3D numerical modeling of ridge-transform faults

using a newly developed multigrid finite element code written in MATLAB

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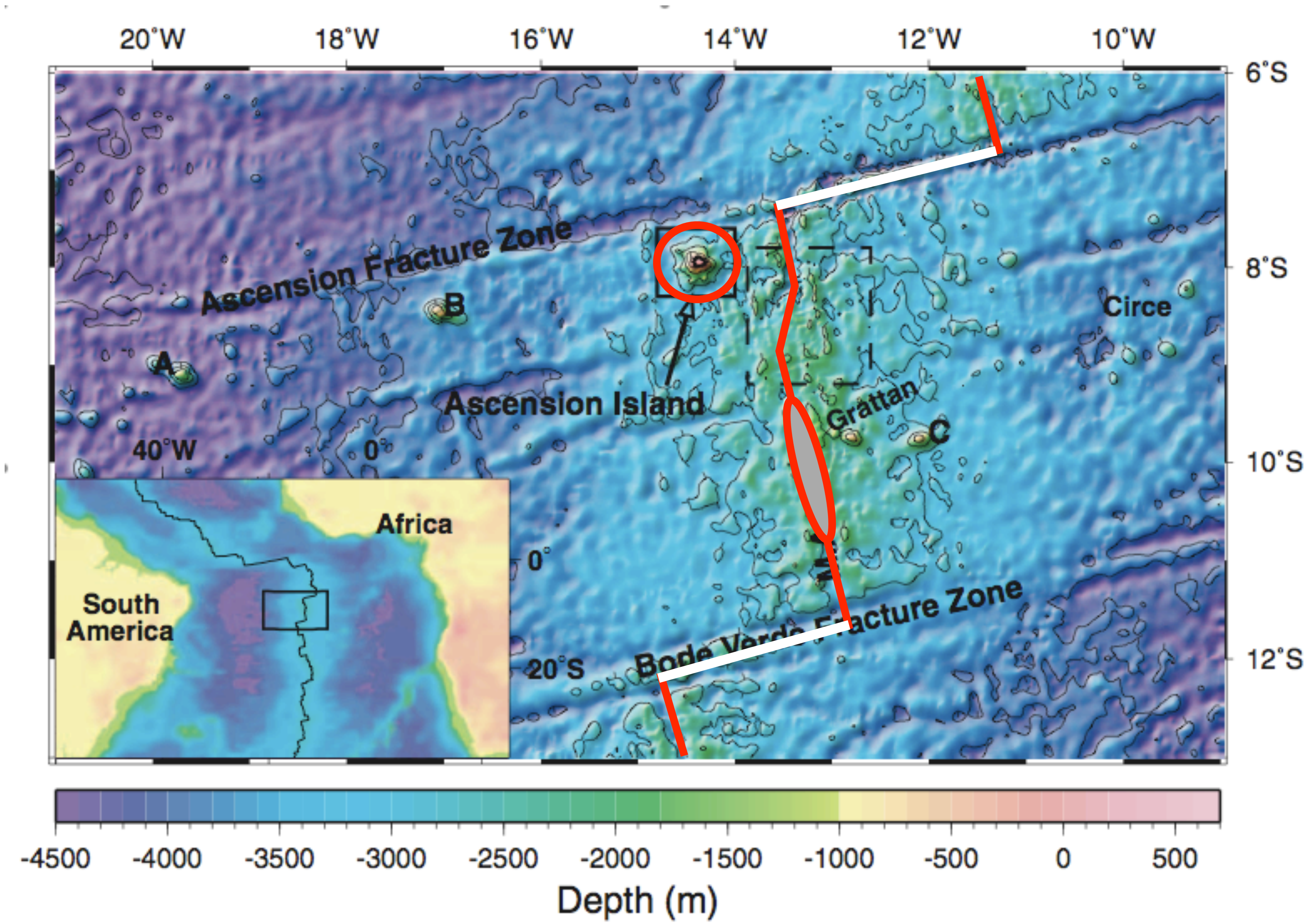
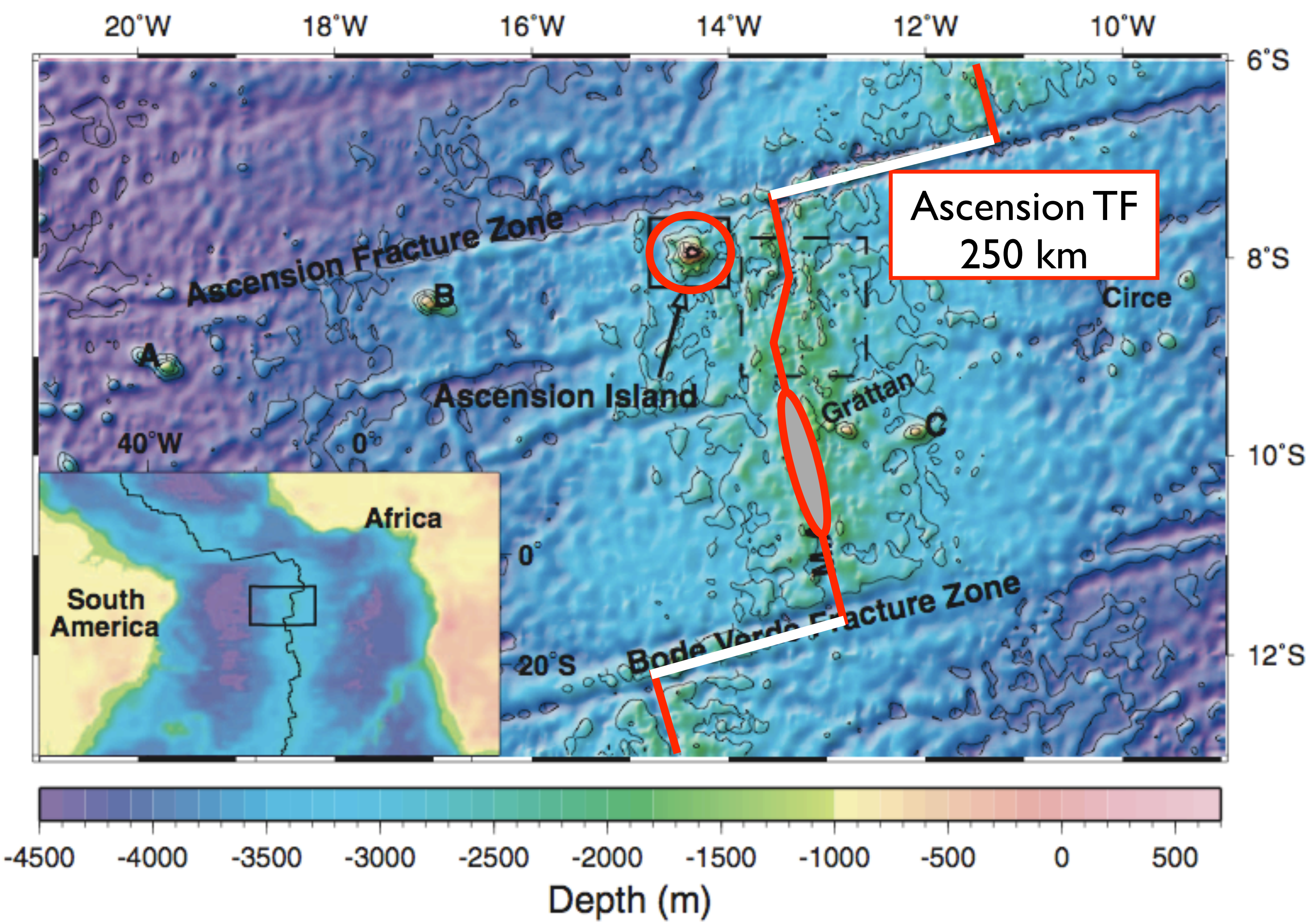
Motivation

