Geo-INQUIRE Transnational Access Project Report

Project ID: C2-TA2-531-2-2 (2nd Call) OpenFOAM Applications in Volcanology

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Project title: Simulating flow focusing and solidification in basaltic fissure eruptions

Project acronym: FLOWFOCUS

Hosting installation: OpenFOAM Applications in Volcanology (TA2-531-2)

Hosting team: Federico Brogi, Simone Colucci, Chiara Montagna, Istituto Nazionale di Geofisica e Vulcanologia, Pisa, Italy

Period of access: 28/05/2025 – 16/06/2025

Report of activities:

This project aims to validate numerical simulations developed in OpenFOAM against large-scale analogue experiments from the artificial fissure (ArtFISH) apparatus in use at the University of Otago. These experiments involve delivering a temperature-dependent Newtonian fluid (PEG600) to high aspect ratio slots, representing magma that is subject to flowing, cooling and solidifying in dykes and fissures. Combining these two approaches supports multi-model validation and improves our understanding of how fissure eruptions evolve from a long fissure – tens or hundreds of metres to several kilometres long – to a localised eruption.

During the stay at INGV-Pisa, foundational work was established to replicate the *ArtFISH* experimental setup within OpenFOAM. Initially, simple 3D simulations of a rectangular box domain with tetrahedral grids of different resolution were generated using *blockMesh* to mimic the simplest geometry (uniform width). Mesh resolution tests showed the complexity of working with high-aspect ratio geometries. The *pimpleFoam* solver was chosen for simulations under isothermal conditions. By comparing velocity profiles at fixed downstream positions, we noted that the numerical and experimental velocity fields are only consistent in some scenarios. These discrepancies require further simulation tests to improve the validation.

The research then transitioned to non-isothermal conditions to account for cooling and solidification of magma flowing in a fissure. Using the *icoReactingMultiphase* solver, the domain was configured to allow for liquid-solid phase changes within a bounded box. Preliminary results show that the model is able to reproduce flow in dikes as well as the thermal evolution of the system within timescales that are comparable to the volcano-magmatic system.

While the current setup primarily accounts for the solidus transition, subsequent work will incorporate temperature-dependent viscosity and perturbations in fluid velocity, fissure width and temperature to explore the spatio-temporal development of flow focusing within active fissures. This will be further addressed in the remote portion of the TA, upcoming phase during which we also aim to benchmark our results against other simulations of a viscous fluid flowing through a narrow fissure (Taylor-West and Llewellin, 2025), furthering collaborations.

Project outcomes:

Results from the non-isothermal simulations were presented by Javiera Ruz Ginouves at the IAVCEI Scientific Assembly, following the access period at INGV Pisa (Session 1.8 Volcanic plumbing system models to inform volcanic unrest processes)

