult to find once it is buried. With an understanding of energy balance at the surface of the snow—and daily observations of radiation, cloud and vegetative cover, and wind patterns—inferring where and when surface hoar is likely to form becomes easier. For example, surface hoar is more likely to form in clearings and less likely to form in a dense forest because the tree cover interferes with radiation cooling. Additionally, surface hoar tends to form on clear nights, not on cloudy nights, again because clouds interfere with radiation cooling.

Photos below show surface hoar deposited on snow surface and buried surface hoar.



Recommended Reading:

The Avalanche Handbook – Selection from Chapter 3

Surface Hoar: Formation and Growth Conditions, p.49-52

Persistent and Non-persistent Weak-layer Forms, p.67

Notes:

1.2.7 Weak Layer Characteristics

For a slab avalanche to occur, a weak layer that prevents the slab from bonding to the bed surface is required. It is in this layer that shear (and perhaps compression) fractures occur and propagate. The Avalanche Handbook distinguishes between weak layers (the Avalanche Handbook refers to these as "non-persistent" weak layers) and persistent weak layers.

Learning Outcomes

- Know the difference between persistent and non-persistent weak layers.
- Understand the conditions that promote persistence of weak layers.

Weak Layers

Non-persistent weak layers consist of snow grains that (while creating a weak layer after forming) strengthen quickly and bond to the slab and bed surface readily. These weak layers commonly consist of new snow grains, decomposing and fragmented grains, rounds, and perhaps wet grains. These types of grains metamorphose readily into stronger forms that bond well to each other and surrounding layers. Generally speaking, non-persistent weak layers will show observable strength gain and improvement in bonding in a matter of hours or days.

If a weak layer is related to new or recent snow (new snow or DF grains), note the depth of the fracture lines and watch the trend of avalanche activity. If avalanches are running in the layer of storm snow and activity tapers off in the first 24 - 36 hours after the storm ends, instability is almost certainly related to a non-persistent weak layer and stability will likely improve dramatically by the time 48 hours has elapsed.

If a weak layer is related to wet grains, watch (measure) air and snow temperatures above and below the wet layer. As air and snow temperatures fall to well below freezing, the problem will likely resolve itself quickly as the wet grains freeze. A wet layer may persist if temperatures are very warm and the grains do not freeze on an interface between grain types, as exemplified by density changes in storm snow.

Persistent Weak Layers

Persistent weak layers strengthen slowly (or continue to weaken) and do not bond readily to the bed surface or slab. Persistent weak layers usually consist of facets, either near-surface facets, depth hoar, or surface hoar. These grains do not metamorphose readily into stronger forms and do not bond well to each other or adjacent layers. Persistent weak layers may get weaker over time--even when strengthening persistent weak layers take many days, weeks, and sometimes months to show significant increases in strength or improvement in bonding. Persistent grain types forming above or below stiff layers and crusts can be durable and last for weeks, months, or even throughout the season in a mountain snowpack.

Persistent weak layers are often associated with mountain climates where extended periods of cold, dry weather are common, and where there are fewer precipitation events and accumulations are moderate or light.

Persistent weak layers are much harder to assess and forecast. Avalanches associated with these layers may occur sporadically when the layer first forms. Sometimes no avalanches occur until some time after the layer has formed and some combination of seemingly minor events triggers failure. Persistent weak layers are difficult to assess as they may go through cycles where strength decreases, increases, and then decreases again. In conjunction with these strength fluctuations, persistent weak layers often go into extended dormant periods before becoming sensitive to triggering.

Persistent weak layers require ongoing, long-term monitoring using a variety of observation, testing, and recording methods to ensure one does not lose track of their locations and characteristics (observation and testing methods are discussed later when we talk about observing and recording instability factors). Typically, persistent weak layers also call for a more conservative approach to terrain selection and hazard forecasting.

Notes

Questions

Describe the factors and conditions that lead to the development of surface hoar.

Describe conditions that promote the persistence of weak layers.

List three persistent weak layers that factor into a large percentage of avalanches, and describe conditions that would lead to the disappearance of these layers.

1.3 Avalanche Formation and Release

Learning Outcomes

- Relate key characteristics of avalanche formation to avalanche release; including the characteristics of loose snow avalanches, slab avalanches and cornices.
- Describe conditions that promote triggering of loose snow and slab avalanches, and cornice fall.

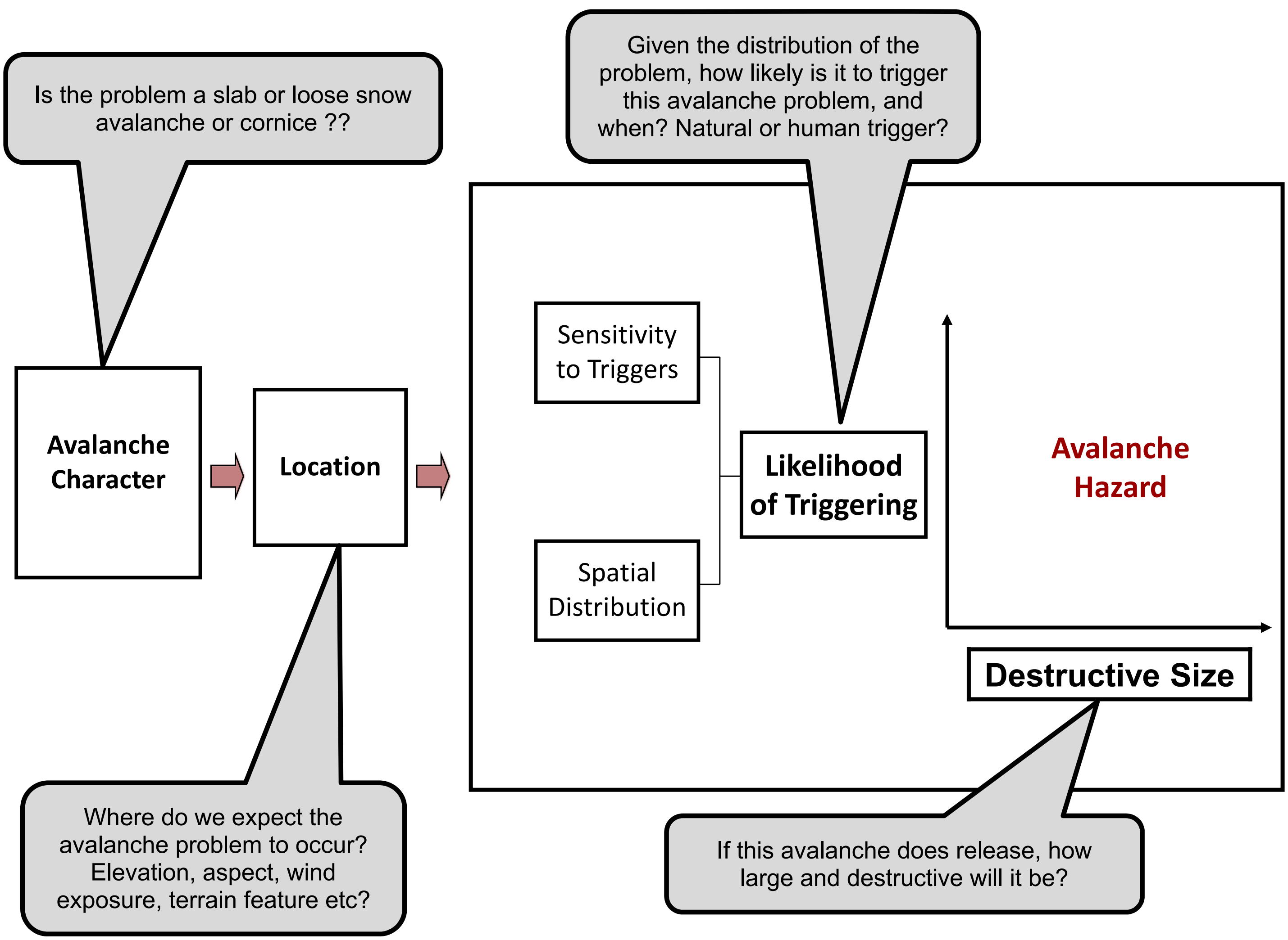
Key Concepts

- Loose snow avalanches (dry and wet)
- Dry slab avalanches (storm slab, wind slab, persistent slab, deep slab)
- Cornice hazard
- Glide avalanches
- Likelihood of triggering x destructive size = avalanche hazard
- Avalanche release
- Settlement
- Creep
- Glide
- Propagating crack
- Tensile fracture
- Crown, flank, stauchwall

Understanding "The Problem"

As an important component of evaluating avalanche risk, experts assess the avalanche hazard. The following diagram illustrates a commonly used approach when assessing avalanche hazard:

Chart from ADFAR2 Project: Parks Canada, CAC, G.Statham et al. Comments, AIARE



Our ability to evaluate the avalanche hazard relies on our understanding of how the mountain snowpack develops over terrain. This includes understanding how snow layers become relatively strong or weak, and it includes relating snowpack instability to a loss of cohesion of near surface snow or to propagating cracks through weak layers. This is knowledge of how avalanches form and how avalanches release.

Understanding the mechanism of *avalanche release* improves our ability to:

- Determine where (distribution) and when (timing) avalanches could occur.
- Determine the probable extent and consequence resulting from avalanche release.
- Better understand which field observations and tests provide valuable clues that describe the avalanche problem.

Students are advised to bookmark the AIARE Avalanches and Observations reference (Section 3.1, p.74) and refer to the chart while reading the following section. It supplements this chapter's information on "how avalanches release" by targeting the important field observations and tests specific to each avalanche type and characteristic.

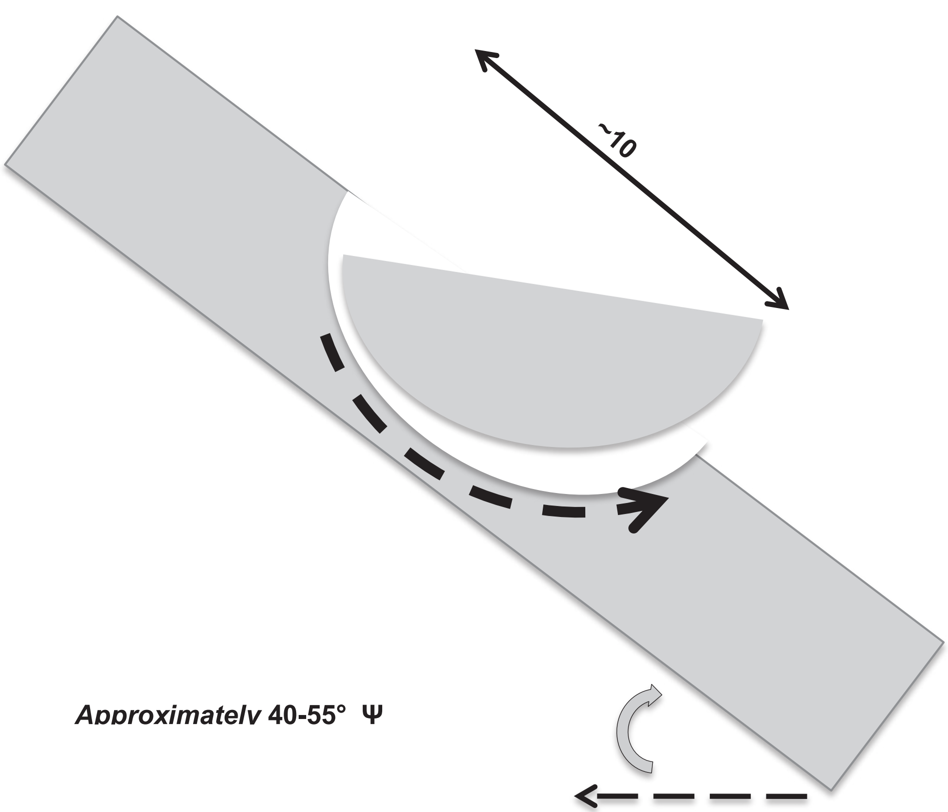
Loose Snow Avalanches

Loose new snow has low cohesion. Loose snow avalanches begin when a localized area of cohesion-less surface snow begins to move downhill; setting into motion additional subsurface loose snow (entrainment). The result is a fan-shaped avalanche initiating from a point in steep terrain (approximately ≥40 degrees) and widening as it proceeds downhill. (AHB: Chapter 4).

Loose *dry snow* avalanches are also referred to as point release avalanches and sluffs. Larger avalanches of this type tend to entrain subsurface loose snow or gain mass and speed on longer, larger slopes. The loss of cohesion occurs in both loose new snow and loose faceted old snow on steep slopes.

Loose dry snow avalanches tend to be small (size 1-2) though destructive potential increases with slope size or the exposure of those at risk to cliffs or terrain traps. Loose dry snow avalanches can trigger larger destructive slab avalanches.

Figure: Loss of cohesion at the snow surface, AIARE



A brief summary of factors that promote triggering loose dry snow avalanches includes:

- Steep terrain with a start zone incline approximately ≥40º.
- Loose *new* snow.
- Rapid snowfall rates (>4cm/hr) and slow settlement (cool temperatures).
- Mechanical action that can also trigger the initial loss of cohesion includes rockfall, rolling snow chunks, and skier/snowboarders.

R1 D1, loose wet snow avalanche.

Loose *wet snow* avalanches also release as a result of localized loss of cohesion at the snow surface. Wet snow is defined as snow at 0ªC. This avalanche type can be more destructive than loose *dry snow* avalanches, as the release can entrain denser, wetter snow with more destructive potential. Loose wet snow avalanches may be the trigger for larger, more destructive, slab avalanches.

Observers note that it may be hazardous to travel on steep slopes subject to a wet snow avalanche condition. Timing is critical when forecasting the problem and avoiding the hazard.

The factors that promote triggering of wet loose snow avalanches include:

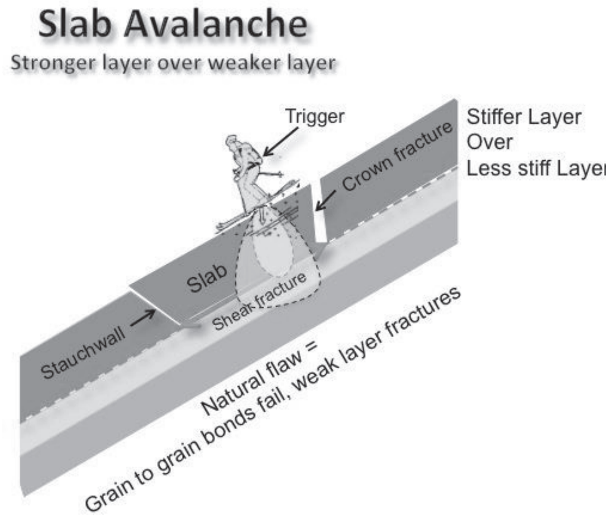
- Rapid warming of the snow surface, rocks, or trees, from radiation (sunny aspects during a diurnal cycle) or rainfall.
- Continued temperatures (day and night) of above 0ªC (cloud cover at night) resulting in surface snow temperatures reaching 0ªC.

Notes

Dry Slab Avalanches

Slab avalanches form when a cohesive snow layer forms over a less cohesive and weaker snow layer.

Under the influence of gravity a snow slope settles in a vertical (settlement) and down slope (creep) direction. Larger, angular grains (facets, depth hoar) settle and creep at a different rate than smaller, uniform grain types (fragments and rounds). Natural flaws develop between grains at the interface of layers with different *grain type, size*, *stiffness*, and *mass*.

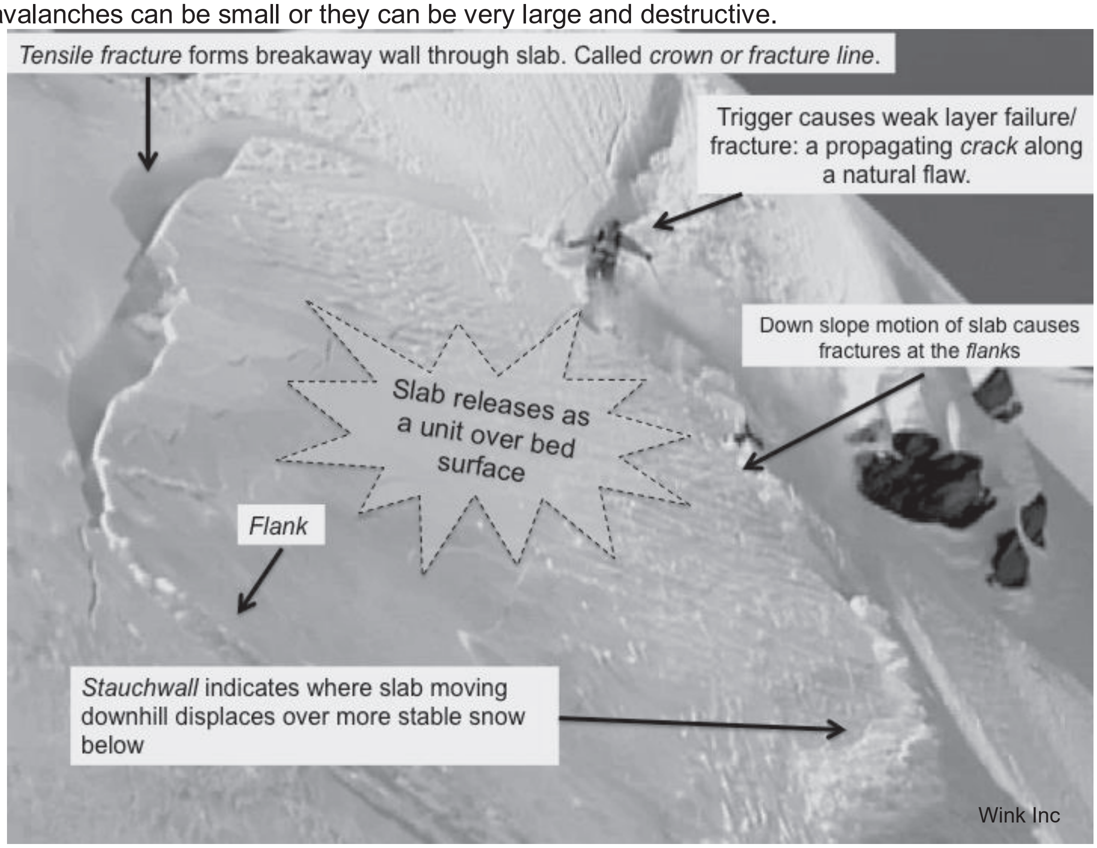


When avalanches are *not* occurring, the snowpack deforms slowly and reduces the strain rate at the weak layer interface. In other words, the snowpack adapts well to *slow* change.

