**Persistent Weak Layers and the Winter of 2007-2008**

Prepared by: Karl Klassen
Avalanche Forecaster, Canadian Avalanche Centre

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If you have read the first version of this paper, nothing has changed except for this update. If you have not read this paper before, then you should read the whole thing, starting at the header "ORIGINAL PAPER FROM JANUARY 30TH" first and then read the update, which follows, last.

## FEBRUARY 27 UPDATE

### What's happening with the October, November, and December persistent weak layers?

All these layers have been dormant for an extended period of time. The odd isolated event involving the December 5th has been reported recently, usually involving a large trigger like a cornice or a smaller avalanche impacting a slope below. These slides, when they occur, have been large and destructive. It's likely that October 31st or November 24th was a player in a fatal size 3.5 (very large) avalanche in the Rockies that occurred February 18th. These are classic examples of a dormant deep slab/persistent weak layer instability: they're not particularly easy to trigger, the chance of triggering is low, the number of avalanches is few, but the size of avalanches that do occur is large and consequences of being caught are dire.

### What's new?

In addition to the facets on crust layers discussed in earlier versions of this paper, there are now two more persistent weak layers of concern in the 2007-2008 snowpack. These are January 26th and February 25th.

January 26th formed in the latter half of January during a clear, cold period that was windy at the outset then mostly calm for an extended time. Its characteristics are:

- Windcrust in wind exposed locations at and above treeline. Often there is a thin layer of facets on top of the crust. In some areas, surface hoar formed on these crusts instead of or in addition to the facets. (See below for an overview of surface hoar.)
- In wind sheltered areas, a layer of facets (up to 10-15cm thick), often with surface hoar on top.
- A thin suncrust on very steep, very sheltered, very sunny slopes. In some areas facets or surface hoar or both are found on top of the crust and facets may also exist below the crust.

January 26th is widely distributed and found in most locations throughout BC and Alberta.

February 25th formed in the middle of February during a clear, mostly calm, warm period. Its characteristics are:

- On moderate to steep, sheltered, sunny slopes: a suncrust of varying thickness. In some places, facets probably formed below the suncrust, more likely at higher elevations.
- At low elevations on all aspects: melt-freeze crusts from warm temperatures.
- On many colder, shaded slopes, especially at and above treeline: a layer of facets (up to 10-15cm thick).
- At all elevations and aspects: surface hoar. You'll find it in combination with the facets and crusts or as a discrete layer in locations where facets and crusts are not prominent. This surface hoar is generally larger at lower elevations. Some areas reported sizes to 140mm below treeline in areas sheltered from wind and sun. The surface hoar is generally smaller and/or deformed in wind- and sun-exposed slopes. Surface hoar may have been destroyed on slopes that experienced strong winds, very warm temperatures, or intense solar radiation just prior to the first snowfalls. However, skies were cloudy, temperatures cool, and winds calm in many areas the last day or two before Feb 25th was buried so I wouldn't bet the farm on the surface hoar being gone unless you have extensive local knowledge.

February 25th is widely distributed and found in most locations throughout BC and Alberta.

**Are Jan 26th and Feb 25th performers?**

January 26th was initially buried by several cold, dry, light snowfalls under calm conditions. For 7-10 days there was not enough load and/or slabs were not cohesive enough to create a widespread cycle on this layer. Eventually however, the overlying snow settled or was blown by wind into a slab and continuing snowfalls added enough load that January 26th began producing good sized avalanches. In many areas the cycle peaked around mid-February when a wind event triggered a round of large avalanches. Things died down for a few days and then another cycle occurred on this layer, initiated by warm temperatures and strong solar radiation. This solar induced cycle often involved cornice triggers and step-down avalanches (see following for more on this phenomenon), which gradually tapered off and ended a few days ago when temperatures cooled off and skies clouded over. Recently, Jan 26th has become dormant with only the occasional, isolated avalanche occurring. Slides are, however, becoming increasingly large and destructive.

