The Facet Layer of November 1996 in Western Canada

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Introduction

In November 1996, a layer of faceted crystals formed on a crust throughout much of the Rocky Mountains, Columbia Mountains and Coast Mountains of Western Canada. Unfortunately, the "November facets" formed the failure planes for avalanche accidents in all three ranges. This faceted layer stabilized in many areas by early January 1997—except in a few areas such as the North Columbia Mountains where it released numerous large and often destructive slab avalanches throughout the winter.

In this paper, we summarize the November weather in two areas of the Coast Mountains near Whistler and in the North and South Columbia Mountains. Based on the weather records, we propose that the facets were weaker and slower to stabilize in areas that had less snow on the crust during the cold period from November 13 to 23rd. Also, we outline two ways in which a underlying crust can contribute to the formation of facets and instability.

Based on the shear strength, load, temperature and temperature gradient of the facets at Mt. St. Anne in the North Columbia Mountains, we discuss strength changes and two shear frame stability indices.

Weather of November 1996 in the Coast Mountains near Whistler

From November 8th to 12th air temperatures at the Blowdown Mid weather station at 1890 m in the Cayoosh Mountains along the Duffy lake Road reached well above freezing (Fig. 1). Rain fell to ridgetops. With the advancing arctic air, temperatures dropped on November 13th forming a widespread crust. Temperatures remained well below normal until November 23rd. At 1550 m on Blackcomb Mountain, temperatures were 2-3 degrees higher during the 10-day cold period than at Blowdown.

During this cold period from November 13 to 23, an estimated 90 cm of snow fell at 1550 m on Blackcomb Mountain while only 28 mm of precipitation fell at Blowdown Mid. Although temperatures at the two sites were similar, more faceting occurred in the thinner layer of dry snow above the crust at Blowdown than further west near the where the snow above the crust was roughly twice as thick (S. Aitken, personal communication).

