# DEEP SLAB INSTABILITY, DECISION MAKING, AND CONSEQUENCES: A CASE STUDY

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ABSTRACT: On March 8th, 2008 an avalanche occurred on Mt. Eyak, near Cordova, Alaska. It resulted in the death of an avalanche forecaster, and the broken femur of another person. Through a summary of weather observations and snow profile data taken in the same area for weeks prior, this case study explores many factors associated with this event, including deep slab instabilities, stability tests, strain softening, triggering mechanisms, human factors, decision making, and consequences.

KEY WORDS: deep slab instability, human factors

## 1. INTRODUCTION

Life is like driving down the highway looking through the rear view mirror. You don’t know where you are going, but you can adjust your course by seeing where you’ve been.

Cordova, AK, a coastal community of about 2500 people, is located on the north coast of the Gulf of Alaska between the Copper River and Prince William Sound. With over 3 meters of precipitation a year, it is considered a temperate rain forest. Storms usually come in with an east wind, and at times pick up to hurricane force. Because of the proximity of the ocean, winter temperatures fluctuate around freezing. During the 07-08 winter, however, the temperature mostly stayed below freezing, and lots of snow fell down to sea level.

## 2. EVENTS

The morning of Saturday, March 8th, 2008 began as most of the days that winter. Snow was falling at sea level, the wind blew moderately from the east, and the temperature was below freezing. It had been storming for the last week, with warm temperatures bringing rain to the peaks of the local mountains. Much precipitation had fallen and the wind had blown to hurricane force, a typical Gulf of Alaska storm. The storm was on its way out, and a “weather window” was expected before the next storm crept in. Hoots checked the weather on the internet and called Mike and Kirsti. It appeared the window was already upon them and quickly closing. Mike, with the help of Hoots and Kirsti, was forecasting the avalanche hazard for the highway, the hydro electric facility, and for the backcountry. They had, so far, a great season, with many days in the backcountry and lots of snow. The recent prolonged nasty weather, however, left them compelled to get up into the mountains to check conditions and get some exercise, though none of them considered doing anything out of the ordinary. The day before, Mike had the backcountry avalanche hazard at high for the mid-upper mountain.

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The three, with their three dogs, met at the ski hill, where they could quickly and safely access the upper elevations. The previous days had blown hard and had caused the chairlift to derail. The crew was working on fixing the cable, but needed assistance clearing the snowdrift at top station so they could run the lift. Mike, Kirsti, and Hoots climbed up to top station and shoveled for a half hour so the chairs could get through. Afterwards they continued up Eyak ridge to 600m where they routinely dig snow profiles on the northwest slope below the ridge. At some point during the snow profile, the three were joined by another friend, Tully. Mike dug the profile 170cm deep. A weak layer, created on February 18th, sat about 145cm deep. They had been referring to it as the Valentine’s layer. They recorded stability tests, but they didn’t test the Valentine’s layer. In all practicality, it was too deep to test. After the profile was complete, they continued up to the antenna, where a huge cornice had formed over the NW slope. The slope below had filled in beautifully. All the features were smoothed over. As usual, they attempted to cut the cornice to drop a large load onto the slope below and thereby test it further. Mike was able to get a large but not huge piece of it to break free. The piece was enough to release a fracture at what looked like the 50cm instability. The slab propagated only 10m wide and traveled less than 100m to the first bench in the upper path.

It was then they discussed descent options. The peak was obscured, and they didn't feel like climbing higher to descend the ridge in flat light. They had noticed during the climb that the usual descent routes back to the ski hill had been wind scoured, so the NW slope below them was tempting. Though they had gone down that slope before, it was not a regular descent route due to many factors. It definitely wasn't a good ascent route due to avalanche exposure. An instability existed within the new snow, but did not appear consolidated enough to propagate significantly. The Valentine's instability was considered too deep too trigger, had not released with the significant rain and snow received the last two days, and had not been triggered by the cornice drop or subsequent small slab release. Tully confessed that he had left his beacon in the car. They agreed that it was really up to him whether he followed or not. Kirsti ski cut the upper slope, traversed back to the ridge, and stopped at a good vantage. Hoots put in one hard turn with his snowboard to feel the snow, then he took an aggressive line to about mid mountain (300m). Kirsti followed next, telemarking another route. After she got down to Hoots, Mike skied a different line. Tully followed last, snowboarding yet another line. They covered most of the slope including potential trigger spots with no avalanche activity except for a small pocket that Tully triggered at a small convex feature near where they regrouped.

