Exploring the mechanical influence of mush poroelasticity on volcanic surface deformation

Rami Alshembari, James Hickey, Ben Williamson, and Katharine Cashman

VIENNA, 23 MAY 2022

EGU General Assembly

VMSG

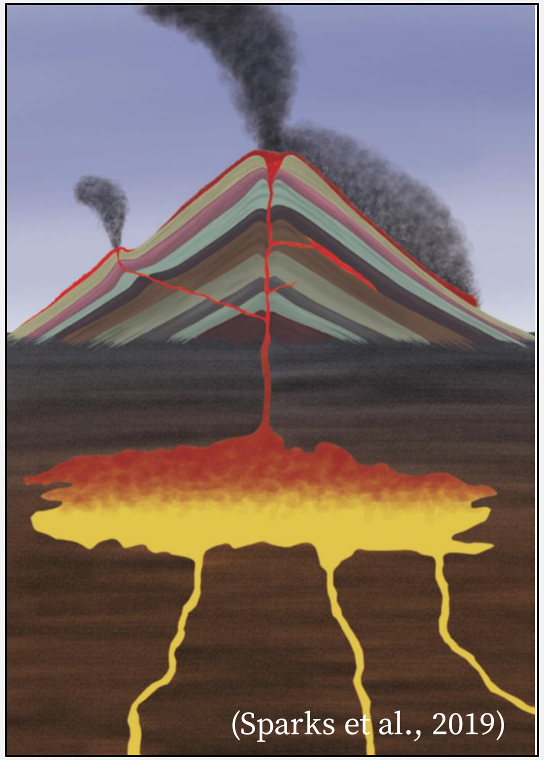
UNIVERSITY OF EXETER

UNIVERSITY OF OREGON

Overview:

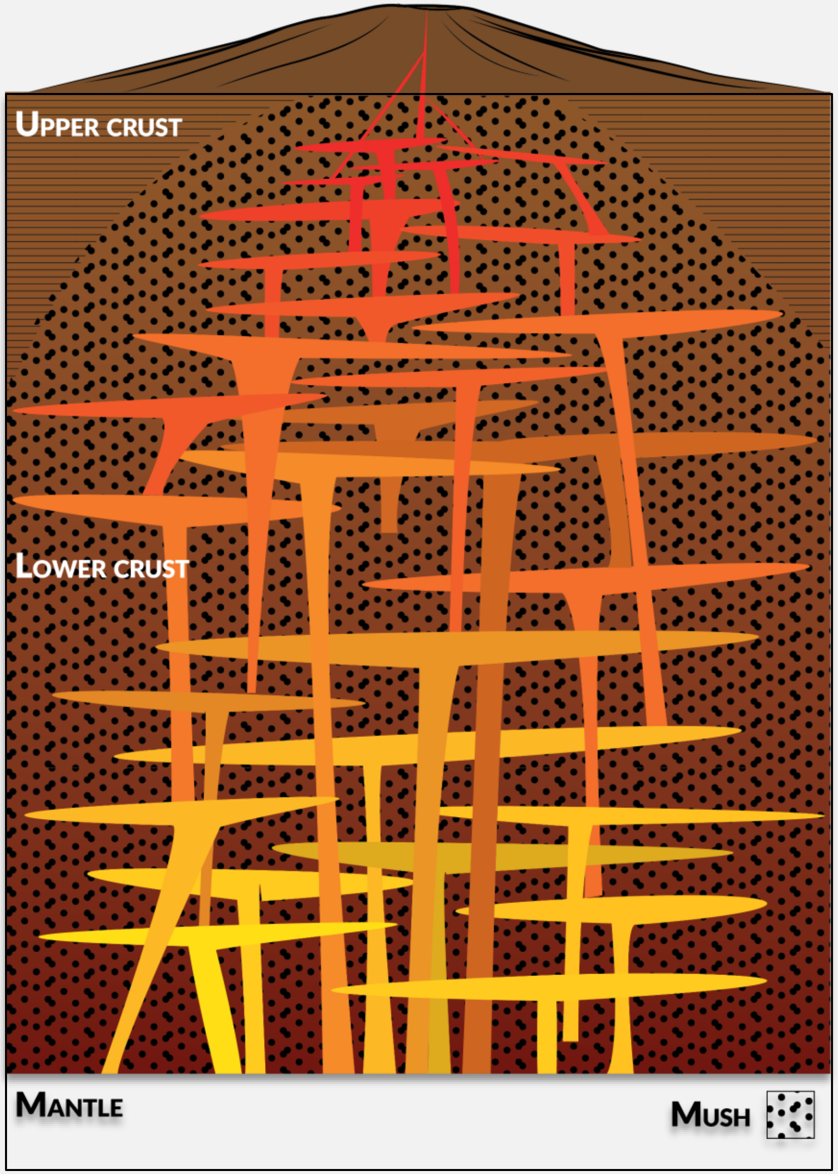
The physical model of the volcanic process (Thermal, Mechanical) suggests that a melt dominated magma chamber is difficult to form and maintain. TCMS was instead introduced, which comprised multi-level melt dominated lenses impended into a larger mush dominated system extended from the upper crust until the mantle

