The phreatoplinian phase of the March 28-29 1875 eruption at Askja, Iceland: where did the external water come from?

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1. The problem

The 1875 explosive rhyolite eruption of Askja, Iceland is the third largest silicic explosive eruption since settlement. It was part of the volcano-tectonic episode which took place on the northern rift zone in 1874-1876. It is one of the very few eruptions that showed both phreatplinian and Plinian phases and the only historical record of phreatoplinian volcanism. The eruption began the 28th of March (9 pm) with a subplinian event (phase B) which lasted for ~1 hour. In the early morning of the 29th, after a pause of ~ 6.5 hours, the eruption continued with a phreatoplinian phase (phase C1), which lasted ~1 hour. This phase was followed by ~2 hours of explosive activity which was characterized by the emplacement of dilute density currents (phase C2), which became dryer with time. At 7 am the Plinian phase D commenced and lasted for about 5-6 hours. Activity continued throughout the afternoon with diminishing intensity toward the evening. The vents were positioned within the 1875 Öskjuvatn caldera in correspondence of the marginal faults. The Askja caldera is bound by steep-sided hyaloclastitic mountains on all sides and the floor is filled by Holocene and historical lava flows (>100 m thick). Prior to the March 28-29, 1875 eruption, there was no standing water present in the caldera apart from a very small pond occupying the bottom of a new circular depression at the March 28-29 eruption site. The amount of water in this pond is not enough in order to produce the degree of explosive magma-water interaction required for the C1 phreatoplinian phase. For these reasons the source of external water which drove the phreatoplinian phase are not obvious. To test whether groundwater flow through the permeable lava pile can provide enough water to drive the hour-long phreatoplinian eruption, we run numerical simulation with the novel CSMP++ code using a geologically realistic model of the Askja caldera. Our hypothesis is that the FCI leads to radial flow of groundwater toward the conduit (i.e. the conduit acts like a well), which provides the water for the phreatoplinian eruption and causes the subsequent dryout as the groundwater level declines.