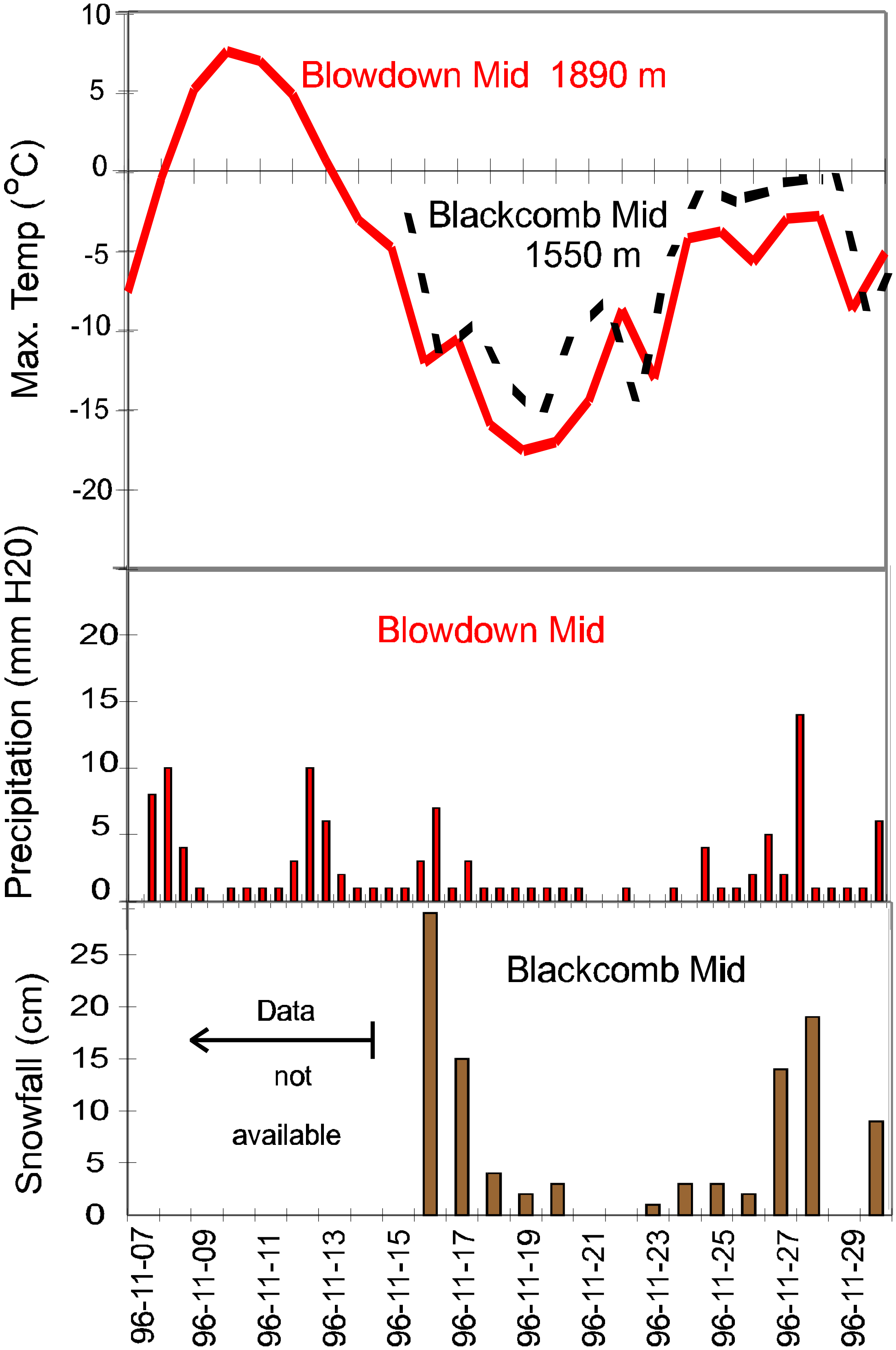

Figure 1 November 1996 weather from Blowdown Mid station in the Cayoosh Mountains and Blackcomb Mid station in the Outer Coast Range.

Stability of the November Facets in the Coast Mountains near Whistler

In the Cayoosh Mountains along the Duffy Lake Road, a major avalanche cycle on December 8th removed the facets from many slide paths. However, the November facets remained unstable in shallower areas not affected by this cycle. Subsequently, occasional dry slab avalanches ran on the November facets as late as March 10th.

In the heavier snowfall area of the Outer Coast Range near Blackcomb where the facets on the crust were less developed, the faceted layer stabilized by the middle of January 1997.

Two factors probably contributed to the November facets stabilizing faster near in the Outer Coast Range near Blackcomb than in the Cayoosh Mountains along the Duffy Lake Road:

- In the Outer Coast Range, the thicker layer of dry snow above the crust resulted in less temperature gradient and less faceting compared to the Cayoosh Mountains where less snow was on the crust during the 10-day cold period.
- The Outer Coast Range usually receives more snow than the Cayoosh Mountains and greater load usually contributes to gradual strengthening of buried weak layers.

Weather of November 1996 in the Columbia Mountains

For November 7 to 30th, maximum air temperatures from two weather stations in the South Columbia mountains (Stagleap, 1780 m, at Kootenay Pass and Galena Pass, 1570 m) and two in the North Columbia Mountains (Fred Laing, 1080 m, near Mica Creek and Mt. St. Anne, 1900 m near Blue River) are plotted in Figure 2 along with precipitation data from Fred Laing and Galena stations.

The temperature reached above 0°C at Stagleap and Fred Laing during heavy precipitation on November 8th, although Kootenay Pass below the Stagleap station received snow rather than rain. From November 9th to the morning of the 13th all stations reported maximum temperatures above freezing, with 5-10 mm of precipitation per day. Rain fell in many areas of the Columbia and Mountains.

Maximum temperatures dropped below freezing at all four stations on the 13th or 14th as arctic air spread over BC. This cold air mass kept temperatures below normal for 10 days. From November 17th to 19th the Fred Laing station in the North Columbia Mountains was several degrees colder than Stagleap and Galena in the South Columbia Mountains. Mt. St. Anne in the North Columbia Mountains was often 5-8 degrees colder than the two stations in the South Columbia Mountains from November 16th to 22nd.

During the cold weather from November 13th to 26, the North and South Columbia Mountains received different amounts of precipitation. Fred Laing and Mt. St. Anne in the North Columbia Mountains received 32 and approximately 40 mm of precipitation, while Galena and Stagleap in the South Columbia Mountains received approximately twice as much, 60 and 87 mm, respectively. In particular, Kootenay Pass received 121 cm of snow! Clearly, there was substantially more snow on top of the crust in the South Columbias than farther north.

