FRACTURE PROPAGATION: Recent Research and Implications

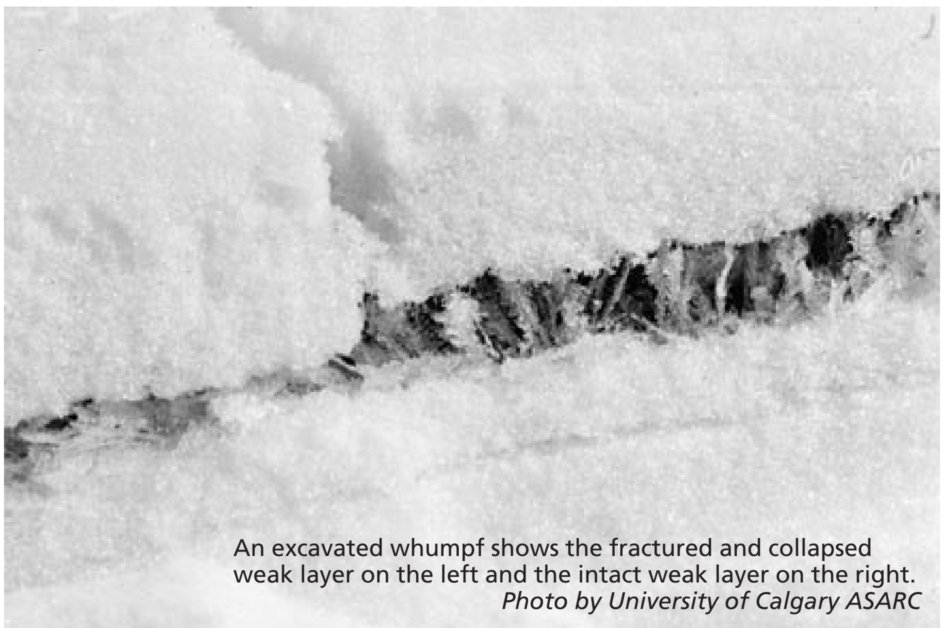
Story by Karl Birkeland, Jürg Schweizer, and Bruce Jamieson

A quick perusal through some recent ISSW Proceedings demonstrates a greater emphasis on fracture propagation. The Whistler ISSW boasted 16 papers and posters on fracture propagation and associated field tests, and the evening's beer-fueled discussions often came around to talk of fracture propagation. In her usual nice way, TAR editor Lynne Wolfe cornered us at that conference and encouraged us to write a quick article summarizing some of this work; out of her encouragement came this article. We attempt to synthesize some of the recent research and ideas, and discuss some of the implications for avalanche practitioners.

Propagation versus Initiation

While several new tests are available, many of the ideas about fracture propagation are not new. We have known implicitly that avalanches require both fracture initiation and propagation, though this has only been emphasized in our writing and teaching for about the last five or 10 years *(e.g., Schweizer, et al., 2003)*. Until quite recently, our field tests and much of the research have predominantly emphasized initiation over propagation. Likewise, some of the recent new models of fracture propagation simply provide an improved explanation for phenomena that practitioners have known and observed for many decades, such as avalanches remotely triggered from flat terrain.

This most recent emphasis on fracture propagation began when researchers formalized what many practitioners had long observed about stability tests – that it is important to not only observe how much dynamic force (or load) it takes to fracture a weak layer, but also to look at how that fracture occurs. With rutschblocks this meant observing the type of release (whole block, part of the block, or the edge), as noted by Schweizer, et al., *(1995a)*.

