A STUDY OF REPEATING PERSISTENT SLAB AVALANCHES ALONG THE PARK CITY RIDGELINE: THE EFFECTS OF REMOVING NEW SNOW ABOVE A WEAK LAYER

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ABSTRACT: Slide paths containing shallow snow depths can present a more unpredictable hazard. When a thick slab is unable to form above a persistent weak layer (PWL) to begin the healing process, it may be possible for weak layers to remain active through an entire season. This case study, from the Park City (PC) Ridgeline (Utah) during the 2024-25 season, documents how starting zones remained thin & weak due to repeated persistent slab avalanche release, as terrain adjacent to the "repeater" paths began to strengthen much earlier. The goal is to better understand and quantify how removing stronger snow above a PWL can lead to delayed strengthening and future reactivity. Field observations, snow profiles, weather data and avalanche activity are combined throughout three major cycles in upper elevation, northerly aspects (Intermountain snowpack). Early-season drought produced a shallow snowpack with continuous near surface faceting that became reactive during loading events in late December. Weak layers were then left exposed in starting zones with no slab above. Snow profile data suggests these weak layers were unable to heal during extended high-pressure periods and remained prone to reactivation with subsequent loading events. In contrast, adjacent terrain that did not avalanche maintained deeper and more uniform slab development, allowing faceted layers to strengthen more quickly. Repeater avalanche paths required significant slab thickening without additional avalanche release to reduce temperature gradients and allow faceted grains to round and strengthen. Sintering of these weak layers occurred in mid-March and coincided with spring warming trends and two prolonged storm cycles with evenly-distributed precipitation over roughly 48- and 36-hour periods. When new snow is removed above a PWL, healing is delayed and the weak layer can remain reactive well after surrounding terrain has stabilized. RAC systems, hand charges and other explosives can create the "repeater avalanche path scenario" as they can strip the slab leaving behind exposed weak layers and a shallow snowpack with thin future trigger locations. Repeater avalanches (whether released naturally or artificially) can create dangerous hazard throughout the season, requiring the use of more explosives and necessitating longer closures during persistent slab avalanche cycles.

KEYWORDS: SLAB FORMATION, SHALLOW SNOWPACK, REPEATER SLIDE-PATH, PERSISTENT WEAK LAYER

1. INTRODUCTION

Weak layers formed by surface faceting during periods of high pressure can be common to the Intermountain Snowpack. Given the right conditions, droughts lasting several weeks can leave continuous weak layers that have a prolonged effect on the season's stability, Birkeland (1998). With an already shallow pack, faceting can occur more quickly with increased temperature gradients. Healing can normally take place when a thick slab is able to develop without avalanche release, allowing for a lower temperature gradient and sintering of faceted layers - best achieved through consistent or abundant snowfall.

The 2024-2025 season had a dry start. This is not atypical, yet what set the season apart was that a thick slab was never able to develop in the slide paths that released with the initial cycle in late December. Nearly every storm thereafter brought reactivity on the weak layers that formed months prior, leaving a shallow snowpack composed of large grain facets and depth hoar in the starting zones. The thin pack remained unpredictable with dangerous avalanches throughout the season.

This case study combines field observations, snow profiles, weather data, and avalanche activity over three large avalanche cycles. Observations focused on identifying how early-season weak layers initially formed, how avalanche activity influenced snowpack structure within repeater paths, and which weather events contributed to either prolonged instability or eventual stabilization. The shallow snowpack of the repeating avalanche paths is also compared to locations just outside the starting zones that did not avalanche, and contained a stronger pack far earlier in the season. Different trigger types are reviewed in the Discussion, and we will look at

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how explosives & RAC systems can artificially create a weak repeater snowpack.

2. LOCATION

The Wasatch Mountain range in NE Utah is a small section of the Rocky Mountains that stretches across the Western USA and Canada. Located between the Continental climate of Colorado and the Maritime climate of the West Coast, the Intermountain snowpack shares characteristics from both locations. Having dryer air, cooler temperatures and less snowfall than the Maritime climate, the Transitional snow will normally develop (ideally) short-lived persistent avalanche problems, “but occasionally persistent instabilities can plague these areas for much of the season” – Avalanche.org (2017-2026). Depth hoar development is common during periods of cold and clear high pressure, Elder and Newcomb (1994). Notable results are covered throughout the Central Wasatch (Big and Little Cottonwood Canyons); however, most data, observations and reactivity in this study are from the PC Ridgeline, which is between Big Cottonwood Canyon and Park City. With large slide-paths on all aspects throughout the Central Wasatch, upper elevation ridgelines reach 3,400m.

