SERNAGEOMIN
Ministerio de Minería
Gobierno de Chile

*'Understanding volcanoes and society: the key for risk mitigation'*

CITIES ON VOLCANOES 9

Puerto Varas - Chile

November 20th to 25th, 2016

# FIELD GUIDE

## OSORNO AND CALBUCO VOLCANOES: FEATURES AND IMPACTS OF THE APRIL 2015 ERUPTION - COMMUNITY AWARENESS AND PREPAREDNESS

INTRACONFERENCE FIELD TRIPS FTB1 & FTB2

November 23rd, 2016

Mauricio Mella B.
Hugo Moreno R.
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## INTRODUCTION

Calbuco Volcano (2.003 m a.s.l.) is located at 41,3° and 72,6 °'W, 30 km NE of Puerto Montt (the Los Lagos Regional Capital with *ca*. 221.000 inhabitants) and toward the E of Puerto Varas (~40.000 inhabitants). The villages closest to the volcano are Ensenada 14 km N, Colonia Río Sur 10 km W and Correntoso 11 km S (Figure 1).

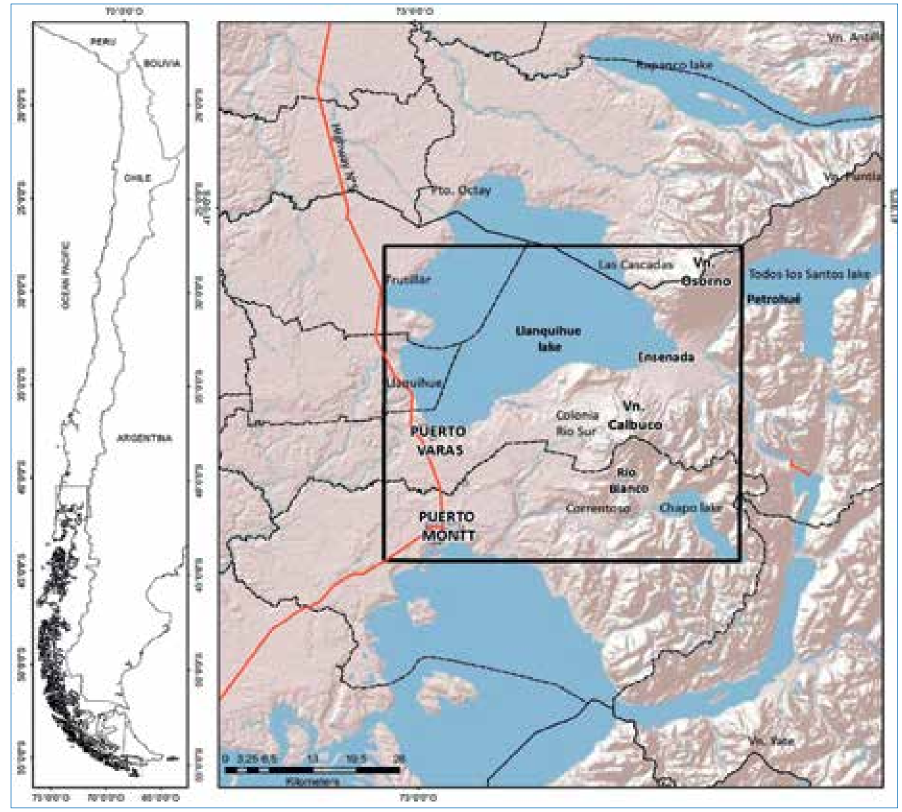


Figure 1. Location of the area to visit.