February 25th is being buried as I write. It's starting to perform in areas where there's more than about 25cm of new snow on the layer or where winds and/or warm temperatures have created slabby or stiffer surface layers (notably, this seems to be occurring in the Northwest and favoured, upslope areas on the west side of the northern and central Columbia Mtns.). This layer has all the signs of being a performer, so just because you are not seeing anything in your area yet, I'd suggest great care be exercised for the next week or so—we are back in the storm track and ongoing light to locally moderate snowfalls are expected with sunny, dry breaks between systems.

Once there's 30cm or so of new snow and/or a bit of windslab on they Feb 25th layer, I expect a fairly widespread avalanche cycle throughout the province. In many areas, this could occur in the next few days (Feb 29th to Mar 2nd) if the weather forecast is accurate. Even though Jan 26th and Feb 25th look similar, I will not be surprised if Feb 25th performs more readily and on a more widespread basis than Jan 26th did. Avalanches on the Feb 25th layer also present the potential to step down to the Jan 26th or deeper PWLs. Farther east in Alberta, the problems with Feb 25th might not be as widespread, as snowfalls are expected to be lighter but I'd be very careful in windy areas where even small amounts of new snow are being drifted into deeper slabs in leeward and crossloaded terrain.

**What is surface hoar?**

To make a long story short, surface hoar is the winter equivalent of dew. It forms in calm, cool conditions and is associated with clear skies, although local fog banks enhance formation of surface hoar when skies are clear above the fog.

Surface hoar is most easily observed when it is still on the surface of the snowpack. Although it's found in a variety of forms, classically it's a glittery, icy-looking crystal with a feathery shape. It can be very small (a millimetre or two) to very large (as big as 100mm or more). Once buried, surface hoar grains (especially smaller ones) can be much harder to find and identify. They sometimes lie flat and form an extremely thin layer that even experts have a hard time seeing, and sometimes they become mixed with other grains from layers above and below making them difficult to pick out. Surface hoar tends to form a more unstable layer when:

- It takes a classic feathery shape (although one should not write off other common shapes such as needles or cups, especially if the following conditions occur).
- There are many crystals packed closely together.
- The underlying surface is firm, hard, and smooth (e.g. wind or especially suncrust).
- New snow does not penetrate into the pore spaces between the surface hoar grains.
- There is a slab of cohesive snow on top of the layer. Be careful here, especially when new snow is warm and there's a lot of it, slab properties can occur in layers as soft as four finger resistance. One of the biggest avalanches I was personally caught in involved a 100cm deep slab with a fracture line 300m wide on a 23 – 26 degree slope. Ski penetration was 80cms and ski quality was excellent; we were getting face shots in what felt like bottomless powder. This was one of the scariest days of my life which taught me never to underestimate the potential instability of surface hoar layers and to never assume that ski quality alone is a reliable indicator of slab characteristics.

Surface hoar often forms in pockets; conditions might be right on one part of a slope while just a few metres away, they are not. Surface hoar is easily destroyed when exposed to sun or wind; one part of a slope might be affected by wind or sun while an area nearby is sheltered. This often makes for highly variable distribution of the layer. Once buried, surface hoar is one of the most persistent of all weak layers.

**The potential for step-down avalanches.**
When there are multiple weak layers in the snowpack, a smaller slide involving shallower weak layers could impact an area where a deeper weak layer exists, subsequently triggering a failure in the deep weak layer. While this situation is not limited to persistent weak layers, it's of particular concern when there is a PWL in the snowpack and a deep slab avalanche is possible, because:

- Persistent weak layers are often buried very deeply in the snowpack (January 26th is now about 100cm down in most areas of BC, December 5th is easily 200cm or more, while November and October are even deeper) so there's a lot of mass available to avalanche.
- Deep slab avalanche usually involve hard to very hard layers of snow that can propagate over very wide areas and across terrain features that are normally considered safe. I clearly recall a PWL from November (1996 I think?) that failed in March and propagated from ridgecrest in one alpine bowl around a very pronounced ridge, then ran down below treeline and back up into the alpine in an adjoining bowl. The entire fracture line cleaned out both bowls as well as the terrain between them and was over 2000m in length. The debris took out mature trees in two separate drainages. You could smell freshly broken timber from the helicopter as we flew over the valley bottom!
- When and where persistent weak layers exist and may provide step-down potential is hard to predict. Unless you are completely familiar with the entire winter's history of a slope it's impossible to tell whether there's a PWL step-down potential.

