Can mantle convection by distant rifting induce intraplate volcanism?

Min-Seok Jang[1*], Byung-Dal So[1]

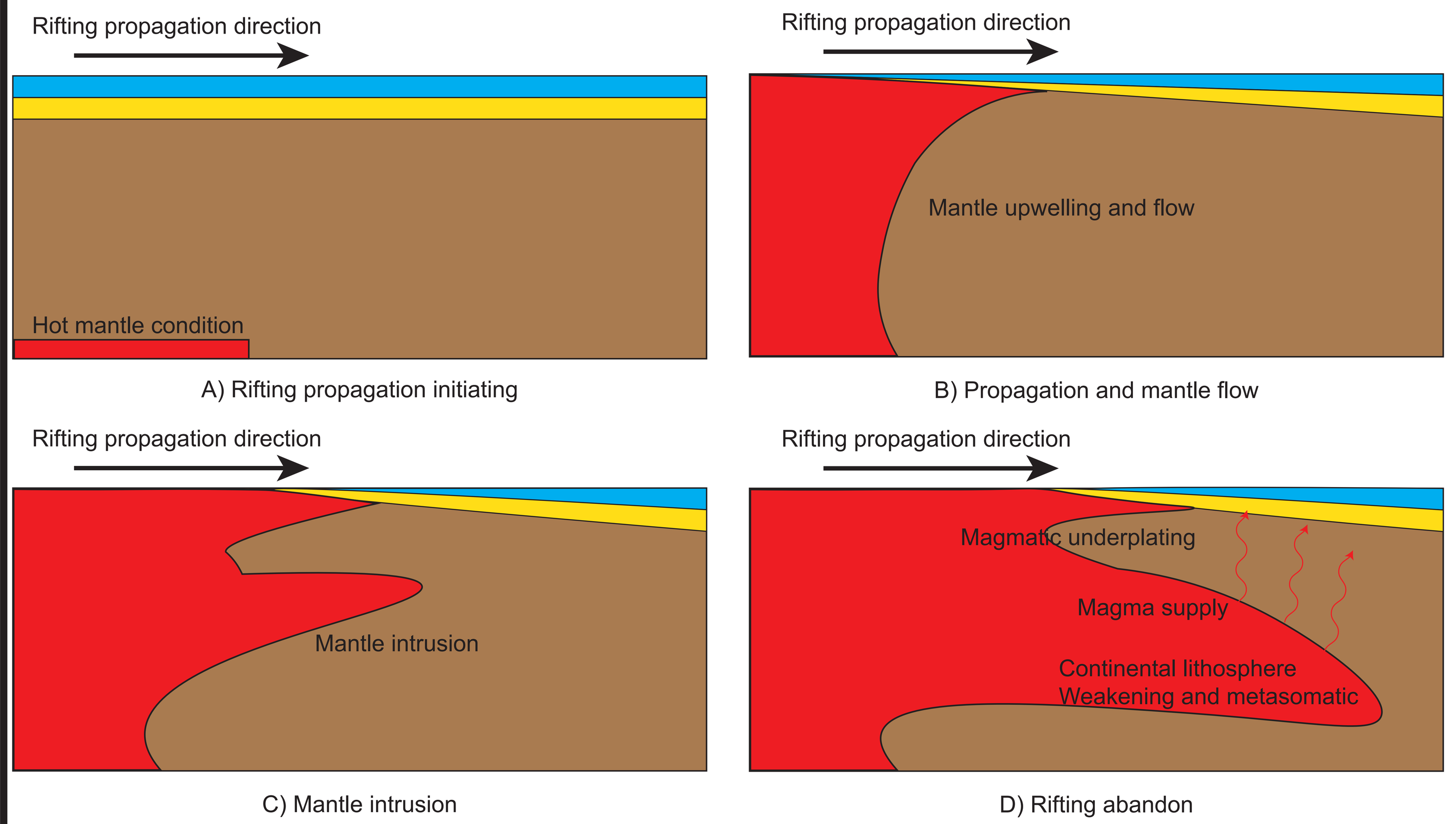
[1*] Department of Geophysics, Kangwon National University, Chuncheon, Republic of Korea