However, when a trigger is introduced, a rapid loading of the weak layer occurs. Grain-to-grain bonds fail in rapid succession at the weak layer interface and a crack propagates along this natural flaw (shear fracture) displacing the slab downslope over the *bed surface*.

On the snow surface *shooting cracks* are visible to the observer as the cohesive slab displaces as a unit from the mountain slope. The shooting cracks are also called *tensile fractures* that fracture through the thickness of the slab as it breaks away and moves downslope. The displaced slab leaves behind identifiable features including the *crown fracture* indicated by the breakaway wall at the top of slope. The *flanks* mark the left and right fracture line on each side of the slab, formed as the slab moves downhill. The lowest feature is called the *stauchwall*, where the toe of the slab fractures and is displaced over the more stable snow below. Often the stauchwall fracture is obliterated by slab material moving downhill. (*AH. Chapter 4: Characteristics of Dry Slab Avalanches)*

Slab avalanches can be small or they can be very large and destructive.



Persistent slab avalanche

Public avalanche bulletins refer to different types of avalanches (described as “the avalanche problem”) by their forming characteristics. **Storm slab avalanches** are defined as a release of a soft cohesive layer (a slab) of *new* snow that breaks within the storm snow, or on the old snow surface. Storm slab problems typically last between a few hours and few days. Storm slabs that form over a persistent weak layer (surface hoar, depth hoar, or near-surface facets) may be termed persistent slabs, or may develop into persistent slabs. **Wind slab avalanches** differ in that the cohesive layer of snow (a slab) is formed by the wind. Wind typically transports snow from the upwind sides of terrain features and deposits snow on the downwind side. Wind slabs may have a smooth or wavy snow surface, and may sound hollow under a skier’s weight, and can range from soft to hard. Wind slabs that form over a persistent weak layer (surface hoar, depth hoar, or near-surface facets) may develop into persistent slabs, and may be termed a **Persistent slab avalanche**,*.* Persistent layers include: surface hoar, depth hoar, near-surface facets, or faceted snow. Persistent weak layers can continue to produce avalanches for days, weeks or even months, making them especially dangerous and tricky. As additional snow and wind events build a thicker slab on top of the persistent weak layer, this avalanche problem may develop into a persistent deep slab**.**

Therefore, a **Deep slab avalanche** involves an underlying persistent weak layer, deep in the snowpack or near the ground. The most common persistent weak layers involved in deep slabs are depth hoar, deeply buried surface hoar, or facets surrounding a deeply buried crust. Deep slabs are typically hard to trigger but may be remotely triggered where the weak layer is less deep. Deep slabs are very destructive and dangerous due to the large mass of snow involved, and can persist for months once developed (from CAIC, CAC, Parks Canada and others).

Each avalanche problem can be identified by specific field observations and specific tests. Refer to the AIARE Avalanches and Observations reference (AIARE Fieldbook p. 4) to assist to help target, and manage the hazards associated with slab avalanches.

Factors to Consider With Regards To Dry Slab Avalanche Release

Naturally occurring slab avalanches
Observing natural slab avalanches is always an indicator that conditions are unstable and prone to natural or human triggers. Unfortunately persistent and slab avalanches can be sensitive to triggering for long periods of time, and, *may not release naturally*.

Timing and sensitivity to triggering
Storm slab and wind slab avalanches commonly have a “window of opportunity” where they are more reactive to triggers. Avalanche control teams take advantage of this knowledge and attempt to control the problem soon after it forms. The storm slabs and wind slabs are formed by either deposition of new snow or wind deposit. Once the weak layer (often decomposed or fragmented grains or graupel) is buried roughly 25cm deep, the slab becomes reactive to a trigger. As the slab thickens with additional snow or wind deposit, it remains sensitive to triggering for anywhere from a few hours to 48 hrs, though in certain conditions up to a week (*TAR* article in press, Lazar et al). Weight from overburden and time encourages the weak layer to decompose, settle, bond and stabilize. In contrast, *persistent weak layers*, however, can stay unstable for days, weeks and even months.

Relating the depth of the weak layer and character of the slab to avalanche release
Studies *(Jamieson)* and the Avalanche Handbook *(Schaerer, McLung)* suggest that the majority of skier triggered avalanches are 50cm deep or less. However a significant portion of “unexpected” avalanches reported by avalanche professionals (Jamieson ‘99) were 50-100cm deep. This suggested that *unexpected* slab avalanches were thicker than most *skier triggered* avalanches. Consider two compelling factors when triggering slabs: 1) A deeper weak layer (>1m) is less likely to be triggered by a “skier”, and 2) Slightly stiffer, thicker slabs, while harder to initiate, *favor propagation* and result in larger, more destructive avalanches. When observing deeper weak layers, observers recognize that the weak layer may be remotely triggered, or triggered from a shallow area.

Most “skier” triggered slabs are 4F (and 4F+) stiffness, and increasing in stiffness adjacent to the weak layer interface. These are recorded as “soft” slabs. Yet, many (less than half in a survey of professionals by Jamieson) “unexpected” events were described as “hard” slabs (1F or stiffer). It has been suggested (S. Thumlert, ASARC, University of Calgary) that the presence of stiff crust layers on the snow surface or “mid pack” reduces the likelihood of skier/snowboard triggering.

Preliminary work by Thomas Exner (ASARC, University of Calgary) suggests that as the slab warms (sun or heat) the stress applied by a human trigger doesn’t penetrate any deeper into the snowpack. However his studies suggest the human applied stress affects a "wider" area of the weak layer, and given the penetration of the stress to the depth of the weak layer, can increase the likelihood of initiating the weak layer failure/fracture.

Chapter 1 briefly introduces the concept of relating snowpack observations to the possibility of avalanche release. Chapter 2: Making Quality Observations relates in detail the importance of craftsmanship/technique, site selection, experience with interpretation and application, and verification when assessing snowpack observations in the context of hazard and risk forecasting.

Relating the weak layer / interface characteristics to potential for avalanche release
The Snowprofile Checklist helps to identify the weak layer and interface characteristics most often associated (67-75%) with skier triggered slab avalanches. (*Using a Checklist to Assess Manual Profiles, Schweizer, Jamieson 2005*). If the underlying weak layer and interface has five or six of the following properties, the weak layer is more likely to be human triggered.

Weak layer properties:
- Persistent grain type (V, DH, FC)
- Grain size >1mm
- Weak layer <1F

Interface Properties:
- Grain size difference >0.5mm
- Hardness difference >1
- Depth of the interface 25-85cm

Relating fracture character in column tests to the possibility of avalanche release
Sudden fractures in compression tests and deep tap tests (and whole block fractures in Rutschblock tests) have been correlated to increased likelihood of skier triggering (Jamieson, Campbell, Cameron and others).

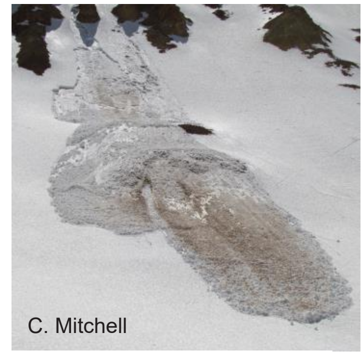
Observing propagating cracks while testing the weak layer, and shooting cracks on the snow surface
Extended Column Tests and Propagation Saw Tests that produce results for propagation have also been correlated to skier triggering of slab avalanches (Birkland, Simonhoise, Gauthier, Cameron, Jamieson, and others).

Whumping under a rider's weight indicates the presence of a large, persistent grain types (DH, SH), and propagating fractures in the weak layer. *Shooting cracks* visible on the snow surface, and initiated by a rider's weight, are tensile fractures indicative of slab fracturing and displacement without slab release (low angled slope or a localized area of unstable snow).

Relating localized loading to the potential for avalanche release
Scott Thumlert (ASARC, University of Calgary) has compared localized dynamic loading on a mountain snowpack. His measurements suggest that snowmobiles exert considerably more stress to the snowpack (3 to 5x) than skiers increasing the probability of a slab release. In addition, the sled penetrates stress 3x deeper into the snowpack. There was a significant decrease in stress with increased depth (this agreed with previous studies), and an observed "bridging effect" from supportive snow layers (stiff crusts) that reduced the measured depth of the applied stress.

Mr. Thumlert's findings importantly suggest that, understanding the transmission of stress due to localized dynamic loads may help people avoid situations in which they can trigger avalanches". (Source: http://www.sciencedirect.com/science/article/pii/S0165232X1200167X)

Wet Slab Avalanches



Wet slab avalanches occur from the release of a cohesive layer of snow (a slab) that is generally moist or wet from a rain on snow event or a prolonged period of sun and warm air temperature. Wet slabs release when liquid water weakens the bond between the slab and the bed surface. Wet slabs can be very destructive. This problem may be difficult to forecast and observe. It is dangerous to cross or conduct tests on steep slopes suspected to be prone to wet slab conditions. Timing is critical as wet slabs can quickly stabilize during cooling trends, and quickly become unstable when subject to additional heat and/or rain.

Factors that contribute to triggering:

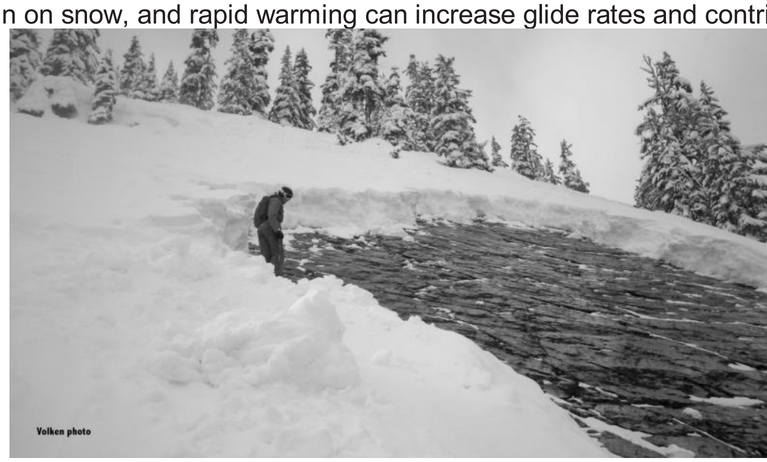
- Rain on snow provides the most common trigger. Rain simultaneously weakens surface snow, provides additional load, and rapidly transmits heat into the snowpack (via latent heat exchange). Continued rainfall can percolate through the snowpack to a weak layer.
- Often loose wet snow avalanches precede and/or trigger wet slab releases.
- Prolonged periods of above freezing temperatures. During spring months, there is longer and more intense daytime solar radiation. Nighttime cloud cover can keep air temperatures above freezing and cause a portion of the snowpack to become *isothermal* (at zero degrees Celsius) and lose cohesion and strength.
- Nearby exposed rock and vegetation. Dark objects absorb radiation. Exposed rock and vegetation also inhibit snowpack settlement and provide channels for water percolation to the ground or lower snowpack layers.

Glide Avalanches

A glide avalanche is defined as the release of the entire snow cover as result of gliding over the ground. Glide avalanches can be composed of wet, moist, or almost entirely dry snow. They typically occur in very specific paths, where the slope is steep enough and the ground surface is relatively smooth. They are often preceded by full depth cracks (glide cracks), though the time between the appearance of a crack and an avalanche can vary between seconds and months (*TAR* article in press, Lazar et al).

Factors that contribute to triggering:

- Glide avalanches are unlikely to be triggered by a person, are nearly impossible to forecast, and thus pose a hazard that is extremely difficult to manage.
- Rain on snow, and rapid warming can increase glide rates and contribute to a full depth release



Glide avalanche at Alpental, WA

Cornice Hazard

Cornice fall is described as a release of an overhanging mass of snow that forms as the wind moves snow over a sharp terrain feature, such as a ridge, and deposits snow on the down-wind side. Cornices range from small wind lips of soft snow to large overhangs of hard snow that are 30 feet (~10 meters) or taller. They can break off the terrain suddenly and pull back onto the ridge top and catch people by surprise even on the flat ground above the slope. Even small cornices can have enough mass to be destructive and deadly. Cornice fall can entrain loose surface snow or trigger slab and deep slab avalanches (*TAR* article in press, Lazar et al).

Factors that contribute to triggering:

- More common triggers include rain or heat (daytime warming) on the cornice top.
- Less common triggers include new snow or wind deposited snow load.
- Other factors include weakening of the cornice "root" or cornice attachment point on the windward side from scouring or radiation. "Reversed" winds effect can scour and undermine the scarp and face below the cornice and create an unstable overhanging mass of snow.

Conclusion

In the conclusion of section 1.2.7 The Layered Snowpack, it was stated that in order to predict, anticipate, and make terrain choices, the observer must understand how snowpack layering occurs and how these layers combine (weak and strong layers) to form unstable snow.

Section 1.3 Avalanche Release described how near surface unstable snow forms loose dry or loose wet snow avalanches. Additionally, if the unstable snow is buried underneath a slab of more cohesive stronger snow, slab conditions were described in terms of how dry and wet slabs form and release. Also key are factors that promote triggering of either loose or slab avalanche problems.

Importantly, these concepts link to the forecasting of the avalanche problem. The understanding of 'how avalanches form and release' is inextricably linked to being able to name and describe the problem, including matching field observations to avalanche characteristics.

An understanding of how layering changes over time and varies over terrain is crucial to understand the notion of snowpack instability. Chapter 3, the Snow, Weather and Avalanche Recording and Observation Guidelines (SWAG, 2010), and the AIARE 2 field exercises are all tools employed on the AIARE 2 course to introduce observation techniques and recording methods that help the forecaster and guide to observe snowpack characteristics and apply this information in a hazard and stability forecast. Weather, snow and avalanche observations should begin with an objective that is created from the forecaster's knowledge of the history of the weather, snowpack and terrain.

The relevancy of weather, snow and avalanche observations depends on the site selection, craftsmanship, and interpretation of the observation. Chapter 3 and much of the AIARE 2 program introduces the importance of quality observations in the process of evaluating snow stability and avalanche hazard.

Introducing snowpack characteristics into the hazard evaluation process shouldn't distract from the most important tool: historical and current avalanche observations. Snowpack characteristics are merely one more piece of the puzzle. Carefully observed and recorded observations as to *where in the terrain avalanches are likely to occur*—especially relating to seasonal weather patterns and seasonal snowpack development—assist the observers with making prudent and sensible terrain choices and creating terrain options. Field exercises during the AIARE 2 Course will link the theory, the techniques, and the observations into terrain choices as part of the decision-making process.

By the end of this course each student may ask themselves the following questions, each time they travel in the backcountry:

"Given the conditions, what types of avalanches are likely to occur?"

"What are the observations that help me understand whether the snow is unstable?"

'Where in the terrain are avalanches likely to occur? Where in the terrain are avalanches likely to be triggered?

"If avalanches occur, what could be the consequence?"

Recommended Reading

The Avalanche Handbook – Sections from Chapter 4

Deformation in the Alpine Snowpack, Snowpack Creep, Snow Gliding, p. 73-79
Loose Snow Avalanche Formation, p. 87-90
Characteristics of Dry Slab Avalanches & Dry Slab Avalanche Formation, p. 91-98
Wet Slab Avalanche Formation, p. 100-103

Questions

Why is it challenging to assess the potential size and destructive potential of a wet loose snow avalanche?

You are investigating a particular slope. Five riders have descended the slope with no problems. You observe a persistent weak layer is buried 80cm deep under a stiff 1F slab. Is this *Persistent Slab* a problem? If not, why? If so, why?

What characteristics would indicate that a *Storm Slab* is less likely to be rider triggered?

Why refer to the AIARE Avalanches and Observations reference?

1.4 Chapter 1 Summary

The Chapter 1 reviews how terrain and mountain weather interact to create the mountain snowpack, and discusses how this can evolve into an avalanche problem. The mechanics of how loose and slab avalanches form and release were reviewed, as were the factors that contribute to the triggering of avalanches.