## Geologic background

Calbuco volcano is located to the West of the main trace of the Liquiñe-Ofqui fault zone (ZFLO). The volcanic edifice corresponds to an irregular truncated cone, with an avalanche theatre opened towards the NE-E, partially filled by a lava dome, lava flows and pyroclastic deposits The volcano has been built over the last ~ 300 ka, along four main volcanic stages: Calbuco 1 (~ 320-110 ka), Calbuco 2 (110 - ~ 14 ka), Calbuco 3 (14 ka-Upper Holocene) and Calbuco 4 (Historic; Sellés and Moreno, 2011). The Calbuco 3 stage ended with the debris avalanche. The documented historic activity, mentions at least 12 eruptive cycles, 4 of them occurred in the Twentieth century, which consisted in explosive and effusive activity. Andesite is the main composition of Calbuco, prevailing intermediate to silicic andesites (57-62% $SiO_2$) with scarce basaltic andesites (Sellés and Moreno, 2011). Taking into account the Calbuco geologic evolution, a zoned volcano hazards map was made (Moreno, 1999) indicating that the possible future pyroclastic density currents (PDCs) and hot lahar impacts could occur, mainly towards the NE and E flank, where the active dome is located, affecting Blanco Norte – Frío and Tepú river valleys, where Ensenada is located. The PDCs as well as lahars could also have an effect on river valleys that born on the S and SW flanks of the volcano where today is located the Correntoso-Lago Chapo villages.

The map of the 2015 April eruptions, made by the different volcanic processes that took place (Mella *et al.*, 2016), showed that the 1999 Volcano Hazards map remains valid. According to the specific risk ranking (Lara *et al.*, 2011; SERNAGEOMIN, 2015), Calbuco volcano is in the third place.

## Last eruption cycle (April - May 2015): volcanic products, impacts and emergency management

On April 22$^{nd}$, 2015 afternoon, Calbuco volcano reawakened (18:04 hrs) after 54 years of silence since its last major eruptive cycle in 1961. The 2015 cycle began with a first pulse that generated an eruption column of 15 ± 0, 5 km above sea level, for over 1.5 hrs. The second major pulse on April 23$^{rd}$, at 01:15 hrs, generated a column of 17± 0.3 km above sea level, during, approximately 6 hrs. Finally, a third pulse on April 30$^{th}$ at 12:10 hrs, generated an ash column of 3 km above the crater, with a plume dispersion toward the SE for less than 1 hr (Figure 2: sequence of the three pulses).

Several studies have defined this eruption as subplinian based on its volume and column height (Bertin *et al.*, 2015; Mella *et al.*, 2015; Romero *et al.*, 2016). However, from the point of view of the ejecta morphology, mainly collected from the second pulse (Figure 2B) it does not correspond to a typical subplinian eruptive style, although it was a permanent lava source fountaining more than 2 km high, with dense pyroclastic rocks (2 g/cm$^3$) that generated radial pyroclastic density currents (PDCs) on the slopes of the volcano.


Figure 2. The three pulses of the April 2015 eruptive cycle

The main volcanic products of the 2015 eruptive cycles were pyroclastic fall deposits toward the NE (Figure 3: volcanic products and Figure 5), together with PDCs and lahars, mainly to the S. These products generated several impacts on people and exposed infrastructure, such as:

i) damage by lahars in houses, farms and roads in the river basins Blanco Sur, Blanco Este, Correntoso and Pescado (Figure 4a);
ii) destruction of the Ensenada hydroelectric power plant
iii) effects on the Llanquihue Forest Reserve by PDCs at the Frio-Blanco Este and Tepú rivers (Figure 4b);
iv) roof collapses by the dense pyroclastic falls in Ensenada (Figure 4 c);
v) a total of 6.685 evacuated people;
vi) damage by pyroclastic falls in the crops, apiculture, salmon industry, mussel culture, livestock and tourism;
vii) Air traffic disruption in the Southern Cone (Figure 4: impacts; Nick *et al.*, 2015).

Subsequent to the 2015 eruptive cycle, rains reworked the PDCs deposits in the river valleys Frio-Blanco Este and Tepú, generating secondary lahars that affected the road network close to them.


