Between a slab and a hard layer:

Part 3 - Two field studies of facets growing above wet layers

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1. Introduction

Poorly bonded crusts can release dry slab avalanches weeks or occasionally months after facets form on the buried crust. One way that facets on crust can originate involves a strong temperature gradient when dry snow overlies a wet layer (e.g. Jameson and others, 2001; Colbeck and Jamieson, 2001). The first article in this series (Avalanche News 70) focused on the formation of poorly bonded crusts and their distribution over terrain. The second article (Avalanche News 71) summarized field data from the Columbia Mountains regarding the persistence of facets and surface hoar above melt-freeze crusts. This third and final article describes two field studies of facets that formed above wet layers – and became poorly bonded crusts. These results were presented at the International Snow Science Workshop in Jackson Hole, Wyoming.

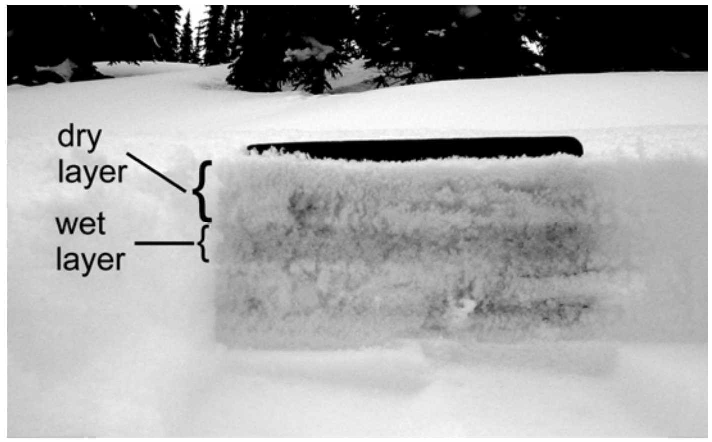

Fig. 1. Photograph of a pit wall of the upper snowpack showing the wet layer and overlying dry snow on 14 March 2003 on Mt. Fidelity.

Fig. 2. Photograph showing three vertically oriented pairs of thermistors that were placed in wet snow before dry snow fell. Only the top thermistor of each pair is visible above the dry snow. The thermistors are connected to a datalogger in the white box that reads each temperature every two minutes and records the average temperature of each thermistor every hour.

In the winter of 2002-03 on Mt. Fidelity, and again in 2003-04 on Mt. St. Anne, we monitored cases of dry-on-wet faceting (Fig. 1) and the evolution of the resulting facets on crusts. For each of these cases, the measurement sites were near automated weather stations at approximately 1900 m that provide hourly measures of temperature and precipitation. The temperature gradient across the dry layer was measured with thermistors (Fig. 2) calibrated to ±0.1°C and recorded hourly with a datalogger. Manual snow profiles were observed several times within a week. By pulling a 250 cm^2 shear frame placed a few millimetres above the wet layer or crust (Fig. 3), the shear strength was measured (e.g. Perla and Beck, 1983) and adjusted for size effects (Sommerfeld, 1980).

2. Wet layer buried 2003-03-14 at Mt. Fidelity

On 2003-03-14, dry snow fell on a wet layer at 1890 m elevation on Mt. Fidelity. At 1300 h with light snow falling at –2.5°C, we observed 3.5 cm of dry new snow (PP) on a 1.8 cm thick wet layer (Fig. 1). A pair of thermistors was placed across the dry layer. Overnight the air temperature approximately 2 cm above the snow surface cooled to –4°C and the magnitude of the temperature gradient across the dry layer reached 59°C/m at 2100 h. Data from an upward-facing long wave radiometer approximately 200 m from the study site indicate the sky remained overcast overnight except from 0300 to 0500 h. The upper boundary of the wet layer froze at 0200 h on 2003-03-15. At 0900 h, the crystals just above the crust and 2 cm above the crust were FC 1, and DF 1 FC 0.5-1, respectively, indicating the faceting was more advanced just above the crust. On 17 March 2003, the crystals just above the crust were observed to be FC 0.5-1 indicating that no further faceting was apparent. In subsequent observations on 17, 18 and 22 March 2003, the crystals just above the crust showed evidence of rounding (Fig. 4).

