CRUSTAL VISCOSITY AND ITS CONTROL ON VOLCANIC GROUND DEFORMATION PATTERNS

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VISCOELASTICITY

How are ground deformation patterns modified by a temperature-dependent viscosity distribution?

Does the choice of ambient thermal regime change the predicted ground deformation patterns?

Observed **deformation field** is a function of:

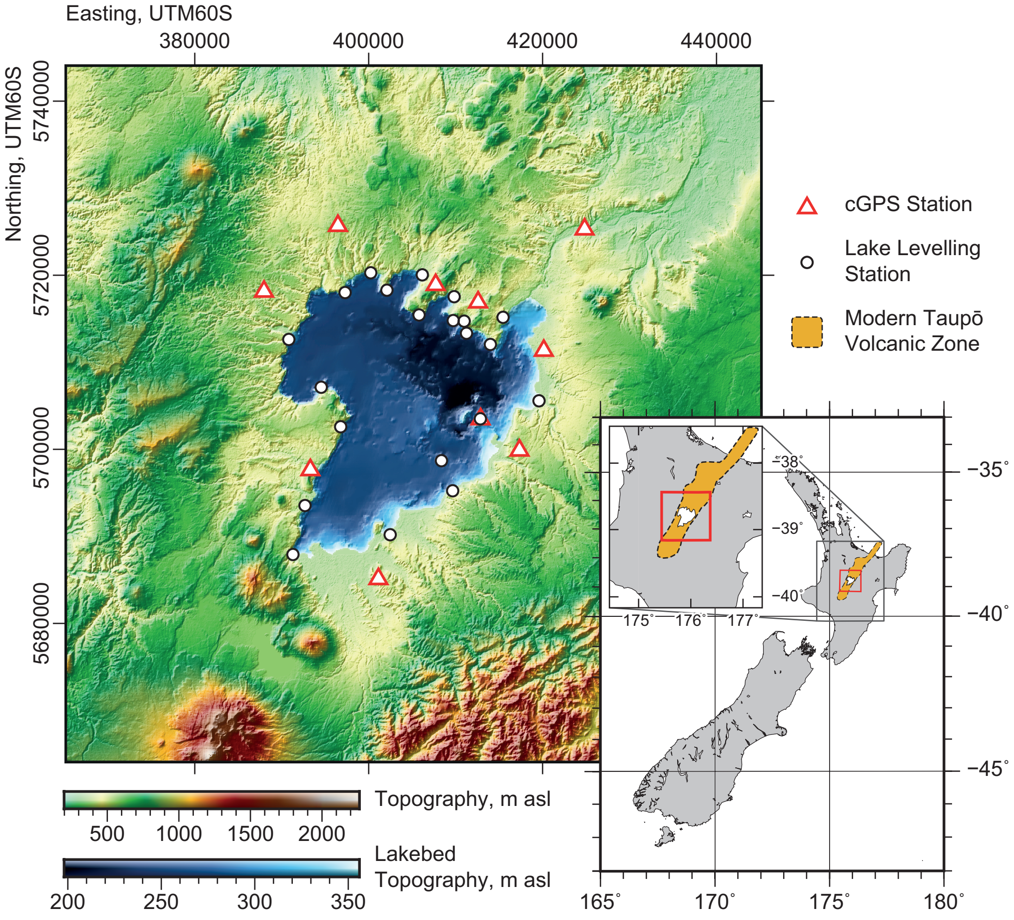
- Source processes involved
- Surrounding crustal structure
- **Rheological response**

Shallow or long-lived magmatic systems induce **elevated thermal regimes**

- Invalidates elastic assumption?
- Time-dependent rheological effects?
- Thermomechanical strain partitioning?

Compare popular **viscoelastic** configurations, **Maxwell** and **SLS**, in an overpressure-driven thermomechanical deformation model

