LESSONS FROM THE CERRO COCINERO AVALANCHE: AEROSOL DYNAMICS AND IMPLICATIONS FOR SEARCH AND RESCUE OPERATIONS

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ABSTRACT: On August 27, 2010, a large avalanche struck Cerro Cocinero (2,281 m), destroyed a mountain hut and buried three occupants. Due to delayed alert, search and rescue (SAR) operations began two days after the event, under challenging conditions including deep burial, fresh snowfall, and uncertain location data.

Initial assessments identified a debris field approximately 300 m long and up to 8 m deep. Early search efforts were hindered by inaccurate GPS positioning and misleading surface indicators, leading to excavation in incorrect locations. Despite systematic probing strategies, including a standard downhill search cone, no evidence of the buried structure was initially found.

After several weeks, a detailed field analysis of the avalanche path provided critical new insights. Observations of tree damage patterns indicated that a powerful aerosol phase impacted the refuge at an estimated angle of approximately 70°, prior to the dense flow. This suggested a significant lateral displacement and structural fragmentation of the refuge, challenging the assumption of a purely gravity-driven burial directly downslope.

Based on this revised interpretation, a new search area was defined. Recco detector signals identified anomalous targets, leading to the recovery of structural elements and personal equipment. These findings supported the hypothesis that the upper section of the refuge had been displaced and partially filtered through the forest, illustrating a “sieve effect” caused by vegetation interaction with the aerosol cloud.

This case study highlights the importance of considering avalanche aerosol dynamics in post-event analysis, particularly for buried structures. It also underlines the limitations of conventional search geometries and the value of combining terrain analysis, vegetation damage interpretation, and technological tools in SAR operations.

KEYWORDS : avalanche dynamics, aerosol phase, search and rescue, recco detection, avalanche impact, field case study

1. INTRODUCTION

Large-scale avalanches that impact occupied structures present a distinct search-and-rescue challenge compared to the more typical scenario of locating individuals buried directly within avalanche debris. Search timelines often diverge significantly, and the avalanches involved introduce complexities of an entirely different magnitude. Furthermore, such events leave more pronounced and enduring scars on the mountain landscape—features that remain identifiable not only during the summer months but for many years afterward to those skilled in interpreting alpine terrain.

This paper presents a retrospective case study of the 2010 Cerro Cocinero avalanche, with emphasis on the evolution of the search strategy and on the field evidence used to reconstruct the event. The objective is not to provide a quantitative dynamic model of the avalanche, for which no direct measurements of velocity or impact pressure were available, but to document how a revised interpretation of vegetation damage and debris distribution changed the operational search hypothesis.

2. EVENT AND OPERATIONAL CONTEXT

2.1 Event chronology and site conditions

During the night from Thursday, August 26, to Friday, August 27, 2010, following several days of heavy snowfall, a massive avalanche swept

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down the slopes of Cerro Cocinero (2,281 m), carrying away the eponymous mountain hut in its path. Three mountaineers were spending the night inside.

It was not until Saturday that the alarm was raised, as the mountaineers failed to meet the scheduled pickup vehicle at the base of the mountain. On Sunday, improved weather conditions allowed a helicopter reconnaissance flight, during which the disappearance of the hut was confirmed.

By Monday, the first rescue teams on-site could only assess the extent of the destruction. Where a hut had once stood at the edge of a stream and a forest of 7–8 m tall trees, there was now a vast white deposit over 500 m long and up to 8 m thick.

Picture 1: First part of the hut found more than 300m from the basement.

2.2 *Initial Search Efforts*

A preliminary surface search located a fragment of the hut in a rock face more than 500 m below its original location, rescuers faced a critical question: where to begin the search for the victims?

Picture 2: Canine search.

Canine search was attempted, but the effectiveness of sent-base methods was reduced by :

- The large number of rescuers who had already traversed the area, disrupting scent trails.
- The sheer size of the deposit.
- A subsequent snowfall of over 1 meter that covered the deposit, limiting access to scent chimneys

Because the avalanche occurred at night, rescuers also considered it likely that the victims had remained inside the sleeping area of the hut.

To recover the victims, it was essential to determine the hut's exact location. The reference GPS point led to the excavation of a 10 m deep hole—without success. It took 10 days to discover the hut's actual location, buried 6 m deep.

This was achieved by:

1. Comparing photographs of the hut with the altered terrain.
2. Probing with gas pipes to identify structural remnants.

The GPS point was found to be over 20 m off from the true location.

Only elements from the hut's lower section were recovered; no traces of the attic, which served as the dormitory, were found.

Picture 3: Basement of the hut found after several days with triangulation technic based on old pictures.

