TRIGGERED AVALANCHE – A CASE STUDY IN THE ITALIAN ALPS

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ABSTRACT: The 6th February 2014, two parties of 25 Heli-skiers (6 guides and 19 clients) and 3 snow observers were on activity on a large bowl at 2800 m elevation in the western Italian Alps. The snow observers were executing stability test inside a snow pit on the upper-right side of the bowl while the group of Heli-skiers were performing several runs along the central sector. A large soft-slab avalanche was triggered and caught 12 people (3 guides and 6 clients + 3 snow observers) with 1 fatality from trauma and 1 fully burial completely recovered after rescue. The prosecuting attorney initially charged the snow observers for the accident, but further investigation has officially assessed a different dynamic and a total discharge for them. This accident will be examined in detail discussing the mechanism of nucleation and propagation of fracture across the bowl and the sequence of depositional lobes stacking in the run-out zone as well as their depositional structures. We do hope that sharing this information will help to prompt procedural changes, including improvements to internal safety procedures, both for European Heli-ski industry and avalanche warning services.

KEYWORDS: Heli ski; triggered avalanche; accident case study

1. INTRODUCTION

Commercial helicopter skiing in Italy is still an immature industry and several accidents did occurred in the last years. Usually heli-skiing activity consists of groups of three to four guests and one Alpine Guide being transported to the top of their run via helicopter. Companies are quite small and the operations vary due to their structuring degree and up to two helicopters are used on a daily basis to service between twelve and forty guests.

Typically, several heli-ski locations have been used as good backcountry ski terrain or free-ride locations thus creating potential conflict situations with other recreational categories. The total safety of heli-ski customers cannot be guaranteed but, unfortunately, not all companies have yet prioritized investments, resources and efforts on creating safety operations procedures complying to the international best practice. The avalanche accident on 6th February 2014 at Cheneil - Valtournenche (Aosta Valley - Italy) proved to be a very unexpected and noteworthy accident. This accident highlighted the challenges which professionals face while trying to locally forecast areas, and raised some difficult questions regarding assessing avalanche size potential, and avalanche runout zones. This accident will be examined in detail discussing the most probable mechanism of nucleation and propagation of fracture across the bowl and the sequence of depositional lobes stacking in the run-out zone as well as their depositional structures. We do hope that sharing this information and some general conclusions to this challenging issue will help to prompt procedural changes, including improvements to internal safety procedures for all professionals.

2. TERRAIN

Cheneil bowl (“Comba de Cheney” in the local dialect) is located nine kilometres (5’ flight) SSE of Breuil-Cervinia in Valtournenche – Aosta Valley (Western Italian Alps - Italy) – (Fig. 01).

The bowl’s base elevation is 2096 m with a summit elevation of 2849 m ASL. It encompasses over 105 hectares of primarily W and N facing terrain.

The lower part of the bowl shows a complex morphology and it tapers along the creek while the upper part, where the accident occurred, is wide and divided by several slightly diagonally sloping grassy and rock bands and ridges which create eight sub-basins and mid slope convexities and

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steep break overs as you descend (Fig. 02 and 03).

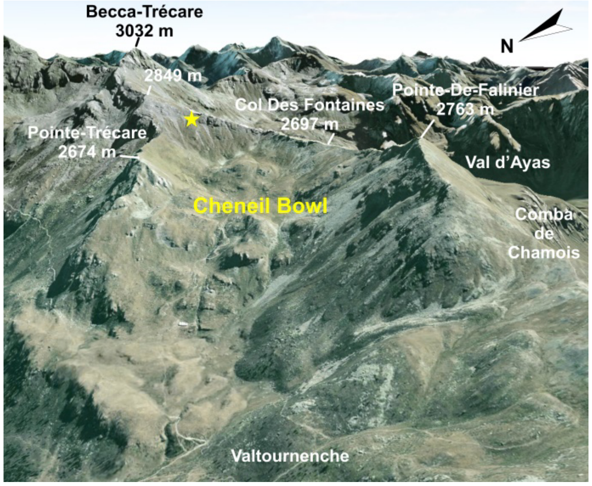

Fig. 01: The Cheneil Bowl in Valtournenche - Aosta Valley - Italy. The yellow star marks accident site. [Image courtesy Valle d'Aosta Region – TerraExplorer©].