They realized that Mike's dog had not followed them down the steep slopes. Immediately, Mike began putting on his skins to climb back up for his dog. Kirsti and Hoots contemplated what to do, feeling that they really didn't want to climb up that slope. They remained in down hill mode. Their dogs had continued on down, and they thought they should follow them. Tully was putting his splitboard into ski mode when their dogs returned, so Kirsti and Hoots decided to climb back up as well. By the time Tully, Kirsti, and Hoots had changed gear and began climbing, Mike was about 100m above them and 200m below the ridge. Kirsti was skinning just ahead of Hoots, who was on snowshoes. Tully was skinning on a splitboard just below them. They were following Mike's switchbacks up a 10m wide slope between subtle ridge like features. Mike had crested the next bench and was beginning to climb up the next steep pitch. The dogs had caught up to him. A very loud and very sharp crack abruptly pierced the air. Mike screamed "get out of the way" as a large crown line appeared above him.

## 2.1 WEATHER

Just after Valentine's Day, a large, warm storm brought warm temperatures, heavy precipitation, and strong wind to Cordova. From February 17$^{th}$ through the 19$^{th}$, about 115mm of precipitation fell with the freezing line above 600m. At the end of that storm, the temperature dropped, bringing the snow line back down to sea level. From February 20$^{th}$ through the 22$^{nd}$, another 28mm SWE fell as about 20cm of snow. These events produced a significant weak layer (the Valentine's layer) that will be discussed below. A week of milder weather brought a trace of snow before another big storm arrived on the last day of February. Over the next ten days, February 29$^{th}$ through March 9th, 236mm SWE of precipitation fell: 58mm came in the first two days and then just over 10mm fell each of the next four days. Most of this came as snow down to sea level. On March 6th, a warmer storm brought 50mm of precipitation as rain up to 600m and strong to hurricane force east wind. On March 7$^{th}$, the wind continued to blow strong from the east, but the temperature dropped back below freezing and another 50mm SWE fell as snow down to sea level. The day of the avalanche, March 8$^{th}$, a transition between storms brought scattered snow showers. The wind started to slow down but still blew moderately from the east. Snow devils spun on the ridges, while plumes flew off the peaks. Visibility came and went.

## 2.2 SNOW PACK

On February 14$^{th}$, Valentine's Day, the height of the snowpack was just over 200cm at 400m. The warm, wet storm after Valentine's Day shrunk the snowpack to just over 160cm at 400m. By March 8$^{th}$, the snowpack had increased back to over 200cm at 400m. In the wind loaded start zones above 600m, the height of the snowpack exceeded 500cm. The rain during the Valentine's storm saturated the snow in turn creating a thick, hard layer of melt freeze polycrystals when it refroze. This layer got thinner with elevation and did not exist above 700m, as the temperature remained mostly below freezing. At the end of this storm, the temperature dropped bringing 20cm of snow. The transition at the end of the storm, from warm to cold, produced a localized, near surface faceting of the preexisting polycrystals. A fine layer of 3mm facetted polycrystals sat loose between the melt freeze and the new snow. Stability tests at 600m produced moderate to hard but good quality (Q1) results. Snow continued to accumulate on this layer with few avalanches occurring at it. On March 6$^{th,}$ rain changed most of the snowpack to polycrystals. The next day 20cm of snow fell with a strong east wind. On March 8$^{th}$, they dug a snow profile at 600m on a northwest facing slope with a 36` incline. The 20cm of new snow had blown into 40cm of 4F, 0.5mm rounds. The rest of the snow was melt freeze polycrystals most of the way down to the Valentine's layer, which at that time and location was about 145cm deep. All the layers were moist with the exception of a 10cm layer about 50cm deep which was wet. Stability tests produced moderate to hard results with poor quality at the wet layer 50cm deep. The Valentine's layer was not tested due to depth. Stability was also tested by cutting a cornice. A small slab (R1D1) fractured about 50cm deep and 10m wide. They descended the slope one at a time to about 300m. Nothing released except for a small pocket (R1D1) that Tully kicked off a steep rollover at the bottom of the run.