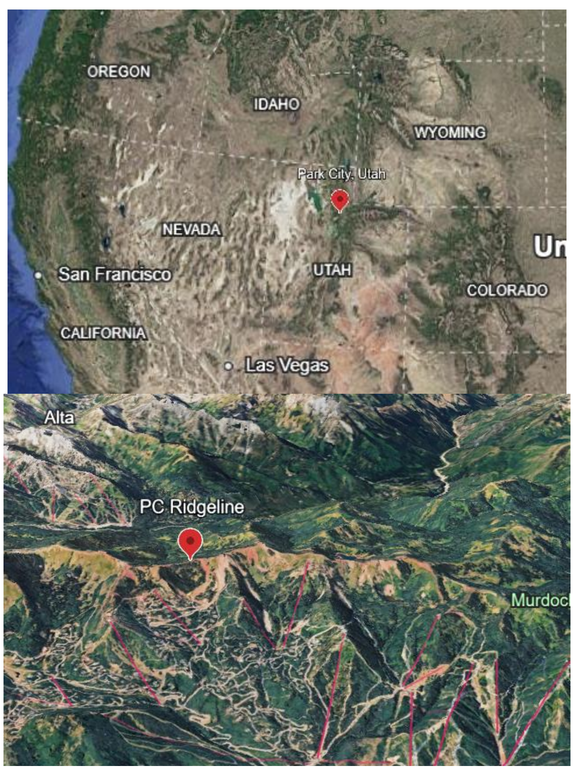

Figure 1 & 2: Location map of the study area. Google Earth (2025).

Being lower than the Central Wasatch, the PC Ridgeline tops out at 3,050m with the largest paths facing East and NE. Wind loading plays a major role along the ridgeline with westerly winds being dominant in the region. In the rain shadow of the Central Wasatch, Park City receives less early season snow and typically holds a thinner snowpack by the time larger winter storms arrive. Historically, these large east-facing “indicator paths” show reactivity much earlier than the larger paths of the Central Wasatch. Though Park City contains neither the 1500m slide paths nor the ski mountaineering terrain of Big and Little Cottonwood, there are plenty of 300m, NE facing slide-paths with 37° starting zones that can occasionally produce D3 avalanches.

3. FORMATION OF PERSISTENT WEAK LAYERS

Though the Wasatch Mountains can see abundant snowfall in November and December, the 2024-25 season began with only a handful of small storms. November storms produced 1.25m of snow over nine days. Weak La Nina conditions took over in early Dec after being ENSO neutral through the summer and fall, National Weather Service (2024). Temperatures increased in December as a very resilient high-pressure ridge formed along the West coast and blocked any approaching storms until late in the month; only 30cm of snow fell prior to a large storm cycle that began Dec 27 and produced almost 1.5m of snow over 7 days. Prior to late December, snow profiles showed an average height between 70-80cm along the PC Ridgeline with two very evident PWLs.

3.1 October PWL

Mid-October storms left a m/f crust 10-15cm above the ground which melted below 2800m on all aspects other than NE through N through NW. A colder storm followed late in the month, producing 15-20cm of snow that immediately faceted, forming what would become the first PWL of the season. Warm temps formed another crust, leaving the weak October snow sandwiched between crust layers once buried in November. We know from *Crusts and Facets*, Schauer et al. (2023) that when crusts form above and below a layer of facets, healing can be delayed. The crusts keep facets well preserved in the snowpack while also providing a great sliding surface, which can lead to season-long avalanche problems. The setup along the PC

Ridgeline described here is no exception to that Case Study.