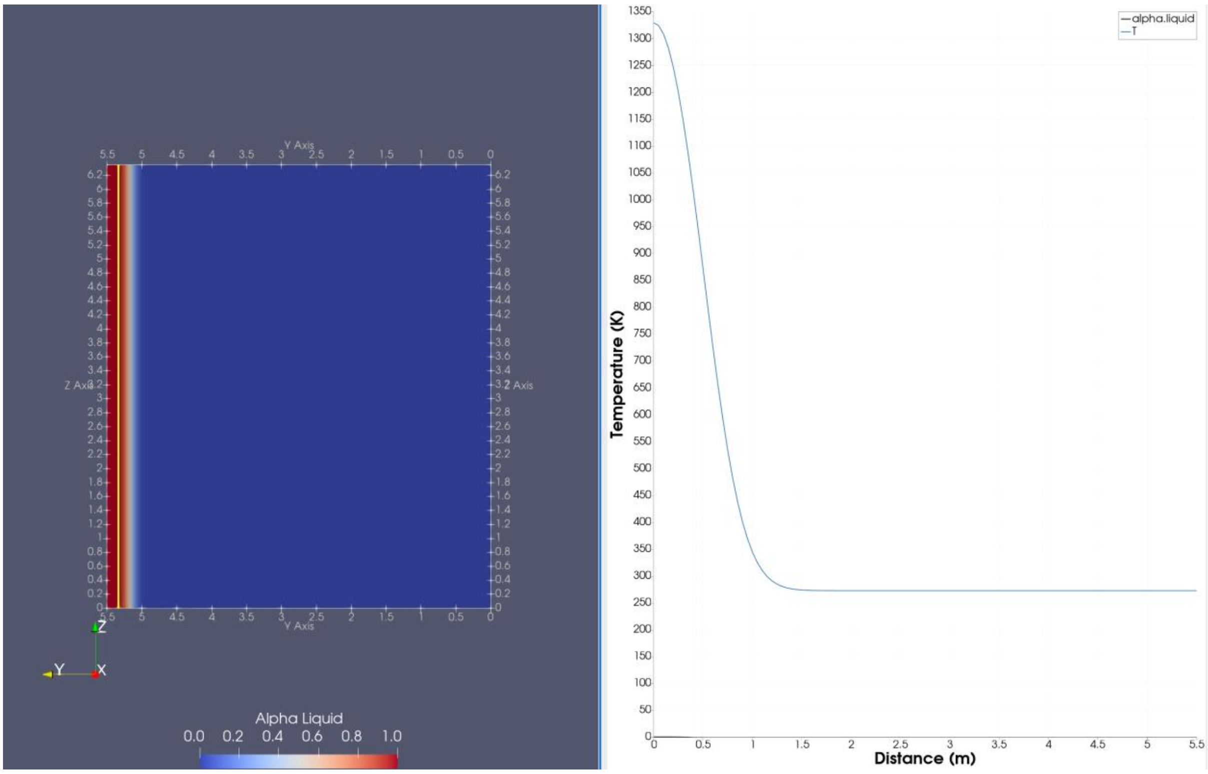

Figure 1 Heat diffusion into country rock from a cooling magmatic dyke. Simulation accounts for solidification (change of phase) from a liquid to a solid. Dyke loses heat to the surrounding country rock by diffusion. Left: Proportion of liquid is measured in a scale from 0% to 100% (or 1 in scale). Right: Temperature profile across Y-axis. Time ~35 hours.