Taupō Volcano



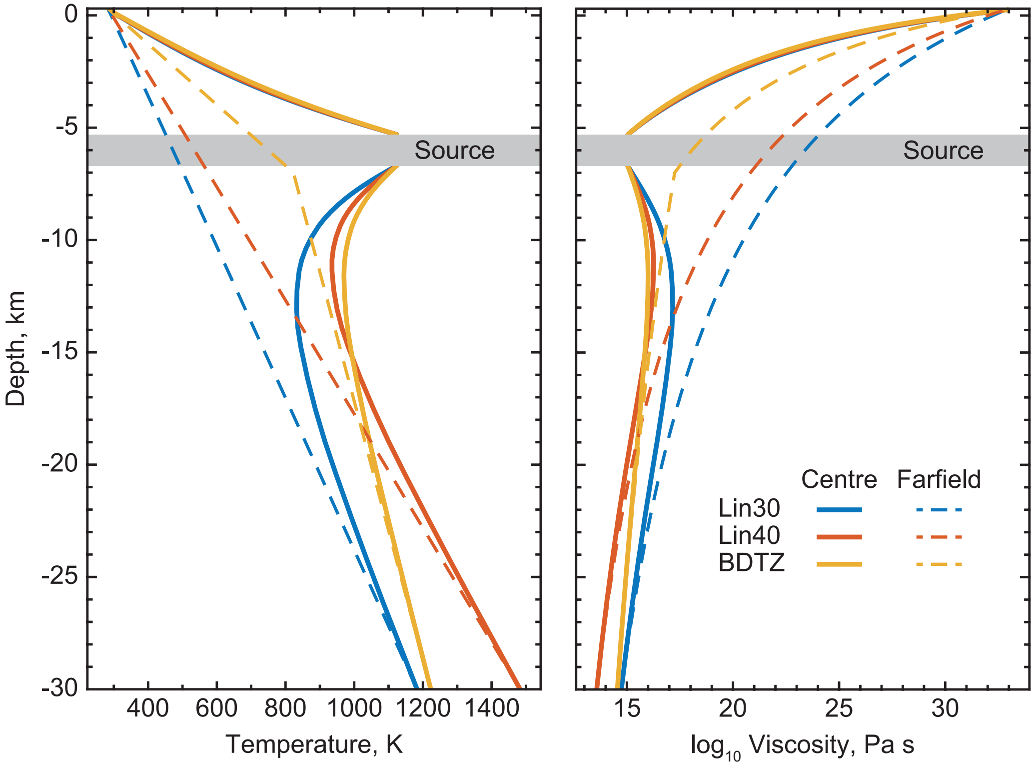
Taupō volcano, New Zealand, is a **large silicic caldera complex** in the Taupō Volcanic Zone

- Two caldera-forming events; **1.8 ka Taupō (VEI 7)** and **26.5 ka Oruanui (VEI 8)** eruptions
- Region of high surface heat flow, resulting from volcanism and rifting

High heat flow assumed to reflect **elevated temperatures** at depth, long-lived magmatic system residing in **thermally-primed crust**

We model a hypothetical deformation episode, based on inferences of the **1.8 ka Taupō eruption** (e.g. Ellis et al, 2007)

Modelling



Resultant temperature and viscosity profiles

Consider 3 thermomechanical set-ups, with a **magmatic temperature** of **1123 K** (850 °C)

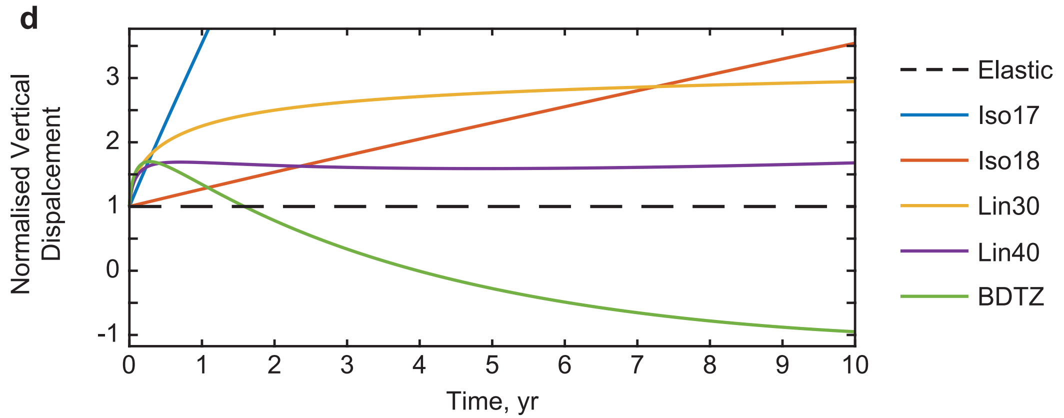
- "**Lin30**" – 30 K/km linear geotherm, with no additional constraints
- "**Lin40**" – 40 K/km linear geotherm, with no additional constraints
- "**BDTZ**" – Temperature constraints for basal and mid-crust, producing a ramped geotherm

Models produce near-identical viscosity profiles above the modelled reservoir

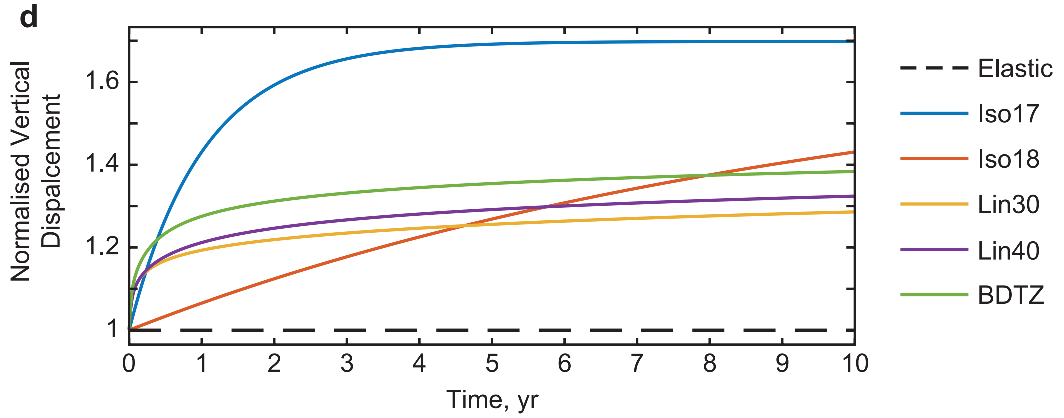
Compare against "expected" viscoelastic responses seen in isoviscous models (e.g. Head et al., 2019)