In the worst case scenario, we have four or perhaps even five persistent layers at various depths in some parts of BC. In the best case scenario there are probably at least two or three. We are definitely in a winter where step-down avalanche potential currently exists and probably will remain for the rest of the season.

**How do I manage my risk with these new persistent weak layers and the potential for step-down avalanches?**
While January 26th and February 25th are not facets on crust PWLs like the ones from earlier in the winter, they behave similarly as and after they are buried and managing risk is more or less the same. Refer to "How do I manage risks associated with PWLs and deep slab instability?" in the original version of this paper, below. I'll quickly review some of the factors to keep in mind in terms of potential reactivation or triggering of a typical PWL. This applies to all the PWLs we are currently dealing with.

Deeply buried, dormant, persistent weak layers tend to be triggered or reactivate when:

- Large triggers are applied. Cornice fall triggering is common. Sleds are bigger triggers than skiers. A sledder or skier jumping onto a slope is a bigger trigger than one who is not jumping.
- Step-down avalanche potential exists. Weather factors such as new snow, rain, wind, temperatures, and solar radiation are common triggers for storm snow or surface avalanches, which then step down to PWLs.
- Rapid, significant new snow loads are added. I hesitate to suggest a general rule but 30cm in 12 hours is certainly something to think carefully about.
- Rainfall adds warmth and load to the snowpack. Any amount of rain is of concern if the existing snow is dry. Things might hold up a bit better if the snowpack is a thick crust or very firm old snow that has been previously warmed or melted and refrozen.
- Wind is loading snow onto a slope. Even relatively small snowfalls can accumulate quickly and deeply when wind starts moving snow around. It's not at all beyond the realm of possibility that a 5cm snowfall could accumulate a 50cm deep slab within a few hours in a windloaded area. Remember that windloading can occur on leeward slopes as well as in pockets on crossloaded or even windward slopes.
- Temperatures rise rapidly. Three degrees C in an hour would be something to watch, especially starting at -10 or warmer and more so if temps are getting close to or going above the freezing point as they rise.
- Strong solar radiation affects a slope. The snow need not feel wet or slushy for it to become unstable. Remember that solar radiation is often stronger and hits earlier on high elevation slopes. Even on a shaded north or east facing slope, solar radiation can be a factor if the backside of a cornice has the sun shining on it at ridgetop.

If more than one factor exists on a slope at any one time, the effect is greater than the sum of its parts.

In my experience, a significant proportion of serious accidents involving PWLs occur in late winter and spring on blue-sky days. I suspect there are a number of factors at play:

- It takes at least several days for PWLs to adjust to stress from new snow or wind events. People don't wait long enough after a storm before they push out on a nice day.
- It takes at least a couple of days for most non-persistent, storm snow instabilities (which might trigger a step-down avalanche) to settle out. People don't wait long after a storm before they push out on a nice day.
- On clear days, warming and solar radiation can quickly destabilize slopes or cornices above, which then trigger a PWL or a step-down avalanche. People don't look up enough, and they tend to underestimate the strength of the sun when assessing warming and solar radiation on slopes or cornices far above, especially if they are in the shade in the valley below or on a "cold" slope such as a north or east aspect.
- There's less tendency to stop and reassess current, local conditions in good weather. People miss changes happening around or above them.
- People are more willing to push into bigger, steeper, more complex terrain when the weather is good.
- People ride more aggressively on blue-bird days.
- People tend to discount their intuition or "gut feel" more on blue bird days. If something doesn't feel right, they are more willing to push on a clear warm day than on a cold, foggy, snowy day.

