DI31A-2553 Dynamic coupling of bulk chemistry, trace elements and mantle flow

Huw Davies, Hein van Heck, Andy Nowacki, James Wookey, Tim Elliott, Don Porcelli
Cardiff University, Utrecht University, University of Leeds, University of Bristol, Oxford University

NERC SCIENCE OF THE ENVIRONMENT

Mantle GeoDynamics

Introduction

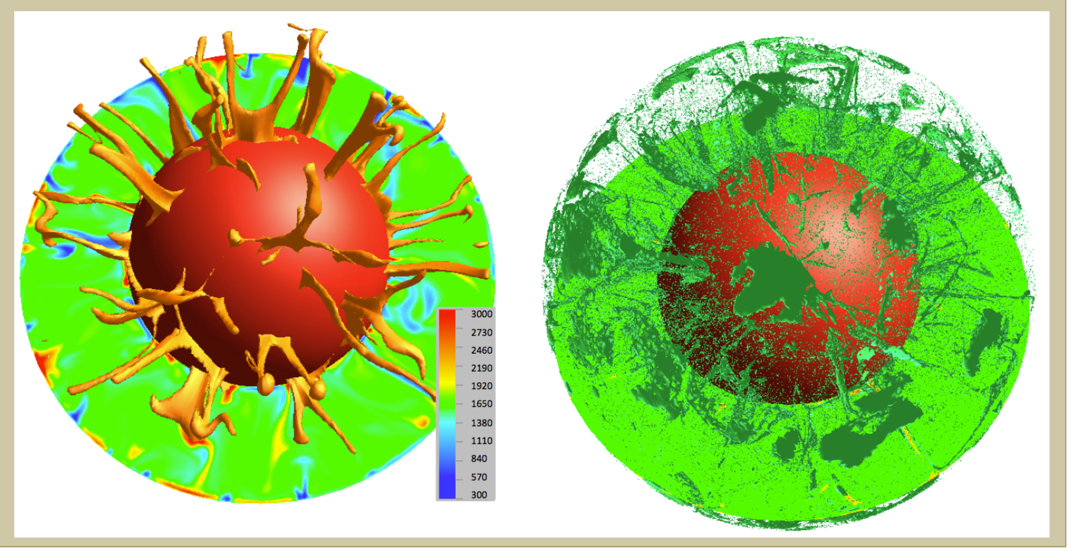
Fully dynamical models that not only track the evolution of chemical heterogeneities through the mantle, but also incorporate the effect of chemical heterogeneities on the dynamics of mantle convection are now emerging. We extend our existing numerical mantle convection code that can track fluid flow in 3D spherical geometry and tracks both bulk chemical components (basalt fraction) and different trace elements. The chemical components fractionate upon melting when and where the solidus is crossed. Now, the chemical information will effect the flow of the fluid in the following ways: The bulk composition will link to density and the (radioactive) trace element abundance to heat production.

Calculation Setup

We use a 3D-spherical finite element code (TERRA) to model convection. With particles to track bulk composition. To test our implementation we use a simplified setup:

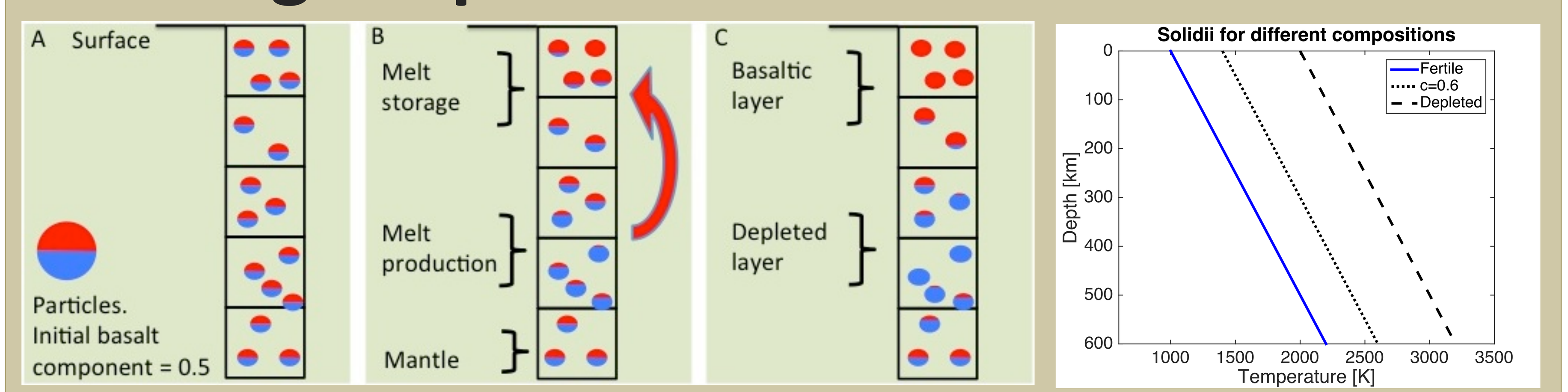
- Incompressible.
- Layered viscosity $3*10^{21}$, increase by 30 at 660 km.
- Grid resolution 22 km.
- Max 35 particles per cell.
- “Plume-driven” melting.