Magma Chamber



(Sparks et al., 2019)

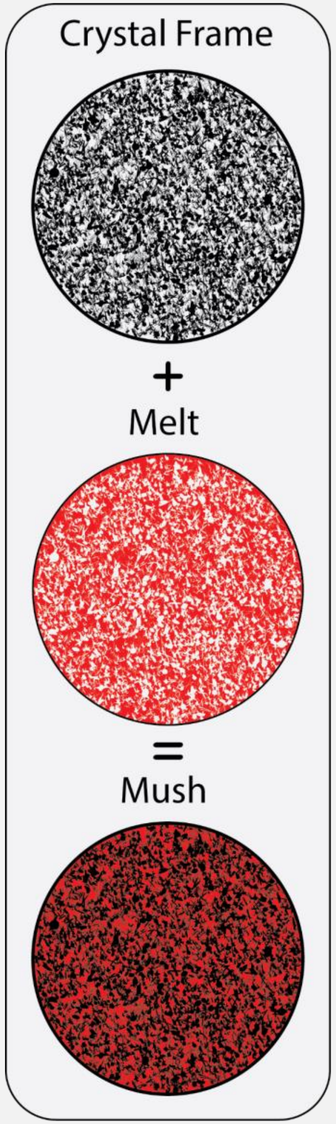
Trans-crustal Magmatic System (TCMS)



• Askja, Iceland	**(10% melt)**	(Greenfield et al., 2016)
• Altiplano Puna, Andes	**(20-35%)**	(Ward et al., 2014)
• Montserrat, Caribbean	**(3-13 %)**	(Paulatto et al., 2019)
• Laguna del Maule, Chile	**(~14 %)**	(Bai et al., 2020)
• Santorini, Greece	**(4-13 %)**	(Farrell et al., 2014)

