UCLouvain

HOW DOES LAVA FOLD?

Simulating ropy pāhoehoe lava with MigFlow

MigFlow

FIELD OBSERVATIONS

What do lava folds look like ?

When basaltic lava flows down a slope, its surface cools into a thin, highly viscous crust while the hot interior keeps flowing. As the terrain flattens, the crust is compressed faster than it can flow and buckles into the characteristic rope-like folds of ropy pahoehoe lava.



Ropy lava flow - Hawaii | Yusuke Suzuki - Youtube | Typical length of the order of 10 m

Similar to a tablecloth pushed from one side, this compression-driven instability produces folded cross-sections. These become visible when the upper crust fractures and exposes the internal structure.

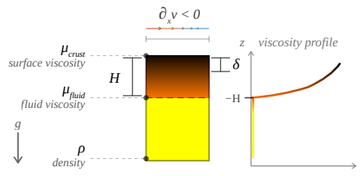


Scan to see the complete 3D model

Solidified ropy lava cross-section - Fagradalsfjall (Iceland) | Sketchfab, Universität Hamburg | Typical arclength of a fold of the order of 10cm

BUCKLING PHYSIC

What controls the formation and shape of lava folds?



Fink and Fletcher's analytical model defines the critical conditions for folding and predicts the resulting wavelength λ based on R, S and δ.

VISCOSITY RATIO

$$R = \frac{\mu_{\text{crust}}}{\mu_{fluid}}$$

μ_{crust} : surface viscosity

μ_{fluid} : magma viscosity

THERMAL THICKNESS

$$\delta = \frac{H}{\ln R}$$

H : crust thickness

STRESS RATIO

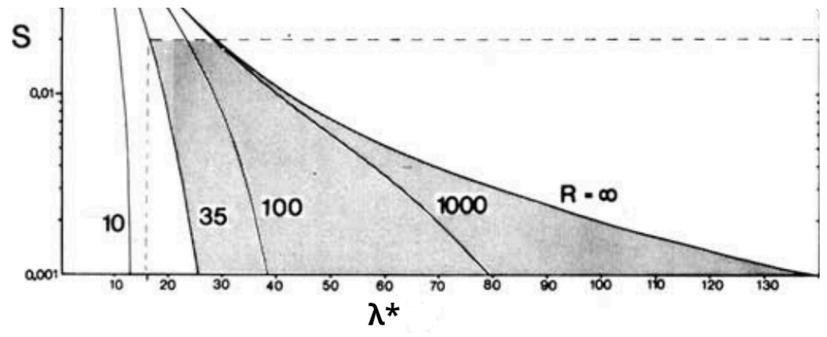
$$S = \frac{\rho g \delta}{4\mu_{\text{crust}}\partial_x v}$$

hydrostatic pressure vs compressive viscous stress

ρ : lava density g : gravity

$\partial_x v$: shortening rate

Folding occurs if and only if $R \gtrsim 35$ and $S \lesssim 0.02$, and the resulting λ^* is then fully determined by R and S.



DIMENSIONLESS WAVELENGTH

$$\lambda^* = \frac{\lambda}{\delta}$$

λ : fold wavelength

Source: *J.H. Fink & R.C. Fletcher – Ropy pāhoehoe: Surface folding of a viscous fluid – J. Volcanol. Geotherm. Res. 4, 1978 – doi:10.1016/0377-0273(78)90034-3*

SIMULATION RESULTS

How do the folds dynamically appear ?

GEOMETRY

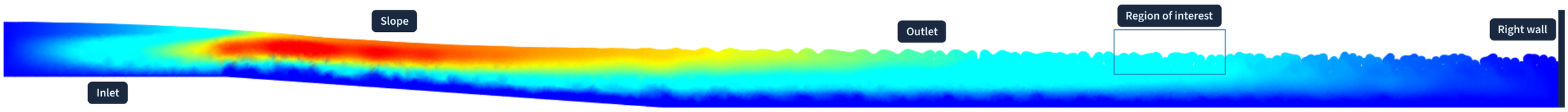
Slope length	**4.0 m**	Slope inclination	**4.0°**
Inlet length	**2.0 m**	Inlet flux	**0.01** $\frac{m^2}{s}$
Outlet length	**8.0 m**	Outlet height	**0.4 m** (controlled by an outlet flux)
Right wall	imposed ground temperature & convection, no velocity		
Left wall	imposed magma temperature, no horizontal velocity		

NUMERICS

Mesh size	**0.0067–0.20** m
Time step	**0.0667** s
Ground velocity	**(0, 0)**
Free surface pressure	**0** Pa