(alstjr2264@kangwon.ac.kr)

ABSTRACT

Rifting is a large-scale planetary evolution process that forms a new oceanic crust with mid-ocean ridges in an extensional environment. In this process, mantle convection occurred and material circulates, forming a volcano in the surrounding area. It is well known that mantle flow of rifting causes volcanism, but most of the volcanic processes are concentrated in the mid-ocean ridge and rift center axis. Recently, many of theory (lithosphere delamination, edge-driven convection, slab tearing, etc.) have been discussed to explain intra-plate volcanic mechanisms at non-plume and non-extension conditions. However, has been rarely studying the correlation between intra-plate volcanism and distant rifting. To identify the origin of occurring volcanoes in the continental margin and intra-plate is necessary studying to evolution mechanism and lower mantle. The formation of rifting and continental margin is closely related, and it is assumed that mantle convection significantly affects intra-plate volcanism. Well known through previous studies that mantle convection Along the rifting axis affects various evolution such as rift propagation, ridge jump, rift fail or end tip with transform fault. In this study, we estimate the possibility mantle convection can induce intra-plate volcanism at rifting end tip and continental beyond the margin. We adopt the open-source finite element geodynamics software, ASPECT, which makes a 3-D rifting model for observing the evolution process and mantle convection below the continental margin.

INTRODUCTION



- Rifting drives large-scale mantle flow during evolution

- Mantle flows in the direction of extension are known to produce volcanic structures such as LIPs and volcanic island chains

- Recent studies of ridge jumps and rifting propagation suggest strong mantle flow in the axis-parallel direction

- The axis-parallel mantle flow reaches the lower lithosphere before rifting propagation and has various effects

- We study the intrusive mantle flow during propagation and mantle convection after rifting abandon and its association with intraplate volcanoes using numerical modeling

MODEL SETUP

ASPECT

Advanced Solver for Problems in Earth's ConvecTion

Governing Equations

(1) Continuity equation

$$\nabla \cdot u = 0$$

(2) Momentum conservation equation

$$-\frac{\partial P}{\partial x_i} + \eta \frac{\partial^2 u_i}{\partial x_j^2} + \rho g \delta_{i2} = 0$$

(3) Energy conservation equation

$$\rho C_p \left(\frac{\partial T}{\partial t} + u \cdot \nabla T \right) - \nabla \cdot k \nabla T = \rho H$$

Rheology

(1) Mohr-Coulomb Failure

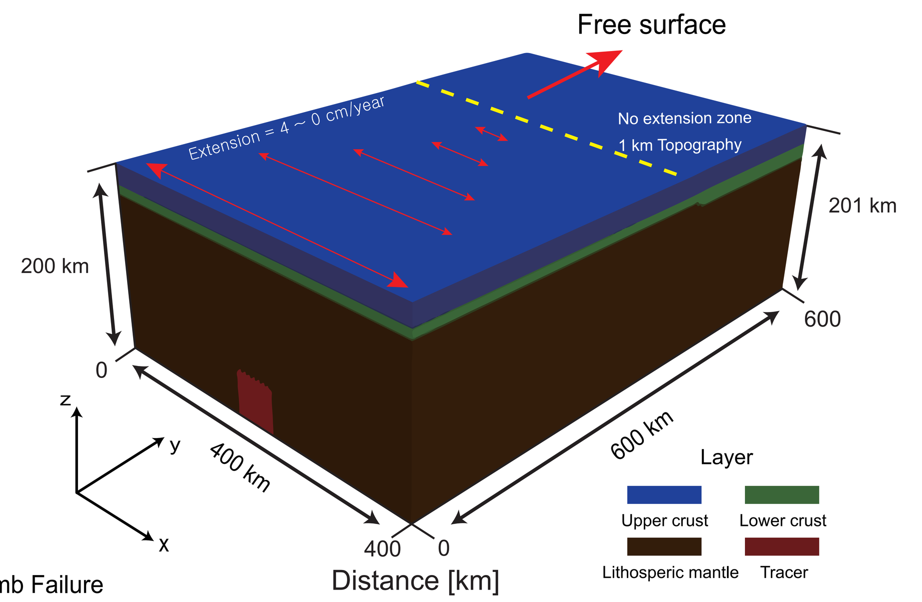
$$\eta_{brittle} = \frac{\rho g z \tan\phi + C}{\dot{\varepsilon}_{II}}$$

