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THE Avalanche REVIEW

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STORM stories

Trolling for something to do, I ventured an earnest call. “Uhh, 3 Mary 5-0, this is 3 Mary 5-2; is there anything I can do from here?” Pause. Jerry, with the whole world listening and a storm puking 3" an hour, replied, “Thanks 5-2, uhh yea...when we get this lady out we’ll be escorting her back to Silverton for the night, but she might not be able to find a place to stay...doesn’t speak very good English, think she’s Romanian...you think she could camp on your sofa for the night?” I pause, suspicious. “Uhh, yea, sure, I guess so.” Jerry: “Great! And one other thing...I think she’s from the circus...and I think she has a monkey with her."

Long pause. “Did you say MONKEY?” Jerry: “Yea, I think it’s a monkey. Will your dog be okay with that?”

—for more of this story, turn to *Avalanches & Monkey Business*, page 15

Last January's seven-day storm dumped a record 91" on Silverton, Colorado, resulting in numerous slides which covered over 11,000' of roadway in avalanche debris. It took days to dig out, while rat-trapped residents anxiously waited to escape their forced isolation.

Photo by Susan Hale

in this issue

It was not until after the accident that I really starting pressing for information. Before, I felt I needed to make my own evaluations, and it felt like cheating to ask.

—from Laura Adams's story on Judgment & Decision-making, pg 5

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The mission of the AAA is:

A. To provide information about snow and avalanches;
B. To represent the professional interests of the United States avalanche community;
C. To contribute toward high standards of professional competence and ethics for persons engaged in avalanche activities;
D. To exchange technical information and maintain communications among persons engaged in avalanche activities;
E. To promote and act as a resource base for public awareness programs about avalanche hazards and safety measures;
F. To promote research and development in avalanche safety.

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Articles, including editorials, appearing in ***The Avalanche Review*** reflect the individual views of the authors and not the official points of view adopted by AAA or the organizations with which the authors are affiliated unless otherwise stated.

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from the aaa

AAA held its semi-annual governing board meeting in mid-September at the Bridger Bowl ski area. The board communicates frequently throughout the year using e-mail and phone, but it is always good to get some face time together. Here is a summary of the business that was conducted.

Our financial status is in good shape as of this writing. This has been a real turnaround from our position only eighteen months ago where we had to dip into our "rainy day" account in order to get the *Observation Guidelines* printed. The publication and excellent sales of the *Observation Guidelines* has had a major part in our improving financial condition. The membership dues account for the major portion of our operating funds, but the membership has been increasing only very slowly. We receive many new applications for membership each year, but this is somewhat offset by members who leave the profession or lose interest in AAA.

The inaugural AAA Professional Avalanche Worker School (PAWS) just finished its first session in December in the Cottonwood Canyons of Utah's Wasatch. There was almost unanimous enthusiasm for this school at our annual meeting during the Jackson Hole ISSW in fall 2004. Don Sharaf organized the first school; his report will be in the next issue of TAR. The faculty had impressive credentials —this and future schools cannot help but be successful. Thanks Don and the AAA Education Committee.

A topic that has evolved over the last several board meetings regards AAA professional membership criteria. It has been the opinion of more than a few of the board that the criteria are not specific enough to help aspirant professional members know how much and what kind of experience is necessary to attain professional membership. The four years of professional experience necessary for pro status as stipulated in the AAA by-laws remains unchanged, but what constitutes a year? A year has always been considered one winter season. Applicants will have to document a certain number of days of focused snow and avalanche activities. This work is still ongoing at the time of this writing, but will be in place before the April board meeting. The purpose of this effort is to make the process more objective for the AAA Membership Committee and the applicants. Board members Blase Reardon, Janet Kellam, Bill Glude, and Membership Committee Chair Stuart Thompson have worked hard on this issue over the last few months.

I continue to receive many positive comments about *The Avalanche Review*, both for its new color look and the continued excellent content. We had some tough times a few years ago, but have persevered and come through better than ever. The credit has to go to former editor and current Publications Chair Blase Reardon, editor Lynne Wolfe, new assistant editor Toby Weed, our fantastic designer Karen Russell of Fall Line Design, and our advertising manager Marcia Lemire. On behalf of the membership I want to thank you. TAR is our main product and purpose, and something we can all be very proud of.

A topic we need some feedback on is the commercial use of our mailing list by businesses. We do not provide our AAA membership mailing to anyone nor do we have any intention of doing so. However, that being said, we received an inquiry this fall from a well-known provider of avalanche-safety equipment who wanted to offer discounts to AAA members. Some members may not have ready access to this kind of "pro deal" and may find this sort of offer very helpful. There are several ways we could provide this information to businesses, but we need to know if this would be valuable to you, the membership. Any future use of the mailing list will be of practical use to the membership, a board decision, and taken on a case-by-case basis. These offers will only be available to members, not TAR subscribers. Let myself or any AAA board member know your thoughts.

In conjunction with the board meeting in Bridger a one-day continuing education professional development seminar was held. AAA has offered this as an off-ISSW year opportunity for members to socialize, hear some fresh ideas, and quaff some refreshments. Part of my responsibility is to organize this get together. So far it has only enjoyed modest success. Attendance has hovered in the 30-60 attendee range. We don't intend to make money on these events, only to break even at best. We look at this as a membership benefit. The board would like to see these events better attended and become practical and anticipated events for AAA members. Any ideas or suggestions you have about these will be appreciated. Planning for the Continuing Ed seminar for the fall of 2007 will begin this spring.

AAA will celebrate its 20th Anniversary this fall at the Telluride ISSW. As an early member and one who attended the gathering on the deck of the Squaw Valley Theater in the fall of 1986, I am really looking forward to this milestone. We have come so far in 20 years. I hope you are planning to come to Telluride and help us celebrate as well as attend what has become the premier rendezvous for us snow folks.

It has been a little dry in this part of Colorado as of the middle of December. I wish you all abundant snows in 2006. Good luck, good hunting, and stay on top. Your comments and suggestions are always appreciated.

Contact AAA at 970.946.0822 or by e-mail at aaa@avalanche.org.

—Mark Mueller, your Executive Director

from the editor

It is the thick of the winter. Here in the Tetons we have seen the sun twice since Christmas. So far this winter I have taught five avalanche courses, skied an unmentionable number of days, and lost an old friend to a large avalanche on Mt. Taylor, which we ironically see on the cover of the 2004 ISSW proceedings. Her accident has underscored my dedication to furthering avalanche education. As I compose a PowerPoint presentation about this avalanche for my upcoming level 2 classes, I hope that insights into science, terrain, and the ripple effects of decision-making come across to my students.

Now is the time of year where we are sleep-deprived and caffeine-poisoned, working hard in the snow. Ideas and projects come at us in a non-stop flow, and we have to prioritize the precious hours of light so that we aren't peering into computer screens late at night. Here at *The Avalanche Review* we have no obvious theme for this issue, but are able to bring you evidence of how your peers are spending their time. Once again the CAIC crew in Silverton gives us a great cover story and some breathtaking photos from a storm cycle in the San Juans; John Brennan shares his interest in the mechanics and history of the Avalauncher; and we get to see Andy Gleason's investigations into bridging in full color. We have another set of insights into how the human factor affects decision-making from the prolific Laura Adams, and François Louchet and Alain Duclos share their work on skier triggering.

In this issue we also have a short obituary of Sue Ferguson, the founder of both *The Avalanche Review* and the American Association of Avalanche Professionals—now the AAA. I met Sue at the Big Sky ISSW, where her confidence and competence were simultaneously intimidating and inspirational. Her loss has set me to musing on the role of mentors in our learning. If you have insights or comments on this topic (or any other snow-related topic) then send them to me by February 15 for the next TAR. *—Lynne Wolfe, editor, The Avalanche Review*

Steve Conger demonstrates the stuffblock Test at an AIARE Instructor Training Course at Alpental, Washington, December 15, 2005. Conger, ex-officio editor of *The Avalanche Review* and AAA Publications Committee chair, is currently a grad student at University of Vancouver. *photo by Tom Murphy*

metamorphism

AAA thanks the following members for contributing an additional donation to further our efforts in 2005. In fiscal year 2004/05, donations totaled $6,760 and amounted to 11% of our total income.

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call for submissions

- Seen any good avalanches lately?
- Got some gossip for the other snow nerds?
- Developing new tools or ideas?
- Learn something from an accident investigation?
- Send photos of a crown, of avie workers throwing bombs, teaching classes, or digging holes in the snow.
- Pass on some industry news.
- Tell us about a particularly tricky spot of terrain.

SUBMISSION DEADLINES
Vol. 24, Issue 4. 02/15/06
Vol. 25, Issue 1. 08/01/06

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Sue Ferguson, TAR Founder, Passes

Sue Ferguson, former director of both the Northwest Avalanche Center and the Utah Avalanche Center, lost her battle with cancer on Sunday, December 18, 2005. Sue made many enduring contributions to our field; she founded *The Avalanche Review* and co-founded the American Avalanche Association (formerly the AAAP). She will be greatly missed. The picture above was taken while she sailed with friends on Lake Washington in September.

We will present a more in-depth look at Sue's achievements in the April issue of *The Avalanche Review*. If you have stories or photos of Sue to share with the avalanche community, please contact the editor.

Changes at Manti-La Sal Av Center

From Max Forgensi at the Manti-La Sal Avalanche Center: **Evan Stevens**, after a few years of being of part of the center, has gone to the whiter slopes of British Columbia, where he and his wife Jasmin are working as guides for his in-laws.

This means that we have a new avalanche forecaster: **Dave Medara** has returned to the Manti-La Sal Avalanche Center as the newest/oldest avy forecaster. Dave is very attuned to the La Sal Mountains as he previously spent 13 years in Moab, where he worked as an avalanche forecaster from 1992-1995 and again from 2001-2002. It's great to have Dave and all of his knowledge back on board.

what's new

Roaring Fork Avalanche Center Opens in Aspen, Colorado

Looking up the popular Yule Creek drainage from Marble Peak outside Marble, Colorado. This area receives a lot of backcountry skier traffic each winter. *photo by Brian McCall*

Heavy early-season snows with typical Colorado bluebird skies have made the 2005/06 season ideal for at least a small group of avid backcountry skiers in Colorado. Three former Aspen Highlands Ski Patrollers: Brian McCall, Lance Lary, and Jimmy Newman founded the Roaring Fork Avalanche Center (RFAC) and their timing could not be better.

The RFAC, formed in March of 2005, is a 501c3 non-profit supported entirely by generous donations, member dues, and grants. Affiliated with the Colorado Avalanche Information Center in Boulder and the U.S. Forest Service office in Aspen, the RFAC looks to augment statewide forecasting with more localized information for the active backcountry community in the Roaring Fork and Crystal River valleys.

"The impetus for the RFAC comes purely from demand from both locals and visiting skiers headed to Tenth Mountain Huts from the Front Range and beyond," McCall explains. "The CAIC does a tremendous job. However, they do not have the capacity to put observers in the field throughout the state, let alone throughout our localized areas on Independence Pass, Ashcroft/Pearl Basin and up in Marble. With their support we look to provide more detailed field information to allow users to make more educated decisions in terms of avalanche conditions."

Digging into the details, McCall points out that Colorado traditionally has led the country in avalanche accidents and incidents. Pitkin County, where Aspen is located, ranks second in the state for accidents behind Summit County, which has a bigger population base and is closer geographically to the Front Range, so therefore draws from larger urban centers.

Since opening in mid-November, the RFAC has seen traffic to their site rise steadily from an average 200-300 hits per day in the first few weeks to over 500 on a recent busy weekend day. Additionally, they have been excited by the feedback they have received regarding local avalanche/field observations with detailed aspect, elevation, and triggers. This on-line feature, which allows anyone to post what they are seeing and experiencing on any given day, gives locals insight into conditions at popular backcountry destinations.

Beyond identifying the demand and having the motivation to undertake starting their own center, McCall, Newman, and Lary have had to work hard to set up the structure of their organization. Initially the three approached the CAIC and the Forest Service about the possibility of a new office for Roaring Fork Valley. Neither organization had the budget to fund any new jobs or offices. Undeterred, they set up a non-profit corporation to fund this project and signed a Co-Operator agreement with the Aspen Ranger District of the Forest Service to provide avalanche forecasts as a service. This allows the RFAC to be covered by government liability protection, which is required in order to provide forecast information. The RFAC also signed a memorandum of understanding with the CAIC to work closely with them on a daily basis to mutually strengthen both their daily forecasts.

In the U.S., two other centers are set up in a similar format: Crested Butte Avalanche Center in Colorado and Eastern Sierra Avalanche Center in Bishop, California. Both have opened in the last few years, and if the early success of the RFAC is any indicator, these three centers may be viewed as a green light to assist backcountry skiers in gaining more detailed information about their local avalanche conditions.

For more information, visit www.rfavalanche.org ❄

Aspen ski patroller Brian McCall helped found the Roaring Fork Avalanche Center.

Funds and Resources Available

The AAA extends a warm welcome to H.P. Marshall, who recently became the AAA Research Committee Chair. He sent us the following brief bio and tells us that money is available to support small projects (~$1000), and there are two competitions: one for graduate students and one for practitioners. Data loggers are also available for loan. Contact H.P. at marshalh@colorado.edu for details.

H.P. Marshall began his snow science career 12 years ago doing research on wet-snow avalanches in the Washington Cascades with Howard Conway and spent summers participating in glaciology research on Blue Glacier, Mt. Olympus, while working on his physics degree at the University of Washington. He took a year off before entering graduate school and taught at-risk youth in the small remote Athabascan village of Old Crow in the Canadian Arctic. He has spent two field seasons in Antarctica and currently works in Alaska, the Canadian Arctic, and the San Juan Mountains of Colorado. His Ph.D. work in geotechnical engineering through the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado at Boulder has focused on measurements and modeling of snow-slope stability. He now works remotely from Durango for both INSTAAR and the Cold Regions Research and Engineering Lab. ❄

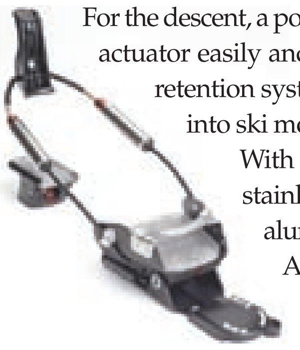
3rd Intl Avalanche Conference Set

The Third International Avalanche Conference will be held September 4-8, 2006, in Kirovsk, Murmansk, Russia—just beyond the Polar Circle in the Khibini Mountains.The conference will cover results of ongoing avalanche work and provide idea and information exchange between members of the world avalanche community.

Topics for 2006 will include snow-cover stability; avalanche dynamics; temporal and spatial avalanche forecasting; avalanche control techniques; awareness, education and public warning systems; avalanche search and rescue; slushflows; properties of snow and snow-cover evolution; snow drift; instrumentation.

Registration and information is available at www.cas.kirovsk.ru ❄

New G3 TARGA Ascent



Conserving uphill energy through an innovative patent-pending, free-pivoting system, the Ascent eliminates the resistance created by stiff boots and spring cartridges which works against the climber's efforts to ascend. To maximize downhill power, an active built-in 3° wedge reduces rocker launch and improves the transfer of energy from boot to ski by immediately engaging the spring cartridges upon initiation of the turn, producing a more active binding. While in tour mode, G3's system allows for exceptionally efficient touring.

