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The Australian Newer Volcanics Province as an Example of the Interaction of a Mantle Plume and a Lithospheric Step

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Motivation & Problem

Numerous areas of intra-plate volcanism are located in a favorable region where edge-driven convection (EDC) is likely to better account for the recorded surface volcanism[1]. In Australia, multiple volcanic centers, clustered in a region called the Newer Volcanics Province (NVP), have been shown to lie on an extremely thin lithosphere[2] (Figure 1), south-east of the Proterozoic Curnamona Craton. They were all dated in the last 6 Ma, without any age- nor spatial progression being observed. Numerical modeling[3] has demonstrated that EDC can develop in the vicinity of the NVP, with upwelling velocities on the order of 1 $cm.yr^{-1}$. However EDC is unlikely to be the only mechanism at work as such areas of rapidly varying lithospheric thickness are thought to have remained stable for tens of millions of years, a period for which no volcanism was recorded within the NVP. Intriguingly, the recently inferred Cosgrove track[4] (Figure 1), which extends from North Queensland to Victoria, and which is believed to be the surface expression of a mantle plume, seems to vanish approximately at the same time and location that the NVP initiates. Nevertheless it remains unclear how the NVP relates to the Cosgrove track and if the latter influenced the former in any way. We therefore investigate here, through two-dimensional numerical models generated using the framework Fluidity[5], the spatial and temporal interaction of a mantle plume with a lithospheric step.