(2) Dislocation creep

$$\eta_{disl} = \frac{1}{A_{disl}^{-n}} \dot{\varepsilon}_{II}^{(1-n)/n} \exp\left(\frac{E_{disl} + pV_{disl}}{nRT} \right)$$

(3) Effective viscosity

$$\eta_{eff} = \min(\eta_{brittle}, \eta_{disl})$$

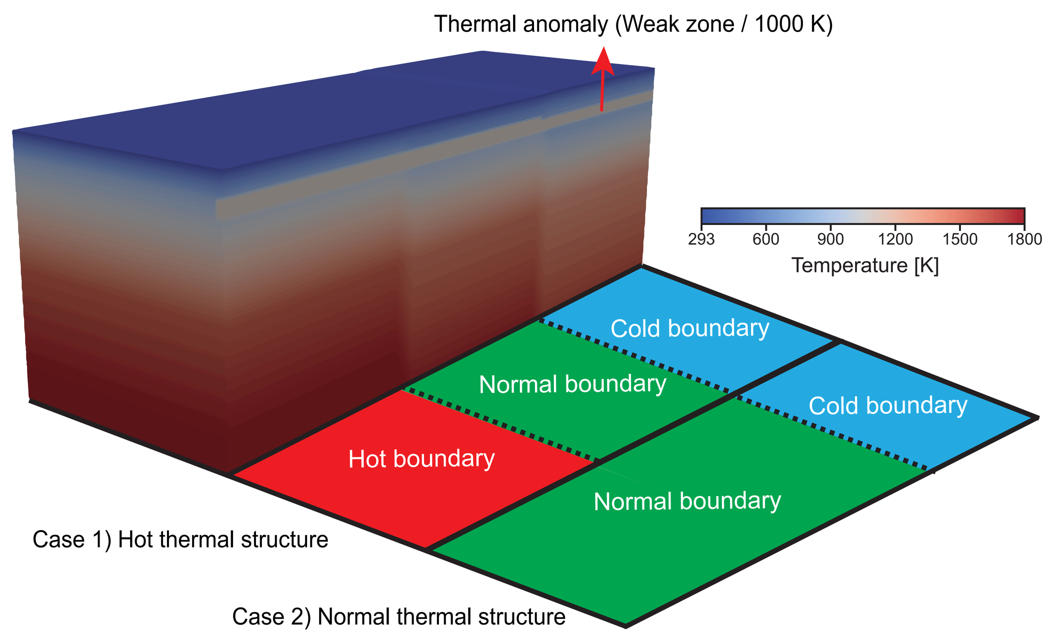


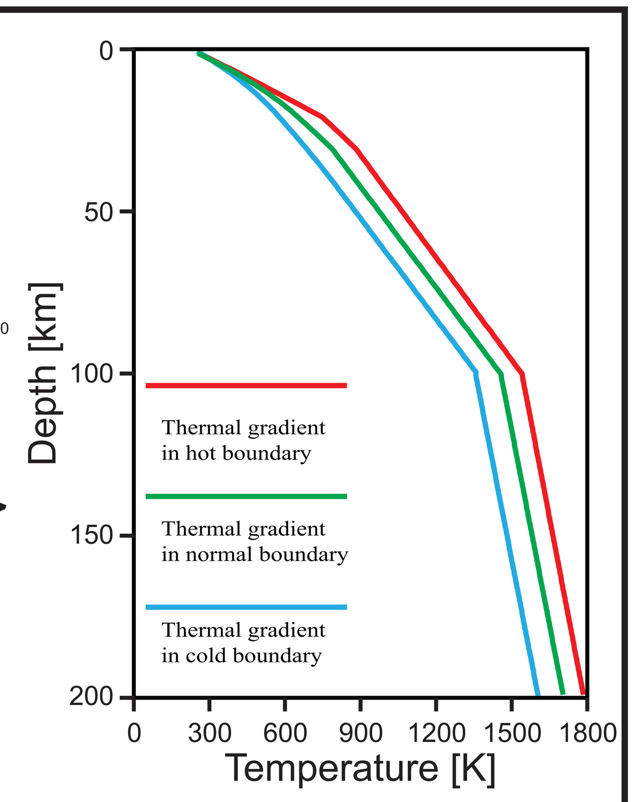
Model properties

Properties \ Layer	Upper crust	Lower crust	Lithosperic mantle	Tracer
Density [$kg \cdot m^{-3}$]	2800	2900	3300	3300
Heat capacity [$m^2 \cdot s^{-2} \cdot K^{-1}$]	750	750	1250	1250
Thermal diffusivity [$m^2 \cdot s^{-1}$]	$1.19 \cdot 10^{-6}$	$1.14 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$
Thermal expansivity [K^{-1}]	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$
Prefactor for dislocation creep [$Pa^{-n} \cdot s^{-1}$]	$8.57 \cdot 10^{-28}$	$5.78 \cdot 10^{-25}$	$1.72 \cdot 10^{-14}$	$1.72 \cdot 10^{-14}$
Power-law exponent [-]	4	4.7	3.3	3.3
Activation energy [$J \cdot mol^{-1}$]	$2.23 \cdot 10^{5}$	$4.85 \cdot 10^{5}$	$5.02 \cdot 10^{5}$	$5.02 \cdot 10^{5}$
Activation volume [$m^{-3} \cdot mol^{-1}$]	$6.4 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$
Cohesion [Pa]	$2 \cdot 10^{7}$	$2 \cdot 10^{7}$	$2 \cdot 10^{7}$	$2 \cdot 10^{7}$
Friction angle [degree]	20	20	20	20

- A three-layer lithospheric structure of 600 x 400 x 200 km extends along the y-axis at a rate of 0 to 4 cm/yr (gradually decreasing from 0 to 400 km along the x-axis) and causes rift propagation

- Rifting will continue for 6 million years, after which expansion will cease and be abandoned for 1.5 million years. During this time, a tracer at the 0 km point on the x-axis moves along the mantle convection, indicating the extent of the intrusion