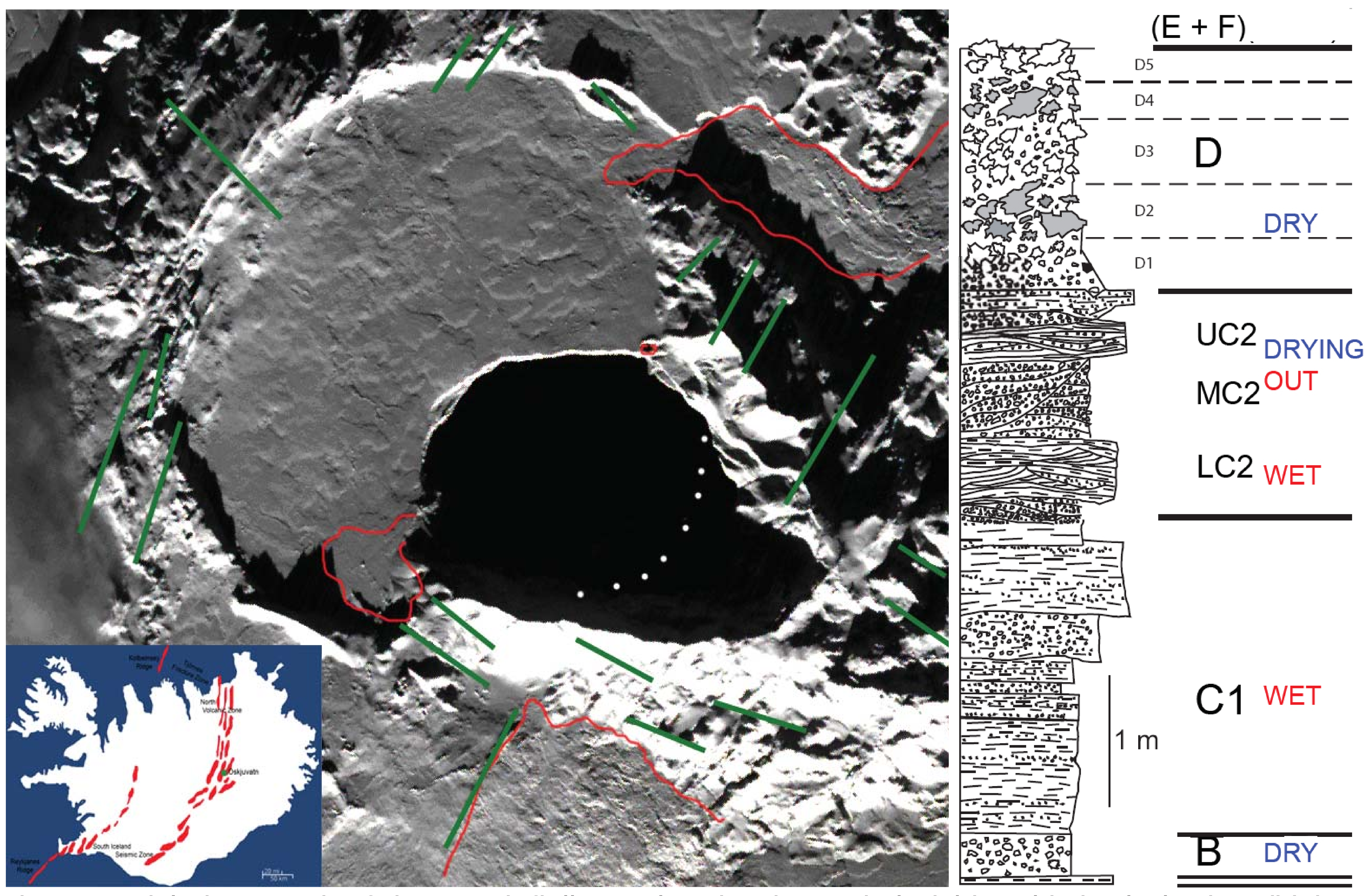

Fig. 1a Aerial photograph of the Dyngjufjoll complex showing: subglacial basaltic hyaloclastites (high topography at the right-hand side), the main Askja caldera and the nested 1875 calderas, 3) the old margin of the Askja caldera (dotted line), recent lavas (after the 1875 activity) bounded by red line and tectonic lineaments (green lines). Fig. 1b statigraphy of the main eruption after R.J. Carey 2008.