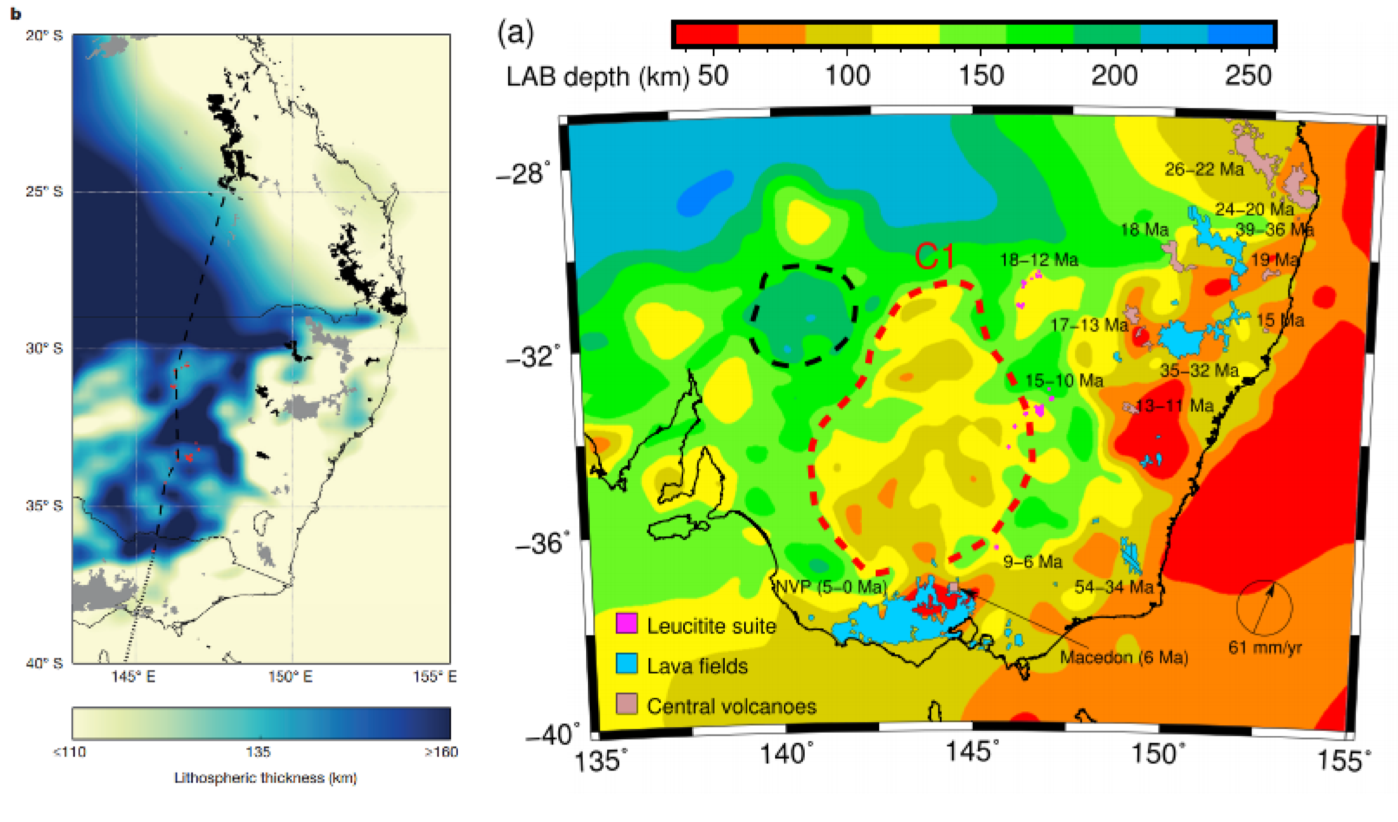

Fig. 1: *Left*: Distribution of eastern Australian Cenozoic volcanic centres and their relationship to regional lithospheric thickness variations (originally produced in [4]). *Right*: Lithosphere-asthenosphere boundary depth with distribution of Cenozoic volcanism at the surface superimposed (originally produced in [2]).

Model Setup

Work in Progress

- The Stokes system and the energy balance are solved for inside a two-dimensional domain which is 1000 km deep and has an aspect ratio of 4:1.
- No-slip velocity boundary conditions are imposed at the top and bottom of the box, while a free horizontal flow is solved for on both sides.
- The surface and upper-mantle potential temperature are set to 300 K and 1600 K respectively; both sidewalls are insulating.
- The initial thermal state follows the half-space cooling model and is used to define three structures in the upper part: a thick lithosphere to the left, a thin lithosphere to the right and a linear transition step in between.
- A temperature- and pressure-dependent diffusion creep viscosity law is used[6] and constrained by recent results from gravity[7], postglacial[8] [9] and tectonic[10] studies.
- After 1 Ma, anomalously hot material is injected into the bottom of the domain: the associated velocity and excess temperature follow a gaussian profile, the former reaching 15 $cm.yr^{-1}$ and the latter 300 K, both of them vanishing 140 km away from the peak.
- Basic melting conditions are investigated by comparing the adiabatic temperature profile (0.5 $K.km^{-1}$) to a wet peridotite solidus[11] ($X_{H_2O} = 0.1$ wt%).

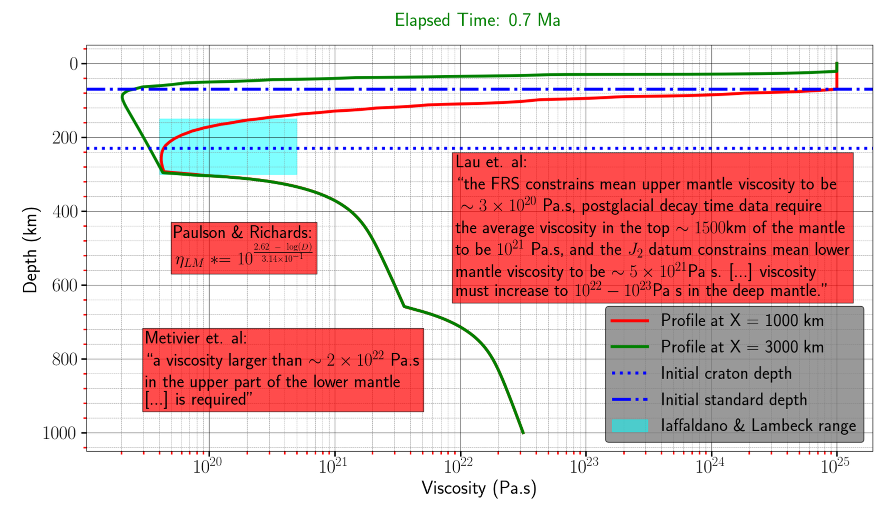

Fig. 2: Viscosity structure used in the models.