- We are part of the DFG priority program SPP 1144
- Energy-, material- and life-cycles at spreading axes
- ~20 groups working in different fields:
  geochemistry, biology, hydrothermal processes,
  tectonics and geodynamics
- Interaction between groups required:
  Hydrothermal field locations ⟷ Tectonic environment
  Hydrothermal energy release ⟷ Biology
- 2 study regions at the Mid-Atlantic Ridge

The Southern Study Area



The Southern Study Area



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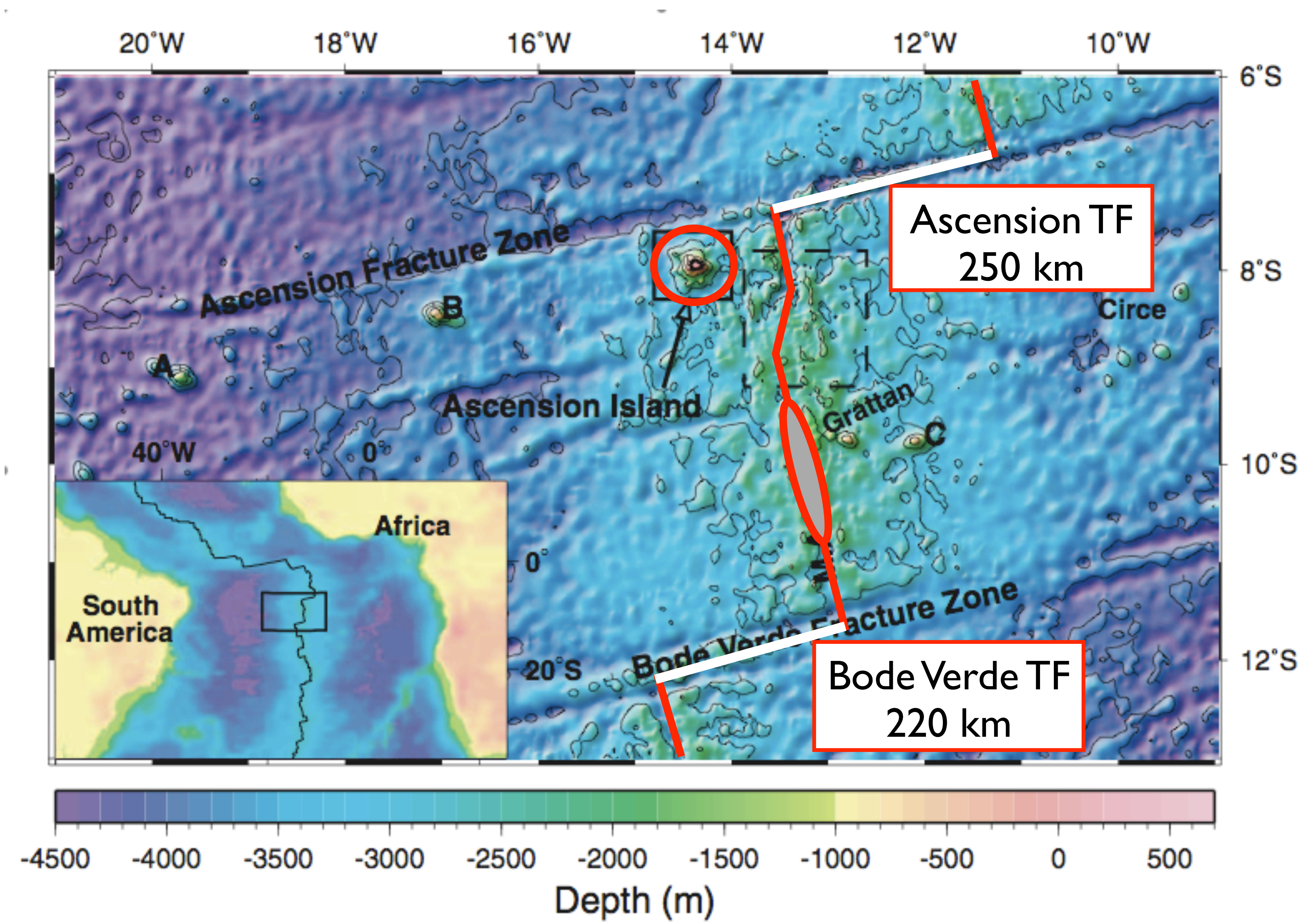

