Recycled Powder and Other Types of Near-Surface Faceting:

Sometimes Today's Great Skiing Creates Tomorrow's Avalanche Headache

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You've seen it before...the snow falls and the skiing is decent, but not quite up to your high standards. You give this snow maybe a 5 out of 10 on your personal powder scale. Clear, cold weather follows the storm and a few days later you venture to one of your favorite backcountry powder stashes and, despite the fact that no new snow has fallen, the skiing has improved substantially. The surface snow is less cohesive and maybe a bit noisy. It might not be that 4% density, waist deep, choking-back-the-flakes, snorkel-wearing powder, but the skiing quality has inched up to an 8 on your powder scale. As long as the clear weather lasts and the temperatures stay cool, you find stash after stash of this "recycled" or "loud" powder on protected slopes. However, when the next storm rolls in and buries the layer that gave you such good skiing you've got a new problem. The interface between the new and old snow is especially sensitive and avalanche conditions remain particularly unstable for week or more, even though no surface hoar or other blatantly obvious weakness existed...just a layer of small-grained faceted crystals. What is going on?

Recently in Montana we've been trying to better understand processes that affect the snow surface, and therefore affect future avalanche conditions. An analysis of fracture line profiles gathered since 1990 throughout southwest Montana shows that small grained faceted crystals formed near the snow surface comprised almost 60% of the weak layers observed (Birkeland and others, 1996; Birkeland, 1998). These layers are obviously major players in our snowpack even though they have not received the attention of more widely studied weak layers such as depth hoar and surface hoar.

We have begun calling snow that becomes faceted in the upper part of the snowpack *near-surface faceted crystals*. Field observations and a review of the available literature indicate that three main processes result in the formation of near-surface faceted crystals, and the purpose of this article is to quickly outline those processes and to suggest terminology. Don't forget that these processes, like everything going on in the snowpack, are hard to compartmentalize. They sometimes take place in complex combinations, which make it difficult for an observer to pick out the exact process that created a specific layer. However, I separate the three processes for clarity. Finally, this article is a summary of a paper recently published in *Arctic and Alpine Research* (Birkeland, 1998), and interested readers are encouraged to check out the complete article. If you don't have access to a library, contact me to get a copy.

Strong near-surface temperature gradients are required to form near-surface faceted crystals. Typically these gradients are extreme, with values up to 200 C/m (i.e., Fukuzawa and Akitaya, 1993; Birkeland and others, 1998). Since upper snowpack layers are often low density, these gradients can quickly metamorphose surface layers into faceted crystals. The three main processes identified are termed *radiation recrystallization*, *melt-layer recrystallization*, and *diurnal recrystallization*, and their characteristics are summarized in Table 1.

Radiation recrystallization

Radiation recrystallization has been well documented in the San Juan Mountains of southwestern Colorado. This term, first coined by LaChapelle (1970) and later discussed in detail by Armstrong (1985), has found its way into the popular avalanche literature. This process occurs preferentially at high elevations and low latitudes on southerly aspects. In essence, on clear days incoming solar radiation is absorbed just under the snow surface, warming (or perhaps melting) the snow immediately below the surface (Figure 1). Concurrently, the surface itself is cooled by longwave radiation losses, resulting in extremely high temperature gradients and significant faceting that can occur within hours (Armstrong, 1985). The end result is a thin layer of faceted crystals, often on top of a melt-freeze crust. With a weak layer and bed surface in place, subsequent snowfall quickly creates dangerous conditions, and this process is a significant contributor to avalanche formation in the San Juans (LaChapelle and Armstrong, 1977; Armstrong, 1985). We have also observed radiation recrystallization in southwest Montana, though it is not as common as in southwest Colorado.

Melt-layer Recrystallization

Melt-layer recrystallization is a second process that forms near-surface faceted crystals. In this process either rain or sun forms a melt-layer. While the melt-layer is still wet, new snow falls on top of it, thereby creating a strong temperature gradient between the relatively warm (0° C) melt-layer and the colder snow on top of it (Figure 2). The process is facilitated if the new snow layer is thin and is followed by a clear night, and temperature gradients can approach 200 C/m (Fukuzawa and Akitaya, 1993). This process also results in a layer of weak faceted crystals overlaying a strong bed surface, and the deposition of new or windblown snow can rapidly result in dangerous avalanche conditions. Melt-layer recrystallization has been documented in both Japan (Fukuzawa and Akitaya, 1993) and Canada (Jamieson, 1997), and has been observed by many avalanche workers throughout the western U.S. We have observed it occasionally in southwest Montana.

