Part 2: Avalanche Fundamentals

2.1 - Avalanche Types and Characteristics

Learning Outcomes

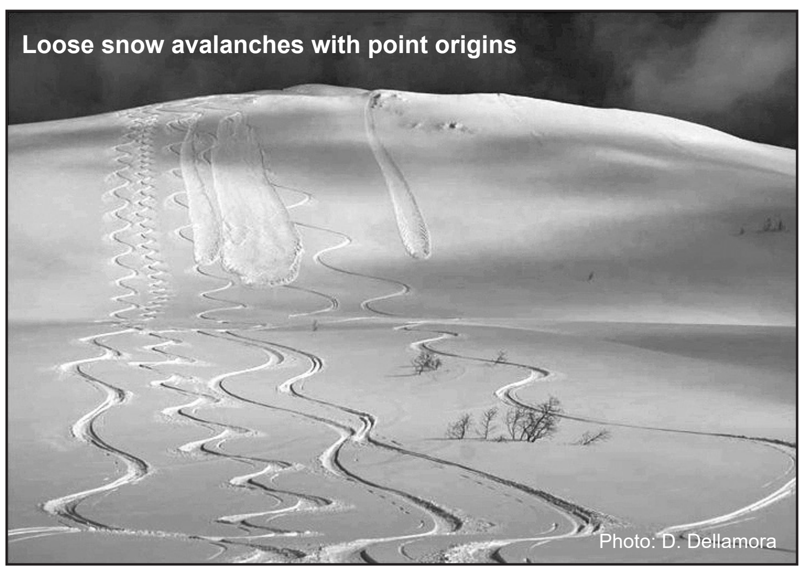
- Identify the avalanche problem by its characteristics as described in a public bulletin.
- Associate the relationship of the avalanche problem to potential consequences for backcountry travelers.
- Relate knowledge of avalanche motion to risk and safer travel techniques.
- Outline the classification system for size and destructive potential.

Avalanche type refers specifically to the physical characteristics of an avalanche. The types of avalanches include loose snow, slab, and cornice avalanches. The word “avalanche” is often used interchangeably with the word “slide.”

Backcountry travelers note patterns in avalanche distribution and characteristics - their destructive potential, width, slab thickness, trigger etc... These patterns in the types, characteristics, location and extent throughout the terrain are described as “avalanche problems,” “concerns” or “issues” in avalanche advisories or bulletins issued by avalanche forecast centers. Avalanche problems are categorized by how we treat different kinds of avalanches in the field.

Loose Snow Avalanches

Loose snow avalanches begin as loose, unconsolidated surface snow. They usually start from a point, gathering mass and speed as they flow down the slope. They result in a “fan shaped” trail of disturbed surface snow. Because they have a characteristic start point, loose-snow avalanches are commonly referred to as point releases or sluffs. The disturbed snow left behind after an avalanche is the bed surface. The pile of debris where the avalanche comes to rest is the deposit. Loose snow avalanches are easier to predict than slab avalanches. The conditions, timing, and snowpack characteristics at the point of slope failure are, relatively speaking, easier to observe and assess. This is not to say that loose snow avalanches should be taken lightly - an error in prediction or underestimating the destructive potential, size or trajectory can lead to serious consequences.



Loose Dry Snow Avalanches

Experienced backcountry travelers expect loose dry snow avalanches (sluffs) in freshly fallen new snow during or shortly after a storm on steep slopes. They are observed before the storm snow has time to settle and strengthen. Loose dry snow avalanches can be triggered naturally from new snow loading, from snow chunks falling from rocks, trees or cornices; or as a result of a rider's track in steep terrain. Also, riders in steep terrain notice that loose dry snow avalanches occur days or weeks after a storm in loose faceted (sugary) old snow that has been exposed to cold temperatures.

Loose dry snow avalanches involve the surface or near surface layers and are therefore smaller and less destructive as compared to slab avalanches. While small loose snow avalanches are relatively insignificant in terms of volume or impact force, they often occur on steep hazardous terrain. NOTE: Even a small sluff can have significant consequences if a person is in a precarious position or a terrain trap exists below (e.g., a climber on steep, technical ground above cliffs, water, or confined terrain where snow could pile up deeply). Backcountry travelers can attempt to manage the loose dry-snow avalanche hazards in the several ways:

- **Avoid steep terrain with traps below** (gullies, creeks, tree wells, road cuts), especially when loose dry snow avalanches are observed. The debris pile may bury a rider even on a small slope. Timing is a critical factor when the hazard is initiated by sun affect or warming.
- **Initiate the sluffs intentionally**, wait until the moving snow stops, and descend within the area of the disturbed snow.
- **Sluff management is applied by expert riders** who descend the "steeps" when they perceive low consequences and their concern is primarily the loose surface layers. This involves taking a diagonal line where any sluff triggered will pass down and behind the line of descent. If a trailing sluff is gaining mass and momentum, pull out onto high ground, changing fall-lines, or wait until the sluff passes prior to continuing down the original descent line. NOTE: this technique requires expert judgment and descent skill and errors could obviously have fatal consequences.

Loose Dry Snow Avalanche

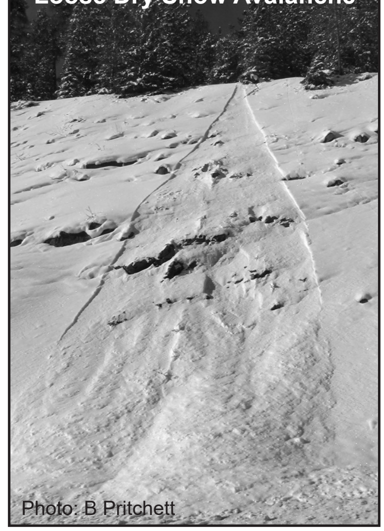


Photo: B Pritchett

Loose Wet Snow Avalanches

Warming, solar radiation, rain or a combination of these factors can result in the surface layers warming to 32°F / 0°C. The surface wet layer results in a localized loss of cohesion and a point release similar to a loose dry snow avalanche. A slower moving loose wet snow avalanche may be small and localized. It may entrain a greater mass of snow, leaving grooves or striations in the bed surface, even scouring the entire depth of the snowpack (usually in shallow continental snowpacks) resulting in large destructive avalanches. Despite their slow motion, loose wet snow avalanches are difficult to escape, similar to a cement flow. They may involve large wide sections of the slope and result in a dense debris pile that could quickly trap or bury the rider with few options for survival. Loose wet snow avalanches may result in a channeled or ribbed deposit that may run for some distance across the flats. In slush flows water may be visible on the deposit.

This wet loose slide injured the rider who triggered it

Photo: A. Parmet

Photo: AIARE files

Loose wet snow avalanches are often preceded or triggered by “pinwheels” or snowballs gathering momentum on solar aspects. Loose wet snow avalanches may trigger wet slabs during rapid warming, rain events or spring conditions. This lends an unpredictable element to conditions that result in loose wet snow avalanches. Wet slabs (see below) can be very destructive and involve the entire snowpack.