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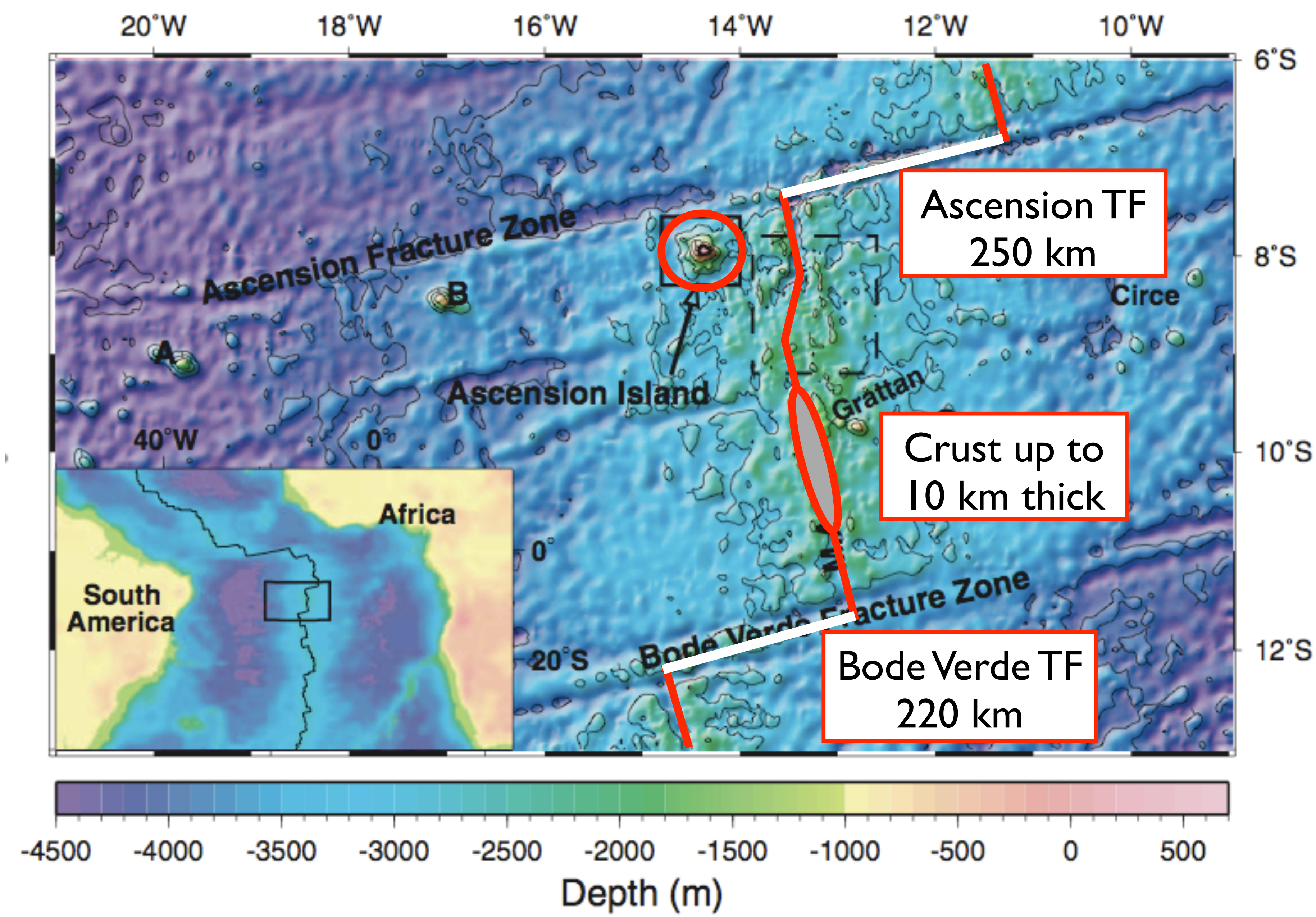

