# Tolhuaca volcano (southern Chile, 38.3° latitude S): New learnings from surface mapping and geothermal exploration wells

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**Abstract.** Tolhuaca is a glacially scoured stratovolcano that hosts several prominent craters, and an active geothermal system. Data from surface mapping of remote and poorly accessible areas with deep geothermal wells provide a glimpse of the stratigraphy of the volcano and its evolution. Previously undocumented pyroclastic deposits which are markers in the wells may correlate with units exposed on the surface. Dike, fault and fracture strikes are predominantly within the range of N40W to N40E, with a subordinate set that is nearly E-W.

**Keywords:** Tolhuaca volcano & geothermal system, surface geology, stratigraphy in exploration wells

## 1 Introduction

The Tolhuaca geothermal system is located on the upper flank of Tolhuaca volcano in southern Chile (Figure 1). A conceptual model of the geothermal system and its evolution has been discussed elsewhere (Melosh et al., 2012). This contribution concentrates on presenting new results from wellbore lithology and relating lithology and stratigraphy shown in the wells with surface geology. Two slim holes were drilled in 2009 and 2010 (Tol-1 & 2; 1073 and 1274 vertical meters, respectively) while more recently (2011 & 2012) larger diameter wells up to 2117 m vertical depth have been completed to demonstrate commercial permeability and confirm neutral reservoir fluid chemistry (Tol-3 & 4). Tol-1 was the only core-drilled hole and its results are being evaluated in the context of Tol-2 and the surface geology. Detailed structural studies of Tol-1 (veins, veinlets and faults) are in progress (see Pérez et al., this meeting).

## 2 Well logging and surface mapping

A standardized logging nomenclature and procedure was established to facilitate consistent core and cutting descriptions. After drilling the two slim holes, lithologies, alteration mineralogy and assemblages were integrated with petrographic descriptions of thin sections, clay and bulk XRD, plus fluid inclusion homogenization temperatures into graphic logs, in order to refine the interpretation of the well geology.

In parallel, several campaigns of surface mapping have been performed providing stratigraphic context for the geology found in the wells and allowing integration into subsurface geologic models and well targeting at Tolhuaca.

Tolhuaca volcano hosts two upper craters as well as a lower elongate amphitheatre-like crater, all facing N to NNW, that have been enhanced by glacial action. The over-steepened south face appears to have suffered some combination of collapse and glacial scouring. As described later, some eruptions appear to have quenched against glacial ice, leaving very steep embankments.

## 3 Results and Further Work

The rocks encountered in Tol-1 and 2 wells are mainly of basaltic andesite composition, although the whole rock chemical range varies from basalt to dacite. Deposit types observed are mainly lavas and related breccias, volcaniclastics and minor tuffs. The correlation of the major rock types in the two wells is shown in Figure 2. Two sequences of pyroclastic rocks of probable dacitic composition are useful markers between wells. The first major tuff unit is named Andenrose by virtue of its rose colour (Figure 3a). It consists mainly of non-welded pumice and was probably deposited from plinian fallout and near-source ash flows from Tolhuaca volcano. It is possible that this unit correlates with a dacitic plinian sequence observed on the main access road near Cono Colli (Figures 1 & 3b). However, this unit has not been observed elsewhere on the surface despite intense searching. It is non-welded and partially altered to clay, making it susceptible to erosion or burial. The second pyroclastic sequence is called the Green Flame Tuff (Figure 2). This unit consists of a sequence of fallout and surge tuffs overlain by a partially welded ash flow tuff (Figure 4). The name of the unit is derived from the distinctive chlorite-green altered flattened pumice, or fiamme that have “flame shapes” at their margins. This unit could be tentatively correlated with greenish, pumice-rich tuff deposits filling paleovalleys on the northern flank of the volcano (Figure 1).

Hyaloclastites and pillow breccia occur at five different levels between 300 and 1000 m depth in Tol-1 core (Figure 5a). This indicates that lavas erupted during several time periods encountered glacial ice and/or water. On the

surface, most of Tolhuaca lavas issuing from the main craters seem to have been affected by glacial erosion as evidenced by striations (Figure 5b). Furthermore microcolumnar lavas filling paleovalleys on the southern and south-western side of the volcano, forming abrupt cliffs (Figure 6) and presenting perlitic texture, suggest cooling against ice. The deep position of lavas affected by magma-ice interaction in the well suggests that they could be related to different glacial periods during the last 2 Ma. The boundary between Tolhuaca lavas and Malleco Formation (Plio-Pleistocene age; 4.4 to 0.8 Ma K-Ar ages; Suárez & Emparán, 1997) is difficult to determine in the wells without any constraining geochronological data.

A thick sequence dominated by volcaniclastic rocks makes up most of the bottom portion of both wells. This may be the Miocene-aged Cura Mallín Formation (Guapitrío Member; Niemeyer & Muñoz, 1983). In Tol-3, both the Malleco and Cura Mallín formations are cut by numerous weakly altered, fine- to medium-grained intrusions that are interpreted as feeders to the Tolhuaca volcanics.