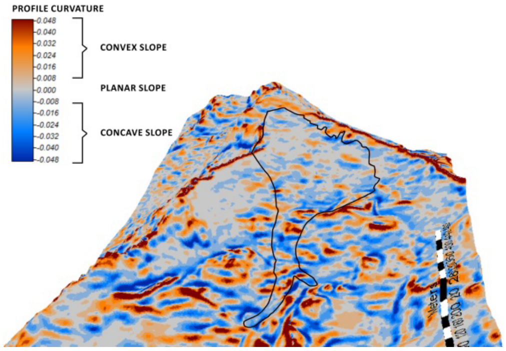

Fig. 02: Profile curvature slope analysis for the Cheneil Bowl area. The black line is the avalanche perimeter.

The bowls shows an average slope angle of 35°degrees with short portions exceeding 45° (Fig. 04).

The bowl is cross-loaded with the prevailing storm track (from N – NW winds) and can be heavily wind-loaded as a leeward side by the less common SE or W winds which deplete, as a fetch, a large untried slope on the SE facing side of a nearby valley (Comba de Chamois) or the bottom of the bowl itself.

Those events usually lead to significant wind deposits (slabs) on persistent weak layers.

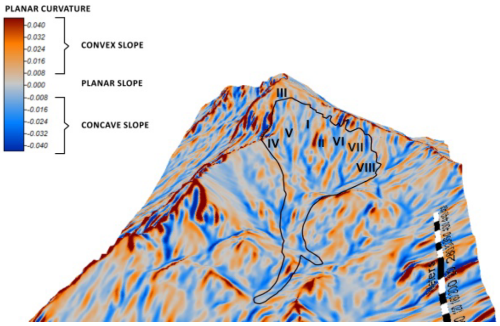

Fig. 03: Planar curvature slope analysis for the Cheneil Bowl area. The black line is the avalanche perimeter. Convex slope marks the watersheds between sub basins (numbered).

The bowl slopes are mostly devoid of significant vegetation in the upper two thirds with only a few small shrubs and large patches of short- to long-stemmed grass alternating with scree of medium to small-sized slab bedrock and sparse angular boulders, with little or no dirt.

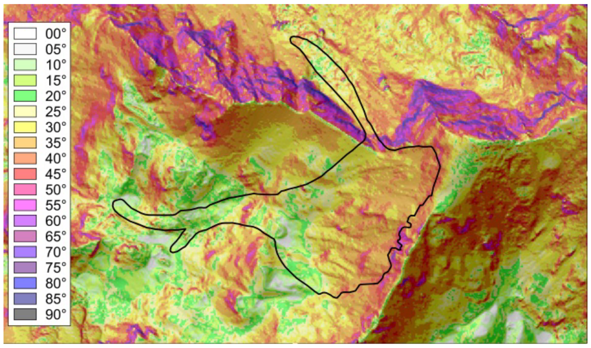

Fig. 04: Terrain slope analysis for the Cheneil Bowl area. The black line is the avalanche perimeter.

3. SNOWPACK HISTORY

The snowpack evolution has been characterized by a rapid succession of snowfalls, generally accompanied by moderate winds and short episodes of strong winds (Fig. 05). On Sat. 25th January 2014, the topmost snowpack was already characterized by variably sintered wind slabs. Onto this partially hardened surface, loose snow was repeatedly deposited as thin soft slabs by strong N-NW winds which sintered, in the end, the new surface. On such wind crust, a new moderate snowfall deposited, with strong wind from N-NW, during Sun. 26th Jan.. On Mon. 27th Jan. a new moderate snowfall deposited onto this new wind crust accompanied, again, by strong winds from the N-NW and by a slight rise in temperatures.