Figure 3.Products of the April 2015 Calbuco volcano eruptive cycle. **A:** pyroclastic fall dispersal toward the NE where is located the village of Ensenada. **B:** channeled pyroclastic flows in the river valleys of Frio-Blanco Este, Tepu and Blanco Sur. **C:** lahars of the rivers Blanco Sur and Este towards the area of Río Blanco farmhouses and Lago Chapo.

To manage the emergency and the specific requirements of services and authorities, the Calbuco 1999 Hazards Map was very useful and versatile. In addition, different maps of the eruption products and processes were generated. Dynamic hazards maps of the possible ash dispersion were also made, together with daily reports of the seismic and volcanic activity behavior. They helped to determine areas that could possibly be affected if similar pulses were generated and also were a support for the neighbor inhabitants within the post eruption phase. Finally, the socialization of the 1999 hazards map together with several talks on volcanology with the authorities and community, before the April 2015 eruption, were very useful to the National Emergency Office (ONEMI) and the communication with different authorities, the media and, of course, the surrounding inhabitants that were prepared in the case of an eruption onset.


Figure 4. Impacts of volcanic processes of Calbuco volcano 2015 cycle. **A:** houses, road, bridge and fish farming destroyed by lahars of the Blanco Sur and Pescado rivers, the arrow indicates the position of the Church of Río Blanco and fish farm of Pescado river. **B:** fall of pyroclastic rocks in the town of Ensenada where some houses collapsed.

## Osorno volcano

The Osorno volcano is a composite stratovolcano of Mid-Pleistocene to Holocene age (<ca. 200 ka) located in the Andes of Southern Chile (41.1°S and 72.5°W). It forms, along with La Picada, Puntiagudo and Cordón Cenizos volcanoes, a north-east-trending transversal volcanic chain. In their foothills, the lakes Llanquihue, Rupanco and Todos Los Santos complete the most emblematic landscape of this region, witness to a complex and long history of interactions between volcanic construction and the erosive action of glaciations.

The first eruptive stage (Middle Pleistocene, <200 ka) built a central volcano during the Santa María glaciation, which was deeply eroded at the end of this glacial era. Above the eroded structure, the present volcano began to be raised during the interglacial period between Santa María and Llanquihue glaciations (ca. 125-100 ka). A central volcano grew in an ice-free environment but with glacial lobes along the main valleys. Volcano rising continued during the Llanquihue Glaciation being at same time eroded by the main glaciers. Postglacial eruptive activity is characterised by both central and flank eruptions. The latter are isolated basaltic pyroclastic cones and dacitic domes with a radial distribution and composed cones and fissures in NE-SW trending alignments. The central vent also have produced explosive eruptions during the past 10 ky as evidenced by basaltic pyroclastic flows and dacitic tephras that are extensively distributed in the area nearby. Historical eruptive activity is mostly characterised by low explosivity eruptions such as the outstanding 1835 AD event, although more explosive activity has been recognised in the Late Holocene.