If any of the above factors is at play, and especially if more than one are a potential, you should very carefully examine your motivation for exposing yourself to slopes where PWLs are known or suspected to exist. It is strongly recommended you back off and go to slopes where PWLs are not an issue. Or choose low angle, simple terrain that is not exposed to slopes above. If you feel you must expose yourself to slopes that might contain PWLs, give them several days to adjust to new stresses before reconsidering them as an objective. I would suggest you use those several days to obtain as much information as possible from credible local sources about the slope you want to tackle and continue to question your motivation.

Here are some sobering numbers:

- PWLs are known or suspected to be the failure layer in 11 of 14 fatal accidents so far this year.
- 85% of all reported avalanches reported to the CAC's incident reporting database to date this year involve PWLs.

This season's snowpack is currently a complex risk management problem and will likely remain so for some time to come. The snowpack this year is not something to mess with or take for granted.

My intention is not to scare people out of going into the mountains. It is possible to manage risk, maintain reasonable margins of safety, and make informed decisions in these conditions. But my personal approach to a snowpack like this one is very different than when there are fewer or no PWLs involved. Local knowledge of the snowpack and experience with similar conditions are critical components in managing risk this winter. The most important factor in managing risk in these circumstances (and, in my personal opinion, at all times) is understanding and utilizing terrain effectively. You can learn about terrain by taking an Avalanche Skills Training (AST) course that follows the curriculum established by the Canadian Avalanche Centre. More info on AST courses at www.avalanche.ca under the CAC link.

In closing, I thought I'd leave you with some thoughts from some of my mentors that I think are highly are applicable in these times:

"The snowpack is a capricious, erratic acquaintance who you never really get to know very well. The terrain is a steady and predictable friend that you can always depend on."

"When you have low confidence in the snowpack, there are three things that are of the utmost importance in managing risk: terrain, terrain, and terrain."

Your comments, questions, and thoughts are welcome. You can reach me at: kklassen@avalanche.ca

## ORIGINAL PAPER FROM JANUARY 30TH

This winter, backcountry users in western Canada are faced with a particular problem—a persistent weak layer in the snowpack of many popular mountainous areas. This discussion is intended to help you better understand how these layers formed and the challenges related to managing this type of risk. This article is not intended to provide answers to all the questions you might have. Instead, it provides general guidance and some tips to help you ask the right questions and gather information that can help you make an informed decision.

I must stress there is no 100% guarantee of safety in the mountains. You could be caught in an avalanche, injured, or killed even if you follow every piece of advice in this discussion and "do everything right." This being said, in at least half of the avalanche fatalities to date this season, the victims were either not equipped with appropriate rescue gear or did not heed clear warnings. Many avalanche accidents are preventable—it's up to you to get the training, information, and appropriate equipment to properly manage your risk if you choose to go into the mountains.

**What's the problem?**

A persistent weak layer (PWL) is so called because it does not strengthen over time, and in some cases it even becomes weaker over time. A PWL can remain unstable for weeks or even months and is often the cause of avalanches long after it originally forms and is buried.

A PWL often results in what is referred to as a "deep slab instability"—a deeply buried weak layer beneath a thick slab or slabs of snow comprised of accumulated snow from numerous storms. Deep slab avalanches are generally large and highly destructive due to their size and mass. A PWL that formed in the fall of 2002 and the resultant deep slab instability was the underlying cause of most of the 29 fatalities that occurred in the winter of 2002-2003 (the worst avalanche season in recent years), including two large avalanches that each killed seven people in the Selkirk Mountains.

