Patterns in Unexpected Skier-Triggered Avalanches[1]

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Summary

To determine recurring weather, snowpack and terrain characteristics of unexpected skier-triggered avalanches, we surveyed 153 experienced avalanche workers in Western Canada. Each person answered up to 27 multiple-choice questions about an unexpected skier-triggered dry slab avalanche. To determine if the characteristics of unexpected avalanches are atypical, some results are contrasted with a dataset of 1390 skier-controlled avalanches from the Columbia Mountains. Some of these patterns in unexpected skier-triggered avalanches may help with future decisions about where and when to ski in avalanche terrain.

For the unexpected dry slab avalanches, the weather was usually fair (69%) and the temperature stable (69%) or cooler than the previous day (21%). Half the unexpected avalanches occurred when there was a lack of recent avalanche activity. Half the slabs were hard slabs and most were thicker than skier-controlled slides. Over half the avalanches failed on a layer deeper than the storm snow and almost three-quarters of the failure layers consisted of persistent grains such as surface hoar, facets or depth hoar. Spatial variability was an important factor since 41% of the unexpected avalanches were remotely triggered and the location of 33% of the trigger points were surprising. The snowpack for the unexpected avalanches was generally thinner or much thinner than for skier-controlled avalanches. Seventy percent of the avalanches started where the slope angle was reported to be 35° or less. Remarkably, 42% occurred on cross-loaded slopes and almost half were in the alpine.

Introduction

Between May and December 1998, 153 experienced avalanche workers each completed a questionnaire consisting of 27 multiple-choice questions. They were ski guides, avalanche forecasters and controllers for highways, ski areas and mountain parks as well as avalanche consultants and researchers. We asked each person to select **one** unexpected dry slab avalanche that had been triggered by a skier or snowboarder and about which they recalled most facts about the weather, snowpack and terrain. It did not matter if the avalanche occurred during work or recreation. Although the questionnaires were completed in Western Canada, those surveyed were free to select events that occurred outside Canada. While it is possible that more than one person may have chosen the same avalanche, we expect that redundancy in the data set is very limited.

If most unexpected avalanches have a certain characteristic, we often want to know if that characteristic is unusual. For example, if 65% of unexpected avalanches occur on north and east aspects, we might be tempted to be raise a warning flag for these aspects. However, if about 65% skiing in avalanche terrain is on north and east aspects, then the warning flag is inappropriate. Fortunately, for several of the questions we were able to contrast the results for unexpected avalanches with results for 1390 skier-controlled avalanches in the Columbia Mountains. These occurrence data were provided by two heli-skiing operations: the Canadian Mountain Holidays near Bobby Burns Lodge from 1996 to 1998 and Mike Wiegele Helicopter Skiing from 1990 to 1999.

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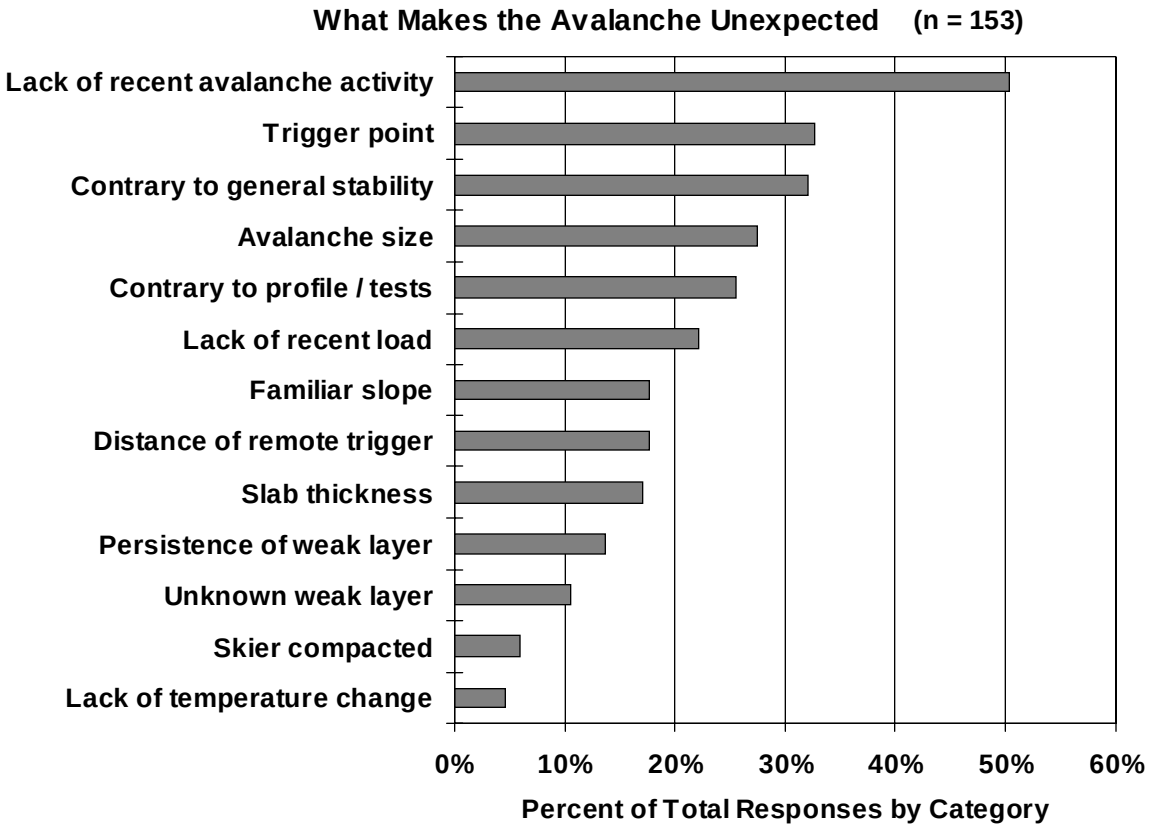
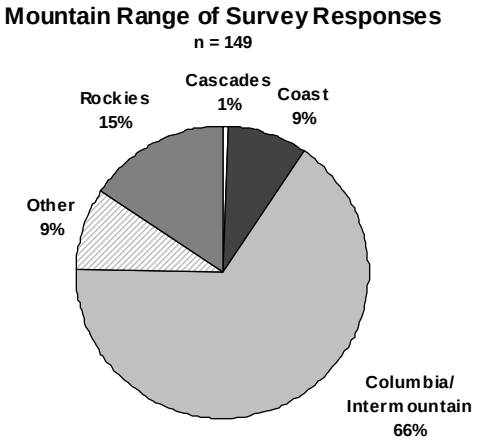
What was Unexpected about the Avalanche?