2. Was there enough groundwater to maintain a phreatomagmatic eruption for 3 hours?

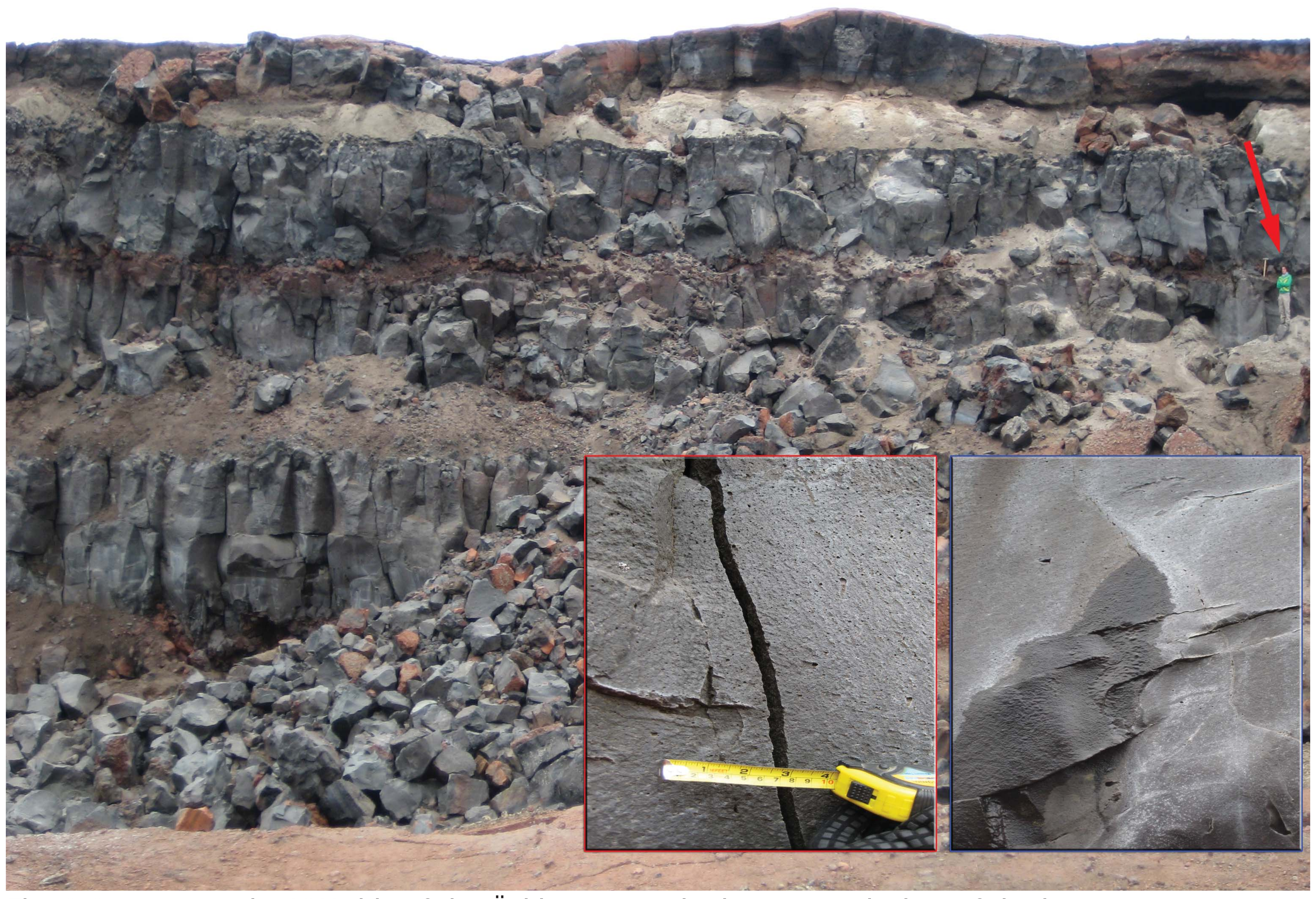

Fig. 2 Outcrop on the NW side of the Öskjuvatn. In the boxes: particulars of the lavas

	C1 Phase	C2 Phase
Mass of Erupted Material [kg]	$2.448 \cdot 10^{11}$	$1.656 \cdot 10^{10}$
Mass of Water involved assuming $0.3 = M_W / M_M$ [kg]	$7.44 \cdot 10^{10}$	$4.96 \cdot 10^{9}$
Mass Discharge Rate [kg/s]	$6.80 \cdot 10^{7}$	$2.30 \cdot 10^{6}$
Lasting of the Activity	1 hour	2 hours
Total mass of water involved		$7.936 \cdot 10^{10}$
Total mass of erupted material		$2.6136 \cdot 10^{11}$

