WHUMPFING OF A PERSISTENT DEPTH HOAR WEAK LAYER: ANALYSIS OF A RARE COMBINATION OF MANUAL STABILITY TESTS AND AUTOMATED SNOW MEASUREMENTS

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ABSTRACT: Whumpf sounds indicate the collapse of a buried weak layer and are associated with fracture propagation over distances of tens of meters without avalanche formation. We investigated a whumpf event triggered on 26 February 2026 at the well instrumented Weissfluhjoch test site, Switzerland, during repeated dynamic loading of a non-isolated snow column. Field observations were combined with snow stratigraphy, automated snow-height and pressure-based snow water equivalent measurements. The event produced a surface settlement of approximately 7 mm and a rapid increase in the pressure recorded by snow scales, followed by relaxation toward pre-event pressures over 2–3 hours. We interpret these observations as evidence of rapid stress redistribution within the snowpack during fracture propagation due to strain softening, followed by a slower recovery toward pre-whumpf conditions through slab hardening associated with sintering and progressive bond strengthening.

KEYWORDS: Depth Hoar, Persistent Weak Layer, Whumpf, Fracture Propagation, Snow Stability

1. INTRODUCTION

Whumpf sounds are widely recognized as an indicator of avalanche danger (e.g. Schweizer et al., 2021). They are the result of the collapse of buried persistent weak layers like surface or depth hoar triggered under dynamic loading in flat fields or slopes below ~30°, thus too flat for avalanche formation. The rapid compaction can be accompanied by a measurable surface settlement and lateral stress redistribution and can be linked to fracture propagation over tens of meters (e.g. Bergfeld et al., 2025). Despite their practical importance, the transient mechanical response and stress redistribution within a snowpack following a whumpf remain incompletely understood.

The mechanical response of a snowpack to localized dynamic loading depends on the properties of both the weak layer and the overlying slab. In particular, the ability of a weak layer to collapse and transmit a fracture is controlled by its microstructure, strength, stiffness, and the mechanical coupling to the surrounding snowpack. Conventional snow stability tests, such as the Extended Column Test (ECT), provide information about fracture initiation and propagation under standardized loading conditions, but may not fully capture the response of a spatially continuous snowpack to localized dynamic loading. Consequently, observations of naturally occurring or field-triggered whumpf events provide an opportunity to investigate the processes involved at a larger spatial scale.

Here, we investigate a whumpf event that occurred at the Weissfluhjoch test site of SLF near Davos, Switzerland, at 2540 m a.s.l. on 26 February 2026. The observation of a whumpf event at a well-instrumented test site is rare. The event occurred during an informal stability test conducted by students participating in the 10th Snow Science Winter School (SSWS). Snow stratigraphy and stability observations are combined with automated measurements from the Weissfluhjoch site. We focus on the collapse of a basal depth-hoar layer and its associated fracture propagation, surface settlement, and subsequent stress redistribution.

2. METHODS

The students of the 10th SSWS excavated a snowpit to the ground to characterize the vertical snow stratigraphy (Fig. 1). Snow layers were identified using a snow crystal card and magnifying loop, with crystal type and size recorded for each layer. Layer hardness was assessed using

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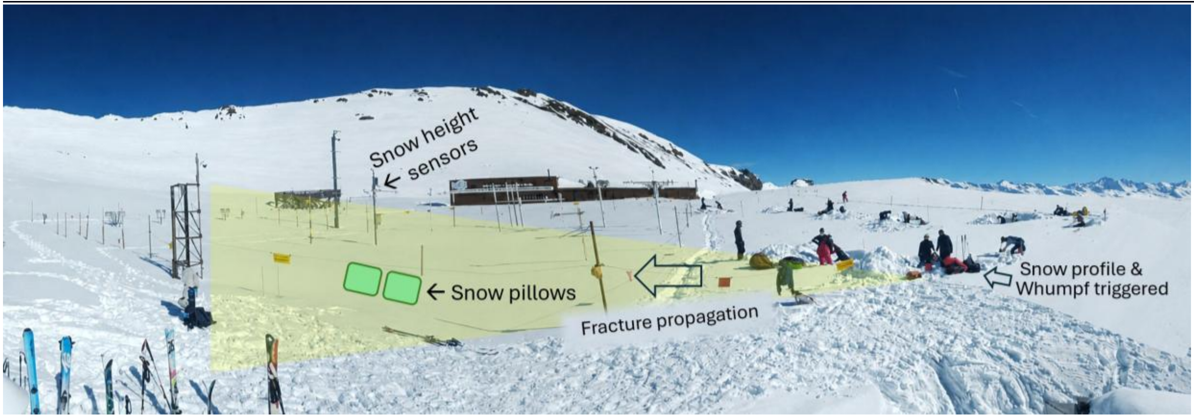