This was the only question that allowed multiple answers. The most common factors were lack of avalanche activity (50%), the location of the trigger point (33%), the event contradicted general stability (32%), the size of the avalanche (27%), the event contradicted profiles and/or snowpack tests (25%) and lack of recent load (22%). If only 25% of the unexpected avalanches were contrary to profiles and tests, does this imply that 75% were consistent with profiles and tests? We don't think so. There may have been some in the "grey zone" where the profiles and snowpack tests were neither consistent with, nor contrary to, the occurrence. Also, some of the tests and profiles may have been done after the event at sites indicated by the avalanche and not obvious prior to it.



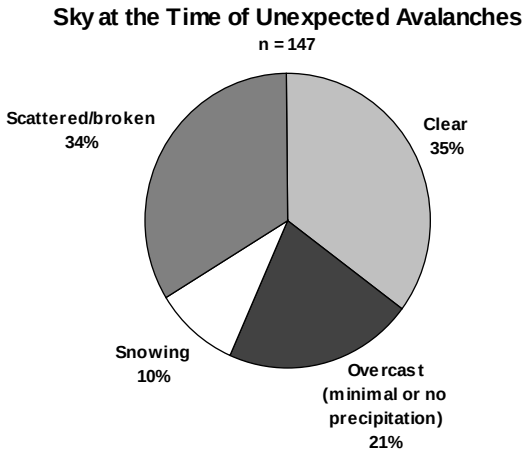
Mountain Range

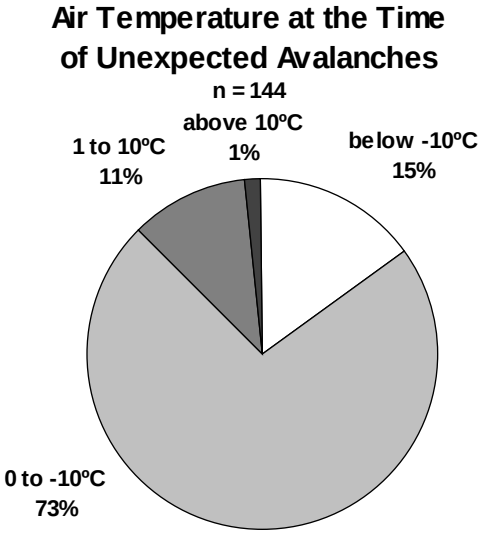
Sixty-six percent of the reports are from the Columbia Mountains of Canada or the Intermountain regions of the United States. Fifteen percent are from the Rocky Mountains and 9% are from the Coast Range. This concentration of reports from the Columbia Mountains probably reflects the fact that many of the avalanche workers who completed the questionnaire are ski guides who work in the Columbia Mountains.