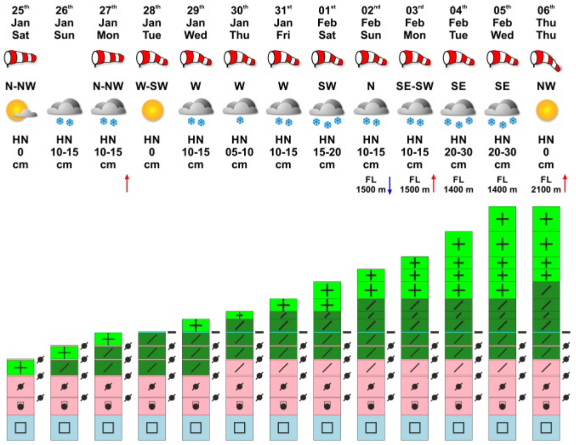

Fig. 05: The snowpack and weather evolution in the Cheneil Bowl area between the 25th Jan. and the 06th Feb.. Cumulated thicknesses do not take into account compaction.

Tue. 28th Jan. was a day characterized only by moderate WSW winds activity and a strong sunshine which allowed the formation of a sun crust subsequently buried by moderate (Wed. 29th and Frid. 31st) and weak intermittent snowfalls (Thu. 30th) all accompanied by moderate W winds. New snowfalls with moderate SW wind were again deposited, during Sat. 1st February 2014, on such previous layers and during Sun. 2nd Feb. their intensity decreased accompanied by a temperature drop due to moderate N winds. On Mon. 3rd Feb. the snowfalls increased again to moderate accompanied by slightly rise in temperatures due to S moderate winds. During Tue. 4th and Wed. 5th Feb. snowfalls intensified and reached valley bottoms always accompanied by moderate SE winds. Spontaneous avalanche activity (loose snow and soft slabs) started early on Tue. 4th Feb. but only with small sluffs and R1, D1 sizes from the steepest slopes. Only on Thu. 6th Feb. the first real bright spell started due to light to moderate NW winds and a progressive temperatures rise. With such conditions, all professionals and recreationists were lured into action as powder fever hatted them all. At such elevations (around 2800 m ASL) the snowpack maintained cold temperatures (-6°/-9°C) despite a slightly warmer air (-3°/-5°C) which allowed moderate faceting conditions enhanced by crusts presence.

Valtournenche's snow pits revealed at least two hard wind slabs sitting onto a weakening base composed of developing facets. Each wind slab was composed of RGwp or RGxf (the lowermost was 60-70 cm thick; the uppermost was 25-30 cm thick) with intercalated wind or sun crusts, all buried under several layers of DFbk – DFdc or PPpl – PPsd - PPnd (approximately 60-90 cm) deposited as an extremely soft wind slab. This fresh snow exhibited poor superficial bonding progressively increasing towards the bottom but moderate to high strength scores (due to progressive compaction). The underlying hard slabs could, therefore, broke over the basal facets only with very high additional loads and in the thinnest areas.

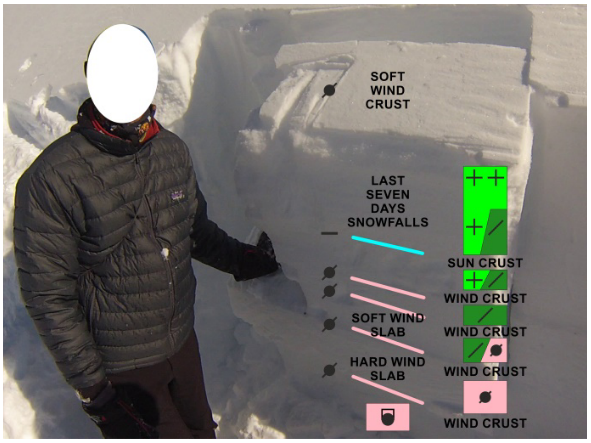

Fig. 06: The snowpack at the snow pit site. Compare with Fig. 05.

The snowpack total thickness was of 170 cm (at the snow pit site) and three critical discontinuities were noted each corresponding to a wind or sun crust (Fig. 06). One was 65-70 cm from the top of the snowpack and yielded at an average extended column test score of 50 (value well above the standard 30 taps) with an average shear high quality (Q2) by a resistant planar fracture (RP) along the wind crust. The other supposed critical surface (wind crust) was at the top of the second wind slab, now buried 45-50 cm down, and did not yielded developing a fracture. The rustchblock test released only the edge at the third, mid-block, jump with an uneven shear (Q3) along the sun crust at 30-35 cm from surface. The issued danger level for that area of Aosta Valley Region was 3 – considerable due to the presence of wind slabs and fresh snow piles.