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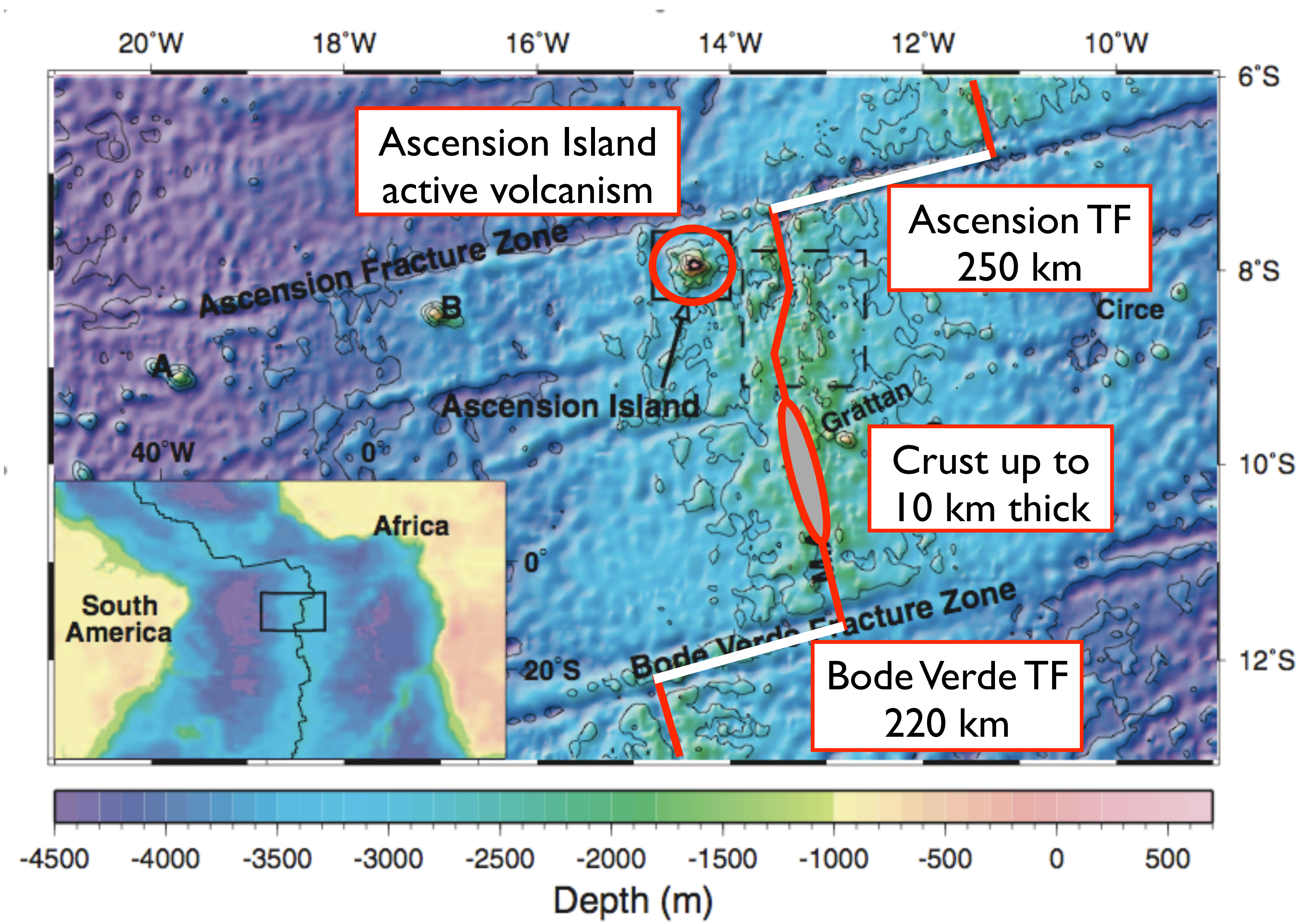