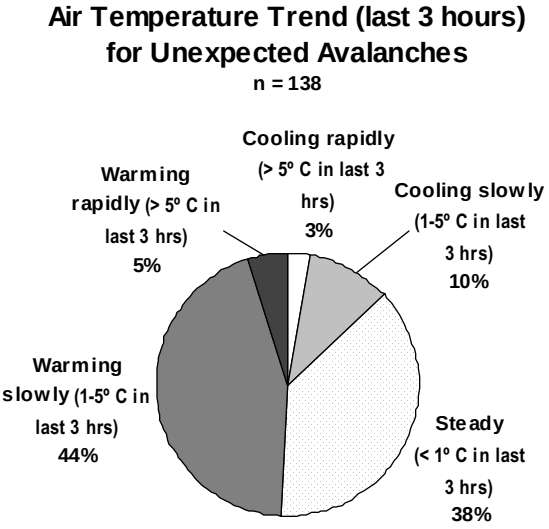
Weather

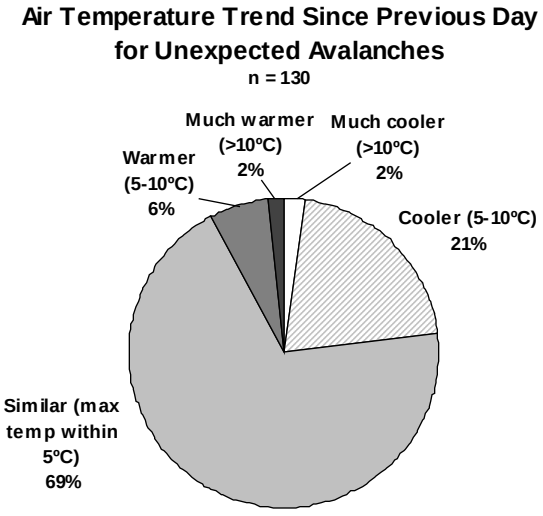
For 35% of the avalanches, the sky was clear and an additional 34% occurred when the sky was scattered or broken, indicating that most unexpected avalanches happen when the weather is fair. Presumably we select avalanche terrain more often in fair weather than during stormy weather. However, fair weather may also make us feel optimistic or euphoric and thereby lead to decisions that, in hindsight, are high-risk.





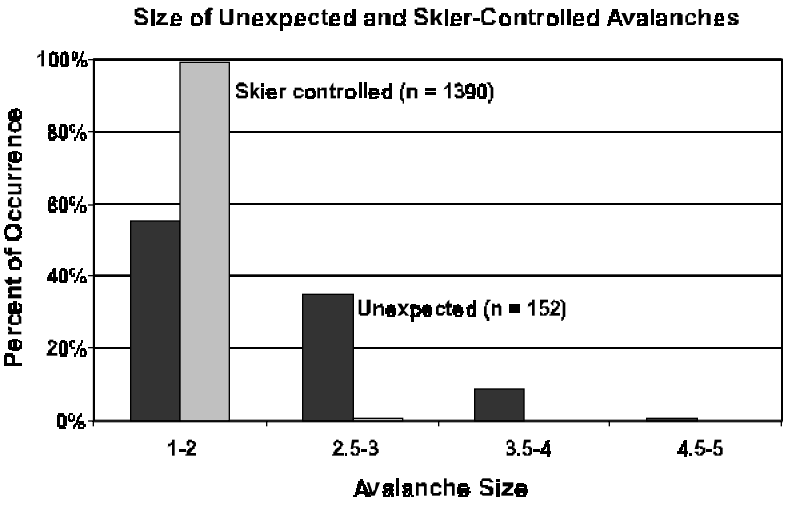
The air temperature was usually between 0°C and -10°C (73%) which are probably just the common temperatures for skiing. In most cases the temperature was steady in the last 3 hours (38%) or rising by 1 to 5°C (44%) which is common during the skiing day. For 69% of the avalanches, the temperature was similar to the previous day (±5°C) and for 21% the temperature had cooled by 5 to 10°C. This cooling may be associated with clearing after a storm since skiers often return to avalanche terrain when the weather improves. Warming by 5 to 10°C was only reported in 6% of the avalanches.

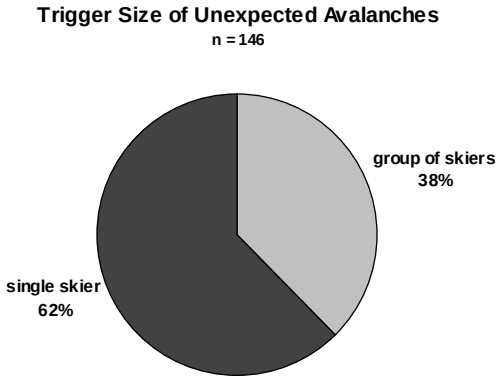




The Avalanches

The avalanches were all dry slab avalanches since the questionnaire asked for such avalanches. Using the Canadian size classification (CAA, 1995), 55% of the unexpected avalanches were size 1 or 2, 35% were size 2.5 or 3 and 10% were size 3 or larger. This is in sharp contrast to skier-controlled avalanches in the Columbia Mountains which are mostly size 1 or 2 (99%).