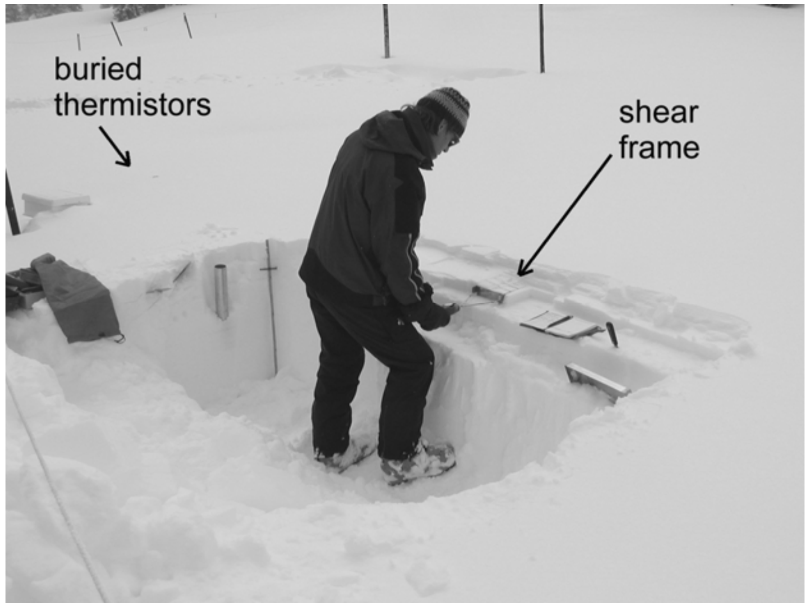

Fig. 3. Photograph of operator performing a shear frame test on a layer of facets on a crust. The bottom of frame is placed a few millimetres above the facet-crust interface and pulled to fracture within a second. The layer being tested was buried 2004-01-15 at Mt. St. Anne.

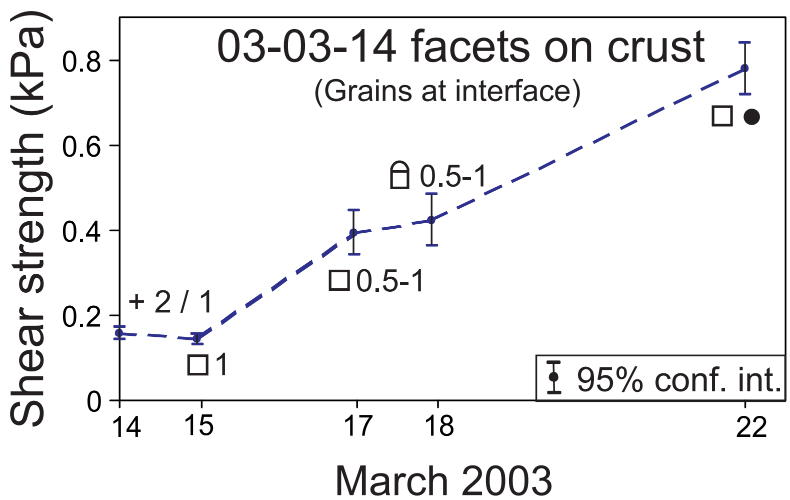

Fig. 4. Change in shear strength and type of grains just above the wet layer (later a crust) buried on 2003-03-14 on Mt. Fidelity in the Columbia Mountains.

For the grains at the interface, the mean of 12 shear strength tests on each of the observation dates is plotted in Figure 4. The strength change from 14 to 15 March was statistically insignificant. The expected strength gain given the warm snow temperature favourable to densification and bonding (0°C then cooling to –4°C after the wet layer froze) did not occur probably because the strong temperature gradient caused faceting of the crystals just above the wet layer. As with many other cases of small faceted crystals (e.g. 0.5 mm) we have observed, this layer gained strength quickly. At Glacier National Park and at nearby backcountry ski operations, no slab avalanches were reported on this weak layer. On 19 February 2003 at a site 50 m lower and about 250 m south of the 1890 m study slope, a snow profile showed 1 mm rounded facets (FCmx) on a 1.2 cm thick crust, indicating that the facets-on-crust existed outside the study slope, at least within a narrow elevation band.