Slab Avalanches

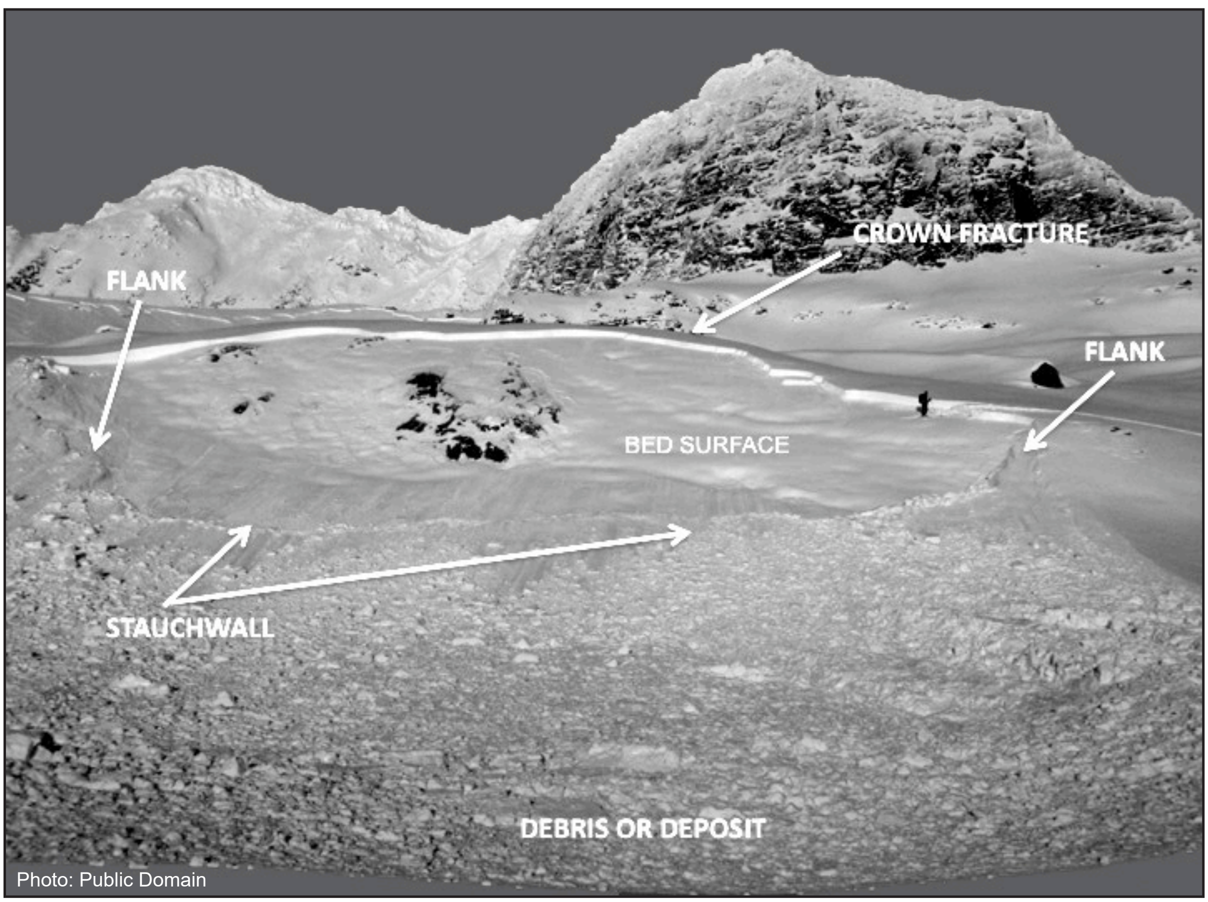


Photo: Public Domain

Slab avalanches start as a unit of cohesive snow. The unit of snow becomes fractured and separated from the surrounding snow. The unit (slab) often quickly (sometimes almost instantaneously) breaks into smaller, angular chunks as it moves down the slope. If the avalanche moves far enough and fast enough, the chunks eventually break up into smaller and smaller pieces.

The *slab* is the unit of snow that initially fails and displaces. The wall of snow left behind at the upper limit of the slab is the *fracture line or crown.*

The sides of the slab are the *flanks*. The surface left behind is the *bed surface*. The layer where bond failure between the slab and bed surface occurs is called the failure layer or weak layer. The failure layer is often thin (<0.5” / 1cm) and sometimes indistinguishable to the untrained eye. The lower limit of the original slab is the *stauchwall*. In most cases, the stauchwall is overrun and obliterated by the passage of the slab and is generally unrecognizable. The pile of debris an avalanche leaves behind is referred to as the deposit. For a slab avalanche to occur there needs to be a slab that overlies a weak layer, a bed surface and a trigger.

A slab avalanche generally has an angular shape, with the fracture line usually running close to horizontal across the slope and with the flanks parallel to the slope. The fracture line and flanks may be straight or irregular. The bed surface is usually smooth, but occasionally contains steps or irregularities across some portion of the slope.

As the entire slab displaces from the slope, those caught have a difficult time getting off the moving snow towards the flanks of the avalanche. The rider’s action in the first one or two seconds offers the best hope of exiting to either slower moving snow or a safe zone to one side of the avalanche. To escape off the slab itself, one must act when the slab is moving in gliding motion and before it gains speed and the blocks disintegrate into flowing motion (see avalanche motion below). Most avalanche fatalities involve slab avalanches.

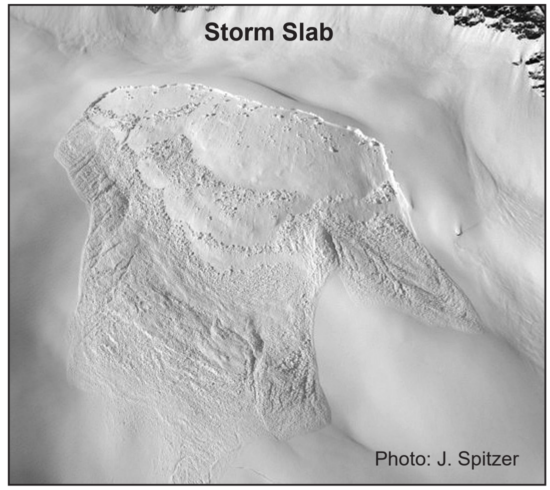
Wind slabs

Whenever there is sufficient wind (>12mph / 20kph), loose dry surface snow, and suitable terrain, wind slabs will develop. The wind picks up and transports freshly fallen or loose surface snow from the windward slope, breaking up the snow into smaller particles, and deposits the fragments onto the lee slope. Wind slabs commonly occur below ridges, below cornices, below convexities and to one side of mid slope moraines. The recently deposited snow rapidly settles and strengthens into a cohesive layer. When this slab sits over a weak layer of recent snow or does not bond well to the old snow surface avalanche conditions can develop.

Wind slabs are often triggered naturally by additional overloading of new snow or wind deposit during or shortly after a storm. Recent wind slabs may be softer in stiffness (one finger easily penetrates) or hard enough that skis or even boots won’t penetrate the surface. Soft slabs forming within hours or days of the storm tend to be more reactive to skier triggering. Slabs may sit undisturbed by a natural trigger until a skier or rider provides the trigger.

Fresh snowfalls may hide visual clues that wind slabs formed during the storm. Local history and expert advice is the best indicator of where wind slabs have formed and whether they are likely to be triggered. Wind slabs may be thin, rapidly tapering slabs or large resulting in destructive avalanches. Watch for snow “plumes” or snow blowing off the ridgetop for evidence that wind slabs may be forming. Watch for recent avalanche activity, especially crown fractures below the ridge crest, for evidence of wind slab avalanches. Watch for mid-slope cross wind effect near ribs parallel to the fall line and tree islands after periods of strong winds. Wind slabs sitting over storm snow may strengthen after a day or two. However, wind slabs sitting over persistent large irregular grain types may develop into Persistent Slabs (see Persistent Slabs).

Storm Slabs


Storm Slab
Photo: J. Spitzer

Throughout the year storms depositing significant loads (>12" snow / 30cm) can form widespread soft slabs. Storm slabs occur as the overburden of the new snow forms a denser, stronger layer over a less stiff, weaker layer bonds poorly with the old snow surface. One scenario where this can occur is when a storm deposits a new load over weaker surface snow. An alternate scenario can develop within the new snow when the top of the storm snow settles more rapidly than the bottom, creating a relatively stronger more cohesive layer above a less dense layer of new snow. The problem is exaggerated if temperatures warm as a storm ends, creating "upside down" layers.

Larger storms can result in storm slabs over a great range of terrain and elevation. As the storm progresses smaller releases on steeper slopes may be followed by larger avalanches on lower angled slopes.


Paths that may run naturally during storms
Photo: B. Pritchett

As the storm continues and the overburden grows, paths that do not avalanche frequently may become active, often referred to as a widespread avalanche cycle. Without persistent weak layers below, a storm slab avalanche cycle tends to end in two or three days. Storm slabs are usually "soft slabs" and prone to triggering during or shortly after the storm. Storms where the air temperature warms during the event may also be accompanied by high winds aloft. "Upside down" riding conditions may result in triggering storm slabs below treeline and triggering wind slabs in open exposed alpine terrain.

Recently formed "snow cones" or settlement cones around small trees give clues that the storm snow is rapidly changing. Skiers may notice their ski penetration has lessened or snowboarders may notice their boot penetration had decreased. This could illustrate the storm snow is settling and gaining strength; or if there is a buried weak layer it may indicate the formation of a storm slab. If that weak layer is composed of large sugary grains (facets), the avalanche problem may linger as a Persistent Slab (see below). Powder fever and storm slabs lie at the heart of many backcountry accidents.

Wet Slabs

During periods with above freezing temperatures, especially with intense sun or rain the snowpack may become warmed to a moist snow condition (32^0F / 0^0C) and the underlying weak layer is affected by liquid water. Wet slabs may be triggered by a loose wet-snow avalanche or fracture and release independently.

Wet slabs occur during prolonged warming events common to spring conditions or during rain events. Depending on the depth and nature of the weak layer, wet slabs may be small and confined to steep, rocky, solar-radiated terrain or involve the full width of start zones during rain on snow events. Large wet slabs tend to initiate slowly, break into smaller sections and run full path if the terrain permits.


Photo: C. Mitchell

Timing is critical to avoid sunny aspects as they heat during the day. During warming events night time cloud cover or haze may prevent diurnal cooling and stabilization; the following day's warm up may result in avalanches earlier in the day than would otherwise occur.

Rain events will affect all aspects simultaneously and may affect large portions of a mountain range. Rain does not have to penetrate to the weak layer to trigger slab avalanches! Avalanches may begin within minutes of rain falling on cold snow! Continued rain events may result in the same path avalanching more than once in the same cycle with full depth slope failure.

Persistent Slabs and Deep Slabs

Soft or hard slabs overlying a reactive weak layer made up of surface hoar, facets, a facet/crust interface, or depth hoar are referred to as a persistent slab (see Formation of Layers in the Mountain Snowpack). This condition may be the most dangerous avalanche condition to manage: may be difficult to forecast, may be easy or stubborn to trigger, and likely will persist through the initial storm avalanche cycle evolving into larger more destructive avalanche conditions.