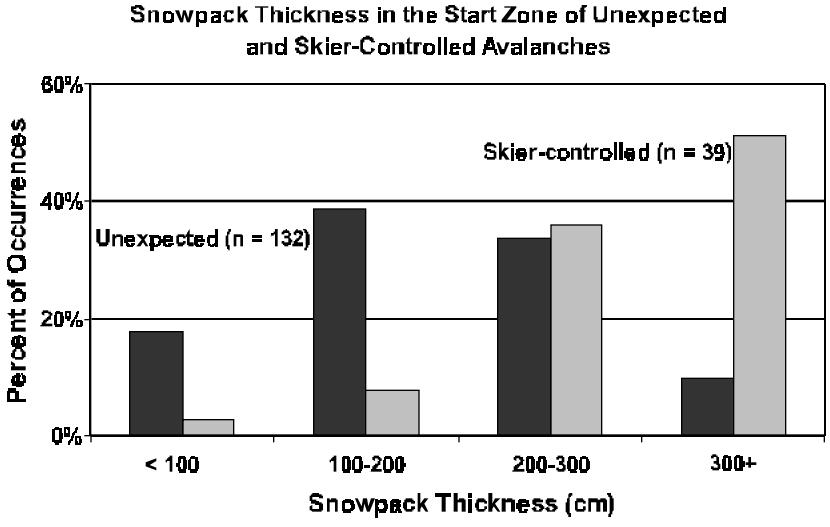




Thirty-eight percent were reportedly triggered by a group of skiers rather than a single skier (62%). Groups of skiers are considered strong triggers in the Canadian snow stability ratings (CAA, 1995, p. 94) and the European Avalanche Danger Scale but not in the Canadian or US Avalanche Danger Ratings (Dennis and Moore, 1997).

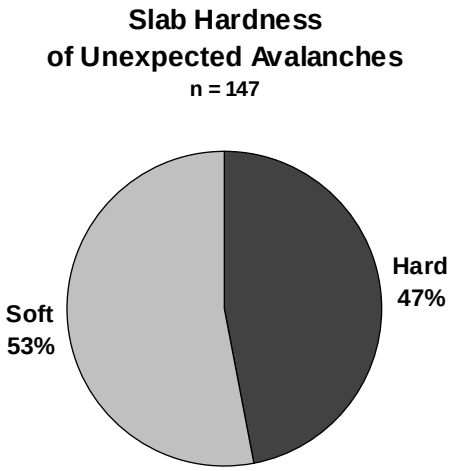
Snowpack Thickness

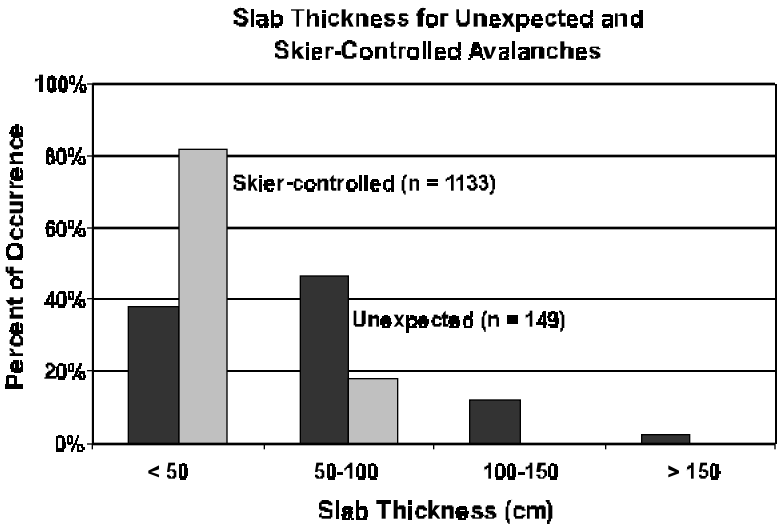
In the start zone of over half the unexpected avalanches (57%) the snowpack thickness was 200 cm or less. This contrasts with skier-controlled avalanches in the Columbia Mountains (Jamieson and Johnston, 1998) where only 10% started where the snowpack was 200 or less cm thick and most started where the snowpack was over 300 cm thick. We conclude that many unexpected avalanches occur where the snowpack is shallower than average, and perhaps much shallower than average.



Slab Properties

About half the slabs were hard and half were soft. Our field experience indicates that most skier-controlled dry slab avalanches are soft slabs, indicating that hard slabs are more difficult to forecast.