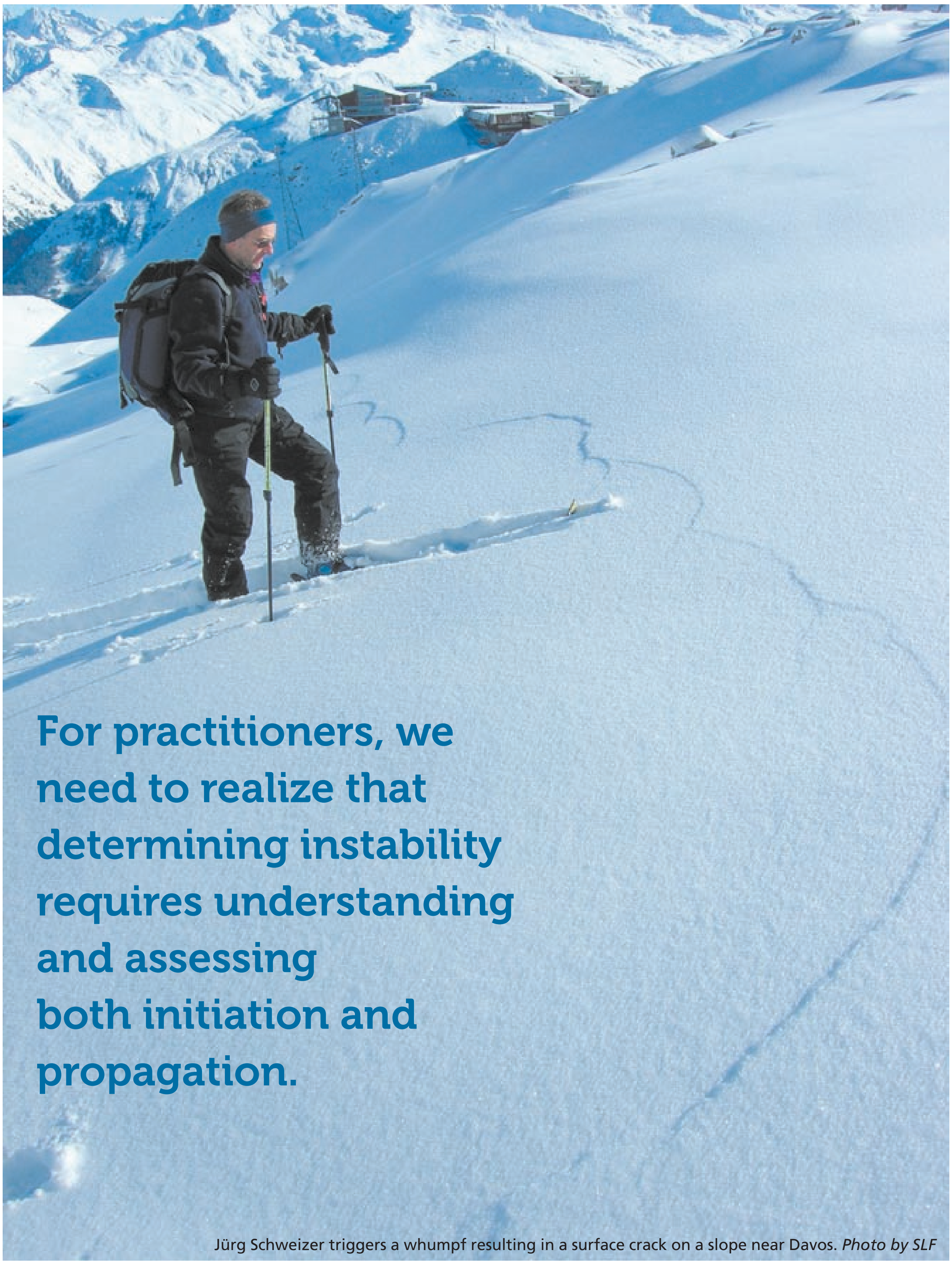

An excavated whumpf shows the fractured and collapsed weak layer on the left and the intact weak layer on the right. *Photo by University of Calgary ASARC*

A later survey of avalanche forecasters indicated they were typically more interested in the way a rutschblock fractured than in the actual rutschblock score *(Schweizer and Wiesinger, 2001)*. With compression tests and stuffblock tests, researchers began to look at shear quality *(Birkeland and Johnson, 1999; Johnson and Birkeland, 2002)* and fracture character *(van Herwijnen and Jamieson, 2002, 2004)*. Johnson and Birkeland *(2002)* hypothesized that shear quality might provide a qualitative measure (at a small scale) of how a fracture might propagate. Observing the way these tests fractured and whether fractures were "clean" or "sudden" had been done by practitioners for a long time, but research showed that taking this into account when interpreting stability tests could reduce the number of "false stables" or test results indicating stable conditions on slopes that showed other obvious signs of instability *(Johnson and Birkeland, 2002; Birkeland and Chabot, 2006; Schweizer et al., 2006)*.