Figure 1: Weissfluhjoch field site where the Whumpf was triggered next to the measurement field, resulting in the collapse of a depth hoar weak layer and fracture propagation across the entire area.

the snow hand-hardness scale, while snow density was measured using a density cutter. Snow temperature was measured for individual layers using a digital thermometer.

Snow stability was evaluated using an Extended Column Test (ECT). In addition, an informal dynamic stability test was conducted. The upper approximately 70 cm of cohesive snow was removed from a non-isolated column, after which three students repeatedly loaded the remaining snowpack by jumping (Video – Whumpf! There it is, 2026). During the loading sequence, progressive cracking was observed in the upper layers, followed by a sudden collapse of the snow above the basal depth-hoar layer.

The collapse was documented and analysed in the following using the field observations and 30 min automated measurements from the Weissfluhjoch monitoring system. Two laser-based snow-height sensors (OTT SHM-31, Campbell SDMS-30) were used to quantify surface settlement. Two pressure-based SWE sensors (snow scales, Sommer SSG-1 & SSG-2) were used to investigate changes in the apparent snow load associated with the collapse and subsequent stress redistribution.

3. RESULTS

3.1 Snow stratigraphy

Snow stratigraphy measurements (Fig. 2) show a total snow height of 172 cm with a well-developed basal layer of persistent depth hoar (0-30 cm) beneath a cohesive slab. The depth hoar crystal size was up to 4.5 mm, indicating strong temperature gradient metamorphism during its formation, resulting in low stability and low density (~230 kg m^{-3}). The snowpack temperature profile shows a typical moderate vertical gradient, with near ground temperature of 0°C, cooling towards the top, and a temperature increase near the surface due to diurnal solar heating.

3.2 Snowpack stability

Extended Column Tests (ECT) indicated that the snowpack was relatively stable, with no signs of a high propensity for fracture propagation. However, under increased loading through repeated dynamic impacts (informal stability test), the depth hoar weak layer collapsed (Video – Whumpf! There it is, 2026). The video reveals a delay of several tens of seconds between the group landing on the snow surface and the subsequent settling of the snowpack. The fracture propagated across the entire Weissfluhjoch test site (Fig. 1) indicating efficient stress transmission and high propagation propensity within the weak layer. This collapse was accompanied by a strong whumpf sound and a measurable surface settlement of approximately 7 mm, as measured by the automated snow height sensors (Fig. 3) and as filmed by the students (Video – Whumpf! There it is, 2026). The pressure-based SWE sensors (snow scales) recorded a sudden increase in pressure, followed by a gradual return to pre-whumpf values over the subsequent 2-3 hours (Fig. 4).

4. DISCUSSION

The observed event illustrates the strong dependence of snowpack response on loading conditions. The ECT indicated relatively stable conditions and that a collapse of the weak layer is unlikely to be triggered by a skier, yet repeated strong loading during the informal test resulted in a collapse of the well buried basal depth-hoar layer and fracture propagation over tens of meters. The final collapse of the depth hoar released a stress perturbation that was efficiently transmitted through the slab and the spatially continuous weak layer.