Add heating and density

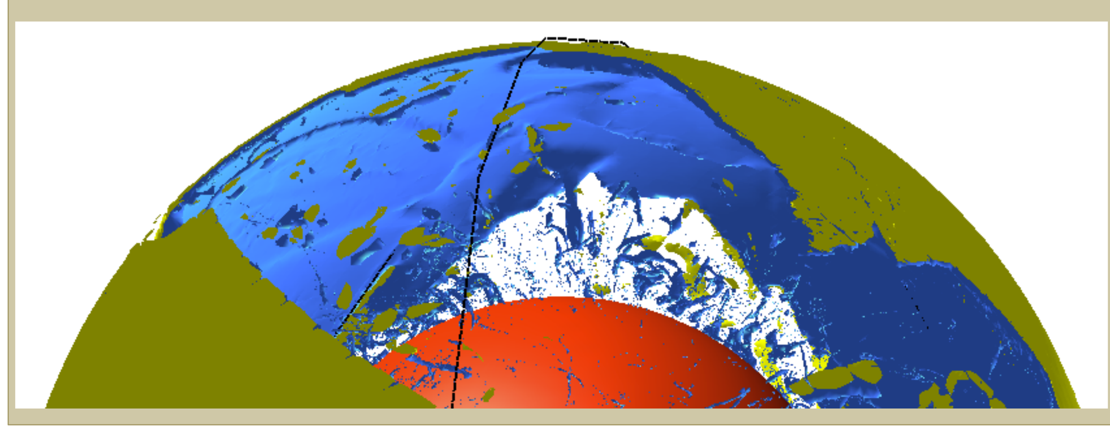


Melting via particles

van Heck et al., GMD, in review

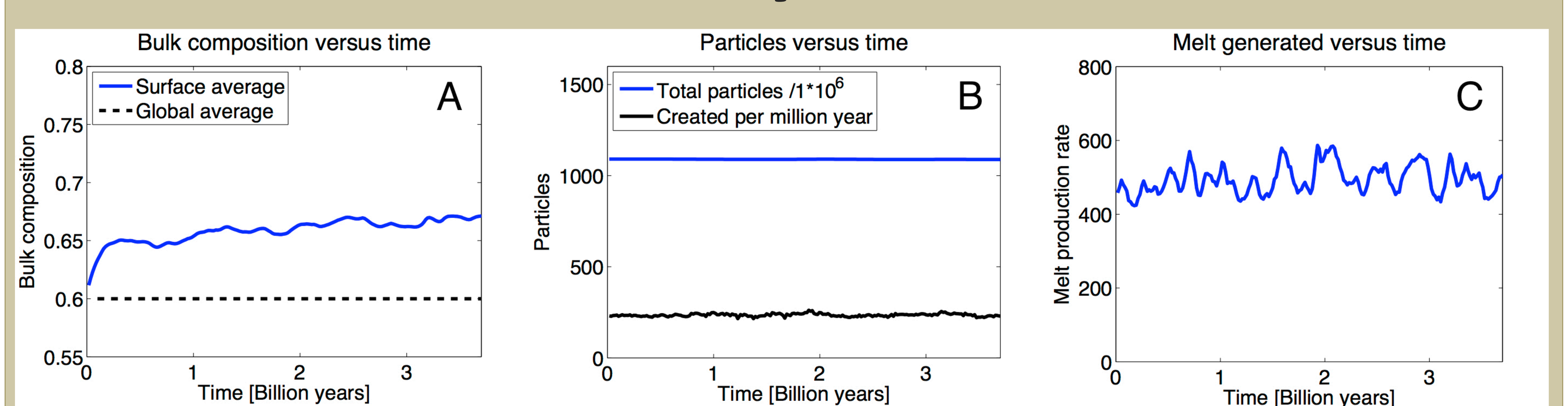


Sketch illustrating how melting separates a basaltic and depleted layer.



Left: Example of composition separation, plate formation.
Blue: depleted composition
Yellow: enriched composition (c=0.2 vs c=0.6)
Red: core-mantle boundary.

Stable for 3.5 Billion years

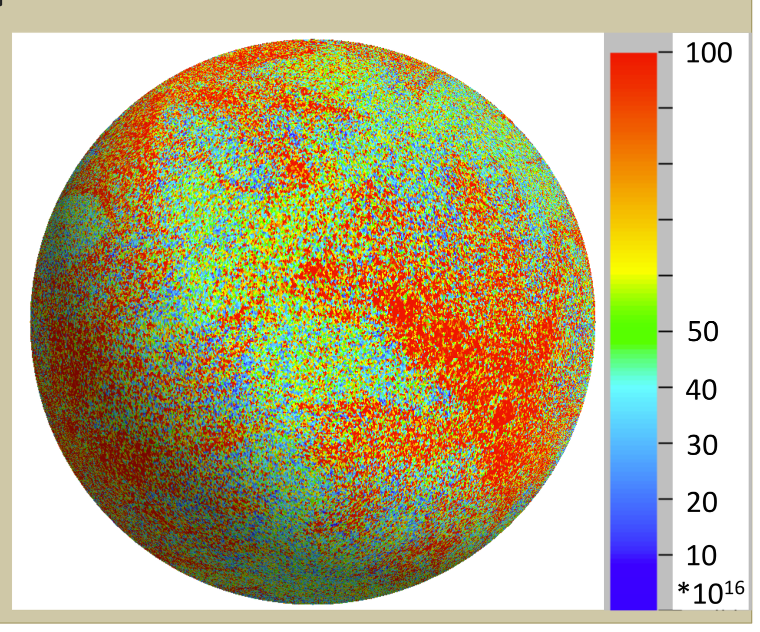


Since we have to split and merge the particles. After an initial phase, the number of particles stabilizes. On splitting/mergin, bulk composition is scaled to the mass of the particles, isotope abundance is simply added / divided.