Snowmobile triggered slab on surface hoar

Photo: avalanche.ca

Unlike storm snow avalanches where observed avalanches point to increased danger, fatalities have occurred involving persistent slab avalanches when NO or few natural avalanches are occurring! This is a condition where close attention to the bulletin and digging and observing the snowpack layers and completing a few basic snowpack tests (such as a Rutschblock test) may be the best method of observing the buried instability.

Deep Slab remote triggered on depth hoar.

Photo: L. Castillo

A thick, hard slab sitting over a deep or basal weak layer is referred to as a 'deep slab'. While it is less common to ski trigger slabs deeper than 3', they may be triggered from spots with weaker shallower snow. If the weak layer is a persistent grain type, they can be triggered from a location distant from the actual fracture, known as a remote trigger. Deep slabs are destructive, with fractures that may propagate for long distances across the slope, may run full path with significant impact force, and involve thousands of tons of snow in the deposit. A noteworthy portion of avalanche research involves attempting to understand the nature of large slab avalanches that have historically affected transportation corridors, mountain villages, and backcountry recreation.

Cornices

Cornices are overhanging snow structures that form from wind drifting of snow across the top of a ridge. The wind tumbles and fragments snow particles into small even-sized grains that pack together and bond quickly. Cornices are layered and can range from small wind lips to mature 30' (10m) overhangs of snow. Cornices can collapse suddenly fracturing back right onto the top of the ridge. The subsequent cornice fall can be hazardous pulling the inattentive climber or skier off the ridge onto the slope or over the cliff below. Even small cornice chunks are dense and heavy and can be destructive and deadly. The cornice fall can entrain loose surface snow or trigger slab avalanches resulting in significant and destructive avalanches. Backcountry travelers are wise to avoid slopes with large cornices above especially on days with warming, light rain or intense solar radiation.


Photo: T. Carter

Mature Cornice

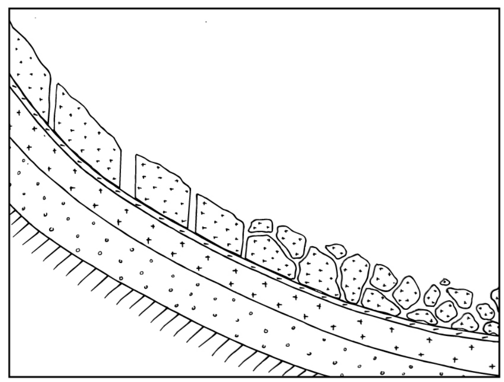

Photo: T. Carter

Mature Cornice Pull Away

AVALANCHE MOTION

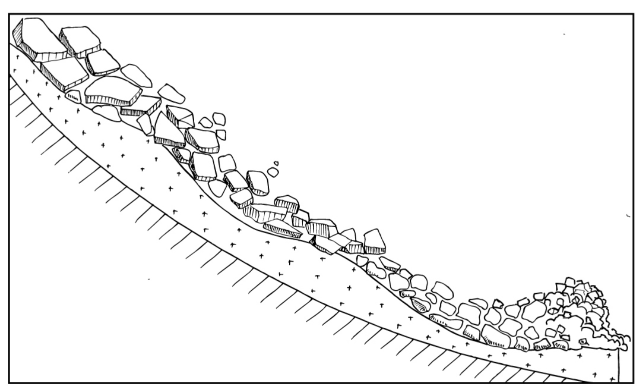
Gliding Motion

- *Speed:* 0-15 mph (0-25 kph).
- *Movement Characteristics:* Some break-up of the initial mass may occur. Blocks of various sizes tend to stay intact while the avalanche moves. No or very little mixing or turbulence.
- *Powder Cloud:* No significant airborne snow component (no powder cloud).
- *Deposit Characteristics:* Deposits from avalanches of hard snow usually contain angular chunks of a similar size as those that formed during movement. Deposits from avalanches of soft snow may contain smaller chunks and perhaps some fine-grained snow.
- *Constraint by Terrain:* Gliding motion avalanches are relatively easily constrained or stopped. They tend to follow or flow around terrain features such as gullies, mounds, banks, hills, etc.
- *Comments:* Gliding motion is experienced early in an avalanche, before enough speed or mass creates turbulence.
- *Hazards:* In general, less destructive than other types of motion. Can be serious if terrain traps exist. Slow, twisting mechanism injuries. Impact with solid, stationary objects.

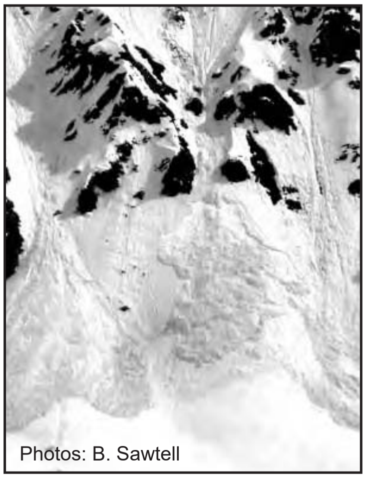


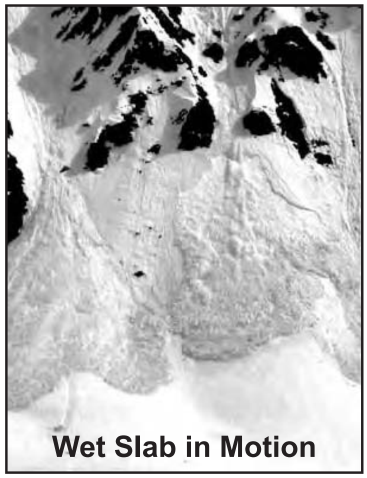
Wet Flowing Motion (in wet snow avalanches)

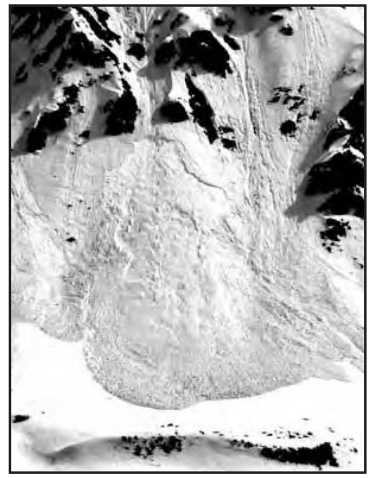
- Speed: About 15-40 mph (25-60 kph).
- Movement Characteristics: Break-up of the initial mass occurs. Rounded particles of up to 4" (10cm) in diameter and/or rounded lumps up to several meters/ yards in diameter often form while the avalanche moves. Very wet snow may have no particles or lumps, and a slush mixture may form while the avalanche moves. Mixing and turbulence occurs.
- Powder Cloud: No significant airborne snow component (no powder cloud).
- Deposit Characteristics: Deposit usually contains rounded particles and lumps. Often these are of a similar size as those that formed during movement. In very wet conditions, the deposit may consist of small, fine grained particles. Channels, runnels, ribs and ridges are common.



- *Constraint by Terrain:* Like wet cement, wet flowing motion avalanches tend to flow around or be constrained by terrain features such as gullies, mounds, banks, hills, etc.
- *Comments:* Any time moisture content is high wet flowing motion can occur in loose-snow or slab avalanches.
- *Hazards:* Slow, twisting mechanism injuries. Impact with solid, stationary objects. Wet snow is very dense and has little trapped air leading to suffocation hazard.

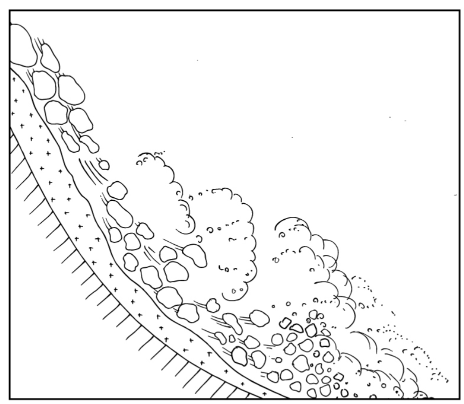

Photos: B. Sawtell


Wet Slab in Motion



Dry Flowing Motion

- *Speed:* 15-75 mph (25-120 kph).
- *Movement Characteristics:* Break-up of the initial mass occurs. Rounded particles of 4”-12” (10-30cm) create the core mass of the moving avalanche. A high degree of mixing and turbulence occurs. A series of waves is often observed in the core.
- *Powder Cloud:* An airborne snow component (powder cloud) forms above, around, and in front of the core mass. This powder cloud often gives the impression that the avalanche is much larger and travels much farther than actually occurs. The powder cloud has less destructive potential than moving debris.
- *Deposit Characteristics:* Deposit usually contains small, fine-grained particles with few lumps or chunks.
- *Constraint by Terrain:* Dry flowing motion avalanches often do not follow terrain features and are not easily constrained or stopped. Once they attain top speeds and turbulence, they can easily jump terrain features such as gullies, mounds, banks, hills, etc. Walls or banks are often jumped where a gully or similar feature makes a curve or bend. Large flat areas and even small hills are often overrun. In some cases, large, dry flowing motion avalanches have been known to run uphill significant distances before stopping.
- *Comments:* This type of motion is generally associated with large, dry slab avalanches. It produces the greatest destructive potentials.
- *Hazards:* High speed impact injuries. Impact with solid, stationary objects. Impact with solid objects in debris flow.