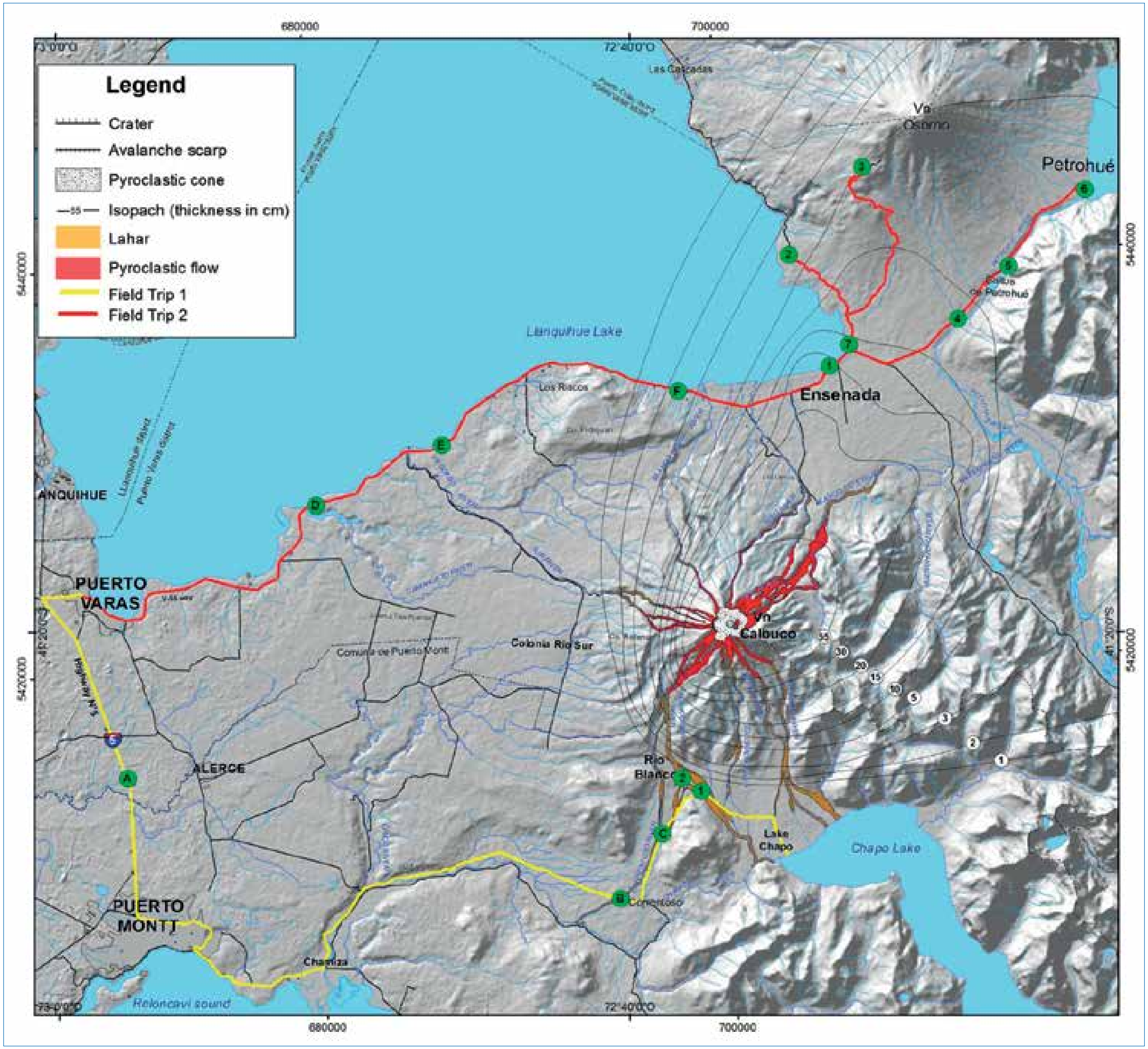


Figure 5.
Field Trips **FTB-1** Puerto Varas - Rio Blanco (yellow) and **FTB-2** Puerto Varas - Ensenada (red)

# FIELD TRIP FTB-1

## FTB-1 FIELD TRIP TO CALBUCO SOUTH

Leaders: Hugo Moreno; Mauricio Mella; Alejandro Verges; David Quiroz.

### ITINERARY

| | |
|---|---|
| 9:00 | **Depart from Patagónico hotel** |
| 9:00 – 10:30 | **Puerto Varas to Río Blanco route** |
| 11:00 – 12:00 | **Stop N°1 - Lahars in Río Blanco around the school and church** |
| 12:30 – 14:30 | **Stop N° 2 - House and industrial fish farming destroyed by lahars at Blanco Sur River - Lunch** |
| 14:30 – 16:30 | **Stop N° 3 – Meeting in Río Blanco school with the organized community** |
| 17:00 | **Return to Puerto Varas** |

### Puerto Varas City

The geomorphology where the city of Puerto Varas is located comprises: i) hummocks located in the high part of the city characterized by frontal moraines; (ii) lake, beach and fluvioglacial terraces in the lower part of the city, product of Llanquihue lake different levels after the last glacial retreat (Llanquihue glaciation ca.14,000 aAP; Mercer, 1976), Figure 6.