### *2.3 TERRAIN*

The terrain below the antenna on Eyak ridge was very complex and convoluted. A rocky ridge rolled over steeply onto a bench followed by a series of steep rollovers and benches. Several drainages formed tight ravines with alders on the upper slope and young hemlock and spruce on the lower slopes. It was an obvious avalanche path that had gone all the way into upper Fleming Creek. The elevation of the ridge was about 600m and predominately it had a northwest aspect though there were many features. This aspect caught a lot of snow with storms usually blowing in from the east. Relatively safer routes and escapes existed towards the west. Although safe descent was possible, generally speaking one would not ascend this slope due to difficulty and duration of exposure.

### *2.4 HUMAN FACTORS*

So why did they go down that way? The overall picture was bleak. Every detail, however, had reasoning. First off, they were up there because they had been weathered in for days and a "window" between storms was upon them. They wanted to check out the snow, they wanted exercise, and they wanted to ride some good snow. The route they would normally follow back to the ski hill had been scoured by the wind. The slope they descended was beautifully smoothed over from the wind loading. It was very inviting. They were having a great season, with many descents, and had confidence that their ability would keep them out of trouble. Although they normally didn't descend that way because of the terrain, they had gone down that way on occasion. They visited and tested the area routinely. It literally was Hoots' backyard. They weren't really concerned with the 145cm deep Valentine's layer. It was too deep for them to affect. Previous testing at that layer produced hard results, and their cornice test didn't seem to affect it. Besides it rained 50mm two days prior and snowed about the same SWE the next day and nothing happened. The instability at 50cm, however, was something that they could affect, but testing had moderate to hard results with poor quality. The cornice test showed them that it didn't want to propagate. They could even justify Tully going without a beacon as long as he didn't go first because if they didn't think it was safe, the rest of them wouldn't go that way regardless of having a beacon or not. And it was safe. They descended with no results except for what they expected to see. All they had left to do was find a route through the lower mountain slopes to the trail to Hoots' house.

So why did they climb back up? Mike's dog didn't follow them and was still on the ridge; she didn't like steep rollovers. It was nothing new for Mike to hike back up to get his dog. They didn't even really discuss it; he just started putting on his skins. Hoots and Kirsti sat there in down hill mode for a couple minutes trying to decide what to do. They were going to follow their dogs who had already continued down, but the dogs returned just as they decided. They knew the slope was safe because they just descended it, no problem. They might as well stick together and get another run.

## 3. DISCUSSION

It is easy to see, with hindsight or from an outside perspective, what mistakes were made. As outlined in the Avalanche Handbook, there were some basic rules that applied to the situation on March 8$^{th}$, which the group ignored yet fully understood.

- Be cautious after storms, most avalanches occur during or immediately after storm activity, especially if more than 25 cm of snow has fallen in a short period of time, strong winds have been present and there is a rapid rise in temperatures, or unusual weather or snowpack conditions have occurred.
- Be cautious of lingering weak layers, ie. Faceting.
- Be wary of wind loaded lee slopes where winds have caused larger amounts of dense snow to from slabs

So why did they ignore these basic and long established precepts. They had data on the storm intensity including duration, temperatures, precipitation, and wind direction and velocities; they had made local observations regarding the storm such as such as the chair derailment, lateral shift of the ridge, and relative water content in the snowpack. Clearly, the weather had loaded the slope and was continuing to do so. The snowpack had a smooth, hard bed surface, a persistent weak layer, and a recently loaded, hard cohesive slab. The terrain alone was dangerous. Instead of letting weather observations govern their decisions they were distracted by variables that led them into thinking the slope may be safe to ski. There were no natural avalanches of any magnitude observed in the surrounding mountains, stability tests results were hard and occurred at shallow depths, and the cornice drop results supported their stability tests. The Valentine's crust was now over 1m deep, and they thought it was too deep for a skier to trigger.

Above all, the assumptions about the deep slab instability were wrong. In the February 2008 issue of The Avalanche Review, Atkins and Williams summarize the facts of deep-slab instability. "…there is very little information about deep-slab instability," Atkins (2008).