R. J. Carey, 2008 - PhD Thesis

Table 1. Key parameters of the eruption

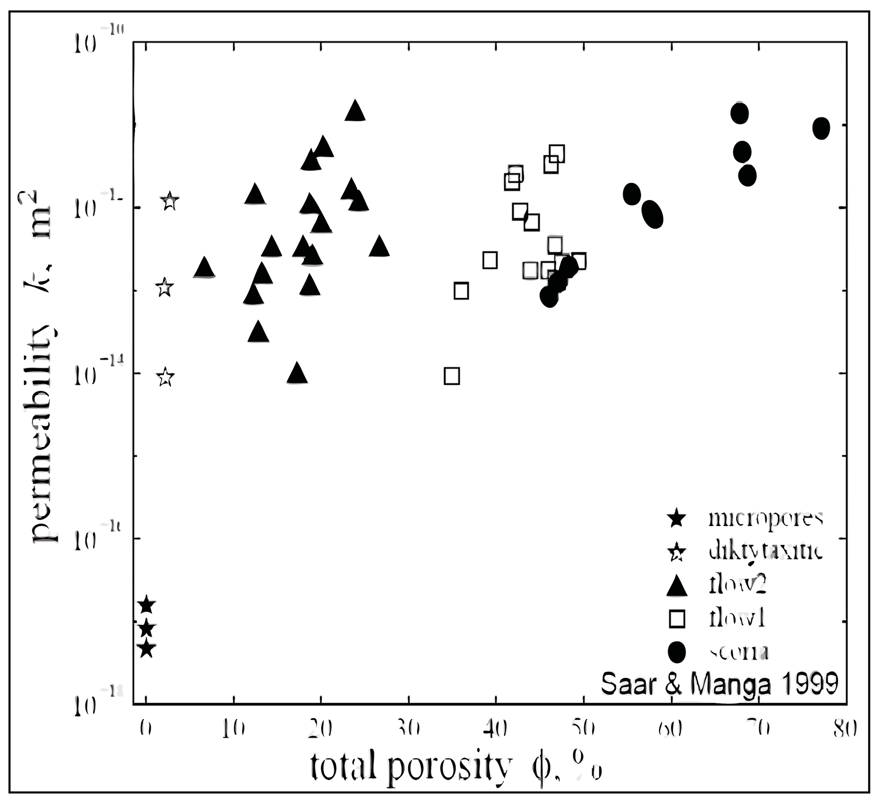

Table 2. Permeability Vs Porosity plotted by Saar and Manga, 1999

- The groundwater stored whithin the lava pile was enough (at least 10 times more than the necessary) to mantain the phreatomagmatic eruption even considering low values of porosity
- **Problem**: the natural groundwater flow does not transport water fast enough to the conduit as should be required (at the eruption regime, every second, the volume of water of 2 olympic swimming pools is involved)