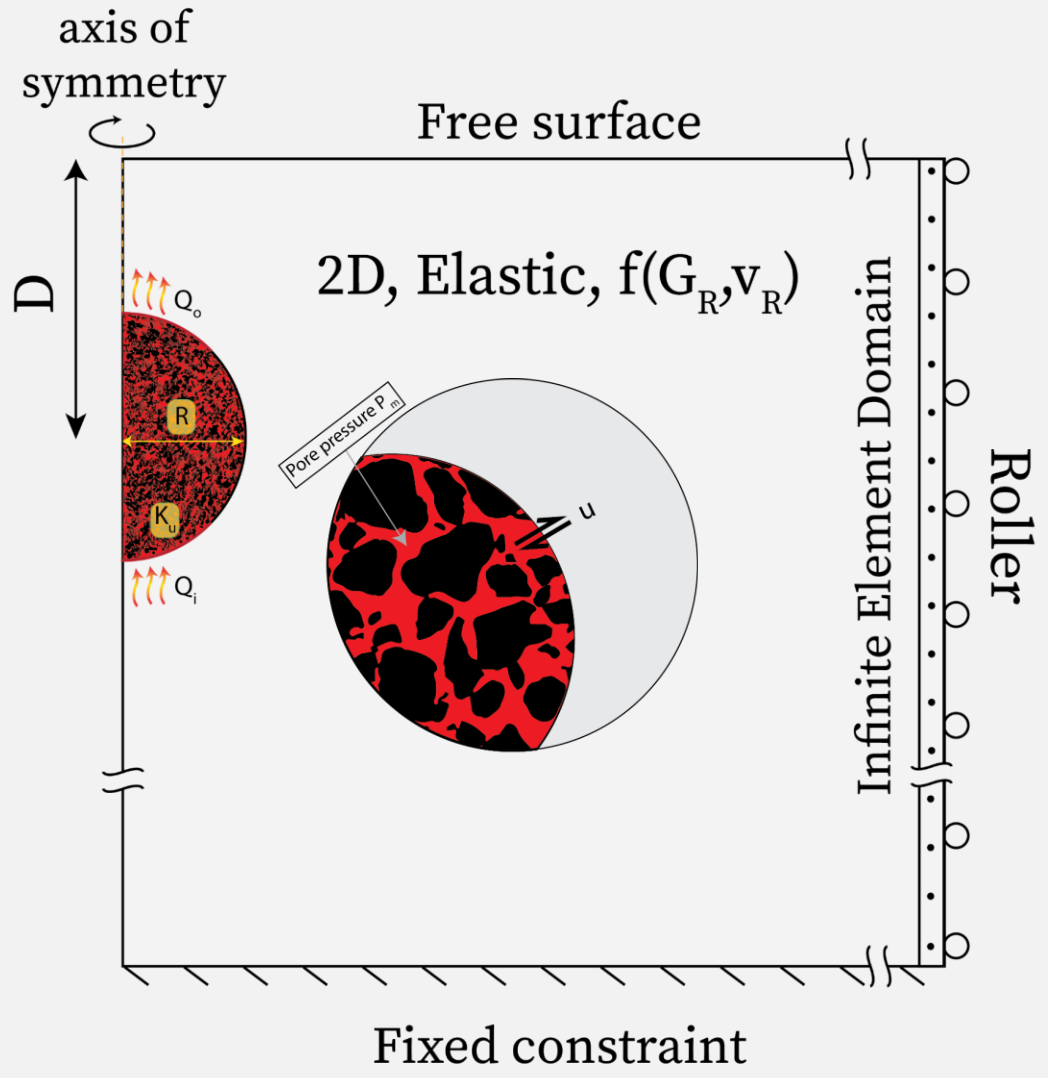
Crystalline magma chamber (mush) poroelastic response

- As the fraction of the solid crystals increases in the magma to reach a critical point of crystallinity (~50 %), the point when the solid crystals interact to assemble a contiguous skeleton of crystal and form with the melt, the crystal mush
- Because of the magma wetting properties, the pores form an interconnected network that is permeable at a vanishingly small volume fraction of melt
- The liquid fraction can still flow and percolate through the resident mush and follow Darcy's law for fluid flow in porous media



MODEL SETUP

- A new conceptual model for a crystalline magma reservoir subjected to melt injection and withdrawal events
- The model assumes a 100% poroelastic reservoir (i.e., there is no melt-filled component within the mush)
- The interaction between the fluid and solid phases and the surrounding solid rocks is solved by integrating the fluid flow and solid deformation in space and time
- A single-phase melt is injected at the reservoir base at a constant volumetric rate during the period (Δt_{inj}= 2 *yrs*). The same rate of melt withdrawal at the top of the reservoir to simulate the syn and post eruption