Figure 6. View of Puerto Varas city with front moraines **(1)** and lake, beach and fluvioglacial terraces **(2)**.

### Puerto Varas – Puerto Montt route (Point A – Alerce Ignimbrite)

Route 5, which links Puerto Varas with Puerto Montt, is characterized by a geomorphology dominated by hummocks and smooth hill slopes, which correspond to moraines and fluvioglacial deposits respectively. Both, record of the Llanquihue Drift recent advances and retreats. Subsequently, roadcut outcrops of a large PDC, product of an explosive activity of Calbuco Volcano can be seen (the Alerce Ignimbrite ca. 6.5 ka; Sellés y Moreno, 2011), Figure 7.

Figure 7. Debris flow and hyperconcentrated facies from the Alerce Ignimbrite with a prismatically jointed bomb (PJB).

### Puerto Montt - City

Puerto Montt (Melipulli, which means four hills in native language), is the Los Lagos regional capital is built on different levels of terraces associated with the Llanquihue glaciation (Antinao *et al.*, 2000) latest advances and retreats. The hummocks are frontal and lateral moraines located in the highest part of the city, the intermediate low terraces are glacial drains characterized by deposits (gravel, sand and silt).

### Puerto Montt – Correntoso route (point B – Correntoso Bridge)

The coastal road shows gravelly sand-silt deposits associated with glaciolaustrine and fluvioglacial of the Llanquihue Glaciation last glacial retreat. The road to Correntoso from Chamiza shows gravels of fluvial terraces and lateral moraine hummocks. Then begins to dominate a valley basin morphology, filled by large lahars from Calbuco volcano. The bridge of the Correntoso river shows some 2015 lahars damage upside the bridge. In that course lahars were diluted by some trunks, so the bridge resisted its impact (Figure 8).

Figure 8. Impact and damage in the Correntoso bridge by 2015 Calbuco lahars.

## Correntoso – Río Blanco Church route

Roadside cuts show the Calbuco volcano lahars range of deposits characterized by different debris flow and hyperconcentrated facies. (Figure 9: lahars).

Figure 9. Lahars from the 2015 Calbuco eruption.

## **Stop N°1:** Lahars in Río Blanco around the School and Church

The Río Blanco School and Church saved itself only by meters from the lahars. They are located 200 meters from the Blanco Sur river bridge, where the lahars flooding facies (hyperconcentrated) can be seen, together with coarser debris flow deposits (Figure 10A and 10B). Lahars split in two branches, one towards the Correntoso river and another one, more voluminous, flowed down along the road toward the Chapo lake, damaging houses and cutting the bridge. The current River Blanco Sur Bridge was rebuilt, since the old reinforced concrete bridge was destroyed by the lahars and carried 100 meters downstream. The laharic wave heights still can be seen in trees near Río Blanco Bridge, where the barks were peeled and battered by the rock impacts (Figure 10C).