For the descent, a pole-activated powerful actuator easily and securely moves the retention system into place to lock into ski mode.

With aluminum toe plates, stainless steel toe bars, and aluminum heel tubes, the Ascent weighs only 1440gr. It is sold with choice of G3 XRace or WorldCup cartridges and includes a pole-activated climbing heel, anti-ice plates fore and aft, and optional crampons. ❄

Ortovox Introduces New Beacon Checkpoint Devices

Ortovox introduced two new beacon checkers for the 2005/06 season. Compatible with all avalanche transceivers on the market, the beacon checkpoints are designed to provide confirmation of a beacon's transmit function before users enter into avalanche-prone terrain.

Available in two models, the beacon checkpoint with the information board is designed to be permanently mounted at key backcountry entry gates. Beyond checking the transmit function of a beacon, this weatherproof board provides valuable avalanche information and backcountry safety tips. With additional room for logos, the board allows for multiple sponsorship opportunities and retails for $1900 U.S..

The smaller beacon checker is designed to be mounted directly to a wall or backcountry gate. Offering the same functionality as the larger board, the beacon checker guarantees that a user's transceiver is operating properly before heading out of bounds. Powered by 110v, the smaller unit retails for $800 U.S.

In other Ortovox news, the U.S. Army's 10th Mountain Division has recently purchased an Ortovox Search Training System for use in avalanche safety training.

For more info, visit www.ortovox.com. ❄

education

Avalanche Judgment & Decision-making Part II
The Influence of Human Factors

Story & Photos by Laura Adams

Skinning up in the southern Selkirks, British Columbia.

It is widely recognized that human factors heavily influence the way we think and behave in life. As the findings of my master's research on avalanche experts suggest, human factors exert a significant influence in avalanche judgment and decision-making. The decision process involves the integration of complex information from a variety of sources, and occurs within a dynamic interaction of human systems that brings widely different perceptions and values to the decision process. Thus, decisions are not made as isolated events or individual moments of choice, and understanding the human context that surrounds the decision process is essential.

Human factors exert both positive and negative impacts in avalanche judgment and decision-making. While human factors have received considerable interest in high-stakes decision-making domains, much of the focus has been on their negative influence in judgment and decision processes. It is curious how little research has been directed towards identifying and examining human factors in light of their positive influences. In this article, I discuss the human factors that negatively influence avalanche experts' ability to make sound judgment and decision actions. In Part III, I will examine the positive human factors that support decision success, within the context of recent advancements in strategies for decision-skills learning, decision support, and effective avalanche-accident prevention. The first part of this series (TAR 24/2) provides the fundamental background in which I describe the processes and strategies that avalanche experts use to solve the decision problems they face in their profession.

- Human factors exert both positive and negative influences in the decision process.
- Human factor influences include individual, team, client, organizational, and sociopolitical categories.
- Avalanche decision-makers face conflicting challenges as they strive to achieve a balance between the widely varying goals and objectives within the realms of human influence, and the dynamically changing conditions in the physical and environmental systems of influence.
- Repeated experiences of non-event feedback or false positive events can result in dysfunctional strategies for future decision-making.
- The fear of appearing incompetent and uncertainty regarding performance results in anxiety that significantly decreases judgment and decision accuracy.
- The quality of communication within teams correlates directly with the quality of decision actions.
- Avalanche decision-makers require a high level of personal mastery and strong leadership capacities to avoid being overly influenced by negative human factors.

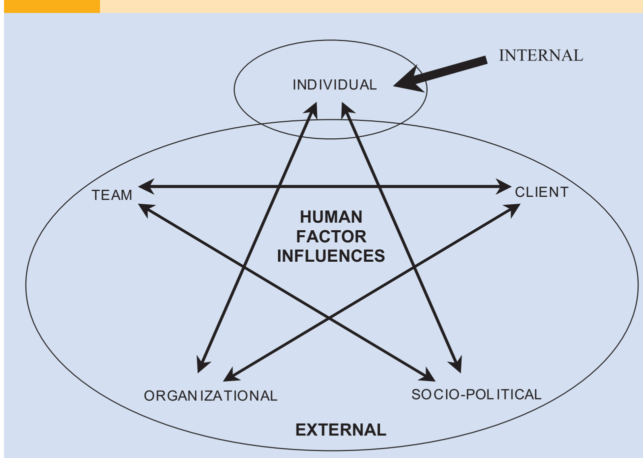


Figure 1: Human-Factor Influences in avalanche judgement and decision-making

COGNITIVE	PHYSIOLOGICAL	PSYCHOLOCIAL
• Inadequate knowledge • Inaccurate perceptions • Limited processing capacities	• Time Pressure • Fatigue • Mental & Emotional Stress • Environmental Influences	• Goals and objectives • Emotional influences • Pride and ego • Overconfidence

Table 1: Individual Human Factors

CATEGORIES OF HUMAN FACTORS

Avalanche-related judgments and decisions occur within a dynamic context that is influenced by internal and external categories of human factors. Internal human factors are directly related to the individual decision maker and include cognitive, physiological, and psychological influences. External human factors include team, client, organizational, and sociopolitical human influences *(Figure 1)*.

A. INDIVIDUAL HUMAN FACTORS
1. Cognitive Factors

Cognitive factors relate to our perception and understanding, and result from how we interpret the current information and situation in relation to our mental model *(Table 1)*. Mental models, which can be thought of as the lens through which we view the world, are developed from our life experiences. They are conceptual structures in the mind that drive our cognitive processes of understanding.

In Part I, I described how experience, knowledge, and skills along with information relevant to the human, physical, and environmental systems of influence were the foundation of sound avalanche decisions. Interestingly, deficits within this core foundation were the fundamental factors contributing to the close calls and avalanche accidents in this study. For example, a highways avalanche forecaster described to me how his lack of specific knowledge and experience influenced his decision-making: "My knowledge did not include snowpack or weather conditions characteristic of the day of the involvement." In another case, a ski-area forecaster related, "There was no wind and snowfall data available and no information regarding alpine conditions other than visual observations that were limited due to weather." This finding is consistent with those reported in aviation accidents where a lack of relevant knowledge and information led to the misdiagnosis of problems and to the choice of a poor solution.

2. Physiological Factors

Physiological factors such as fatigue, mental, emotional, and environmental stress impact our human functions and significantly degrade our

Continued next page ➡

DECISION-MAKING

continued from previous page

capacities to execute sound judgments and decisions actions *(Table 1)*. For instance, a ski guide related, "The accident happened late in the day. I was feeling tired, but wanting to please the guests and squeeze another run in on the way back." In another situation, a ski-touring guide described, "It is amazing how fatigue starts whispering, 'Oh it will be okay; the other safer route is so long.'" This theme had two distinct timeframe characteristics. In the first, participants described the effects from a long day or several days of challenging decisions, and in the second, the cumulative effects throughout a season.

The theme of time-pressured decisions also emerged within this finding and was identified by a majority of participants in my research. For example, a ski-area forecaster related, "We are expected to open everything as quickly as possible, with as little staff as possible, and under budget of course." In another case, a ski-area forecaster explained the critical effects of time pressure on his decision-making. "The clock is my personal nemesis. I am never more likely to put myself at risk than when I pay too much attention to the time our avalanche-control operations are taking. I never let the clock push my teams into danger; however, I sometimes let the clock push me. That is my biggest weakness at work, but at least I'm aware of it." Physiological factors have long been recognized as a key influence in our ability to execute sound decisions. Recognizing their presence, as explained by this forecaster, is fundamental to reducing their impact.

3. Psychological Factors

Psychological factors such as goals and objectives, emotional influences, pride, ego, and overconfidence are a third significant influence in our judgements *(Table 1)*. For example, a national parks forecaster described how group goals influenced a decision. "I believe the decision to enter the slope in the first place was influenced by our desire to complete the trip as planned. It would have been new ground for all of us and establish the aesthetics of the line we were attempting." In another situation, emotional (affective) influences were described by a ski guide who stated, "The beauty, snow, and calmness that covers the mountains in winter show little sign of the monster sleeping, and the white rush we get is a powerful force that beckons us on."

Pride, ego, and overconfidence also have significant psychological impacts, such as in the case of this participant who stated, "The reward of being a hero led to taking unreasonable risk." In another case, a highways forecaster related to me, "I thought I had more ability to forecast the extent of the activity than I actually did. This misconception, combined with an eagerness to serve the clients, led me to err on the side of recklessness rather than caution."

As the findings of my research suggest, psychological factors are inherent in avalanche decision-making. A high level of personal mastery and the use of mindfulness (metacognition) and critical thinking are powerful strategies to ensure we are not overly influenced by these factors.

B. EXTERNAL HUMAN FACTORS

1. Team Factors

The avalanche experts in my study described how team human factors negatively influenced their capacity to gather critical information and resources, to engage in critical thinking, and to arrive at an objective and well-informed decision *(Table 2)*. For example, an avalanche-safety specialist for extreme-ski events related, "This was probably the most stressful mountain decision of my life due to enormous outside pressures and lack of confident peer exchange." In another situation, a helicopter ski guide explained, "I had asked the guides for advice on an alternate line I had been eyeing with little response. After the avalanche incident, another guide said, 'I never ski there unless the slope has slid.' That single piece of advice would have prevented my close call."

Inadequate communication was also described within the context of the team atmosphere. For example, a ski-area forecaster explained, "It makes a huge difference if team members are respectful and investigative, rather than self-focused and judgmental. If the environment is non-supportive and dismissive of input, then I am prone to withhold information or take an observing role rather than contributing." Participants emphasized how the atmosphere created by the lead guide, team supervisor, or dominant member in the group often set the tone in which the exchange of information and resulting decision-making occurred. They also described a culture of pride and self-sufficiency that existed within some operations and expressed the serious implications this had upon their ability to inquire for information in order to reduce the uncertainty they were experiencing during field and office-based decisions. One participant expressed, "It was not until after the accident that I really started pressing for information. Before this, I felt like I needed to make my own evaluations and it felt like cheating to ask."

In another case, a ski-touring guide described resistance to a differing

TEAM	CLIENT
• Inadequate communication • Resistance to differing opinions • Failure to challenge assumptions about goals or values • Being overly influenced by the judgments and decisions of others • Social pressures to conform	• Pressure to access avalanche terrain • Inadequate communication • Loss of visual contact
ORGANIZATIONAL	**SOCIO-POLITICAL**
• Lack of risk comprehension by management • Financial, logistical, and time pressures	• Collective sense of professionalism and pride

Table 2: External Human Factors

opinion. "At the morning meeting, another guide was adamant about not skiing a piece of terrain. I found myself frustrated and trying to manipulate his decision. He was correct in his decision not to expose people to a hazard that was totally unnecessary in an unusual year. The human element was definitely what failed me in this situation."

2. Client Factors

Client human factors were also a significant influence in my research. I define clients as the people for whom avalanche-safety services are being provided—for example, visitors to national parks, public traveling on highways, film crews, or ski resort, helicopter, snowcat, or ski touring guests. Pressure from clients to access avalanche-prone terrain was the most commonly cited client human factor in this study *(Table 2)*. Participants described the tremendous pressure they experienced from ski-resort guests demanding terrain to be opened, highways vehicle traffic needing to continue their journeys, or backcountry ski and snowboard guests requesting to be guided in more aggressive terrain. For instance, a ski-touring guide explained how client pressure during high avalanche hazard resulted in him being seriously injured in an avalanche accident. "I chose to take my group into some conservative terrain where I had dug a snow profile several days before. The group was not very happy with that decision since they had skied there once before and suggested I find some different terrain where they had not been. I wanted to stay conservative, but at that point was pushed into pleasing my guests on their last day."

In another case, a ski-area forecaster described the decision-making challenges he faced as a result of demanding clients during conditions of terrain closures. Even with guarded control lines, aggressive skiers would jump the lines to access untracked powder, thereby placing themselves and his avalanche-control teams who were working in the area in potentially perilous situations. Clients' reluctance to follow terrain-use guidelines resulted in high levels of stress for these avalanche experts, since the safety of clients who are in avalanche terrain is ultimately their responsibility.

Inadequate communication with clients was a key factor in the close calls and avalanche accidents in this study. A ski-touring guide explained to me how a group's reluctance to be guided influenced the quality of his communication. He was given a group that had skied unguided at the same lodge for the previous five years. However, the lodge owners had concerns regarding the group's avalanche skills and assigned them a guide that season. "On our first descent, they all took off on their own. I take the blame for not being more clear about the experience of being guided even before setting foot on the slopes."

Loss of visual contact was another related factor, as described by this ski-touring guide. "I went a bit too far down the run and realized I had lost sight of the group. I called back up to the group to let them know that I was coming back up. All they heard was an incomprehensible voice so they assumed it was a go. A skier began his descent above me and triggered an avalanche on his second turn, which caught and partially buried me."

3. Organizational Factors

Avalanche programs managed by people who did not understand the phenomena presented great challenges to effective decision-making by the avalanche experts in my study *(Table 2)*. For example, an avalanche forecaster described to me how difficult it was to secure management support for his decision to close a mine-access road during a mid-winter storm cycle. "No avalanches had reached the road through December and most of January, and the new foreman of the operation became more and more sceptical of the avalanche program."

A safety specialist working on a mountain film related a similar experience. "I told the boss the risk was too great. There was a cornice overhanging a steep rock face directly above. If it fell off, it would probably sweep across the upper glacial bench with enough momentum to carry on down the ice tongue to where 80 people were destined to be. My opinion was the likelihood of it occurring was possible, that the magnitude of destruction could be a large number of fatalities, and that the risk of being under it with an 80-person crew for 12 hours was unacceptable. He thought it would have fallen by now if it was going to and that besides, it probably wouldn't reach the film crew location. I disagreed because it felt like a decision based on 'by guess and by god,' that the likelihood of a disaster was 50/50. I was overridden by the boss and moved on to the next task – minimizing the risk now that we were going there."

Financial pressure was an additional organizational human factor influence. As a helicopter ski guide related, "We'd been dodging clouds all day, when the pilot saw a stake and said he could put me there. In order not to burn more dollars, we landed there, got out, and the helicopter headed for the bottom." Participants also faced logistical pressures, as explained by this forecaster. "There was great pressure on the avalanche crew to keep the road open. I allowed this pressure to override safety concerns." In another case, a ski-area forecaster explained, "It was logistically difficult to close off this slope in the middle of a busy spring day, which added weight to keeping it open."

4. Social / Political Factors

Social and political human factors were another negative influence in the judgements and decisions of the avalanche experts in this study *(Table 2)*. Participants described how a collective sense of professionalism and pride in accomplishing the complexities of their craft influenced their decisions. For example, a mountain-safety specialist described the pressure he experienced. "Our professional pride is what cranks up the pressure to venture forth into the fine line where the acceptable risk is blending with the unacceptable risk. That is why we are hired – to make the ultimate decision. Can we do it or not?"

THE IMPACT OF HUMAN FACTORS

As the findings of my study suggest, human factors exert significant influence in both the internal and external realms

Continued next page ➡

DECISION-MAKING

continued from previous page

of avalanche decision-making. While human factors encompass both positive and negative influences, I have limited my discussion to the negative impacts in this article. These negative influences can produce a narrowing of attention, a failure to search for new alternatives, and may interfere with recognizing the inappropriateness of our actions. In addition, our judgments are subject to systematic biases that result from time pressure, spatial variability, incomplete information, limited cognitive-processing capacities, and a lack of understanding regarding methods to reduce uncertainty. Under these circumstances, decision accuracy is often decreased through faster and less discriminate use of information and the increased use of heuristic strategies. Heuristics are cognitive shortcuts that enable us to make evaluations on the basis of one or a few simple rules or cues. However useful heuristics can be in complex decision-making, they can also result in sacrifices in accuracy and severe errors and biases in judgment.