### *3.1 PERSISTENT WEAK LAYER*

"The weak layer is days, weeks, or even months old. Persistent weak layers are the usual problem layer in deep-slab avalanches," Atkins (2008). In this case, the weak layer was created weeks before the avalanche and persisted for months after. Cold snow fell on warm, wet snow. This created a difference in temperature as well as water vapor pressure in a very small distance, thereby producing large, unobservable gradients. The melt layer recrystalization resulted in an almost indiscernible layer of loose, 3mm, facetted polycrystals. This avalanche was another example of faceted snow in a maritime climate.

### *3.2 TESTING*

When considering stability and testing of deep slab instability, results can be misleading. "The snowpack appears to be very strong and able to withstand lots of weight." "When the weak layer is buried more than a meter down it is difficult to assess the weakness." "Because the weak layer is deep and often old, stability tests often score in the moderate to high (stable) range for two reasons. First, because the weak layer is deep, the thick slab attenuates the applied stress, reducing its affect on the weak layers. Second, it is easy to unknowingly dig in the wrong spot, where the weak layer is deep or is strong," Atkins (2008). In addition, it appears that even though test results may be moderate to high (stable) the quality of shear will be good, i.e. planer.

### *3.3 TRIGGERING*

"We know from work done primarily by the Swiss Federal Institute of Snow and Avalanches in Davos, that the deeper the weak layer, the less stress a person exerts on the layer. In fact, a person's weight has little additional effect on weak layers buried deeper than about one meter," Atkins (2008). This was the reasoning for not being concerned with the deep Valentine's layer. A problem, however, exists with this reasoning. "Deep slabs are triggered where the slab is thin. This fact is key to understanding human-triggered deep-slab avalanches. Though our records tell of human-triggered avalanches up to 12ft deep, it is essential to recognize that the fracture line did not occur underfoot. The victim triggered the avalanche from a thinner spot where their body weight could affect the weak layer," Atkins (2008).

### *3.4 STRAIN SOFTENING*

It can be assumed that it was the weight of Mike and the dogs finding a shallow spot at the base of the highly stressed slab, which triggered the avalanche. There is a tendency, however, to think of it as a natural because nothing they had done before had affected it. Thinking about the size of it and the energy involved, how could "little old me" set that in motion unless it was at a teetering point anyway. Maybe it would have released even if they had continued down. They had dropped a cornice on it, they descended four different lines covering the slope Mike was climbing, and nothing happened. Or had it? Curiously, the upper crown line, which was instantaneously sympathetic to the crown that broke directly above Mike, ran from their snow profile to the small crown line from their cornice test. Maybe these events and their descent did affect the snow stability, a sort of strain softening. With this reasoning, testing could have decreased stability. Also, things could have already been in motion before they started climbing. If they had continued down, the avalanche might have released later, naturally.

### *3.5 HARD SLAB*

Although there was definitely a wet component to the slab, the hard component to the slab was what allowed the slab to get so loaded without releasing. It was also the component that allowed the avalanche to propagate so huge. “Deep instability often involves hard-slab avalanches.” “Hard-slab avalanches are nasty and unpredictable beasts….” “Deep-slab avalanches produce large forces and crushing weight.” “Certainly a deep-slab avalanche implies more snow, but also the density of that slab will likely be greater, resulting in an even more massive avalanche,” Atkins (2008). This brings in the idea of consequences into the discussion of decision making. The stronger the slab, the less likely it will release, but the further it will propagate, and a bigger, more destructive avalanche will result. If one thinks a slope is less likely to slide, the more likely one will expose themselves. Therefore, if the probability of an avalanche occurring measures instability, it appears the consequences may be inversely related to that probability. In other words, the more stable a slope appears, the bigger the consequences will be if it does slide.

### *3.6 ASCENDING VS. DESCENDING*

Realistically, it was probably Mike and the dogs that were the last straw on the camel’s back. Ascending is thought to be more dangerous than descending usually because exposure time is much greater when climbing. It takes longer. The force of a climber, however, has more of an impact on the snow than a skier or snowboarder because of the amount of force needed to gain elevation and duration of the force. When descending, the force exerted on the snow is very dynamic. It does not affect the same spot for long. When ascending, weight affects the same spot for a longer time, thereby affecting it more and perhaps deeper. Given the same slope, this is the fundamental reason why ascending is more likely to trigger an avalanche than descending.