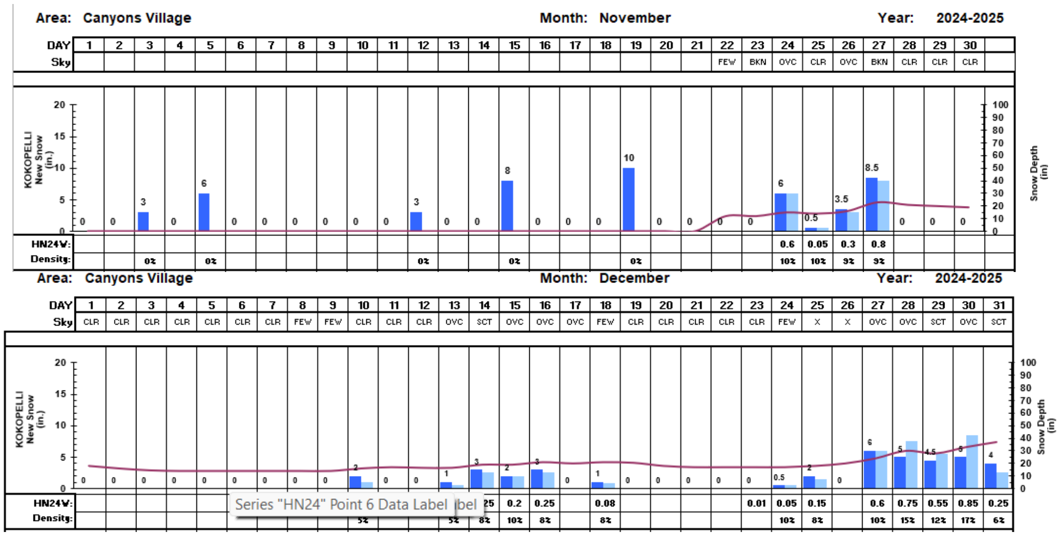

Figure 3 & 4: Seasonal weather data from the Kokopelli Snow Study Plot (manual), Canyons Village Snow Safety.

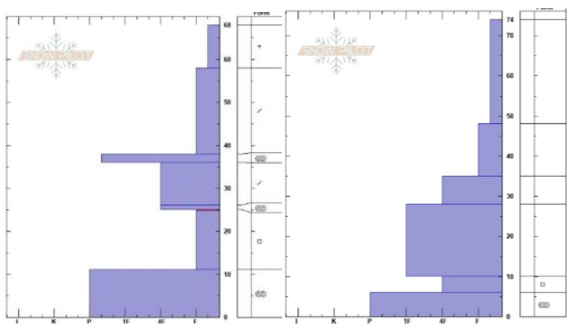

Figure 5 & 6: Average Early season profiles showing both weak layers in late November. North Aspects, 3000m. Seth Dromgoole.

3.2 Early-December NSF Layer

Nov storms capped the Oct PWL before 10 days of high pressure occurred from Nov 28 to Dec 12. We know from Birkland (1998) that low density surface snow can decompose quickly with clear cold nights and warm clear days with subfreezing temps. These ideal conditions for surface faceting are precisely what happened on the PC Ridgeline. The Nov 27 storm dropped 30cm of 7-9% density snow, and the following 4 days were clear and warm, yet below 0°C, which quickly formed the early Dec NSF layer. High pressure with wide temperature gradients continued through the month, and any small amount of snow that fell quickly faceted. This weak layer was much higher in the pack than the Oct PWL, which allowed for greater connectivity. It was also well distributed over mid and upper elevation bands (above 2500m) and now encompassed East and West aspects as well. This was the layer of most concern, and the setup was primed for step-down avalanches to occur in upper elevation terrain that contained both PWLs.

4. MAJOR AVALANCHE CYCLES

Reactivity for the 24-25 season is grouped into three clusters: one large initial avalanche cycle followed by two "repeater" cycles with each path failing only once per round. The second cycle saw spread-out reactivity over three different storms; this led to the snowpack becoming highly variable between neighboring paths (same aspect / elevation) within the same drainages. Difficulties in forecasting are highlighted.

4.1 First Round of Large Avalanches

Moderate precipitation and low wind accompanied the first wave of the storm cycle that began Dec 27. By Dec 29, snow totals hit 50-60cm at both snow study plots with heavier snow and stronger westerly winds, and the first large old snow slides of the season occurred. Natural results showed wall to wall (R-4-5) avalanches on the largest East and NE facing paths along the PC Ridgeline. Yet, with snow depths between 1-1.5m, most slides were in the D2.5-3 range, as they failed 10-20cm above the ground. The storm cycle continued until Jan 3, and produced between 1.25-1.5m of snow, per weather station (averaging 10% density). On Jan 12, another 20-25cm of light density snow (16mm SWE) fell. All slide paths were unreactive besides a single path outside the resort boundary that is controlled when the resort is threatened. This NE facing path *(Hanging Snowfield / Figure 8)* at 3000m with a 37° starting zone slid with AE (two) 1kg along the mid slope cliff band and another step-down slide.

