38° Revisited: A Closer Look at Avalanche Types & Slope Angles

Story by Ian McCammon

Differentiating between avalanche types is an idea that has been with us for a long time. In his 1909 classic *The Ski-Runner*, E.C. Richardson described three kinds of avalanches that today form the basis of the avalanche classification system.

But there's more to avalanche classification than mere taxonomy. As experienced avalanche folks know, the type of avalanche expected on a particular day tells us a lot about which terrain choices are prudent and which are foolish. Route selection when the danger is isolated wind slabs, for example, is a very different game than when the danger is a deeply buried surface hoar layer. Bruce Tremper sums up the link between avalanche type and terrain nicely:

> Each different avalanche condition has its own characteristic patterns, routefinding considerations, forecasting considerations. Knowledge of the snowpack is an extremely powerful tool in the battle against the White Death, and I personally would feel very naked without knowing what kind of avalanche dragon I'm dealing with. *(2008, p. 113-114)*

The dialog about avalanche type and terrain management has recently become more precise with the avalanche character typology introduced by Roger Atkins *(2004)* and more pervasive with the use of avalanche character icons in regional forecasts. Most folks seem to agree that knowing about avalanche types improves our decisions in avalanche terrain, and the trend to be more specific when talking about avalanche types and terrain choices is likely to continue.

So it's a bit of a mystery that we don't have a better quantitative handle on how avalanche types relate to terrain, and more specifically to slope angle. Do different avalanche types happen on different slope angles? Do start zone angles vary by weak layer type or avalanche climate? And how can we best apply this information in our travel decisions in avalanche terrain?

BACKGROUND

Let's start with what we know about avalanches and slope angle. Numerous studies have examined start zone angles and have found that slab avalanches are very rare below 25° and that the majority occurs on slopes of 30° to 45°. Another consistent finding is that avalanche activity peaks around 38° steepness. Examples of such studies include Perla *(1977)*, Logan and Atkins *(1996)*, and Schweizer and Jamieson *(2000)*.

Two things are striking about past research on slope angle. First, results are very consistent across most studies, with less than a degree or two of difference between findings. This consistency suggests that we have a pretty good handle on how the avalanche phenomenon as a whole relates to slope angle. That's good news, since it supports these findings as reliable rules of thumb for avalanche terrain.

Secondly, virtually all past work has focused on dry slab avalanches as a class. As far as I can tell, little quantitative work has been done on the relationship between slope angle and different types of dry slabs. Likewise, there seems to be relatively little literature on how slope angle relates to wet slabs, wet point releases or dry point releases. In *The Avalanche Handbook*, McClung and Schaerer give rough guidelines for starting zone inclines by avalanche type, but lament the lack of detailed studies. That's bad news, since folks without broad field experience don't have much to go on when it comes to incorporating avalanche types into their routefinding decisions.

METHODS

In order to get a rough idea of how avalanche types relate to slope angle, I analyzed start zones angles from recreational avalanche accident reports in the US from 1972–2008. Where a range of angles was given for a particular start zone, I used the arithmetic average. For each incident, I looked at the avalanche climate where it occurred *(Mock and Birkeland, 2000)*, the avalanche type, and the grain type of the weak layer. To assess the spread of the data, I calculated the range of the central 50% of start zone values (interquartile range or IQR) for each avalanche type based on a simple numerical percentage of data points.

Measuring start zones with an inclinometer can be a rather inexact business, and reported data has a tendency to cluster around certain values (e.g., 30°, 35°, 38°). This clustering renders simple measures of spread like the interquartile range somewhat misleading as rules of thumb for choosing slope angles in actual practice. For this reason, I also calculated the proportions of each avalanche type that occurred between 30° to 45° – a useful rule-of-thumb range of slope angles that captures avalanche hazard on most of the slopes where we like to travel.

RESULTS

Start zones for the 496 avalanches in this study show close agreement with prior studies (figure 1). Avalanche activity peaked at the familiar median of 38° (mean = 38.7°), with 50% of the data points lying within a 5° range around the median (IQR = 5°). About 91% of these avalanches involved start zones between 30° and 45° (table 1). No surprises so far.