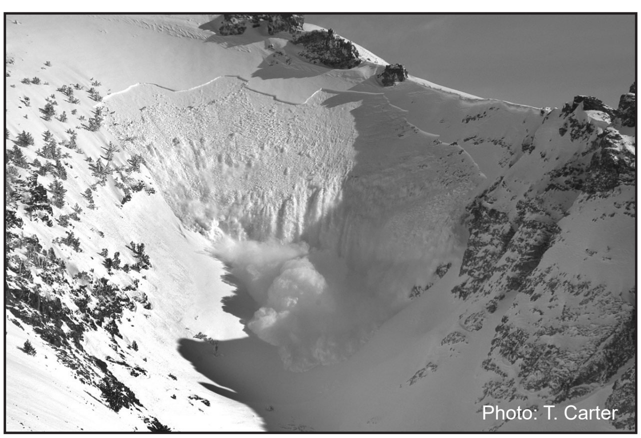


Photo: T. Carter


Photo: J. Royer

SIZE CLASSIFICATIONS

Relative to Path

Avalanches are often classified by estimating the size of the event relative to the terrain feature or path where it occurred. This system uses five classifications, based on the approximate percentage of the path that avalanched, relative to the path's full potential width, length and volume of snow:

- R1 Very Small 0 - 20%
- R2 Small 20 - 40%
- R3 Medium 40 - 60%
- R4 Large 60 - 80%
- R5 Major or Maximum 80 - 100%

This type of system is useful for recording or comparing events over time in the same, known location. Since past avalanche activity plays a large part in determining future snow stability and avalanche hazard, knowing which parts of a slope have previously avalanched is pertinent information when trying to determine conditions on a slope after evidence of avalanche activity has been hidden by subsequent weather events (e.g., drifting or snowfalls).

A relative-to-path-based classification system is less useful when comparing or discussing events in different areas, especially when the locations are not similar or known to all parties. For example, an R5 avalanche on a small slope cannot be compared to an R5 on a large slope. If a rider in the Rockies were talking to a climber in the Sierra, it would be difficult to convey the magnitude of an event by simply using this size classification without an understanding of the actual path dimensions.

Destructive Potential

Avalanches are often classified using destructive potential as the ranking criteria. Size is defined by estimating the maximum destructive potential of the avalanche, taking into account factors such as speed, mass, terrain, etc. This destructive-potential-based system uses five classifications:

- D1: Too small to injure or bury a person.
- D2: Could bury, injure, or kill a person.
- D3: Could bury or destroy a car, damage a truck, destroy a small building, or break a few trees.
- D4: Could destroy a truck, railway car, several buildings, or forest up to 10 acres.
- D5: Could destroy a village or forest of 100 acres or more.

A destructive-potential-based classification system is useful when comparing or discussing events in different areas, especially when the locations are not similar or known to all parties. A D3 avalanche will have similar characteristics no matter where it occurred. For example, a rider in the Wasatch Mountains can discuss a D3 avalanche with a climber in the North Cascades and, to some extent, convey the magnitude of the event by simply stating the classification.

This type of system is less useful for recording or comparing events over time in the same, known location. It is difficult to assess the effect a D3 avalanche might have on future snow stability after evidence of avalanche activity has been hidden by subsequent weather events (e.g., drifting or snowfalls).

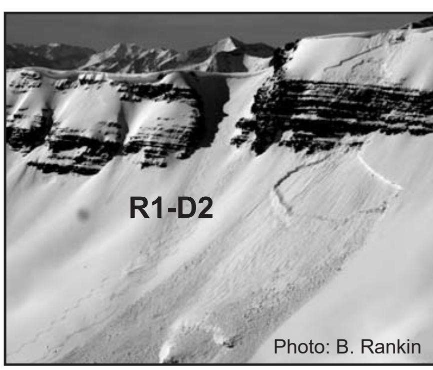


Photo: B. Rankin

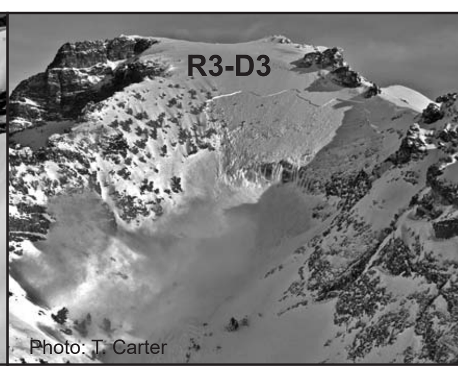


Photo: T. Carter

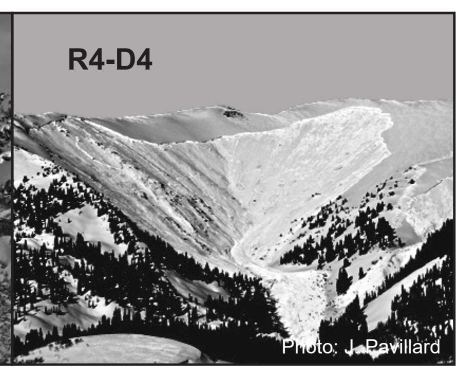


Photo: J. Pavillard

QUESTIONS TO TEST UNDERSTANDING:

1. How does a slab avalanche differ from a loose snow avalanche?

2. How does the expected avalanche character affect one's terrain choices?

3. Using the Destructive Potential scale, what size avalanche could injure or kill a backcountry traveler?

4. If caught in an avalanche, your action taken during the first second or two may be crucial to survival. Why is this and how does it relate to a slab avalanche in motion?

PRESENTATION NOTES:

2.2 Avalanche Terrain

Learning Outcomes:

- Recognize defined and poorly defined avalanche paths and start zones, tracks and run outs zones.
- Explain how terrain modifies the snowpack character by varying exposure to wind and sun.
- Recognize terrain features where avalanches are more likely to be triggered.
- Visualize terrain consequence and avoid terrain traps.
- Improve terrain knowledge, safer route selection and terrain management.

Appropriate terrain selection is the ultimate goal of backcountry decision-making. To understand terrain and avalanche risk, backcountry travelers first need to learn where in the terrain avalanches have historically occurred or under similar conditions in the past. Developing the knowledge and skill to understand bulletin advisories and to identify avalanche terrain requires experience and practice. Once developed, this skill becomes one of your most valuable tools. If you are uncertain about everything else you can minimize risk by traveling in terrain where avalanches cannot start and will not run. While weather, snowpack, and other factors are in a constant state of change, terrain is a relatively stable part of the avalanche puzzle.

RECOGNIZING & AVOIDING AVALANCHE TERRAIN

Essentially, any snow-covered mountainous terrain greater than 25 degrees in steepness can be considered potential avalanche terrain. Additionally, terrain that lies in the “fall line” or along a down hill line of trajectory should also be considered capable of being hit by an avalanche. This coarse description of avalanche terrain falls short of being precise, but from a worst-case scenario is fairly accurate. The reality is avalanches actually run in a smaller proportion of mountainous terrain than one would estimate based on the above criteria.

Avoiding avalanche terrain can be simple. In most cases safe areas include:

- Ridges, with no snow covered slopes above.
- Dense forest.
- Well out in the valley floor, beyond the furthest extent of historic vegetation damage. If vegetation is no help, the Avalanche Handbook (2006) describes methods for estimating runout potential.
- Slopes no greater than 25 degrees in steepness, with slopes no steeper overhead. Avalanche professionals measure the critical incline of the avalanche start zone as the steepest part of a slope with a down slope length of 60ft (20m) or more, (not the average incline) not including cliffs. (OGRS 2008 addendum)

Skiing near avalanche terrain

Photo: D. Svela

Following these guidelines avoids encounters with avalanches but can restrict travel options. Many backcountry recreationists hope to access terrain that these simple guidelines would not allow.

Often, climbers, snowshoers, cross-country skiers, ski tourers and snowmobilers choose not to travel in areas where avalanches start. This approach does not guarantee safety. The avalanche may not start directly underfoot; the exposure may be to an avalanche initiating above. In some circumstances, when the snowpack is highly unstable, failure occurs in terrain that does not appear as a start zone and is at considerable distance from the start zone.

Defined Avalanche Path

A specific location where avalanches repetitively occur may be referred to as an avalanche path. In some cases, avalanche paths are well defined and contain the three recognizable features: the start zone, the track, and the runout zone.

- The start zone is where avalanches typically start.
- The track is where the avalanche typically gains mass and speed as it picks up snow and other debris on its descent.
- The runout zone is where the avalanche begins to slow down and lose mass as snow and debris are deposited.

Poorly Defined Avalanche Path

Be wary of assuming too much about the somewhat arbitrary definitions of start zone, track, and runout zone or the idea that slides start only at the top of the mountain in the steepest part of the start zone. Many avalanche paths are quite poorly defined by comparison to the "classic" path. In many cases, the start zone, track, and runout zone are indistinguishable from one another, and the avalanche path is almost indistinguishable from the surrounding terrain. Given unstable snow, if a slope is steep enough to have an enjoyable descent it is steep enough to slide. If tree openings (glades) are wide enough to travel through at speed they are open enough to permit avalanches to release and run.