New tests focusing specifically on fracture propagation expanded on observations of shear quality, fracture character, and rutschblock release type. Gauthier and Jamieson *(2006; 2008a)*, Sigrist *(2006)*, and Sigrist and Schweizer *(2007)* came up with a test that involved isolating a column parallel to the fall line of the slope, initiating a fracture with a saw, and observing whether or not the fracture then self-propagated through the rest of the column. This test was refined and eventually dubbed the Propagation Saw Test (PST). Simenhois and Birkeland *(2006)* simultaneously and independently worked on the Extended Column Test (ECT), in which a 90cm-wide cross-slope column is loaded on one side with loading steps identical to the compression test.

Both the PST and ECT quickly found their way into the toolboxes of many practitioners, with recent research showing the ECT to have a low false-stability rate and the PST to have a low false-instability rate. Since there are already several articles on both of these tests, we won't go into further details here *(in addition to the papers already cited, check out Birkeland and Simenhois, 2008; Gauthier and Jamieson, 2008b; Moner et al., 2008; Ross and Jamieson, 2008; Winkler and Schweizer, 2008)*. One advantage of the new tests is that we can now begin to investigate some of the factors affecting fracture propagation in the field, such as changes in slab depth *(Simenhois and Birkeland, 2008a)* or surface warming *(Simenhois and Birkeland, 2008b)*.

In addition to some of the new tests focused on fracture propagation, there has been renewed interest in the theory behind fracture propagation. Johnson et al., *(2004)* measured the speed of a propagating fracture across a flat meadow utilizing geophones, finding that the fracture traveled at 20 ± 2 m s-1. van Herwijnen and Jamieson *(2005)* measured fracture speeds with a high speed camera, calculating speeds between 17 and 26 m s-1. These fracture speed measurements helped to reignite a mostly dormant


For practitioners, we need to realize that determining instability requires understanding and assessing both initiation and propagation.

Jürg Schweizer triggers a whumpf resulting in a surface crack on a slope near Davos. *Photo by SLF*

Tests in flat areas might be useful for predicting conditions on nearby slopes.

On this part of a spring tour in the Rockies, Dave Gauthier (in background), Antonia Zeidler (foreground), and Bruce Jamieson were triggering whumpfs every few steps.
Photo by Bruce Jamieson

debate about the relative importance of collapse in fracture propagation. The speeds are consistent with theory proposing collapse as a driving force of fracture propagation *(Johnson, 2001; van Herwijnen and Jamieson, 2005)*, though other work suggests they are also consistent with existing models of shear fracture propagation *(McClung, 2005)*. Gauthier and Jamieson *(2008a)* reported similar PST results on slopes as on adjacent flat terrain, an observation that supports the importance of collapse in driving fracture propagation.

High-speed videos show a variety of weak layers – including thin weak layers – collapsing and shearing, with none of them showing slope-parallel shear fracture without collapse *(Schweizer et al., 1995b; van Herwijnen and Jamieson, 2005; van Herwijnen et al., 2008)*.

Of course, the idea that collapse plays a role in fracture propagation is not new. After all, snow in general and weak layers in particular are highly porous, making collapse possible. Seligman *(1936)* noted that avalanches could be triggered from flat terrain, and Bader *(1951)* stated collapse as one of several methods for fracture under the slab. Bradley *(1968)* developed a field instrument and method for forecasting avalanches related to collapse in depth hoar snowpacks by calculating a bulk strength-to-load index. Lackinger *(1989)* described the bending wave due to a collapsing weak layer. Johnson *(2001)* wrote a simple equation for the bending wave and better described remote triggering from low-angle terrain. Heierli and colleagues *(Heierli, 2005; Heierli et al., 2008; Heierli and Zaiser, 2006; Heierli and Zaiser, 2008)* greatly improved the mathematical description for the collapse and bending wave and then combined this theory with shear-fracture theory.