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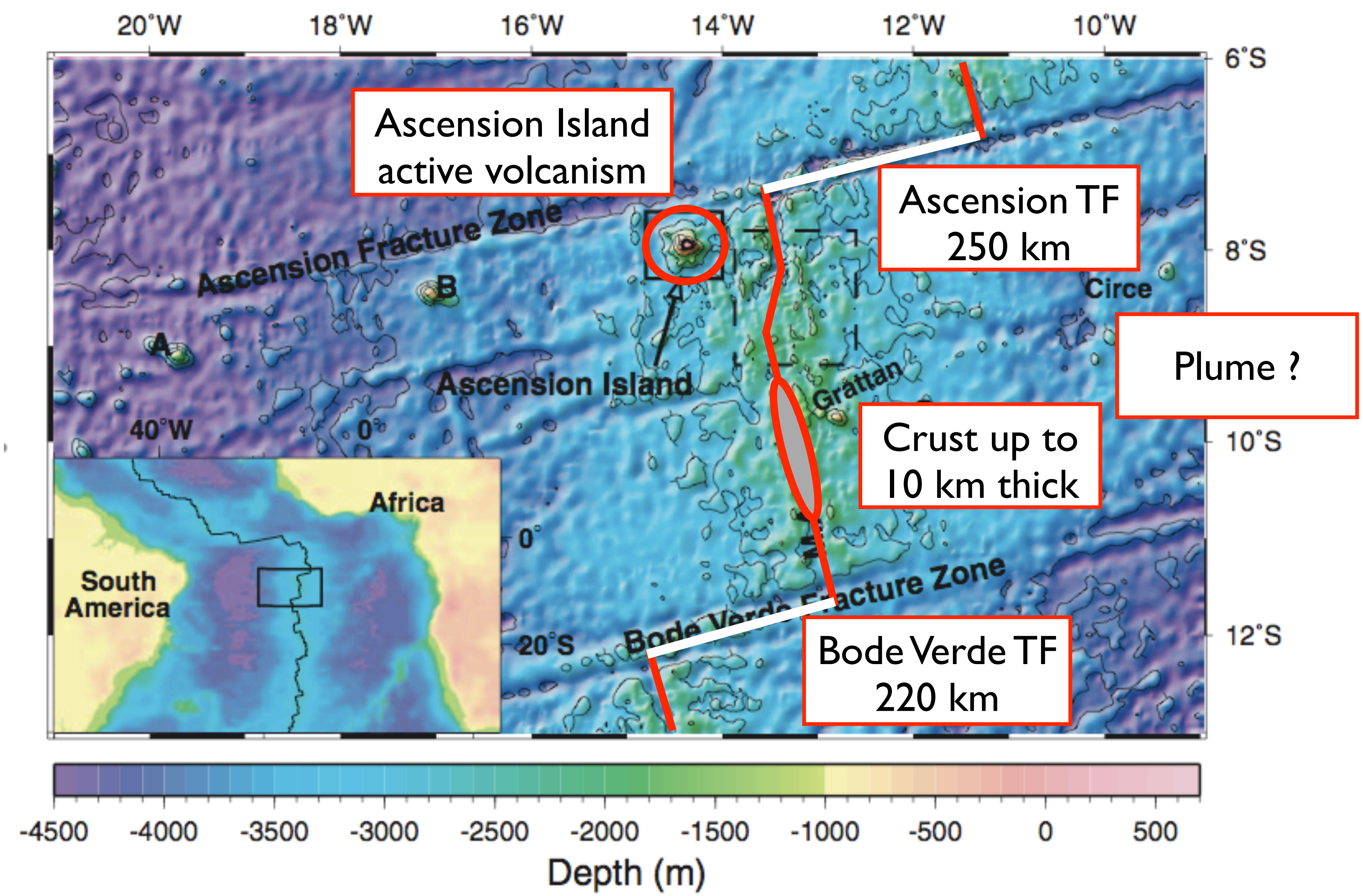