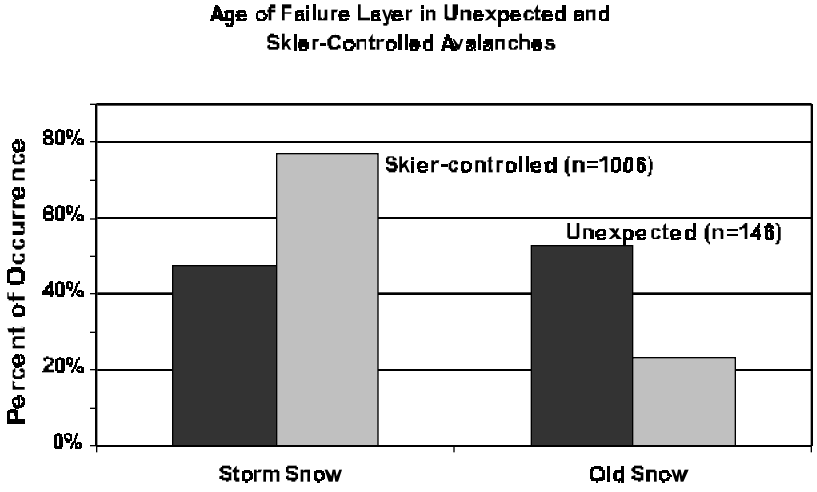




Thirty-eight percent of the unexpected slabs were less than 50 cm thick and an additional 47% were between 50 and 100 cm thick. This is in contrast to skier-controlled avalanches in the Columbia Mountains of which 82% were less than 50 cm thick and 18% were 50 to 100 cm thick. This suggests that unexpected avalanches are thicker than most skier-controlled avalanches. However, it may be that most respondents reported a relatively thick slab avalanche because these are often more memorable. Nevertheless, thicker slabs represent a forecasting challenge.

The Failure Layer

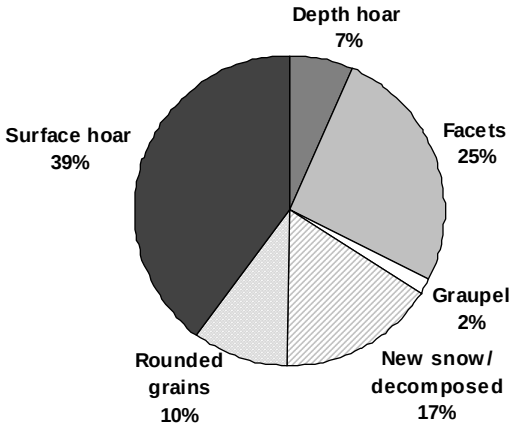
Over half of the avalanches (53%) failed on a weak layer deeper than the snow from the most recent storm. This is in contrast to skier-controlled avalanches in the Columbia Mountains of which only 23% failed on a weak layer deeper than the storm snow. Clearly, unexpected avalanches more often involve deeper slabs with older weak layers than do skier-controlled avalanches.



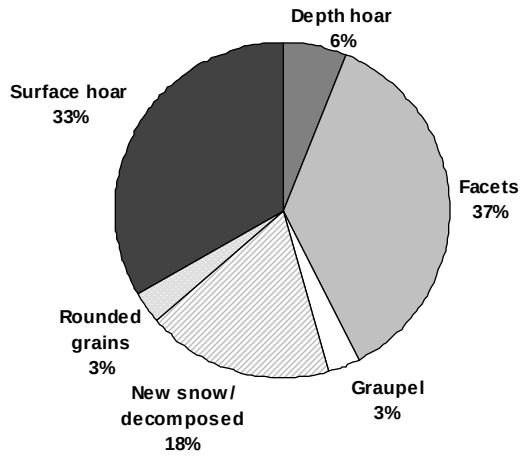
Seventy-one percent of the unexpected avalanches involved persistent failure layers of surface hoar (39%), facets (25%) or depth hoar (7%). The types of grains reported in the failure layers at remote trigger points are similar except that 76% are persistent forms and the percentage of facets rises from 25% to 37%. The grain types for the failure layer in start zones and remote trigger points are similar to a study of fatal avalanches between 1972 and 1991 (Jamieson, and Johnston, 1992) in which 78% failed in persistent weak layers.

Graupel, which often appears as a failure layer in tests such as the compression test or rutschblock test, was only the failure layer for 2% of unexpected avalanches. One reason is that the roughly spherical grains of graupel roll out of avalanche start zones but remain in the less steep locations where we often test the stability of the snowpack.

Grain Type of the Failure Layer in the Start Zone of Unexpected Avalanches
n = 133



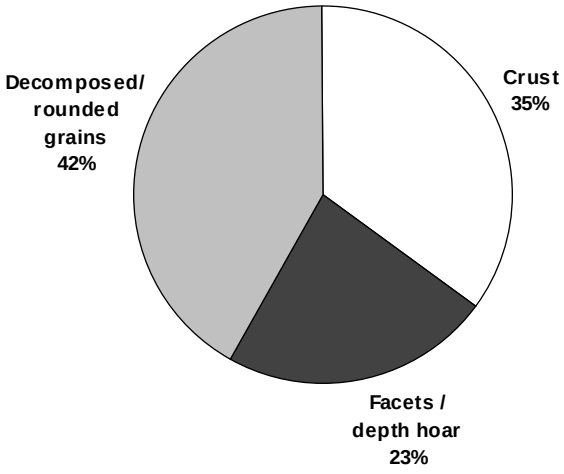
Grain Type of the Failure Layer at the Remote Trigger Point of Unexpected Avalanches
n = 33



The Bed Surface

The bed surface usually consisted of a layer of rounded grains or decomposed and fragmented particles (42%), a crust (35%) or a layer of facets and/or depth hoar (23%). This percentage of bed surfaces of facets and/or depth hoar is certainly not typical of the Columbia Mountains. It suggests that some of the avalanches occurred where snowpack was unusually shallow and weak. The hand hardness of the bed surface was usually pencil (56%), one-finger (21%) or knife (16%).

