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Linking mantle plumes, large igneous provinces and environmental catastrophes

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Large Igneous Provinces (LIPs) are known for their rapid production of enormous volumes of magma, for dramatic thinning of the lithosphere and for their links to global environmental catastrophes [1-5]. Controversy surrounds even the basic idea that LIPs form through melting in the heads of thermal mantle plumes[2-5]. The Permo-Triassic Siberian Traps – the type example and the largest continental LIP, is located on thick cratonic lithosphere and was synchronous with the largest known mass-extinction event [1]. However, there is no evidence of pre-magmatic uplift nor of a large lithospheric stretching of the basaltic sequence, predicted above a plume head [2,4,6]. Moreover, estimates of magmatic CO2 degassing from the Siberian Traps are considered insufficient to trigger climatic crises leading to the hypothesis that the release of thermogenic gases from the sediment pile caused the mass extinction [7,8].

In this study [9] we present petrological evidence for a large amount (15 wt%) of dense recycled oceanic crust in the head of the plume and developed a thermomechanical model of interaction of a thermochemical plume head with lithosphere that predicts no pre-magmatic uplift and requires no lithospheric extension. The model assumes source-composition and temperature based on petrological constraints, employs non-linear elasto-visco-plastic rheology and pressure- and temperature-dependent melting of a heterogeneous mantle. The model implies extensive plume melting and heterogeneous delamination of the thick cratonic lithosphere during a few hundred thousand years. The model suggests that massive CO2 and HCl degassing from the plume could alone trigger the Permian-Triassic mass extinction and predicts it happening before the main volcanic phase.

Numerical tests [9] suggest that rapid lithospheric destruction associated with melting in the heads of thermochemical plumes is valid for the large range of plume parameters and lithospheric thicknesses, and therefore may apply not only to the Siberian Traps but also to other LIPs. An absence of prominent pre-magmatic uplift does not argue against a plume origin of LIPs, but may rather point to a high content of recycled crust within the plume. In such cases, other parameters being equal, the model predicts that eclogite-rich plumes caused the most extensive delamination/thinning of the lithosphere thus best preparing it for possible break-up, produced the strongest volcanism and led to the most dramatic climatic consequences.

Another suggestion of our model – that major mass extinctions are triggered by degassing of plume magmas that predate the main magmatic phase – also seems to be consistent with the observations for many LIPs [5] implying that gas output from plume heads may be much larger than previously thought.

References

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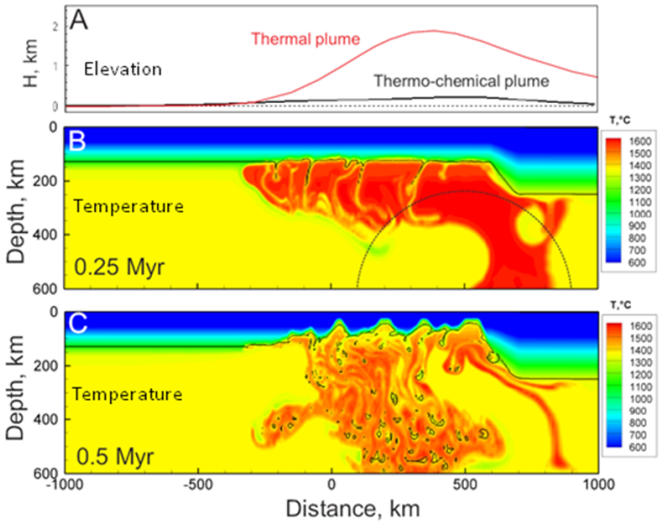

Figure 1: (A): Maximum pre-magmatic surface uplift atop a spreading mantle plume with an excess temperature of 250°C. The red curve corresponds to the purely thermal plume, and the black curve corresponds to a thermo-chemical plume with 15 wt% of recycled crust.(B,C): Potential Temperature (°C) in the model cross-section at model times of 0.25 and 0.5 Myr. Note substantial destruction of thick lithosphere in just few 100 thousand years [9].