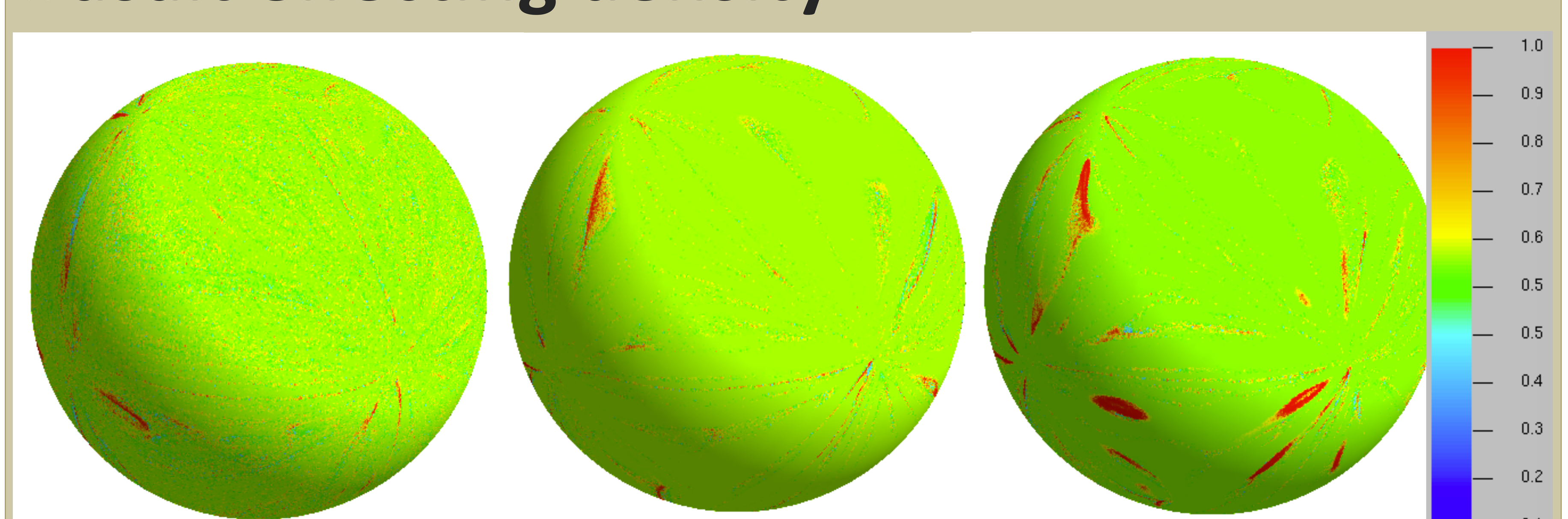
Tracking Radiogenic isotopes

On each particle we track the abundance of radiogenic isotopes (U, Th, K) and their daughters (Pb, He, Ar). The heat produced by decay can be linked to the temperature.

Plotted:
Heat production via U, Th, and K.
Highly incompatible elements, so move with first production of basalt.