After working 58' inside the snow pit and despite such results, the snow observers primary concern was still about the latent instability associated with those crust which were still sensitive to high additional load by an artificial triggering. Such additional load was considered being able to possibly found, elsewhere, a thin “sweet spot” around rocks and boulders protruding inside the snowpack and their associated shallow and thick pockets of depth hoar and facets (Fig. 07).

Fig. 07: The snowpack at the avalanche crown in the skied area. Compare with Fig. 05 and 06. The snowpack is considerably thinner and note the facets and depth hoar pockets around the protruding rocks.

The snowpack total thickness of the Heli-skied area was of 90-155 cm. The increasing number of Heli-skiers, reaching the bowl and their activities over a large area (4943 m^2) were a secondary concern due to the possibility of triggering smaller slab avalanches able to step down into the basal facets and thus releasing full depth ones (Fig 08).

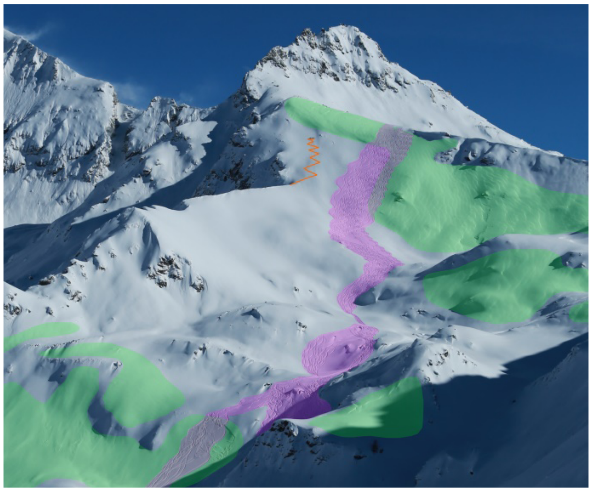

Fig. 08: The Cheneil bowl 32’ before the accident. The orange line is the snow observer’s ascent route to reach the snow pit site. The purple shaded area is the area skied by the Heli-skiers. The green shaded areas are the more surficial and main wind slabs.

Unfortunately, the forecasters were never able to share their concern with the Alpine Guides of the Heli-ski company. The avalanche suddenly released catching them all.

Unbeknownst to all groups, an amateur photographer had just started taking landscape shots of the Cheneil bowl and the surrounding area with a hi-resolution professional camera from the Chamois ridge. Those photos would later be key evidence at trial together with snow observer’s GPS tracks and videos (Fig. 08 and 09).

4. ACCIDENT DESCRIPTION

4.1 *Accident and subsequent rescue*

The 6th February 2014, two parties of 25 Heli-skiers (6 Guides and 19 clients) and 3 snow observers were on separate activity in the Cheneil Bowl, in open terrain, at 2800 m ASL. The group of Heli-skiers started their activities inside the bowl at 11h 19’ 03’’ performing eleven runs along the central sector. The two avalanche forecasters of the regional avalanche warning service (one of them also an Alpine Guide) and a snow observer (an Alpine Guide) entered the bowl from the upper right side at 11h 18’ 56’’, after a long backcountry ascent, and reached the site chosen for the execution of the stability tests after 15’ of climb and 20’ after the start of Heli-skiers activities. There they started digging the snow pit approximately at 45-50 m of distance from the top of the bowl (on the right side of a minor ridge) and 120-150 m away from the skied area. At 12h 10’ 44’’, after snow pit completion, the first ECT was started and was followed by a second ECT and a RB. At 12h 34’ 49’’ a large soft-slab avalanche was triggered, while one of the Alpine Guides and her three clients had started the 3rd run and two more Heli-skiers groups were starting, and caught twelve people [three guides and six clients + three snow observers (Fig. 09)]. At approximately 12h 35’ from the top of the bowl ridge, two other heliski-Alpine Guides made a radio call to the helicopter and to the emergency channel (connected to 112 - European emergency phone number) reporting an avalanche with several people caught. While the survivors and the two alpine guides started, immediately, the self-rescue procedures, the helicopter of the Heli-ski company and the SAR one were able to dispatch the rescue teams of the Border Police (Guardia di Finanza – from Breuil-Cervinia) and of the National Alpine and Speleological Rescue Service (from Aosta) in less than 15’-20’. Upon their arrival, the survivors had already located and partially excavated the two missing persons: one fully buried at 2 m of depth (an avalanche forecaster), responsive and uninjured and one fully buried at 70 cm (an heli-ski Alpine Guide), unresponsive. The SAR medic started immediately life saving measures on the unresponsive person but the Alpine Guide died, unfortunately soon after, during medevac due to several internal organs injuries. The search was called complete after the site was completely searched and cleared by dogs and transceivers and all people were transported at Cheneil hamlet by helicopter save 3 patrollers of the Border Police for the criminal investigations of the site.