Vegetation

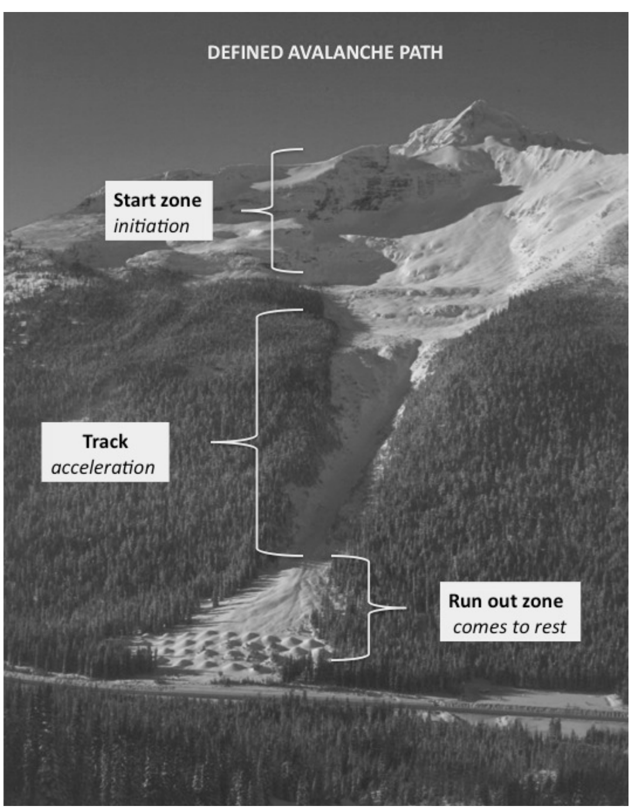
Avalanches that have previously run through an area leave obvious clues. Look for:

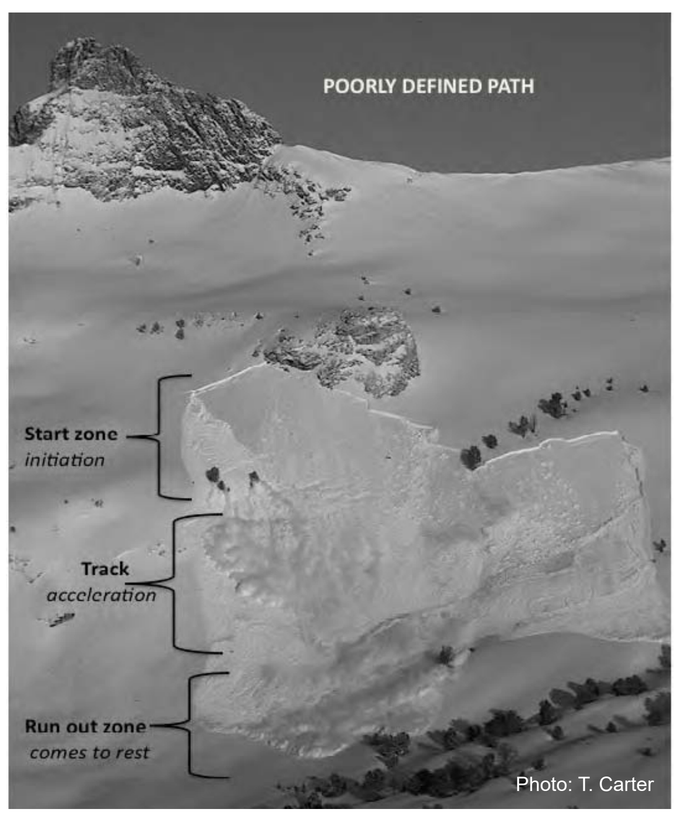
- Unexplained clearings
- All trees above a certain height broken or missing
- Trees broken above ground level
- Branches missing on uphill side of trees
- Lack of smaller trees
- Areas where trees are less dense

Avalanche Debris

Of course, the most obvious clue that avalanches have run in the past is evidence of debris. Fresh debris is relatively easy to spot but older debris can be hard to see. Look for:

- Lumps or chunks
- Piles of snow
- Uneven surface
- Ribs or runnels
- Snow sticking to uphill side of obstructions (trees, rocks, buildings, etc.)





EVALUATING AVALANCHE TERRAIN

The challenge is understanding terrain's influence on the snowpack. The concepts introduced in this lesson and on this course explain how snow cover and terrain interact. The reality is that a 24 hour avalanche course simply cannot ensure a student gains reliable avalanche terrain evaluation skills. The basic tenets of how to avoid avalanche terrain are simple enough to understand and implement. The real-world complexities of how terrain modifies the snowpack, as well as where and why a specific avalanche runs, take years of applied terrain experience to grasp. Field mentoring, observing and analyzing many avalanches and a cautious margin of error are the tenets of successfully learning to evaluate avalanche terrain.

A 'terrain expert' can effectively visualize the snowpack lying over the terrain in 3 dimensions. The most effective manner to acquire these skills is to travel through many miles of snow-covered terrain, frequently using an avalanche probe to measure snowpack depth and layering along the way. Make a prediction about the snow cover over nearby terrain, verify with a probe. Repeat in a variety of terrain features across many a different snowpack.

This lesson cannot provide these hands-on evaluation skills, but rather it introduces the observations we use to evaluate whether terrain is capable of avalanching include. The list begins with more broad scale factors, scaling down to individual terrain feature details:

IMPORTANT TERRAIN FACTORS

Location of the slope within the mountain range

Elevation of the slope

Aspect to Wind

Aspect to Sun

Slope angle (Incline)

Physical characteristics in the start zone (and path)

Location Within The Mountain Range

Weather influences vary from one mountain range to the next (see Snow Climates). Significantly weather influences vary within the mountain range, even from slope to slope.

- Note which areas of the mountain range are true 'snow belts' receiving additional yearly precipitation. Terrain that face into the prevailing storm track, tend to receive the most snowfall. The "favored" areas tend to have avalanche cycles more frequently, with each passing storm. In the long run, these areas develop a deeper, and stronger snowpack (see Formation of Layers in the Mountain Snowpack).
- Observe and remember which are the drier regions. These may be "rain shadows" in the lee of the range receiving less precipitation. Or, they may be distant from the prevailing storm track and receive fewer annual precipitation events. As a result the drier regions may not see as many avalanche cycles, simply because they receive critical snowfall loads less frequently. However, these areas are usually characterized by shallower snowpacks, which promote formation of persistence weak layers. Here the avalanche problems may be long lasting, once critical loads develop.
- Importantly, observe the prevailing winds and regions that are subject to terrain accelerated winds. The windy drier regions are often less predictable.

Elevation Of The Slope

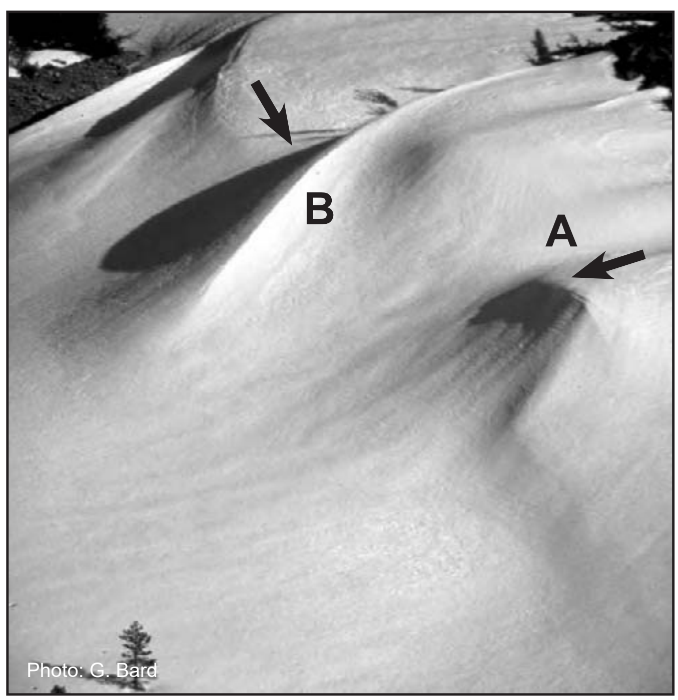
As warm moist air rises it cools and precipitates (rain or snow). When air masses rise over a mountain range it is referred to as orographic lifting. This accounts for a large proportion of snowfall in the mountain ranges. As a result higher elevations receive more total precipitation and more snow than lower elevations. Weather forecasts will mention the expected rain/snow elevation referred to as the "freezing level." Across this critical elevation threshold, expect different avalanche concerns.

Aspect to Wind

Wind has a regular and significant influence on the development of the mountain snowpack. Its greatest effect is *rapid loading of* wind deposited snow in the start zones. Wind accelerates across windward slopes scouring or picking up and moving loose surface snow with speeds as little as 12 mph (20+ kph). Snow grains fragment, bounce along, getting picked up by the wind. The actual wind speed necessary to transport snow varies based on the snow's properties (moisture, texture, stiffness etc.). On lee slopes the wind speed slows, depositing the broken snow grains. This process is sometimes referred to as *redistribution* of snow and *wind loading*. During a storm, wind often loads start zones 3 to 5 times faster than snow is accumulating in sheltered areas. As wind speeds change, wind deposits snow at varying rates resulting in wind slabs and layers (with stiff layers over less stiff layers) in the start zone. Visual clues that recent wind loading has occurred include snow plumes off ridges, recent cornice growth, and snow pillows on or just below ridges. These snow pillows appear smooth and deep or "fat."