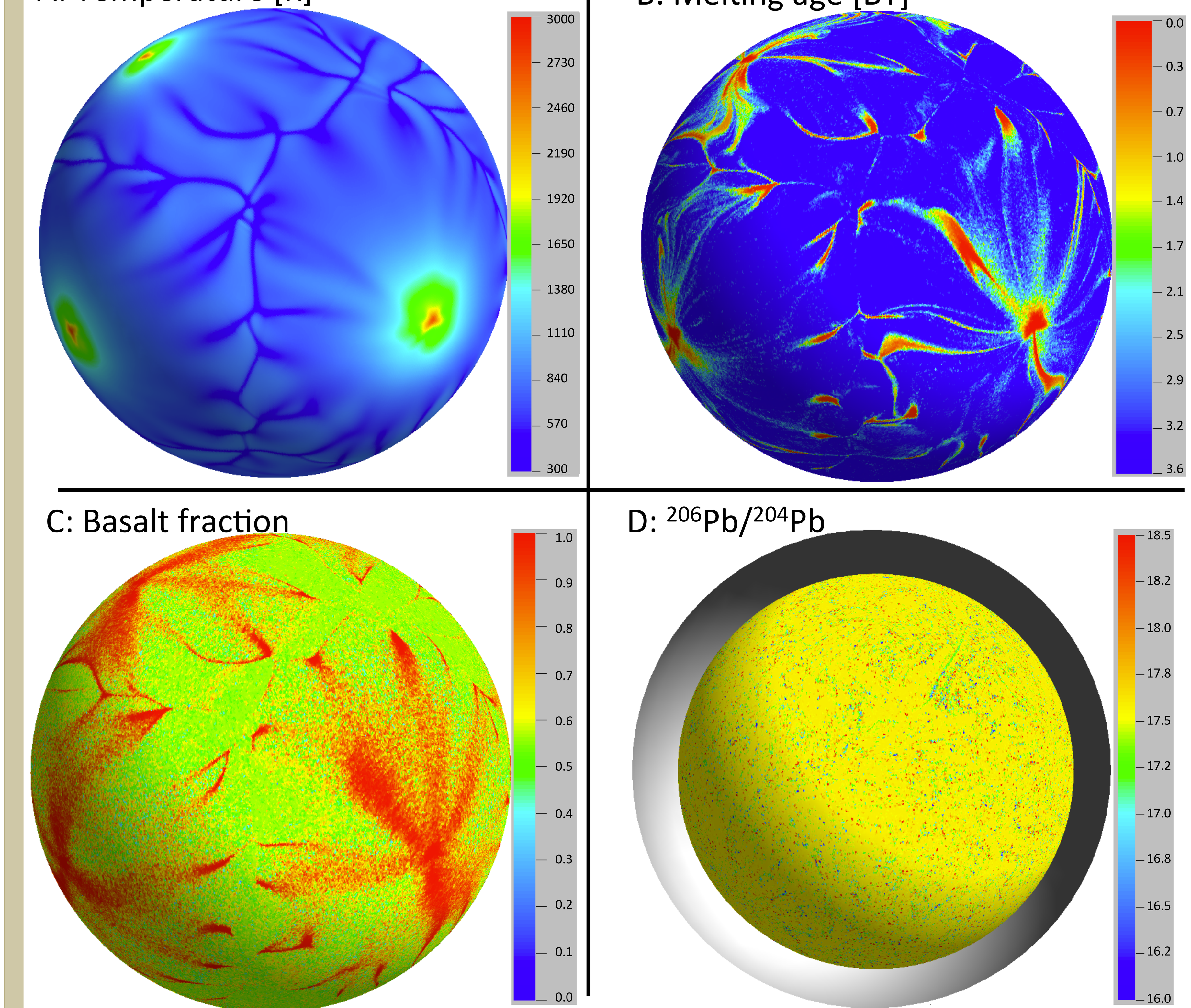


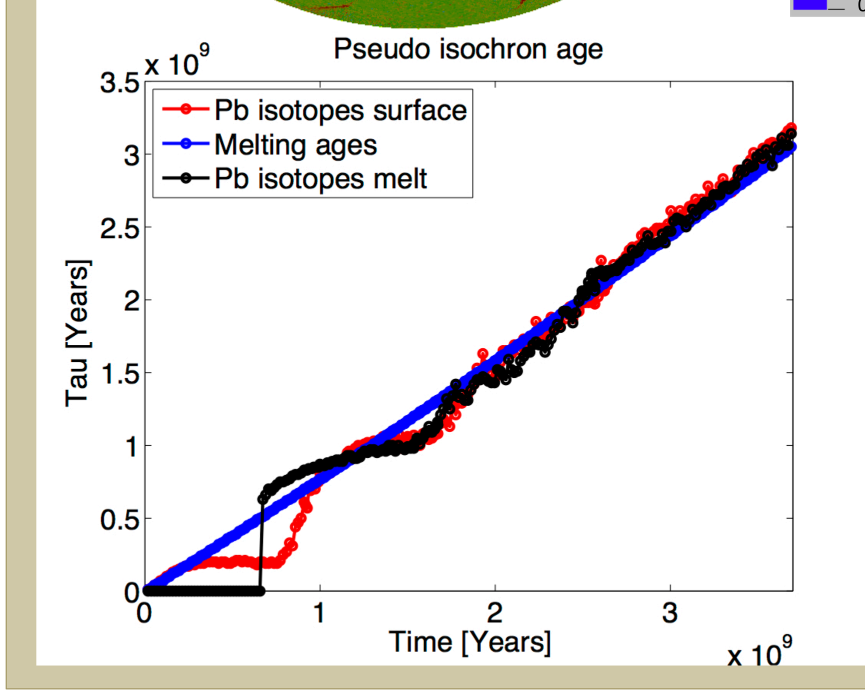
Basalt effecting density



Compositional surface layer at 2800 km depth.
Left: Neutral (reference calculation).
Middle: Basalt 5% denser in the lower mantle (660 km onwards).
Right: Basalt 10% denser in the lower mantle (660 km onwards).

Comparing: temperature, melting age composition and isotopic-ratio.





Comparison to analytical theory

(Rudge, EPSL, 2006)

Pseudo-isochron ages can be estimated from: 1. the distribution of melting ages in all of the mantle, 2. Pb-isotopes at the surface / melt. Both agree in our model.

Conclusions

- Melting, isotope fractionation and mixing benchmarked successfully using comparison to Rudge, 2006.
- Link between bulk chemistry and density works.
  - High density of basalt creates bigger pools of basalt in the lowermost mantle.
- Tracking heat production with particles works.
  - Pattern of heat production at surface follows basalt distribution
  - All aspects not fully tested.

References:

Van Heck, Davies, Elliott, Porcelli, Global scale modeling of melting and isotopic evolution of Earth’s mantle, GMD, under review.
Rudge, Mantle pseudo-isochrons revisited, EPSL, 2006