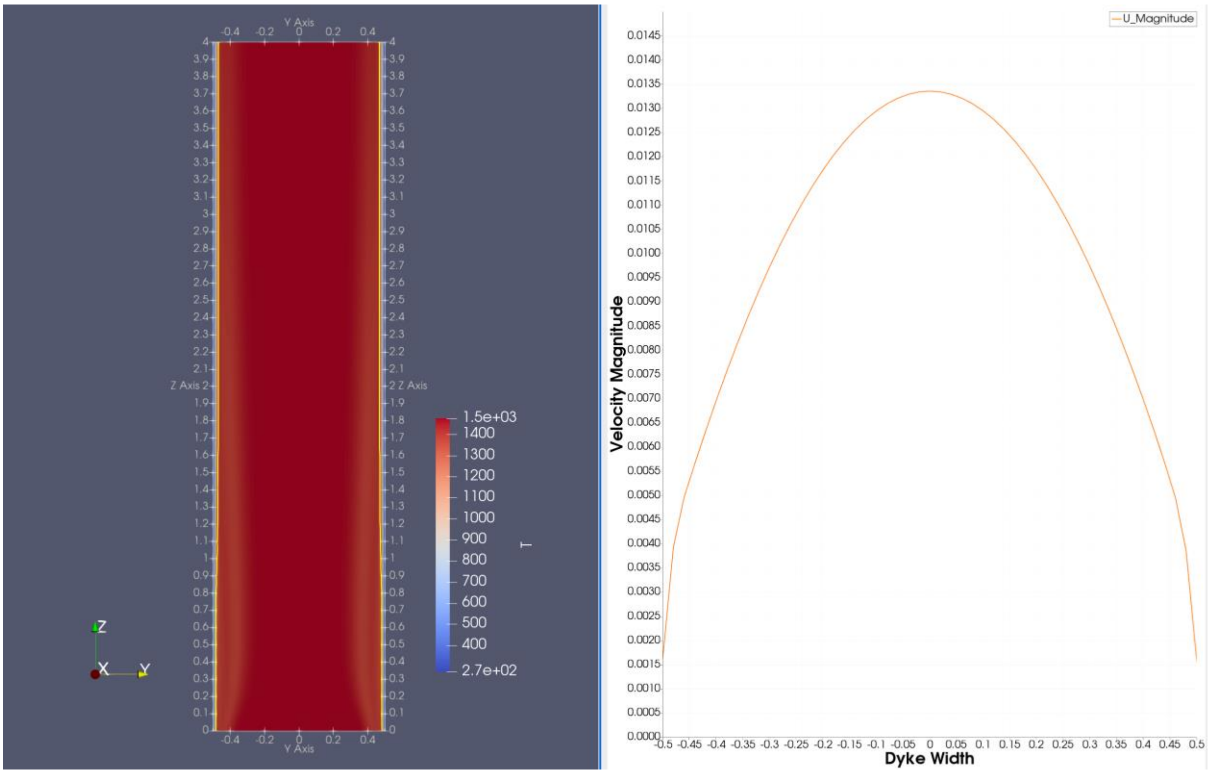

Figure 2 Simulation that incorporates solidification and flow in the Z-direction. Simulation time ~1 hr. Left: Temperature field within the dyke conduit. Yellow line indicates the solidus temperature. Right: Parabolic profile of the magma flow velocity magnitude according to Poiseuille flow.