Bed Surface Grain Type of Unexpected Avalanches
n = 131

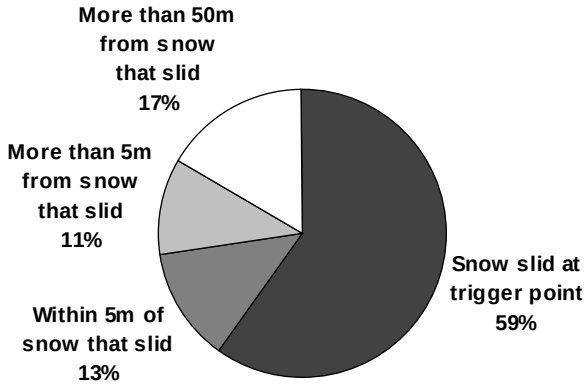


Remotely Triggered Avalanches

Remarkably, 41% of the avalanches were triggered remotely, that is, from a point where the snow did not slide. For remote triggering, the fracture spreads along a weak layer and releases an avalanche where the slope is steep enough. Consequently, even when not in avalanche terrain, skiers are potential triggers, capable of releasing nearby slopes and sometimes the slopes above them.

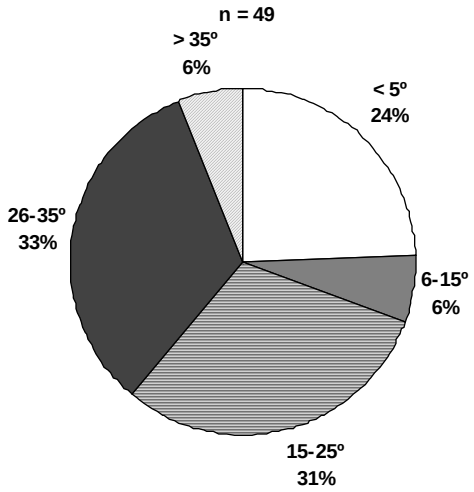
Trigger Point of Unexpected Avalanches

n = 149



Slope at the Remote Trigger Point of Unexpected Avalanches

n = 49

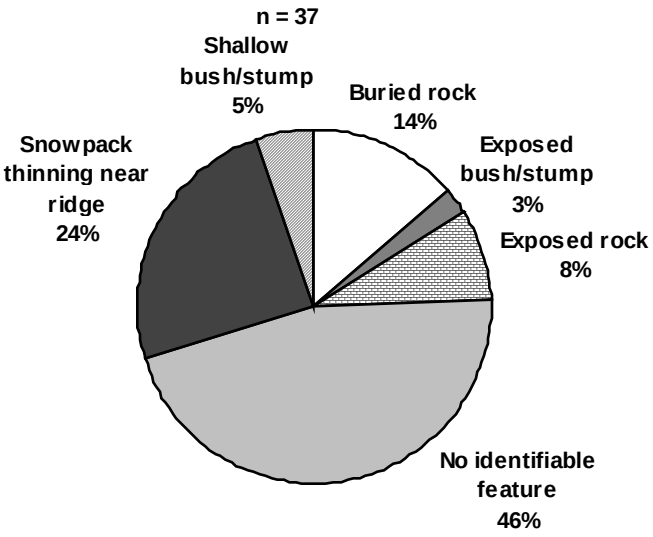


In 61% of the remotely triggered avalanches, the slope at the trigger point was 25° or less. However, the slope was more than 35° – and therefore steep enough to slide – in 6% of the remotely triggered avalanches.

In over half of the remote trigger points there was an identifiable feature. These included snowpack thinning near a ridge (24%), buried rock (13%), exposed rock (8%), a shallow bush or stump (5%) or an exposed bush or stump (3%). This supports the idea that skier triggering can occur at small areas of low stability where the snowpack is thin and weak (Logan, 1993) and the fracture propagate through larger areas of relatively stable snow (Jamieson, 1995, p. 185-194).