3. Wet layer buried 2004-01-15 at Mt. St. Anne

During the night of 2004-01-14, light rain was reported at lower elevations in the mountains near Mt. St. Anne. At 1200 h on 2004-01-15 (Fig. 5) at 1600 m elevation on Mt. St. Anne, 4 cm of dry new snow (PP) had accumulated over about 5 hours on a 6-cm-thick layer of rain wetted (moist) snow classified as Wet grains (WGcl). The air temperature was 1°C, snow was falling at 2 cm per hour and the sky was obscured by fog. Four thermistors were positioned similarly to the placements in shown Figure 2. Initially, the upper thermistor was about 3.5 cm above the snow surface. The shear strength of the dry snow just above the moist snow was 0.36 kPa (Fig. 5). The moist layer had a hand hardness of 4-Fingers (4F). According to readings from an ultrasonic snow depth sensor at 1900 m on the same mountain, the upper thermistor was buried by 1600 h.

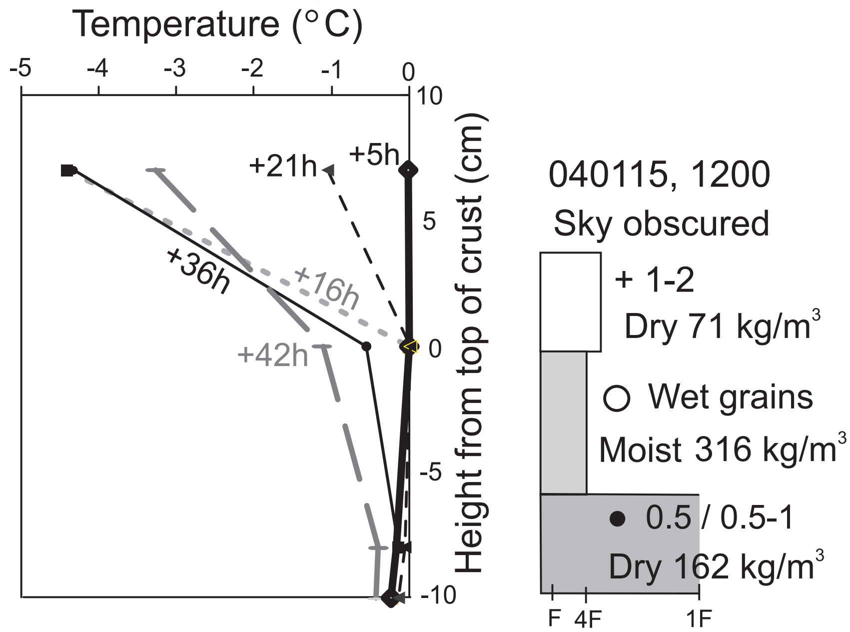

Fig. 5. Graph of five different temperature profiles taken from the hourly profiles of the dry-on-wet interface buried 2004-01-15 at 1600 m on Mt. St. Anne.

At midnight, 16 h after the wet layer was buried by dry snow, the magnitude of the temperature gradient between the top two thermistors spanning most of the dry layer was 63°C/m. Three hours later, the magnitude of the temperature gradient in the dry layer reached a maximum of 91°C/m. The top of the initially moist layer froze between 21 h (Fig. 5) and 26 h after burial by dry snow.

The next day at 1000 h (about 27 h after the start of dry snowfall on the rain-wetted layer), the air temperature was –2°C, snowfall had stopped and the sky remained obscured by fog. The upper 3.5 cm of the initially moist layer had frozen and was a Pencil-hard (P) crust. The grains at the interface were classified as decomposed and fragmented particles (DF) and faceted crystals (FC). Shear frame tests revealed a 50% drop in shear strength (Fig. 6), which we attribute partly due to the formation of facets at the interface and partly to a shear stress concentration resulting from freezing wet layer and consequent stiffening of the crust.

At the site of thermistors, profiles and shear frame tests (elevation 1600 m) on 2004-01-17 at 1100 h, 7 cm of dry snow lay on the initially moist layer that had now frozen into a knife-hard (K) crust. The dominant grain type in the 2-mm-thick layer on top of the crust was facets (FCfa), overlain by decomposed and fragmented particles. Shear frame tests showed a slight increase in the mean shear strength. Observations and tests on this layer on 20 and 23 January showed rounding of the grains at the interface and substantial increases in strength (Fig. 6).