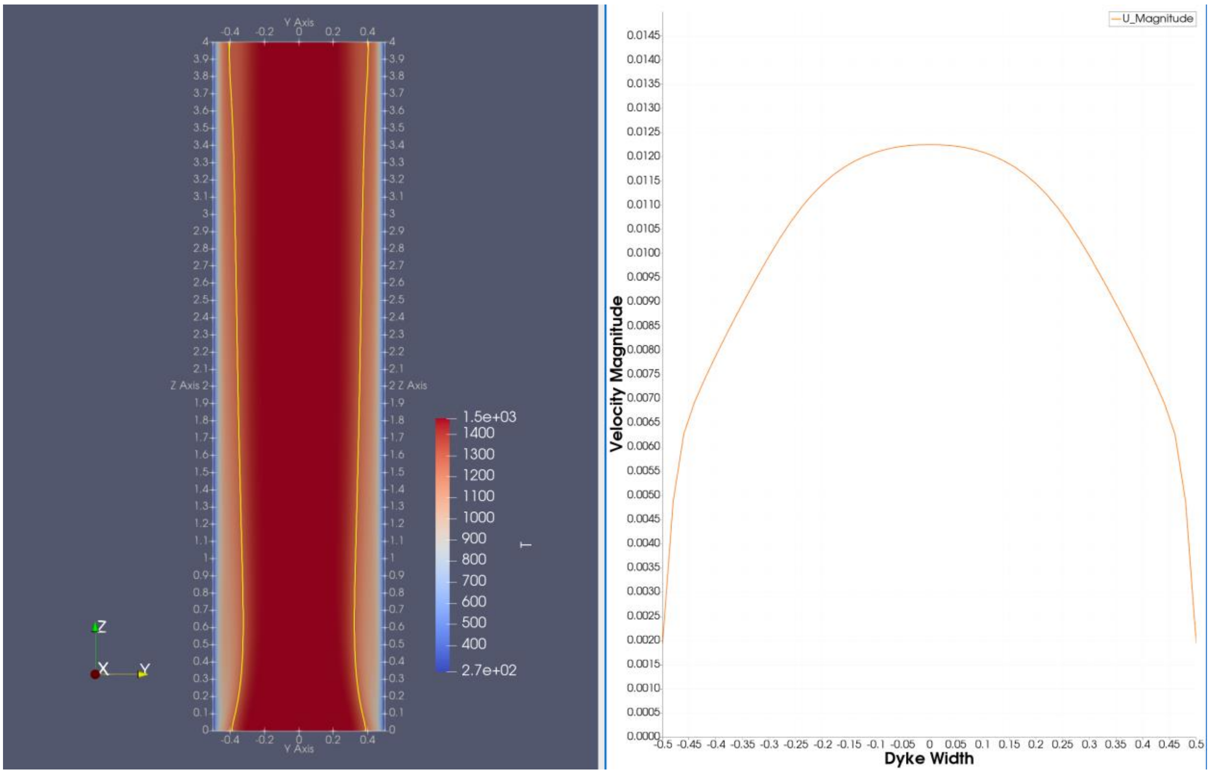

Figure 3 Simulation that incorporates solidification and flow in the Z-direction. Simulation time ~2.7 hrs. Left: Temperature field within the dyke conduit. Yellow line indicates the solidus temperature. Right: Parabolic profile of the magma flow velocity magnitude according to Poiseuille flow.

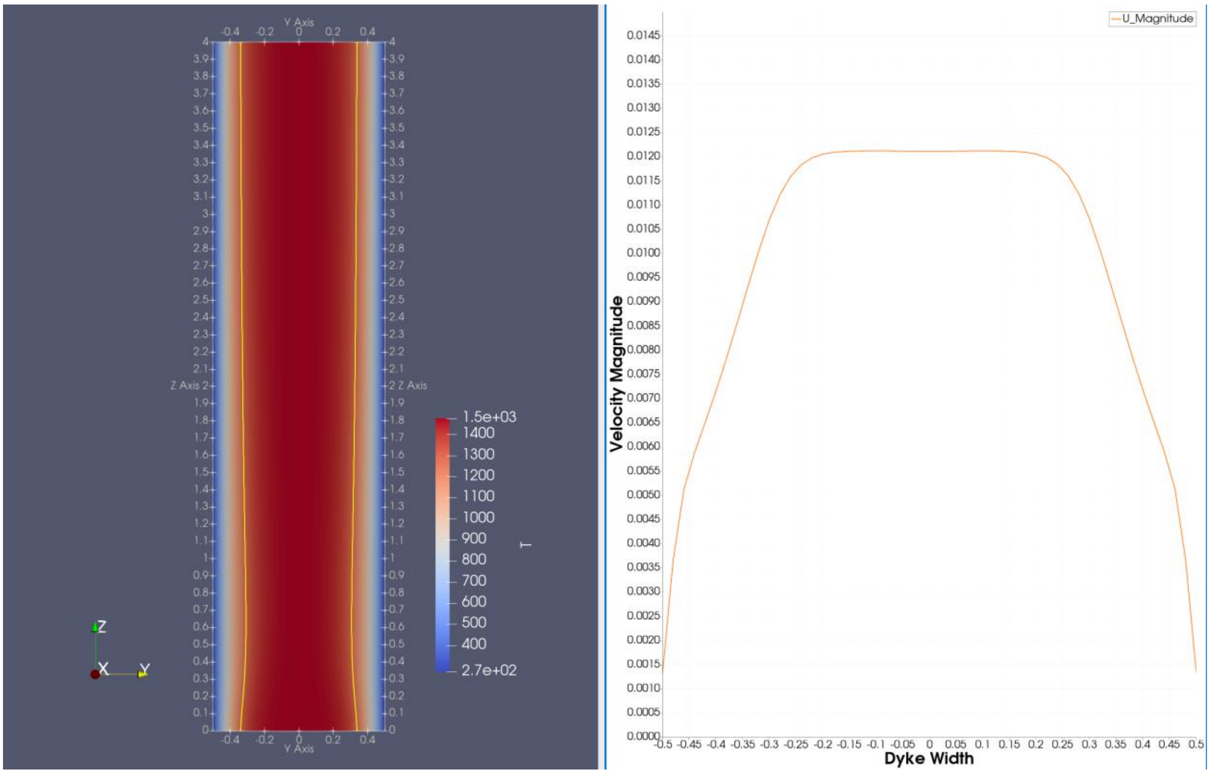

Figure 4 Simulation that incorporates solidification and flow in the Z-direction. Simulation time ~14 hrs. Left: Temperature field within the dyke conduit. Yellow line indicates the solidus temperature. Right: Parabolic profile of the magma flow velocity magnitude according to Poiseuille flow.