In order to understand the avalanche phenomena and estimate where and why avalanches could occur, the forecaster must have a data set of daily field observations. Chapter 2 deals with the integration of quality data into the decision making process. This includes international standards and guidelines for weather, snow, and avalanche observations. It also discusses the need for craftsmanship and a process for verifying the data set. It is important to manage human factors in the integration of these observations into the decision making process (outlined in chapter 3).

Notes

Chapter 2: Making Quality Observations

2.1 Snowpack Data Classes and Instability Factors

Learning Outcomes

- List the three data classes as described by The Avalanche Handbook.
- Prioritize observations based upon these three classes.
- Use the Avalanche and Observation Reference to identify red flag values or thresholds for each observation.

A large amount of data from a variety of sources is required to assess snow instability. The Avalanche Handbook divides the observations and information into three data classes. The following discussion points may help with the AHB definitions.

Instability Factors (Class 1)

Class 1 includes factors that provide direct evidence that the snow is actually unstable and avalanches are likely to occur:

- Current avalanche activity on adjacent slopes.
- Shooting cracks, whumphing.
- Positive, verified tests that illustrate propensity for fracture propagation (RB with whole block release type; PST or ECT positive test results).
- Compression tests on representative sites combined with sudden fracture character or Q1 shear quality.
- Class 1 data is the most pertinent and relatively easy to interpret, requiring less training or experience (i.e. avalanche observations). Representative snowpack data is always interpretive and most often falls into Class 2 data. Current avalanche observations may be difficult to acquire because one must be in the field at a time and location where avalanches are occurring. Observations must be made before evidence is obscured and is still relevant. Distant observations in poor weather may be hard to qualify and verify.

Snowpack Factors (Class 2)

Snowpack observations (within the snow cover) provide information about “presence, strength and loading of weak layers” (AHB). In other words, Class 2 data provides information about snowpack characteristics and requires interpretation to understand the relationship to instability (observations include: full and test profiles, small and large column tests, etc.). Experience with extrapolation and relevancy of observations across the terrain is important to the usefulness of Class 2 data.

Meteorological Factors (Class 3)

These factors influence the snowpack and therefore affect snow stability. They include weather and snow surface observations that do not provide direct evidence of instability. Interpretation and extrapolation are required to determine what the effect on snow stability is or may be. Obviously when precipitation (rain or snowfall) amounts exceed critical values (example, >3 cm/hr for 10 hrs), there is less interpretation and more observation of instability (avalanches) and Class 3 become Class 1 data.

Observations are primarily formal and may take place continuously (automated weather stations with data loggers), at scheduled intervals (manual daily/twice daily weather plot observations), and/or selectively (field weather observations). Observations are made at established sites (weather stations or plots) or at targeted locations (field weather).

The information is often applicable to entire regions or mountain ranges. These observations are mostly numerical. Experienced analysts/forecasters who work on a large, regional scale such as forecasting for an entire mountain range (synoptic-scale analysis and forecasting) rely heavily on wx data. This data is easy to obtain. However, *it can be the least pertinent in terms of stability*. To assess its effect on stability requires extrapolation on the part of the analyst/forecaster and to do this effectively requires a great deal of experience.

Discussion

The descriptions and discussions of data classes are based on conventional thinking and may not reflect how practitioners actually work in the field. In reality, forecasters who work on a regional scale (for example, avalanche danger bulletins) can and do use Class 1 and 2 data although they may not have obtained that data firsthand. Similarly, range-scale forecasters (for example, avalanche control programs) use Class 1 and 3 data. Slope-scale forecasting (deciding whether to ski a specific slope or not) should obviously rely on Class 2 and 3 data as well as local avalanche observations. It is important to recognize that the line between the classes, applicability, usability, and pros/cons is not always simple or clear. Some data might fit into more than one class depending on how one thinks and how directly pertinent it is. This discussion is not intended to "pigeon-hole" the data or to limit forecasters, but to provide a general overview of the data classes, their applicability to a variety of forecasting situations, and how other literature (for example, the Avalanche Handbook) approaches this concept.

In the AIARE 1 Course, field observations in the information categories of avalanches, snowpack, and weather activity are linked to individual avalanche concerns using the Avalanches and Observations Reference table. The student is asked to record the concern as outlined in the bulletin, identify the clues observable in the field given the problem, and once in the field "observe" to confirm and identify the primary issues for each day. The clues are prioritized into Critical/Red Flag Observations, Field Tests and Relevant Observations and Important Considerations for each avalanche type and associated problem. For the AIARE 2 student, The Avalanche Handbook offers a more complete look at the three data classes and observations that affect or influence snow instability and instability trends. The Avalanches and Observations Reference table is located near the front of the AIARE Field Book and in this workbook in section 3.1, p. 74.

The idea of data classes, information categories, observations, and red flags is not new or unique. Practically all decision makers who have an instability analysis process use a formal checklist for daily analysis. The information presented here is organized in a checklist form to help when analyzing instability. The PM Avalanche Hazard and Risk Assessment form (section 3.3, p. 84) is one way to organize the information, help remember it, and make sure the right questions get asked before coming to a conclusion about snow instability.

Weather and snowpack data lend themselves relatively well to this organizational system; avalanche activity data does not. This system is not inflexible nor is it an infallible set of rules that govern instability. Nor is it a "plug and chug" formula that can be used to assess instability. It is purely an information gathering system.

This information gathering system does not contain all the information that may be necessary or pertinent to snow instability analysis—it does ensure that all major classes and categories are covered. Additional observations may be necessary and, at times, observations that are not included in this system may be as pertinent as or more pertinent than the factors listed here.

Assessment of instability requires more than just gathering observations. A recording system of some kind is helpful (this will be discussed shortly) and, most importantly, one has to *reflect on and analyze* the data. Data must be taken into consideration both discretely and in combination with all other pertinent factors. It is essential to recognize that the main tool in analyzing data is personal experience. There are very few usable formulas or computational methods for assessing instability; those that do exist are not practical for practitioners who do not have access to large databases of information and sophisticated computer software. Even when computers, databases, statistical models, and other computational methods for assessing snow instability are used, in practically all cases the final analysis falls on the shoulders of an experienced analyst/forecaster who incorporates judgment and intuition to the process before making any decisions related to snow instability.

Notes

Recommended Reading

The Avalanche Handbook – Selections from Chapter 7

Evaluation of Instability, p.166
Nature of Factors, p.167
Data Collection, p.168
Analysis, p.169
Class 1: Instability Factors, p.172
Class 2: Snowpack Factors, p.181
Class 3: Meteorological Factors, p.197
Character of Data Types, p.208

Snow, Weather, and Avalanches

Preface, p.iii
Introduction, p.1

2.2 Introduction to Weather, Snow, and Avalanche Observation and Recording Guidelines (SWAG)

Learning Outcomes

- Explain why the avalanche industry has national guidelines and standards for observations and recording.
- Practice and receive coaching on weather, snowpack and avalanche observations to SWAG standards.

In 2004, the American Avalanche Association and USDA Forest Service National Avalanche Center published the first edition of Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States. Publishing this document was a milestone for the U.S. avalanche industry. For the first time, practitioners had a common language. The document relies heavily upon the Canadian Avalanche Association's Observation Guidelines and Recording Standards for Snowpack and Avalanches. While viewed as a "living document," the SWAG serves as a valuable and practical reference for avalanche observers. The guidelines are used by all manner of avalanche observers, from recreational travelers observing the snowpack to make more insightful terrain choices or reporting to their local avalanche centers on up to large-scale forecasting operations.

Each of the three chapters in SWAG describes the observations related to the data classes, as well as a glossary and nine appendices including symbols and abbreviations, avalanche danger, hazard and (in) stability scales, snow grain classifications, weather station guidelines, and more.

Task: SWAG overview

Thumb through the SWAG to become familiar with the document layout. The most recent version of this document was updated in 2010 and should be your current reference.

2.3 Interpreting Field Weather and Snow Surface Conditions

The guidelines for observing field weather and snow surfaces are detailed in the Snow, Weather, and Avalanches document. The following paragraphs provide supplementary information on the usefulness of the data collected.

Often field weather and snow surface condition are the most easily obtained data. Experienced recognition relies heavily on these data as a basis for pattern recognition. The spatial variability across the mountain slope is a well know conundrum when assessing snowpack instability. However, given the mobility provided by skis, snowmobiles, and helicopters, ski guides or forecasters can observe variability across a drainage or even at the range scale by observing these visual clues. For the observer to gain insight into the enormous variation across the mountain slope, it is best understood by taking regular snow surface observations over time and over space.

For example, in a daytime operation (where no monitoring or activities are undertaken at night), when assessing instability in the morning, the morning weather observations are often the only new information available. This is especially true early in the season when days are short and analysis/forecasting is taking place before dawn; it's also the case in poor weather when visibility and travel are limited. Under these circumstances it is essential that accurate weather data be obtained and that the data is interpreted and extrapolated to best assess its impact on instability.

If analysts/forecasters live in the valley and do not have ready or direct access to start zones or on-site weather, they may have to rely on local weather and extrapolation to assess instability and instability trends. This is very common in maritime climates where there may be a significant difference in temperature from valley bottom to start zone; temperatures, rainfall, and other factors, when interpreted and extrapolated, translate into useful information for higher elevation problems.

Another common situation where weather data plays a crucial role is in synoptic or regional scale forecasting where it is simply not possible to see all the avalanche activity or dig profiles and make snowpack observations in all the potential problem areas. Weather, being a much larger-scale factor, then becomes very important for assessing general stability and trends.

Photo below shows observer at a manual study plot.

Some useful relationships for interpreting and extrapolating a few weather observations include:

Orographic lift
The amount of snowfall on the upslope weather side of a mountain or range will be more than on the down slope weather side. Classic examples are:

- The New Zealand Alps: 4.6 meters water equivalent per year at the divide, 0.2 meters at the town of Twizel only 50 km to the east (i.e. Donner Summit/Reno area)
- Columbia Mountains, interior British Columbia, west side of the Selkirks/Monashees, looks almost like the coastal mountains; east side (Purcells) looks like the Rockies

There is no formula here; one learns by experience. But it is possible to extrapolate what may have happened on the other side of the mountain if attention is paid to the local weather and precipitation patterns/amounts. Consider that on exposed (alpine) upslope aspects the snowpack may be shallower due to wind scouring.

Elevation
Generally there are greater accumulations of snow at higher elevations and less at lower elevations. Similar to lift, there is no set rule, but local experience can produce astonishingly accurate estimates.

In some regions/climates, even though the amount of snow on the ground at higher elevations is greater, the actual load is similar. For example, at 1500 meters above sea level you get 10 cm of snow at 100 kg/m^3 (10%) and at 3000 meters you get 20 cm at 50 kg/m^3 (5%). The load is the same and if one extrapolates, one can estimate loads at higher elevations by looking at densities or water equivalents at lower elevations.

Drifting snow
Dryer, lower density snow will transport more readily than moist, higher density snow. By assessing how much snow, what kind of snow—and considering the temperature and density range from lower elevations to higher regions—one can begin to estimate how snow that is far away and out of sight might be reacting to winds.

Threshold wind speeds must be attained before snow will move. The speed required is based on density, moisture content, grain type, grain size, and other characteristics of the snow on the ground. It is also dependent on previous winds. If snow has been moved by wind once then it will tend to take greater speeds to move significant amounts again. For example, if the snow was moved by a 40 kph wind yesterday and the wind then died down, you are unlikely to see significant transport until subsequent wind speeds exceed 40 kph.

Light winds (<25 kph/15 mph) don't move much snow. Gusty winds tend to not create a consistent loading pattern. High winds (>80 kph/50 mph) may blow the snow far enough down the slope that it does not load start zones. Extreme winds may cause the snow to sublimate into the atmosphere as water vapor, especially at high elevations and in dry climates. The most problematic loads come from moderate winds that blow steadily and for long periods of time.

Fetch
How much snow will be available for transport is limited by the size and configuration of the windward area from which it will be picked up by wind (the fetch). A greater fetch will make greater wind loading possible and vice versa.

Temperature lapse rate
In moist, saturated air (near 100% humidity), the temperature will drop by about .5ºC/100 meters of elevation gain. This is the lapse rate. The lapse rate for dry air/clear conditions is about 1.0ºC/100 meters. With an inversion, temperatures rise with elevation. By learning how these lapse rates work in different weather patterns and climates it is possible to make decent, educated guesses as to what temperatures are doing at various elevations and in remote locations. This can help establish freezing levels and may be of use in determining what is happening to the snowpack and stability even when one can't get out there and poke around in person.

Freezing level
Precipitation will remain snow for 150–250 meters (500'–800') below the freezing level. That is, if the freezing level is at 1750 meters (5700') above sea level (perhaps you have cleverly calculated this using your newfound knowledge of lapse rates) it is likely snowing dryer snow at 2500 meters (8200'), snowing wet snow at 1500 meters (4900') or so, and raining below 1500 meters. This can help assess where and what type of load is observed and how susceptible the snow will be to wind transport.

Water equivalent
The general rule of thumb for fresh snow is that the ratio of water to air is 1:10. If you record 1 mm of rain in the rain gauge at your weather plot and you know it is cold enough to be snowing up higher, you can expect about 1 cm of new snow is on the ground. This is a rough rule of course and it depends on the climate, actual elevation change, lapse rates, type of snow that's falling, and a variety of other factors. Again, some attention to detail and learning local patterns can improve your educated guesses.

Foot Penetration and Settlement
Storm snow settlement is indicated by several observations: snow cones appearing around the snow stake or bamboo poles, and most accurately by comparing the height of storm snow (HST) to the added depths of new snow over a period. Settlement indicates the process of decomposing, rounding and sintering of storm snow grains.

Comparing the foot penetration depth at the same site over a few days can be a crude but early indication of recent new snow settlement. At times, given low-density HST, when the observer's foot penetrates through the depth of recent HST into the old snow below, the foot penetration indicates the HST hasn't settled into a slab over the old interface. Loose snow avalanches on steep terrain are still a possibility. Depending on temperature, wind, and humidity, storm snow layers can settle at different rates. Often when the foot penetration stops just above (5–10cm) the HST/old snow interface the snow has settled to the point where slab avalanches can be skier triggered.

A more accurate measurement of sintering compares the sum of the heights of the (twice daily) new snow reading (H2D) with the height of the storm snow (HST) as read on the snow boards in a weather study plot. To calculate storm snow settlement rates for a given period:

$$\frac{[\text{Sum of H2D}] - [\text{Current HST}]}{\text{Sum of H2D}} \times 100 = \text{Settlement \%}$$

Given:

- H2D is snow depth observed on the standard (12 hour) board read and cleared each reading.
- HST is snow observed on the storm board. This is not cleared until the end of the storm.
- Settlement is in %.

Storm snow settlement rates of 15–20% are generally considered "good" for stability. Lower rates indicate the storm snow is not settling or strengthening quickly. Higher rates usually indicate rapid settlement from warm temperatures and/or solar radiation which tend to settle the upper part of the storm snow layer faster than the lower part, potentially resulting in a warmer, firmer slab over a colder, softer weak layer.

Notes

Task: Field Weather Observation

Observe and record a complete set of field weather obs using the AIARE Fieldbook as a template.

1. Discuss each observation and learn the usefulness of each.
2. Return to the class and record the field observations taken. The first record is to be used as a template for the field obs taken each day.

Questions

Discuss record keeping in daily journal form versus record keeping by subject. What is the advantage of recording by subject?

Why observe and record "Thin Cloud" cover under the Sky category?

Describe the significance and formula for observing settlement in new snow. (AHB p.202-203)

Why record the aspect and elevation of the field weather observation?

Why record snow temperature (T20) 20cm below snow surface?

2.4 Interpreting Snow Profiles

Learning Outcomes

- Compare and contrast full, test and fracture-line profiles.
- Describe the observations to be taken and recorded for each.
- Practice completing a snow profile, with coaching from the instructor.
- Use the Snowprofile Checklist (yellow flags) to identify critical interfaces.
- Record your profile in your AIARE Field Book.

The guidelines for observing snow profiles are detailed in the Snow, Weather, and Avalanches document. The following paragraphs provide supplementary information on the usefulness of the data collected.

In contrast to snow surface data that provides information on snow variation at the mountain range, drainage, or even slope scale, snow profiles provide only point data. These point data collected in a profile provide useful information about how layers change over time, given the critical caveats that the site is selected with a specific objective in mind and these data are compared in context through a larger-scale assessment of snow instability (see the PM Avalanche Hazard and Risk Assessment form in section 3.3). For the observer, these data are most relevant when evaluating persistent and deep avalanche problems (see Avalanche and Observation Reference in section 3.1).