An important consideration when evaluating the effect of recent wind is to differentiate between prevailing wind directions and local terrain influence on the wind. Many weather stations are positioned to record the prevailing "free air" wind directions. Keep the prevailing wind directions in mind, but on a slope scale, personally watching snow, and observing wind textures and the location of fresh deposits offers a much more accurate picture than simply generalizing about aspect in relation to the prevailing wind. The ability to relate prevailing winds to local wind loading patterns is a specific skill that takes experience and coaching to develop. Wind slabs are the most common type of avalanches triggered by backcountry travelers during or just after snow storms.

Cross loading occurs when wind moves snow across a slope and the wind-blown snow settles into hollows or gullies. The photo on the right shows patterns of snow loading from two different wind directions. A southerly wind originally loaded this slope from the right to left **(A)**. After the storm the northeast wind cross-loaded the slope from top left to bottom right **(B)**.



Aspect to Sun

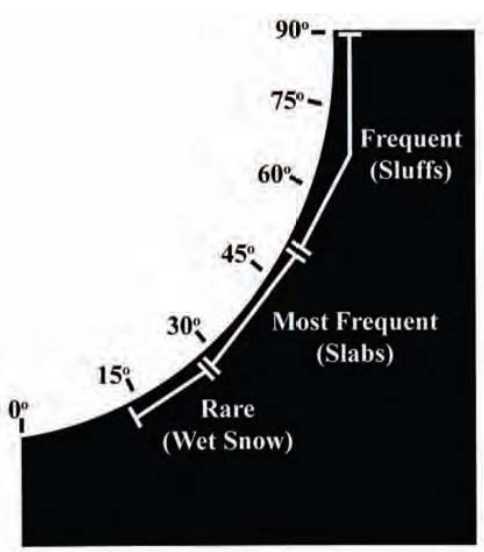
Solar radiation (sun) dramatically impacts the snow cover by changing the temperature of the snow surface and warming the air above the snow's surface. Effects range from melting the snow surface and snow cover, to forming crusts, to softening the snow surface (see Formation of Layers in the Mountain Snowpack). Depending upon the time of year and latitude, small changes in aspect or slope incline can dramatically change the influence of the sun's radiation.
Early in the season, the presence or absence of snow varies with aspect. In continental snow climates, often these early season snows form persistent weak layers. Later in the season, anticipating crusted vs. non-crusted snow surfaces depends upon aspect and incline. Terrain experts anticipate and observe radiation influence constantly.

Slope Angle (or incline)

Inclines of 30 - 45 degrees are ideal angles for skiing, snowboarding, high marking and *avalanche start zones*. Not surprisingly, this is where a large proportion of human triggered slab avalanches start. Slopes at this inclination allow unstable snow to slide readily yet are low angle enough to promote significant accumulations of snow before an avalanche starts.

Slope Angle	**Avalanche Characteristics**	**Slope Equivalent in a Resort Setting**
0º – 25º	Infrequent wet snow avalanches and slush flows.	Beginner to intermediate slopes – green and blue slopes
25º – 30º	Infrequent slabs in unstable conditions. Those that do occur tend to be large.	Intermediate slopes –blue slopes
30º – 35º	Slabs in unstable conditions.	Advanced slopes – black diamond
35º – 45º	Frequent slab avalanches of all sizes.	Advanced to Expert terrain – double black diamond
45º – 55º	Many loose avalanches start, often dry; some slabs, usually small	Out of Bounds: cliffs and couloirs
55º +	Few avalanches start, sometimes loose dry.	Out of Bounds: alpine climbing terrain

Consider the influence of poor visibility on one's ability to estimate slope angle. Perceptions of slope angle also vary with perspective. For these reasons, decisions related to slope angle should be measured, not estimated (see Part 5).



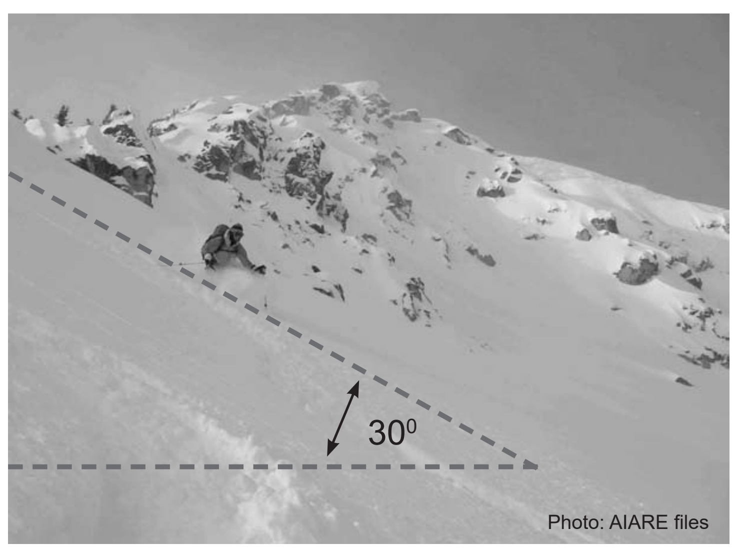


Photo: AIARE files

Physical Characteristics in the Start Zone (and Path)

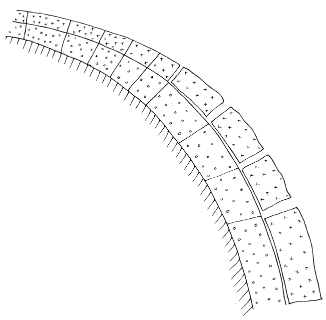
The size and shape of an avalanche path is key to determining areas of strong snow, weak snow, and destructive potential. Avalanche terrain can range from slopes as small as ten's of feet (several meters), to entire mountain faces. Considering the effect of slope size can dramatically alter the consequences of an avalanche. Slope length, incline throughout, and forest and rock cover relates to how far, and through how many obstacles a victim will be dragged. Slope width and connectivity to adjacent slopes often relates to how much snow will be entrained in the slide. Slope shape (along with the type of avalanche motion) will determine the flow of an avalanche and whether the debris will spread out or converge. Terrain experts combine these factors to envision the size of an expected avalanche and potential consequences if caught.

The character of the start zone determines the snowpack character and the development of strong or weak areas in this part of the slope where avalanches are likely to initiate. The presence of convexities (roll overs and bulges), concavities (scoops), rock ribs, trees and other vegetation affects snowpack layering. It changes how the snowfall accumulates and settles, how wind deposits the snow, and how the snow deforms and strains during the down slope creep of the snowpack under the unending influence of gravity. The weak snow that forms around localized terrain features are called trigger points.

Trigger Points

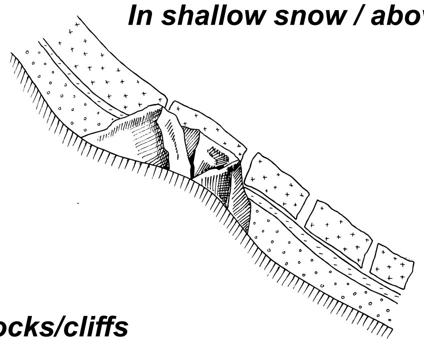
Understanding the notion of trigger points is crucial for backcountry travelers in avalanche terrain. A trigger point is a specific location where localized fracturing of the snow begins and leads to the propagation of an avalanche. These trigger points often occur at places where strain on the snowpack is concentrated or weak areas in the snowpack. Think of trigger points as land mines where avalanches tend to initiate. Knowing where avalanches initiate easiest helps one to avoid triggering avalanches while travelling in avalanche terrain.

Convex rolls

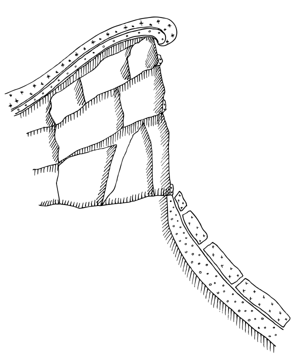


Around protruding objects

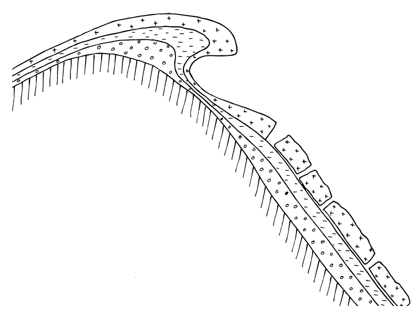
In shallow snow / above buried objects



Below rocks/cliffs



Below cornices



Terrain Traps

Any feature in the terrain that raises the consequence of being caught is a **terrain trap**. Examples include:

- Cliffs
- Gullies which cause moving avalanches to converge and speed up, as well as debris to pile up
- Bodies of water (creeks, lakes)
- Trees or exposed rock
- Benches or roads where debris will pile up
- Crevasses / Bergschrund / Ice fall