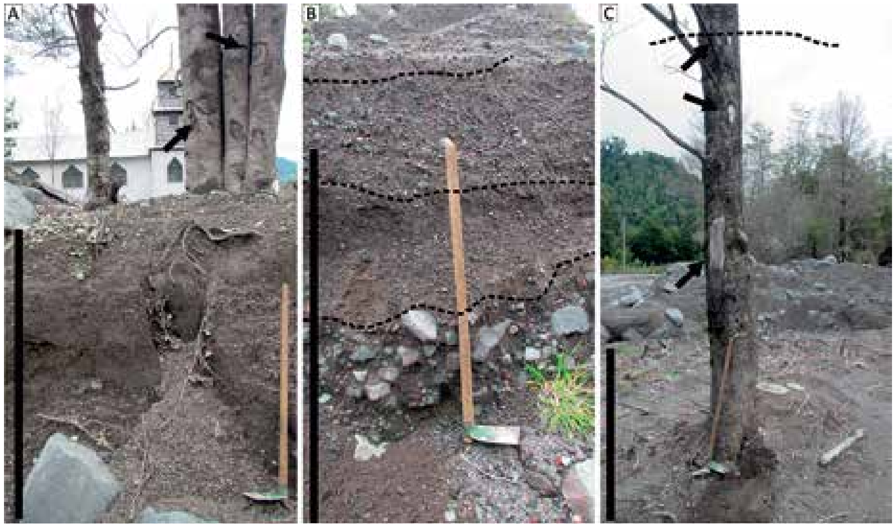


Figure 10. **A:** Hyperconcentrated deposits around Río Blanco Church. **B:** Debris flow (below) and hyperconcentrated facies from Blanco Sur river lahars. **C:** Height of the lahar wave and rocks marks in trees near Blanco Sur river.

## **Stop N°2:** House and industrial fish farming destroyed by lahars at Blanco Sur River - Lunch

Around the road to access the Río Blanco destroyed industrial fish farming there can be seen lahar deposits, characterized by different debris flow and hyperconcentrated facies (Figure 11A and 11B). Also there is a house affected by a lahar (Figure 11A). Lahar wave marks still can be seen in trees near the road, where the barks were battered by the rock impacts (Figure 11C). From the road toward the volcano you can see the industrial fish farming destroyed.

## **Stop N° 3:** Meeting in Río Blanco school with the organized community

Social leaders and inhabitants of the affected community will be together at the Rio Blanco School to meet the conference participants and share their experiences when the 2015 eruption took place surprisingly and the lahars disturbed their lives.