Consequently, the temperature gradient in the snow above the crust would have been roughly twice as high in the North Columbias than farther south. As a result of the greater temperature gradient in the North Columbia Mountains, the snow above the crust became more faceted than in the South Columbia Mountains.

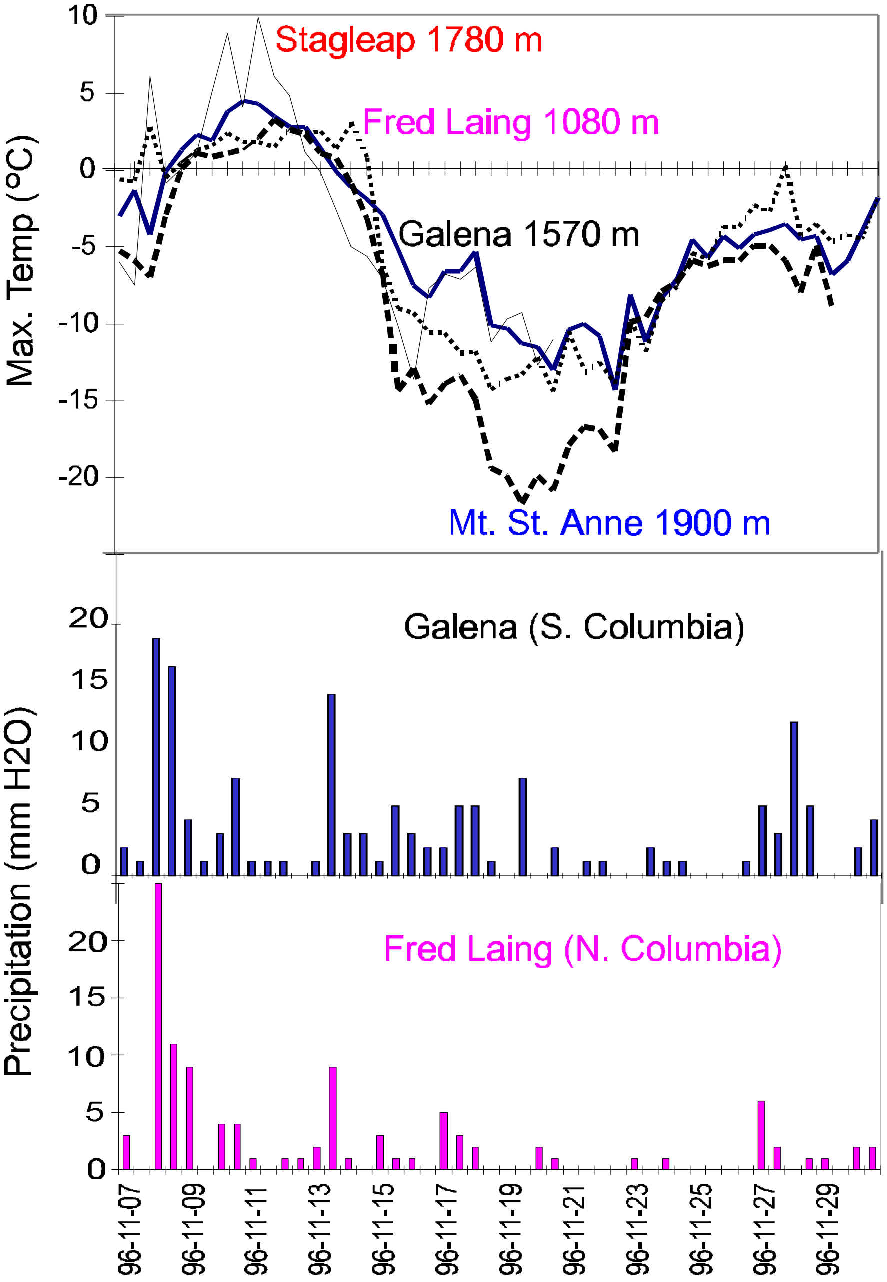

Figure 2 Weather from November 1996 at Stagleap and Galena stations in the South Columbia Mountains and Fred Laing and Mt. St. Anne in the North Columbia Mountains.