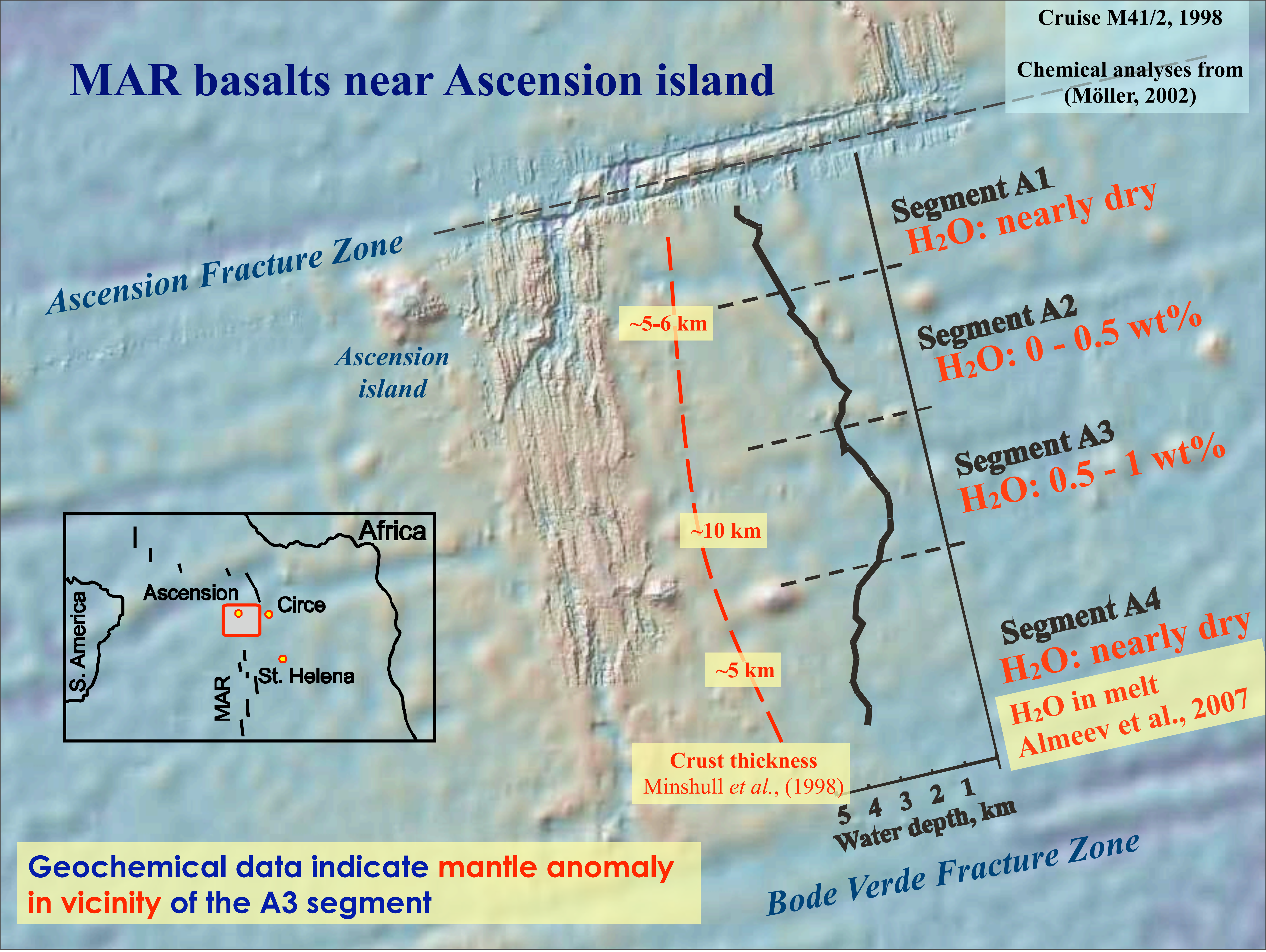
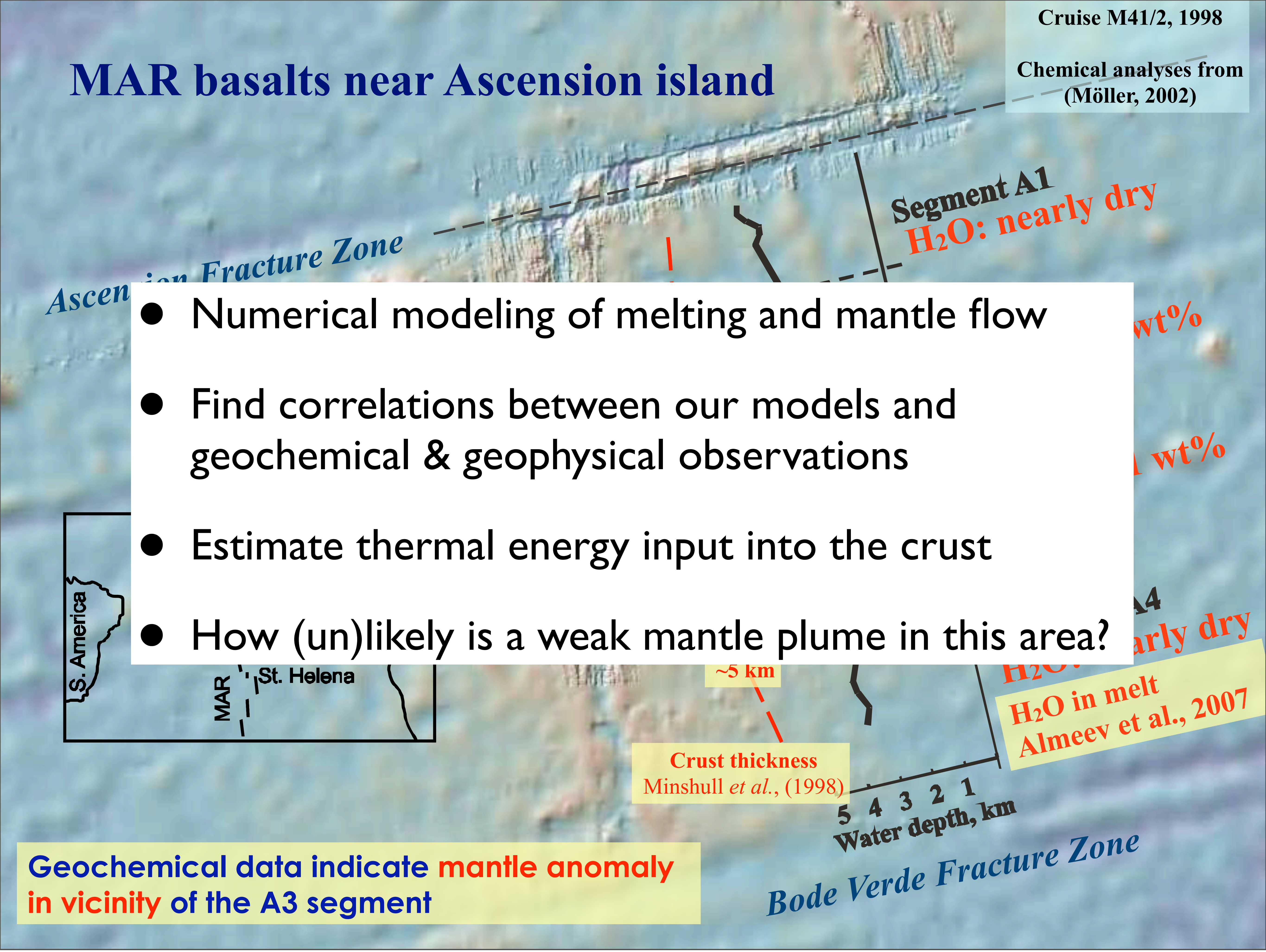