3. A proposed model to explain: 1) Why C2 progressively dried out 2) Why D was dry?

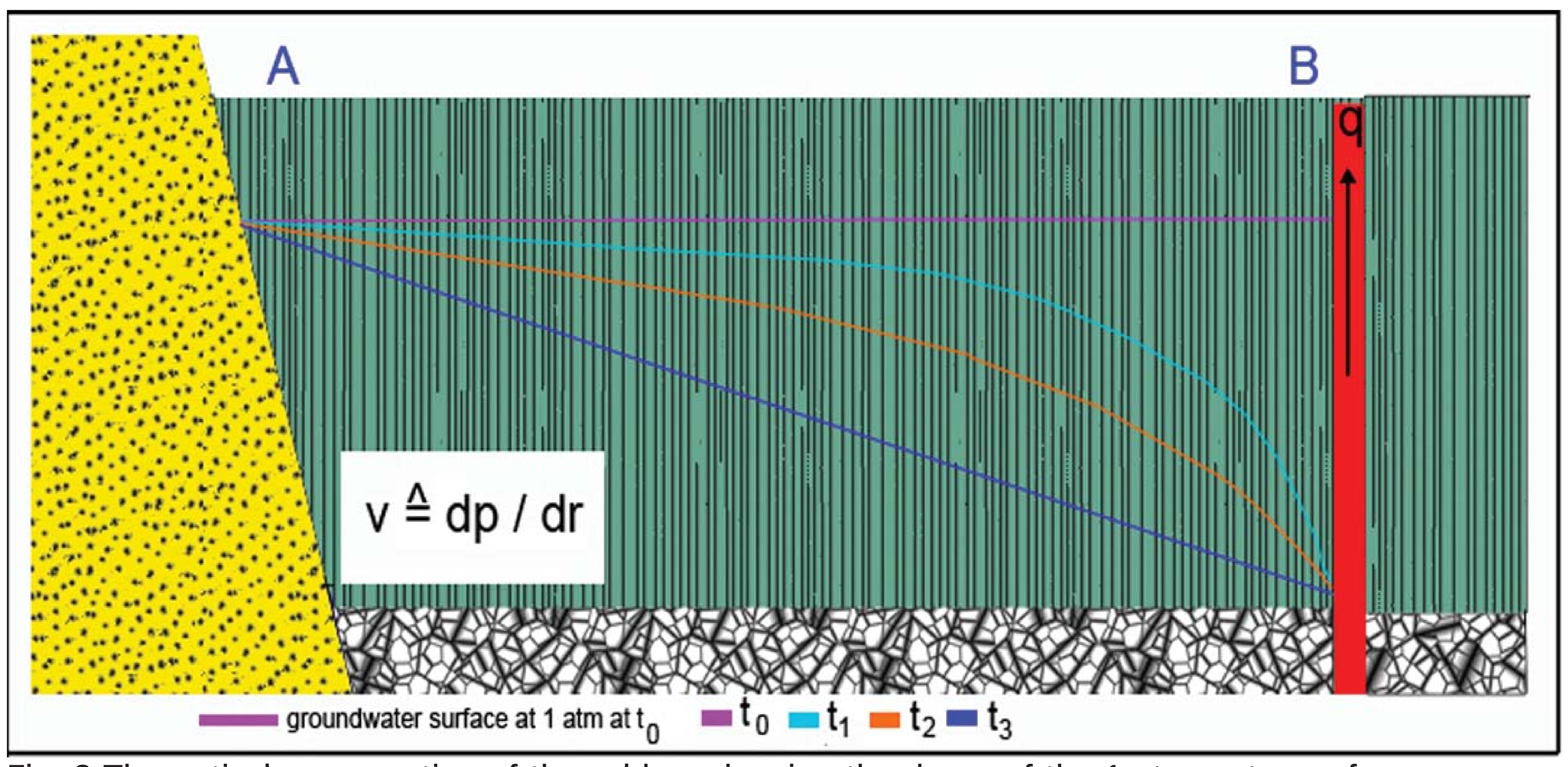

Fig. 3 Theoretical cross section of the caldera showing the decay of the 1 atm water surface