4.2 *Technical details of avalanche*

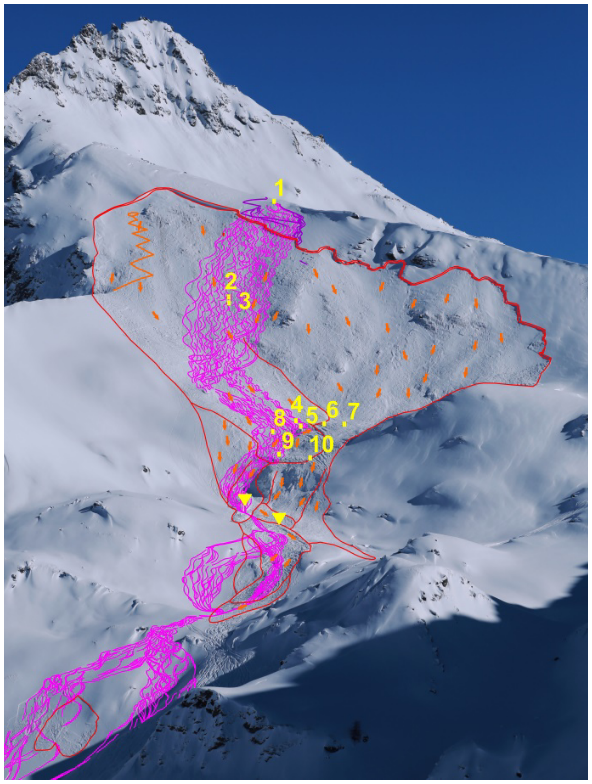

Fig. 09: The Cheneil bowl 3' after the accident. The orange line is the snow observer's ascent route to reach the snow pit site. The purple lines are the ski lines skied by the Heli-skiers. The orange arrows are the avalanche flow marks (scratch). Violet lines are the last ski lines (entering the bowl) skied by the Heli-skiers. Yellow rectangles and numbers are the survivors and the yellow triangles are the buried ones. The red lines are the avalanches perimeter and their depositional lobes.

Avalanche examination found it to be a size 3 artificially triggered dry soft slab. The start zone maximum elevation was at 2801 m, and the minimum deposit elevation was at 2497 m ASL.

The start zone incline average was of 35°-40°, with a total crown width of 384 m (several pockets), and a crown line average depth of 95-180 cm (several pockets up to 255 cm). 40000 m^2 of release area and 30230 m^2 of deposit area (Fig. 09). The slab avalanche was fist/four finger hard in its topmost part and it then stepped below the sun crust and entrained older slabs, finger/pencil hard, and almost all old snow close to the ground.

Snow observer's GPS data logger analysis fixed a time of detachment at 12h 34' 49'' local time, a duration of event of 1' 18'', an average avalanche speed of 36 km/h, and a maximum avalanche speed of 174 km/h [DOP 1,78 m; ± 12 km/h].

The prosecuting attorney initially charged the snow observers for the accident, but further investigation has officially assessed a different dynamic, which will be illustrated below, and a total discharge for them.

5. ACCIDENT ANALYSIS

5.1 *General analysis*

Based on available data, the Cheneil bowl's snowpack was composed of at least three wind slabs partially overlapped and separated by various types of crusts (Fig. 05, 06, 07 and 10).