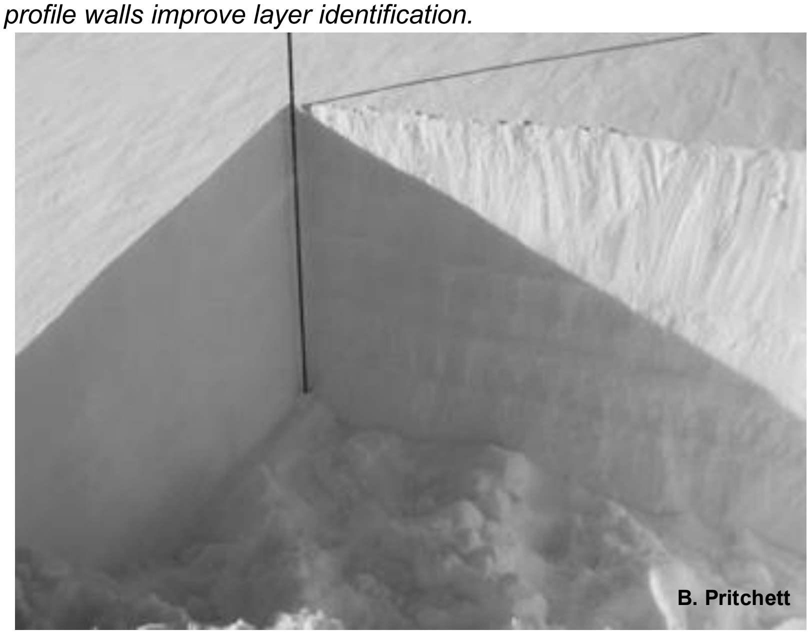
These snow profile observations involve digging into the snowpack and making a series of relatively formal and predetermined observations and tests, which are recorded using a standardized format. There are three types of snow profiles: full profiles, test profiles, and fracture-line profiles.

Full Profiles

These are sometimes referred to as "study plot" profiles. They are generally carried out at prepared sites that are considered representative of the average snowpack for a geographic region. Profile sites are usually near or below treeline, on a north aspect, and on a flat slope. This provides for an average snow depth minimizing the influences of elevation, aspect, wind and radiation.

Full profiles are generally done at regular intervals, the timing of which depends on the climate, the type of operation, and the needs of the analyst/forecaster. The goal of full profiles is to obtain and update baseline data through the depth of the snowpack and to track changes over time.

Clean profile walls improve layer identification.



Test Profiles

These are sometimes referred to as "field profiles." Test profiles are carried out at sites that are deemed representative of a specific snowpack for a given area (see the discussion in Data Classes and Observation Sites).

Test profiles are observed when they are necessary and useful for assessing instability. The interval will depend on the climate, the type of operation, and the needs of the analyst/forecaster. The goal of test profiles is to obtain site-specific data and to verify and complement information gained from full profiles. Test profiles are useful for tracking changes over space (noting influences of slope, aspect, elevation, wind, radiation and avalanches) and over time.

Fracture-Line Profiles

Fracture-line profiles are observed at or near the crown or flank fractures of a slab avalanche, and they are essentially test profiles. They are carried out when confirmation of what caused an avalanche is useful. Observers may choose when and where to do them and carry out the tests and observations that are relevant to the objective.

Task: Snow Profile Observation

1. Observe the demonstration of full profile observation techniques.
2. Return to class to record the day's observations.
3. Discuss the differences between the site selection of a full, test and fracture line profile.
4. Use the "yellow flag" parameters to describe the layer and interface characteristics. Describe the layer that is most important to observe and track in various field tests and test profiles during the week.

Examples of Snow Profile Recording Methods

Recording Example: Fieldbook

Date: 20120227 Time: 0800 Observer: Jeff Jones

Location: Rolling Thunder Bowl, 50m below heli landing zone on smooth planar slope

Objective: Test profile; observe the depth and distribution of Feb 19 V buried under the recent storm snow; testing this weak layer's potential for propagation

Elev: 9050 ft. Aspect: NE Incline: 36° Profile Type: Test profile

Sky: BKN, VF 7000-7600' Wind Dir: SW Wind Sp: Light BloSno: Mod

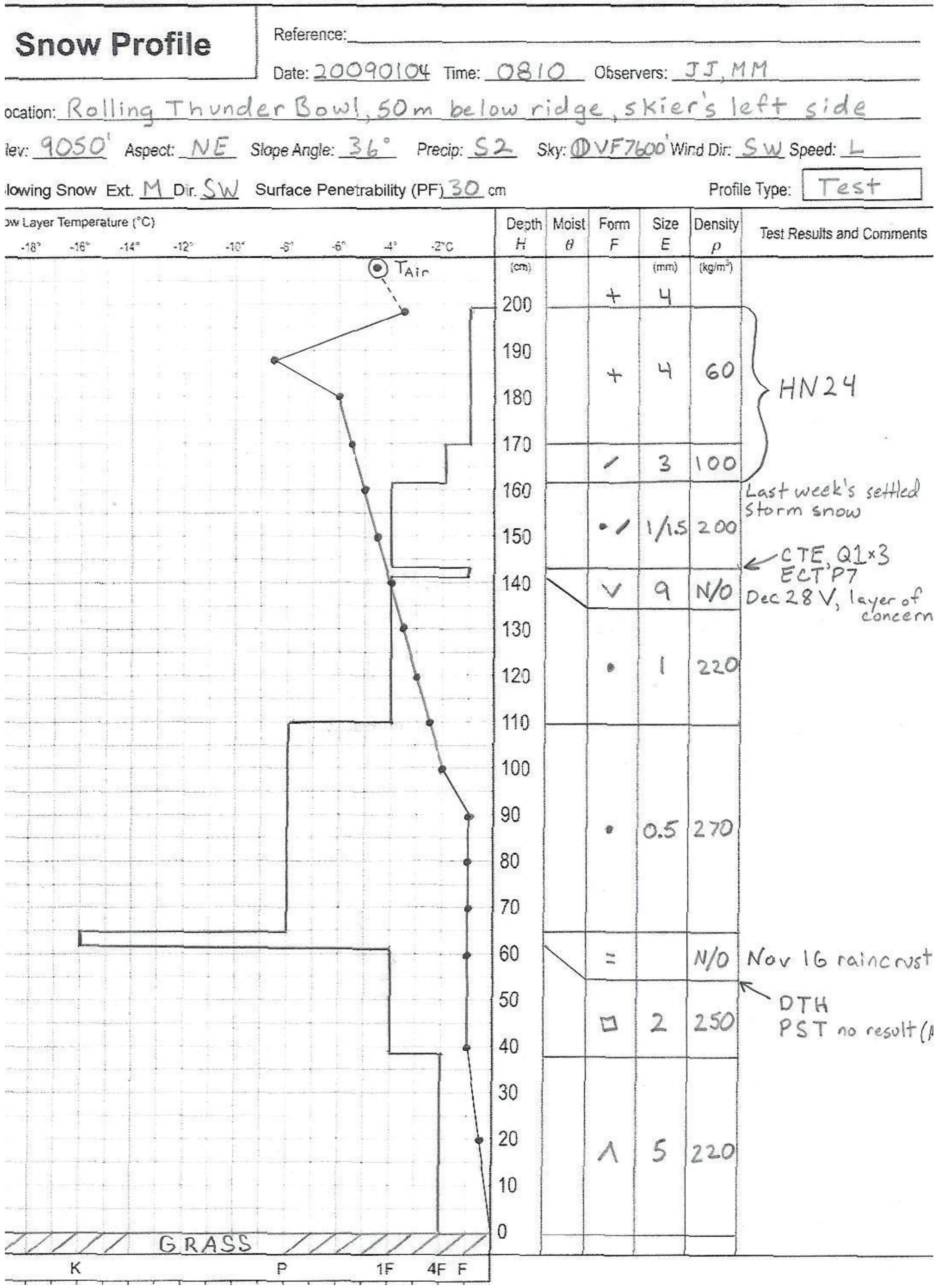
HS: 198cm PenFoot: 30 cm Precip. Type/Rate: S-1 Air Temp: -4.5

Snowprofile Checklist Layer Properties: Average grain size: >1mm; Hardness: <1F; Grain type: Persistent SH FC DH

Snowprofile Checklist Interface Properties: Difference in grain size: >.5; Difference in hardness: >1; Depth of interface: 20 - 85cm

Heights (cm)	Moisture Content	Grain Form	Size (mm)	Resis-tance	Density (kg/m³)	Yellow Flags (Layers): Avg grn sz	Hardness	Grn typ	Yellow Flags (Interfaces): Grn sz diff	Hard diff	Depth	Sum (Count)	Test results and comments	H(cm)	T (°c)
0		+	4.0											Tsurf	-4.5
	D	/	2.0	F	80	◺	◺						← Recent HST	T10	-8.5
36									◺	◺	◺	5		↓20	-5.0
	D	●(/)	1.0 (2.0)	1F	200	◺							← Last Week's Storm Snow	↓30	-4.5
55									◺	◺	◺	6	CTE (SC), ECTP 13 ↓ 55cm on Feb 19 V	↓40	-4.0
	D	∨	7.0	F		◺	◺	◺					← Layer of Concern (Feb 19 V).		
56									◺	◺	◺	6	2nd test 20m away, same elev., deeper HS showed:	↓53	-4.0
	D	●	1.0	1F	220								ECTX, PST 35/100 (end) ↓ 90 on V.	↓55	-4.0
89												0		↓57	-4.0
	D	●	0.5	P	270										
133										◺		1		↓188	-0.5
	D	■		I									← 4cm Ice layer, from Dec 16 rain	ground	0.0
137									◺	◺		4	DTH (RP); PST 80/100 (END) ↓ 137 on ∧.		
	D	□	2.0	1F	250	◺		◺							
169									◺			4			
	D	∧	3-5	4F	320	◺	◺	◺							
198		ground											3rd test site @ 8,200', above high pickup, showed:		
													PST 32/100 (end) ↓ 45cm on Feb 19 V,		
													Whumping nearby.		

Recording Example: Graphical / Hand-drafted version



Using the Snow Profile Checklist (Yellow Flags)

The AIARE Field Book has columns designated to use the snow profile checklist as an integral part of the snow profile procedures. Researched and promoted by Bruce Jamieson and Jürg Schweizer in their paper, "*Using A Checklist to Assess Manual Snow Profiles" (March 2005),* the checklist has been found to be useful to assess and prioritize critical layers and interfaces in the snowpack.

Jamieson and Schweizer found that while snowpack tests (example: compression test) are a good tool to identify layers and determine the layer likely to *initiate* a fracture when the snowpack was deformed, more information was required to gain insight as to whether that fracture, once initiated, would propagate.

The snow profile checklist can be used to identify the crucial structural properties of the snowpack by noting relevant values in both layer properties and layer interface properties. The values are described as observed to be consistent with avalanches. These criteria (yellow flags individually) may add up to a "red flag" value in the snowpack if five or six "flags" are identified at the interface of a layer.

Table: Yellow flag criteria for identifying potential failure layers.

Property	Critical range (Columbia Mts.)
Weak Layer Properties	
Average grain size	> 1mm
Hardness*	< 1F (3*)
Grain Type	Persistent (SH, FC or DH)
Interface Properties	
Difference in grain size	> 0.5mm
Difference in hardness*	>1*
Depth of Interface	20 to 85 cm

* hand hardness F, 4F, 1F, P, K is assigned a value of 1, 2, 3, 4, 5, respectively. Fractional values are allowed, e.g. 4F+ and 1F- are 2.3 and 2.7, respectively.

The table above is a copy of the checklist from "Using a Checklist to Assess Manual Snow Profiles", *Avalanche News*, 2005 Jamieson, Schweizer

Practitioners note that when one observes the combination of 1) *yellow flag* criteria (snowpack structural properties); 2) *fracture character* observed in compression tests; and 3) *fracture propagation observations* from large column tests (ECT, PST), one begins to get a much better notion of whether the fracture, once initiated, may propagate across the terrain.

Task: Snow Profile Checklist
Using the Snow Profile Checklist, tabulate the values for each layer and interface of a profile in your Field Book.

Notes

Recommended Reading:

"Using a Checklist to Assess Manual Snow Profiles", Bruce Jamieson1 and Jürg Schweizer2

1. Dept. of Civil Engineering, Dept. of Geology and Geophysics, University of Calgary
2. Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland
   (Also reprinted in The Avalanche News, March 2005)

Snow, Weather, and Avalanches – selections from chapter 2
Snowpack Observations, p.21 (Sections 2.1–2.4)

Questions

List three reasons the full profile is useful to the forecaster.

Why are the full profile and weather instrumentation often at the same site?

What is one weather instrument that is often distant from the study plot location?

2.5 Snowpack Observations: The Importance of Craftsmanship, Relevancy, and Verification

Learning Outcomes

- Describe why site selection is critical to collect good snowpack information.
- Practice and explain appropriate use and the limitations of small and large column snowpack tests.
- Explain why it is imperative to use good technique and to verify data, prior to making a statement on snowpack instability.

The Weight Of Evidence

The important job of gathering and interpreting snowpack information includes evaluating the weight of each bit of information as it is applied to snowpack instability and avalanche hazard. This means determining the *quality* of the data (the skill of the observer, site selection, and verification with nearby complementary tests) and the *quantity* of data (the number of relevant observations). Experienced practitioners are aware of the terrain and snowpack variability; and are aware of the challenges of extrapolating and interpolating snowpack observations. The following checklist helps to ensure quality and relevancy of information:

- Does the test provide more information about the current avalanche concern?
- Is the observation site representative (relating to the location of the layer(s) of interest, and the reported distribution of the avalanche problem)?
- Is the observer skilled at performing the test and interpreting the result?
- Has the test been verified with similar or complementary additional tests?
- Has the observation or test been confirmed using similar findings from “nearest neighbor” professionals?

Outside of current avalanching and red flag observations, experienced observers tend to steer away from drawing conclusions from a few snowpack observations. They recognize that errors occur during the extrapolation process. Inexperienced observers, when prioritizing information, may gravitate towards a loud note in the score (such as a compelling snowpack test result) and apply too much importance to one test result. In addition there are times when the above criteria *can’t be* applied (poor weather prevents access to good sites), or *hasn’t* been applied (few observations) yet assumptions are made and conclusions derived. The process of observation and understanding isn’t complete. As Dr. Bruce Jamieson, the ASARC researcher understated, during a CAA course lecture on spatial variability of the mountain snowpack, “…inaccurate assumptions can have serious consequences”. Decisions made from a deficit or even partial deficiency of information (required to understand the avalanche problem) should be considered “uncertain” (ISO 31000)—at least until placed in context by the criteria discussed in the above checkbox. Meanwhile as the degree of uncertainty increases, so increases the emphasis on safer terrain choices.

The Issue of Consistency

Regional and operational consistency with technique, application, and interpretation ensures the quality of data gathered, recorded and communicated. Practice, technique, and a meticulous day-to-day consistency with observations, recording and communication should never be undervalued nor should the scope of the task be underestimated:

- Each snowpack test requires an objective. Know what you're looking for prior to the observation.
- Experience, and an ability to visualize how the snow is layered over the terrain, is required for relevant site selection for field test sites.
- Tests are skillfully conducted using standardized, practiced techniques. Observers' use established guidelines when conducting, recording, and communicating weather, snowpack and avalanche observations. (*Snow, Weather, and Avalanches: Observation Guidelines For Avalanche Programs in the US*. American Avalanche Association, 2010; *Observation Guidelines and Recording Standards For Weather, Snowpack and Avalanches*. Prepared by the Canadian Avalanche Association. 2014)

The Application and Limitation of Snowpack Field Tests

To observers, it must be stressed that standard snowpack observations are part of a very large and complex puzzle. As illustrated above, results from these tests are seldom conclusive and require skilled interpretation. A snowpack test result should not be used as a single indication that a slope is stable or unstable. One repeatable test is only one observation, and is interpreted in combination with other information as part of the process of risk assessment and risk reduction. One of the most useful tools to help learners is the AIARE Avalanches and Observations Reference inspired by Dr. Bruce Jamieson's article "Which Obs for Which Avalanche Type?" (ISSW 2010). In this article Dr. Jamieson suggests that prior to the terrain selection process smart ski guides would identify the primary avalanche problem that may affect safe terrain choices. He went on to complete a field study that underlined the set of observations that are best suited for each avalanche concern. The AIARE Avalanches and Observation Reference help learners identify a set of field observations that best match the avalanche problem as identified in the bulletin. Proper application combined with an understanding of the limitation of each test sets the observer off on the right approach: the right test, for the right conditions, in the right place, completed at the right time (and by the right person!).

The following summary may provide insight into how practitioners interpret and apply the common snowpack observations and tests (*sources noted*).

Observation: Foot (PF) and Ski Penetration (PS)

While imprecise in terms of numerical value, ski and foot penetration are like a set of eyes an everyday tool. A few examples:

- Ski penetration "feels" how the surface changes over the terrain including forming surface hoar, surface faceting, thin crusts, moist surface layers and wind slabs/redistribution. This is a valuable tool for many practitioners. The heliski guide whose mobility permits rapid observation over a tremendous range of elevation and aspect has an advantage if they careful track and record the distribution of the old snow surface prior to becoming a buried layer weak layer!

- A change in foot penetration is often the first indicator of settlement within recent storm snow (HST). For example, foot penetration *through* low-density storm snow (into old snow below the depth of the buried weak layer) may indicate no slab formation; and in this case, loose snow avalanching would be the primary concern. A day or several days later, the observer records the PF to a height well *above* the weak layer—possibly indicating the HST has settling into a slab (over the weak layer). This may be an early warning sign that skier triggering is possible.
- Foot penetration may help to observe the strengthening mid pack without digging. Early season in a shallow continental snowpack it is common for the foot to penetrate to near ground layers. Given warming and continued snow fall the strengthening mid pack begins to support ski penetration and subsequently foot penetration. This may be an early indication that (given snow cover over ground roughness) enough mass and stiffness now exists for a slab avalanche release over a basal depth hoar or facetted weak layer.