## **17:00 hrs. Return to Puerto Varas**

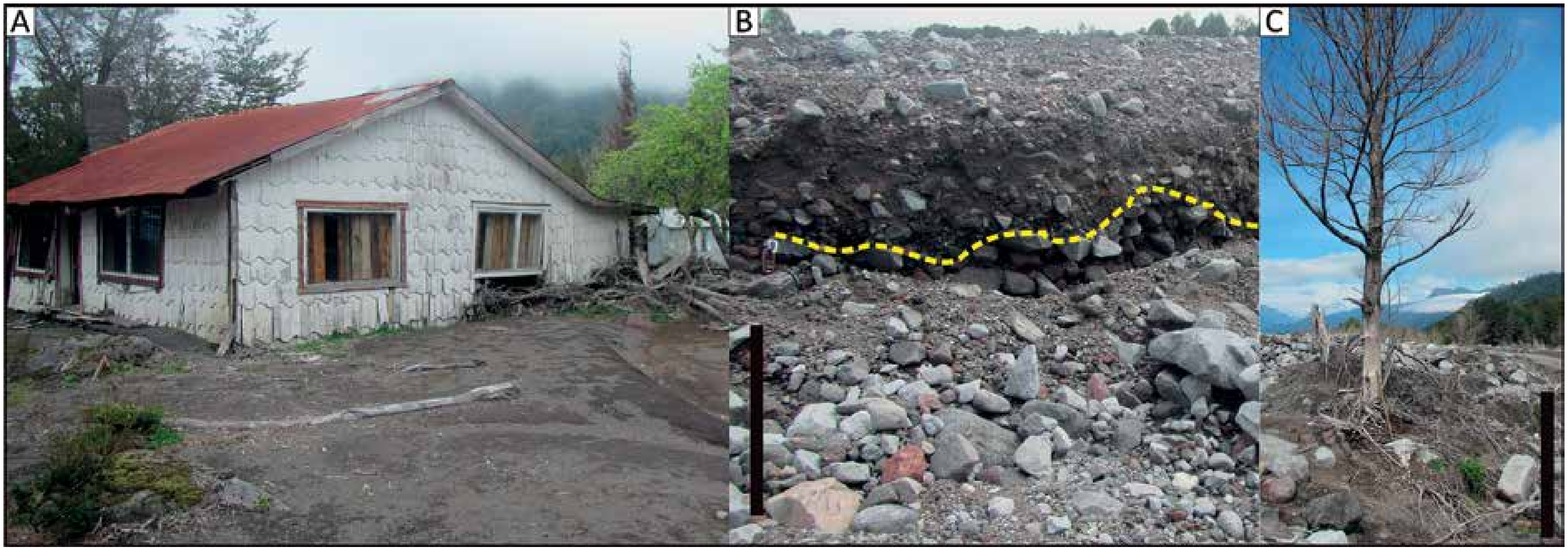


Figure 11. **A:** house affected by lahars (hyperconcentrated facies). **B:** lahars stratigraphy is characterized by debris flow (bottom) and hyperconcentrated deposits (top); under the lahars an aluvial deposit can be observed. **C:** marks in trees by rock impacts.

# FIELD TRIP FTB-2

## FTB – 2 FIELD TRIP TO CALBUCO AND OSORNO VOLCANOES

Leaders: Alvaro Amigo; Daniel Bertin; Leslie Fuentes; Felipe Flores; Oscar Valderrama.

## ITINERARY

| | |
|---|---|
| 8:30 | **Depart from Patagónico hotel** |
| 8:30 – 10:00 | **Puerto Varas to Ensenada route and Osorno volcano Ski Center** |
| | **Stop N°1 - Osorno volcano Ski Center** |
| | **Stop N°2 - Osorno 1835** |
| | **Stop N°3 - Ensenada beach** |
| | **Stop N°4 - Lahar deposits – Petrohué route** |
| | **Stop N°5 - Petrohué lavas** |
| | **Stop N°6 - Todos Los Santos lake - Lunch** |
| 16:00 – 17:00 | **Stop N°7 - Ensenada EPSON School meeting with organized community** |
| 17:00 | **Return to Puerto Varas** |

### Puerto Varas city

The geomorphology where the city of Puerto Varas is located comprises: i) hummocks located in the high part of the city characterized by frontal moraines; (ii) lake, beach and fluvioglacial terraces in the lower part of the city, product of Llanquihue lake different levels after the last glacial retreat (Llanquihue glaciation ca.14,000 aAP; Mercer, 1976), Figure 12.


Figure 12. View of Puerto Varas city with front moraines **(1)** and lake, beach and fluvioglacial terraces **(2)**.

### Puerto Varas – Ensenada route (roadcuts A, B, C)

The geomorfology of the road between Puerto Varas and Ensenada is dominated by hummocks associated with lateral moraines, terraces with fluvioglacial and glaciolacustrine deposits with drop stones (Figure 13A), record of advances and retreats of the Llanquihue Drift (Mercer, 1976). Subsequently, at *ca.* 14 ka was generated the Calbuco debris avalanche (Figure 13B; Sellés and Moreno, 2011). These two main units are covered by different types of pyroclastic deposits (figure 13C) and were eroded by river waters that deposited gravels. At 22.7 km along the route, road cuts of the Calbuco debris avalanche can be seen. At 34 km, starts to appear on the surface, the 2015 fall deposits. The Ensenada village is located on top of a large alluvial, laharic and PDCs mixed fan from Calbuco volcano.


Figure 13. **A:** Fluvioglacial, lake and beach deposits with drop stone of glacial lakes from Llaquihue glaciation; **B:** Calbuco avalanche deposit; **C:** Pyroclastic fall deposit (3) on glacial kemes and moraine associated to Llaquihue glaciation.