Photo: B. Pritchett

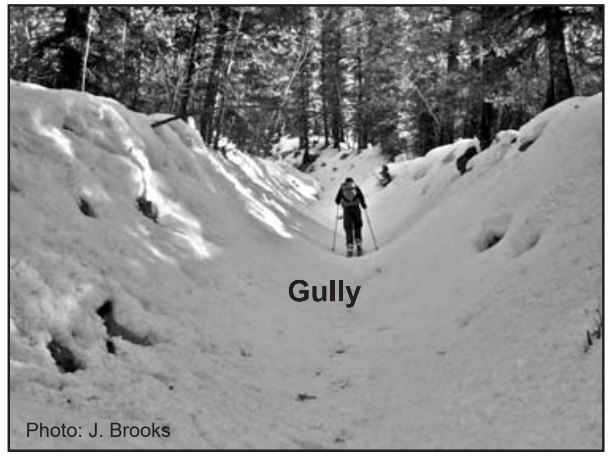


Photo: J. Brooks

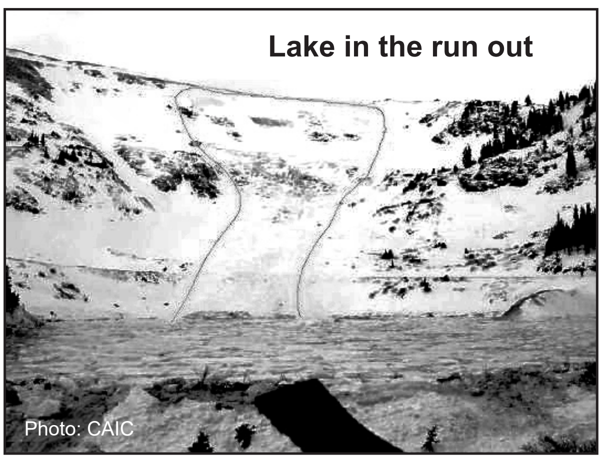


Photo: CAIC

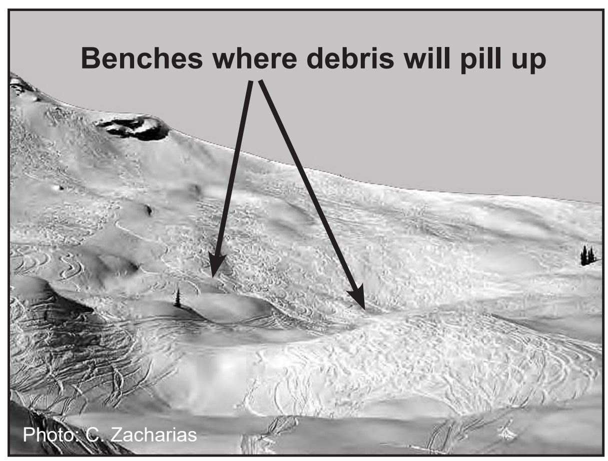


Photo: C. Zacharias

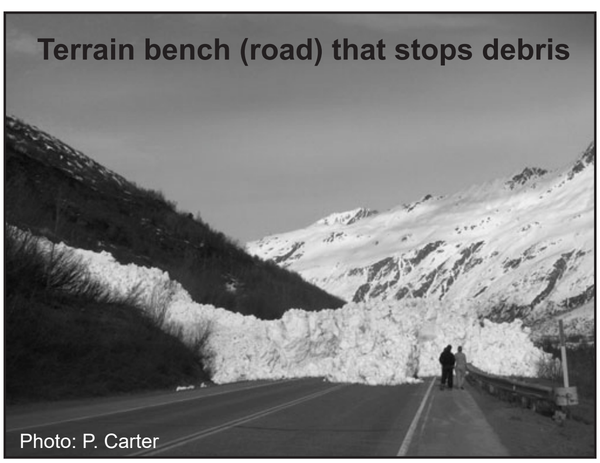


Photo: P. Carter

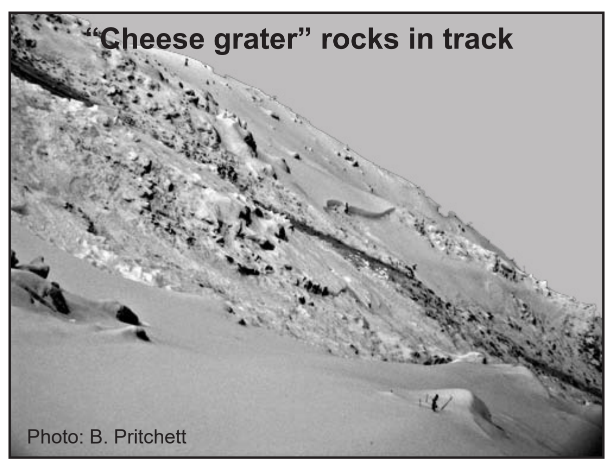


Photo: B. Pritchett

WHEN CHOOSING TERRAIN

Prior to traveling in the backcountry without an expert present, one needs be able to perform the following avalanche terrain evaluation skills reliably:

- Identify avalanche terrain
- Evaluate where in the mountain range and where in specific terrain avalanches may occur given current snowpack and weather conditions
- Anticipate the likelihood of encountering avalanches when traveling in the backcountry
- Anticipate the size and consequence of an avalanche occurrence
- Identify terrain choices that mitigate the hazard and reduce the risk

(See Chapter 5: Choose Terrain and Travel Wisely for a continuation of the topic - decision making in avalanche terrain)

QUESTIONS TO TEST UNDERSTANDING

1. How do you know if you are in avalanche terrain?

2. If you are unsure of the danger on a given day in the backcountry, how can you best manage your risk?

3. Name the six key recognizable terrain factors that create variation in the snowpack in the start zone?

4. How is it possible to trigger an avalanche from outside the start zone?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2.3 – Formation of Layers in the Mountain Snowpack

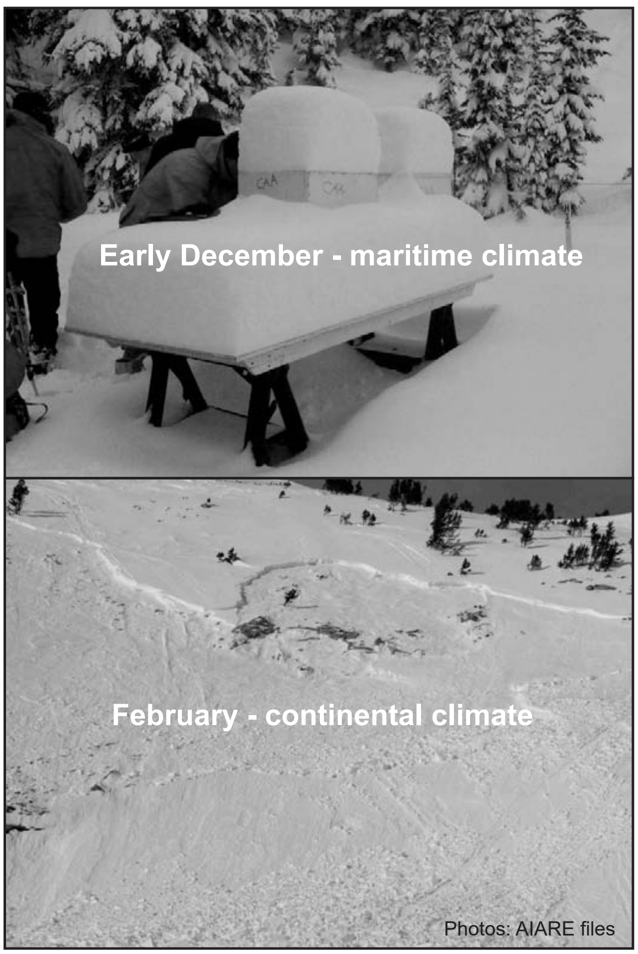
Learning Outcomes:

- Describe how snowpack layers form and metamorphose over time.
- Recognize the influence of wind, rain, temperature & sun and how they may form weak layers in the snowpack.
- Relate weather / snowpack patterns that lead to faceting, rounding, surface hoar, crusts & corn snow.
- Explain the importance of recognizing and tracking weak layers in the snowpack.

SNOW CLIMATES

The mountain snowpack varies in character, depth, density, and strength. Each layer is related to both the shape of the terrain (as previously discussed in this chapter) and the seasonal effect of climate and weather. The mountain snowpack varies from season to season. The snowpack varies from mountain range to mountain range. And, the snowpack varies within the range. The geographic location of the large mountain ranges in the North American continent and the prevailing climate differences from between ranges have given names to three principle snow climate regions within the continent. These are Maritime (coastal), Intermountain (or Interior) and Continental (Rocky Mountain) snow climate zones.

The maritime snowpack, proximal to the moist air masses arriving from the Pacific, is characterized by warmer temperatures, frequent precipitation and a deeper denser snowpack. This climate may see regular (monthly) rain events to ridgetop and infrequent influence of the cold Arctic front.



Photos: AIARE files

The intermountain region also has regular winter snowfall events and a relatively deep snowpack. The weather results from the back and forth influence of both the Arctic front (clear cold northerly air), and the warm Pacific air (warmer temps, snowfall, wind). Rain events to ridgetop are unusual. Persistent weak layers are common in addition to quality powder skiing.

Continental snow climates are frequent influence by cold dry arctic air and occasional visits from the distant milder Pacific air. Fewer seasonal snowfall events occur with comparatively long dry periods.