Effects of Crusts on Faceting

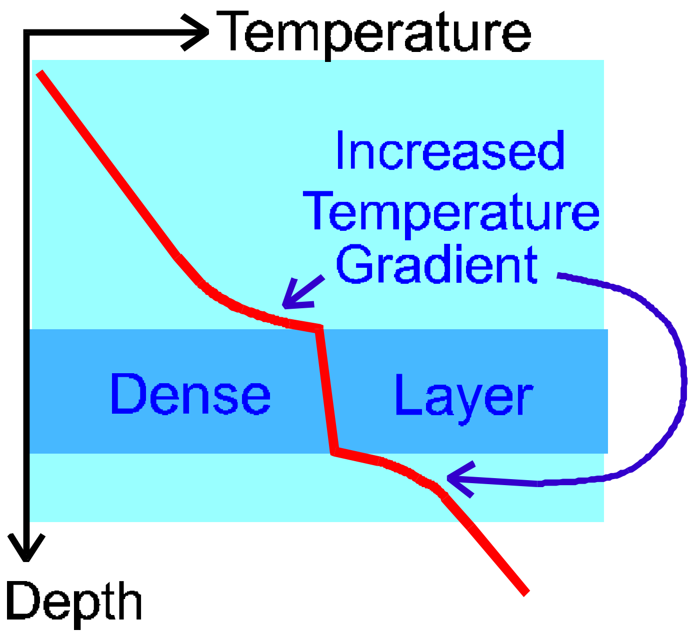

Figure 3 Effect of dense layers such as crusts on temperature gradient (after Colbeck, 1991)

Dense layers such as crusts tend to increase the temperature gradient (Fig. 3) just above and below the crust (Colbeck, 1991). Although this increase in the temperature gradient is often too close to the crust to be easily measured, it explains the observations of facets just above and below crusts when the major layers above and below the crust show no evidence of faceting (Moore, 1982).

As a result of rain or air temperatures above freezing from November 9th to 13th, a surface layer of wet snow formed. Due to warmer temperatures at lower elevations, this layer of wet snow was thicker at, and below, tree line than at higher elevations. This layer of wet snow was buried by cold dry snow on about November 13th, 1996 and froze over time to form a crust. In many areas, cold temperatures in the following 10 days caused faceting in the snow above the crust.

In the following months, many guides and avalanche workers reported that the facets on the crust were more developed and weaker at, and below, tree line. This is likely a consequence of three factors:

- During the cold weather, there was less snow above the crust at lower elevations and consequently a stronger temperature gradient.
- Cold air may have pooled in valleys causing stronger temperature gradients at lower elevations.
- The layer of wet snow would be thicker—and perhaps wetter—at lower elevations. Because of its stored heat and latent heat, the thicker layer of wet snow at lower elevations would remain at 0°C longer when the arctic air arrived and be slower to cool after it froze. Consequently, the temperature gradient would be greater and faceting would be increased compared to higher elevations where the layer of wet snow/crust would likely be thinner (Fig. 4).