Probing (and ski pole test), "Hand shear" tests, Shovel tilt tests

Often termed "quick" tests, these are specific field observations useful to observe and record the distribution of near surface weak layers, crusts, wind effect, and seasonal variation in snow cover.

- Limitations include not being "standard" tests with common methods or descriptors; and until recently "quick tests" had little supportive field study (see *Which Obs For Which Avalanche Type,* Jameson, Schweitzer, Statham, Haegeli, ISSW 2010).
- "Kick tests, jumping above tracks or on unsupported snow mushrooms, hand shear tests and shovel tilt tests are helpful for observing structural properties of the HST (to 45cm deep, *Schweitzer/Jamieson)* and observing the HST/old snow interface (including fracture character/shear quality).
- Probing is useful to observe the distribution of the seasonal snow cover (during periods of stable snow) and to track the depth of recent snowfall over stiff layers or crusts.
- Layer characteristics observed are usually "not exact" or limited to a few snowpack characteristics (example, depth of a SH layer and stiffness of soft slab above). These types of tests provide information that is a supplement to observer's memory but is hard to record on a form and communicate for use to other observers or forecasters.

Recent studies suggest that field observations rather than snowpack tests are the most reliable indicators for *non-persistent* avalanche types. Comparatively test profiles and small and large column tests may be the best tool when observing the layer characteristics of *persistent slab* avalanche types (*from Jamieson, Harvey, Schweitzer et al*). The AIARE Avalanches and Observations table illustrates how profiles and field tests help observers better identify the persistent and deep slab types.

Full Profile, Test Profile, and Fracture Line (Crown) Profile

These tests are useful for observing and testing structural properties of the snowpack.

- Full profiles observe changes in the snowpack over time. While conclusions relating to the avalanche problem may not be immediately apparent in a study plot full profile a better understanding of the *long-term influence of terrain* *shape, elevation, wind, and radiation* is derived from a comparison of study plot profiles to site specific test profiles.

- Profiles allow the observer to visually inspect the layering of the snowpack. Using a clean profile wall the eye may see layers (especially a weak layer protected by a stiffer lens) that you can't feel with ski or foot penetration or probing; and may illustrate deeper layers not obvious to the "quicker" tests.
- The snow profile checklist is a good indicator of likelihood of initiation and a valuable tool to prioritize between multiple weak layers/layer interfaces (*similar to expert systems from McLung 1995, "Lemons" from ISSW Poster McCammon, Schweizer 2002, "Yellow flags" from Schweizer and others ISSW 2004, Snow Profile Checklist from Jamieson, Schweitzer, Avalanche News 2005).*
- Observe the characteristics of both the slab and the weak layer.
- Thin, persistent, weak layers may be hard to find using standard test profile observation techniques.
- Profiles are time-consuming and at times difficult to complete during a busy operational or recreational day.

Compression Tests, Shovel Shear Tests, Deep Tap Tests

- The Compression test combined with fracture character is helpful for identifying thin, hard-to-observe persistent weak layers (*Birkeland, Johnson '99*). Observed *sudden* fractures (Q1) have been associated with the frequency of skier triggering in field studies (*Van Herwijnen, Jamieson 2002*). Sudden fractures indicate a persistent grain form (surface hoar, depth hoar or facets). Sudden collapse (also Q1) may be associated with observed "whumping" and a thicker layer of persistent grain types, and may indicate a possibility of "remote" skier triggering of the layer (*from Jamieson*). Recording compression tests with fracture character manages slope scale variability better than recording only the number of taps (*from Jamieson*).
- Good techniques with all small column tests are important. Poor techniques (such as rough walls or inadequate column clearance) may result in "missed" or misidentified fracture character. Example: a *sudden fracture*—Q1—being observed as a *resistant fracture*—Q2.
- There is an increasing likelihood that fractures may not indicate as the weak layer is located deeper than 80cm; thought the CT can indicate up to 120cm deep. Each tap penetrating into the snowpack is affected by mid pack crusts and stiffer (hard slab) mid pack conditions. Therefore the Deep Tap Test can be employed to observe weak layers located deeper or in snowpack conditions that would be problematic for a CT. Fracture character can also be observed in a deep tap test.
- Shovel shear tests are useful observing layer changes over time in a study plot. The observer can utilize a similar block size as the layer depth increases over time and the overburden or "load' increases. Progressive compression (Q2) fractures (often a DF layer) are impractical to observe using a shovel shear test. Sudden collapse (Q1-"drops") may be harder to accurately observe using the shovel shear test (*Jamieson*).

Propagation Saw Test, Extended Column Test, Rutschblock Test

These "large column tests" may be useful for observing the propensity for fracture propagation *(Jamieson, Gauthier. Simonhoise, Birkeland)*. As a consequence, the large column test is used to add to layer character and likelihood of initiation related information gathered from CT and DT tests. The suggestion is that a column with a beam length of around 1m (*Gauthier, Jamieson, Ross*) can give an idea of whether propagation will continue once the fracture has initiated in the weak layer (free propagating cracks).

- One field study has suggested the ECT is *most* valuable for observing weak layers in the depth range from 27cm to 70cm thick (*Cameron Ross and others, ISSW 2008*). The SWAG, OGRS both describe the test as useful in certain snow conditions to depths of approximately 1m (*Simonhois,Birkeland 2009*). Several studies suggest the ECT provides a consistent result balancing false stable or unstable indications (*Schweizer, Jamieson and others 2010*).
- Propagation saw test is useful to indicate propensity for propagation. Research suggests the PST may be able to test instabilities located at a deeper depth (*Ross, Jamieson*), or under a stiffer midpack (*Gauthier*) than can be tested using a CT or ECT. The Propagation Saw Test may indicate inaccurate results in thin soft slab conditions (ie wind slabs ≤40cm depth) that may be ski triggered (*Gauthier*).
- Whole block release types in Rutschblock tests-- are comparable to sudden (Q1) sudden fracture character in small column tests. RB results that reveal “whole block” release types are more likely to indicate a tendency for propagating cracks (unstable conditions) than partial block release types (*from Schweizer 1995*). Also consider that the RB is largest sample size of most tests (2m x1.5m).
- Large column tests are time consuming and may require a large saw (or two persons and a RB cord with metal swages) to cut through stiffer mid pack layers. The RB may require two persons to accurately observe release type. The RB has a similar snowpack depth range to a compression test.

Clues Provided By Field Tests				
Snowpack Test	**Identifies weak layer of concern**	**Illustrates failure/fracture in weak layer**	**Illustrates propensity for further propagation**	**Illustrates the possibility of avalanche release**
Shovel Tilt Test	(Limited to top 45cm)			
Profiles w/ checklist		(checklist may give false unstable indication)		
Compression Test **with fracture character**	(limited to top 100cm)		(tends to false unstable)	
Deep Tap Test **with fracture character**	(ID layer prior to test)		(SP, SC give prop. clues)	
ECT		(stress from taps may not affect deeper layers)		
PST	(ID layer of concern prior to test)			
RB **w/ Release Type**		(stress may not affect deeper layers)		
Explosives		(deeper weak layers may require well placed or larger trigger to avoid false stable)		(no result may not provide useful information)

Figure above: from Jamieson 2009

Ski And Explosive Tests

These tests can illustrate the extent of fracture propagation across the slope and the magnitude of avalanche release.

- Explosive tests provide important information about the terrain that is likely to produce avalanches. Slope tests can provide useful information about sensitivity to triggering, extent of propagating fractures, and magnitude of avalanche release.

- Results may be “less artificial” in comparison to a column of snow completely isolated by a saw cut, and in theory, provides a test that applies a force on an intact slab over undisturbed layers.
- Explosives tests are one of the few tests for a deep persistent weak layer—or a weak layer protected by stiff layers that may give false stable indication when applying loading steps (taps or jumps) in column tests.
- May trigger slopes from weak snow areas.
- Allow triggering from safe location but require expertise and certification.
- Air blasts affect a larger slope area but can be complex to deploy.
- Small explosive charges (<1kg) deployed into deep low-density storm snow may not have the desired effect.
- Ski triggering can affect a larger area of the start zone than single explosive tests; but can also be hazardous. Slopes may not slide from a single explosive test but may slide during a subsequent ski test.
- Explosive or ski tests that produce “no results” can be difficult to interpret.

Managing The Possibility Of False (Stable Or Unstable) Indications In Tests

Snowpack tests can illustrate snowpack layering, weak layer fracturing and propensity for propagation in the absence of obvious signs of instability (cracking, whumping and avalanches). Experience interpreting test results provide the forecaster with information on both stable and unstable snowpacks. The five bullet points outlined in the first paragraph describing “the weight of evidence” provide a functioning checklist to ensure the test data is accurate, relevant and verified.

As stated, understanding and assessing *where we are getting our information* from is a crucial link between gathering information and applying it to a hazard analysis. This is at least partially because it is often not possible or practical to go to truly representative sites and it is notoriously difficult to critically assess observation sites when one is unsure of start zone or trigger point characteristics. Understanding the *history of how the snowpack lies over the terrain* helps to locate relevant sample sites. Knowing where the terrain tends to form strong and weaker snow given the seasonal snowpack development is important. While persistent weak layers tend to have a broader distribution, sun or wind effect can result in feature scale variability in weak layer character. DF layers can be unstable locally but may not be problematic on a drainage scale. Expect a higher incident of false stable test results when observing locally unstable layers like DF’s, graupel or early season sun crust interfaces.

How one interprets each test result is crucial to applying the information to the overall picture of slope stability. For example, the snow profile checklist (a.k.a. “*yellow flags*”, “*lemons*”) provides important clues as to which layer is most likely to result in failure initiation given a trigger; but has a tendency to overestimate instability (false unstable=false alarm)—determining whether fracture propagation will occur (Winkler & Schweitzer, ISSW 2008). The large column snowpack tests that employ taps or jumps to apply a load to the slab (ECT, RB) tend toward false stable results where the weak layer is deeper than 80cm (depending on snowpack characteristics). The illustration left (Salm, Fohn, Schweizer, Camponovo) shows that an 80kg theoretical load on the snowpack has less than ¼ of its effect at 80cm depth. Yet, slabs are commonly ski triggered, and remotely triggered, on persistent weak layers at that depth or in the terrain from nearby shallower or weaker area.

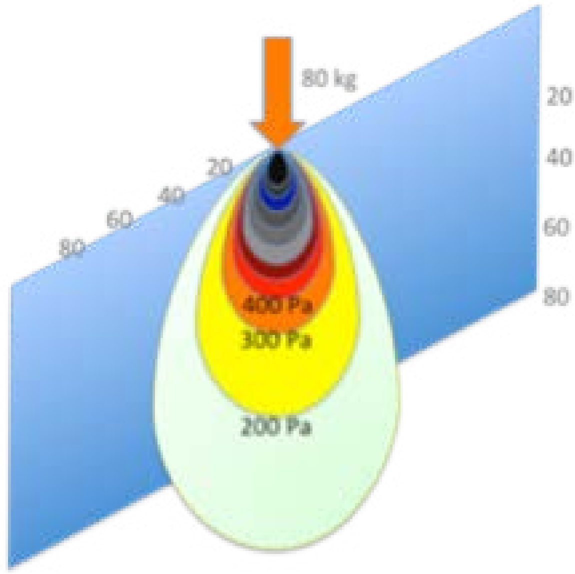


Figure above: Salm 1971, Fohn 1987, Schweizer & Camponovo 2001

The Schweitzer, Jamieson article *Snowpack Tests For Assessing Snow-Slope Instability* (2010: Annals of Glaciology) provides an updated and excellent perspective directed at a general audience on snowpack test use and limitation. The following points have been paraphrased from the article:

- A good test method should predict stable and unstable scenarios equally well.
- Column tests are particularly helpful for assessing persistent slab conditions.
- Small column tests (CT and DTT) are useful for identifying weak layers and likelihood of initiation but have a tendency to overestimate instability (false unstable) conditions. Observing fracture character improves to a degree the interpretation of the test results. These tests are a better indicator of layer character than instability.
- Large column tests are better at predicting propensity for fracture propagation than small column tests; particularly when used in combination with other large column tests. Comparative studies suggest that the RB, ECT, and PST have comparable accuracy.
- With large column tests, repeated test results in the same location are useful but the tests repeated on similar, nearby slopes has more value.
- Each tests has a margin of error. In addition, even with very experienced observers an error rate of 5-10% is to be expected. Site selection and interpretation require experience.

The bottom line is snowpack tests used to predict instability are not foolproof. As Schweitzer/Jamieson state obviously and importantly in the aforementioned article, “decisions about traveling in terrain should not be based solely on stability (snowpack) test results”.

Thanks to:

Cam Campbell, CAA Level 2 M3 Lecture, *Testing for Initiation and Propagation Propensity*, 2008

Gauthier, Ross, Jamieson, *How To: The Propagation Saw Test*, Oct. 2008

B. Jamieson, *Risk Management For The Spatial Variable Snowpack*, 2003; *Which Obs For Which Avalanche Type*, ISSW 2010

B. Jamieson, *Mountain Snowpack and Spatial Variability lectures;* CAA Level 2 Mod 1 course, 2009

J. Schweitzer, B. Jamieson, *Snowpack Tests for Assessing Snow-Slope Instability,* Annuls of Glaciology, 2010

K. Klassen, *AIARE Level 2 student manual* version 2002

Cameron Ross (Gauthier, Jamieson), *Fracture Propagation Tests*, ISSW 2008

Simonhoise, Birkland, *An update on the Extended Column Test*, 2007

Recommended Reading

Snow, Weather, and Avalanches (SWAG) – selections from chapter 2

Snowpack Observations, p.24-55 (sections 2.4.1-2.7.3, 2.7.5, 2.8, 2.9, 2.9.1, 2.9.4-2.9.6, 2.9.8)

2.6 Additional Information on Test Skiing, Explosives, and Cornice Testing

Test Skiing

"The best method of instability evaluation is to load the snow in an avalanche-starting zone until the snow fractures, for example, by test skiing or application of explosive charges" (AHB p.166).

"Ski cutting (also known as test skiing) is one of the most dangerous methods used to observe or test the snowpack. It is also perhaps the one that is most often misapplied or carried out incorrectly, even by experienced practitioners" (Karl Klassen).

"In general, test skiing is limited to short slopes where no serious consequences would result if an avalanche or fall by the skier takes place" (AHB p.174).

Test skiing is one of more important instability tests available to the backcountry skier. In the context of *instability analysis* (as opposed to avalanche control), test skiing should be used with **extreme caution** and it is **essential** the safety of the tester/observer, group, and other skiers be carefully and fully considered before using this technique, especially in the backcountry. **Do not** ski cut slopes where the size of the slope, terrain configuration, or slab properties could produce a large enough avalanche to bury or injure a skier. Therefore, any potential for an avalanche more destructive than Class 1 should automatically preclude test skiing as an option. Ski onto a short, steep slope similar in aspect, elevation, and terrain characteristics to the slope you want to ski. Next note any obvious clues of instability ("whumphing," cracking, and/or avalanching.) If there is cracking, determine at what level beneath the snow surface and identify the failure layer. Carefully evaluate the consequences of being caught in an avalanche on the slope you are testing. One's definition of a short, steep slope is relative. Are we in Alaska or Colorado? Take a close look at the terrain before you commit to test skiing. Is the slope unsupported? Are there hazards in the runout zone (crevasses, cliffs, trees, etc.)? Does the runout fan out gradually or end with an abrupt transition?

In the context of avalanche control, test skiing (also known as ski cutting) is a common method of initiating small, controllable avalanches before conditions develop and increase the potential size of the forecast avalanche.

"You must start and end the ski cut at safe points, staying as high on the slope as possible. Do not stop while in the start zone or at trigger points. Push turns, check turns, and kicking while cutting across the slope should only be carried out when at the very top of the slope and are appropriate only when they will not stop or significantly slow progress to the safe end point of the ski cut" (Frank Coffey).

Bottom line, the information that can be gained from ski testing can be quite valuable, albeit potentially dangerous and difficult to acquire. It can be considered indicative of instability if carried out in an ideal location—*safe* and representative. It is important to note that negative results do not indicate stability. The forces applied by a skier attenuate rapidly with depth; the snowpack varies across the slope; and fractures that initiate in the weak layer may begin to propagate and stop in stronger snow (at the test location). The skier may have simply not tested the "sweet spot." Consider the number of times control workers begin to ski cut a slope, get an eerie feeling and retreat. On their next pass, small charges placed in ideal locations cause the slope to release. In contrast, positive results certainly reveal instability.

Explosive Tests

Explosive testing is an invaluable tool when test skiing is not an option and when other snowpack tests (for example, Rutschblock and compression tests) are not viable or too dangerous. Many times the only effective tests of deep weak layers (more than 80 cm deep) are explosive tests. The effectiveness of the detonation is a direct function of where the charge is placed on the slope, where it is located in relation to the snow surface, and the weight of the explosive.