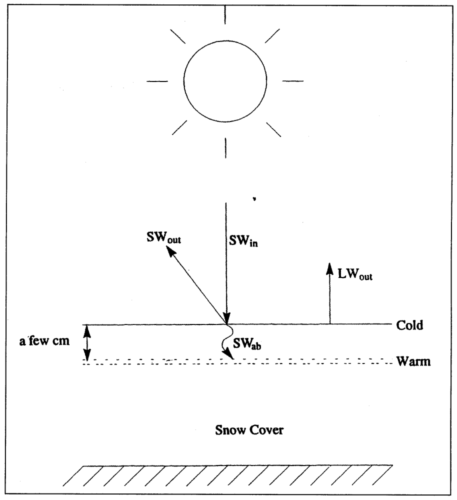


FIGURE 1. Radiation recrystallization occurs preferentially on southerly (southeast to southwest) aspects in response to a delicate balance between incoming and outgoing radiation. When incoming shortwave radiation (SWin) reaches the snow surface, most is reflected (SWout). Some shortwave radiation is absorbed (SWab), however, and warms the subsurface snow, sometimes creating a melt-layer. Meanwhile, outgoing longwave radiation (LWout) cools the snow surface, resulting in a strong temperature gradient between the warm subsurface snow and the cooler snow surface, and the formation of near-surface faceted crystals (from Birkeland, 1998).

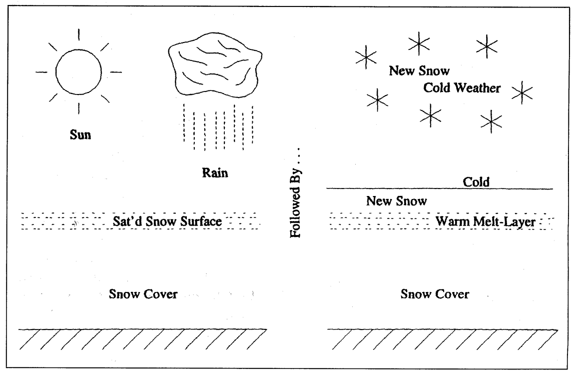


FIGURE 2. Melt-layer recrystallization occurs after rain or warm weather raises the temperature of the snow surface to the melting point. If this warm surface is subsequently buried by new snow as temperatures drop, a strong temperature gradient forms between the relatively warm melt-layer and the colder new snow, resulting in the formation of near-surface faceted crystals. This process is enhanced if the new snow layer is thin and has a low-density, and if the new snow is followed by a cold, clear night (from Birkeland, 1998).

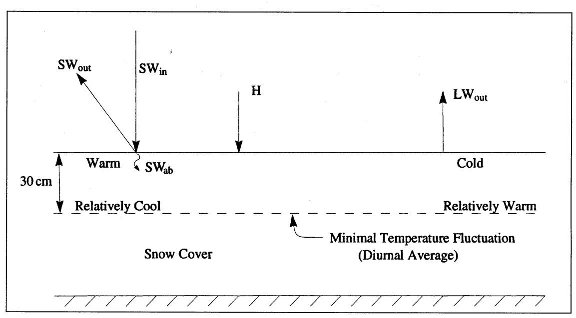
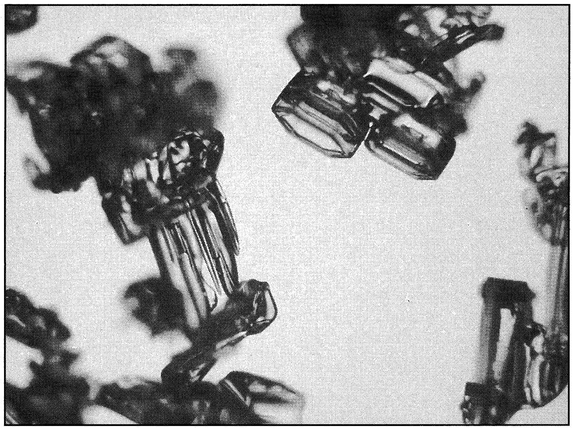
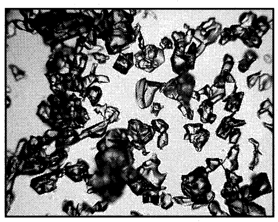


FIGURE 3. Diurnal recrystallization occurs in mid-latitude mountains when cold, clear nights alternate with warm days. While the temperature 0.30 m below the snow surface remains relatively constant, snow surface temperatures change dramatically in response to changes in the diurnal surface energy balance. The surface becomes extremely cold at night (largely in response to longwave radiation losses (LWout)) and warms during the day (primarily due to incoming sensible heat (H) and some absorbed shortwave radiation (SWabs)). The end result is strong negative temperature gradients at night, followed by strong positive temperature gradients during the day, resulting in the formation of near-surface faceted crystals (from Birkeland, 1998).