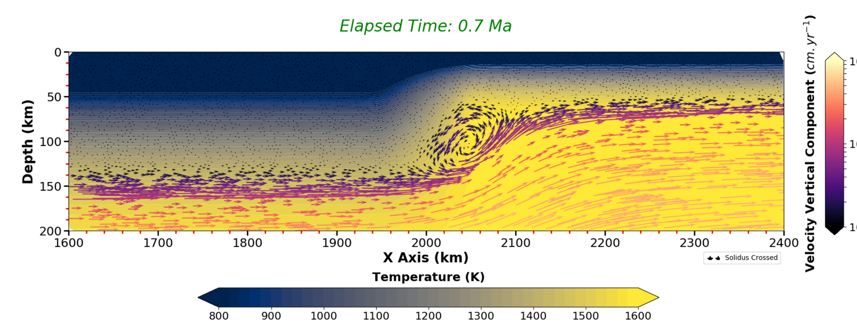

Fig. 3: Mantle flow and edge-driven convection cell generated before the material is injected. The solidus is never crossed under the simulated scenario.

Results

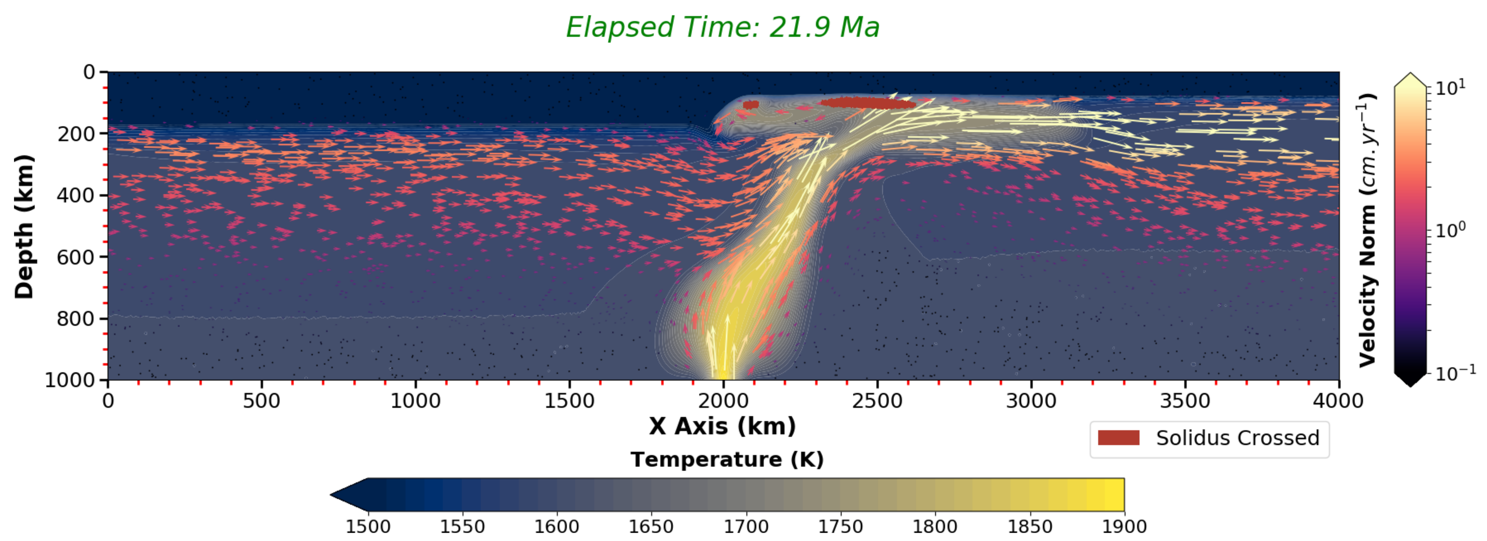

Fig. 4: Plume and mantle flow generated with a central injection at the bottom of the domain. The solidus is crossed at the step location due to the interaction with the pancake material.