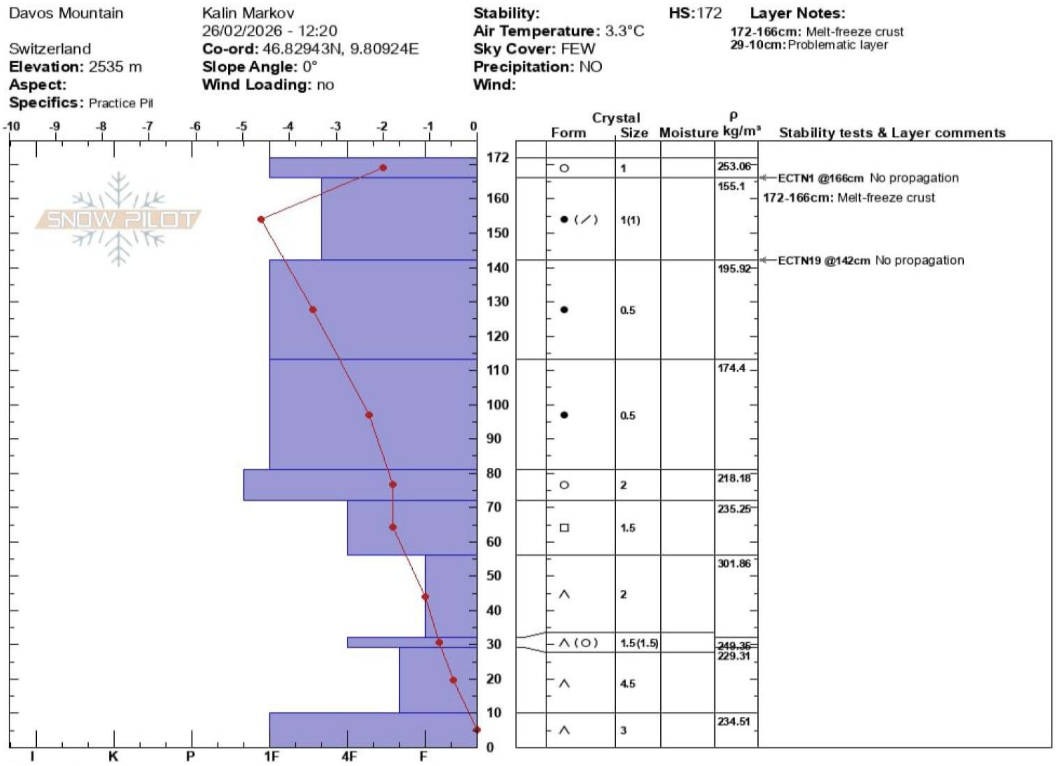

Figure 2: Snow profile from 2026-02-26 made next to the WFJ study site by the students of the 10th Snow Science Winter School. The profile shows a depth hoar layer of low stability and low snow density (~230 kg/m^3) from 10-30 cm, consisting of large faceted, weakly bonded depth hoar crystals.

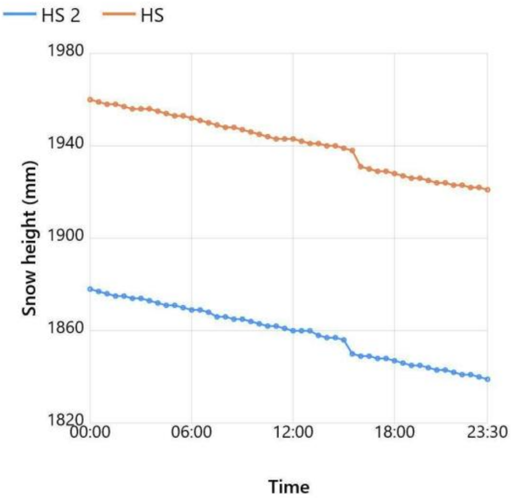

Figure 3: Snow height evolution at WFJ (Fig. 1) with two sensors (HS 2 and HS), both showing a 7mm drop in snow height at around 15:30.

The approximately 7 mm surface settlement (Fig. 3) demonstrates that weak-layer collapse can occur with a relatively small change in total snowpack thickness while still producing a substantial mechanical response. However, assuming the densification took place solely within the depth hoar weak layer, a 7 mm compaction of the 300 mm depth hoar layer results in a 2.3% volume reduction or density increase.

Immediately after the whumpf, the pressure on the snow scales increased (Fig. 4), consistent with a reduction in a potential bridging effect (Johnson and Marks, 2004; Pritchard et al., 2021) of the surrounding snowpack, and increased load transmission to the pressure sensors. We hypothesize that during the whumpf, the weak-layer collapse induced rapid deformation rather than a purely elastic response of the overlying slab, likely causing irreversible damage and microcracking (Fig. 5). This damage reduced the slab's effective stiffness (strain softening) and bridging capacity, redistributing stress toward the snow scales and explaining the observed increase in load. The weak layer collapse could theoretically also result in a load reduction on the snow scales, depending on the initial stress distribution (Fig. 5, left) within the spatially inhomogeneous snowpack and underlying ground.