A variety of crystal forms can contribute to a PWL, but the current concern is a "facets on crust" layer. Back in the early days of the season, rain saturated the surface of the snowpack (this is called a "rain on snow event"). As or shortly after that wet layer froze, facets (sugary snow grains) formed on top of the icy rain crust. Now, that layer of facets has become a PWL.

This year's facet on crust PWLs are known or strongly suspected as the cause behind nine of 11 avalanche fatalities to date, spanning a time frame from December 8, 2007 to January 16, 2008 and occurring in the Alberta Rockies, the Cariboo Mountains, and the southern Monashee Mountains. The most active period to date was the first week of January when numerous fatal accidents made avalanches front page news. The untold story are the many close calls involving this year's PWLs that didn't make the news starting in mid-November and, as of this writing, continuing to January 24$^{th}$, occurring in practically all the mountain ranges of BC and Alberta. You can see reports about many of these close calls on the Canadian Avalanche Centre's Discussion Forums at: http://www.avalanche.ca/default.aspx?DN=586,558,3,Documents.

Experience has shown that PWLs go through cycles where periods of high avalanche activity are interspersed with periods during which few avalanches occur. When, where, and why these cycles occur can be difficult to predict with a high degree of accuracy and are not fully understood. Unstable periods are often related to changes weather factors such as increased wind, snowfalls, rain, temperature changes (especially from cold to warm), and solar radiation. A PWL that has produced avalanches and then shows signs of stability is generally treated with scepticism by knowledgeable practitioners, most of whom describe such a layer as dormant rather than stable, the assumption being (as Monty Python once said): "…it's not dead, it's just sleeping."

**Where is the problem?**
One or more rain on snow events occurred in pretty much all the mountain ranges of BC and Alberta in the fall of 2007. It is common practice to name a PWL according to the date on which it is buried by subsequent snowfalls. To date this year, rain on snow events occurred:

- Near the end of October at most elevations and on all aspects in most BC and Alberta mountain ranges. This layer is generally referred to as October 31st or the Halloween crust, although it is dated as early as October 27th in some areas.
- Around the third week of November at most elevations and all aspects in practically all BC and Alberta mountain ranges. This one is referred to as November 24th, plus or minus a few days.
- In early December on all aspects to treeline or just above treeline in most BC ranges. This most recent layer is commonly known as December 5th although it might be anything from December 3rd to 10th, depending on where you are.

The October layer, while quite widespread in BC and Alberta is not a great concern in most of BC at this time. It is, however, considered a problem in the Alberta Rockies. The November layer was considered a potential problem in many ranges but in most areas of BC it seems to no longer be a significant concern. At this time, however, it remains an issue in parts of the Alberta Rockies and perhaps in isolated areas in BC that have a snowpack of less than about 150cm on average. The December layer did not occur in the Alberta Rockies but is widespread in BC. That said, there are numerous areas where these layers either do not exist or, if they do, have shown no signs of instability from the outset.

Following is a breakdown of the regions where this year's facets on crust PWLs are more prevalent. I must stress that this is a very general overview and local anomalies are a certainty. Please note that in areas where a professional avalanche control program is in place, the problems associated with these layers are significantly or wholly mitigated; this includes for example, transportation corridors and ski areas. On a regional scale, October and November PWLs are currently considered prevalent at all elevations in:

- The entire east slope of the Alberta Rockies from the US Border to at least Jasper and probably to Grande Cache.
- Limited information indicates the November layer was a concern in the North Rockies but its current state there is uncertain.

The December layer is considered a greater problem around treeline and in open areas below treeline in:

- The west side of the southern Rockies from around Elkford (and maybe a little farther north) to the US Border, including the Fernie area.
- The Boundary region east of Osoyoos, west of Kootenay Pass, and south of Castlegar. The mountains around Rossland have been described the "epicentre" of the December PWL.
- The Monashee and Selkirk Mountains south of a line running more or less from Vernon to Nakusp.
- The Purcell Mountains.
- Inland regions of the South Coast Mountains.
- Limited information suggests this layer is of concern in the North Rockies, especially in the eastern parts of the region where the snowpack is shallow.