## **Stop N°1** - Osorno volcano Ski Center

From the Osorno volcano Ski Center it is possible to observe the complete Calbuco volcano edifice, the avalanche scar, the central dome and the large PDCs/ lahars mixed fan that reach the Ensenada locality. In this site the 2015 Calbuco tephra fall was only 5 cm and now it is gone. There are basaltic lava flows and scoria cones of the Osorno 1835 eruption described by Cap. Fitz Roy (Moreno *et al.*, 2010). In this site there is a monitoring station that belongs to Southern Andes Volcanic Observatory (OVDAS) – SERNAGEOMIN. It corresponds to a seismic station which also hosts a webcam, both transmitting real-time data to the OVDAS. The 2015 Calbuco eruption was preceded by few and weak activity recorded by this station, among others.

## **Stop N°2** - Osorno 1835

The last eruption of Osorno volcano occurred in 1835 AD constrained over the southwestern flank of the volcano. The eruption was observed from the distance by Charles Darwin and described by Cap. Fitz Roy during the voyage of the HMS Beagle (Moreno *et al.*, 2010), who made important observations of this eruptive cycle. This activity was characterized by two stages: (1) January 19, 1835 – Feb, 1835; which built up scoria cones distributed along a NE-SW array accompanied with basaltic lava flows (51-52 wt.% $SiO_2$). (2) Nov, 1835 – 1837; which build up coalescent scoria cones over NE-SW trending eruptive fissures, from where basaltic (49-53 wt.% $SiO_2$) lava flows of up to 8 km away were emitted.

## **Stop N°3** - Ensenada beach

Tephra fall deposit of the 2015 Calbuco volcano eruptive cycle can be seen nearby the Ensenada town. The deposit shows a noticeable zoning; the top, up to 1-2 cm thick, is composed by fine lapilli-sized grey dense scoria fragments; and the base, up to 13-17 cm thick, is characterized by coarse lapilli-sized brown vesicular scoria fragments (Bertin *et al.*, 2015; Castruccio *et al.*, 2016; Figure 14). Both fragments are basaltic andesites with similar chemistry compositions (Castruccio *et al.*, 2016).

Figure 14. The 2015 lapilli fall deposit from Calbuco volcano at the Ensenada beach. Is possible to observe the different scoria color on top of the sandy beach deposit.

## **Stop N°4** - Lahar deposits – Petrohué route

Throughout the Ensenada – Lake Todos Los Santos route several laharic deposits can be seen, the most outstanding ones are characterized by sequences of debris and hyperconcentrated flow deposits as well as alluvial and fallout deposits, filling narrow and steep gorges (Figure 15).

Figure 15. Osorno Lahars in Ensenada – Lake Todos Los Santos route

## **Stop N°5** - Petrohué lavas

Located in the southeast foothills of Osorno volcano, a relatively continuous lava escarpment is exposed, up to 5 m height and parallel to the road in this narrow valley. The surface of this landform exhibits intensely fractured, features that can be attributed to lava and ice interaction. Dated in 124.5 ± 40.9 ka, this unit represents the Osorno volcano second constructive phase, contemporaneous with the penultimate lateglacial period. These basaltic andesites (52-54% $SiO_2$) present phenocrysts of plagioclase, olivine and clinopyroxene. Modern intermittent alluvial and laharic erosive processes have carved smooth hanging gullies over this escarpment, accumulating consolidated debris flow deposits that form small deltas in the bed of mighty Petrohué river.

## **Stop N°6 -** Todos Los Santos lake - Lunch

## **Stop N°7** - Ensenada EPSON School meeting with organized community

Social leaders and inhabitants of the affected community by the heavy lapilli fall, will be together at the Ensenada EPSON School to meet the conference participants and share their experiences when the 2015 eruption took place surprisingly. The roof collapses by the dense scoria fall, was the main impact in Ensenada village.

## **Return to Puerto Varas**

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Local Organizing Committee
for Cities on Volcanoes 9 Conference
Servicio Nacional de Geología y Minería
Avenida Santa María 0104
Providencia
Santiago
Chile

www.sernageomin.cl
www.citiesonvolcanoes9.com
cov9@sernageomin.cl