The measured pressure (or SWE) on the snow scales subsequently decreased towards its pre-whumpf values over approximately 2–3 hours (Fig. 4), indicating a slow post-collapse redistribution of stresses. We interpret this relaxation as progressive sintering of the damaged snow, restoring intergranular bonds, slab stiffness, and bridging capacity, thereby relaxing the load on the scales toward its pre-collapse value.

Herwijnen and Miller (2013) showed that the increase in snow stiffness during sintering is primarily governed by bond strengthening over timescales of hours, thus comparable to the relaxation observed here, while the relatively warm snow temperatures during our observations (> −5 °C) promoted rapid sintering.

The pre- and post-whumpf baseline pressure indicates both a temporally stable pressure on scale 1 that settles at a lower value after the whumpf, and a continuous pressure reduction for scale 2 (Fig. 4). These baseline pressure trends were similar for the previous and the consecutive days, indicating that a long-term stress redistribution took place around scale 2 but not at scale 1. Similar stress redistributions around the snow scales are typically observed during periods of a warming snowpack (Johnson and Marks, 2004), i.e. a few weeks before the snowpack becomes isothermal at 0°C and the melting season begins. We interpret this stress redistribution because of enhanced small-strain viscous deformation (creep) (Scapozza and Bartelt, 2003).

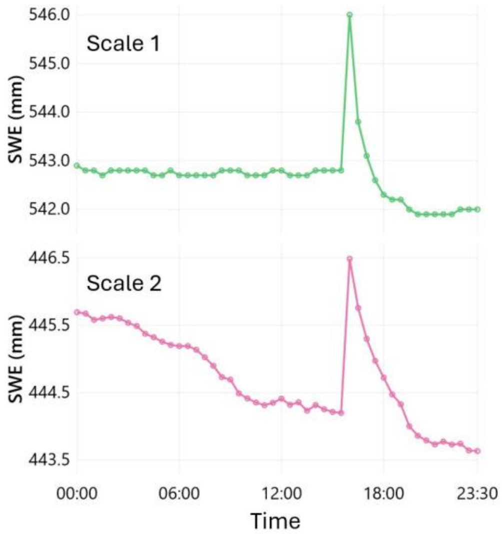

Figure 4: Pressure (or SWE) as measured with the two snow scales.

5. CONCLUSION

Our observations indicate that weak-layer collapse induces rapid deformation and damage of the overlying slab, resulting in strain softening, reduced bridging capacity, and a transient redistribution of stresses. Over the subsequent hours, hardening associated with sintering and bond strengthening progressively restores slab stiffness and bridging capacity, allowing stresses to relax toward their pre-collapse state. This softening–hardening behaviour provides a mechanistic insight into the transient mechanical response of a snowpack during weak-layer collapse and whumpfing.

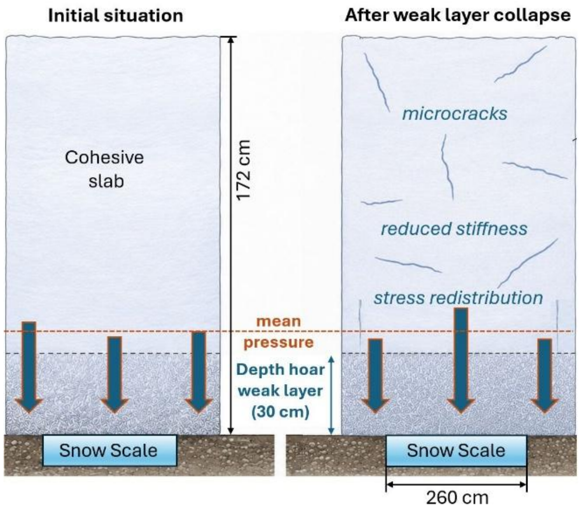

Figure 5: Illustration (not to scale) of pre- and post whumpf pressure distribution around the snow scales, indicating a higher pressure (SWE) on the scale after the weak layer collapse.

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Video - Whumpf! There it is. 2026. Short clip showing the dynamic loading of the snowpack followed by weak layer collapse and a concurrent snow surface settlement, https://www.youtube.com/shorts/tpbEpwBfGUk