Charge Placement

"The ideal locations are those with the lowest stability—the most likely location for a primary fracture to begin. Due to the fact that such specific locations cannot be identified precisely, the entire potential release zone must be totally encompassed by the effective ranges of the individual shots. In order to accomplish this in an economic fashion with a minimum amount of explosives, one should strive for the largest possible effective range, and begin control work at locations of pretended lowest natural stability" ("*Artificial Release of Avalanches*"; H. Gubler).

Effective Range
The effective range is defined as the radius of an area with the point of detonation at the center. "We define the effective range for a detonation of a given charge about 1m above the snow as the 100% range. The effective range of 100% of a 1 to 1.5 kg of a high detonation speed, high work factor and gas volume amounts to about 85m. This 100% range reduces to about 50m if the area has to be skiable after a stability test with explosives." (H. Gubler) The effective range of a charge detonated at the snow surface is 40% of a detonation 1 meter above the snow surface. Surface blasts have a range of 20 meters; a detonation 30cm below the surface has a range of 15 meters. Effective ranges may vary within 25% for commonly used explosives. A loud, high pitched blast indicates a greater effective range. The more muffled the sound, the smaller the effective range. In wet snow shockwaves attenuate dramatically and the effective range is limited, by and large, to the crater zone.

Size of Charge
The industry standard for hand charges is one kilogram. Studies at Big Sky Montana showed that increasing the charge size 100% increased the area of influence 144%. Explosives deployed from helicopters generally detonate below the snow surface. In heli-bombing the size of the charge is increased [minimum 5 kilograms] to increase the effective range. The standard avalauncher round weighs about one kilogram. With avalaunchers the effective range improves markedly when charges detonate either in shallow snow or at rock surfaces.

Interpreting Test Results
The results of explosive tests are interpreted like those seen with ski tests. Explosive-triggered avalanches indicate at least fair and possibly poor stability. Note aspect, elevation, and terrain characteristics if you are triggering avalanches with explosives. Determine the fracture depth and the failure layer. Does the avalanche "step down," triggering failures at deeper layers? When avalanches are not being triggered, closely inspect the crater zone. Are there cracks radiating out from the crater? Is there significant propagation? To what level beneath the snow surface do the cracks penetrate?

Significant cracking indicates potential lingering instabilities. While this is obvious to experienced practitioners, in 2006, Birkeland et al. illustrated this point using a study of two case studies where a first charge produced visible cracks and obvious weak layer fracture, and then a second charge released a sizable avalanche. They also referred to examples when a series of charges repeatedly produced visible cracks without slope failure and avalanche release. Bottom line: a slope with cracking following explosive testing should be considered suspect rather than considering it stabilized with the "energy released."

Cornice Testing

Dropping a piece of cornice can be an excellent test for stability. It is essential that the safety of the observer/tester and the group or other skiers be taken into consideration. Do not control cornices that are large, overhang big slopes, or are above other skiers. Consider the worst-case scenario before trying cornice control techniques.

A variety of cornice control methods can be employed, including unbelayed kick, kick with ski pole belay, and cutting off a chunk of the cornice with a piece of cord. In all cases, be aware that cornices often break farther back on the slope than one might expect. A careful inspection is an important first step. Approach all cornices with caution, keeping well back from the edge until you are certain your working area is safe. If using kick techniques, start well back and work your way out; always keep weight centered on the rear ski (the one farthest from the cornice edge) and do not put weight on the front ski after a kick; pull yourself back onto the rear ski after each kick so that if the cornice breaks you don't go over the edge with it.

Cornices that require more extensive measures or greater safety precautions than those described above are beyond the realm of the backcountry traveler and fall into the role of professional avalanche control measures.

Do not carry out cornice control techniques without prior instruction, demonstration, and supervision. Any doubt as to the safety of the procedure should exclude it as an option.

Recommended Reading

“Uncertainties in Assessing the Stability of Fractured Slopes”; Karl W. Birkeland, Scott Savage, Simon Trautman, Kalle Kronholm, Spencer Logan, and Jürg Schweizer. 2006.

“Artificial Release of Avalanches by Explosives”; Gubler, H. 1976. Symposium on Applied Glaciology; Proceedings of the Fourth Symposium on Glaciology, Cambridge (England) September 13-17, 1976. Journal of Glaciology, Vol. 19, No. 81, p419-429, 1977.

2.7 Avalanche Observations and Recording Techniques

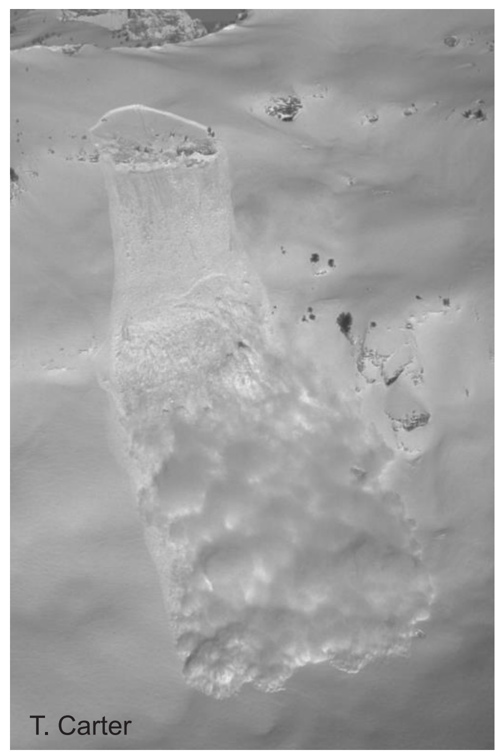
Learning Outcomes

- Describe the importance of avalanche observations.
- Know the standard observations taken when recording avalanche activity.
- Practice taking and recording these observations.

The best information about snow strength is that which is obtained directly from the avalanche occurrence:

- **Location**: Describe the position of the avalanche in the mountain range using mountain or path names, coordinates, elevation or other descriptors. Consider supplementing these descriptions with a photo of the event, both to support the description and for later reference of exactly where the avalanche ran.
- **Time of Occurrence**: Note if the recorded time is estimated or actual. Timing is critical in certain avalanche cycles. Are the conditions deteriorating; was this an “indicator slope” being the first to fail? Was the incident after the cycle indicating that in many areas the weak layer has slid on steeper slopes but now the lower angled slopes are releasing with more destructive potential?
- **Path Characteristic**: Further detail of where in the path the avalanche ran including aspect, incline, start zone shape etc…
- **Event Characteristic**: Note the number of occurrences, size, type, trigger, slab thickness / width, weak layer, vertical fall, or other notable details about this observation.

Actually going out onto the slide path and observing/feeling/measuring the snow is going to provide more-detailed, firsthand information, which is more useful when assessing what happened and when applying that information to a snow instability analysis.


T. Carter

For many, especially backcountry travelers, getting onto the slide path or to the fracture line is not possible or practical. In these cases, choose a vantage point that allows the best visual scan of the avalanche path. A pair of binoculars can help see details better. Use features on or near the slide to estimate scale and size. Compare what you see with other points of view. Record all observations as estimates or measurements. Use a camera to record and post observations.

Task: Avalanche Observation

Record an avalanche in your AIARE Field Book on your Field Observation page. Hint: use the prompts in the back the field book on p. 63 for a reference.

Recommended Reading

Snow, Weather and Avalanches – Chapter 3

Avalanche Observations, p.69

2.8 A Chapter Summary of Factors Commonly Used To Assess Snowpack Instability

Weather Factors	Observation Tools	Objective
Weather Forecast • Forecast the potential effect of weather on the mountain snowpack across range, across slope, effects of terrain shape and elevation • Short term, longer term, timing, duration, intensity	• Govt. and private weather forecast • Avalanche bulletin weather interpretation • Web weather resource	**What effect will the current and forecast weather have on the properties of the mountain snowpack?** **Will the weather affect the ability to gather quality field observations?**
Weather and Snow Surface Observations **Wind** • Past and present wind and effect, speed, direction **Precipitation Amounts** • Depth of storm snow, weight of precipitation during storm (measured as water equivalent) • Depth of new snow, intensity of snow fall, density of new snow **Blown Snow** • Snow transport by wind estimates **Air Temperature** • Previous temperatures, present temperatures, temperature trend **Snow Temperatures** • Effect on metamorphism, Temperature near surface, Temperature at weak layers **Solar radiation** • Effect of sun, influence of cloud cover **Penetration** • Penetration by foot, ski, or ramsonde **Snowpack Settlement** • Total settlement of snowpack, amount of settlement and rate of storm snow settlement • As a rough rule of thumb, a settlement rate of 15% in a 24-hr period indicates a slow increase of strength of the new snow.	• Standard 2x daily study plot weather observations • Daily field weather observations • Field weather summary record	**Is the current weather trend increasing or decreasing snow strength?** **Are new layers being created?** **Are weak layers being buried?**

<table>
<tr><th colspan="3">Snowpack Observations</th></tr>
<tr><th>Snowpack Factors</th><th>Tools and Tests</th><th>Objective?</th></tr>
<tr><td>Observing Snow Cover on the Ground (Depth variations, Slope use & Compaction)
• Adequate snow pack to cover terrain roughness (>30 cm on smooth ground)
• Distribution of snow cover due to wind exposure, elevation, and terrain configuration
• Variations of snowpack weaknesses and loads across different terrain features
• Effect of skier or other traffic in the snowpack, continuous skiing compacts and strengthens affected layers
Past Avalanche Activity
• Location/distribution where avalanches occurred (Isolated, Regional, Widespread?)
• Effects of past avalanches on snow stability</td><td>• Daily and seasonal observations
• Photographic records
• Probing
• Height of snow stakes</td><td rowspan="4">Is the snow unstable?
Where is weak snow?
Where is strong snow?</td></tr>
<tr><td>Snowpack Properties
Identify/date the significant weak layer
Note the slab on weak layers, the strength of weak layers, the stiffness of snow above weak layers, the strength and stiffness of snowpack, the bond of new snow to old snow surface.
Identify significant layers
• Average grain size,
• Grain type,
• Layer hardness
Identify significant interfaces
• Difference in grain size,
• Difference in hardness,
• Depth of interface
Comment on persistence of weak layer</td><td>• Full Profile baseline data to note changes of layering over time
• Compare baseline data to site specific test profiles noting variation over terrain
• Field tests: probing, hand tests and other quick tests to note extent and distribution of layering
• Use the snowprofile checklist to prioritize and note critical structural properties.</td></tr>
<tr><td>Observe Weak Layer Fracture Character
Observe bond of new snow to old surfaces, strength and stiffness of snowpack, stiffness of snow above weak layer and observe fracture character during tests</td><td>Small column tests
• Compression Test w/fracture character
• Shovel Shear Test
• Deep Tap Test w/fracture character
• Shovel Tilt Test</td></tr>
<tr><td>Observing The Propagating Crack within the Weak Layer
Once the failure initiation occurs observe the propagating crack</td><td>Large Column Tests
• Propagation Saw Test
• Extended Column Test
• Rutschblock Tests with WB release
Evidence of shooting cracks, whumpfing
• Natural occurrence
• From ski, explosive tests</td></tr>
</table>

Avalanche Activity and Terrain	Observation Tools	Objective
Current avalanche activity and terrain factors Visual indicators of unstable snow Location and slope exposure where avalanches are running • Upper, mid, lower slope • Elevation, aspect, incline Slope shape and characteristics Depth of fracture, width, slope length of avalanche path Widespread nature of avalanches • Isolated, regional, widespread Size and destructive potential of avalanches	• Observations, photos of natural avalanche occurrences • Fracture line snow profiles • Ski tests resulting in avalanches • Explosive tests resulting in avalanches • Cornice control Comparative analysis using info from historical records, avalanche atlas, photos, anecdotes, vegetative clues, estimation, comparison to other indicator slopes	**Relate terrain and snowpack factors to avalanche events:** • **Can the terrain produce an avalanche?** • **Where in the terrain can the avalanche be triggered?** • **What is the size and consequence of an avalanche occurring?**
Triggering Load required to trigger: light, heavy, natural, human, explosive Terrain proximity to triggers: Remote or on-slope trigger • High or low on slope • From shallow, rocky, or deeper snow Loose snow or shallow slab steps down to a deeper layer?	• Ski or foot trigger • Explosive trigger • Cornice drop	

Notes

PRESENTATION NOTES:

Chapter 3: Applying Observations to the Field Decisions

3.1 Trip Planning and Hazard Forecasting for Avalanche Terrain

Learning Outcomes

- Explain the relationship between Avalanche Danger, Hazard and Likelihood of Triggering.
- Use the Trip Plan as a hazard forecast checklist for travel in avalanche terrain.
- Lead a group discussion aided by the Communication Checklist.
- Explain how small groups can manage risk better than individuals.

Forecasting Danger vs. Hazard vs. Likelihood of Triggering

In some contexts, the terms danger and hazard are used synonymously, in other contexts a distinction is drawn. From a practical perspective, the words represent essentially the same concept – the potential for avalanches to cause damage.

Historically, the distinction between Danger and Hazard was intended to highlight a recreational context versus an operational context. The definitions below come from the 2010 edition.

Avalanche Danger – (SWAG p.132) Danger ratings are descriptors on a five-tiered scale used by regional and local avalanche forecast centers to represent to the public the probability of avalanche activity, the general parameters of degree and terrain distribution of avalanches, and to recommend backcountry travel precautions.

Avalanche Hazard – The potential for avalanches 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 of exposure to avalanches. Avalanche danger and hazard are synonymous and are commonly expressed using relative terms such as high, moderate and low. (SWAG p.129, 133). In practice, hazard generally refers to an operational estimation of the threat avalanches pose to people or structures in a specific location and operation. In North America, the Avalanche Hazard Scale is used by transportation and highway operations to describe, given the snowpack conditions, the possibility avalanches will reach the highway, and the amount of snow that will affect the highway. The OGRS (2007 edition) suggests "different operations tailor their hazard ratings (scale) to their operational needs." The terms used by both the Colorado Department of Transportation and the Ministry of Transportation in British Columbia are similar and not to be confused with the Avalanche Danger Scale.

Snow Stability – Snow stability "refers to the chance that avalanches will not initiate, and does not predict the size or potential consequences of expected avalanches" (SWAG p.131). Stability relates instability (or unstable snow) to a given "triggering level or load" (SWAG).

Likelihood of Triggering – Practically speaking, snow instability is discussed in terms of the *Likelihood of Triggering*. Likelihood of triggering considers the slope sensitivity (to a natural or artificially trigger) given the defined location of the weak layer across the terrain (see figure at the beginning of section 1.3 avalanche release). Descriptive parameters include: Almost Certain, Very Likely, Likely, Possible, Unlikely.

Theoretical Example
Conditions: On a north aspect above tree line, 30cm of storm snow has been recently deposited on a surface hoar layer. There has been a 30kph SW wind at ridge top for the past three hours. Two local guides decide to investigate and if possible ski the slope high above a highway.

- The avalanche danger to backcountry skiers is rated by the public bulletin as *CONSIDERABLE* danger over a range of aspects and elevations. Natural and human triggered avalanches are *LIKELY* on the north aspect below ridge top. Human triggered avalanches with a destructive potential of 2.5 have been reported and travel is *not recommended* on north and northeast aspects in wind-loaded alpine terrain.
- The local guides who are backcountry skiers do several profiles and tests on nearby safer slopes and observe the weak layer. Both ski tests on small slopes and large column tests, along with a week's worth of field observations, indicate that the likelihood of triggering *VERY LIKELY*; they decide that avalanches on the north aspect above the highway may be triggered by light (single skier weight) loads. They radio this information to another group skiing nearby.

- The department of transportation and highways rates the hazard to the highway as *LOW*. While areas of unstable snow exist and the likelihood of triggering is *POSSIBLE*, the highway travels through the end of the run-out zones and though natural avalanches are estimated to run to the "upper track" of the avalanche path as a maximum extent, they are not expected to reach the highway. Normal highway operations continue until additional snowfall or continued wind makes conditions worse.

Using the Trip Plan in the AIARE Field Book

Complete the Trip Plan in the AIARE Field Book prior to each trip. It provides a pre-trip checklist of critical avalanche danger factors and a place to summarize available information generated by the local avalanche bulletin. Backcountry users are advised to seek out additional information generated by the community of snow experts including professional guides, forecasters and veteran travelers prior to departure. This information is to be referenced to field observations noted on the facing page of your field book during the decision making process.

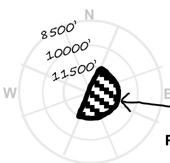
Fill out the form as a group and include each person's opinion. Small groups make better evaluations than individuals.

6

TRIP PLAN

DATE: 20130419 | **TIME:** 0730 | **FIELD LOCATION:** Up Gold Glade, down Green Glade or Blue Bowl

AVALANCHE DANGER: AVALANCHE ACTIVITY? • BULLETIN DANGER RATINGS?
"Where are avalanches likely to occur?" "Describe the problem?" "Specifically, which slopes will we avoid?"



Loose Dry ☑ Steep & sheltered
Loose Wet ☐
Wet Slab ☐
Storm Slab ☐
Wind Slab ☑ Above Treeline on NE to S.
Persist. Slab ☐
Deep Slab ☐
Cornice ☐

- Danger rating: MODERATE near and above treeline, LOW below treeline.
- Expecting touchy wind slabs.
- Yesterday, size 2 wind slab, E aspect, @ 12,000' on Red Ridge.
- Will avoid any wind slabs in upper Blue Bowl (N) by decsending to Green Glade (NW).