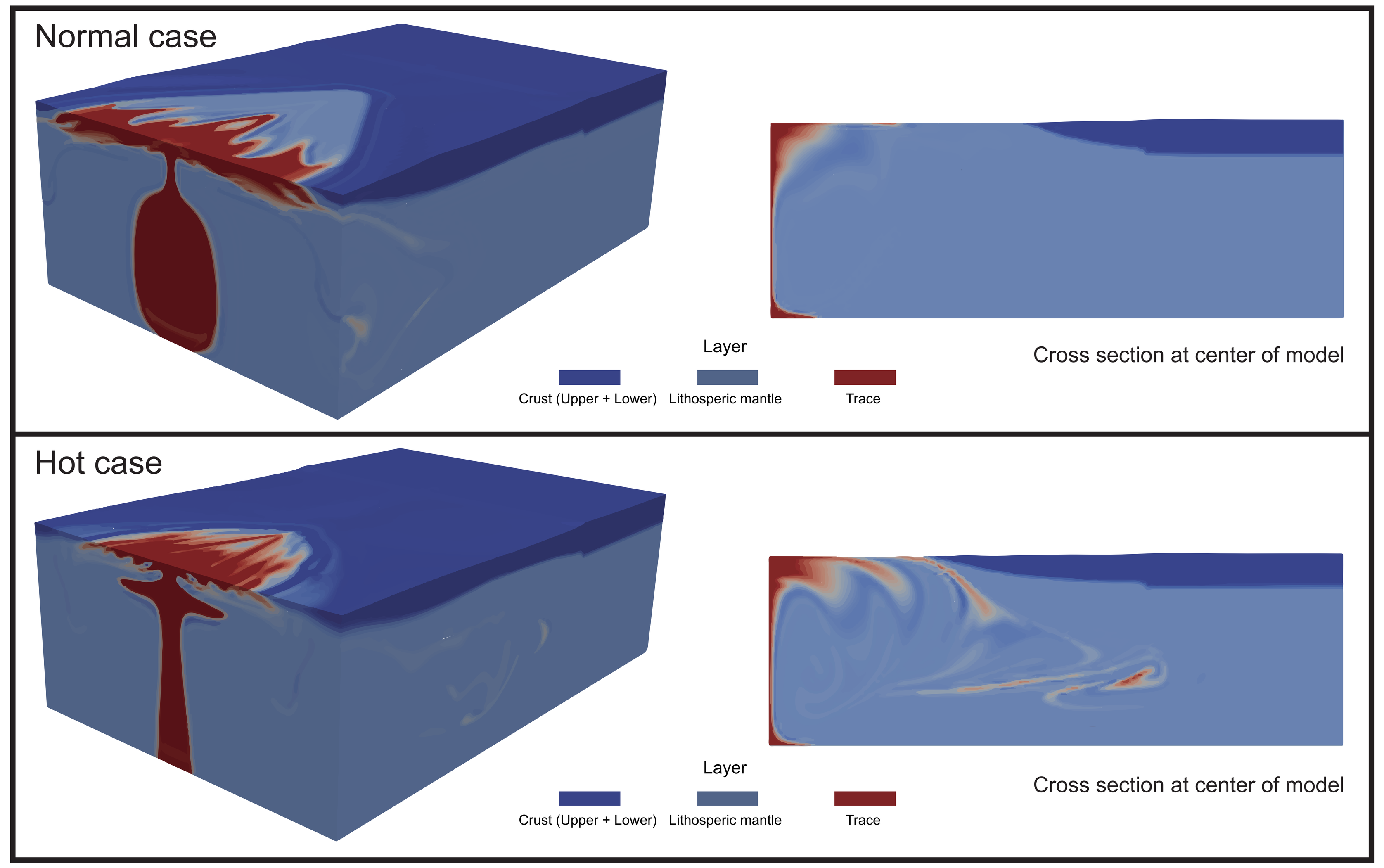


- Each 200km along the x-axis has a different temperature boundary and structure and is divided into hot and normal cases

- We apply a 1000 K thermal anomaly at a depth of 20 km in the model's center to form a weak zone where rifting begins