Even in areas noted above, there are locations where PWLs are less of an issue or perhaps not an issue at all. Knowledgeable local experts (e.g. guides, ski patrollers, and avalanche professionals) who have been tracking and testing the snowpack throughout the winter and who use a recognized snow stability analysis and forecasting process to assess hazard and manage risk, will know if PWLs are an issue in their area or not. Unless you have credible local knowledge and are certain a problem PWL does not exist, it's probably wise to assume there is an issue in the above areas.

Tthe potential for triggering a deep slab instability on a PWL is greater in:

- Shallow snowpacks (less than 200cm on average).
- Variable depth snowpack areas (shallow areas interspersed with deep areas on the same slope).
- Rocky slopes.
- Slopes with small, isolated trees sticking out.
- Complex slopes. (check out terrain classification at: http://www.avalanche.ca/default.aspx?DN=599,428,4,558,3,Documents)
- Steep, convex, unsupported features.

**How do this year's layers look and feel?**
A facets on crust PWL is characterized by a layer of firm or frozen snow with weaker facets above and/or below it. The firm layer is generally hard to very hard, sometimes even an ice layer, anywhere from perhaps a centimetre or two in thickness to 10cm or more. If you poke the firm layer, it will be difficult or impossible to push a single, gloved forefinger into it. The facet layer is soft or very soft, is typically thinner than the crust, and can be as thin as a few millimetres. It's difficult to assess the hardness of thin facet layers but they are often relatively easy to see (a darker, sometimes bluish line in the wall of a hole dug in the snow). Under 8-10x magnification on a dark background, facets look like sugar crystals and the grains separate easily when removed from the snowpack.

A problem PWL, or one that is likely to become a problem, usually displays a certain "fracture character" when tested. The layer will generally produce a "pop" (sudden planar) or "drop" (sudden compression) fracture when tested using the Compression (CT) Test. In Rutschblock (RB) tests it often results in a whole block (WB) or most of block (MB) failure. In the case of PWLs, most avalanche professionals weight the pops and drops or WB/MB fracture characteristic more than the amount of force it takes to create the fracture in the first place. That is, even if it takes a lot of force to make the layer fail, if the layer pops/drops or produces a WB or MB failure, these layers are still considered significant.

One of the problems with the CT and RB tests is they only work when the PWL is less than 150cm below the surface. In many areas, this season's PWLs are already buried deeper than 150cm and assessing them requires more complex tests that provide less definitive answers. Testing, assessing, analyzing, and predicting the behaviour of very deep instabilities falls into the realm of highly experienced professionals who have seen many similar problems in the past and who can combine technical and scientific information with their broad knowledge and intuition in the analysis of these layers.

You can learn how to do CT or RB tests in avalanche courses or from an experienced, professional avalanche practitioner. You can find out more about training at: http://www.avalanche.ca/default.aspx?DN=350,579,558,3,Documents. Read more about pops, drops, CT and RB tests at: http://www.mec.ca/Main/content_text.jsp?FOLDER%3C%3Efolder_id=2534374302881865

**How long will these layers persist and what will make the problem go away?**
Most PWLs will perform (produce cycles of high avalanche activity) several times throughout a winter, with dormant periods lasting as long as several weeks. However, even in dormant phases, these layers can and do produce large, destructive avalanches.

In my opinion, it's almost certain that, where this year's layers are prevalent, they will persist for the remainder of the season. That said, just because a layer is there, does not necessarily mean it will wake up again and even if it does become active again, it may not produce as widespread a problem as we experienced in early January.

As to what it will take to make these layers go away, there is no definitive answer. A heavy rain event, while it would probably produce a major avalanche cycle in the short term, would likely create a very strong overlying layer of icy snow which, much like a bridge, would support further loads and minimize or eliminate the chance of a PWL below from failing. At the moment however, there is no such event on the horizon according to current long term weather forecasts. Otherwise, the only thing that will improve this kind of layer is if the crust becomes softer and/or the facets become harder and the whole combo becomes more homogeneous with the surrounding layers. There are some indications that this may be occurring with the December layer in some areas. However, this idea is based on limited data from isolated locations and should not be considered a general trend at this time.