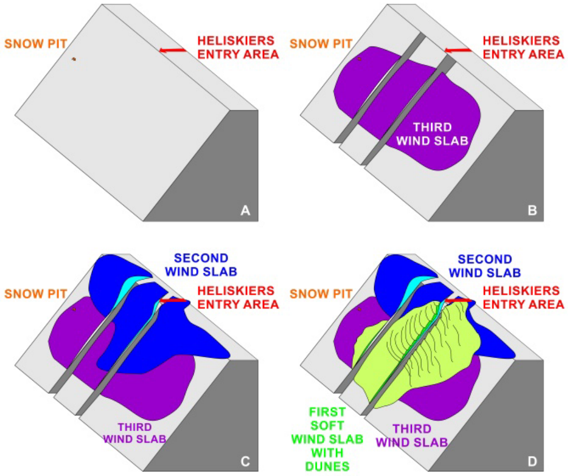

Fig. 10: 3D conceptual model showing the simplified geometrical relationships (overlap) between the three wind slabs in the Cheneil bowl. Wind slab's deposition time sequence is from A to D.

The deeper wind slab was one-finger to pencil hard and the thicker (60-70 cm in the snow pit area and less than 40-50 cm in the skied area). The second wind slab, pencil hard, was particularly thick in the ridge area (up to 155 cm) but it laterally tapered to thin deposits (25-30 cm in the snow pit area and less than 10-15 cm in the skied area). The surface wind slab, fist/four finger hard, showed very variable thickness and was locally covered with a "soft" newly formed wind crust laterally discontinuous. It was also characterized by the widespread presence of snow dunes, of various amplitude and wavelength, particularly visible in the bowl's left sector (see also Fig. 08 and 09).

In artificially triggered avalanches, the initial cut and collapse beneath the slab is achieved due to an applied instantaneous or cyclically repeated additional load especially over the thinnest and less rigid sector of the slab (e.g. Perla and LaChapelle, 1970; Brown et al., 1973; Lang and Brown, 1975; Bradley et al., 1977; McClung, 1979, 1981; Conway and Abrahamson, 1984; Gubler and Bader, 1989; Bader and Salm, 1990; Duclos, 1998; Tremper, 2001.2008; Schweizer and Jamieson, 2001; Schweizer et al, 2003; Failletaz, 2010). Thus, the lowest values of stability are found in the thinnest areas of the wind slab (Stewart, 2002; Kronholm, 2004; Campbell, 2004; Föhn, 1989; Jamieson, 1995).
Such triggering mechanism can be enhanced if the reduced thickness of the slab is increased by rocks or trees protruded within the snowpack (e.g., buried at a shallow depth) which will allow the subsequent extension of the fracture even in areas of particularly thick slab (Jamieson, 1995). It is indisputable that the area covered by the heli-skiers presented thicknesses of less than half of those measurable in the snow pit area, therefore the first one was the more prone to avalanche triggering. It is also worth noting that a heli-skiers party detached, during one of the previous runs, a small wind slab further downslope but, tragically, that event was never brought to the attention of all the other Alpine Guides nor of the Snow Observers (Fig. 09).

This recent wind slab could erroneously being interpreted (e.g. by heli-skiers) as powdery snow as they were skiing immersed, up to their knees, in the surface soft wind slab and slipping directly on top of the second slab. The second wind slab resistance was further reduced by the repeated skiers activity which cyclically applied an additional load thus weakening the snowpack due to a fatigue phenomenon. The Alpine Guide and its clients, contrary to previous runs and misled by their previous positive experiences (an example of heuristic trap), began their last run all together and side by side (tight turns) on one of the steepest parts of the bowl (43°) – [see violet lines in Fig. 09 and 12]. The Alpine Guide did soon stopped the three clients, probably realizing their initial mistake, just before the primary slope break over and continued alone the run, on even steeper terrain, to trace the path. The three clients, staying on top of the break over, probably clustered to comment the run thus inducing a strong additional load and favouring the lateral shear fracture propagation in a few tenths of a second. The induced stress created by the partial collapse of this second slab and of the overlying soft slab, has subsequently led to fracture also the underlying deeper slab thus completing the detachment of the avalanche.