Stressful conditions may also result in high levels of anxiety as we assess our personal resources that are available to meet the task demands. Greater uncertainty regarding task performance increases our anxiety and, when coupled with the fear of appearing incompetent, significantly impairs our decision performance.

A failure to simulate consequences (mental simulation) when experiencing time pressure or increased cognitive workload was an additional related factor in my study. This was particularly prevalent when conditions in the human, physical, and/or environmental systems of influence were undergoing subtle changes. This concept is consistent with Klein (1998) who reported that failure to simulate outcomes frequently leads to errors in choosing decision actions.

These findings suggest that limitations of cognitive and emotional processing are inherent in avalanche decision-making. As I discussed in Part I, situation awareness, mindfulness (metacognition), and critical thinking are powerful strategies to counter the influence of these negative human factor influences in the decision process.

COPING STRATEGIES

When faced with difficult choices and negative human-factor influences, I found participants adopted several strategies to cope: (1) Managing the uncertainty, (2) sticking with the status quo by continuing with their original goals, (3) explaining away the hazard, (4) being influenced by the judgment and decisions of others. Cognitive economics and negative human-factor influences appeared to be equally influential.

1. MANAGING UNCERTAINTY

Our ability to make rapid and effective judgments is particularly crucial to successful avalanche decision-making. However, the risk analysis process is complicated by inherent uncertainty resulting from complex human, physical (terrain), and environmental (weather, snowpack) factors. Lack of information, time pressure, dynamically changing risks, and human-factor influences resulted in uncertainty and exerted significant limitations on the cognitive capacities of the avalanche experts in my study.

An avalanche forecaster explained to me how spatial variability presented great challenges in managing avalanche risk. "It is easy to identify the safe areas and it is easy to identify the unsafe areas, but it is difficult to manage the gray areas." Participants emphasized how complicated it is for them to make decisions that fall within this zone of uncertainty. For example, a rescue specialist explained, "None of us on-scene really knew for sure that there would not be another release. In the end, I decided that the need to complete the rescue outweighed the risks."

Uncertainty is a sense of doubt that blocks or delays our actions. It is also a subjective factor, since different people will experience different levels of uncertainty when faced with the same situation. As a result of complex situational and human-factor influences, it is unrealistic to assume that uncertainty can always be reduced. However, it can be managed effectively. In Part III of this series, I will examine the effective management of uncertainty in order to enhance decision success.

2. GOALS AND OBJECTIVES

Goals and expectations influence how our attention is directed and how information is perceived and interpreted within our mental models. We select decision actions that line up our perception of the environment with our goals and objectives. As a result, we may have a clearer understanding of what we want to do (goals and objectives) compared to assessing more cognitively complex factors within the decision problem. This factor has also been referred to as the commitment heuristic.

3. EXPLAINING AWAY THE HAZARD

We may respond to complexity by ignoring information about probabilities that do exist or by accepting the status quo. For example, a ski guide explained, "There were a number of factors indicating avalanche potential, yet the data I collected started to outweigh the potential and point to a better picture. Was this a matter of my perception? The group had the vision of experiencing one more great run, and I twisted the picture to justify my decision and give them what they wanted."

There are many task goals in dynamic decision situations that may be in conflict with each other, and generating reasons enables us to justify decisions to ourselves and to others. While explaining away the hazard may appear to be an irrational response, decision researchers argue that this strategy is a coping mechanism that helps us avoid the paralysis of being unable to effectively deal with uncertainty. In addition, decision-makers often find it difficult to change their plans when faced with uncertainty and negative human factor influences, since the presence of expensive consequences (for example: cancelling a day of helicopter skiing) requires high confidence levels.

4. INFLUENCED BY OTHERS

Participants were heavily influenced by the decisions and actions of others when faced with situations of uncertainty. For example, a helicopter ski guide explained how he resolved his uncertainty about the snowpack stability of a particular slope by observing the actions of a respected peer. "It must be okay if the lead guide is going there." In another situation, a guide described how assumptions about what team-mates were thinking resulted in a close-call. "This near-miss was the result of groupthink, where each guide based their opinion of the morning terrain selection on what they thought the other guides were thinking. I was thinking that if guide 1 and guide 2 are comfortable with that slope, I guess it must be okay. I suspect that in turn, guide 1 was thinking that if guide 2 and guide 3 think it is okay, then it must be okay. I considered all of us experts and had a great deal of respect for the other guides. I feel these factors all contributed to this case of groupthink."

TEAM DECISION-MAKING

I found the capacity of teams to make effective decisions was a direct function of the quality of interactions among team members. This finding correlates directly with research in the aviation field showing that minimal communication, negative expressive styles, and low task motivation results in poor coordination and high performance errors.

Social factors exert a significant influence on judgment and decision-making and create goal conflicts that can result in an unwillingness to admit lack of knowledge and to continue even in the face of uncertainty. Orasanu et al., (2001) suggested that implied expectations among team members may encourage risky behavior and may result in people behaving as if one is an expert, while in fact they may lack the knowledge to effectively execute an independent decision. An example provided by the experts in my research described how assistant guides are often expected to assume complex tasks of significant responsibility with limited supervision or discussion—for example, snow safety for helicopter ski operations. While these experiences offer tremendous learning potential for less-experienced avalanche decision-makers, they may result in high levels of performance anxiety and acute stress. Baumann et al., (2001) found uncertainties regarding performance and the fear of consequences of failure separately contribute to the level of anxiety experienced, and result in significant reduction in decision performance.

Status or conformity pressures exert strong influence against checking one's assumptions. Groupthink (Jannis and Mann, 1977) is the most well-known failure in team decision-making, and occurs when an individual and/or group suspends its judgment in order to maintain group cohesion. This finding is also consistent with heuristics research. For example, McCammon (2002) described this as the "expert halo." The experience of negative team interactions was particularly strong in situations involving supervisors, lead guides, or individuals with higher status. Orasanu and Salas (1993) reported a similar finding in their aviation research, stating, "High status can be used effectively to manage a team, or it can lead a team to disaster." They found that the pilot's point of view carried more weight, regardless of whether or not he was correct.

This finding emphasizes the critical role that avalanche team supervisors have in leading their teams towards decision success. Verbalizing thoughts so the entire team can develop a shared situational model, encouraging diverse views, and providing positive feedback and direction during difficult tasks are examples of exemplary team leadership. Thus, individual skills and knowledge alone are not sufficient for successful team performance. Communication must be a key emphasis within the team decision-making process, and has significant potential in decreasing human error and increasing decision success.

EXAMINING DECISION ERRORS

Decision errors can often be attributed to the situation assessment as opposed to the selection of actions. While accurate perception is fundamental to good decision-making, our goals and mental models are integrally linked and are critical to the formation of accurate situational models. Endsley (1997) argued that decision-makers often make the correct decision for their perception of the situation, but that perception may be in error.

In Part I, I identified experience as the key element in the formation of mental models and the fundamental component of the avalanche expert's decision foundation. Repeated experience develops mental models and expectations about future events that predispose us to perceive information that is in agreement with our mental models. However, all experiences are not equivalent in their capacity to develop good judgment and decision capacities. As I found in this study, repeated experiences of non-event feedback or false-positive events can result in dysfunctional strategies for future decision-making. For example, snowpack instabilities exhibit spatial variability in the terrain, and areas within which it is possible to trigger a propagating fracture for a slab avalanche may be as small as one meter. If a skier does not make contact with this area, the slope may not release, resulting in a false-positive result for the decision-maker. As one participant related to me, "Positive reinforcement is a powerful learning impetus."

Avalanche accidents and close calls are infrequent; therefore, they are an insensitive indicator to the quality of our decisions. False-positive feedback experiences may reinforce poor decision actions and may lead to overconfidence or inaccurate perceptions. Research has shown that if a person repeatedly makes dysfunctional decisions, those dysfunctions would become automatized. For example, Orasanu et al., (2001) found that pilots' experience and success in risky situations in the past, (e.g., making a landing in poor weather conditions), influenced their expectations to succeed the next time. In a study of recreational avalanche accidents in the U.S., McCammon (2002) found the familiarity that resulted from past experiences and actions led avalanche-accident victims to believe their behaviors were appropriate in the current situation.

The impact of goals and mental models on judgment and decision-making is particularly problematic in the high-stakes avalanche domain. The avalanche decision-making environment is often not structured to provide effective feedback or to show our limitations. I suggest that the use of critical thinking and mindfulness (metacognition) can correct these biases by requiring decision-makers to think about the reasons and assumptions that underlie their judgments and choices. In addition, it is of critical importance to seek external feedback when available and to reflect upon our judgment and decision actions in order to build accurate mental models to support future decision-making (a point discussed further in Part III).

UNDERSTANDING DECISION ERRORS

Decision actions do not stand alone as events that can be judged independently from the broader situational and task features. While the biases and decision traps I have reported may appear to be an irrational response, we must consider the strong influences of the individual, team, client, organization, and sociopolitical realms in these processes. Cognitive limitations, spatial variability, physical and environmental stress, fear of appearing incompetent, social pressures within teams, pressure to open avalanche-prone terrain by clients, logistical and financial pressure from organizations, and desires to maintain cultural cohesion within associations are several examples that resulted from my study. Additionally, varying perceptions of risk and varying levels of acceptable risk exist within these human realms.

The successful reduction of uncertainty and negative human-factor influences is cognitively taxing and requires time, motivation, and the use of structured thinking processes such as metacognition and critical thinking. In retrospection, a majority of the participants in my study recognized the human influences present; they simply succumbed to the excessive pressure they faced. My research illuminates the conflicting challenges that avalanche decision-makers face as they strive to achieve a balance between the widely varying goals and objectives within the internal and external realms of human influence and the dynamically changing conditions within the physical and environmental systems of influence. It also highlights the fact that avalanche decision-makers need a high level of personal mastery and strong leadership capacities to avoid being overly influenced by these factors.

Skiers get up close and personal with a small avalanche in the southern Selkirks, British Columbia.

CONCLUDING REMARKS

Avalanche judgment and decision-making must be examined in a holistic manner in order to discover efficient, adaptive, and satisfying solutions to the decision problems we face. Human factors exert both positive and negative effects in the decision process. How the decision-maker recognized, considered, and managed the presence of negative human factors made the critical difference between decision success and human error. I suggest that a more complete understanding of the influence of potentially negative human factors will enable avalanche decision-makers and stakeholders to recognize and manage their presence, thereby reducing the frequency of human-factor decision errors in avalanche accidents. However, human factors also have a positive side. In *Developing Expertise in Avalanche Decision Making, Part III*, I examine the positive human factors that influence successful judgments and decisions, and I discuss these findings in light of recent advancements in strategies for decision-skills learning, decision support, and effective avalanche-accident prevention.

ACKNOWLEDGMENTS

My research is dedicated to a group of Canadian avalanche professionals who took the time to reflect upon their experiences and relate their insight to me. We can all learn a great deal from their experiences of decision success and human error. My thanks are extended to the Canadian Avalanche Foundation, Selkirk College, and the Social Sciences and Humanities Research Council of Canada for providing financial support, and to Arc'Teryx for outdoor clothing and equipment. I wish to acknowledge Bruce Jamieson and John Tweedy who offered valuable insight and good thinking in their role as avalanche expert advisors to my research, and to Roger Atkins, Ian McCammon, and Kim Kratky for reviewing my draft.

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The First Annual TAR Photo Contest

A warning sign at the Chinook Pass / Cayuse Pass area of State Route 410 near Crystal Mt., Washington, during spring clearing several years ago.
photo by Andrew Longstreth

Many thanks to the photographers who provided the following photos in time for this edition of *The Avalanche Review*. For those who have not yet shown off their goods, the contest continues to the next issue of TAR, with a February 15 deadline for photo submissions.

DEADLINE— February 15, 2006

CATEGORIES—
- AVALANCHE crowns, powder clouds & debris fields
- PEOPLE at work and at play
- CLASSIC shots from the archives, digitized

PRIZES—
AAA logo gear, SWAG copies, TAR subscriptions, ski lift tickets, the honor of being published in TAR

THE FINE PRINT—
Digital images only, high resolution (300dpi or higher) submitted on CD or DVD to:
Lynne Wolfe, PO Box 1135, Driggs, ID 83422 -OR- via e-mail: lwolfe@tetontel.com

tom murphy

Tom Murphy is the brains behind AIARE in Crested Butte. Tom faithfully attends AAA board meetings to further the cause of better avalanche eduction for all.

AAA Education co-chair Michael "MJ" Jackson practices his own brand of risk management at Gooseberry Mesa, Utah.

mike bartholow

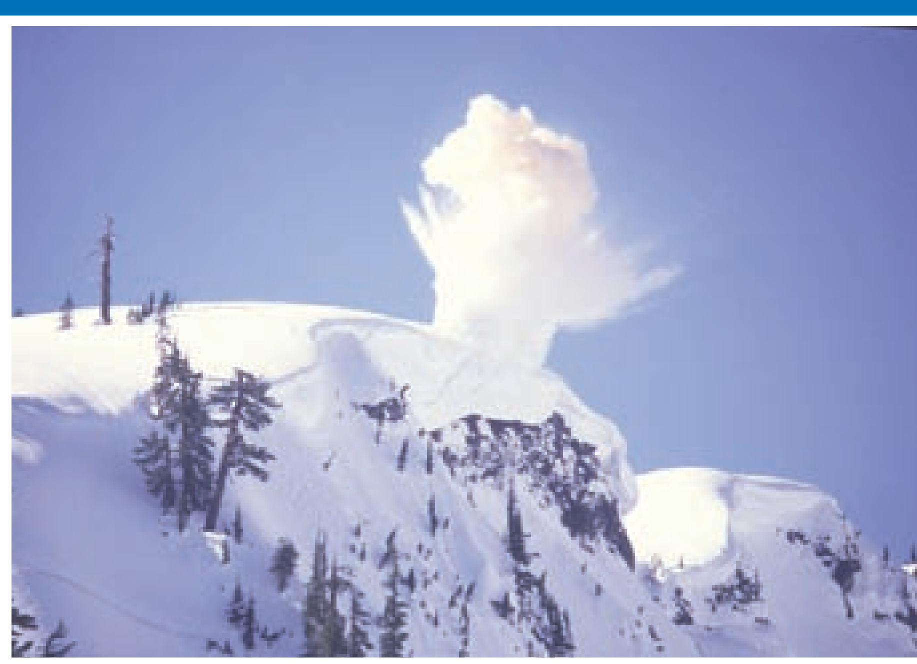
Mike Bartholow lives in Juneau, AK, where he works for the Forest Service, teaches avalanche courses, and patrols at Eagle River ski area.

Jake Hutchinson of The Canyons, Utah, during an American Avalanche Institute Level II course at The Canyons in February, 2004. "During pit work, I managed to excavate two crusts well connected by percolation columns. The facets that were inbetween the crusts and columns simply blew out like fine feathers."

