Ash and snow, impact on the avalanche hazard of ash layers in the snowpack.

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ABSTRACT: On the 4th of June 2011, the Cordon del Caulle Volcano situated in the Chilean Andes exploded sending a huge amount of ash and volcanic material into the atmosphere. Winds blew this material from Chile to Argentina. Some of the thinner particles even disturbed the airplane traffic in South Africa, Australia and New Zealand. During the whole winter, the volcano spread and deposited ash on the snow cover of the Argentinian Andes. During the whole winter layers of alternating ash and snow resulted in an incredible snowpack. Worried about the avalanches that this unusual snowpack might produce, the ski resort of Cerro Bayo, 40km from the volcano, asked Preventura to study the stability of this snowpack.

KEYWORDS: Ash, Volcano, Avalanche, Snow, Snowpack, Stability

1 INTRODUCTION
On the 4th of June 2011, the strato-volcano Puyehue – Cordón Caulle (CVPCC) (40°35’25”S - 72°7’2”W) located in the Republic of Chile started an eruption that would last for 8 months. The first explosion set up a 10 000m high and 5 000m wide plume of gases and pyroclastic materials.

More than 20cm of ash and volcanic material covered the Villa la Angostura area, where Cerro Bayo ski resort is located.

An estimated total of one hundred million tons of ash, sand and pumice stone were ejected during the whole eruption.

As the eruption weakened, the ash layers started to be thinner. The frequency of the snow storms and the changes of the wind direction explained how the snow-ash pack from Cerro Bayo was totally different from a snowpack 20km away.

Biggest pyroclastic material fell closer to the volcano while the finest ash was found as far away as South Africa, Australia, and New Zealand. Some of this material even returned back to Chile carried around the world by high altitude winter.

Volcano eruption intensity, direction of the winds and snow storms resulted in different layers of pyroclastic material and snow. The first volcanic layer was the biggest.

FIGURE 1: Satellite image of Puyehue ash and gas cloud.

FIGURE 2: the incredible snow-ash pack at Cerro Bayo ski resort during winter 2011.

2 AVALANCHE HAZARD

Faced with such an unusual situation, authorities decided to close all roads and access to the upper parts of the mountain.

When the eruption slowed down in July, the Cerro Bayo ski resort had to decide if the ski resort could open or not.

Snowfall had covered the ash layers so that skiing was thinkable. The real worry was about the avalanche hazard.
3 STABILITY TEST AND SNOW PROFILES

Diego Seba, Cerro Bayo ski patrol and in charge of the snowpack analysis and avalanche bulletin, and I went to the upper part of the mountain to evaluate the stability of the snowpack.

We decided to start looking for the worst stability configuration in a 45° slope, and supersizing the test.

We did Compression Tests (CT), Shovel Shear Tests (ST), Extended Column Tests (ECT), and Rutshblock Tests (RB), and none of tests presented any sign of instability.

Moreover, we did the column test on a 160cm column, which should generate a structural instability of the column and had no result.

When I decided to pull down the column, I could not manage to do it on my own and had to ask Diego to help me. We broke the column at its base, in an ash layer, but if you pull down a column you will often break it at its base (like a stick in concrete).

Even throwing down the column on to the 45° slope it not break it. The column only broke when it hit a big rock.

4 SOME DATA

The densities of the ash layers were around 700 to 800Kg/m³.

We were surprised to find liquid water in a sand/ash layer with a temperature of -3°C. When this layer got exposed to the air at -8°C only then did the water start freeze.

Some chemical element of the ash had prevented the water to freeze at -3°C.

This opinion was confirmed later by the chemical analysis of the sands and volcanic ash.

FIGURE 4: X-Ray fluorescent analysis of the elements.

<table>
<thead>
<tr>
<th>Element</th>
<th>g/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon (Si)</td>
<td>32,25</td>
</tr>
<tr>
<td>Aluminium (Al)</td>
<td>7,93</td>
</tr>
<tr>
<td>Iron(Fe)</td>
<td>3,70</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>1,78</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0,28</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>---</td>
</tr>
</tbody>
</table>

Main composition of the volcanic material was (Na (Si,Al)O₈) Albite (NaAlSiO₅) is a plagioclase feldspar mineral. It is the sodium endmember of the plagioclase solid solution series. As such it represents a plagioclase with less than 10% anorthite content. The pure albite endmember has the formula NaAlSiO₅. It is a tectosilicate.

FIGURE 5: pH analysis.

<table>
<thead>
<tr>
<th>Element</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10g/25ml of water</td>
<td>7,3</td>
</tr>
<tr>
<td>+25ml of water</td>
<td>7,3</td>
</tr>
</tbody>
</table>

FIGURE 6: Granulometry analysis.