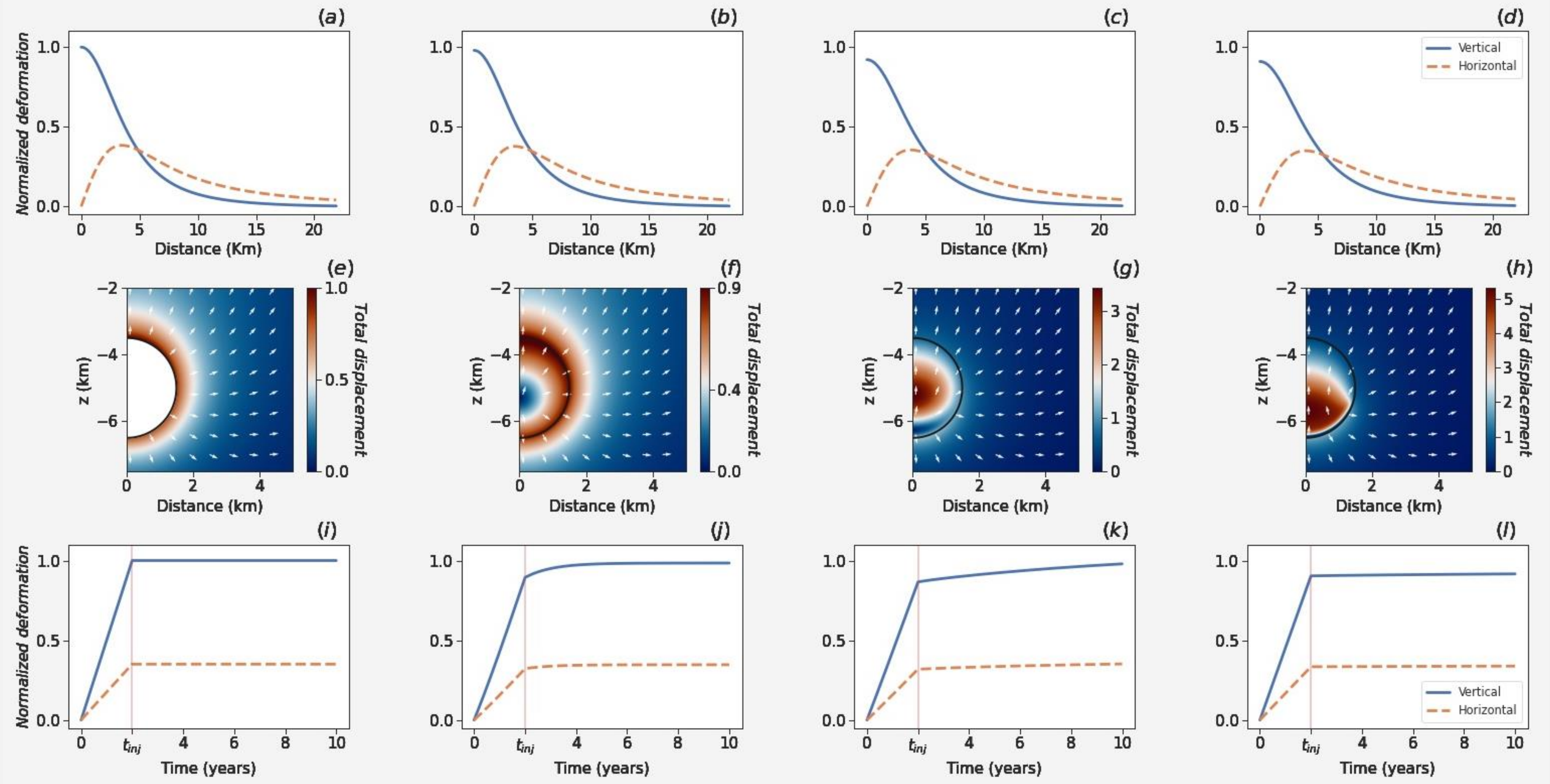


Model configuration schematics

Syn and post injection deformation

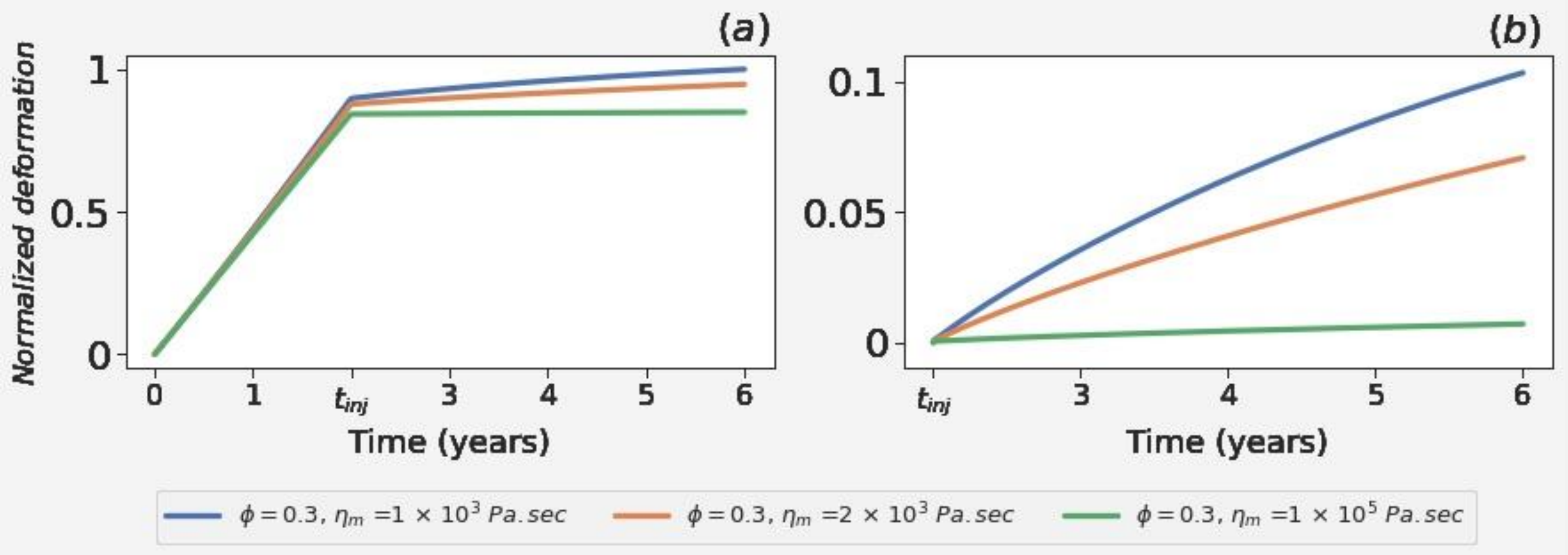
- Solid line → vertical displacement
- Dashed lines → horizontal displacement

Melt dominated | Porosity (∅) = 0.5 | Porosity (∅) = 0.3 | Porosity (∅) = 0.1



The hydraulic diffusivity $c = \frac{k}{S\,\eta_m}$, $S = \emptyset X_f + (\alpha - \emptyset)\frac{(1-\alpha)}{K_d}$ The diffusion time: $t_{diffusion} = \frac{4 * a^2}{c}$