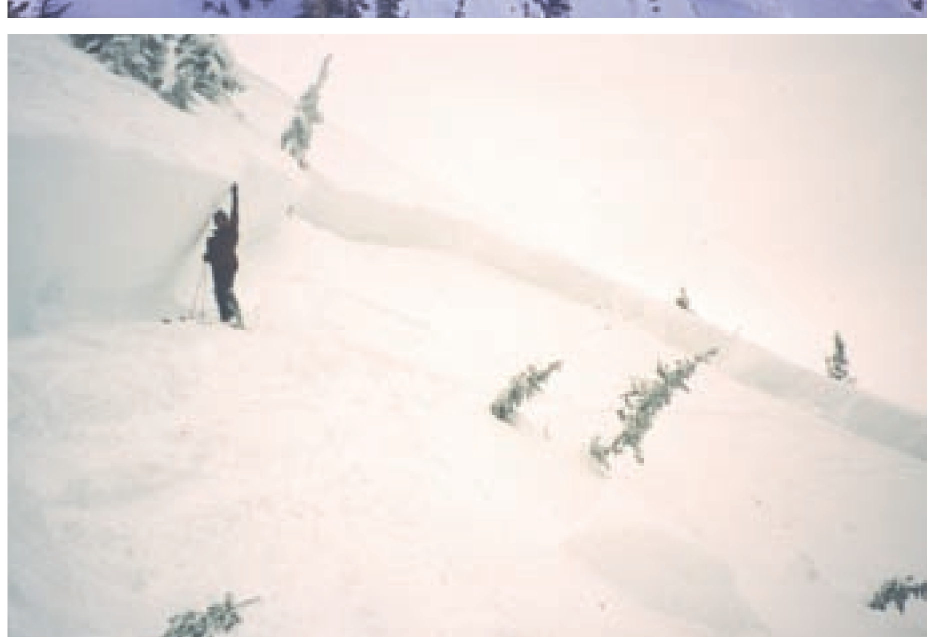
andrew longstreth

Andrew Longstreth started his patrol career in 1983/84 at Mt. Baker. He has been at Crystal Mountain since 1991/92 and is currently the paramedic program director, a certified member of the AAP, and head toboggan judge. He also works as a paramedic/firefighter for Olympia, WA.

Boxes and a bag of ANFO indicate a busy morning of avalanche control at Crystal Mountain.

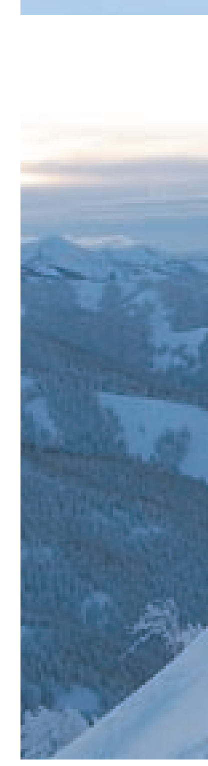


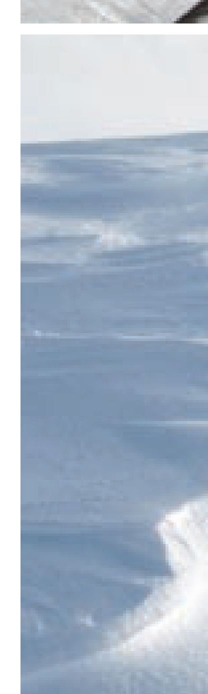
150 lbs of ANFO blew a cornice above "Blueberry" at the Mount Baker ski area.



A big crown on "Kempers path" into Mt. Ranier National Park near Crystal Mountain. This photo was taken several days after a class 5 avalanche ran almost to Hwy 410 several years ago.

don shar



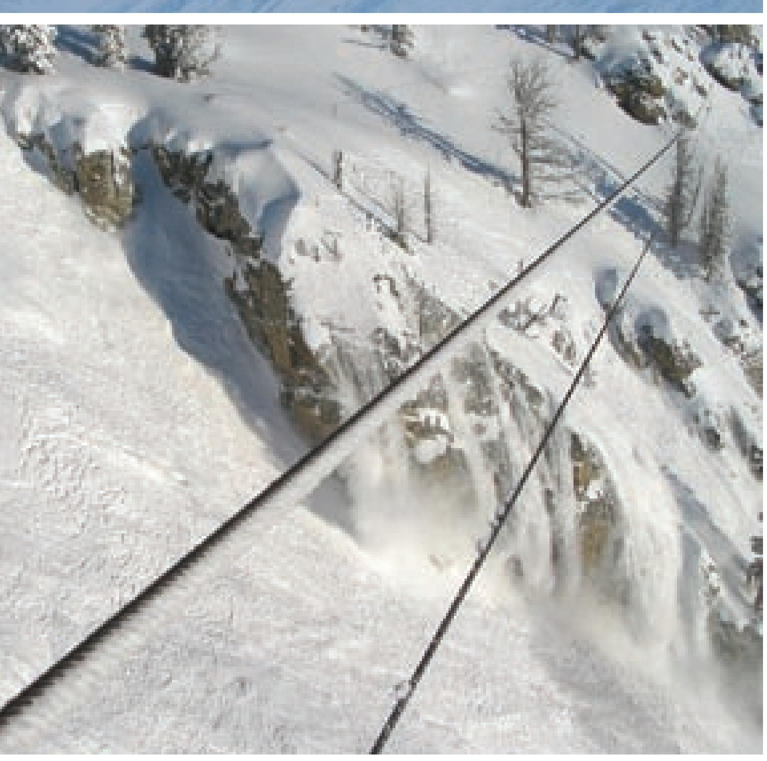


af

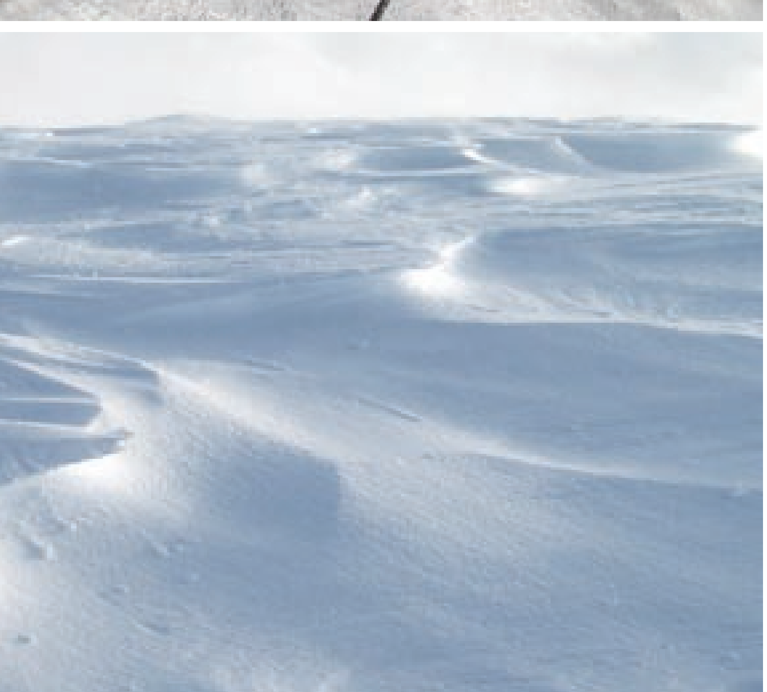
Don Sharaf sent these photos from the Tetons, where he runs Teton Avalanche Forecasting when he is not powder skiing. He has put house-building plans on hold til summer in order to return to the Chugach for another season.

Patrollers load the bomb trolley at Jackson Hole ski resort.

Amos Callenberger skis near a Gasex cannon on Twin Slides above Teton Pass, Wyoming.



Casper Bowl shatters after a blast from the bomb trolley at Jackson Hole ski area.



Wind-whipped sastrugi turns the summit of Mount Taylor into a frozen ocean.

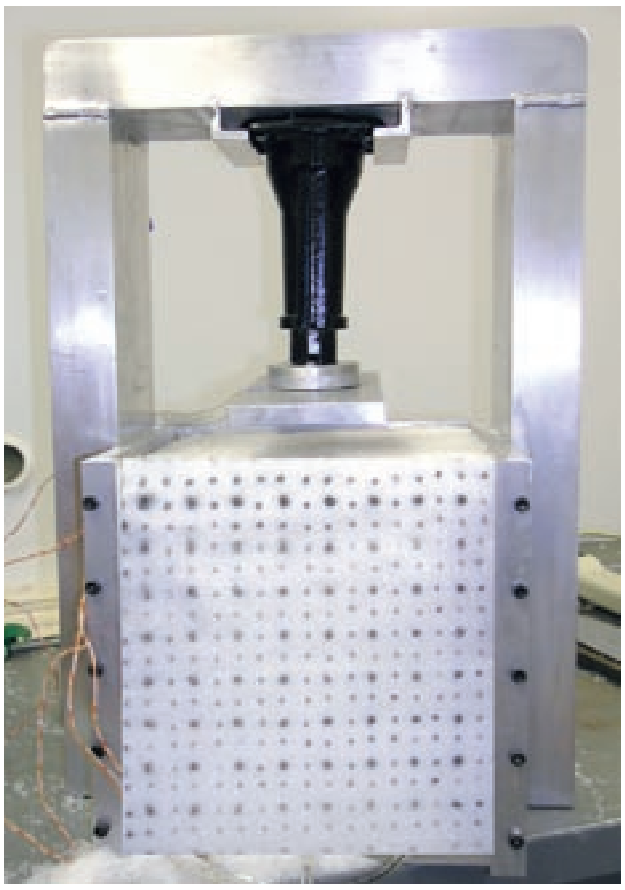
snow science

PARTICLE IMAGE VELOCIMETRY:
A New Technique To Measure Strain in Loaded Snow

Story and Photo by Andy Gleason

The rheological properties of snow are not well understood and constitutive relationships are not developed enough to explain the mechanical behavior of snow under varying loading conditions. Better understanding of snow mechanics is useful for various fields including vehicular movement over snow, calculating snow loads on structures, avalanche studies, and military applications. There is a phenomenon in the avalanche field that most people call "bridging." This is a situation where a hard dense layer or slab of snow overlies a less dense weaker layer, but the hard slab is thick enough or rigid enough to support the weight of a person or vehicle. This hard slab layer forms a sort of bridge that distributes the load on the surface and prevents it from affecting the lower layers of the snowpack. A bridge, in effect, prevents the weight of a person from initiating an avalanche even though there is a weak layer somewhere in the lower part of the snowpack. While bridging is a phenomenon that has been frequently observed by avalanche specialists, it is not well understood. There has been little formal research directed at determining just how thick and rigid a hard slab must be to attenuate or distribute a load on the snow surface.

Various workers have studied the response of snow to vertical loading. Yosida investigated the mechanical properties of snow using a piston to penetrate snow in order to define the limits of the pressure bulb in which the snow was disturbed. Brown used a volumetric constitutive law for snow to demonstrate the specific power needed for vehicle mobility in snow where the pressure bulb is assumed to reach the ground surface. Fohn developed an equation to calculate shear stress beneath a skier and showed a modeled stress bulb through a snowpack beneath a load. Schweizer calculated skier-induced stress distribution using finite element modeling. Schweizer and Camponovo put load cells in a snowpack beneath a skier to measure stress distribution below. While success has been shown in measuring stress beneath loaded snow, empirical measurements of strain beneath loaded snow have only been performed posthumous to the loading. Previously, researchers have not been able to accurately measure strain within the stratigraphy of the snowpack.



Snow-loading apparatus with seeded snow visible through lexan. Piston pushes down into snow. Snow height & width is 25cm.

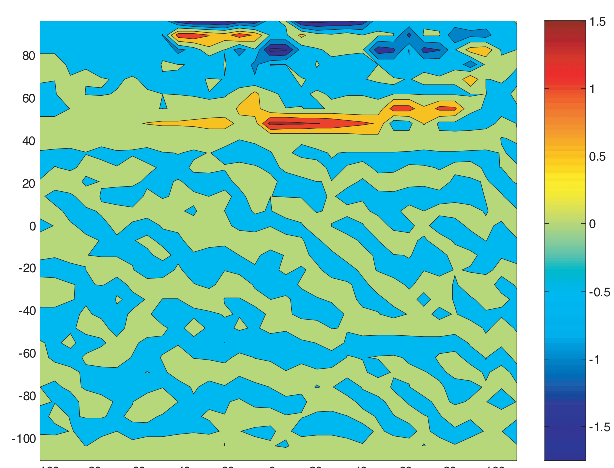


Fig 2: Strain in a layered snowpack shown to be concentrated at snow-layer boundary between dense and less-dense snow. Scale on right is strain.

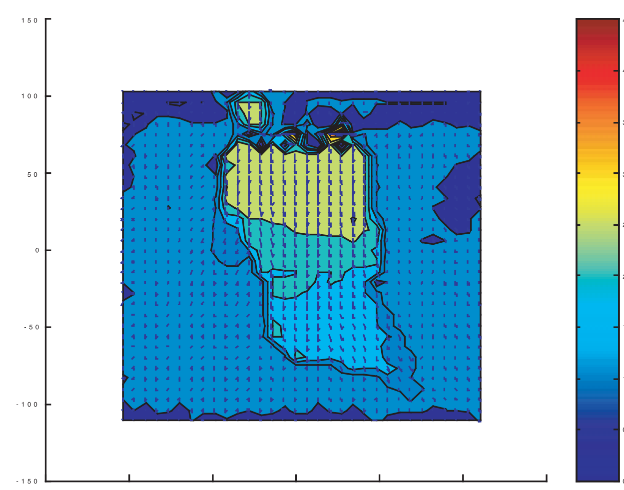


Fig 4: Displacement of a relatively uniform snowpack. Displacement occurs in vertical direction beneath the loading plate.

A new technique to measure displacement of snow under a band load has been developed using particle image velocimetry. Particle image velocimetry (PIV) is a technique which utilizes a method of non-intrusive velocity measurements designed for the measurement of flow velocities in fluids. A fluid is seeded with tracer particles such as oil or small solid particles. A plane of laser light in a moving fluid illuminates these tracers. A series of sequential digital images are taken at rates of up to 15 times per second. Image processing algorithms follow the tracer particle's displacement between images. Post processing software computes displacement vectors between two sequences of images to produce a field of displacement vectors. The displacement field is measured locally across the field of view of the images, scaled by the image magnification and then divided by the known pulse between images to calculate flow velocity at each point. The PIV software automatically calibrates the interrogation window that is used to follow the particle image through space.

Because PIV must utilize images of a plane to calculate flow, I realized that PIV could be used to measure displacement on a plane of snow under a load. To accomplish this, I constructed an aluminum box (25 x 25 x 25cm) with a clear lexan side that allows snow to be loaded from above and displacement observed in the layers below *(see photo)*. Snow is loaded with a 0.025 m2 aluminum plate (8 x 25cm) attached to a piston that exerts a vertical force downward into the box of snow. The piston is an upside down carjack that is rotated with a power drill.

Snow grains by themselves did not have enough contrast for the PIV camera to accurately measure displacement. Snow was seeded using a 1cm grid of painted dots. A digital camera, hooked up to a dedicated computer, took a rapid sequence of photos of the snow through the clear lexan wall as the snow was loaded from above. The PIV software generates a field of vectors that shows the actual displacement of the snow through time *(Fig 1)*. The displacement can easily be converted to strain to create a picture that shows how the load affects the snow *(Fig 2)*. With this technique, I can measure exactly how a load on the surface affects a layered snowpack.