For the remainder of the season on the PC Ridgeline – these were the only paths that would continue to release persistent slab avalanches. If a path did not release with this storm, it had no persistent slab results in the 24-25 season. (Study omits an unrelated RR cycle from late Feb on SE aspects that did not involve early season weak layers).

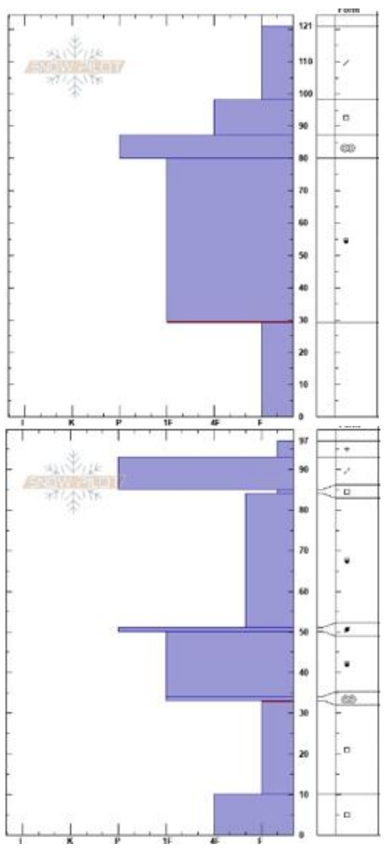

Figure 7 & 8: Profiles in late Jan ready for more reactivity. Profiles contain both PWLs, yet Hanging Snowfield (Right) has a very evident late January NSF layer. This path will fail one more time while profile on left will fail twice more and become one of our weakest paths (Nutty Putty, Wasatch Backcountry map). Tyler St Jeor

<u>*4.2:* Repeater avalanches begin: Variable snowpack created through spread-out reactivity</u>

Jan 18 another storm came through and deposited 25cm of light density snow (12mm SWE). A major wind event followed with extreme gusts from a variety of directions E through N through NW. Hard slabs were created in normally protected areas, yet no natural avalanches were released. Activity began as backcountry skiers stepped out with two catch & carries (Jan 23 and 26) along the PC Ridgeline (D1.5) with avalanches failing on the old weak layers.

January ended with another drought accompanied by single digit and sub-zero Fahrenheit temps (-18°C) for 10 of the final 12 days of the month, an unusual amount of time for such cold temps to remain in the Wasatch. These conditions created a late January NSF layer. With snow depths well below 1m in starting zones that had previously avalanched, weak layers remained weak or continued to fully facet.

February began with a storm that produced 20cm of light density snow, and the slide paths along the ridgeline remained intact. Feb 2 a storm deposited just 7.5cm of overnight snow, but it contained almost 13mm SWE (16% density) accompanied by extreme westerly winds. The new upside-down snow tipped the scales once again, and hard slabs that were created a week earlier avalanched when the lower facet layer failed. The resulting natural cycle was almost as large as the first as the same paths released with similar dimensions, this time from 25mm SWE over two days (R4-5 / D2.5).

The few remaining intact paths hung on through a week of non-freezing temperatures ahead of the next storm. With predominantly overcast days, and temps hovering in the mid-40s (5-9°C) at 3000m. Before cool temps could lock up the snowpack, the next storm began with 5cm of graupel and produced 25cm snow. Backcountry skiers stepped out, yet the faceted layers had not healed during the warmup, and there were numerous near misses and burials. The graupel from the storm's arrival led to step-down slides, once again (D2) in the 37-38° starting zones. Most results mirrored prior avalanches from the initial cycle, and in most instances - slide paths had multiple ski tracks visible at time of avalanche. Two different snowpacks form in repeater starting zones after this cycle, reviewed in *Section 5.2*.

At this point, repeater avalanches were spread out between loading events, as some paths remained intact one storm before sliding the next. We saw a variety of snowpacks throughout the Wasatch with major variation from path to path even within individual drainages. Snow profiles showed a wide variety snow depths & structures with weak layers at various stages of healing.