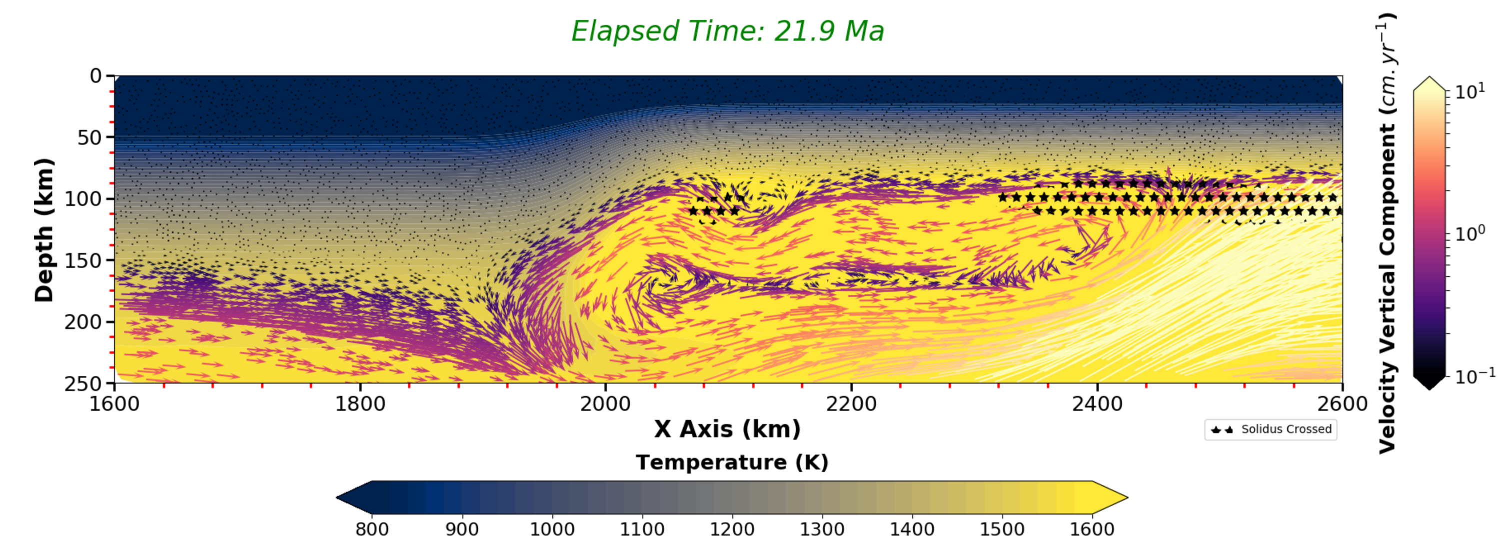

Fig. 6: Zoom on the left side of the plume pancake from Figure 4. An EDC cell interacts with multiple small-scale convection cells, generating an upwelling that crosses the solidus.