The loading experiments were conducted in a cold lab held at a constant -6º C. Most of the snow utilized consisted of a layer or layers of sieved snow to achieve a uniform 2mm grain size with harder (more resistant) and denser crusts composed of 0.5-1mm round grains at the surface. The 2mm grain size was chosen to minimize boundary influences by having the width and depth of the experiment 125 times larger than the grain size. Various iterations of snow layers were used to approximate different layered conditions in the snowpack. Images were taken at rates as slow as one frame per second and as fast as one frame per 0.06 seconds.

The results from preliminary experiments show that the load is more horizontally distributed in layers of snow that are harder and denser. A hard dense layer of snow (315kg/cm3, pencil hard) approximately 5cm thick on top of 20cm of lower density (210kg/cm3, 1 finger hard) snow was loaded at the surface. Displacement caused by the loading plate was distributed horizontally across the harder bridged layer at the surface *(Fig 3)*. Strain was concentrated at the boundary between the hard dense layer and the less dense sieved snow *(Fig 2)*. In a relatively homogenous snowpack, with snow grains sieved at 2mm throughout the entire 25cm height of the box, the displacement occurred only underneath the loading plate and was not distributed horizontally *(Fig 4)*.

Particle image velocimetry is a practical technique to measure displacement and strain in snow underneath a band load. Snowpacks with hard layers distribute a band load horizontally compared with relatively uniform snowpacks which are displaced mostly in the vertical direction. This research is in the preliminary stages and more types of snow, including snow taken directly from a natural snowpack, need to be analyzed using the PIV technique. Further research will include varying the snow layers in density, crystal type, and resistance (hardness) as well as varying the thickness of the harder denser bridged layer at the surface. Load cells will be placed beneath the snow and on the piston to measure stress and strain rate. I would also like to adapt this technique so that PIV could be used in the field to measure the strain beneath an actual skier or snow vehicle.

The American Avalanche Association supported this research through a graduate research grant. I would like to thank Doug Smith at the University of Wyoming who allowed me to use his PIV machine and HP Marshall who helped with the Matlab code for the figures.

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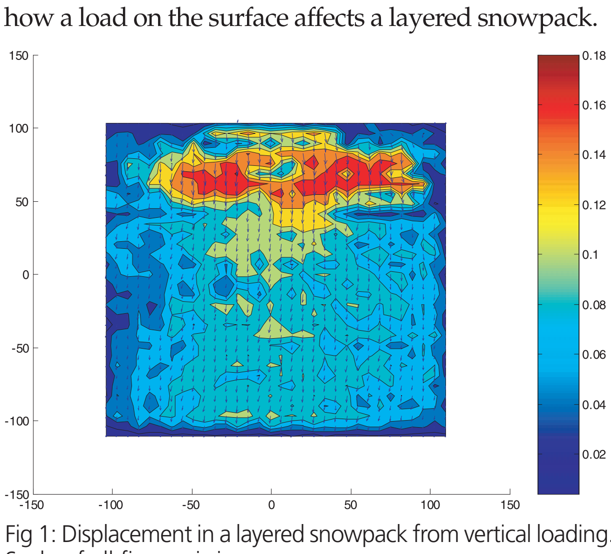

Fig 1: Displacement in a layered snowpack from vertical loading. Scale of all figures is in mm.

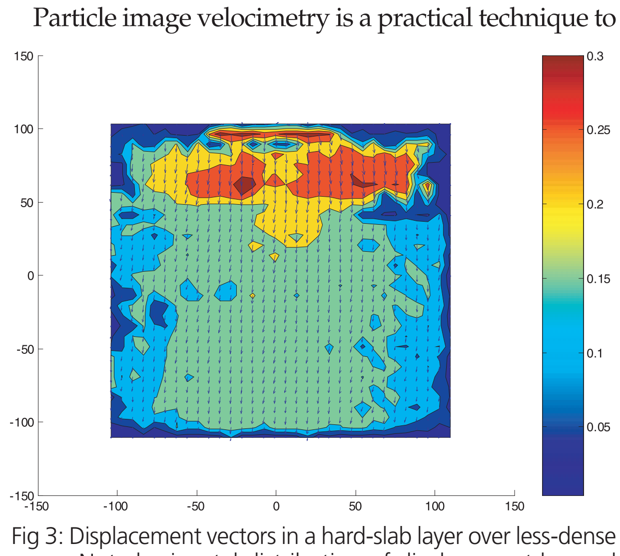

Fig 3: Displacement vectors in a hard-slab layer over less-dense snow. Note horizontal distribution of displacement beyond the loading plate at the top.

Insight into Slab-Avalanche Triggering:
A Combination of Four Phenomena in Series

Story by François Louchet and Alain Duclos

Tragedy struck the small village of Aussois in the French Alps on February 14, 2005, when a huge hard-slab avalanche caught and fatally wounded a well-known local avalanche worker. Pompon, a local IFMGA-certified mountain guide and ski patroller with about 20 years of professional avalanche experience, triggered the fatal avalanche in a wide bowl called Les Balmes. The upper section of the 300-meter-wide bowl is divided into several separate gullies or thalwegs which can normally be controlled individually with hand charges from above. Apparently intending to view the negative results of the first shot placement on his familiar control route, or perhaps to test the snow resistance, Pompon slid slightly out onto a convex slope measuring less than 30 degrees on the upper fringes of the second gully. Strong winds the day before had loaded Les Balmes with a significant amount of snow, and the avalanche Pompon triggered was much bigger than expected. His partner watched the quasi-simultaneous release of the entire bowl as the massive avalanche carried Pompon more than 600 vertical meters and mortally wounded him. He died a few months later after suffering a deep coma.

This casualty tragically illustrates how an avalanche specialist, with a perfect knowledge of the field, might eventually be trapped by a larger-than-expected slab-avalanche release. Both rupture mechanics and statistical physics can bring new insight into this problem. These theoretical approaches perfectly fit field observations. They explain why some unexpected avalanches may release and also, more commonly, why nothing happens even when most conditions for triggering seem to be met.

A few basic concepts

Avalanche-release phenomena may be classified into two main categories: spontaneous and artificially triggered ones. Spontaneous failures are of a ductile nature. They result from a strain rate increase during snow creep or reptation, up to a critical point at which failure suddenly occurs. We shall focus here on accidental and artificial avalanches. Such failures occur within a much shorter time scale, correspond to a rapid change in the controlling parameters, and are of a brittle nature. Any physical evolution process needs a driving force, which may or not be balanced by a resistance. In order to understand the phenomenon, we need to identify both the driving force and the resistance.

• Driving force:

A process is likely to occur spontaneously if it contributes to a decrease in the energy of the system down to a stable state. In the avalanche problem, the available energy stems from the snow weight. The weight of a skier (some 80 kg) is extremely small as compared to the weight of the snow involved in the avalanche-triggering mechanism (several millions of kg).

• Resistance:

The reason why the snow cover remains on mountain slopes is snow cohesion, which provides resistance to rupture. This is not the case for water, which would immediately flow downslope as it has no cohesion. Snow cohesion contributes in keeping the snow cover in a metastable state . Two types of resistance have to be overcome in order to release an avalanche: i) the shear resistance of the bonding between the slab and the older snow substrate, known as weak layer; and ii) the rupture stress of the cohesive slab. The local action of a skier may gradually damage the weak layer, which is more similar to a brittle house of cards than to ball bearings. It may also contribute to opening a crown crack across the slab thickness. Therefore, the skier's action only deals with possible changes in the resistance of the weak layer or of the slab and not with the driving force.

A simple sketch of the system

In the case of accidental or of artificial triggerings, both the cohesive slab and the weak layer behave as elastic/brittle bodies; they may deform elastically under stress and fail in a brittle way if the stress exceeds a threshold value. The elastic/brittle slab is represented in the above diagram as a series of blocks linked by brittle springs, which can extend or contract depending on the stress they experience or split into parts if the stress exceeds a threshold value. In a similar way, the slab is connected to older snow by elastic/brittle bonds, represented as some kind of flexible and brittle flat house of cards, which might fail and collapse if the stress is large enough. Based on the above-mentioned properties we can detail the different steps involved in the avalanche-triggering chronology.

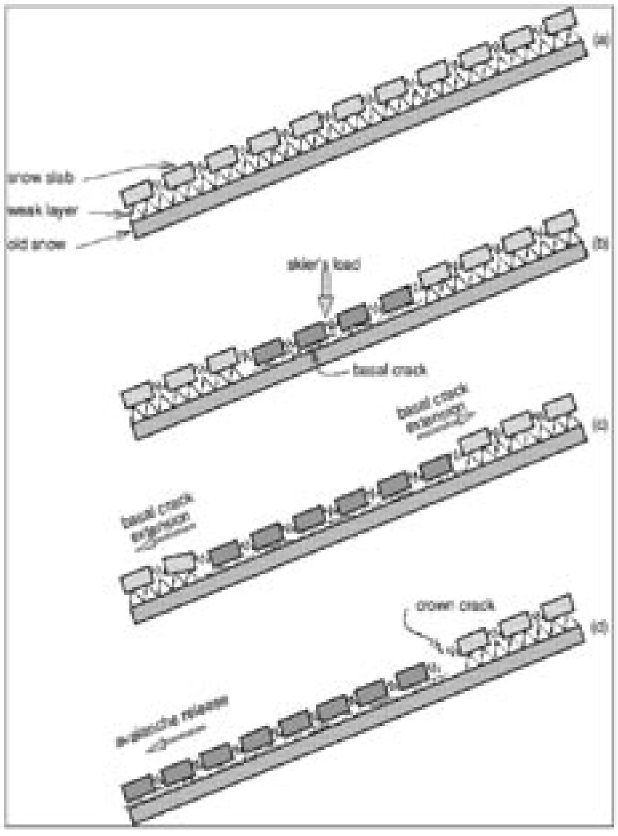

Fig 1: (a) A slab on a weak layer may be seen as a series of blocks linked by elastic/brittle springs lying on a collapsible house of cards; (b) the skier's load may collapse part of the house of cards (basal crack); (c) driven by either the skier's action or the snow weight, the basal crack may extend; (d) when the extension of the basal crack is large enough, the weight of the hung part of the slab initiates a crown crack at the top, resulting usually in the avalanche release.

A Combination of Four Steps In Series

We propose that accidental or artificial avalanche release stems from four mechanisms:

1. collapse of the weak layer that results in the nucleation of a basal crack,
2. propagation or expansion of the basal crack
3. opening of the crown crack at the upper rim of the basal crack
4. expansion of the crown crack, which leads to the avalanche release.

These mechanisms operate in series; if any single one does not occur, the avalanche is not released.

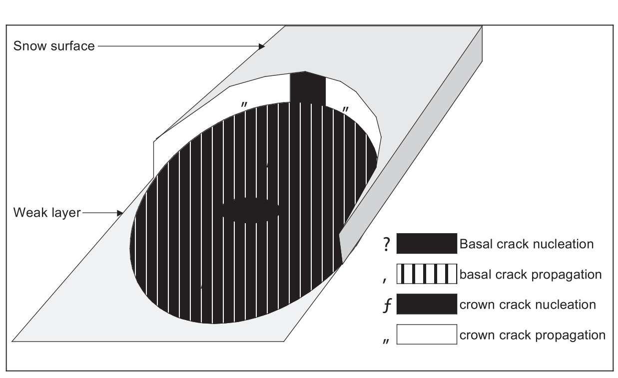

Figure 2: Four successive steps involved in avalanche release.

1. Basal crack nucleation

On a slope, the weak layer experiences both the shear (parallel to the slope) and compression (perpendicular to the slope) components of the slab weight, both of which increase with its depth and density. The weak layer may be damaged when the load locally exceeds its mechanical resistance. The weight of a skier or a snowmobile does not significantly increase the total load experienced by the weak layer, but this load is applied on a very small surface (e.g. ski bases), and results in a significant pressure that may cause local damage of the weak layer. An explosive has a similar effect. Depending on the nature of the weak layer, the resulting collapse of these zones reduces their shear resistance to almost zero. The damaged zone or basal crack then extends along the skier path. The weak layer may also collapse on flat ground. In which case the whole slab weight is now along its compression component.

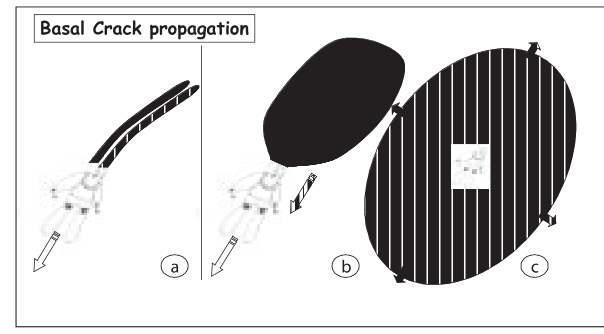

Fig 2: Basal crack propagation. (a) A weak layer covered by a shallow slab made of fluffy snow may collapse only along the ski track without further expansion; (b) the bending of a stiffer slab under the skier helps a wider collapse of the weak layer, resulting in a wider basal crack (artificial growth); (c) reaching a critical size, the crack may extend rapidly under the load of the snow itself (spontaneous growth).

2. Basal crack expansion

Basal crack expansion may result from one of two different mechanisms:

a. Owing to the gradual damage produced by the skier's additional local pressure, a crack may extend step-by-step in an area around the skier's path.
b. A crack initiated by the skier might extend over much larger distances under the effect of the snow weight itself.

On a slope, the driving force consists of the compressive and shear components of the stress due to the slab weight. In other words, it results from the energy release experienced by the slab as the weak layer collapses. The skier's weight has no more effect at this stage, as the involved snow mass is enormously bigger.

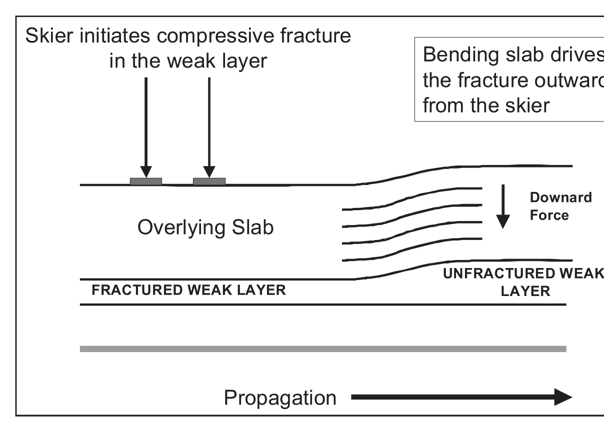

Fig 4: Diagram showing the collapse of the weak layer and expansion of the basal crack. The overlying slab is bent, providing the downward force to progressively fracture the weak layer.

More precisely, such a spontaneous propagation of an existing crack obeys a specific law, known as Griffith's criterion. In spite of possible modifications related to slab geometry and stiffness, Griffith's criterion basically states that under a given stress, a large crack is more likely to expand than a small one. This is also the case for a sheet of paper that tears off more readily if it contains a large crack. Spontaneous propagation takes place when the product of the stress by the square root of the crack size exceeds a threshold value Kc, called fracture toughness. Spontaneous propagation of the basal crack only occurs if the crack reaches a critical size—the larger the load, the smaller the critical size. Beyond this critical size, the energy release rate of the slab can no longer be balanced by the resistance to slab propagation; the basal crack extension velocity is now much faster. Velocities of the order of 20 m/s have been reported.