TIME	***Operationnal development***
Night 26-27	Avalanche destroys the hut.
28 Aug	Alarm raised when the mountaineers fail to meet the scheduled pickup vehicle.
29 Aug	Improved weather permits helicopter reconnaissance; disappearance of the hut is confirmed.
30 Aug	First ground rescue teams assess a debris field extending several hundred metres, with reported depths up to approximately 8 m.
~Day 10	The actual hut location is identified approximately 6 m below the surface; the reference GPS position is found to be more than 20 m from the true location.
Day 33	New hypotesis for the avalanche dynamic
Day 34	First elements of the upper part of the hut found, confirming the theory
Day 36	Bodies found, End of the rescue operation

2.3 Systematic Search and a New Theory

For several weeks, rescue teams conducted a methodical and exhaustive probing operation within a 60° cone extending downward from the hut's presumed location and along the avalanche's path. Despite their efforts, no traces of the victims or the hut's upper structure were found. The sheer scale of the deposit, combined with the rapid burial under fresh snow, made traditional search methods ineffective.

After 26 days of fruitless efforts, a detailed analysis of tree branch patterns on the avalanche's flanks provided a critical breakthrough. The avalanche aerosol—a high-velocity powder cloud—appeared to have impacted the hut long before the dense flow arrived. The trajectory of the aerosol, reconstructed from vegetation damage and snow deposition patterns, suggested it had struck the hut at an angle of over 70° relative to its orientation.

This extreme angle indicated that the hut, already buried up to the base of its roof by the initial snowfall, may have been decapitated by the aerosol's blast wave. The force of the aerosol could have lifted and laterally displaced the upper structure before the dense flow engulfed the entire site, carrying away the remnants.

This new understanding led to a revision of the search strategy. A second search cone, offset by over 60 m from the original area, was established to account for the lateral displacement caused by the aerosol. This adjustment was based on the hypothesis that the victims and structural elements might have been pushed sideways rather than buried directly beneath the avalanche's main path.

Picture 4: RECCO search.

2.4 RECCO detections and final recovery

A new search cone, offset by over 60 m from the original, was established. A Recco detector search revealed two faint signal returns. After five consecutive blind searches, both points were consistently confirmed.

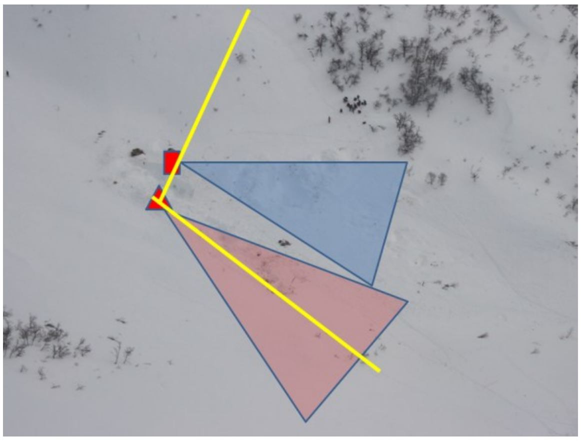
First probe: A touch was detected at 1.3 m depth, uncovering a wooden plank. A nail securing a hinge had acted as an antenna, reflecting the Recco signal.This plank was the first identified element of the hut's upper section.

Second signal: A down jacket containing a mobile phone and a headlamp confirmed the theory. The aerosol had blown off the hut's upper roof, projecting debris onto the valley's flank. The dense flow then followed the valley floor's topography, while the forest acted as a sieve, allowing only smaller debris to pass through.

Progressive probing subsequently uncovered additional victim belongings and structural elements.

It took over 5 days to trace the recovered elements back to the hut.

Finally, the roof and the three victims were found only ~50 m from the hut's original position, buried 5 m deep but laterally displaced from the avalanche's main flow path.



Picture 5: Source schematic comparing the initial search sector with the laterally offset revised search sector.

3. POST-EVENT ANALYSIS: DENDROCHRONOLOGY AND HISTORICAL CONTEXT

A return to the site the following summer, accompanied by Alejandro Casteller, a dendrochronology specialist, allowed for a comprehensive post-event analysis.

The investigation focused on reconstructing the avalanche’s dynamics and understanding the historical context of similar events in the area.

Picture 6: The hut, days before the avalanche.

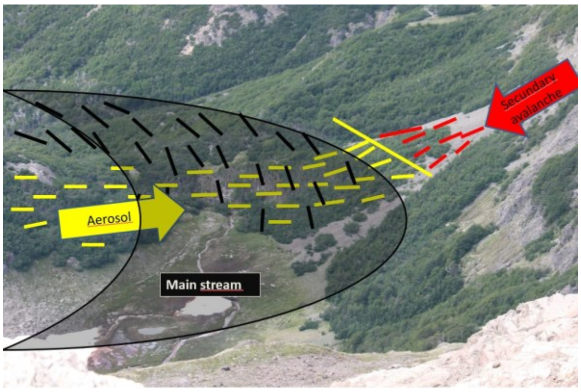
3.1 *Initial Trigger and Cascade Effect:*

The avalanche was initiated as a slab avalanche in the cirque’s bowl. Given the meteorological conditions—rapid and heavy snowfall over a short period—the weak layer likely consisted of a thick accumulation of poorly bonded snow particles. This instability triggered the initial release, which then "pulled" the adjacent slopes, entraining a massive volume of snow and transforming the event into a large-scale avalanche.