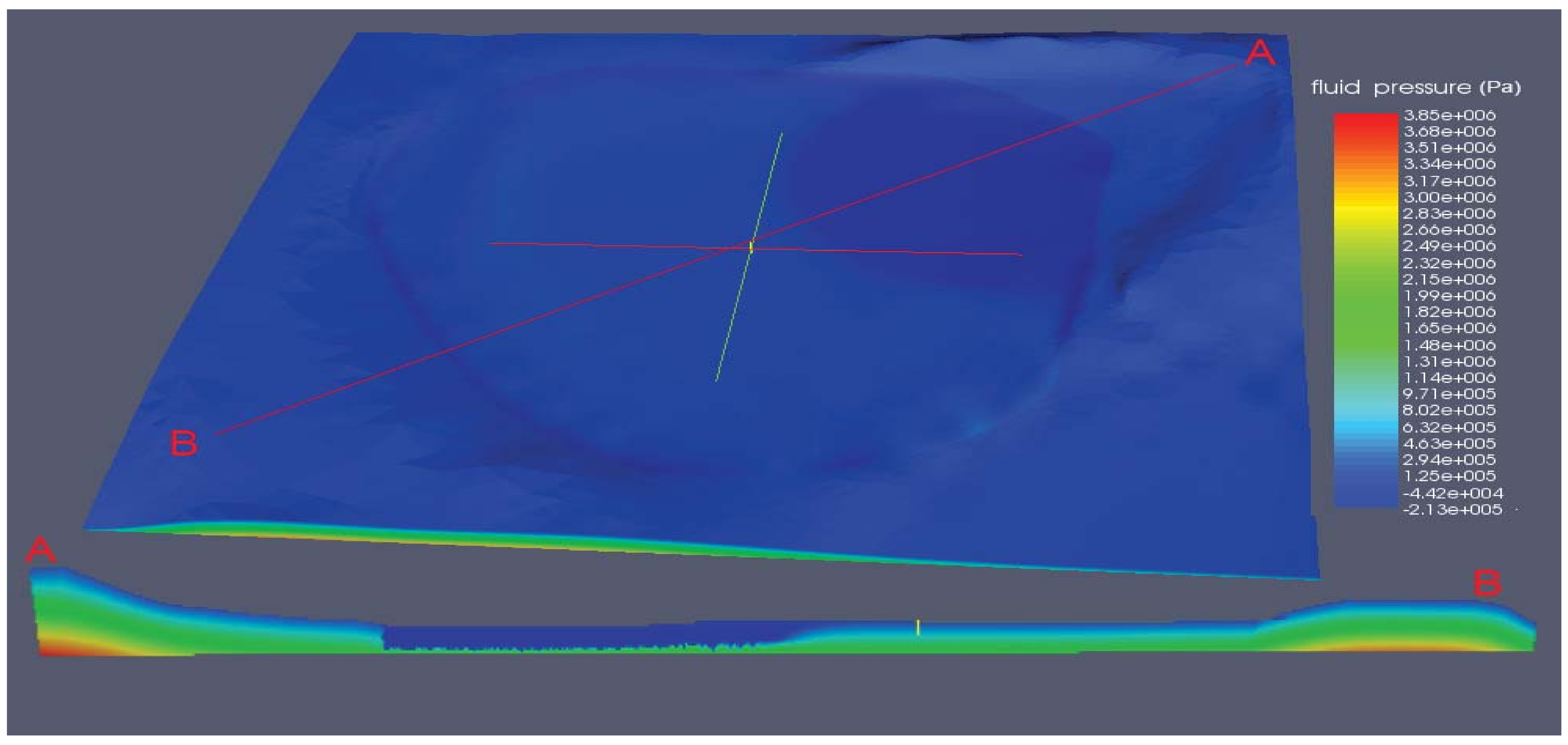

Fig. 5 Model developed for this study and the NW-SE cross section of it. In dark blue is represented the low pressure area induced by the eruption

$$\left(n\frac{\partial \rho_f}{\partial p}+\rho_f\frac{\partial n}{\partial p}\right)\frac{\partial p}{\partial t}=\nabla\cdot\left[\frac{k\rho_f}{\mu_f}\cdot(\nabla P+\rho_f g\nabla z)\right]+q$$

Fig. 4 Pressure equation solved in the model

ρ_f = fluid density, k = permebility
p = pressure, μ_f = fluid viscosity
n = porosity, g = gravitational acceleration
t = time, z = thickness of the aquifer
q = source or sink of fluid (sink in our case)

Carey R. J., PhD Thesis 2008
Delaney P.T., 1982. Journal of geophysical research, vol 87
Saar & Manga, 1999. Geophysical research letters, vol 26

4. Conclusions

1) At the eruption time, enough groundwater was stored within the lava pile in order to manintain the phreatoplinian phase for 1 hour and the following explosive activity for 2 hours
2) The dry out of the pyroclastic density currents was due to the decreasing rate of fluid flow toward the conduit
3) We can reproduce the required low pressure area which represents the decline in groundwater for relatively high permeabilities (10-11 m^2)
4) The low pressure area is large enough to explain why the D phase is dry although the new vent was only ~ 1 km away (R.J. Carey PhD Thesis, 2008) from the vent related to the C1 phase. However negative pressure occur close to the vent site which is non physical. A possible explanation is that we do not account for the transition from liquid to vapor which increases the fluid volume and can maintain high pressures at the magma-water interface (Delaney, 1982)