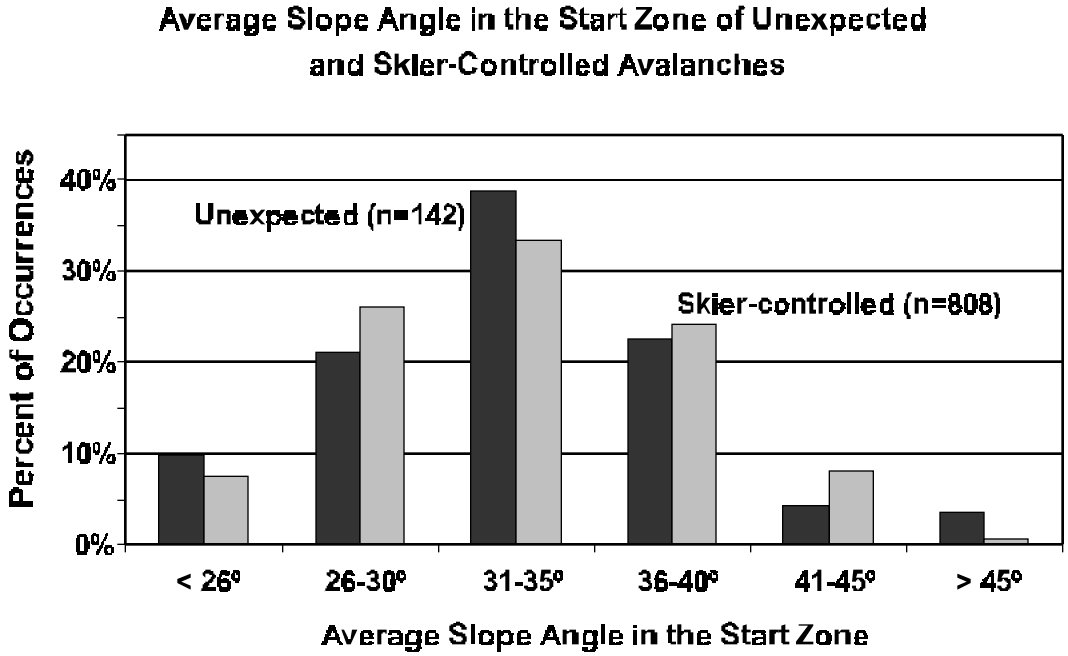
Feature at the Remote Trigger Point of Unexpected Avalanches

n = 37

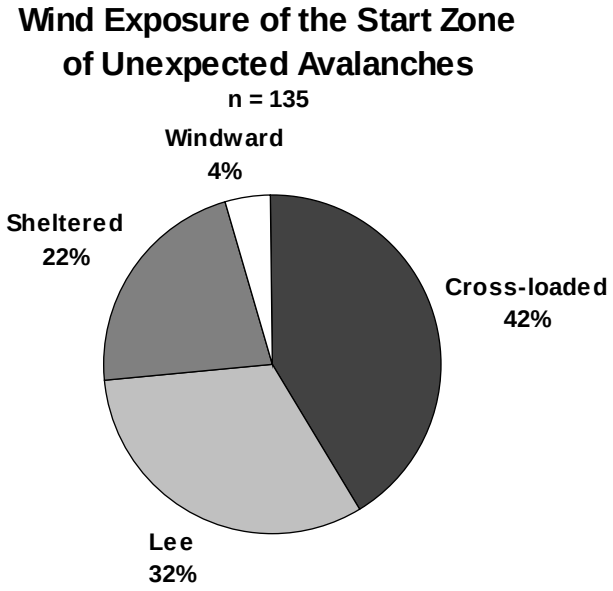


Terrain

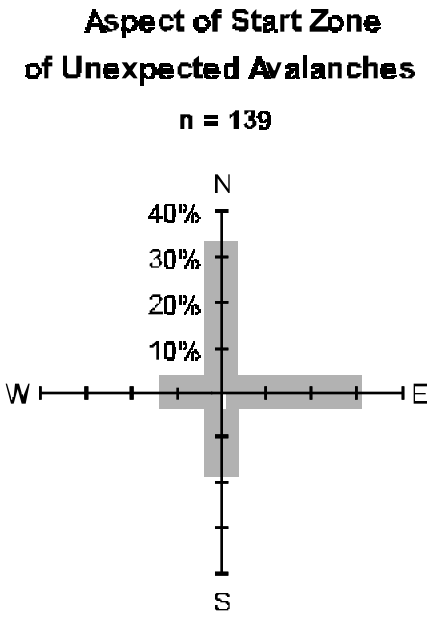
The slope angle is usually considered the most important terrain characteristic for avalanching. Often, the average of the slope angles in the start zones of slab avalanches is 38° (Perla, 1977). However, for unexpected avalanches, 70% are reported to have start zones of 35° or less, and 31% have start zones of 30° or less. These figures are similar for skier-controlled avalanches reported by ski guides in the Columbia Mountains. While the slope angle of most of these start zones was probably estimated rather than measured, it is a strong reminder to "think avalanches" even when the slope angle appears to be less than 35° or even 30°.