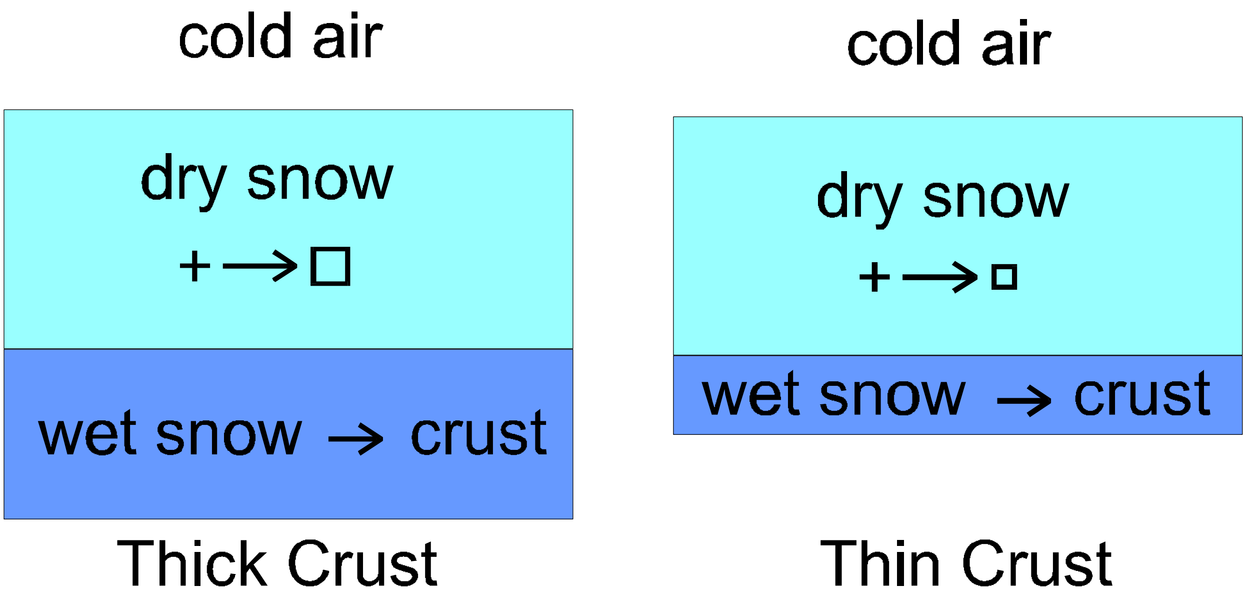

Figure 4 When dry snow and cold air overlie a layer of wet snow, the dry snow is likely to become faceted. The dry snow above the thicker layer of wet snow on the left is likely to become more faceted than the dry snow above the thinner layer of wet snow on the right.

Changes in Layer of Facets at Mt. St. Anne over Winter of 1996

At 1900 m on Mt. St. Anne, the shear strength of the November facets was measured with a 250 cm^2 shear frame about once a week from Dec. 11, 1996 to March 21, 1997. As shown in Figure 5, the shear strength increased from 1.5 to 8.4 kPa while the load increased from 160 to 910 mm of water, the temperature of the facets increased from -3.5 to -2.0°C and the temperature gradient decreased from 0.8°C/10 cm to 0.1°C/10 cm. The relatively warm temperature of the facets (> -5°C), the low temperature gradient (< 1°C/10 cm) and the heavy and increasing load all favour strengthening of the facets, which we measured.

While the November facets gained considerable strength during the winter, the large natural avalanches that slid on the November crust in the North Columbia mountains (most of which occurred during warming or snowstorms) indicates the facets never fully stabilized. In comparison to many other layers of facets in the Columbia Mountains, the 2 mm facets from November 1996 were well developed in the North Columbia Mountains, a factor which may have slowed stabilization. Also, shear due to creep would have been concentrated where the facets met the harder crust. Clearly, the avalanche activity indicates that the layer did not gain strength fast enough to support the increasing load and resist the changes in creep caused by warming. Our current understanding of snow metamorphism and field techniques for measuring snowpack properties do not allow us to quantitatively explain why the layer did not stabilize.

From the shear frame measurements, we calculated two stability indices: the Stability Ratio, SF, (Schleiss and Schleiss, 1970; CAA, 1995) and RBcalc. However, neither index has, to our knowledge, been used for slabs as deep as those that failed in the November facets in the North Columbia mountains—many of which were more than 2 m thick. Schleiss and Schleiss (1970) proposed SF for “new” snow, and our experience with the shear frame stability index, RBcalc, is primarily within the top 1 m of the snowpack. Nevertheless we plot SF and RBcalc in Figure 6 to assess the suitability of such indices for deep weak layers.