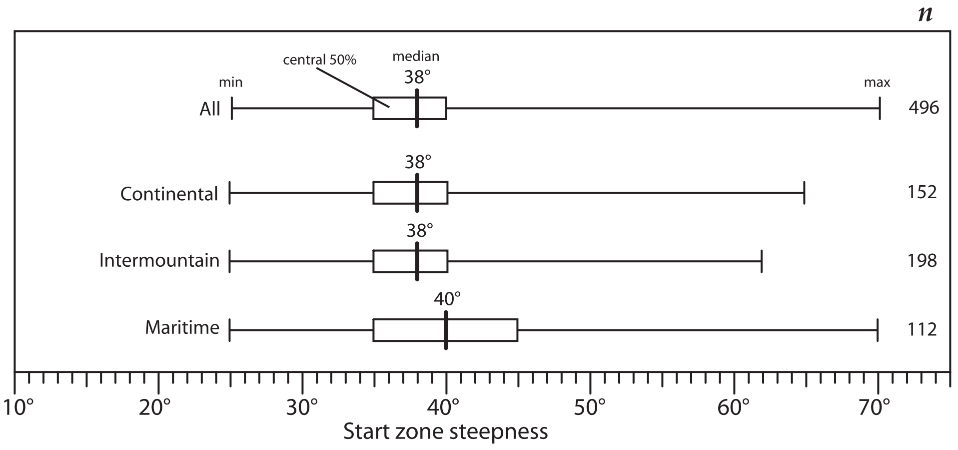

Figure 1: Start zone steepness for all avalanches in this study, and broken out by avalanche climate. The variable *n* indicates sample size.

Avalanche Climate

Avalanches in continental and intermountain climates mirrored the familiar pattern of releasing in start zones around 38° (figure 1), with over 90% of avalanches releasing in start zones between 30° and 45° (table 1). But maritime avalanches occurred in steeper start zones (mean = 40.5°), a trend that was statistically significant (PANOVA = 0.0019) and distinct from both intermountain and continental avalanches (Tukey test). Maritime avalanches also occurred over a broader range of start zone angles (IQR = 10°) than intermountain and continental avalanches. The statement sometimes heard in avalanche courses that "over 90% of accidents involve slopes between 30° and 45°" appears to be true only for intermountain and continental climates (table 1).

Avalanche Type	Mean	30°- 45°
All	38.7°	91%
Continental	38.3°	91%
Intermountain	37.9°	94%
Maritime	40.5°	84%
SS	38.5°	91%
HS	37.6°	95%
WS	40.5°	87%
WL	44.0°	58%
L*	50.8°	25%
DH or FC	37.8°	93%
SD*	42.1°	88%
DF	44.3°	76%
WG	45.4°	57%
SH	35.8°	98%

Table 1: Mean start zone angle and the proportion of avalanche types that released in start zones 30°–45°. An asterisk (*) indicates results that should be viewed with caution due to small sample sizes.

Avalanche Type

Hard slabs and soft slabs were by far the most common avalanche type in reported accidents (figure 2). While there was no statistical difference between start zone steepness for hard slabs and soft slabs (Pt-test = 0.103), significantly more hard slabs than soft slabs released in start zones 30°–45° (PBartlett = 0.0004). In other words, hard slabs in this sample released over a narrower range of slope angles than soft slabs.

Fewer accidents involved wet snow, but these avalanches generally released in steeper start zones and over a greater range of angles than dry slabs. Loose avalanches (wet or dry) appeared to favor even steeper start zones, a trend that has been qualitatively noted in the literature *(see Tremper, 2008, p68 or McClung and Schaerer, 2006, p112)*. Due to the small number of cases, particularly for dry loose avalanches, these results should be viewed with caution. Nevertheless, it is worth noting that for avalanches that are not dry slabs, the interval of 30–45° represents considerably less than 90% of start zones in these accidents (table 1).

Weak Layer

Over 70% of weak layers in reported avalanches were comprised of depth hoar (92 cases), faceted grains (86 cases) or facet-crust combinations (38 cases). There was no statistical difference between these distributions (PANOVA = 0.713) and hence all three were combined. About 93% of these avalanches released in start zones between 30°and 45° (table 1), with activity peaking around the familiar 38° (figure 3).

Other weak layer types showed a distinct tendency to release on steeper slopes. Stellar dendrites (SD), decomposing forms (DF), and wet grains (WG) generally released on slopes steeper than 38°, with wet grains showing a broader range of start zone angles (IQR = 11.5°) that is consistent with wet avalanche types in figure 2. It is worth noting that stellar dendrites were the only precipitation particle reported as a weak layer; graupel and other precipitation types were notably absent from avalanche reports where start zone steepness was known.

Surface hoar (SH) was less common than facets or depth hoar as a weak layer, but it showed a marked tendency to release on lower angle slopes (median 36°) than other crystal types. The variability of start zones for surface hoar avalanches was remarkably low (IQR = 3°), with 98% of start zones residing in the 30°–45° range (table 1).

DISCUSSION

This brief analysis tells us much that we already know: that most avalanche activity peaks around 38° and that most accidents involve start zones between 30° and 45°. This "Rule of 30–45°" applies especially well to past accidents in intermountain and continental climates that involve dry slabs running on depth hoar or facets.