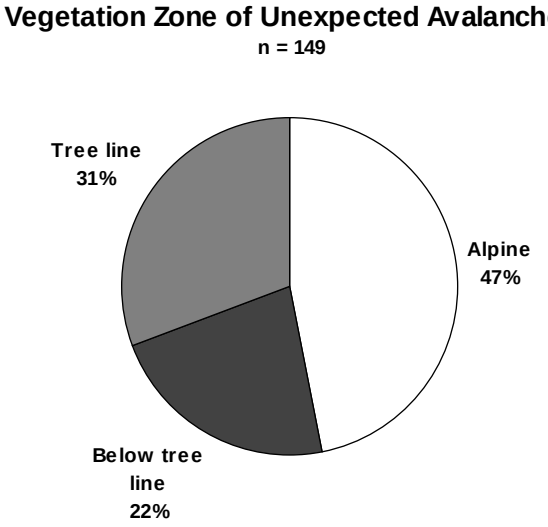


Most books on avalanches indicate that orientation to wind is the most second most important terrain characteristic (e.g. Fredston and Fesler, 1994). Often lee slopes are identified as particularly problematic. However, for unexpected avalanches, 42% are cross-loaded and only 32% are lee slopes. Twenty-two percent are sheltered slopes, mostly below tree line. These results suggest that cross-loaded slopes deserve additional caution.



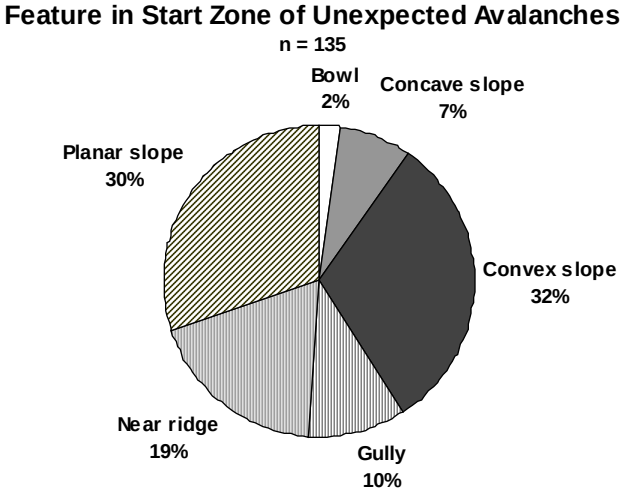
Thirty-five percent of unexpected avalanches occurred in the north quadrant (NW through NE) and 30% occurred in the east quadrant (NE through SE). This is not surprising since these slopes are often lee slopes with deeper than average snow and therefore attractive to skiers.





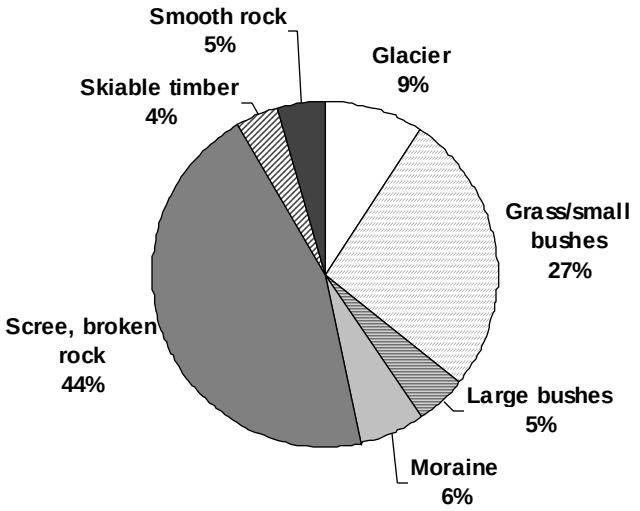
Forty-seven percent of unexpected avalanches were triggered in the alpine, 31% near tree-line and 22% below tree-line. We doubt that 47% of skiing in avalanche terrain occurs in the alpine, which implies that experienced avalanche workers get surprised more often above tree-line than at, or below, tree-line.

Thirty-two percent of unexpected avalanches start on convex slopes, 30% on planar slopes and 19% near ridges. These features may simply reflect the avalanche terrain that is commonly skied. Although fracture lines for storm snow avalanches are often found on convex slopes, these unexpected avalanches occurred as often on planar slopes.



Forty-four percent of unexpected avalanches reportedly occurred where the ground cover consisted of scree or broken rock and 27% occurred where the ground was covered with grass and small bushes. These may be typical of the skied avalanche terrain. The fact that only 6% of the unexpected avalanches occurred in moraines is interesting. Moraines are associated with rocky terrain often with boulders including some areas where the snowpack has been thinned by the wind. Consequently, moraines should have many areas of weak snow which may be triggered by skiers. Perhaps the reason moraines have so many areas of weak snow and so few reports of unexpected skier-triggered avalanches is that moraines are so conspicuous. Experienced avalanche workers probably ski over boulders on grassy slopes without realizing it but they do not ski moraines without recognizing them. This probably means that avalanche workers wait for quite stable conditions before skiing moraines.

Ground Cover in the Start Zone of Unexpected Avalanches
n = 133



Acknowledgements

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