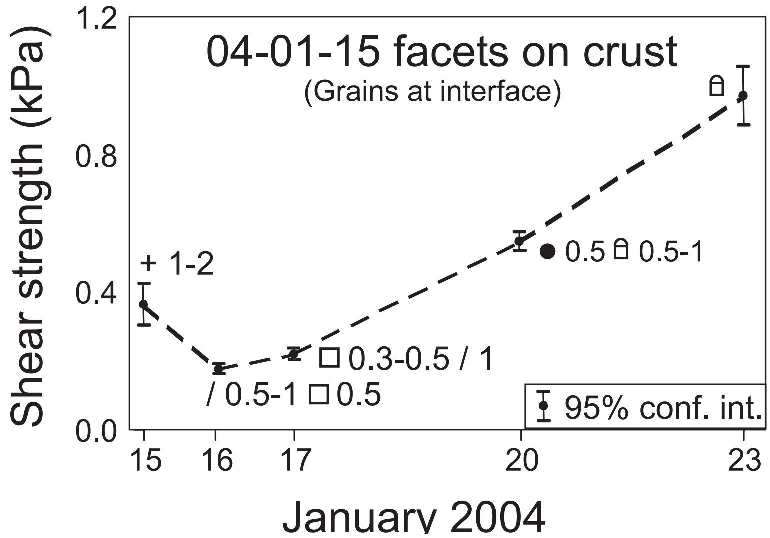

Fig. 6. Change in shear strength and type of grains at the upper boundary of the wet layer (later a crust) buried on 2004-01-15 on Mt. St. Anne in the Columbia Mountains.

On 2004-01-16, the crust was found in a profile on Mt. St. Anne at 1900 m but it was only 1.6 cm thick—much thinner than at 1600 m. No facets were found on the crust, probably because there was insufficient latent heat in the initially moist layer to sustain the temperature gradient in the overlying dry snow. These observations at 1600 and 1900 m apparently bound the minimum conditions for forming a weak layer of facets.

On 2004-01-21, profiles 10 km to the south-southwest at 1745 m and 1905 m revealed the crust, 2 cm and 0.2 cm thick, respectively, but no facets were found on the crust at these elevations. We attribute the thinner crust and the absence of facets to less rain on the night of 2004-01-14 at these elevations and hence less latent heat to sustain the temperature gradient in the overlying dry snow. Two kilometres to the west and 100 m lower, the rain crust and the overlying facets were more developed. Between 2004-02-06 and 2004-02-12 (23 to 29 days after the wet layer was buried), we observed a total of five profiles, 37 rutschblock and 12 compression tests. The facet layer produced fractures in all these tests. The median rutschblock score was 4 and the average compression score was moderate (19 taps). As further evidence of the instability at this elevation, while traveling on skis, we triggered two whumpfs where the faceted layer fractured but the slab only moved a few centimetres down-slope. Compared to the site of the thermistors and shear strength measurements located 100 m higher on the mountain, the profiles revealed a thicker layer (1-1.5 cm) of larger facets (1-2 mm) on a thicker rain crust (> 10 cm) that was, by this date, 52 to 72 cm below the snow surface. Clearly, the facets on the rain crust were more developed and less stable for longer at a slightly lower elevation where more rain created a thicker wet layer with more latent heat to sustain the temperature gradient in the overlying snow for longer.

4. Conclusions

The magnitude of the temperature gradient at a dry-over-wet interface can exceed 50°C/m for hours while heat is drawn upwards towards the cooler surface of the snow. Facets can form within a day at the interface where dry snow overlies wet snow and the snow surface temperature is below 0°C.

As outlined in Avalanche News 70 and described in Section 3, facets that form in dry snow on a wet layer can be better developed – resulting in a weak bond to a crust – within an elevation band, Facets can continue to grow after the wet layer freezes (Jamieson and Fierz, in press); the relatively small area of bonds between facets and the tendency of facet layers to resist densification can contribute to additional faceting.

As noted in the first article in this series, facets that form at the base of dry snow overlying wet layers form an important portion of the facet-on-crust combinations in the Columbia Mountains. These include poorly bonded rain crusts in early and late winter and poorly bonded sun crusts in March and April.

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