Diurnal Recrystallization

A third and perhaps more widespread process is termed *diurnal recrystallization*. The Diurnal simply means that the process has a daily cycle, and this is the process responsible for improving the skiing and causing the formation of that "recycled powder" discussed at the beginning of this article. I first began looking at layers formed by diurnal recrystallization while working as a ski patroller in Utah after reading a couple short papers by John Stratton on what he termed "Upper Level Temperature Gradient Snow" (Stratton, 1977). This process is also discussed by Ed LaChapelle in his *Field Guide to Snow Crystals* (LaChapelle, 1969); he calls the resultant crystals true powder snow, and remarks on the improved skiing conditions they provide, though he does not comment on their contribution to avalanche formation. Check out page 68 of the *Field Guide to Snow Crystals* for his description of the process and page 70 for a photograph of some near-surface faceted crystals.



Near-surface facet crystals
Photos by Joseph Stock

Diurnal recrystallization results from a combination of the insulative properties of the snowpack and the rapidly changing snow surface temperatures that take place on a daily basis. Since the snowpack is an excellent insulator, daily temperature changes typically only affect about the upper 0.30 m of the snowpack. Thus, the snow temperature at 0.30 m represents something of a "diurnal average" temperature. Meanwhile, temperatures at the snow surface may vary radically, especially during clear weather when warm sunny day alternate with clear cold nights (Figure 3). Resulting temperature gradients are negative at night and positive during the day, and may exceed 200 C/m (Fukuzawa and Akitaya, 1993; Birkeland and others, 1996; Birkeland and others, 1998). These conditions can rapidly create a layers of small-grained faceted crystals with a variety of forms (Table 1). Once buried, these layers create dangerous and persistent weaknesses in Montana's snowpack (Birkeland and others, 1998), and their contribution to avalanching has also been noted in Switzerland (Fierz, in press) and Japan (Fukuzawa and Akitaya, 1993).

TABLE 1: Characteristics of three types of near-surface faceted crystal formation (from Birkeland, 1998)

	Radiation Recrystallization	Melt-layer Recrystallization	Diurnal Recrystallization
Unique conditions	Precise balance between incoming shortwave and outgoing longwave radiation	Combination of a relatively warm old snow surface and a subsequent cold snowfall	Not a surface or boundary interface phenomenon, can involve 0.10 to 0.15 m of snow thickness, bi-directional gradient
Source/sink of temperature gradient	*Source*: incoming shortwave radiation warms the subsurface snow *Sink*: snow surface cools due to longwave radiation losses	*Source*: melt-layer formed by incoming shortwave radiation or rain *Sink*: cold snow deposited on the melt layer	*Source*: relatively warm subsurface snow (night) or snow surface (day) *Sink*: relatively cold snow surface (night) or subsurface snow (day)
Direction of temperature gradient	Negative (uni-directional)	Negative (unidirectional)	Negative at night and positive during the day (bi-directional)
Crystal forms typically observed	Small faceted grains (ICSSG* Class 4fa, 4sf, or 5cp)	Small faceted grains (ICSSG* Class 4fa, 4sf or 5cp)	Small faceted grains (ICSSG* Class 4fa, 4sf or 5cp), stellar arms with facets (intermediate between Class 4sf and 2dc), long needle-like grains with faceted ends (like Akitaya's (1974) depth hoar needles)
Location found	Southerly aspects	Southerly aspects when the melt layer is caused by sun, all aspects when the melt layer is due to rain	All aspects and elevations
References	LaChapelle (1970); LaChapelle and Armstrong (1979), Armstrong (1985)	Fukuzawa and Akitaya (1993); Jamieson (1997)	Stratton (1977); Fukuzawa and Akitaya (1993); Fierz (in press); Birkeland and others (1998)

* International Classification for Seasonal Snow on the Ground (Colbeck et al., 1990)

Summary

Near-surface faceted crystals create undeniably dangerous weak layers in many regions, and understanding the processes that form them is helpful for anticipating future avalanche problems, and how long those problems might last. I encourage using the terminology set forth in this article as a starting point for facilitating communication about near-surface faceted crystals among avalanche workers, avalanche scientists, and the public. Recognizing the conditions responsible for near-surface faceting has added valuable information to our snowpack analyses, and improved our avalanche forecasting in southwest Montana.

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