**If the layer is dormant, when will it wake up?**
First of all, dormant is a relative term. A common pattern with PWL avalanche activity is a gradual decline in the frequency of avalanches. However, the avalanches that do occur tend to be larger. When and where the "low frequency/high consequence" avalanches will occur during a dormant spell is extremely difficult to predict and wondering when a dormant layer will reactivate causes sleepless nights for avalanche forecasters world-wide.

In addition to the difficulty of predicting the low frequency events, it can also be hard to predict when a new cycle of high avalanche activity will start. It's prudent to pull back and wait a few days to see what happens if:

- It starts raining.
- More than 20-30cm of new snow accumulates in a 24 hour period (perhaps less if the snow feels heavy or is associated with winds and/or warm temperatures).
- Wind is drifting snow onto slopes where PWLs are likely to exist.
- Temperatures rise rapidly (more than 3$^{o}$C in a period of one hour), especially if it's -10 or warmer.
- Temperatures are near, at, or above 0$^{o}$C.
- Solar radiation is strong.
- The snow is softening or becoming moist/mushy.
- Large triggers (e.g. cornice fall, avalanches from above, icefall, etc.) may affect a slope containing a PWL.

It's always a good idea to check the avalanche forecasts issued by the Canadian Avalanche Centre (http://www.avalanche.ca/default.aspx?DN=5,4,558,3,Documents) regularly to see if there is information there that indicates the layer is coming alive or is expected to wake up. Another place to look is in the CAC Discussion Forum (http://www.avalanche.ca/default.aspx?DN=586,558,3,Documents) where people who have been out in the mountains discuss their observations and post incident reports.

Some of the most destructive avalanche incidents in Canadian history are related to the end of a PWL lifespan. This is often in late winter or early spring when a PWL is dormant. After a long period of time where little or no avalanche activity on the PWL has been noted, people get lulled into sense of complacency or develop increasing confidence and are then caught by surprise (often in March) when an isolated but very large avalanche event catches the unwary by surprise. I recall a PWL in the 1990s that formed in November, went through several active periods through late spring, then wasn't heard from again until it was suspected as the weak layer in an avalanche that killed a mountaineer in August of the following year.

**How do I manage risks associated with PWLs and deep slab instability?**
Deep slab instabilities associated with PWLs are among the most difficult of all avalanche problems to assess, predict, and manage. Even with extensive training and nearly 30 years professional experience, I struggle with the combination of "low probability-low frequency/high consequence." That is, it's often difficult to trigger a deeply buried instability and the frequency of avalanches is low, but the consequences if caught in a deep slab avalanche are very serious due to the size and mass of the slide. The answer lies in making decisions based on what you know about a slope, its history of avalanche activity over the season, slope use patterns (e.g. compaction), and/or stabilization (avalanche control) measures. In the absence of knowledge the only reasonable way to manage your risk is by leaving a wide safety margin wherever a PWL is known or suspected.

It's important to be aware of the potential risks so you can make an informed decision when determining whether the risks are acceptable to you and your party. There are a number of steps you can take to ensure you are making an informed decision:

- Examine your own motivation and that of others in your group. Check out this article: http://www.mec.ca/Main/content_text.jsp?FOLDER%3C%3Efolder_id=2534374302881868
- Assess the training and experience of your party.
- Use a decision making process or tool like the Avaluator™ to aid in trip planning (http://www.avalanche.ca/default.aspx?DN=428,4,558,3,Documents).
- Ensure all members of the party play an active role in all aspects of planning, preparation, and execution of the trip.
- Talk to the others in your party. Listen to what they have to say. Respect their concerns. Make sure lines of communication remain open between all members of the party at all times.
- Use the information in this discussion and from regional avalanche forecasts to assess general conditions for the area where you will be.
- Talk to credible local experts such as guides, ski patrollers, avalanche professionals, etc. to get a handle on local conditions.
- Watch for signs of instability while travelling, such as whumpfing, cracking, and avalanches on similar slopes. These observations give you a clear signal that things are at a critical state. However in the case of a known or suspected PWL, the absence of whumpfing or avalanches should never be interpreted as evidence that a layer is not active.