In essence, this most recent work allows for both collapse and shear as potential driving forces behind fracture propagation *(Sigrist, 2006; Heierli et al., 2008)*. Fractures in thinner weak layers and on steeper slopes are predicted to be more dependent on shear, while fractures in thicker weak layers and on flatter terrain are more dependent on collapse.

What Does this Mean to Us?

While plenty of new information is available for pondering the theory behind fracture propagation, the big question is: "What are the implications for practitioners?" Before we address this question, we need to remember that the basic observations we have made for years are still valid. For example, practitioners have known of and observed avalanche triggering from flat terrain for many decades. Some of the new theory simply gives us a better mathematical description for that observation. Further, we have known – at least intuitively – that both fracture initiation and fracture propagation are necessary for avalanches.

The first implication for practitioners of some of the new work is that researchers and practitioners need to consider both the slab and the weak layer. Our emphasis in the past has been on fracture initiation, and we tended to focus primarily on the weak layer. This shifted as we came to better understand the role of the slab in initiation, and as we now start to gain knowledge of the role of the slab in propagation we are realizing that it is vitally important to look at both the slab and weak layer together to better understand avalanches. Practitioners should be sure to note the characteristics of when fractures are propagating and integrate this knowledge into stability assessments.

A second implication for practitioners is that we need to realize that determining instability requires understanding and assessing both initiation and propagation. Luckily, we now have – besides things like the rutschblock release type, fracture character, and shear quality – two tests (the PST and ECT) that give us a start at specifically indexing fracture propagation potential, thereby providing us with new methods for assessing snow stability. We also need to be better aware of how fracture-propagation propensity might vary spatially around starting zones. This is an open question, though some preliminary work has been done *(Birkeland and Simenhois, 2008; Hendrikx and Birkeland, 2008; Hendrikx et al., in press)*.

A third implication has to do with the location of our field tests. We don't know if fractures are occurring first in shear or in compression. However, it is clear that both shear and collapse are occurring in some sort of mixed mode and that collapse is an essential energy source for propagation in some cases. Thus, for collapsible weak layers, tests in flat areas or in areas with shallow slope angles might be useful for predicting conditions on nearby slopes, as long as the snow stratigraphy in those flat areas is representative of the slopes in question.

Indeed, a limited dataset shows this to be the case for the PST *(Gauthier and Jamieson, 2008a)*, and some limited and preliminary data from this season suggest that ECTs in flat terrain may provide useful information about the potential for remote triggering *(Simenhois, pers. comm., 2009)*. If these findings are confirmed, it would be extremely helpful for practitioners and recreationists since safe pit sites would be much easier to locate in the flats or at least on gentle slopes than on steep slopes during unstable conditions. Of course, some layers (such as poorly bonded crusts or weak interfaces) are much less collapsible. If they don't collapse – and so far, high-speed videos have not revealed any that don't have at least some collapse – then tests involving such weak interfaces will need to be conducted on slopes.

New Ways to Look at Snowpack

Recent research on fracture propagation and the development of tests attempting to index fracture-propagation propensity provide all of us with new tools and new ways to look at the snowpack.

It is important to remember that these new tools and insights don't replace our proven tools developed over the past several decades, but instead they simply add to our toolbox. Avalanche forecasting and stability assessment still require a holistic approach that takes into account diverse data including weather, avalanche, and snowpack observations. The key is to look into the snow, poke around, and do a variety of tests, while at the same time realizing that there is no ultimate test. Hopefully future research, combined with careful observations by practitioners, will continue to improve our understanding and our methods for evaluating slope stability.

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A crack following a whumpf on a slope in southwest Montana.
Photo by Karl Birkeland

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Jürg Schweizer *(right) is a senior research scientist and head of the Avalanche Formation group at SLF Davos, Switzerland. He continues to be a great fan of the grandfather of most snowpack tests: the rutschblock. However, he has to admit that the snow saw has become his favorite tool for playing in the snow.*

Bruce Jamieson *(left) holds the NSERC Research Chair in Snow Avalanche Risk Control at University of Calgary, and supervises the ASARC field program. He is rather fond of digging square holes in the snow and watching how snow fractures.*