Melt viscosity effect



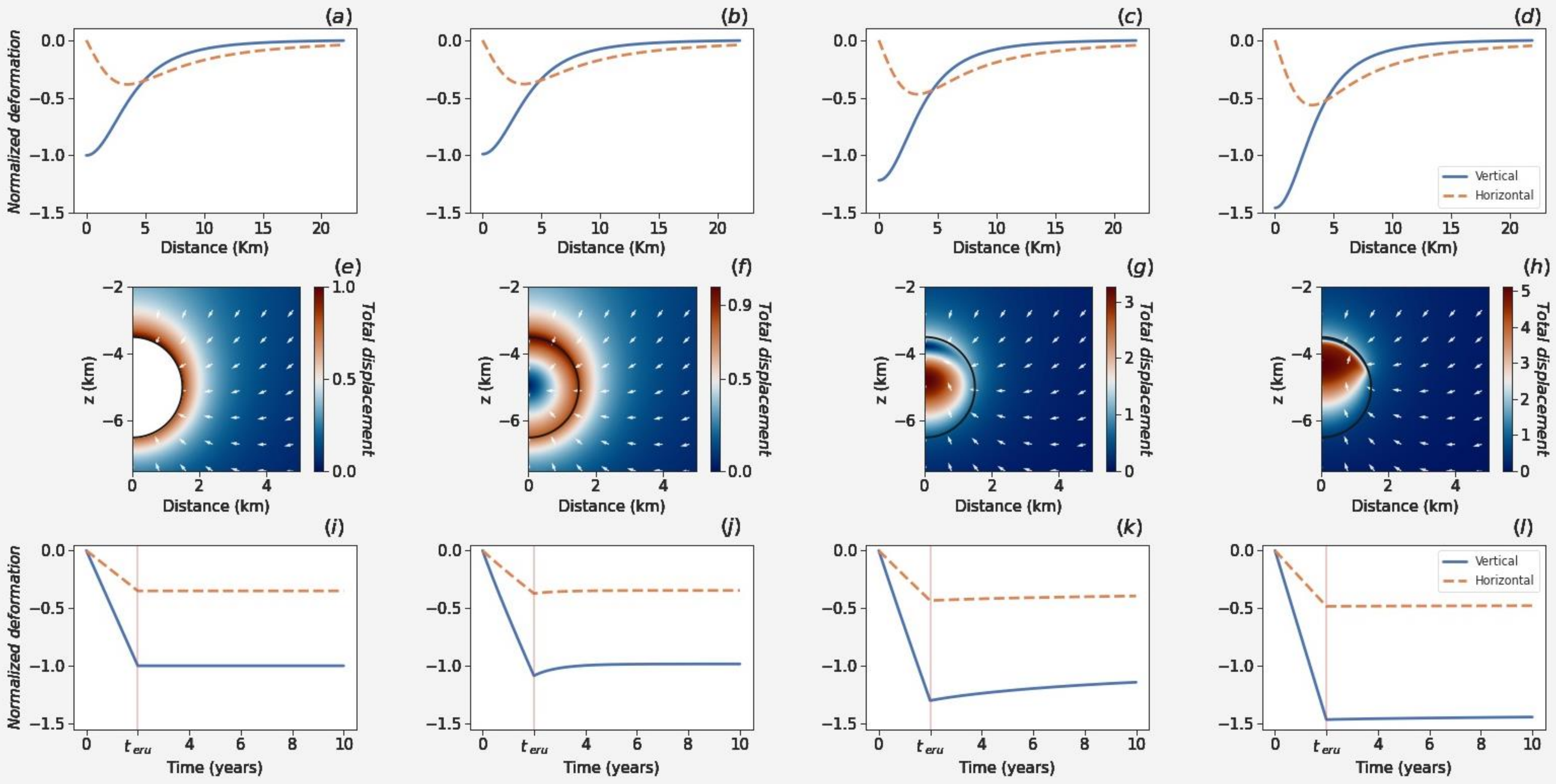
Normalized vertical displacement timeseries the case of 0.3 mush porosity

The hydraulic diffusivity $c = \frac{k}{S\,\eta_m}$, The diffusion time: $t_{diffusion} = \frac{4 * a^2}{c}$

Syn and post eruption deformation

- Solid line → vertical displacement
- Dashed lines → horizontal displacement

Melt dominated | Porosity (∅) = 0.5 | Porosity (∅) = 0.3 | Porosity (∅) = 0.1



Conclusion

- Unlike the classical kinematic models of volcano deformation, when considering the poroelastic behaviour of the mush, the system will continue to evolve after the injection/withdrawal events are terminated
- Understanding the mush poroelastic behaviour is essential to improve our models of the volcano behaviour and potential hazards posed by volcanism
- Further studies are required to understand the mush's micromechanical structures and the hydraulic properties of mush, such as the porosity and permeability
- Combining the mush PoroViscoElastic and the wall rock viscoelastic behaviors can lead to further time-dependent evolution in subsurface stress and the resultant surface deformation

Feel free to contact me at my email (ra500@exeter.ac.uk)