C) Crown crack nucleation:

As the basal crack extends along the slope, the slab weight that was balanced by the weak layer resistance is now transferred into the slab itself at the crack rims. It takes the form of a tensile stress at the top cross section of the slab, where the freed part of the slab is hung. This stress turns into a compression stress at the bottom rim and into shear stresses on both sides. All these stresses obviously increase with the weight of the hanging part of the slab or the basal-crack size. The snow-failure stress is usually smaller in tension than in compression, the shear failure stress being between these two. Therefore, as for basal crack nucleation, a crown crack nucleates

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SLAB TRIGGERING

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at the top of the basal crack when the tensile stress in the slab reaches a threshold value.

Since two different basal crack growth mechanisms can operate, we expect two different types of avalanche triggering to occur *(below)*.

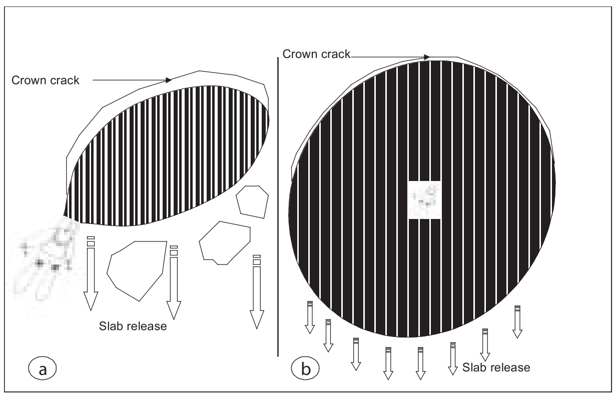

Fig 5: a) subcritical triggering: the starting zone is limited roughly to the area damaged by the skier; b) supercritical triggering: crown crack opening occurs at a large distance from the skier.

Subcritical triggering:

In this case, the basal crack gradually extends step by step in an area around the skier's path. At some stage of this extension, the tensile stress experienced by the slab at the upper rim may exceed the slab rupture stress. The starting zone is limited to the area actually damaged by the skier, who is likely to be located at the boundary of this zone when the avalanche is released. This scenario might happen when the slab cohesion is low. A small-size basal crack is sufficient to reach the slab-tensile-rupture stress. The cut made by the skis in the soft slab may also help the slab failure along the skier's path. By contrast, with stronger slabs, the slab-rupture stress may not be reached, the crown crack does not open, and the skier gets out of the hazardous area without triggering the avalanche.

Supercritical triggering:

Now the slab is significantly stronger (i.e., crown crack opening becomes more difficult), and/or the driving force for basal-crack expansion is larger (i.e., the slab is heavier). The basal-crack size may reach the critical value for spontaneous expansion before a crown crack can open. At this point, the basal crack starts expanding with a significantly larger velocity. Crown-crack opening occurs a short time later, often at quite a large distance from the skier, when the weight of the freed part of the slab has become large enough to trigger the failure of the tough slab. The starting zone is much bigger than in the previous case, and the skier is trapped somewhere in the middle of it. In some conditions, it may result in a "bang" at slab failure. A simple calculation (Louchet 2001 b) shows that supercritical triggering is favored by large slab weights and that conditions for its occurrence are more readily met on slopes around a universal angle of 35.3˚.

4. Crown crack expansion and avalanche release

With some modifications, Griffith's criterion may also apply to the crown crack. If the tensile load is large enough to nucleate an incipient crown crack, it will necessarily be large enough to propagate it, as the increasing crack size requires a decreasing propagation stress. The crown crack grows very rapidly (brittle failure), until the stress concentration at its tips reaches the shear-failure stress on both sides. The bottom rim usually fails in turn at this stage as the whole slab weight is now transferred to it, and the avalanche is released. In most cases, the nucleation of the crown crack is immediately followed by its expansion and by the avalanche release.

For the weak layer, the slab rupture threshold may have scattered values. An incipient crown crack usually appears at one of the weakest places. Its subsequent propagation may meet a tougher zone, which may hinder its growth. In this case, the basal crack goes on extending up further. We often observe stable incipient crown cracks.

III) The theory explains avalanches which are released...and those which are not

In this section, we discuss several field situations and examples of avalanche release from real life, in the light of the four basic steps developed above. We show in these examples that the conditions for avalanche release require that all four conditions be fulfilled. If even one of them is not, the avalanche will not be triggered.

Are huge snow accumulations favorable or unfavorable for avalanche release?

A thick snow cover may favor basal-crack expansion. This is true for natural, artificial, or accidental triggerings. But basal-crack nucleation by a skier or by explosives is impossible if the involved slab is too thick, due to poor pressure transmission to the weak layer. This is probably why accidental releases are more frequent during early winter: weak layers are easily formed during this period and frequently covered with shallow slabs. Basal cracks are therefore more likely to be nucleated.

Avalanche professionals sometimes deplore the poor efficiency of artificial triggerings in spite of huge snow accumulation. Often the snow depth is probably too large to allow artificial triggering, and not large enough to drive a natural avalanche release.

Why should skiers cross a hazardous area one after the other rather than in groups?

This recommendation is supported by at least two reasons. The first reason is that if an avalanche catches one of them, the others might successfully conduct a rescue. The second reason is based on a situation where the weight of a single skier is insufficient to nucleate a basal crack, like on a thick slab, but the combined weight of several skiers crossing the area simultaneously may be large enough to nucleate it.

On shallower slabs, a single skier may nucleate a basal crack (step 1), gradually expand it on a limited area (step 2), and get out from the hazardous zone without triggering an avalanche. In this case, crown-crack nucleation (step 3), could not occur because the hung part of the slab was too small or not heavy enough to open the crown crack. If a second skier, then a third one, and so on, cross the same zone along slightly different paths, the corresponding basal cracks may merge, resulting in a unique crack that may be large enough to either directly open a crown crack (step 3, subcritical mode) or expand it in an unstable way before opening a large crown crack far above (step 3, supercritical mode). The resulting triggering would not depend on whether skiers have crossed the zone together or one after the other. A reasonable recommendation to minimize the risk might be to cross the dangerous area successively and along the same path, although by doing this, the skiers could disturb the weak layer due to deeper penetration of the slab by the successive skiers.

Why are most avalanches observed on slopes around 35˚?

There is a general agreement that the most favorable slopes for avalanche triggering are around 35˚. This observation may be explained using the above considerations. A limited basal crack width (as in Figures 3 a or b) that remains smaller than the critical size for spontaneous expansion (step 2, subcritical mode), may result either in a limited starting zone or in no triggering at all. By contrast, if the basal crack is wide enough (or the critical size small enough), the resulting spontaneous expansion cannot be stopped (step 2, supercritical mode) unless stratigraphy changes. Indeed, the tensile stress experienced by the slab at the upper crack tip continuously increases until the slab-rupture stress is reached, and the crown crack opens (step 3). The avalanche is more likely to be released at this stage, as compared to the case of a limited subcritical growth (step 4).

As the supercritical scenario is favored for slopes around 35˚, avalanches are expected to be preferentially triggered on such slopes and not around the classical 45˚ expected from simple mechanical arguments . This particular observed feature is a strong argument in favor of our present approach.

Why are tough slabs often associated with large avalanches?

The tougher the slab, the more difficult crown-crack nucleation is. This is probably why tough-slab avalanches are usually big. The amount of elastic energy stored in such big slabs can be huge. Sudden release at crown-crack opening may result in an impressive "bang."

Why do crown cracks often open at outcrops or trees?

It is frequently observed that the crown crack starts opening (step 3) at an outcrop or a tree or even on a ski or surf track. These features act as weak points in the slab, which help crown-crack nucleation. The same mechanism takes place at convexities. Such weak points play a dual role: they facilitate slab triggering through crown crack nucleation, but they prevent large-scale propagation of basal cracks, which may have resulted in the release of very large slabs. In other words, large slab avalanches are likely to be found on wide and smooth slopes without weak points or field heterogeneities like trees, sparse rocks, or outcrops.

Why are some avalanches triggered on flat ground?

The propagation of the basal crack (step 2) helps us to understand accidents occurring on gentle slopes, neighbored by slopes steeper than the fateful 30˚. The victims are responsible for the nucleation of the basal crack, which may gradually expand to the steeper slopes. At this point, the driving force is more efficient, and the basal crack may become unstable and propagate rapidly in the supercritical mode, triggering one or several slabs.

Why do "whumpfs" on steep slopes not necessarily result in avalanche release?

Sometimes a whumpf is clearly felt on a rather steep slope (step 1), but without any further consequence. This case may correspond to a weak layer of small dimensions (blown out by the wind as it still was at the surface or swept out by a previous avalanche), at the boundaries of which the basal crack propagation stops (step 2) before reaching the size necessary for unstable propagation or for directly opening a crown crack (step 3) and releasing the avalanche (step 4).

IV) Snow cover variability and triggering scenarios:

The different triggering scenarios therefore depend on the spatio-temporal variability of the snow mechanical properties, which are involved during the four successive steps of the triggering process. The snow cover is most often heterogeneous in thickness and/or mechanical resistance. For this reason, the type of basal crack left along the skier's path may vary: for example from the case of Figure 3a to that of Figure 3b, or worse, that of Figure 3c. This may be the case for instance if snow evolves from fluffy to stiff. Another example is that of an artificial crack growth under a shallow slab (Figure 3b) that can quickly turn to the case of Figure 3c if the slab thickness becomes locally larger. This scenario is especially threatening for experienced mountaineers, who usually pay close attention to the snow condition under their skis but are less aware of the danger due to the snow variability in the neighborhood. In both cases, a slope that seems to be quite safe may suddenly be swept out by a spanning avalanche.

Fig 7: A particularly hazardous situation is found when a slightly loaded slope (where a skier can easily nucleate a basal crack (a)) is bounded by a more loaded and steeper slope. Both the larger load and the steeper slope favor basal-crack expansion and further crown-crack opening.

Experienced skiers sometimes succeed in triggering slab avalanches without being caught in them. It may happen indeed that a skier triggers an avalanche of limited size. Most of the time, this is a subcritical triggering. The tensile stress in the slab resulting

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crown profiles

There was tension in the voices heard over the crackle of the radio – between forecasters and the highway's regional CDOT teams. Then, Jerry's succinct words: "We're in full conditions here, boys and girls," the first hint that we might be witnessing a once-in-a-lifetime storm. But of course, at the time, none of us really knew. It was 11:00 pm, January 8, 2005, and it would be an understatement to say it was a stormy night. Forecaster Mark Rikkers was in one truck racing south towards Molas Pass, while lead forecaster Jerry Roberts and his visiting side-kick Tim Lane were headed the opposite direction up Red Mountain, checking on the rapidly deteriorating road conditions and increasing avalanche hazard threatening Highway 550, from the Uncompaghre Gorge above Ouray all the way to Coal Bank Pass – the north/south life-line of southwestern Colorado.

That night, after an already long day of shooting, I was allowed to stay behind and supposedly catch up on much-needed sleep. A night that was sleepless nonetheless, especially since around here we make a habit of snuggling with our Motorolas; no avalanche forecaster worth their Pisco Sours would be sleeping when it's dumping nearly 3" per hour on a severely burdened continental snowpack. So there I lay, wide awake, eavesdropping.

Using radio call names, Jerry Roberts is anxiously trying to reach Mark Rikkers: "3 Mary 5-1, this is 3 Mary 5-0; what's your 20? Mark Rikkers: "Hey Jer, it's 3 Mary 5-1, I finally made it to Molas Pass – really bad visibility; what's happening your direction?" Jerry: "Mark, I'm with a crazy woman stuck in a snowbank near the Muleshoe turn (below a particularly nasty avalanche path) – will need help getting her out so we can shut this highway down. Can't reach the Red Mountain plow driver – can you try radioing from your location and send him our way?" Mark: "10-4, I'll give it a try."

I can hear that Mark is also having trouble getting out to a plow – the radios are sketchy in both locations. So, trolling for something to do, I ventured an earnest call to Jerry (knowing it was probably a mistake). "Uhh, 3 Mary 5-0, this is 3 Mary 5-2; is there anything I can do from here?" Pause. Jerry, with the whole world listening and a storm puking 3" an hour, replied, "Thanks 5-2, uhh yea…when we get this lady out we'll be escorting her back to Silverton for the night, but she might not be able to find a place to stay…doesn't speak very good English, think she's Romanian…you think she could camp on your sofa for the night?" I pause, suspicious. "Uhh, yea, sure, I guess so." Jerry: "Great! And one other thing…I think she's from the circus…and I think she has a monkey with her."

Long pause. "Did you say MONKEY?" Jerry (with Tim tittering in the background): "Yea, I think it's a MONKEY. Will your dog be okay with that?" Of course the Romanian Circus Woman and her Monkey never materialized, having been created, so I thought, on behalf of my rookie status and over-enthusiasm. Shortly thereafter, both roads out of Silverton were closed and Red Mountain Pass, making national news, remained closed for seven long days.

Neither forecaster nor plow driver was allowed on the road. Mother Nature finally forced a shutdown to rage in privacy; avalanches don't like people watching.

photo by Susan Hale

AVALANCHES & MONKEY BUSINESS

San Juan Highway Forecasting

Story by Susan Hale

That evening, at least for me, marked the apex of what would be the biggest storm cycle that most Silvertonian's could remember. Snowfall rates, storm snow/water equivalents, and avalanche numbers pushed the record-books to new extremes for the month of January. Once Hwy 550, over Red Mountain and Coal Bank Passes, was finally cleared of all traffic, the hazard level was posted at a very rare Extreme. No one, neither forecaster nor plow driver was allowed on the road. Mother Nature finally forced a shutdown to rage in privacy; avalanches don't like people watching.

THE BEGINNING: An avalanche cycle doesn't occur just because a large amount of snow has accumulated in a short amount of time (although it is certainly a very big indicator). Our "shift changing" continental snowpack and any resulting avalanches are shaped by season-long weather events and trends. All these factors are tracked, catalogued, and registered by weather and avalanche forecasters as winter progresses and therefore, such events usually come as no great surprise. However, predicting the duration and intensity of such a storm remains hazardous to the ego – memories can be short, there have been so many drought years, and as those in the know understand, "voodoo" often rules. Mother Nature did the unexpected.

STORM 1: Our big weather/avalanche cycle consisted of three distinct storms, the first of which arrived December 29, on the heels of a long stretch of snow-weakening, cold, and mostly dry weather. These conditions drove the shifty snow grains toward unstable, faceted forms that bond poorly to each other, if at all, resulting in a rotten foundation for future snows.

The first in this series of southwesterly storms arrived fast and furious, setting the pace for the first half of January. It began with a bully layer of slippery graupel (a precip particle that also does not bond well) that was soon topped with heavy wet stuff. This was accompanied by sustained wind averages in the 30s and gusts reaching a whopping 90+ mph. As the storm unfolded, we anticipated that 1.5-2" of water would kick off a natural avalanche cycle, and it did. By late that Wednesday afternoon, in less than 24 hours, 2" of snow water-equivalent led to four natural and seven mitigated avalanches that hit the road on Red Mountain Pass (the Molas/Coal Bank side of Hwy. 550 saw four natural and three mitigated avalanches reach the centerline). Spot road closures for mitigation and avalanche cleanup finally evolved to full gate closures as Mother Nature's wrath of high winds, precipitation rates, and approaching darkness declared, "You aren't the boss of me!" The roads remained closed until 4 pm the next day. Storm totals peaked on Molas Pass at 21" of snowfall and 2.85" of water in just over 24 hours.