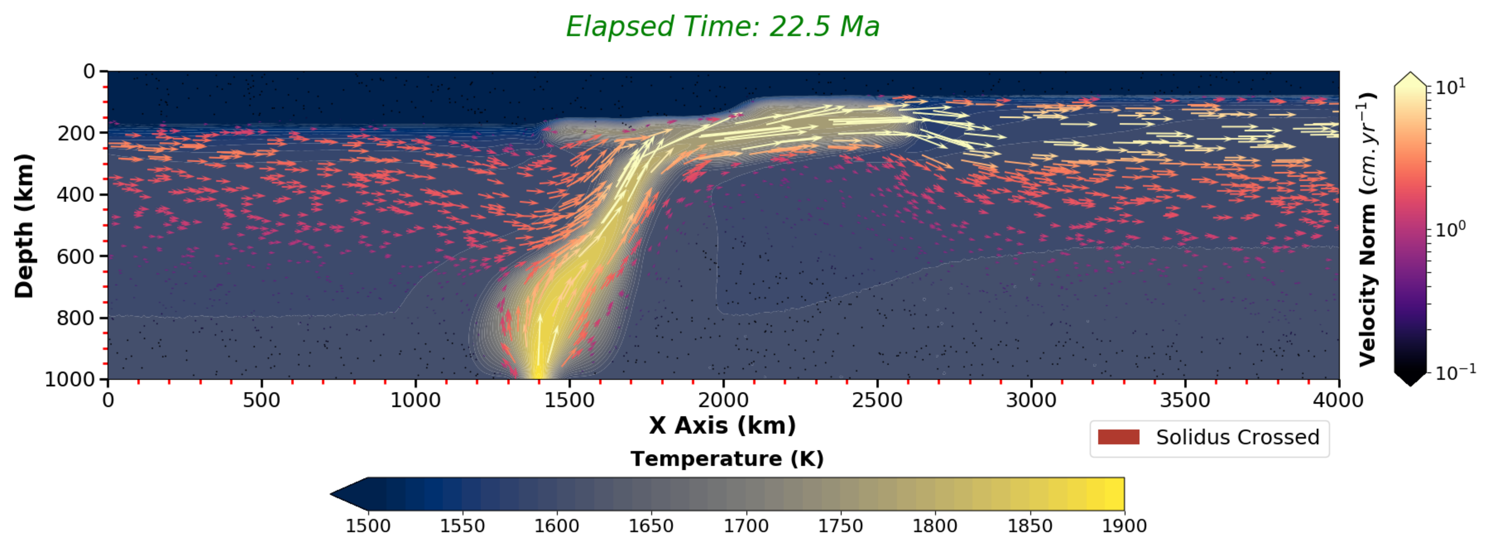

Fig. 5: Same as Figure 4, but with a left-sided injection. A cell still develops at the step, however EDC is overcome by the shear-driven flow; the solidus is never crossed.

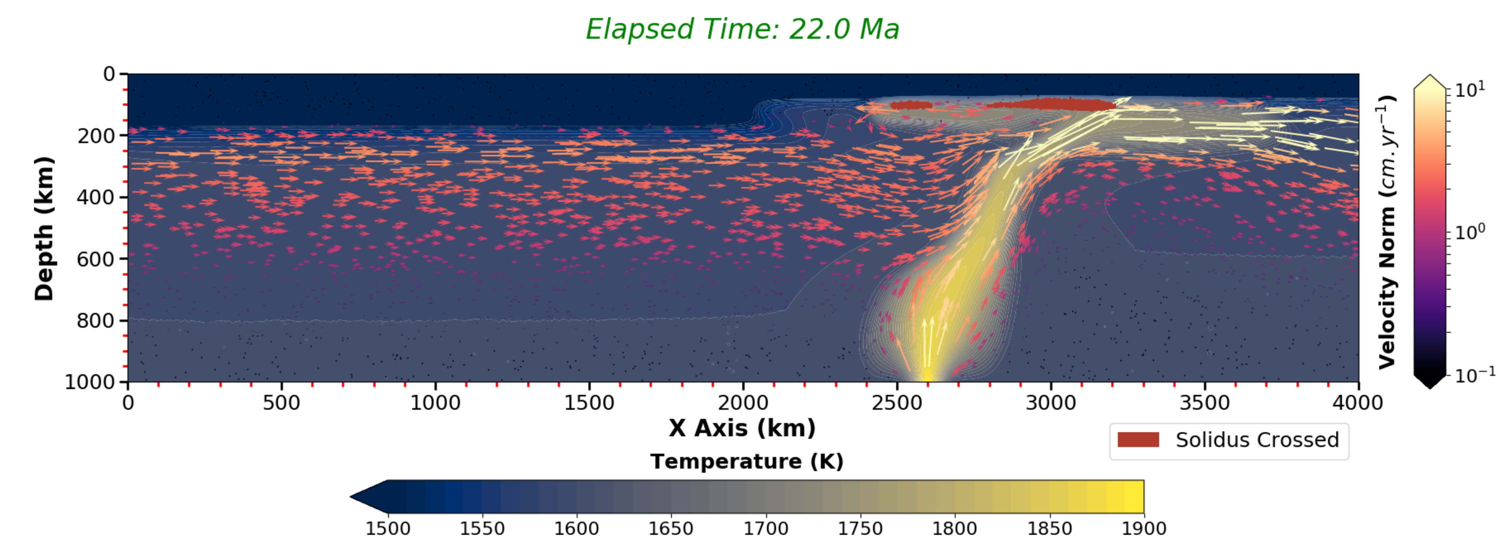

Fig. 7: Same as Figure 4, but with a right-sided injection; no cell is observed. The solidus is crossed at multiple locations in the pancake, but never in conjunction with upwellings.

References

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Perspectives

Our initial models show that unusually hot temperature profiles develop at a lithospheric step when low-viscosity material from a plume pancake comes and interacts. Interestingly, the geometry of the interaction is determining, as shear-driven upwelling, edge-driven convection and small scale convection instabilities can all be at work. It is therefore crucial to extend the analysis to a three-dimensional space, for which new behaviours are likely to be observed. Great care must be paid to the regional lithospheric structure inferred by tomography studies in order to properly apply the model to the NVP area. Additional efforts have to be made to better account for the melting behaviour (quantifying the melt production is crucial) and the way it influences the flow dynamics.