SNOWPACK DISCUSSION: NEW / STORM SNOW? • WARMING? • WEAKLAYER(S) TYPE / DEPTH / PERSISTENCE?
"Where is the best snow?" "What field observations needed?" "Do we have experience w/ these conditions?"

25cm storm snow fell two days ago on a stable spring snowpack. Storm began w/ SW wind, ending w/ NW wind. No significant warming trend since storm. Wind slabs expected on E'ly slopes and below ridgelines. Sheltered slopes still hold nice powder.

Obs to take: plan route to view avalanche activity; track storm snow depth w/ probing & hand tests; check wind slab depth/stiffness; ski tests on small safe slopes.

WEATHER FORECAST: SKY / VISIBILITY • PRECIPITATION • WINDS / BLOWING SNOW • TEMPERATURES • TRENDS
"How will forecast affect snow conditions?" "...affect our observations? communication? decision-making?"

Forecast @ 10,500': Clear sky, NO precipitation, L NW winds, High −2.5°C.
Expecting great visibility / gentle weather -easy visual observations and no weather stress. Watch temps today, but expecting dry snow during intended descent. Snow surfaces may get wet at the valley floors by PM and on steep southerly aspects.

TRAVEL PLAN: OBJECTIVE • OPTIONS • ANTICIPATED HAZARDS • OBSERVATION PTS • DECISION PTS • GROUP MGMT
"Is plan appropriate for our goals, experience, abilities?" "Everyone included in discussion, w/ consensus?"

Up Gold Glade (SW), w/ small detour to knob @ 11,300' to scan area for avalanche activity.

Decision pt. @ 12,200'. Need to see no wind slab / scoured snow surface at Blue Bowl entrance (N) for that option to go. Otherwise, drop (NW) into Green Glade.

Either way, traverse W ≈ 9,400'on road grade back to lower Gold Glade.

EMERGENCY RESPONSE: LEADERSHIP • GEAR ASSIGNMENTS • COMM. PLAN • EVAC ROUTE • EMERGENCY #'S
"Are we prepared & practiced?" "Outside help realistic?" "All concerns voiced re: dangers, risk, response?"

Radios Ch. 11.11; 911 w/ cell; Joe bivy sac/pad/sled; Keys under Jack's rear bumper;
Jen knows tour plan, call her @ 970.349.0000 upon return.
Evacuation route back down Gold Glade skin track."

The date provides a record of your pre-trip and field trip observations. Re-read yesterday's info prior to writing today's obs.

Write the danger rating from the public bulletin. Form an opinion on whether the rating provided by the bulletin matches or disagrees with your assessment of slope scale hazard and risk.

Trend's are the most important addendum to point observations.

Be vigilant when reported layers of concern include "persistent grain types" like surface hoar, depth hoar or facets. Avalanches may be triggered on these layers when few or no avalanches are occurring naturally.

Summarize the terrain to avoid (for example, slopes on NE aspects, steeper than 30 degree, wind-loaded slopes) by shading the terrain in the "rose" (noting range of aspect and elevation). Also write in the elevations on each representative line (example 6000, 9000, 12000). You can also write notes adjacent to the rose as a reminder of observed recent avalanches or recently observed wind-loading.

Plan which observation you will take using the Avalanche and Observations Reference (next page).

Always leave a copy of your travel plan including options with a friend or neighbor.

AVALANCHES & OBSERVATIONS REFERENCE

"The Problem"	Critical / Red Flag Observations	Field Tests & Relevant Observations	Important Considerations
Loose Dry Snow	•Fan-shaped avalanches: debris fine. •Loose surface snow ≥12" (30 cm) deep.	•Boot / ski penetration ≥12" (30 cm). •Slope tests / cuts result in sluffs. •Loose snow surface texture (as opposed to wind-affected, refrozen, or other stiff snow textures).	•Can be triggered by falling snow, cornice fall, rock fall, a brief period of sun, wind, or rider. •Sluffs can run fast and far. •Small slides dangerous with terrain traps / cliffs. •Sluffs can trigger slabs in certain conditions.
Loose Wet Snow	•Rain and / or rapid warming. •Air temp > 0ºC for longer than 24 hours (cloud cover may prevent nighttime cooling). •Pinwheels or roller balls. •Fan shaped avalanches: debris lumpy and chunky.	•Observed and forecast temp trend. •Temps (Air, Surface, T20) / freezing level indicate near surface snow temps at 0ºC. •Note slopes receiving / will receive intense radiation. •Wet snow surface: water visible between the grains with a loupe, may be able to squeeze water out with hands.	•Timing is critical. Danger can increase quickly (minutes to hours). •No freeze for multiple nights worsens condition. However, nighttime freeze can stabilize. •Gullies and cirques receive more radiation and retain more heat than open slopes. •Shallow snow areas become unstable first - may slide to ground in terrain with shallower, less dense snowpack. •May initiate from rocks or vegetation. •Can occur on all aspects on cloudy days / nights. •Conditions may also include cornice fall, rockfall or increased icefall hazards.
Wet Slab	•Rain on snow, especially dry snow. •Current or recent wet slab avalanches: debris has channels / ridges, high water content, may entrain rocks and vegetation. •Prolonged warming trend, especially the first melt on dry snow.	•Consider Loose Wet Snow observations. •Observed melting snow surface (rain or strong radiation) of a slab over weak layer. •Tests show change in strength of weak layer due to water and / or water lubrication above crust or ground layer. •Identify the depth at which the snow is 0ºC. •Monitor liquid water content and deteriorating snow strength using hardness and penetration tests. •Nearby glide cracks may be widening during rapid warming.	•Snow temp of slab at or near 0ºC. •Loose wet snow slides can occur just prior to wet slab activity. •Possible lag between melt event and wet slab activity.
Storm Slab	•Natural avalanches in steep terrain with little or no wind. •≥12" (30cm) snowfall in last 24 hours or less with warmer heavier snow. •Poor bond to old snow: slab cracks or avalanches under a rider's weight.	•Observe storm snow depth, accumulation rate and water equivalent. •Observe settlement trend: settlement cones, boot / ski pen, measured change in storm snow (>25% in 24 hours is rapid). •Tests show poor bond w/ underlying layer (Tilt and ski tests). ID weak layer character. •Denser storm snow over less dense snow (boot / ski penetration, hand hardness).	•Rapid settlement may strengthen the snowpack, or form a slab over weak snow. •When storm slabs exist in sheltered areas, wind slabs may be also present in exposed terrain. •May strengthen and stabilize in hours or days depending on weak layer character. •Potential for slab fracturing across terrain can be underestimated.
Wind Slab	•Recent slab avalanches below ridge top and / or on cross-loaded features. •Blowing snow at ridgetop combined with significant snow available for transport. •Blowing snow combined with snowfall: deposition zones may accumulate 3-5x more than sheltered areas.	•Evidence of wind-transported snow (drifts, plumes, cornice growth, variable snow surface penetration with cracking). •Evidence of recent wind (dense surface snow or crust, snow blown off trees). •≥ Moderate wind speeds observed for significant duration (reports, weather stations and field observations).	•Often hard to determine where the slab lies and how unstable and dangerous the situation remains. •Slope-specific observations, including watching wind slabs form, are often the best tool. •Strong winds may result in deposition lower on slopes. •Commonly trigged from thin areas (edges) of slab. •Wind transport and subsequent avalanching can occur days after the last snowfall.
Persistent Slab	•Bulletins / experts warn of persistent weak layer (surface hoar, facet/crust, depth hoar). •Cracking, whumping.	•Profiles reveal a slab over a persistent weak layer. •Use multiple tests that will verify the location of this condition in terrain. •Small column tests (CT, DT) indicate sudden (Q1) results; large column tests (ECT, PST, RB) show tendency for propagating cracks.	•Instability may be localized to specific slopes (often more common on cooler N / NE aspect) and hard to forecast. •Despite no natural occurrences, slopes may trigger with small loads - more likely when the weak layer is 8-36" deep (20-85cm). •Human triggered avalanches are still possible long after the slab was formed.
Deep Slab	•Remotely triggered slabs. •Recent and possibly large isolated avalanches observed with deep, clean crown face.	•Profiles indicate a well preserved but deep (≥1m), persistent weak layer. •Column tests may not indicate propagating cracks; DT and PST can provide more consistent results. •Heavy loads (cornice drop or explosives test) may be needed to release the slope - large and destructive avalanches result.	•May be aspect / elevation specific - very important to track weak layer over terrain. •Slight changes, including mod. snowfall, and warming can re-activate deeper layers. •May be dangerous after nearby activity has ceased. •Tests with no results are not conclusive. •May be remotely triggered from shallower, weaker areas. •Difficult to forecast and to manage terrain choices.
Cornices	•Recent cornice growth. •Recent cornice fall. •Warming (solar, rain at ridge tops).	•Note rate, extent, location and pattern of cornice growth and erosion. •Photos tracking change over time.	•Cornices often break further back onto ridge top than expected. •Can underestimate sun's effect on the back of cornice when traveling on cool, shaded aspects.

Using the Field Observations Page

This form allows for one day's field observations. Record significant field weather, snowpack, and avalanche observations that contribute to your field decisions and hazard analysis. Use the Avalanche and Observations Reference to target relevant observations for the conditions.

This form allows for 4 separate observations over the course a tour in the vertical columns.

FIELD OBSERVATIONS

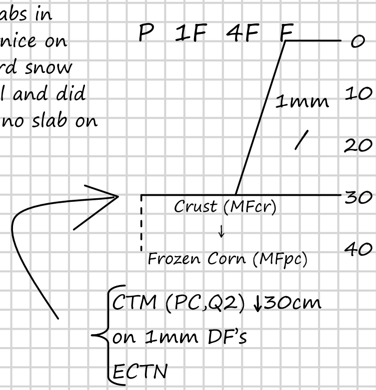
NAMES:	Joe J., Jane J., Jack J.			
Location •Time •Elevation •Aspect	0800, Trail-head, 9,000' valley floor	0930, Gold Glade knob, 11,300' S	1015, Gold Glade ridge / Blue Bowl entrance, 12,200'	1130, Blue Bowl exit, 9,400', N
Sky •Cloud cover •Precipitation	○ , NO	○ , NO	○ , NO	○ , NO
Temperature •Air •Surface & 20cm↓	T_{Air} -6.0° T_{Surf} & T_{20} N/O	-3.5° N/O	-3.0° N/O	-2.0° N/O
Wind •Speed / direction •Blowing snow	Calm None	Calm None	Light N winds, None	Calm None
Snow •Surf form / size •New snow •Snow height •Pen boot / ski	est HST 20cm Stellars & D/F's Boot Pen ↓ crust	>10cm HST on ridge (normally windswept)	HST ≈30-40cm just below ridge Boot Pen 45cm	HST ≈25cm Boot Pen 35

TERRAIN USE • SIGNS OF UNSTABLE SNOW • PATTERNS
Red Flags • Avalanches • Snowpack Tests • Other Observations • Comments

0800 – no fresh avalanches observed on the drive to trailhead. Recent cornice growth above treeline on SE-E aspects.

0930 – seen from Gold Glade knob: 3 wind slabs >12,000' on E and SE aspects below ridge crest (R1-D2) on Red Ridge, Purple Pk. and Maroon Mt. In general, less wind effect on south end of the range closer to town. Soft conditions with no cracks, whumpfs or fresh wind slabs seen so far on S-SW aspects.

1015 – Blue Bowl decision pt: No wind slabs in upper bowl. Dropped block of old hard cornice on N'ly slope @ 12,200' w/ no result. Fist hard snow still on ridge crest. Jane entered Blue Bowl and did two sets of tests, (see profile →) confirmed no slab on frozen old snow.



1200 – sunny slopes getting moist below treeline; crusts tomorrow.

REVIEW THE DAY: *"Were our choices in line w/ our forecast / plan?" "When were we most at risk?" "Where could we have triggered a slide?" "What would we do differently next time?"*

Record names and date across the top row.

Refer to this example each time to assist you in deciding upon which observations are significant.

Use the lower open space to record a variety of observations that may include quick hand tests, ski tests, partial profiles, surface and avalanche observations.

Remember to describe the terrain where the observations were taken.

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RAMPANT
NEW BELGIUM
ACCUMULATION
INDIA PALE ALE
NEW BELGIUM
RANGER
NEW BELGIUM
BREWING
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3.2 Risk Management for Small Groups

Learning Outcomes

- Describe teamwork and small group decision making as an antidote to human factors that can adversely affect pre-trip and field decisions.
- Plan to implement practical communication tools that encourage effective group decision-making.
- Communicate considerations for risk management for small groups in the backcountry in pre-trip meetings, in the field, and after the trip is completed.

Life is full of risks. There are personal, financial and physical risks that we encounter and manage every day. When it comes to travel in avalanche terrain, decisions we make can potentially have life and death consequences. Even the best forecasters and guides can't know *exactly* whether the snow is stable, nor whether the slope will avalanche. Therefore, the best forecasters and guides also have to the ability to extrapolate and be able to draw margins in the terrain and understand how to keep themselves and their party on the safer side of the margin.

Good leaders, by using a strategy to carefully execute a well-informed decision, minimize the chance of an accident. Simply put, this strategy includes gathering and determining the quality and quantity of the information, and applying the information to creating and implementing options. And, most importantly, the strategy includes a process of managing any human factors that can obscure one's ability to interpret information, form accurate opinions and options, or execute decisions.

The most common of these human factors include:

- Individual Bias: The tendency to hold onto a perspective at the expense of equally valid alternatives. For example, a one-sided viewpoint or prejudice.
- Poor situational awareness: Lack of awareness of what's happening in one's vicinity. In particular, being unaware of how one's own actions impact goals and objectives—immediately and in future.
- Poor group interaction: Examples include weighing "my opinion over yours"; or "the majority rules the few". Better interaction includes a shared vision and unanimous decision.
- Poor communication: The inability to communicate important information such as local knowledge, key field observations, or other relevant data that allows the group to make an informed decision.

The antidotes to the aforementioned human factors are simple to state, yet surprisingly complex to deliver; these are—*teamwork and effective communication*, *relevant experience*, and the use of specifically designed *checklists*.

Teamwork and Effective Communication

Small groups *tend* to make more informed decisions than individuals. However, this only occurs in a group with a shared vision and with an experienced facilitator. The leader elicits information from the group, listens to opinions of others and makes decisions from consensus. This process can illustrate and mitigate individual bias. However a few preconditions must occur:

- Know the group and ensure there is a shared vision.
- Complete a trip plan prior to any control route or backcountry trip. Ensure all group members share knowledge of the hazard, the forecast risk, and the plan to mitigate or control the risk prior to departure. Never "assume", always ensure, that communicated knowledge has been heard and understood. Most avalanche professionals write down the plan in a notebook and take it into the field.
- Ensure the group's individual expertise is complementary (local knowledge, good snowpack and terrain skills, a thoughtful decision maker in the group, a stronger person who can facilitate a rescue response or keep the group moving in challenging conditions).
- Ensure complimentary fitness and skills within the group. Or, a group willingness to match the objective to the least skilled and least able.
- Ensure tasks and responsibilities are shared. Group inequalities do not result in unanimous decisions. A healthy group dynamic encourages participation and rewards motivation.
- *Agree to travel together. Agree to decide together. Agree to respect everyone's voice and <u>anyone's</u> veto*. These wise words are from the AIARE Communication Checklist—a tool to help

maintain situational awareness in the field. Prior to departure on either a control route or backcountry adventure the group requires "rules of engagement" to encourage effective group communication and to mitigate individual or group bias. This means agreeing, prior to departure, to regrouping in the terrain and reassessing as a group. Even self-appointed "followers" need to participate in terrain choices, interpret information, and provide an opinion. Acting on decisions is a practiced skill and those who aren't experienced at implementing options should be rewarded with the opportunity to create options. Consider that the inexperienced may have an "outside eye" to a circumstance, and bias maybe distorting the perspective of the most experienced. The antidote is to have a protocol that requires that all decisions to be unanimous, and everyone must have an opinion regardless of their experience or expertise, and that all opinions are respected—regardless of the outcome upon the objective.

- Communicate clearly between any groups in the field. Accidents involving more than one party, or, accidents resulting from groups not relaying key information, are becoming more common. When practical, plan *when* to talk and *what* you will say. For example communicate prior to exercising your option; let your groups know which is the group's preferred choice given what you *now* observe in the field? Talk around radios or cells are popular and frequently carried. Plan to use them!

Relevant Experience

The issues of overconfidence, lack of confidence, uncertainty and unfamiliarity plague the good decision. Many avalanche accidents occur when the group is making ill informed decisions that are out of the depth of their collective relevant experience. This includes:

- The ability to travel through and safely manage the group in the terrain.
- The skills to collect and interpret information and to accurately assess snow instability and avalanche hazard. This includes having a practiced and consistent process for both gathering and evaluating information and making decisions.
- Local familiarity with the terrain. This includes a familiarity with relating avalanche events, to conditions, to specific terrain features – essentially reliable pattern recognition requires familiarity with comparable events.
- Skilled, practiced search and rescue techniques.