RESULT

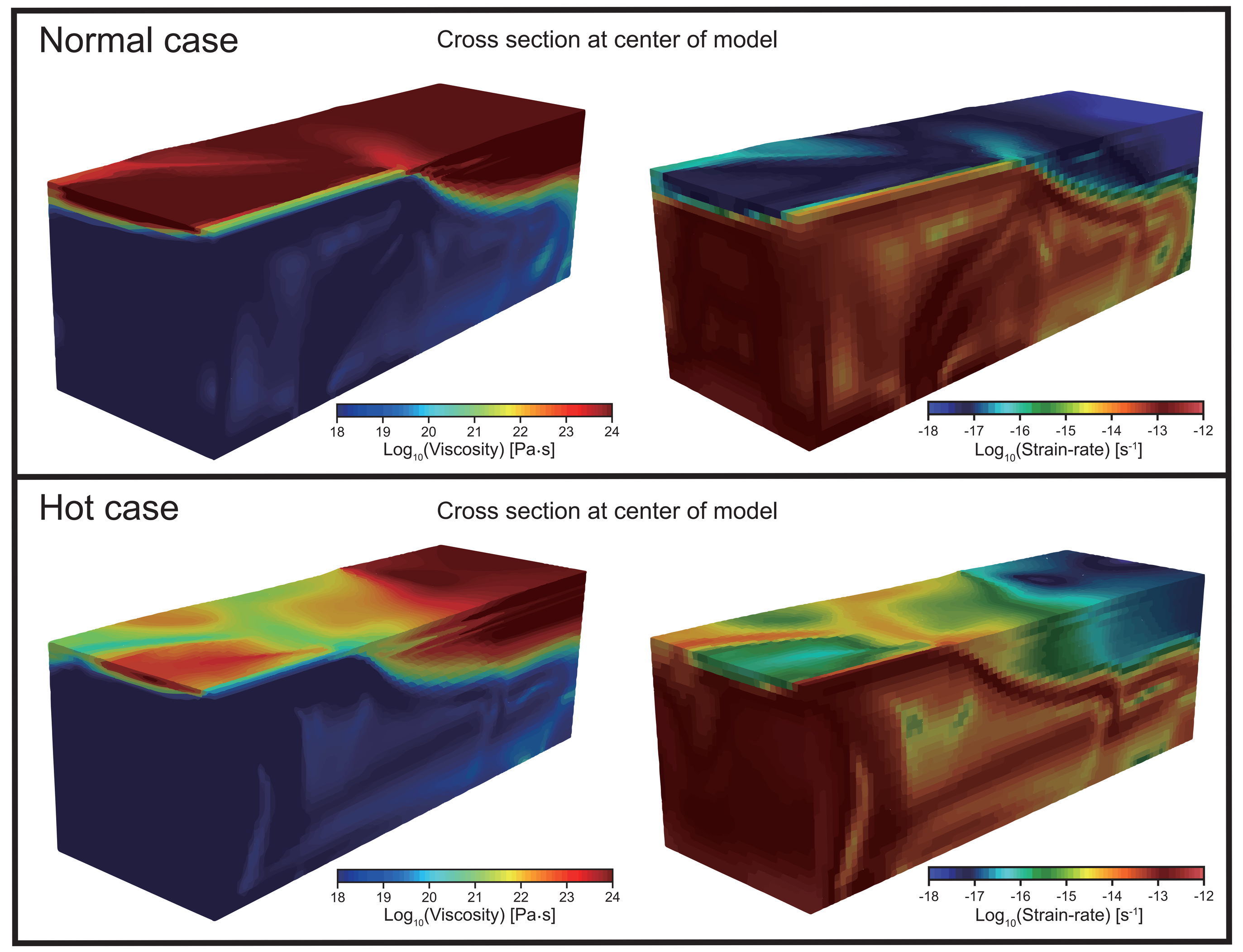
1. Composition compare



- The composition comparison between the two cases shows the difference in the degree of propagation. The normal case propagated to 300 km, while the hot case propagated to 200 km. This is believe to be due to mantle upwelling and flow intrusion to the lithosphere before ridge formation and crustal breakup

- In the normal case, the mantle tracer spread only around the ridge, whereas in the hot case, it flowed more than 400 km into the lower lithosphere due to strong mantle convection