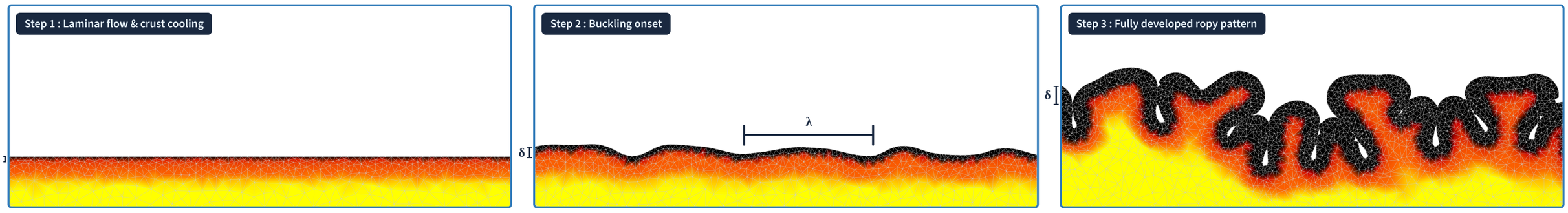
THERMAL CONDITIONS

Magma temp.	**1273.1 K**	Lava conductivity k	**2.0** $\frac{W}{m \cdot K}$
Ground temp.	**573.1 K**	Ground convection h	**700** $\frac{W}{m^2 \cdot K}$
Air temp.	**293.1 K**	Air convection h	**100** $\frac{W}{m^2 \cdot K}$
Heat capacity c_p	**1200** $\frac{J}{kg \cdot K}$		



Velocity v (m/s) : 0 → 0.02 → 0.04

Control parameters: By driving the flow dynamics, **flux terms and terrain geometry** govern the evolution of the **stress ratio** S, ultimately triggering the onset of folding as predicted by Fink & Fletcher.



Viscosity μ (Pa·s) : 10^3 → 10^4-10^5 → 10^6

Control parameter: By controlling heat diffusion, the **thermal conductivity** k impacts the growth of the **thermal thickness** δ, as seen in black above.

NUMERICAL METHOD

How did we simulate it ?

We modelled the lava as an incompressible Newtonian fluid with a free surface. The dynamics are governed by the Navier-Stokes equations, coupled with a temperature-dependent viscosity.

Particle Finite Element Method (PFEM)
At each time step, Lagrangian particles are remeshed with GMSH, allowing the PFEM to naturally track the evolving free surface. This captures complex folding, merging, and splitting without the numerical diffusion typical of fixed-grid methods.

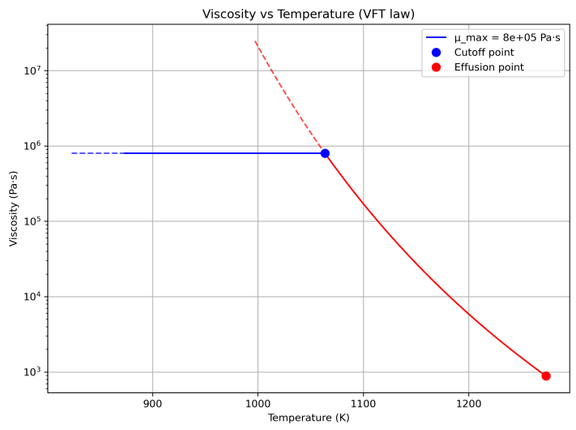
Viscosity varies with temperature at every node via the Vogel-Fulcher-Tammann (VFT) law:

$$\log \mu(T) = A + \frac{B}{T - C}$$

$$A = -4.55 \quad B = 5555.3 \quad C = 532.1$$

A, B, C are constant calculated via a GRD model for a typical basaltic melt.

Control Parameter: The **viscosity cutoff** $\mu_{\max}$ dictates the **viscosity ratio** R. It acts as a numerical proxy for the crust solidification, ensuring stability while mirroring the crust viscosity μ_{crust} of the Fink & Fletcher model.



DISCUSSION & PERSPECTIVES

Where do we go from here ?

Main Strengths

- **PFEM Advantage:** Explicit tracking of complex crust topology.
- **Thermo-coupling:** Captures non-linear viscosity gradients.
- **Robustness:** Stable integration of VFT rheology in high-strain regimes.

Current Limitations

- **Boundary Effects:** Wall-constrained flow replacing natural front dynamics.
- **Thermal Model:** Temperature-dependent $k(T)$ is required for precise crust thickness H.
- **Physics Assumptions:** Current Newtonian assumption omits yield stress and brittle crust fracturing.

Future Outlook

- **Sensitivity:** Automated tracking of λ and H to calibrate the $\mu_{\max}$ *crust solidification proxy*.
- **Hybrid Modeling:** Coupling **PFEM** with **DEM** to simulate brittle crust fragmentation and scoria transport.
- **3D Scaling:** Transition to 3D to capture lateral flow spreading and **orthogonal buckling**.

Join the development: Explore our documentation and open-source solvers for complex fluid-particle interactions.

Scan to visit **migflow.be**

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