5.2 *Avalanche's deposit analysis*

The extensive literature on granular polydispersed gravity flows shows that its material during flow and deposition tends to be segregated into "grain carpets" which reflects roughness (shape), size, density of particles and their speed (Andreotti et al., 2013 cum bibl.). Such dynamical segregation generates several types of structures in the front, sides and tail of each flow (Pouliquen and Vallance, 1999 cum bibl.) – Fig. 11.

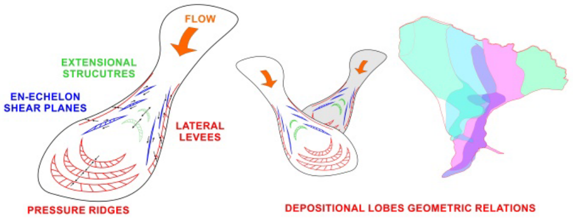

Fig. 11: Conceptual model for dynamical segregation structures in polydispersed gravity flow deposits. From left to right: details of structures in each depositional lobe; depositional lobes geometric relations (stacking and overlap); depositional lobes identified in the Cheneil avalanche event.

In avalanches, in particular, are commonly formed depositional lobes or flow fingers containing other structures like pressure ridges, levees, en-echelon shear planes, channels and sidewalls, scratch marks etc. (see Bartelt et al., 2012 for a detailed discussion and cum bibl.). The analysis and identification of such diagnostic elements of the avalanche deposits and their geometric relationships made it possible to establish a relative chronology (depositional lobe's stacking pattern) of flow concentration times and sub-basins slab release sequence. Due to the size of the avalanche area, as a matter of fact, its release was not contemporary but took place a few tenths of a second or seconds one sector from the other depending from fracture speed propagation and distance from the triggering point.

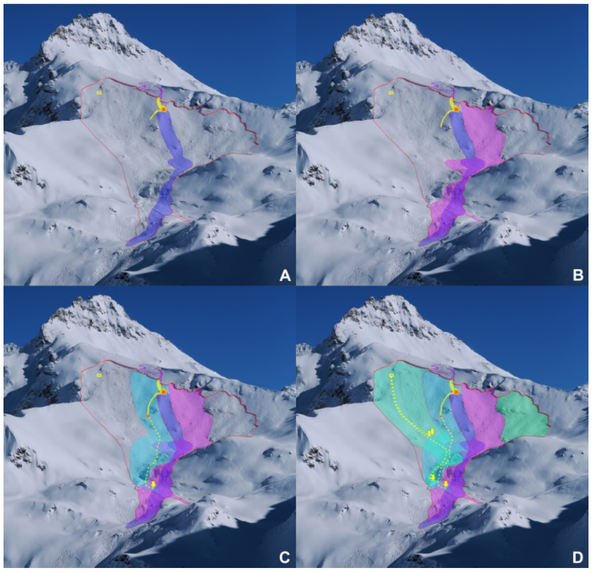

Fig. 12: From A to D: sequence of release of the wind slab avalanche in the Cheneil bowl. Violet lines are the last ski lines (entering the bowl) skied by the Heli-skiers. Yellow shaded area is the inferred skied area. Orange symbol is the inferred triggering point. Yellow rectangle is the snow pit location. Yellow dotted lines are avalanche transport path of caught people (Alpine Guide and Snow observers). Red lines are the avalanche perimeter and its depositional lobes (in shaded colors).

As showed in Fig. 12 and based upon depositional lobes geometric relations, the skied snowpack sector was the first to collapse while the sector where the snow pit was located was the last one.

6. CONCLUSIONS

This avalanche accident was caused by the sum of several factors: the lack of safety operations procedures complying to the international best practice; an incorrect assessment of snowpack conditions and an underestimation of the avalanche bulletin danger scenario; a heuristic trap connected with overconfidence and powder snow euphoria; communication failures between members of the heli-ski group and the Alpine Guides (unreported first small slab avalanche triggering) as well as between the snow observers team and the heli-ski Alpine Guides.

This event had a tremendous impact on several families and has potential to impact on the future of heli-ski industry in Italy. We do hope that all professionals will be able to learn from it. Everyone makes mistakes but we should always learn from them.

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