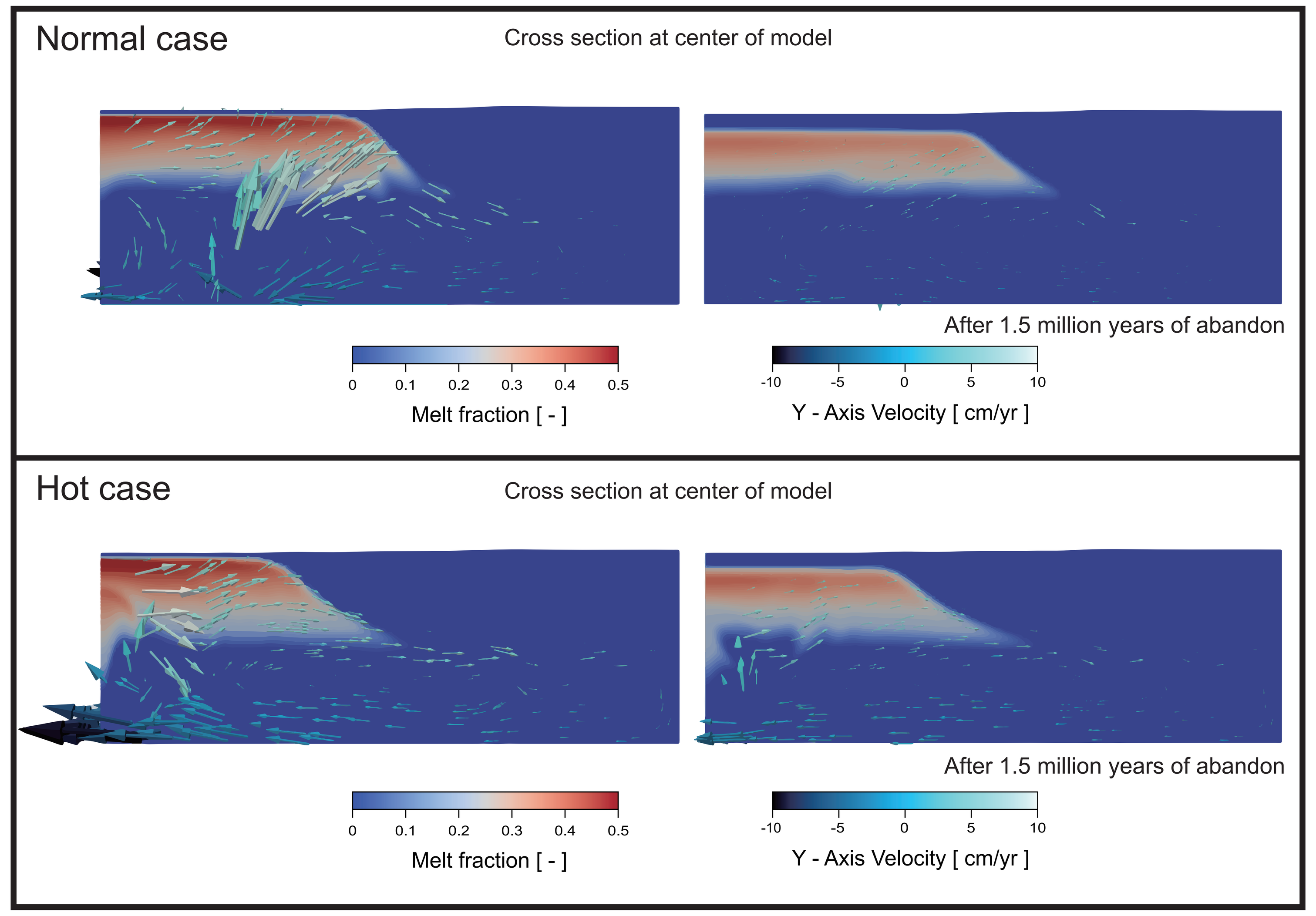
2. Viscosity and Strain rate compare



- The viscosity and strain rate comparisons in the hot case show active flow compared to the normal case. In particular, mantle intrusion is more pronounced

- The Composition comparison shows that the Hot case has strong mantle convection affecting the surface, causing the region to exhibit high strain rates

3. Melt fraction and mantle flow compare



- The mantle flow in the normal case tends to come up and propagate from just below. However, the hot case shows a stronger intrusion flow further back

- After 1.5 million years of abandonment, the melt fraction at the ridge continues to weaken and intrudes into the lower lithosphere along the mantle flow

CONCLUSION

- We developed a 3D rifting model using ASPECT to determine whether lower mantle flows induced during rifting propagation have the potential to trigger an intraplate volcano.

- Observations of the tracer composition show that the hotter the initial thermal structure, the stronger the intrusive flow in the mantle, but the slower the propagation rate of rifting. This is probably due to the fact that intrusive flow is strong than upwelling for propagation and ridge formation.

- In the normal case, the deformation is localized around the ridge. In contrast, in the hot case, there is also significant deformation in the surrounding area, which is attributed to the influence of subcrustal mantle flow.

- Even after rifting is abandoned, the molten mantle located beneath the ridge can continue to flow into the lower lithosphere along with the flow.

- In summary, the propagation process of rifting has a strong mantle intrusion flow depending on the initial thermal structure. This mantle intrusion flow forms a persistent convection cell in the lower lithosphere even after rifting stops, transferring heat with the melting mantle. This result is thought to be potentially capable of producing intraplate volcanoes.

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