But we also see some interesting patterns:

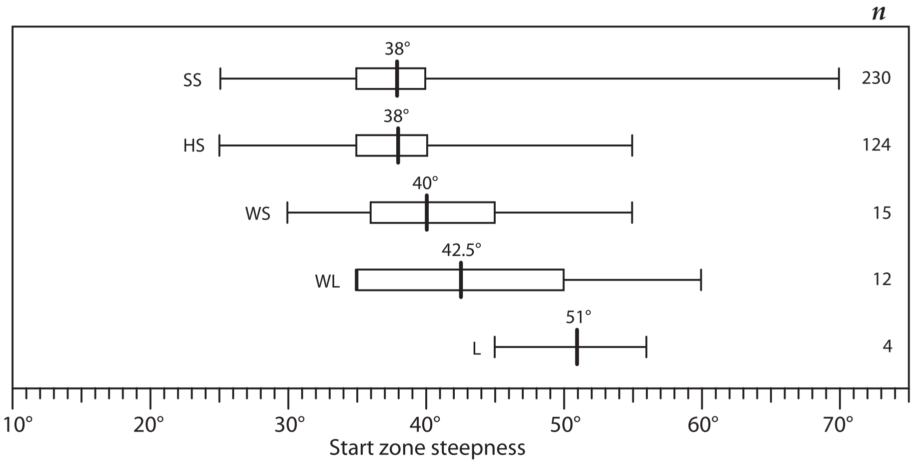

Figure 2: Start zone steepness by avalanche type (SS – soft slab; HS – hard slab; WS – wet slab; WL – wet loose; L – dry loose).

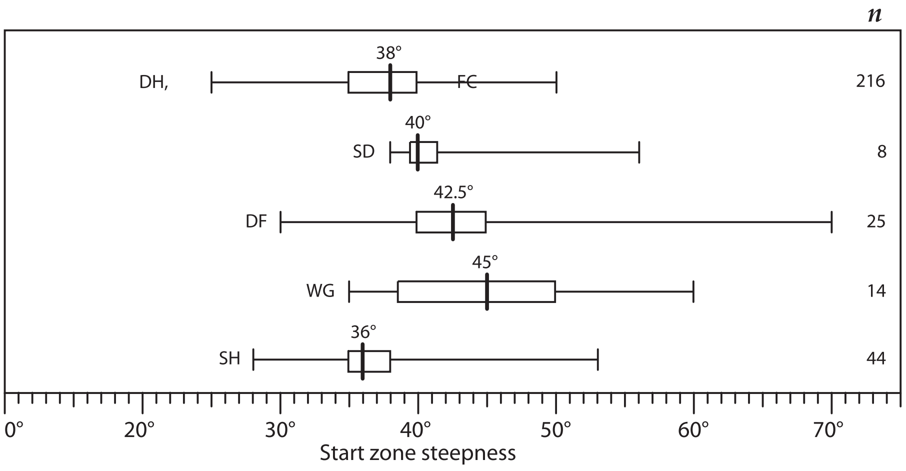

Figure 3: Start zone steepness by weak layer grain type (DH, FC – depth hoar or faceted grains; SD – stellar dendrites; DF – decomposing forms; WG – wet grains; SH – surface hoar).

1) In maritime accidents and in accidents involving wet snow, avalanches typically released in steeper start zones.
2) Accidents involving non-persistent grain types such as decomposing forms and stellars also broke the traditional 38° pattern, with a smaller percentage releasing in the range of 30°–45°.
3) Accidents involving surface hoar generally released in shallower start zones than the standard 38° pattern would have suggested. But 98% of these avalanches released in start zones of 30°–45°.

Predicting avalanche likelihood is a complex problem that goes far beyond simply measuring slope angle. But these results support the idea that avalanche type is an important factor when determining which slopes might be dangerous on a given day.

It is encouraging that these findings mirror field experience, but these results should be viewed and applied with caution. The data on which this study was based are likely biased due to patterns of recreation and the limitations of avalanche investigations. But my hope is that these results encourage further work on this important topic.

CONCLUSIONS

Under most mid-winter conditions, the "Rule of 30–45°" seems to be a reasonable (but by no means absolute) terrain selection guideline, especially for slopes in continental and intermountain climates where the weak layer is a persistent grain type. This traditional concept may prove to be more conservative in maritime climates, when the snow is wet or when the weak layer is a non-persistent grain type. But when the weak layer is composed of surface hoar, it may be prudent to dial back the slope angles you'd otherwise consider safe. While much work remains to be done on slope angle and avalanche type, these early results show promise for improving our decisions in avalanche terrain.