PWLs are associated with high uncertainty and low confidence. With PWLs I don't ask: "Will it slide?" I do ask: "If it slides, what will happen to me or my partners?" This approach leads to greater margins for error, which in my opinion, is the best way to manage risk at times and places where confidence is low. With PWLs and deep slab instability, I am extremely careful in choosing what terrain I use and how I manage my groups in that terrain. Here are some general tips for managing risk at any time and some specific ideas for dealing with the existing PWL problems identified in this discussion:

- Take a more conservative overall approach in areas where this year's PWLs are more prevalent (see "Where is the problem?" above).
- Use a slope assessment tool or process like the Avaluator Obvious Clues™ card to assess each slope before you expose yourself to avalanche terrain (http://www.avalanche.ca/default.aspx?DN=673,428,4,558,3,Documents).
- Take a more conservative approach at elevations from just above treeline to treeline and in open areas below treeline.
- Avoid travelling in avalanche terrain where the snowpack is shallow (less than 200cm on average).
- Avoid avalanche terrain where the snowpack depth is variable (shallow areas mixed with deep areas).
- Avoid slopes that have rocks and scattered trees sticking out of the snow.
- Avoid steep (steeper than a set of stairs in your house) unsupported terrain features especially if there is a pronounced convexity (roll).

- Eliminate or minimize exposure to terrain traps, such as:
    - Depressions
    - Gullies
    - Creekbeds
    - Sudden transitions from steep to flat (lakeshores, benches, roadcuts, etc.).
    - Slopes where an avalanche might carry you:
        - Over a cliff.
        - Into trees.
        - Against obstructions such as rocks or boulders.
- Stay on low angle slopes that are less than 30$^{o}$ incline (less steep than a set of stairs in your house).
- Stay on simpler terrain (http://www.avalanche.ca/default.aspx?DN=599,428,4,558,3,Documents).
- Avoid avalanche start zones and tracks if possible.
- If you must travel in or through start zones or tracks, go one at a time from safe spot to safe spot.
- Spread out when travelling in or through avalanche runout zones.
- Regroup only in safe areas where avalanches will not start or run through/over:
    - High points.
    - Ridges above start zones.
    - Dense timber well away from the track or runout zone.

**Some references for further reading:**
If you are unfamiliar with the terminology used in this discussion, check out:
http://www.avalanche.org/~uac/encyclopedia/index.htm'

You can learn more about facets on crust layers, PWLs, and deep slab instabilities in the following technical articles:

- Formation of Refrozen Snow Layers and Their Role in Slab Avalanche Release by Dr. Bruce Jamieson. Published in the Review of Geophysics, 44 (paper number 2005RG000176). Available online at: http://www.agu.org/pubs/crossref/2006/2005RG000176.shtml
- Terminology and Predominant Processes Associated with the Formation of Weak Layers of Near-Surface Faceted Crystals in the Mountain Snowpack by Karl W. Birkeland. Published in Arctic and Alpine Research, Volume 30, Number 2 1998 . Available online at: http://links.jstor.org/sici?sici=0004-0851(199805)30%3A2%3C193%3ATAPPAW%3E2.0.CO%3B2-H
- Characterization of a Deep Slab Avalanche Cycle by Ethan Green and Greg Johnson. Published in the Avalanche Review, Volume 21, Number 2. Available online at: http://www.americanavalancheassociation.org/pdf/deep_slab.pdf