Trying to keep track of different structures proved problematic for local Wasatch skiers. Dave Richards (2025) expressed as much in a February UAC Observation while quoting Titus Case (Alta's former Avalanche Program Director) – "This season is not the tale of two snowpacks, it's one snowpack with many chapters."

4.3: Third Cycle: Fewer paths released with decreased R-Value

The third cycle began on Valentine's Day with a 50cm storm and large natural results that mirrored the previous two rounds. This time, however, reactivity was only seen in three of the largest paths (D2-2.5). Two days later with 25cm of new snow, a large NE facing path *(Square Top / Figure 15)* naturally released an over 1m deep hard slab. The path's third slide, this one was only R2 as just the skier's right side avalanched. The remaining bed surface in the starting zone contained an extremely stout crust with very weak facets on the surface *(Figure 13)*, appearing to be primed for future reactivity. We also noticed the terrain in the same path left intact had become a 2m pack with healing weak layers (reviewed in *Section 5.3*). This was the last persistent slab avalanche that took place and the only persistent slab avalanche to release after the Feb 14 cycle.

4.4 March 2 Weak Layer; Reactive in shallow terrain only

In early March, a crust formed during a rime / dust layer event. The crust capped an already formed NSF layer, and also developed facets above. This layer existed primarily in the shallow terrain of repeater paths. After receiving just 20cm of snow on March 8 that began with graupel, three weak paths (each with three prior slides) released remotely triggered (ASr) avalanches (D1.5) on faceted grains above the Mar 2 crust and dust layer. Snow profiles in terrain of thicker depth (closer to 200cm) did not contain the problematic new layer, or if present, it had rounded and become unreactive. Paths were skied heavily with no further results.

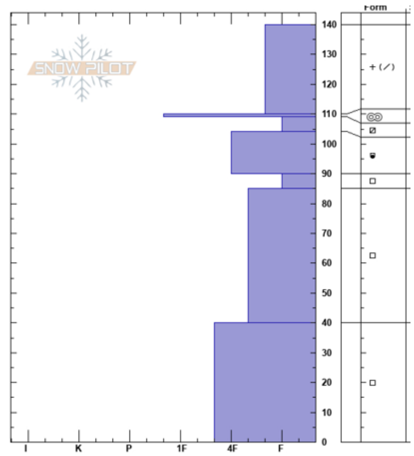

Figure 9: Mar 8 Crown profile from North Bowl. Shallow snowpack feeling the effects of each new PWL created during high pressure throughout the season. ASr soft slab released above the Mar 2 Crust at 110cm (graupel / NSF weak layer).

4.5 Transition to Dormancy

In mid-March, the snowpack was finally able to benefit from the higher spring sun angle as temperatures increased to low 40s (5°C) and Solar aspects transitioned to a melt-freeze state beginning the first corn cycle of the season. Warm temps were followed by a larger 60-80cm (40-50mm SWE) spring storm that lasted two days in mid-March. Incremental loading was spread very well throughout the storm with (at-most) 13mm SWE over each 12-hour period. A few days later, a 36-hour storm (ending Mar 19) deposited 60cm (42mm SWE). The loading was slightly heavier than the mid-March storm (up to 17mm SWE / 12-hr), but still not particularly intense. All repeater paths handled the new load and remained intact again as they gained a 1m slab above the weak layers. This allowed healing to finally take place as new snow quickly became 1-finger rounds. Repeater paths were now at 200cm while adjacent terrain was closer to 300cm! Over one month had passed since the last persistent slab had released, and the Utah Avalanche Center removed the persistent slab problem from the forecast on March 21. A small number of the weakest starting zones remained fairly unsupportable to ski boots and still harbored the early-season PWL layers with occasional ECTP results in the mid-to-upper 20 tap range. Therefore, the following verbiage remained in the forecast to cover future unfavorable weather: "early winter PWLs have trended to dormant, yet reactivity remains possible with either intense snowfall or heating; with reactivity being much more likely only in repeater locations." The repeater paths continued to heal, and no further persistent slabs were released as larger April storms produced snowfall rates closer to 2.5cm SWE / 6-12 hour period.

5. DISCUSSION

5.1 Weather

Unfavorable weather events contributed to prolonged instability, but eventually weak layers transitioned to dormancy.