Many geographic variations exist, notably the American northeast that is considered an “Arctic Maritime” climate, and Alaskan/Canadian Territories that combine the “classic” maritime climate features with arctic factors (e.g., cold temperatures and short days and sometimes high altitudes).

Travelers who grow up in and learn one climate should be careful not to indiscriminately apply the “rules” of their region in areas where a different climate exists. For example: a rider from the Sierra, where the avalanche danger tends to quickly improve after a storm, would not be wise to use this approach in the Colorado Rockies where avalanche danger is often much slower to improve. In addition, many exceptions to the “rules” exist. Rain shadow zones in the coast range and only a few miles east of the snowy divide can develop an unstable shallow snowpack that bears more similarity to a continental snowpack than it’s nearby coastal relative!

THE EFFECT OF WEATHER AT THE SNOW SURFACE

Snow forms and falls to the ground when atmospheric conditions (primarily temperature and humidity) are right. Snow *crystals* are individual grains of snow; the classic "stellar" shape is what we often think of when we talk about snow crystals. In reality, snow crystals come in many different types. A snow crystal's size and shape depend on the environment in the atmosphere at the time it forms. Snowflakes are formed when a number of individual crystals join together as they descend. Once deposited, snow crystals begin to immediately change form.

As well as snow coming in a variety of shapes and sizes snow falls to the ground at different times and under various weather conditions (windy/calm, cold/warm, dry/damp, etc.). Therefore, the snowpack does not develop as a uniform blanket, it forms as a series of layers with or without similar properties.

Snowpack layers undergo continuous change. The snow grains that make up the layers change over time, which in turn changes the characteristics of the layers themselves. The process of change in the snow grains within the snowpack is called metamorphism. Metamorphism takes place over time and is driven primarily by weather factors. At a basic level, effects of weather include short term, near snow surface effects, and longer-term trends driving change within the snowpack.

Metamorphic effects ultimately change the structure of the layers that make up the snowpack: crusts may form or break down, layers may gain or lose hardness, grain size and shape may change, etc. Metamorphism can also change the nature of the bonds at the interface between layers. The bonds may gain or lose strength and failure characteristics may change over time. Weather effects play a role in changing the layers at or near the surface.

Event	Effect on Snow Surface
Wind	Wind etches and erodes soft windward surfaces. Wind battered snow develops thin stiff layers called wind crusts. Thicker wind slabs form where blowing snow accumulates.
Rain	Rapidly changes and weakens the surface layers, also freezes into a hard crust which could become a buried weak layer or sliding surface.
Temperature	Rapid warming or rapid cooling trends have been linked to cornice collapses and avalanche cycles. Warm layers freeze into crusts similar to thin rain crusts.
Sun	Solar radiation can soften and consolidate snow surfaces, enhancing the effect of warm temperatures.

Other weather factors can also play a direct role, but the ones named above are the most common and have the most significant effect. The depth to which these weather effects are felt is not clearly defined, but the strongest effects are at the surface or in the upper layer(s).

SURFACE HOAR

Surface hoar deposits on the snow surface during cold clear nights with calm winds. Some people describe it as "winter's dew." Regularly it is destroyed by sun or wind when exposed on the surface. This often feathery crystal grows large enough to be visible to the naked eye.


Surface hoar on snow surface

Photo: AIARE files

BURIED SURFACE HOAR

But, if buried intact, surface hoar becomes a persistent weak layer. It is important to be able to observe this grain type as it becomes the failure layer for many avalanches.

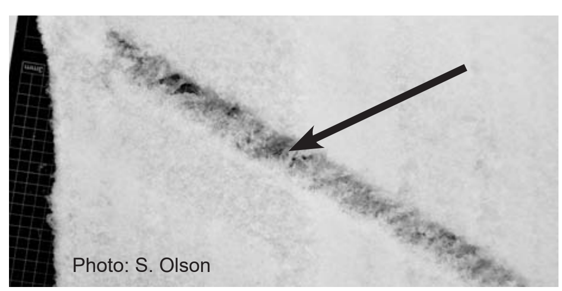


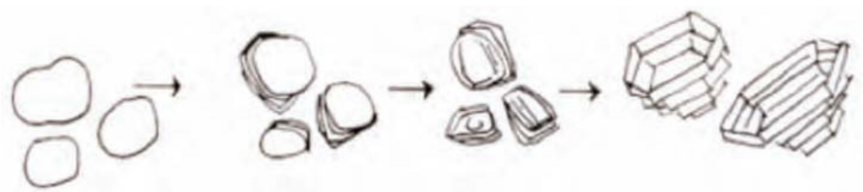
Photo: S. Olson

THE MOUNTAIN SNOWPACK CHANGES OVER TIME

Once snow grains are buried in the snowpack, they become protected from direct weather effects. Metamorphism still occurs in deeper layers and the weather still plays a role, but the effects of weather are indirect. The weather influences the environment in which the grains reside, rather than directly altering the grains themselves. As the environment changes, snow grains metamorphose differently. Metamorphism within the snowpack generally occurs more slowly than metamorphism near the snow surface. The most easily observed factors that influence metamorphism deep in the snowpack are air temperature and snowpack depth.

Faceting

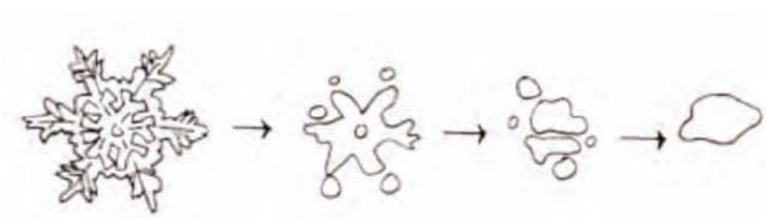
Under certain conditions, usually when the snowpack is shallow and air temperatures are consistently cold for extended periods of time, the snow grains tend to grow into angular shapes with a "sugary" texture, with less cohesion between the individual grains, known as *facets*. The process by which they form is called faceting, which develops porous, weak layers in the snowpack.

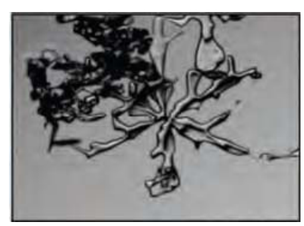


Faceting is common in areas where the snowpack is shallow and air temperatures are cold, e.g., continental snowpacks or early season snowpacks. Faceting can occur throughout the entire snowpack, or it can be isolated to specific layers. Near Surface Faceting can occur between storms, when surface snow is exposed to clear skies and cool temperatures. Observers' notice the loose, angular grains that may sparkle in the sun, feel different than new snow, and make more noise under the ski base. When buried, these grains can form a weak layer. Given the right conditions, faceted grains can form at the snow surface in hours. Older snow layers that facet for weeks develop into advanced faceted grains, called Depth Hoar. Depth Hoar forms within the snowpack after weeks of faceting; it is quite different from a layer of buried Surface Hoar. Whether facets form near the snow surface, or closer to the ground, they may persist as a buried weak layer for weeks or for months if cold and shallow snowpack conditions persist.

Rounding

Under certain conditions, usually when a deep and well-compacted snowpack is exposed to consistently warm air temperatures for extended periods of time, snow grains tend to become smaller and more rounded in shape, know as rounds. Bonds between grains become stronger. This process is called rounding and creates a stiffer, stronger layer of snow.





As the process continues for weeks, bonds between the grains grow in size, "sintering," and form an exceptionally strong layer. Rounding is common in areas where the snowpack is deep and air temperatures are warmer, e.g., maritime snowpack or late season snowpack. Rounding also tends to occur within thick and hard snow layers like old wind slabs. When thick layers of rounded snow rest above a persistent weak layer (commonly faceted crystals or surface hoar), the rounded snow grains comprises the slab component of persistent or deep-persistent slabs. A strong snowpack develops when layer upon layer of rounded snow rest upon the ground, with no weak layers between the rounds.

SUN CRUSTS, RAIN CRUSTS AND SPRING CORN SNOW

Melt-freeze metamorphism is a common result of above-freezing temperatures, strong solar radiation, or rain. This type of metamorphism repeatedly melts and refreezes the upper layer of the snowpack. Common in warm climates and in spring, melt-freeze layers are very weak when melted and “free” or liquid water is present and very strong when the “free” water freezes. As this process continues over time, the free water percolates deeper into the snowpack, eventually driving the dominant metamorphic process in the spring.

This process leads to large uniform grains. Each night these grains freeze together forming a very hard, dense, icy layer. The depth to which this freeze occurs depends on how cold it became and for how long. During the day, solar radiation and warm temperatures loosen the once frozen connection between the grains. The perfect “corn snow” develops when the snow surface has become partially loosened and wet, but the grains below the surface are still frozen together. Once the melting process penetrates to a certain depth, the snow may become subject to wet avalanches.

PRESENTATION NOTES:

QUESTIONS TO TEST UNDERSTANDING:

1. How are layers formed in the snowpack? Describe the weather conditions that form snow grains that once buried become a “weak” layer in the snowpack?

2. What is the process that tends to form sugary snow grains with straight edges ?

3. Describe the process that forms strong well bonded layers in the snowpack? Name the snow grains and the process that binds the snow grains.

4. How is surface hoar different than depth hoar? Why are weak layers composed of these grains so slow to change, bond to each other and gain strength?