- "**Iso17**" – 10^{17} Pa s for whole model-space
- "**Iso18**" – 10^{18} Pa s for whole model-space

Differences in Vertical Deformation



Timeseries are evaluated directly above the source, showing the different deformation responses of the models **Maxwell** (above), **SLS** (below)



Maxwell → expected to produce linear deformation (Head et al., 2019)

- Inconsistent deformation response in thermomechanical set-ups
- Produces uplift at large distances from source

SLS → consistent viscosity-dependent rate-decreasing deformation (Head et al., 2019)

- Rate of deformation is viscosity-dependent
- Thermomechanical models attain ~30-40% more displacement than the elastic model
- *Why do the thermomechanical models differ?*

…Take Home Messages

SLS rheology captures a range of **deformation timescales**, due to viscosity structure

- Viscous effects not limited to long-term

BDTZ model attains ~10% more uplift than standard 30 K/km gradient model

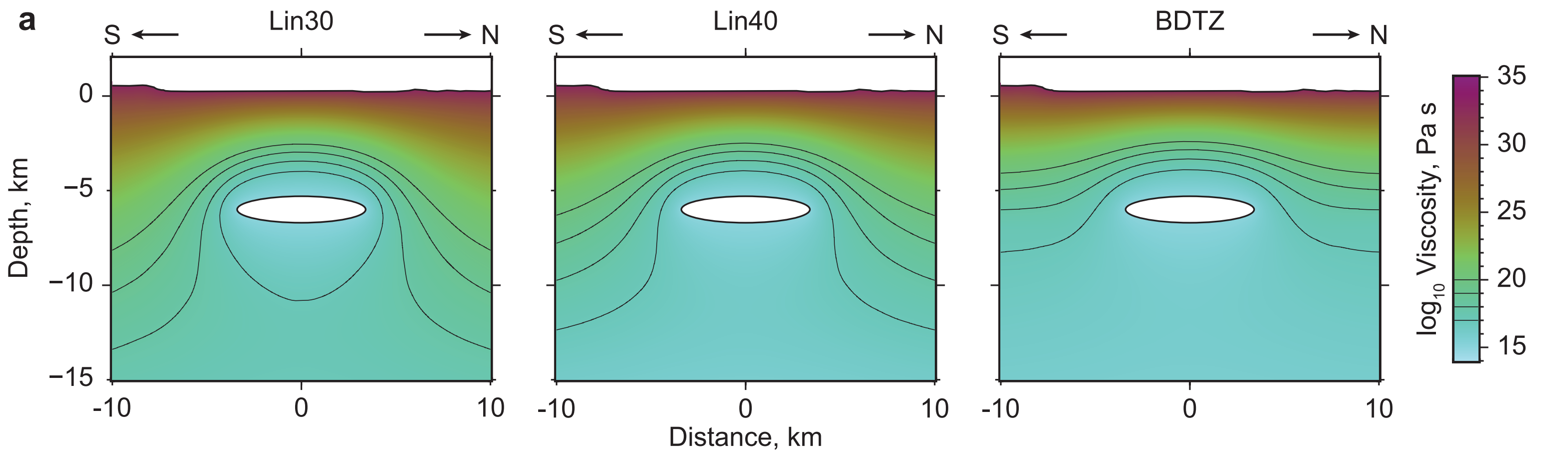
- **Deformation partitioning** due to local viscosity structure – **reduces overpressure** requirements?

Maxwell rheology is a **viscoelastic fluid**

- Viscosity gradients allow crustal material to "flow" in response to imposed overpressures
- Produces inconsistent deformation patterns

Raises questions about **applicability** of this rheology to "solid" deformation studies

Local viscosity structure for each of the thermomechanical set-ups, with contours showing 10^{17}, 10^{18}, 10^{19}, 10^{20} Pa s



APPENDIX

COMSOL Multiphysics® → forward models of ground deformation

- Full 3D geometry with **topography**, **crustal heterogeneity** from 3D seismic tomography (Eberhart-Phillips et al., 2010)
- Steady-state temperature field from **thermal constraints**, calculate **temperature-dependent viscosity** using Arrhenius formulation (e.g. Del Negro et al., 2009; Gregg et al., 2012; Hickey et al., 2016)

$$\eta_{TD} = A_D \exp\left(\frac{E_A}{RT}\right)$$

- A_D – 1x10^9 Pa s; E_A – 1.3x10^5 kJ/mol

Modelling a hypothetical deformation episode, source characteristics based on inferences of the **1.8 ka Taupō eruption** (e.g. Ellis et al, 2007)

- **Oblate spheroid** geometry, horizontal radius of **3.4 km** and vertical radius of **0.7 km**
- Centred at **depth** of **6 km**
- Magmatic temperature of **850 °C**
- BDTZ model basal temperature of **950 °C**, mid-crustal temperature of **550 °C** (Stagpoole et al., 2013)
- Overpressure of 10 MPa

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