The December high pressure ridge over the West coast provided nearly perfect surface faceting conditions with only 30cm of snow falling until late in the month. While problematic NSF layers “can form in a day or two under ideal conditions, the most advanced layers of diurnally recrystallized near-surface facets are exposed to bi-directional temperature gradients for several days”, Birkland (1998). Bi-directional gradients with clear days occurred in 20 of 28 possible days from Nov 28 – Dec 26. This was the perfect setup for an extremely continuous weak layer along the surface to fail once loaded, which could then step down to the Oct PWL containing a crust above the ground – the perfect sliding surface.

High pressure and other unusual weather events led to new PWLs created throughout the season. Snow profiles from late January not only contained the unhealed early-winter PWLs, but also the weakening surface snow that faceted during the late January drought (very cold temps with large temperature gradients) that plagued the forecast over 10 days. The snowpack once again began to weaken, and the late-January NSF layer formed. The snowpack decomposed quickly, and shallow zones (closer to ½ meter) became fully faceted. Though overall it was a season with above average snowfall and temperatures, it was clear, cold and dry at all the wrong times. It should be noted that in areas with a thicker snowpack (1m or greater), early winter weak layers began to heal as the January snow became 1-Finger rounds. Public observations showed ECTX results in thicker terrain and no results with intentional cornice drops onto starting zones. If storms over the second half of January could have provided more incremental loading along with non-facet promoting weather temperatures and cloud cover during the 10 days of high pressure, the season could have exhibited more stability. Yet, the ill-timed cold front & drought totally reversed any healing that had taken place in older facet layers and added another PWL to the mix.

In the second cycle, we saw new snow weak layers lead to step-down slides. Whether from wind slabs, heavy upside-down snow or graupel onto an unfrozen pack, unfavorable weather events contributed to repeater path instability.

Before the third cycle, high pressure contributed to the Feb NSF layer being created during six clear days and nights with 15-20F degree temperature swings. A small amount of surface faceting in deeper terrain created a much more problematic weak layer in shallow terrain, keeping the bed surfaces fully faceted. Also evident as the Mar 2 PWL only showed reactivity in three of the weakest paths with three prior slides, while thicker neighboring terrain remained intact and did not contain the problematic layer.

Finally, in mid-March, weather played a more favorable hand. Intense loading was avoided until April, and by then the repeater paths had become 200cm snowpacks with healed weak layers. In March, we saw perfectly distributed loading over two large storms (Section 4.5). Incremental amounts of SWE fell every 12-hour period during the storms, and eventually 1m slabs composed of 1-finger rounds sat above the weak layers.

5.2 The two different snowpacks remain in starting zones:

After the second avalanche cycle, two vastly different snowpacks formed in repeater sites, though both remained shallow and reactive to tap tests. The first, mainly found in larger paths (capable of producing D3 slides), contained a thick, pencil-hard crust with facets above it *(Figure 13)*. Any small amount of new snow that fell onto the thick crust could immediately facet, while a larger amount of new snow could have created a slab atop the perfect bed-surface to slide on. The second profile was composed of different layers of large-grain facets from surface to ground, all first to 4-finger in hand-hardness *(Figure 14)*. These repeater paths were fully unsupportable to ski boots, even by mid-March.

5.3 Early healing of adjacent terrain:

Any path that remained intact through the first cycle was able to maintain more strength during high pressure with less problematic weak layer development. These paths would not release a persistent slab this season. During the second cycle, paths adjacent to repeaters were able to hold new snow, form a thick slab and become a much stronger 200cm snowpack by mid to late February. Stronger profiles were composed mainly of 1-Finger rounds, and showed healing or fully healed weak layers *(Figures 16, 18)*. Repeater paths that only slid twice were able to heal weak layers earlier than those that released three times. Evident in March profiles *Figure 12* compared to *10, 11* as well as neighboring snow profiles *Figure 15* that slid twice but was outside of the third avalanche, *Figure 13* (same path). Starting zones that failed three or more times maintained unhealed weak layers much later into the season with much greater potential for propagation. Later in March, as thicker terrain reaches 300cm, repeater paths appear to be primed for a fourth cycle, yet no large storm with intense precipitation occurred until April after healing had taken place.