### *3.7 HUMAN FACTORS*

McCammon identified six heuristic traps that govern people’s everyday decisions: familiarity, consistency, acceptance, the expert halo, social facilitation, and scarcity. This group fell prey to several of these traps, with familiarity being perhaps the trap most responsible for their actions.

McCammon finds the effect of familiarity most pronounced in groups with the highest level of training who expose themselves to more hazard in familiar terrain. This accident strongly supported this finding. Mt. Eyak was their ‘backyard’, and the group spent a hundred days or more each winter on the mountain in all weather conditions. They hiked the ridge in the middle of huge storms on as regular basis and knew every square inch of it. March 8$^{th}$ was like any other day for them, same place, same people, different day.

The scarcity heuristic trap also played a role in the group’s decision making. McCammon defines scarcity as placing value on resources or opportunities in proportion to the chance that they may be lost. March 8$^{th}$ was the ‘weather window’, not much of a window if you live in the Sierra Nevadas, but living on the Gulf of Alaska, a sunny day can be defined as a bright spot in the clouds. They may have been growing bored skiing the ‘safe’ ridge all week due to the storm, and wanted to take the opportunity and ski something else, perhaps a bit more exciting!

The decision to hike back up the slope ultimately led to the group’s fate. This decision was governed by tunnel vision, poor communication, the expert halo, and overconfidence. Mike did not communicate with the others about going back up to retrieve his dog. At that moment he had tunnel vision, ‘must get my dog’. So without any consult with the others, he had made the decision. The others made the decision to follow. The heuristic trap, the expert halo, may have contributed to this decision. Mike was the most experienced in the group and if he was going, then surely it was okay.

Overconfidence also was a major contributor. The group had a misconception that the slope had been thoroughly tested and was ‘safe’. They were focused on the moment, the present, they had been on that slope for over an hour, dropped a cornice onto it, and descended four different lines across the entire slope, with no significant results of instability. At that moment, they were not thinking of the past and the last storm cycle. They were caught in the ‘living in the moment’ trap.

## 4. CONCLUSIONS

The discussion of weather, snowpack, and terrain is objective and is usually associated as the science of snow. Human factors are considered more subjective. We cannot quantify them or their affect. The similarities, therefore, between human factors and the ideas implied by recent physics cannot be ignored. Quantum theory for example says the observer affects the observed. The subjectivity of our excepted observation techniques suggests that snow science has an art to it. The art and therefore the science of avalanche work are affected by human factors. “A telling example of the western mind is that what we call ‘human factors’ occupies its own chapter-separated from everything else-instead of being woven into the fabric of avalanche decisions as they really are,” Tremper (2001).

When thinking of human factors, we can think of them as pulling us or pushing us in directions different than we normally would go. They resemble the effect of gravity. They can be described as our gravitations. According to Einstein, gravity is acceleration and can be described as sort of a topography warping the space-time plane. There is not a force in the classical sense, but rather a path of least resistance. The same sort of emotional map of gravitations can be imagined, like a topographic map. Imagine now laying your partners maps over each other. Like waves in a pool, imagine the patterns of interference. Where a peak and a valley existed, they cancel each other out. Where two peaks exist, they double in amplitude. In this way, our emotions affect each other. How much they affect us depends on where we are at on the space-time plane. Though the objective facts are obvious from an outside perspective, they are distorted by the gravitations of our combined emotions. The theory of relativity describes the speed of light as constant to any frame of reference because the faster an observer is moving, the shorter his yardstick and the slower his clock appear to another perspective although they appear unchanged to the moving observer. Understanding that human factors, like gravity, are accelerations and related to motion, gives us an idea why we are blind to our own emotional state but can read someone else like an open book.