STORM 2: With only a few days to catch up, a second strong Pacific storm arrived late January 3. Once again wind averages were in the 30s with gusts reaching the mid 70s, perfect conditions for transporting very large amounts of snow into our avalanche start zones. Temperatures were on the warm side creating high-density snow. Snowfall intensities that reached 2" an hour kicked off another natural avalanche cycle, this time closing Red Mountain Pass for 43 hours! Natural and mitigated avalanches put as much as 15' of snow depth on the road. This time, the Coal Bank study plot won the "most snowfall" prize, with 35" of storm snow and over 3" of water equivalent. With the cumulative snow/water amounts, the accompanying winds, and weak underlying snowpack, natural avalanches were seen on all aspects. Even so, many of our larger paths remained mostly intact – to our dismay. We had hoped that more of our start zones would clean out, especially since the current weather pattern was expected to continue.

BIG STORM: The pattern continued. In less than two short days, a super-storm had formed on another southwest flow. The last storm of our record breaking cycle began Friday, January 7, battering the region through the following Wednesday. Snowfall was very heavy, with precipitation intensity verging on 1" per hour for the entire period. Initial snowfall densities were light but soon became heavy, a textbook scenario for avalanche activity. Strong SW winds (again in the 30s with gusts to 65 mph) compounded the situation early. In the wee hours of the 8th, our nuisance path, Blue Point, woke us up to 3' of snow over 40' of road. Shortly thereafter the East Riverside slide filled the gorge below our only

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MONKEY BUSINESS

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Seemingly endless control measures had become dangerously mundane. Another 91 rounds of explosives were expended on the Molas/Coal Bank side of 550. Would it ever stop? Would we ever sleep?

photo by Jerry Roberts

snowshed, dragging adjacent paths in its wake. These covered the road with 4' of snow and would come down again later to actually pack the shed with 3' of snow. On the Coal Bank side, the Henry Brown path led the charge and things went downhill from there. Wind and snowfall rates prevented efficient mitigation and darkness was fast approaching. Hazardous travel conditions and sanity finally won out and by 11 pm, both sections (north and south) of Hwy 550 were closed – after the Monkey Lady was escorted to safety.

Thus began the never-ending mother of all storms. The sections of road over Red Mountain and up County Rd 110, toward Silverton Ski Area, with their impressive mountain peaks and monstrous avalanche paths, defied all control and would remain closed for seven days.

The next morning, Jan 9, began early. On this day we not only fired 85 Avalauncher rounds (aka "the potato gun"), we brought out the "big gun," a 105 mm Howitzer that shoots 8 lb charges to distances up to seven miles; a real WWII piece of artillery. In hopes of keeping at least one escape route out of Silverton open, we concentrated on the Coal Bank/Molas side. In spite of all the fire power, frustration became the theme of the day. We were getting dismayingly few results for all the hard work. While weather and snowpack conditions certainly validated the previous night's decision to close the roads, we still expected big results to back up our forecasts. Unfortunately a frightened young bighorn sheep caused the most action as it kicked off a series of small slides on East Lime above our Avalauncher site while we were shooting West Lime.

We eventually worked our way back to Silverton, tails tucked, even though we managed to get the Coal Bank side of Hwy 550 temporarily re-opened. (Just in time for my husband to hightail it home from Durango and help shovel snow!) Disappointed, we geared up for one last set of Howitzer shots up the Red Mountain side. There was enough daylight to make a small attempt toward getting Red open, or so we thought. It was late in the day; everyone was tired, cold, and grumpy; and after so little action (other than continuous snowfall) there were no expectations about seeing any results from the final shoot of the day. So off we went, CDOT crew and Forecasters dragging the Howitzer and an entourage of bored observers from the newspaper and Prescott College avalanche students. The plan was to shoot the Battleship, one of the first and most notorious slide paths leading up towards Red.

At 12,400', the wind-loaded, 35-degree start zones of the Battleship rise nearly 3000' above the deep gorge of Mineral Creek, which separates the path from the highway by another 300' of vertical on the opposite side. One might surmise that a 300' rise would be an adequate buffer zone for an avalanche runout. Wrong. The forces and speeds involved in a full scale avalanche from this particular path are so great that the maelstrom driven up the opposite side has deposited as much as 5' of snow and debris onto the road. The wind-blast alone can cause severe damage. Reaching speeds of 200 mph, it has hurled large trees across the pavement.

While a number of folks in the crew had seen the Battleship run, few could remember witnessing such a massive event. The first and only 8 lb lob from the Howitzer hit the sweet spot, shattering the enormous slab and sending a full-depth, full-path Tasmanian Devil down the mountainside. Our observers, with their chaperone Jerry Roberts, had a "close-up-and-personal" encounter with the beast. Situated in the usual safe zone, the group watched, first in amazement and finally with the horror of a deer in the headlights. It was Jerry who finally broke through the paralysis to bellow, "Run like bastards," and run they did!

(Editor's Note: For another version of shooting Battleship, see Mark Rawsthorne's *Tigers on the Road*, TAR vol.22, number 4.)

The "Prescotteers," plastered with snow, manically hugging each other in relief, had witnessed the event of a lifetime. We forecasters had just gotten our most satisfying validation for shutting down the road.

In this business, we like to say, "Close calls are not acceptable." I can still recall, upon my initial arrival into Silverton, Jerry's litany of do's and don'ts on the topic of "being safe out there" and "drama" avoidance: who to ski with, who not; who to talk to, who not; and even who to drink with! Whether this was sage advice or flat-out gossip, it was never taken lightly. But then there are extraordinary situations (and extraordinary storms), and that's when extraordinary things happen…in spite of our conservative mantra!

And so it snowed, and snowed and snowed, inches per hour.

While the Red Mountain side of Hwy 550 was locked down by massive avalanches and full-gate closures, the Coal Bank/Molas side was kept open even though it actually received the most snowfall from this southern storm. (Between January 8 and the morning of January 11, the Coal Bank Study Site had already received 63" of snow that equaled 6.5" of water.) On the Coal Bank side, consequences of massive paths hitting the road are somewhat reduced as compared to Red Mountain. Therefore we attempted to keep this only artery into Silverton open as long as possible, especially since there had already been one health-related emergency evacuation.

By the 11th, seemingly endless control measures had become dangerously mundane. Another 91 rounds of explosives were expended on the Molas/Coal Bank side of 550. Would it ever stop? Would we ever sleep? As the day grew long, visibility deteriorated and the race was on to get one last set of Avalauncher shots off at the paths closest to town: the Jenny Parkers and Peacock. Backed up and waiting on the road were four vehicles, including one very large loaded fuel tanker bound for the one Silverton gas station. While Jerry, Mark, and the CDOT crew were setting up, there was a last-minute decision (born of judiciousness and a bit of prescience on the part of two CDOT managers, Dennis McCoy and Paul DeJulio) to escort that group of vehicles carefully down into Silverton before our shoot. Once they were moved to safety, Dennis turned around to make one last pass up the road, through some of the worst of the hazards, to insure that no one was left behind. In spite of near-zero visibility, he sped through on instinct, but not before fate and timing placed Dennis and an avalanche in the same place at the same time.

Dennis and the Harley Short slide had their own "up-close and personal." With the tingle of adrenaline and a little heebie jeebie, there was a guided, deliberate motion to jam his truck into reverse out of harm's way (CDOT trucks are used to that). He recounted, "That damned thing billowed over my hood and I knew it wasn't just blowing snow!" In a split second, steering with his knee and one hand cranking gears, Dennis grabbed his radio to yell, "Guys, I think it's time to shut her down!" Watching from the opposite side, with a bit of horror and just a little bit of glee, Jerry radioed, "Run, Dennis, run!"

Steering with his knee and one hand cranking gears, Dennis grabbed his radio to yell, "Guys, I think it's time to shut her down!" Watching from the opposite side, with horror and just a little bit of glee, Jerry radioed, "Run, Dennis, run!"

photo by Gary King

Things were starting to happen all at once. With the Avalauncher in tow, Jerry Roberts, Mark Rikkers, Tim Lane, and Paul DeJulio decided it was time to cut their losses and bail off the mountain. Heading back toward town, they found themselves trapped between two paths that ran almost simultaneously. Blocked to the south by the Peacock and Jenny Parker slides that ran shortly after the Dennis incident, they turned to find the road to safety and Silverton blocked by the Gladstone Twins – a narrow pair of identical paths that, prior to that afternoon, had grown in with mature timber and were no longer considered a threat. That day 100-year-old trees were splintered, and several nervous hours passed before the group was chipped out to safety.

In the mean-time, Dennis made his way back up to Molas Pass before he realized his truck was overheating. Time was of the essence and he'd heard what happened to Jerry and Paul, so he pushed cautiously on over Coal Bank Pass. There he was able to coast downhill to the Cascade CDOT Barn, where he discovered a broken fan belt caused by dense snow packed into his radiator and engine.

That series of events issued in the longest full gate closure of the storm cycle for Coal Bank and Molas Passes, lasting 51 hours (over two long days). And we finally got a little sleep.

Already blanketed with 6-7' of snow, the town of Silverton was abuzz with activity. Plows piled enormous rows of goop down the center of Greene Street, obscuring buildings on either side. Residents frantically shoveled roofs to prevent collapse or a creep/glide incident that could break out windows or kill people or pets. It had probably been 50 years since anyone had worried about the Naked Lady path off Kendall Mountain, with a run-out zone that had the potential of reaching a few homes and the Visitor Center. There were other evacuations toward Eureka, where there had already been a close call for the county plow driver and two snowmobilers.

When we crawled out from under our beds on January 15, we discovered paths that had not run full track for decades – many of which took out mature timber. A Verizon Cell building, newly built on Coal Bank Pass and perched in a supposedly safe location, was completely destroyed and buried under 6' of avalanche debris. County Road 110 toward Silverton Ski Area was completely buried as 15 major paths struck the road and ripped out power to the ski area until spring. On Hwy 550, 42 natural avalanches and 32 mitigated avalanches hit the road. West Riverside put 30' of snow on the highway, and in all, over 11,000' of roadway was affected by debris. Coal Bank tipped the scale again with a grand total of 91" of snowfall and nearly 10" of water. By month's end we calculated that this was the wettest January on record.

And so ends the storm story. Silverton continued digging out for days. Record snowfall was the talk of the county and made national news. Once the roads were opened, rat-trapped locals and visitors alike lined up, anxious to make the mass exodus out of town to escape a week of isolation. When the gate was opened, we pulled our CDOT truck over to watch the parade. To my surprise and disbelief, the last vehicle to move through the barrier was a loaded-down, tired old rambler, driven by a dark, mysterious woman. And in the seat next to her was a small, gangly, round-eyed creature…the MONKEY?

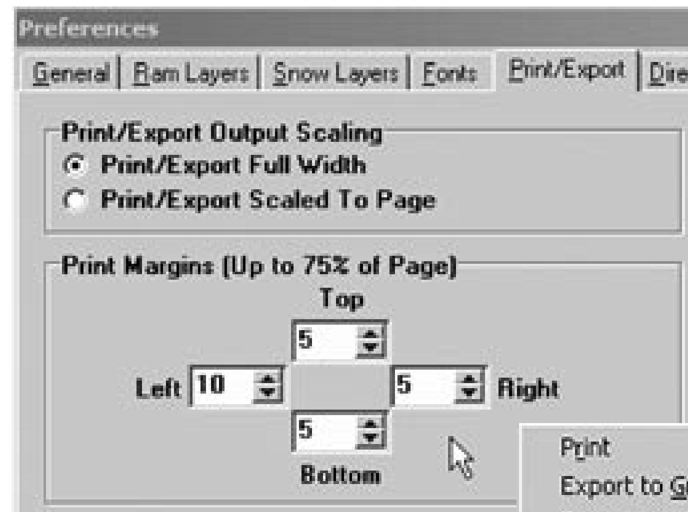
Susan is a Texas Expatriate who has lived in the Colorado Rockies for almost 21 years. She eventually wound up in Aspen, directing a recreational ski race program. After 9 years of mostly desk jockey work she opted for more powder days and less pay and took a job on ski patrol, where interest in snow/avalanches spawned from participation in snow-safety and coordinating the avi-dog program. Another 10 years passed and she is presently mining snow in the San Juan Mountains, working with the Silverton avalanche forecasters – learning about highway forecasting, how to shoot a Howitzer, how to talk CDOT and how to mix Pisco Sours.

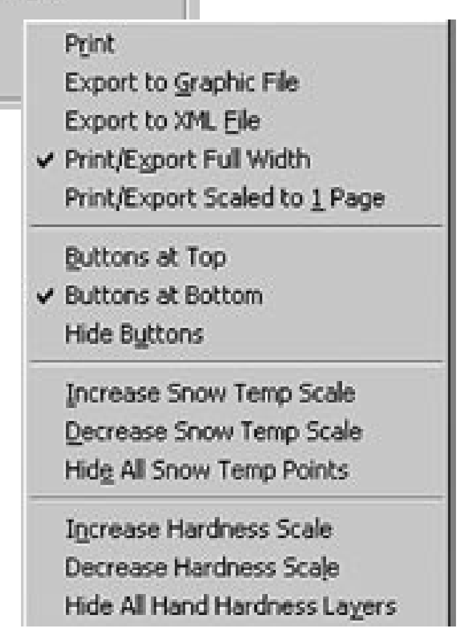
photo by Jerry Roberts

Snowpro Plus+ Tips and Tricks

Story by Gary Sims

Snowpro Plus+ has a rich set of tools for constructing snow profiles and usually provides at least two ways to do anything. The follow tips are intended to help you quickly become proficient in using Snowpro Plus+. Feel free to send specific questions to info@gasman.com. You can download a demo version from www.gasman.com/demorequest.htm





PRINT SIZING

Smaller graphs can be printed by setting print margins larger; the graph scales itself to fit within the defined page size. Print-margin units are based on the percentage of the current selected printer. Scale the graph by selecting the left, right, top, and bottom margins in the Preferences: Print/Export tab. (The graph will scale to fit this if you select the "Print/Export Scaled to 1 Page" by right-clicking the mouse over the graph to get the pop up menu.

SNOW TEMPERATURES

- ▶ The snow temperatures graph points can be dragged from the toolbar to create new points.
- ▶ The snow-temperature point and lines color can be set by right-clicking on Tool Box icons and selecting new colors.
- ▶ The current height and temperature of a snow-temperature point can be viewed by placing the tip of the cursor over the temperature point.
- ▶ Any snow-temperature point can be dragged to a new location on the graph, although they cannot be moved to any height where a snow-temperature point already exists.
- ▶ A snow-temperature point can be deleted by dragging the point from the graph and dropping it on the Trash Can on the Tool Box.