3.2 *Aerosol and Dense Flow Dynamics: The avalanche exhibited a two-phase structure:*

1/ The aerosol phase, a high-velocity powder cloud, followed a distinct trajectory visible in the vegetation. It ascended the opposite hillside before doubling back to strike the hut’s location, effectively "scalping" the structure by removing its upper section.

2/ The dense flow phase followed the valley floor, bending trees—already felled by the aerosol—at 90° angles, indicating the immense force exerted by the moving snow mass.



Picture 7 & 8 : Avalanche scares in the forest

3.3 *Secondary Avalanche Complication:*

Simultaneously, a secondary avalanche on the opposite slope further complicated the deposition pattern. This additional event overlapped with the primary avalanche’s path, creating a complex and layered debris field that made the search and analysis more challenging.

3.4 *Dendrochronological Insights:*

Dendrochronological studies conducted by Alejandro Casteller and his team on the valley's trees—some of which were over 70 years old—revealed that a similar large-scale avalanche had occurred 17 years prior to the 2010 disaster. This historical event had left distinct scars on the vegetation, providing evidence of recurring avalanche activity in the area

Picture 9: Dendrochronological field investigation during the post-event site visit.

3.5 *Hut Construction and Historical Evidence:*

The hut had been constructed 16 years before the accident. Archival photographs from the Trevelin Andean Club's magazine, taken during the hut's construction, clearly show remnants of damage caused by the avalanche that occurred the year before construction. This suggests that the site had a known history of avalanche activity, yet the hut was built in a vulnerable location.

Picture 10: View from the upper avalanche path toward the valley. The red circle marks the pre-event hut location.

4. DISCUSSION :

4.1 *Implications for search-area definition*

The central operational lesson from this case is that the expected transport direction of a destroyed structure should remain a working hypothesis rather than a fixed search geometry. The initial search sector was reasonable under a predominantly downslope transport assumption, but it did not account for the laterally displaced upper structure. When repeated systematic searching produces no supporting evidence, the underlying transport model should be re-examined against field observations.

4.2 *Value of vegetation and debris evidence*

Picture 11: Example of severe vegetation damage observed in the avalanche path.

Vegetation damage provided information that was not available from the snow deposit alone. Differences in damage orientation between the valley floor and the flanks were used to infer distinct flow directions. In this case, combining vegetation evidence with the spatial distribution of debris and electronic detector returns was more informative than relying on any single indicator. The case therefore supports a multi-evidence approach to prolonged SAR operations involving structural burial.

4.3 *Geolocation and detection technology*

The more than 20 m discrepancy between the recorded GPS point and the subsequently identified hut location demonstrates the operational significance of geolocation uncertainty when burial depths are several metres. Independent position verification using photographs, terrain features, and probing was essential. RECCO detection also contributed to the revised search by identifying repeatable targets associated with structural debris and personal equipment. This observation should be interpreted as case-specific evidence rather than a general statement about detection range or probability of detection.

4.4 Limitations

Several limitations constrain the interpretation of this case. The avalanche occurred in 2010 and the reconstruction relied primarily on post-event field evidence rather than contemporaneous instrumentation. No direct velocity or impact-pressure measurements were available. More than 1 m of subsequent snowfall altered the surface expression of the deposit. A secondary avalanche complicated the depositional pattern, and the initial hut position was uncertain. The inferred powder-cloud trajectory and the mechanism by which the upper hut structure was separated therefore remain qualitative hypotheses rather than quantitatively validated dynamic results.

5. CONCLUSION :

The Cerro Cocinero case illustrates the difficulty of defining search areas when a large avalanche destroys and transports an occupied structure. The initial assumption that the missing upper structure and victims would be located predominantly downslope did not adequately explain the observed absence of debris in the initial search sector. Re-examination of vegetation damage and debris distribution led to a revised interpretation of the avalanche flow and to a laterally offset search sector where structural elements and personal belongings were subsequently identified.

Three practical considerations emerge from the case: (1) verify the pre-event position of buried structures using more than one source when possible; (2) use vegetation damage and debris distribution to test the assumed transport direction; and (3) periodically reassess the search hypothesis when observations are inconsistent with expected deposition patterns. The event also demonstrates the value of combining systematic probing, terrain interpretation, and electronic detection tools during prolonged structural-burial searches.

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