5.4 Continued use of explosives artificially created the weakest starting zones:

The Canyons Village backcountry contains slide paths above the operating area that can release into open terrain, which receive explosives nearly every day mitigation occurs. Some of these paths outside the ski area are skied heavily by the public after avalanches are released, while others are not and remain uncompacted. As evident in the Nutty Putty path (no skier compaction), continuous use of explosives (AE (two) 1kg released the third avalanche) contributed to our weakest snowpack that was ridden with depth hoar in early March *(Figure 17)* and still showed ECT propagation later in the month after rounding of weak layers had begun *(Figure 11)*. Further down the ridge we saw 2kg AB routinely strip new snow before strengthening could begin – leaving 60-80cm of depth hoar in the starting zones January through March. An alternative approach to managing a shallow and unpredictable slide path would be to close affected terrain, not use explosives and let a thicker pack build naturally.

Similar circumstances were evident in the Radial Influence of Gaz-Ex (1994) study by Ron Newcomb and Kelly Elder from the Teton Pass, Wyoming where continued use of Gaz-Ex left a shallow slide path dominated by depth hoar. The snow hardened in the blast location. However, very weak snow was left between blast sites, which could become reactive upon future loading. These thinner areas can be encountered by backcountry riders or be triggered naturally during loading events. Extra explosives and added RAC's may be required as unstable snow can remain between blast zones. Shallow paths will be weaker than surrounding thicker terrain, which would contribute to harder to predict avalanches.

6. CONCLUSION

During the 2024-25 Winter season, we saw the unpredictability of shallow starting zones that produced large dangerous avalanches. Whether triggered naturally or artificially via skiers or explosives, the "repeater" slide-paths were reactive well after adjacent terrain that did not avalanche built a thicker pack and stabilized much earlier.

Operationally, we were aware of the weak starting zones, which led to longer closures in affected in-area terrain with more explosives being used after each loading event in backcountry paths that could hit the ski area. We not only saw the use of explosives kick-off reactivity in some paths but also keep others reactive after prior natural slides had taken place. Given the opportunity, closing affected terrain and letting a thick pack build may be the better option than managing a repeater snowpack.

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REMAINING FIGURES:

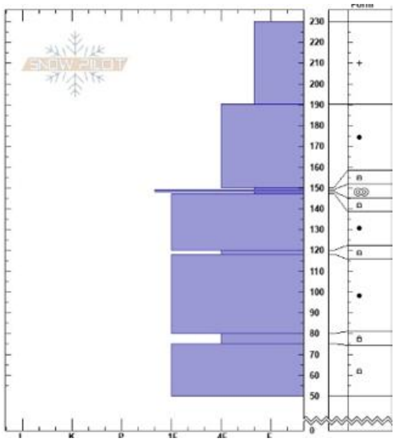

Figure 10 (Figures 10 & 11) from Mar 20 showing our weakest repeater paths that slid three times (North Bowl & Nutty Putty). Finally, a thicker slab of rounds had formed above weak layers allowing healing to begin. Profiles showed ECT propagation in the upper 20's yet no further persistent slabs released. Nut Roll (Right) was shot with (2) 1kg AE and 2kg AB and remained intact. Craig and Dromgoole.

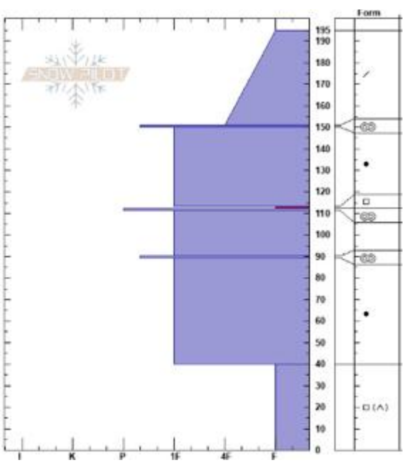

Figure 11

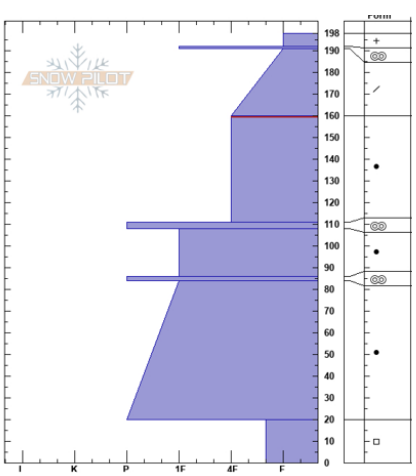

Figure 12: Mar 21 (High Dutch). Path slid twice and profile is stronger than Figures 10 and 11that slide three times. ECTX results. Seth Dromgoole.