RAM LAYERS

- ▶ The ram layer can be dragged from the toolbar to create new layers (for ram hardness only).
- ▶ The ram layer can be moved by left-clicking on layer while holding the mouse button down and dragging to new position or dropping on top of another ram layer. This will swap the layers.
- ▶ The ram layer can be sized by holding shift plus left mouse button and dragging to new size.
- ▶ Ram layers can be hidden (and then re-displayed) by right-clicking on layer or graph and selecting Hide option.
- ▶ The ram layer colors can be set by right-clicking on Tool Box icon and selecting new colors.
- ▶ The current thickness and density of a ram layer can be viewed by placing the tip of the cursor over the layer.
- ▶ Any ram layer can be dragged to a new location on the graph, except they cannot be moved to any height above the surface of the snowpack. All layers will draw from surface top towards bottom of pack.
- ▶ When a new ram layer is dragged from the Tool Box, it is positioned at the bottom of the other layers, but can be dragged to a new position.
- ▶ The default ram-layer thickness is set in the Preferences: Ram tab.
- ▶ A ram layer can be deleted by dragging the point from the graph and dropping it on the Trash Can on the Tool Box.
- ▶ The ram-layer dialog allows specification of which fields to copy and whether density calculations should be done. Set the default with new profiles in the Preferences: Ram tab.

MISCELLANEOUS

- ▶ The Tool Box can be opened by selecting View: Tool Box. The Tool Box can be set to automatically appear upon startup by setting Open Tool Box upon startup in the Preferences: General tab.
- ▶ All windows can be sized and dragged to any location using standard window methods. Most window sizes and locations will be remembered if you set Save Windows State in Preferences.
- ▶ Use the right mouse (Property button) to hide or move the bottom button bar, copy/cut/paste from the clipboard, and perform many other hide or unhide options on objects on the graph.

Gary Sims is the president of Gasman Industries Ltd., in Victoria, BC Canada. He has developed computer software for the skiing and snow industries for over 20 years and has worked with the BC Ministry of Transportation to develop weather station and avalanche data collection software. He has been a ISSW commercial exhibitor and currently sells Snowpro Plus+ software for graphing snow-profile data.

Correction to Snowpro Tips in TAR 24/2: For sizing, use shift key (not Ctrl) plus mouse drag.

Monty Atwater demonstrated the original Mark 10 Avalauncher at Squaw Valley, California, in 1962. The Mark 10, known as the "400-yard Launcher," cost $500. *photo courtesy Monty Atwater, Jr.*

Genesis of the Avalauncher

Story by John Brennan

OK, I'll admit it: I've always been a big Monty Atwater fan. Not only is the man credited with being the father of modern avalanche forecasting and safety in the United States, but he is also responsible for developing the Avalauncher. Through its more than 40-year history, the Avalauncher has gone through many changes yet continues to prove its worth in avalanche-mitigation work.

After Atwater's stint in the 10th Mountain Division in World War II, he took his skills to Alta, Utah, in 1945. It was there that Atwater began applying a practical approach to both studying and mitigating the effects of avalanches, where in 1951 he was able to bring artillery into the picture. Almost as soon as the military weaponry began their assault on the Little Cottonwood Valley, the murmurings of the imminent obsolescence of both the guns and their warheads begin.

While Atwater experimented with a variety of alternatives, each had drawbacks. In the summer of 1961 one of Atwater's supervisors showed him some product literature of a pneumatic baseball-pitching machine. The wheels began turning and after several conversations with the machine's inventor, Atwater was able to view a demonstration of the first Avalauncher late that same year.

Frank Parsoneault was the genius behind both the pitching machine and the Avalauncher. His full-time job was as a fixtures engineer for Douglas Aircraft, but on the side he was an inventor. What made both machines work was a valve that would allow for the almost instantaneous release of compressed gas. By the late 1950s, many Major League teams were using Parsoneault's "Fireball" pitching machine.

While the pitching machine received a patent, the valve assembly itself did not. Soon the valve was copied for many different industrial applications. Today, derivations of the Parsoneault valve are used in air cannons to blast clogging and caking from railway-car hoppers, kilns, silos, power stations, and cement works. In these applications, large quantities of compressed air are sufficiently forceful to remove material obstructions from the equipment to which they are attached.

There are roughly 200 Avalaunchers being used throughout the world today. The first production model was the Mark 10 which sold for $500. Atwater and Parsoneault's sales strategy was to sell the guns at cost, then make their meager profits off the projectiles. Sales for the first launchers began prior to the 1962/63 season. Originally monikered a "400-yard Launcher," the Mark 10 was quickly superseded by higher-pressured, longer-ranging units. Early projectiles, if they could even be referred to as that, were simply a few one-pound cast shots taped together. Conveniently, their 3" diameter mated precisely enough with the standard-sized aluminum pipe that formed the barrel. The rounds were lit, dropped down the barrel, and the fire valve was released.

It doesn't take a rocket scientist to realize there were drawbacks to this projectile. Aside from the glaring safety issues associated with a shot burning in the barrel, the flight characteristics were poor. Fin-stabilized rockets soon followed. Their fusing systems saw a short piece of safety fuse coupling a detonator to the old-style t-handled pull-wire igniter. The t-handle, which was just an old piece of outdated fuse, was removed and the remaining wire passed through a hole in the projectile's base plate. The igniter wire was then tied off to a fixture on the gun. This way, when the gun was fired it would begin the ignition sequence.

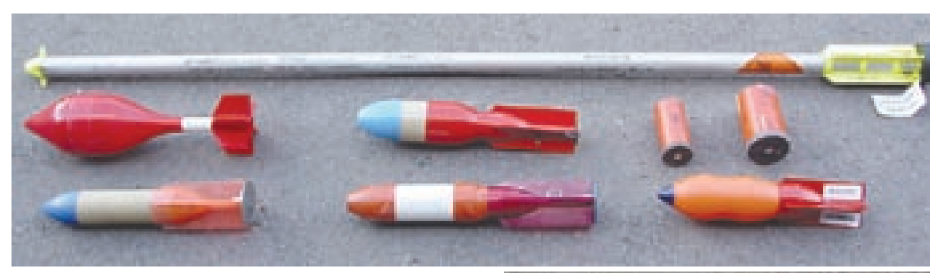
It was an idea that looked good on paper but also one that lead to several accidents. In April of 1966, two Forest Service (USFS) workers lost their eardrums when an in-bore pre-detonation occurred at Tuckerman's Ravine. In September of the same year, three gunners were killed by a similar accident in the Rio Blanco mine in Chile. In both accidents, small amounts of escaping gas proved forceful enough to move the projectiles far enough up the barrels to ignite them, but not forceful enough to eject them completely. While work on an impact-fusing system had begun in the mid '60s, these accidents now saw that system move to fruition.

The idea behind the earliest impact-fusing system was to have a firing pin, which was held in place by a magnet, be driven into a shotgun shell's 209 primer when the rocket hit the ground. A 209 primer is made up of a pellet containing lead styphnate – the same compound found in the ignition mixture of most blasting caps. When the firing pin hit the 209, the energy of detonation would be driven into the open end of a blasting cap.

An accident occurred with this system when Atwater was demonstrating a launcher in 1968 at the Idarado mine in Colorado. At this time the magnets being used were donut shaped because it was easier to induce magnetism into them. Apparently the hole in the old-style baseplate lined up with the magnet hole and when the gas was released it was able to drive the firing pin forward. A gunner was killed and Atwater lost hearing in one ear.

This accident inspired the development of the flight-safety system and the use of solid magnets and base plates. In this system, a spring-loaded pin sits in front of the firing pin. The basic logic was that the firing pin would only be able to travel toward the 209 primer once the shot was approximately 50 yards from the barrel.

In one application the flight-safety system is not used because the target is so close to the barrel: inside mines, where transfer tunnels are bored between mining floors in order to transport ore. When these 6' diameter holes become clogged, the easiest way to unplug them is with an Avalauncher shot. In this situation, the firing is done remotely.



Projectiles *(above)* and their tail fins *(right)* have evolved from the earliest prototypes: taped together one-pound cast shots.

With the first fin-stabilized rockets from the early '60s to the early '70s, projectiles used explosive products designed to be lowered into oil wells. These products, called "perforators" within the industry, were sturdy units built to withstand the extreme pressures found deep within the wells. Ammonium nitrate and TNT oil formed the explosive that was packaged within steel cans. Not only could several of these cans be screwed together, but they had a nose cone that could be screwed onto the top of the can. Parsoneault made dies for stamping out aluminum tail fins and Atwater assembled these together at his home.

In an attempt to find a replacement for artillery, the USFS began accepting contract bids for alternative systems in the '70s. In addition to the Avalauncher, the Bermite Corporation's RAMP system (Rocket Assisted Military Projectile) sought the USFS contract and Honeywell pitched their 57mm recoilless rifle that could fire a plastic-cased warhead. Even though the Avalauncher was being used extensively, RAMPS got the contract. This weapon used a 40mm mortar cartridge to launch the rocket and then an onboard propulsion system kicked in. RAMPS unfortunately were never able to deliver a viable product. The USFS was not only disappointed but also out the contract money. Another contract was never offered.

An interesting woman in the history of the Avalauncher was Jerry Nunn. Jerry began patrolling at age 18 at Donner Pass, California. Despite having seven children by age 30, Jerry continued to patrol. She began working at Squaw in 1957, and when the Olympics came in 1960 she worked with Atwater doing avalanche control. She originally met Atwater in 1957 when she attended the USFS's Snow Ranger course in Alta. Nearly blocked from the course because she was a woman, Jerry went on to become the country's first female Snow Ranger. Over the years, Jerry was credited with selling close to 30 Avalaunchers. She was also responsible for introducing Pete Peters to Atwater in 1973.

Shortly after their introduction, Atwater partnered up with Peters and together they formed Avalanche Control Systems. Peters promptly put $16,000 into the company so that plastic molds could be purchased to manufacture the next generation of tail fins and rockets.

In 1976, at the age of 72, Atwater passed away after a heart attack. Peters took control of the company and continues to manufacture and sell the projectiles. In the late '80s, Peters quit building the guns and their prices began to skyrocket.

Currently there are three commercial producers of Avalaunchers in the world with another company making a similar product. Of the launchers, the U.S.-made weapon of the Launcher Company sells for $15,000, the Canadian SEAR's gun for about $17,000, and the French launcher for $42,000 (all figures U.S.

After seeing this brochure for a pneumatic baseball-pitching machine, Atwater joined forces with its inventor, Frank Parsoneault, to create the first Avalauncher.

dollars). In comparison, Peters sold his last guns for under $1200. While the U.S. and Canadian gun are both designed for Avalanche Control System's 82.55mm shell, the French Launcher shoots an 83mm round that is almost 6' in length. In addition to its pricy gun cost, the French Launcher charges $170 for its projectile. Its binary explosive, which is mandated to become inert within a short time period, drives the total shot cost up even more.

Another gun that deserves mention here is the LOCAT. This is a compressed gas weapon that operates up to 3000 pounds per square inch (psi) - compared to the 400-450 psi max pressures of the previously mentioned Avalaunchers. The higher pressure not only allows greater range, but also the ability to use a military-style detonator. The LOCAT pricetag is a staggering $190,000. Reserved for only those with the deepest pockets, LOCAT ironically stands for Low Cost Artillery Trainer.

With its ability to place several pounds of high explosives up to 2000 yards away, the Avalauncher continues to be a viable tool for avalanche-mitigation work today. Its effectiveness is due to the hard work and foresight of many men and women, not all of whom have been mentioned. There are some interesting prospects for the future of the Avalauncher and I hope to cover those in a later article.

Special thanks for help in this article go to Pete Peters; Monty Atwater, Jr; Mark Parsoneault; Ron Perla; Ed LaChapelle; Jerry Nunn; Paul Hauk; and Marty Schmoker.

John Brennan tells TAR that he has wanted to write this story for a while. After his son was born last April 15, his wife and mother-in-law suggested he take a road trip to research the article, as typically he's laid off after the ski season ends around Easter and doesn't start back on summer trails until around June 1. His goal was to meet the key players in the history and development of the Avalauncher face-to-face. He covered just under 3000 miles and five states in seven days and additionally was able to get small ski tours in each of the states he passed through. ❄

SLAB TRIGGERING

continued from page 14

from the collapse of the weak layer on a limited area is large enough to open a crown crack just above. The avalanche is released, but the skier can escape if able to control his or her trajectory. This is likely to occur with weak and shallow slabs made of loose snow.

Slope cutting usually works, but not always. This could be the reason why Pompon was caught while trying to trigger the bowl of Les Balmes. A slab avalanche may occasionally largely exceed the usual size most often seen on a particular slope. This is the nature of a supercritical triggering. The collapsed part of the weak layer spontaneously and rapidly extends in all directions. The crown crack may open far above the skier, who gets trapped in the middle of a huge triggered slab that may reach widths up to several hundred meters. Escape is impossible, and the outcome is usually fatal. This scenario is more likely to take place when a slab is composed of tough and heavy snow. Being aware of the existence of these two fracturing modes is fundamental for practitioners, as predicting which one of these two is likely to occur is risky, even if the supercritical mode is favored by a continuous weak layer, a heavy, thick, and tough upper snow layer, and slope angles around 35˚.

The layout procedure for triggering devices, like gas exploders, should also take into account these two different scenarios: the separation between two neighbor devices is different depending on whether sub or supercritical avalanches need to be triggered. Frequent subcritical triggerings probably hinders the release of large slabs, whereas optimizing supercritical triggerings may lead to unexpected consequences, owing to the uncontrolled size of the avalanche.

V) From a basic understanding towards a possible prediction?

Despite the large variety of observed avalanche phenomena, their understanding does not require as many models, but may be described by using a few simple concepts. Too simple of an approach, based on a balance between a global snow resistance and a supposed overload due to the skier, would not be able to describe the variety of observed triggerings. By contrast, such a variety of behaviors can be easily accounted for on the basis of the four-step scenario described above.

The final result in terms of avalanche occurrence and size may vary drastically, depending on the way in which these processes are connected. Human action modestly appears limited to a local change in the weak layer resistance, which may nevertheless lead to quite different scenarios depending on the local and global snow cover properties. The snow cover is such a complex system, with such a large spatio-temporal variability, that a deterministic prediction of avalanche release turns out to be impossible. It would require an army of patrollers measuring snow properties all day long, and a slight uncertainty in these measurements might lead to totally different behaviors.

Our ignorance can be dealt with in terms of randomness. Field measurements show that starting zones obey a specific size distribution, taking the mathematical form of a power law, also known as a "scale invariant" distribution. This means that there are many small avalanches and a few big ones. But the ratio between the number of avalanches of different sizes is perfectly well defined, and there is no characteristic avalanche size.

We demonstrated using cellular automata simulations (Faillettaz et al. 2004) that such scale invariance can be reproduced, provided random values are used for rupture thresholds. The consequences are twofold:

- Scale invariant size distributions obtained from field measurements are a signature of the random nature of the snow cover, confirming the necessary use of statistical approaches.
- Introducing disorder leads to a perfectly well-defined statistical organization, which provides some hope of "personalized" avalanche prediction using cellular automata fitted on particular gully topographies.

In the meanwhile, we believe that the basic concepts and mechanisms developed in this paper will be of some help in improving decision-making for professionals and practitioners through a better understanding of the possible underlying mechanisms.

Acknowledgements:

Future innovative developments of the present approach in terms of avalanche forecasting will certainly rest on the statistical simulations developed during PhD work by Jérôme Faillettaz, who is gratefully acknowledged. The authors would also like to thank Bruce Jamieson for permission to reproduce a figure and Henry Schniewind for critically reading the manuscript. They also invite your comments and insight; contact information is provided at the end of each bio.

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