<table>
<thead>
<tr>
<th>TAMIZ IRAM</th>
<th>Partially retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>N°3/8” (9,5 mm)</td>
<td>---</td>
</tr>
<tr>
<td>N°4” (4,75 mm)</td>
<td>1,1</td>
</tr>
<tr>
<td>N°8” (2,36 mm)</td>
<td>2,2</td>
</tr>
<tr>
<td>N°16” (1,18 mm)</td>
<td>9,0</td>
</tr>
<tr>
<td>N°30” (600 µm)</td>
<td>17,9</td>
</tr>
<tr>
<td>N°50” (300 µm)</td>
<td>23,7</td>
</tr>
<tr>
<td>N°100 (150 µm)</td>
<td>11,6</td>
</tr>
<tr>
<td>More than N°100 (150 µm)</td>
<td>34,5</td>
</tr>
<tr>
<td>N°200” (75 µm)</td>
<td>---</td>
</tr>
<tr>
<td>More than 200” (75 µm)</td>
<td>---</td>
</tr>
</tbody>
</table>

Over the course of the season and eruption the ash layers became thinner and the granulometry of the materials smaller. This was also a reason
why we repeated the tests throughout the whole season. None of tests showed instabilities.

5 OUR CONCERN

Some of the ash layers were like frozen concrete. Based on the experience about dust layers*, we were afraid that the melting snow would lubricate the surface, and generate big wet snow avalanches at the end of the season or during a significant rainfall. However, we were not prepared to what happened.

![Figure 7: Ash rose from the under layers and ran over the snow.](image)

Water caused by the melting snow was draining down in the snowpack to the ash layer, melting a part of it to an emulsion (like in a coffee filter) that was coming up through the snowpack to the surface (capillarity?) and then running over the snowpack.

![Figure 8: Melting snow and ash](image)

FIGURE 7: Ash rose from the under layers and ran over the snow.

6 DUST LAYERS VS ASH LAYERS

It seems that the volcanic layers differed from the thin dust layers experienced in Colorado, or in other locales like the Alps or Japan* A. Anderson, T. Painter and C. Landry, observed that thin dust layers facilitated the grow of faceted grains and the formation of weak layers that could be prone to avalanching. They also found that melt water moves horizontally through the weak layer and could lubricated bed surfaces. Seems none of this happened in Argentina. We found strong layers that were well adhered to each other. We had some surface hoars on the surface ash layers and some pipkrakes but with no real impact on the global stability. During melt conditions, the ash actually traveled upwards through the snowpack.

7 ASH SPECIFITY?

Over the years some investigators have used chocolate powder in order to better visualize the snow layers. We had the “luck” to have a daily ash fall that was allowing us to see all the snow layers in the snowpack during the whole winter and to see how it was melting at the end of the season.

When we made the snow profiles, we found some very specific forms. Some layers had rolled over on themselves. Other layers ended abruptly.
8 RAINFALL RESISTANCE

We were surprised to see how long the snowashpack (SAP) afforded the rainfall and the compact it was. The salts lowered the freezing point and there is maybe something about the very fine particles that caused better bonding within a snow layer, and larger particles caused bonding between snow layers. Perhaps the snow-ash pack (SAP) is something like concrete where the mixture of snow and ash (aggregates, like the pebbles and rocks in concrete) are combined and result in a much stronger material than their individual materials. Also, perhaps a high coefficient of friction in the ash might also help the layers adhere. However, it seems like there is some binding process that made the snow pack so strong.

At the end of the season, the snow layers melted but the thickest ash layers acted as an isolator and in some places allowed the snow not to melt during the whole summer.

9 CONCLUSION

Very few experiences have been done on snowashpack (SAP). Granulometry, ash/sand chemical composition, quantity of material, all affect the snow and seem to affect the strength and stability of the whole snowpack.

Are the observations done only a consequence of the ash or is the ash only a revelator of what cannot be seen usually? The ash highlighted all the layers and revealed a much more complicated snow pack stratigraphy -- and over very short distances -- than we had ever imagined. We suspect that when the snow is clean this convoluted structure is concealed by the general uniformity of snow (very similar grain sizes, shapes and hues). This newly observed snow layer complications likely exists everywhere, but we (and the people we have been talking to) have not seen it before. We suspect these local complications only add more complexity to the challenge of assessing snow stability.

No avalanches were observed releasing in or on an ash layer has been observed during the 2011 season and no important lahar at spring time.

Our investigation of the snow and ash pack seems to raise more questions than answers.
We hope other researchers will study these remarkable conditions when they occur.

10 ACKNOWLEDGEMENTS AND THANKS

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