Numerous dikes were also mapped on the surface; most dikes are nearly vertical and NW striking, but trends range from N to NW, WNW to E-W, and N to NE. Faults are also mainly steeply dipping (>60°) and dominantly striking within the range from N40W to N60E. Steeply dipping fractures and sheared joints are similarly most abundant within the range of N40W to N40E, with a smaller set within the range N80W to N80E.

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## References

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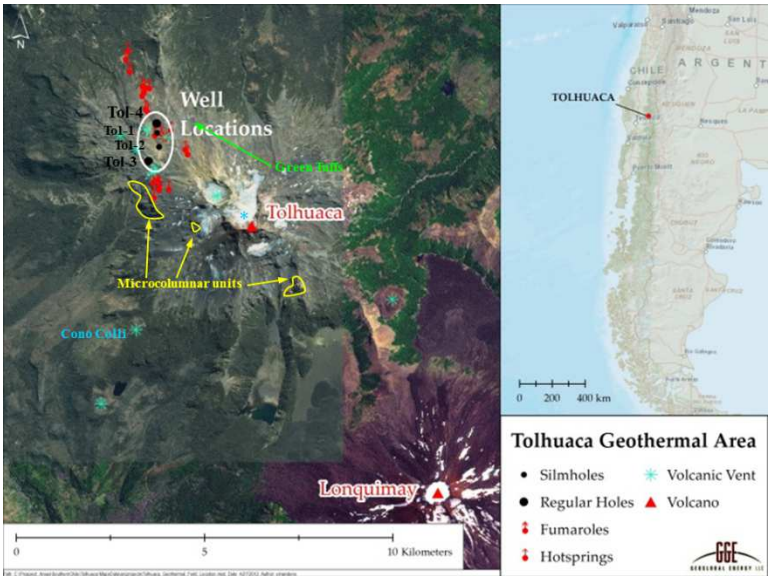


**Figure 1.** Ikonos image showing the location of Tolhuaca Geothermal Field in Southern Chile.

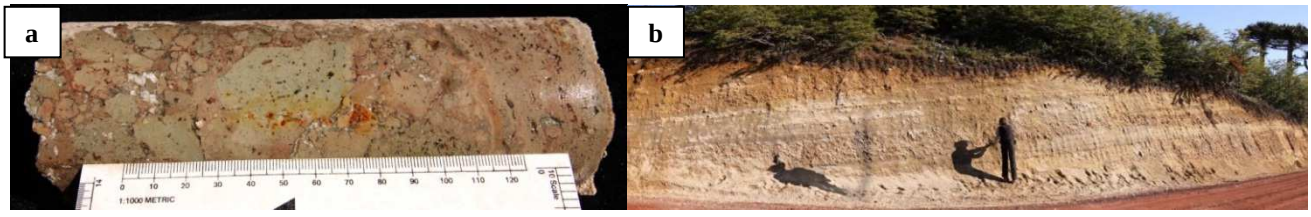


**Figure 3.** a) Pumice-rich lapilli tuff (Andenrose) at about 115 m depth in Tol-1. b) Sequence of dacitic tuffs ("lag fall" ash flow tuffs, fallout and surge deposits) near Cono Colli (see Figure 1 for location). Andenrose equivalent at the surface?