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Ian McCammon is a reliable contributor to TAR and to our overall understanding of translating theory into better practices and decision-making in avalanche terrain. He lives in Salt Lake City where he is learning to say, "No, I cannot take on another project." ❄

A Practitioner's View of Fracture Propagation Propensity

Story by Sarah Carpenter

I don't have a PhD in snow science. In fact, I have an undergrad degree in French. But…what I do have is a lot of time with my head in the snow.

Reading Karl Birkeland's article out loud to Don Sharaf prompted a good discussion on how we incorporate all of this new research into our stability analysis. We're no Ed LaChapelle, but one thing that we both agreed on is that you often get a really good sense of the snow (slab properties and potential weak layers) just by digging. As LaChapelle writes in *The Ascending Spiral*, "By the time I have finished digging a snow pit, I usually know about 90% of what I am going to find from it about snow stability."

As I mentioned, I'm no Ed LaChapelle, so usually I need more information. I still rely heavily on some of the information-gathering techniques taught in my Level 1 class. I poke and prod the snowpack with my ski pole in search of the recipe for a slab avalanche on my ascent. I jump on switchbacks and watch the results. If that little area of snow fails under my skis and propagates another 10', I've got yet another great insight into the properties of a particular slab and weak layer combination. I seek out test slopes and test slope stability on a small scale. And if I still need more information, I stick my head into the snow.

What do I use in my snowpack and stability analysis? I incorporate strength, structure, and energy. This view of the snowpack, as described in TAR 23/3 by McCammon and Sharaf, is a more holistic picture of stability. As much of the research has shown, strength can be incredibly spatially variable, so just looking at CT scores or RB scores paints a very incomplete picture. In all of my reading, my many email queries to Karl Birkeland this fall, and my personal observations, it is my understanding that both energy (shear quality or fracture character) and structure are more spatially uniform. So, when I get a Q1 score in my pit, I tune in. And if I'm getting consistent Q1 scores in my pit, I really tune in. High energy to me means that if I am able to affect the weak layer, I'm going to see a significant avalanche.

And what about those days when I'm getting consistent moderate compression test scores with Q2 results? I have found the Extended Column Test (ECT) to be invaluable at narrowing the gray zone. I use the ECT to clarify the propagation propensity of particular slab/weak layer combinations. Yes, I can initiate a fracture, as demonstrated in my compression test, but will that fracture propagate? The ECT and the PST are invaluable at demonstrating this piece of the puzzle. They are particularly valuable in conjunction with other tests…as are all of the formal stability tests.

And if I'm still confused after poking, prodding, and digging…I'll stand above my snow pit and jump on it. That piece of visual data – how the slab and weak layer combo reacts to my jumps – can fill in quite a few information gaps with minimal effort.

A ski cut is another great assessment tool that I use on a regular basis, especially on layers that are too shallow or soft to be effectively assessed with formal stability tests.

What about the slab properties that Birkeland, Schweitzer, and Jamieson commented on in their article? I would agree that paying attention to slab properties is essential. On the SW Montana AVPro course, Scott Savage gave a great talk on the deep-slab avalanche problem that exists at Big Sky. The effects of slab properties on fracture propagation seem to be at play here, potentially explaining why, at the crown, there appears to be no weak layer in his avalanche, but only an interface between a hard layer and a REALLY hard layer.

Don Sharaf and I hypothesize that a weak layer existed and was affected lower down on the slope. Due to the stiff nature of the slab, that failure propagated up into an area where that weak layer no longer existed. Don has also seen failures that have propagated around a wind-blown ridge through an adjacent slope. Propagation of these failures through the slab, rather than through the weak layer, seems to be the likely explanation.

The bottom line: I am grateful for our researchers. In the field, I find that incorporating recent research alluded to by Birkeland, et. al., *(see next page)* has improved the accuracy and efficacy of my stability analysis. Class-one data, such as avalanche activity, still trumps all other observations. Informal stability tests help paint a picture of snow stability on the fly. And when I get into a snowpit and gather data, I try to gain a holistic picture of the snowpack, looking at strength, structure, and energy. In other words, I look at not only fracture initiation but also fracture propagation. And of course, with all of these tools in my toolbox, I am always in search of safe, fun powder skiing.

Much credit for this article goes to Don Sharaf; I've been riding in a car with him for many hours now, plus have worked with him almost constantly for the last month or so.

Sarah Carpenter is finally home after many days in the field and classroom on both AvPro courses, ski guiding, and other avalanche classes too numerous to list. Now she can turn her attention to her husband Don Carpenter, whose broken fibula prompted his meditation on self-rescue on page 12 of this issue of TAR. ❄