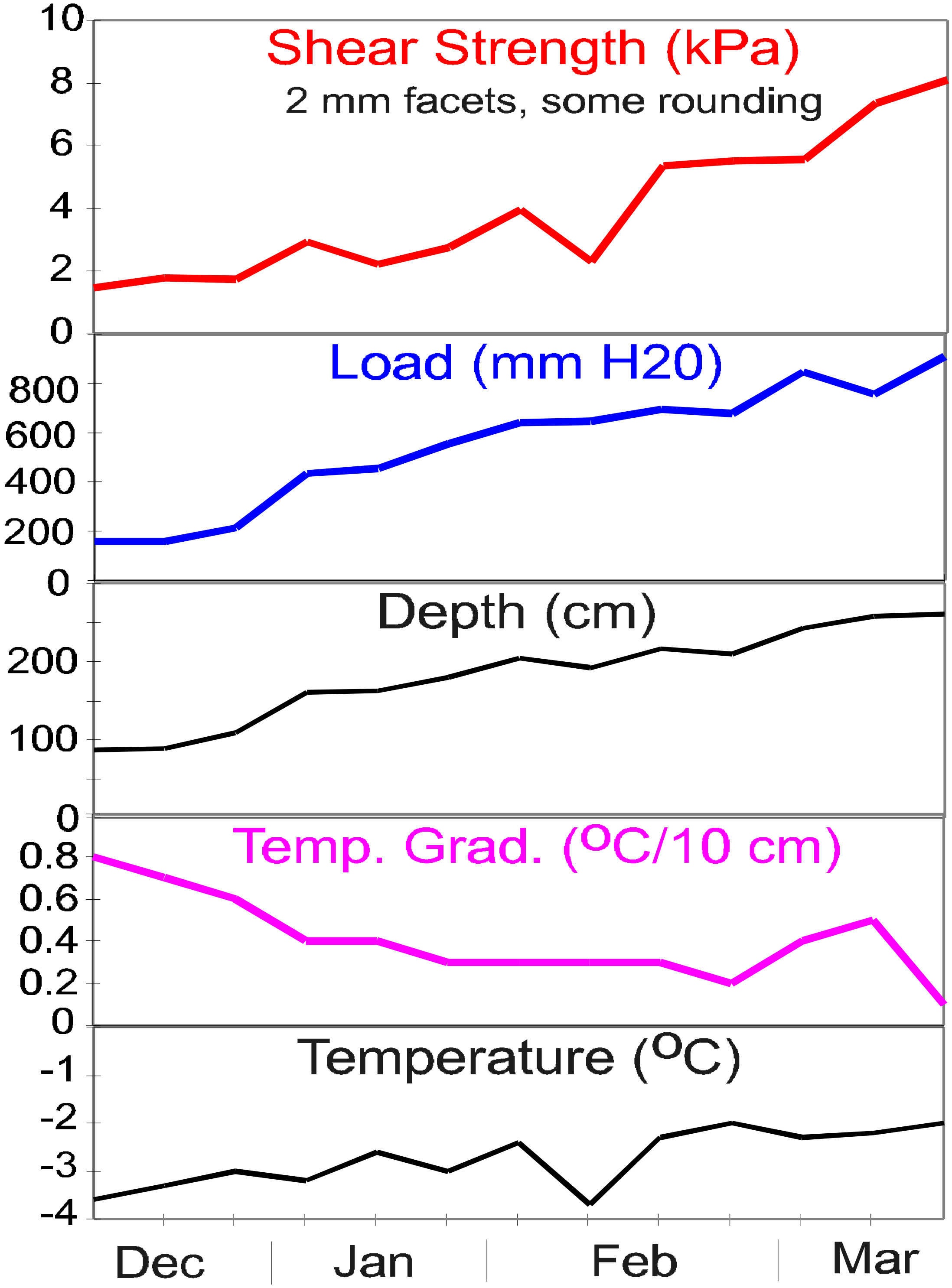

Figure 5 Measurements of the November facets at Mt. St. Anne in the North Columbia Mountains during the winter of 1996-97.