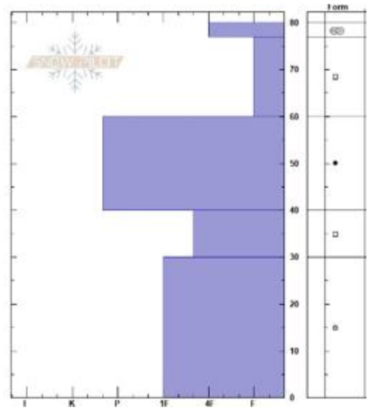

Figure 13: *Bed surface #1* from Square Top starting zone after three slides. Stout crust (great sliding surface) and very weak facets above, appearing to be primed for reactivity with future loading. Mar 1.

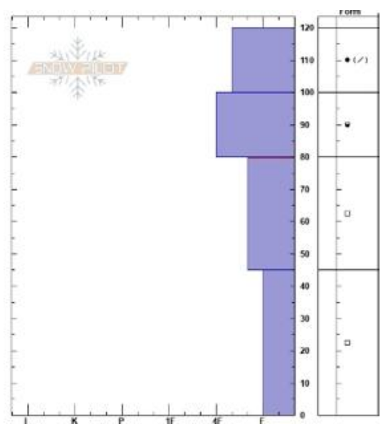

Figure 14: *Bed surface #2* composed of different layers of facets (Fist to 4-Finger). Mar 2, North Bowl starting zone after three avalanches.

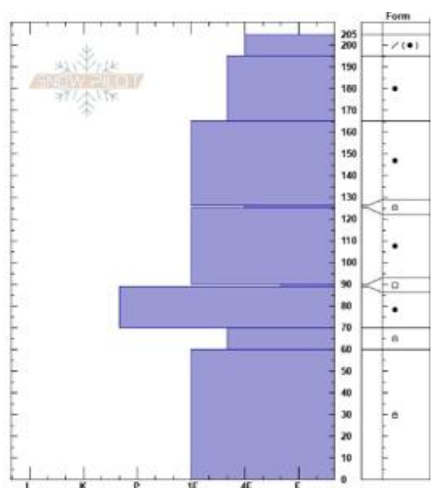

Figure 15: (same path as with Figure 13) Profile from starting zone that slid twice but was outside of the 3rd avalanche. Showing much stronger snowpack; same date. ECTX results.

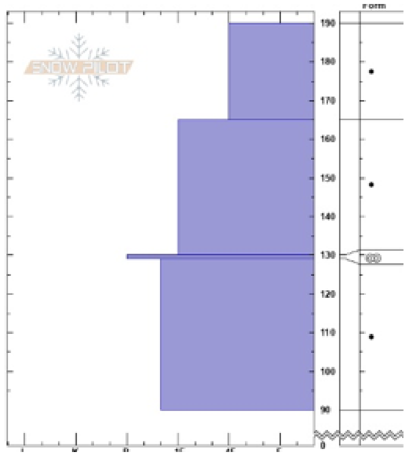

Figure 16: (same path as Figure 14) Profile also shows strong pack just outside of avalanche site.

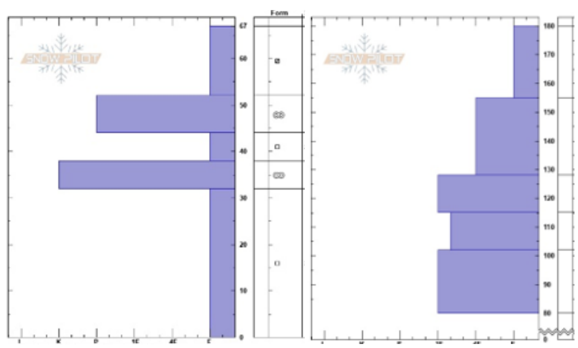

Figure 17 & 18: Depth hoar composed the bed surface after the 3rd avalanche (AE (two) 1kg) in the Nutty Putty path. Profile on right shows strong pack just outside the repeater starting zone. Patrick Murphy, Mar 2.