Pre-trip planning helps to anticipate whether or not the group is prepared to take on the objective as discussed. "Have we been there before?" "Have we been in similar terrain before?" "Are we familiar with the conditions?" "Is this a typical or atypical season or event?" "Will weather allow us to preview the terrain and get a 'feel' for conditions prior to becoming too committed?" These are questions groups often ask to assess their confidence and familiarity prior to departure.

Pre-event rehearsal and a shake-down tour prepare the group for bigger, more complex terrain. Avalanche operations and guiding operations plan for staff training where control routes are rehearsed, teams work together to see how they get along, emergency response exercises are rehearsed to train decision-making under duress and the methodology of a response. Backcountry skiers can do their own versions of the above and become better prepared to make important decisions as a group and respond as a team should their best decision go awry.

The daily debrief is important to assess whether the risk management applications were appropriate. The day end review often serves to evaluate perspective and performance. These questions are listed on the AIARE 2 Evening Hazard and Risk Assessment worksheet: "Were our choices in line w/ our forecast / plan?"; "When were we most at risk?"; "Where could we have triggered a slide?"; "What would we do differently next time?".

Checklists

Checklists are the most important tools employed by decision makers to maintain the group dynamic, maintain situational awareness, and to simply not forget information critical to the day's decisions. It is important to note the difference between a conceptual model, like the AIARE Decision Making Framework (that provides a 'global' view of the decision making process) and a practical checklist that offers a step by step procedural approach to decisions made in avalanche terrain:

Pre-trip risk assessment checklist:
The AIARE Trip Plan is a checklist designed to facilitate a pre-trip group safety meeting. It can be filled out by anyone and employs prompts to facilitate the discussion. It requires the group to research expert opinion and to

form an opinion with regards to weather, snow and avalanche hazard factors. It also requires the group to assess gaps in knowledge, relate factors to current and prior events, and to assess their avalanche risk. It documents the daily decision making process in a water resistant fieldbook that enables the group to carry both the public bulletin information and group discussion into the field to apply to field decisions (as opposed to relying on memory). The checklist also prompts equipment and rescue response preparedness.

Situational awareness checklist:
The AIARE Communication Checklist is designed to maintain situational awareness in the field and to be employed at key stops during the day: at the trailhead, at key junctures in the terrain, at key decision making points. The prompts are in the voice of the “devil’s advocate” ensuring the important process of reflection on intuitive decisions made. “What’s changed?”, and “What’s the consequence if we have a problem?” are examples of reflective questions that encourage each participant’s inner voice.

Emergency response checklist:
At the back of the AIARE Fieldbook the rescue checklist provides a “go-to” list of actions required in the unlikely case of an avalanche accident. It is well known that during the elevated stress of an emergency response even the best trained defer to a set of protocols to ensure nothing is forgotten and the response follows a strategic plan. It is hard to think straight when your partner is buried under one meter of dense avalanche debris.

Debrief checklist:
The questions under the subtitle “Review The Day” in the AIARE Fieldbook and the second page of the AIARE 2 PM Avalanche Hazard and Risk Assessment form are a critical post event risk management checklist. In order to improve on daily decisions it is key to debrief the accuracy of the morning risk management plan in light of the decisions made in the field. Along with the other questions, “What would we do differently next time?” identifies what have we learned from our errors and our successes.

Conclusion

The great New York Yankees catcher and coach Yogi Berra has a saying, “It’s tough to make predictions, especially about the future.” Such is the case when it comes to predicting where avalanches will occur and whether or not we can safely travel in avalanche terrain. Faced with uncertainty, patrollers, forecasters and backcountry travelers must have a process to manage uncertainty and the risk of avalanches.

Consider that case histories reveal contradiction after contradiction when it comes to human behavior and risk management. Anecdotally, “accidents occur because not enough information is available”; “we have trouble recognizing how much information is enough and how much is too much”; “we display risk-aversion when we are offered a choice in one setting and then turn into risk-seekers when we are offered the same choice in a different setting.”

We are all vulnerable to prediction errors. This is an important fact. When faced with uncertainty in making life-and-death decisions, manage that risk; err on the side of safety and live for another day.

3.3 Using a Checklist to Evaluate Snowpack Instability – PM Avalanche Hazard and Risk Assessment

Learning Outcomes

- Apply the PM Avalanche Hazard and Risk Assessment checklist.
- Explain why forecasters use checklists to "cover all the bases" when analyzing complex data. This process reduces the likelihood of error when analyzing snowpack stability.

One method the avalanche forecaster employs to manage and prioritize critical information is a checklist. AIARE has developed the PM Avalanche Hazard and Risk Assessment to use when assessing current snowpack instability.

The checklist helps observers identify and process important information. It prevents the observer from missing something major and assists in putting the information in an orderly format and encourages the process of crosschecking factors. This clarifies the step-by-step method by which forecasters analyze snowpack instability. *Note: the checklist does not consider the all-important terrain factors or human factors—only weather, snowpack and avalanche observations.*

The columns and rows of data do not "sum up" factors. There is no magic formula to suggest whether the snow is unstable or not. Experience is still required to relate relevant snowpack information to the terrain. The checklist merely allows one to organize the information, and allows the observer to indicate and track trends and weak layers.

When to use the PM Avalanche Hazard and Risk Assessment – On the AIARE 2, the form is intended to be used at the end of a day of travel in avalanche terrain. This checklist guides a group or an individual through the process of a) transferring information recorded in the field into an "operational" record, b) reviewing critical factors to form a summary opinion about the avalanche danger observed and c) debriefing the day's decisions and risk management strategies. In contrast, the Trip Plan is the checklist used in the morning to process pre-trip information from the avalanche bulletin, the weather forecast, morning weather, and snowpack observations, and to *forecast* terrain use and avalanche hazard.

How to use the PM Avalanche Hazard and Risk Assessment – During a post-trip debrief, a facilitator follows the prompts to lead a group discussion. Everyone can follow along on the form.

Page 1 of the form is used to record data observed, note trends and form a summary opinion on the avalanche danger level observed in the field by the end of the day.

In the Weather section, use data collected from field weather observations. Consider supplementing or comparing the data to nearby weather station data to improve the quality of the data set. If data comes from any source other than the field observations, make sure to note the source, for example: "high temp of 4°C @ Blue Moon wx station, 9,400'." Snowpack information should highlight critical observations from the day and paint a picture of how snow varied over the terrain observed. Note the objective of field tests and their location to provide context for any raw data, for example: "Investigated recent avalanche in Red Gully. A profile on 20° slope, 30m North of and adjacent to Red Gully's startzone on NE aspect, 10,200', revealed a 2cm SH layer, ↓60cm, slab 4F stiff with good propagation potential – CTM (SC), ECTP21." Detail any avalanches observed and summarize your assessment of the day's avalanche problem in the Avalanche section. Note, the danger rating itself is less important than the process of summarizing and highlighting the most significant instability and hazard factors, and observing trends across the terrain and through time.

Page 2 provides a checklist for a day-end debrief, much like the "Review the Day" questions introduced on the AIARE 1 course. Use these questions to elicit discussion on the choices the group made and why. The process of gaining applied experience at managing risk in avalanche terrain can happen much more quickly and reliably when decisions are reviewed and constructively critiqued.

PM AVALANCHE HAZARD and RISK ASSESSMENT – AIARE 2

DATE:	TIME:	LOCATION:	OBSERVER:

WEATHER

From today's field weather observations, describe the changing weather in the area observed *(Field Book symbols pg. 60)*

SKY: *cloud cover, trend, timing*	
TEMP: *high / low @ elevation, trend*	
FREEZING LEVEL: *observed or est.*	
PRECIPITATION: *type / rate*	
WIND SPEED / DIRECTION: *@ ridgetop*	
BAROMETRIC PRESSURE: *trend (mb)*	

SNOWPACK

From near surface snow observations describe how, during the past 24 hrs, the weather is changing the snowpack

SURFACE: form / size (mm)	
TEMP GRADIENT: *Tsurface to T-20cm (°C)*	
NEW SNOW: *est. past 24 hours*	
SETTLEMENT: *from □ in height or foot pen.*	
BLOWING SNOW: *ext. / dir. note location elev.*	

Describe notable observations and field tests that contribute to your knowledge of snowpack layering and instability
Importantly, address uncertainty by noting gaps in evidence and data

OBS: *whumps, shooting cracks, melting, scouring*

FIELD TESTS: *location, type, objective & relevance, verification*

AVALANCHES

Summarize recent observed and / or reported avalanche activity that indicates instability trend *(Field Book p. 63)*
Note ***size, type and distribution*** *of avalanches (Example: Numerous size 1 to 1.5 Loose Dry, steep N aspects, past 24 hrs)*

Assess today's avalanche problem and prioritize in order of concern
State the depth of important layers; and the date, if known, when the layers were buried (Field Book p. 4-5)

TYPE & CHARACTERISTICS **LOOSE**: *Dry, Wet* **SLAB**: *Storm, Wind, Persistent, Deep* **CORNICE FALL**	**WEAK LAYER, DATE**	**LIKELIHOOD OF TRIGGERING, EXPECTED SIZE, % PATH** *Almost Certain, Likely, Possible, Unlikely, Very Unlikely*	**LOCATION** *Elevation, Aspect, Terrain shape*
1)			
2)			
3)			

DANGER

Rate the avalanche danger for the area observed

ZONE or ELEVATION RANGE	DANGER RATING	TREND / TIMING: *Improved, Little change, Deteriorated*
ALPINE:		
TREELINE:		
BELOW TREELINE:		

MANAGING RISK

Review the day, and debrief today's risk management

Review the morning plan, our risk evaluation and our confidence. *"Were our choices in line with our forecast and plan?"*

Assess uncertainty and target our understanding of instability, hazard, and terrain: *"When were we most at risk?"*

Lessons learned: "*Where could we have triggered a slide?"*

Lessons learned: "*What would we do different next time?"*

3.4 AIARE 2 Post-Course Self-Evaluation and Course Critique

The AIARE 2 Course Leader facilitates the post course student self-evaluation as part of the course closing exercise. Each question can be discussed in a group discussion—to the degree to which the students feel comfortable.

Learning Outcomes

- Self-evaluate your competence with the skills and knowledge you gained on this course.
- Describe the challenges and dangers that exist when applying new knowledge in the backcountry without the oversight of a skilled mentor or expert.
- Discuss whether the course met or exceeded the student expectations; and what was the knowledge or skills each student gained during this course?

1. Did this course meet your expectations?

2. Did this course allow you to improve your skills? List the new knowledge and skills gained this week:

3. What were the three *most* interesting topics? Which were the topics you *least* enjoyed?

4. Describe your instructor's performance.

In the classroom. In the field.

How could they improve?

Did they provide good demonstrations of skills taught this week?

5. It is a fact that many recent avalanche victims are "avalanche aware" (meaning they have completed an avalanche course). How do you plan to apply the skills learned this week and still ensure that your terrain and snowpack decisions reflect your *current* experience?

6. Where do you plan you go *after this course* to continue the educational process?


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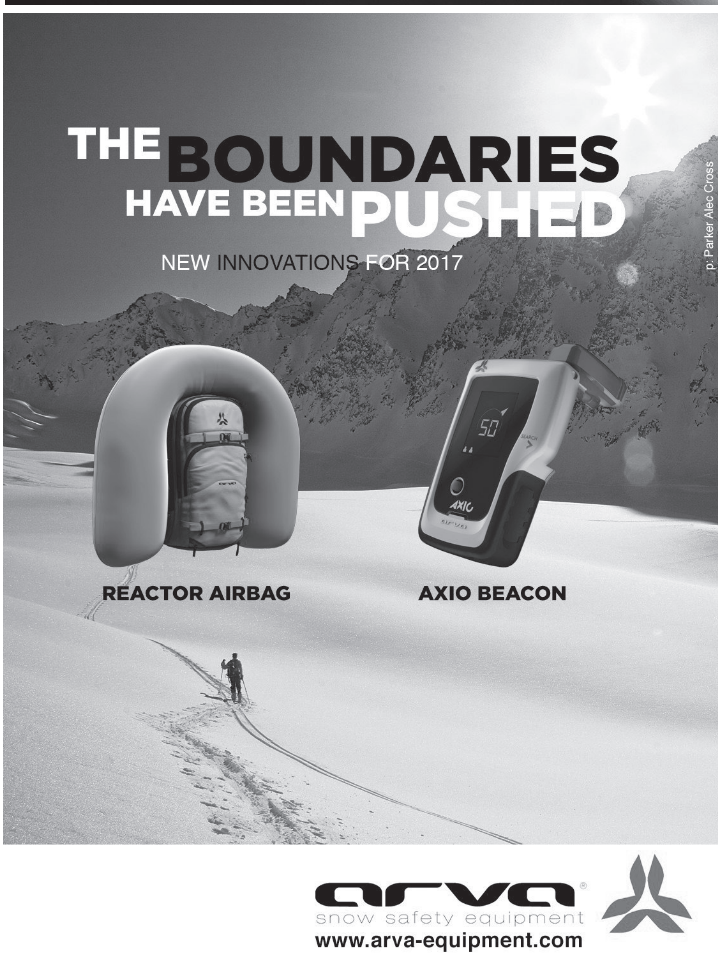
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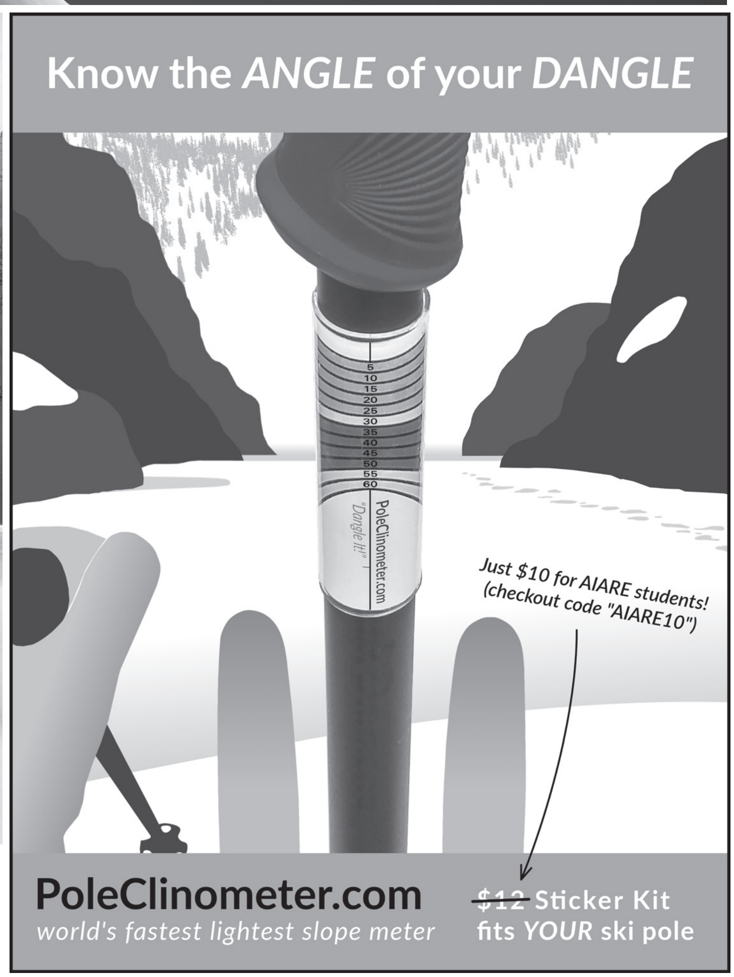
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PM AVALANCHE HAZARD and RISK ASSESSMENT – AIARE 2

DATE:	TIME:	LOCATION:	OBSERVER:

WEATHER

From today's field weather observations, describe the changing weather in the area observed *(Field Book symbols pg. 60)*

SKY: *cloud cover, trend, timing*	
TEMP: *high / low @ elevation, trend*	
FREEZING LEVEL: *observed or est.*	
PRECIPITATION: *type / rate*	
WIND SPEED / DIRECTION: *@ ridgetop*	
BAROMETRIC PRESSURE: *trend (mb)*	

SNOWPACK

From near surface snow observations describe how, during the past 24 hrs, the weather is changing the snowpack

SURFACE: form / size (mm)	
TEMP GRADIENT: *Tsurface to T-20cm (°C)*	
NEW SNOW: *est. past 24 hours*	
SETTLEMENT: *from in height or foot pen.*	
BLOWING SNOW: *ext. / dir. note location elev.*	

Describe notable observations and field tests that contribute to your knowledge of snowpack layering and instability
Importantly, address uncertainty by noting gaps in evidence and data

OBS: *whumps, shooting cracks, melting, scouring*

FIELD TESTS: *location, type, objective & relevance, verification*

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Lessons learned: "*What would we do different next time?"*

Snow Profile

Reference: ____________________

Date: __________ Time: __________ Observers: ____________________

Location: ____________________

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

Blowing Snow Ext. ____Dir. ____ Surface Penetrability (PF)_____ cm HS _____cm Profile Type: [ ]

Snow Layer Temperature (°C) -18° -16° -14° -12° -10° -8° -6° -4° -2°C	Depth H	Moist θ	Form F	Size E (mm)	Density ρ (kg/m³)	Test Results and Comments
I K P 1F 4F F						

Form supplied by the American Avalanche Association, (SWAG)

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