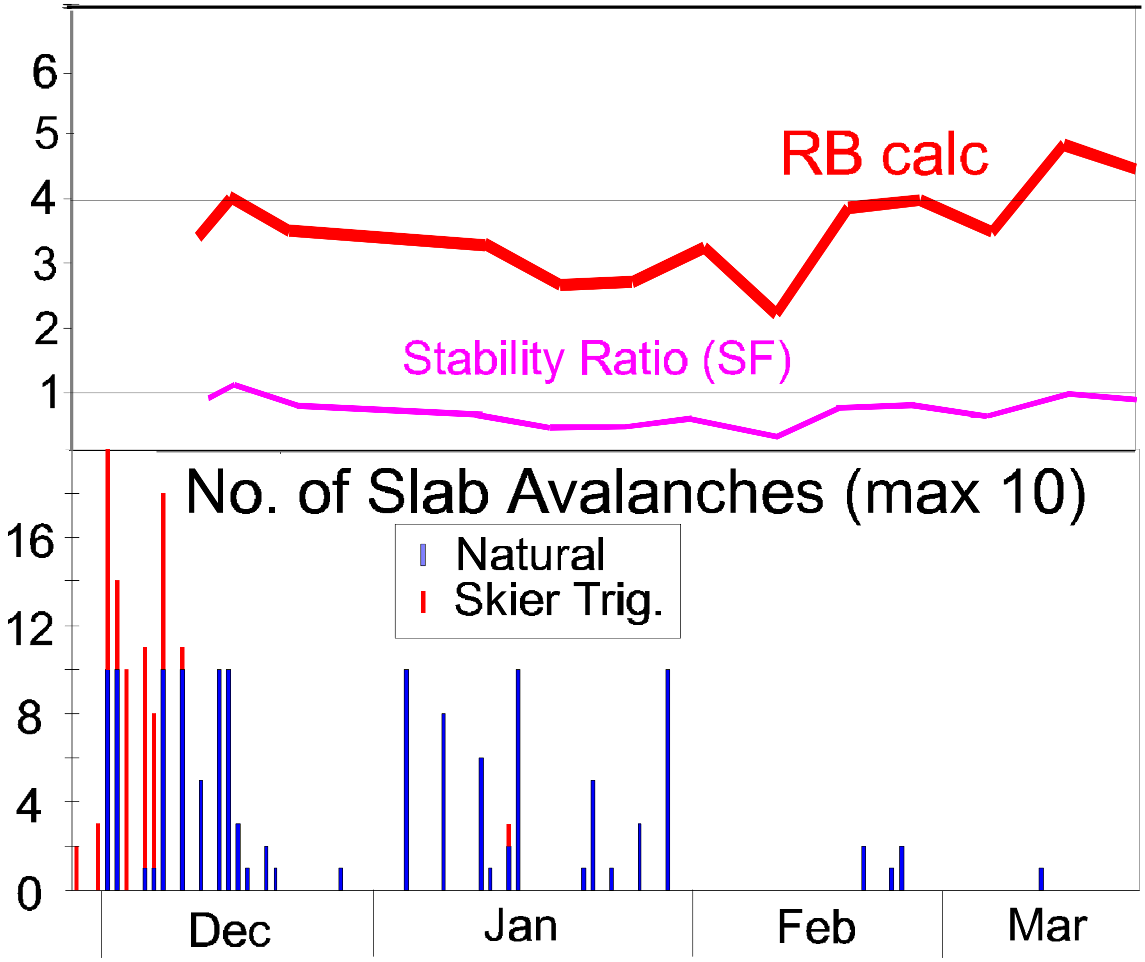

Figure 6 Stability indices for the November facets at Mt. St. Anne in the Cariboo Mountains and number of dry slab avalanches that slid on the November facets in the surrounding Cariboos and Monashees..

For new (storm) snow, SF < 1, suggests instability and values between 1 and 1.5 suggest transitional stability. Most avalanches occurred while SF < 1. However, there are many days in which SF < 1 and no avalanches failed on the November facets indicating the index underestimates the stability.

For skier triggered slabs within the top metre of the snowpack, RBcalc < 4 suggests instability and values between 4 and 6 suggest transitional stability. While the November facets were being tested with the shear frame, most of the avalanches were naturals and occurred while RBcalc < 4. However, there are many days in which RBcalc < 4 and no avalanches failed on the November facets indicating the index underestimates the stability and may not prove useful for such deep weak layers.

Yet avalanche activity decreased in February and March when the indices approached their transitional values. This suggests that shear frame indices might be modified for such deep weak layers. Such a refined index could be occasionally useful since the November 1996 facet/crust combination was, like the November 1985 facet/crust combination, difficult to forecast (C. Israelson, personal communication).

Summary

The November facets were slower to stabilize in areas such as the North Columbia Mountains where less dry snow lay on the crust during the cold period from November 13th to 23rd. We expect the facets were more developed in such areas.

A dense layer such as a crust increases the temperature gradient just above and below the crust, sometimes causing facets to form next to the crust.

Cold snow on top of a thick layer of wet snow is more likely to become faceted than a similar amount of cold snow on top of a thinner wet layer. This probably contributed to the November facets being better developed and weaker at lower elevations than in the alpine.

The stiffness of a crust tends to concentrate shear at the top of the crust. In combination with a weak layer such as facets above the crust, this shear concentration contributes to instability.

Present shear frame stability indices do not appear well suited to a deep instability such as the November facets in the North Columbia Mountains. However, the indices were consistent with the lingering instability of the November facets..

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