Assuming certain theories to be true, physicists have come to three possible conclusions in order to explain certain phenomena. The first possible conclusion, Superdeterminism, says, “it is not possible that the world ever could have been other than it is,” Zukav (1979). Free will is an illusion. “The concept of ‘free will’ is based upon the assumption that ‘I’ exist apart from the universe upon which I exercise my free will. According to Buddhism, the separateness of ego from the rest of the universe is illusionary,” Zukav (1979). Everything is interconnected. We can then conclude that it was fate.

The second conclusion is the Other Worlds Theory. This states that for every possibility there exists a parallel universe with a specific outcome. With this theory we can imagine that somewhere none of this ever happened.

The third conclusion is that it might not be possible to construct a model of reality. Mathematical formulas can be used to determine the probability of an avalanche, but we will never know if one will happen at a particular time and place until it does happen. Knowledge is limited. “Said another way, it is the recognition of the difference between knowledge and wisdom,” Zukav (1979). It can’t be known whether deep slab instability will produce an avalanche. It is wise, therefore, to give deep slab instability a wide berth.

The significance of this story is just that, it is a story, a story that could happen to anyone of any level of training or experience. Which ever way one looks at it, an avalanche is neither good nor bad unless a human is concerned with it. Whether one triggers it from above or puts something of value in its way, human factors affect those decisions. Thus, there is always a human factor at its root. Good decisions derive from bad decisions, and if one can learn from others, one may be spared a tragedy. Though one may try to comprehend the consequences, it is truly impossible until one has experienced them, and they only begin to manifest after the avalanche occurs.

5. EPILOGUE

When I looked up at the sound, and I saw Mike and the crown, I said to my friends, “run like hell” and found my feet moving before I even comprehended what was going on. At one point I stumbled on my snowshoes and muttered to myself, “keep moving, you’ve got to keep moving.” A few more steps after that the first of the debris came rushing past the tails of my shoes. I kept running until I was at the relative safety of a tree that was shorter than me. I symbolically held on, like I was holding mommy’s hand at a busy intersection, and turned to watch the aftermath unfold. The debris rushed by, flowing like water but with large blocks of snow. It had both wet and hard slab characteristics. As the debris started to slow, I relaxed my position. Suddenly, a second wave of debris exploded with such violence, I fell back in awe. A 10m tall tree, standing as vertical as it grew, moved down the slope. I could see Kirsti and we talked as the debris finally slowed. We couldn’t see Mike or Tully so we called out to them. Tully answered, “I’m all right, but I’m hurt.” I ran down to find his skis buried and his body wrapped around a treetop, hanging steeply downhill. I dug out his feet to release his bindings and noticed that something must be broke for the position of his feet. As I tried to reposition his legs, I realized his femur was broken. There was nothing there, like a stuffed animal without enough stuffing. I waited for Kirsti to help reposition, but unknown to either of us, her skis had been buried. After we got Tully more comfortable, I pulled out all the first-aid supplies from my pack and told Tully to look at me. His level of consciousness comforted me enough to re focus my efforts toward Mike. I turned back to the slope and the massiveness of the event. I had no signal on my F1 transceiver. I looked up slope and realized that there was no way possible that Mike was still above us. I started moving downhill, fall line, over the convoluted debris. After going down a long way, I finally picked up a weak signal. I quickly moved in his direction, but was unable to pinpoint any closer than the 2-8m range. I realized probing even with my 3m probe was useless. I picked an appropriate starting point and began shoveling about 5 minutes after the avalanche occurred. Meanwhile, Kirsti quickly splinted Tully’s leg, comforted him the best she could, and then descended to find me. About a half hour after the avalanche occurred, Kirsti and I discussed that Mike was probably dead and that we needed to focus on getting Tully out. Since we were close to town, we decided that Kirsti should go down and get help while I continued shoveling. Kirsti called 911 and then contacted the local heli-ski operation, Points North. Using their helicopter, Tully was airlifted to a waiting ambulance about an hour and a half after the avalanche. A crew of shovelers was dropped off at Mike about two hours after the avalanche. It took us another hour to get to Mike, and another hour after that to get him out, four hours after the avalanche occurred. He had traveled about 300 vertical meters. He was buried 4m deep with his torso wrapped around a 25cm diameter tree. It was obvious that he died from trauma. The crown was 1.5-4m in depth and 150-200m wide. The debris traveled almost 500 vertical meters. We categorized its size as R4 D4.

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