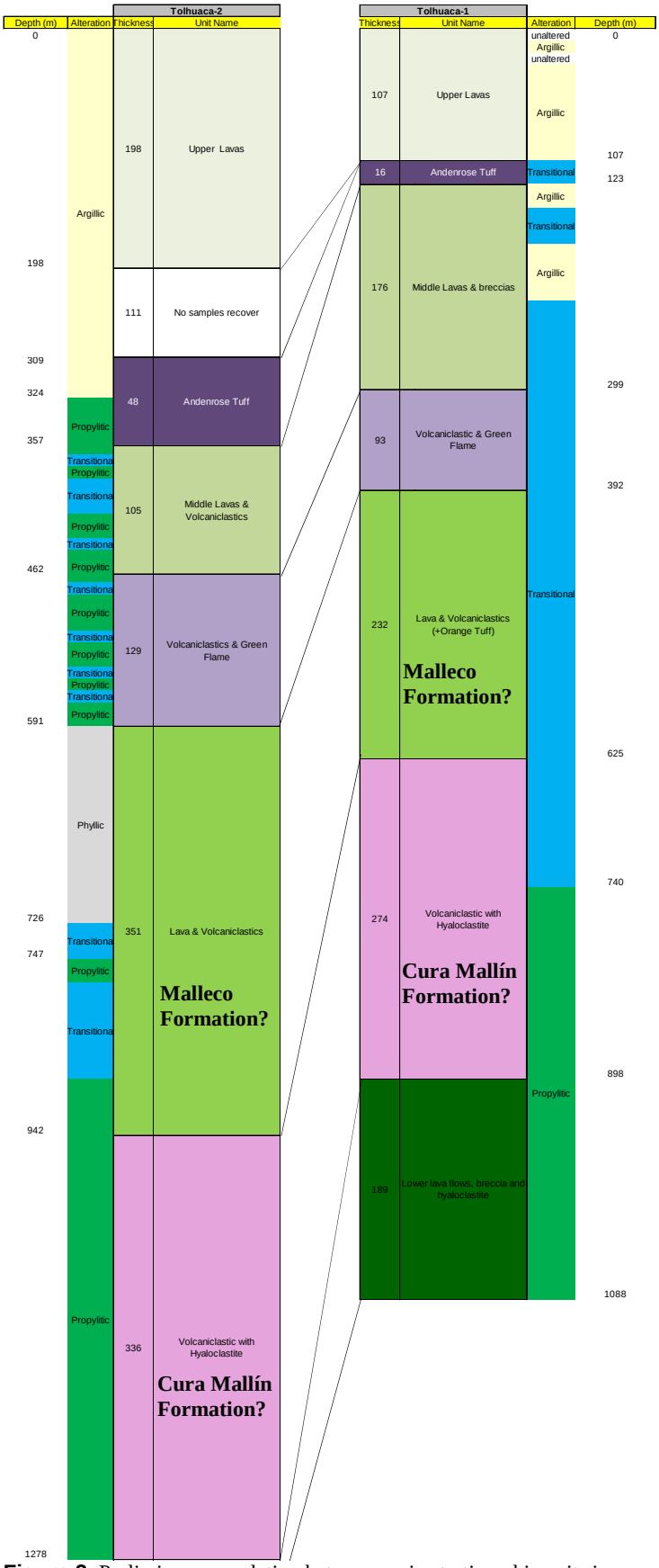


**Figure 2.** Preliminary correlation between main stratigraphic units in Tol-1 and Tol-2 wells.

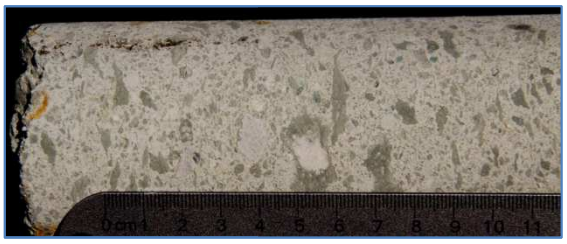

**Figure 4.** The Green Flame Tuff showing pumice-rich ash flow tuff with moderate to strong welding.

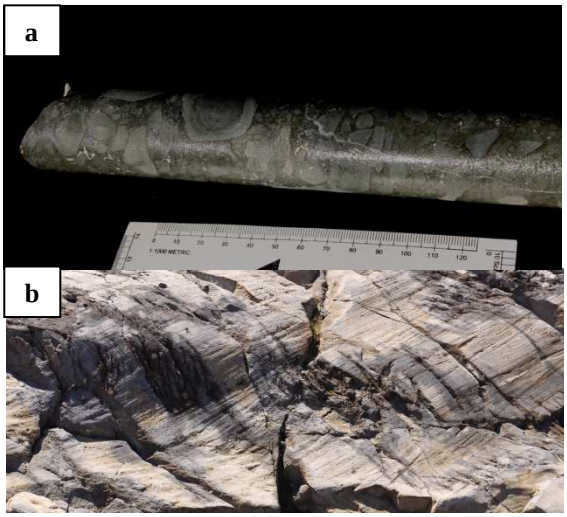


**Figure 5.** a) Hyaloclastite breccia in Tol-1 well, b) Glacial striation on surface lavas (photo is ~6 m across).

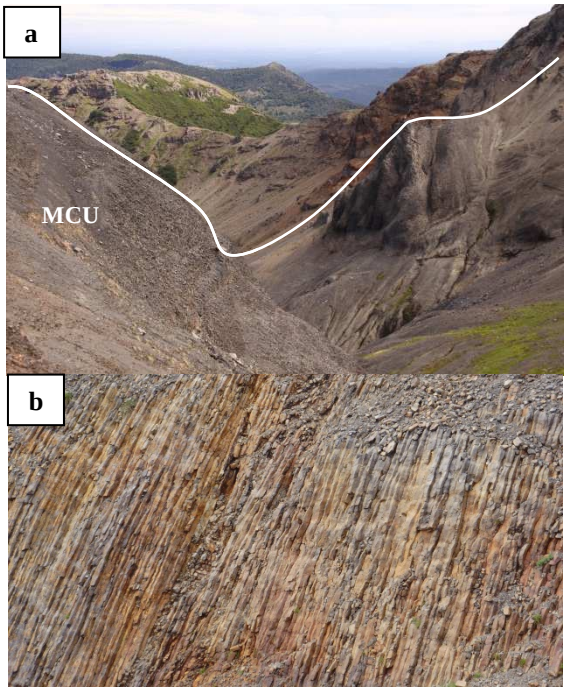


**Figure 6.** Microcolumnar unit (MCU) on W flank of Tolhuaca volcano: a) View down the valley, b) Close-up of the unit (photo is ~5 m across).