MAR basalts near Ascension island
Cruise M41/2, 1998
Chemical analyses from (Möller, 2002)
Ascension Fracture Zone
Ascension island
~5-6 km
~10 km
~5 km
Crust thickness
Minshull et al., (1998)
Segment A1
H_2O: nearly dry
Segment A2
H_2O: 0 - 0.5 wt%
Segment A3
H_2O: 0.5 - 1 wt%
Segment A4
H_2O: nearly dry
H_2O in melt
Almeev et al., 2007
5 4 3 2 1
Water depth, km
Bode Verde Fracture Zone
Africa
Ascension
Circe
S. America
St. Helena
MAR
Geochemical data indicate mantle anomaly in vicinity of the A3 segment

MAR basalts near Ascension island



- Numerical modeling of melting and mantle flow
- Find correlations between our models and geochemical & geophysical observations
- Estimate thermal energy input into the crust
- How (un)likely is a weak mantle plume in this area?

Geochemical data indicate mantle anomaly in vicinity of the A3 segment

A new convection code

- Finite Elements:
  unstructured meshes, highly flexible resolution
- Fast solver for 3D viscous flow
  - tested:
    different types of elements
    iterative solvers, some using multigrid
  - finally chosen:
    6-node triangles (2D), 10-node tetrahedrons (3D)
    Multigrid-Preconditioned Conjugate Gradient
- Melting of multiple mantle components
- Parallel

A new convection code

Why Matlab?

- Powerful developing environment
  incl. editor/debugger/visualization
- Code modifications are simpler
  less programming time for testing different algorithms
- Matlab's "Profiler":
  quickly identify and speed up slow code parts
- Sparse matrix capabilities (FE bookkeeping, operations)
- Distributed Computing Toolbox , -Engine

A new convection code

Tricks to speed up Matlab

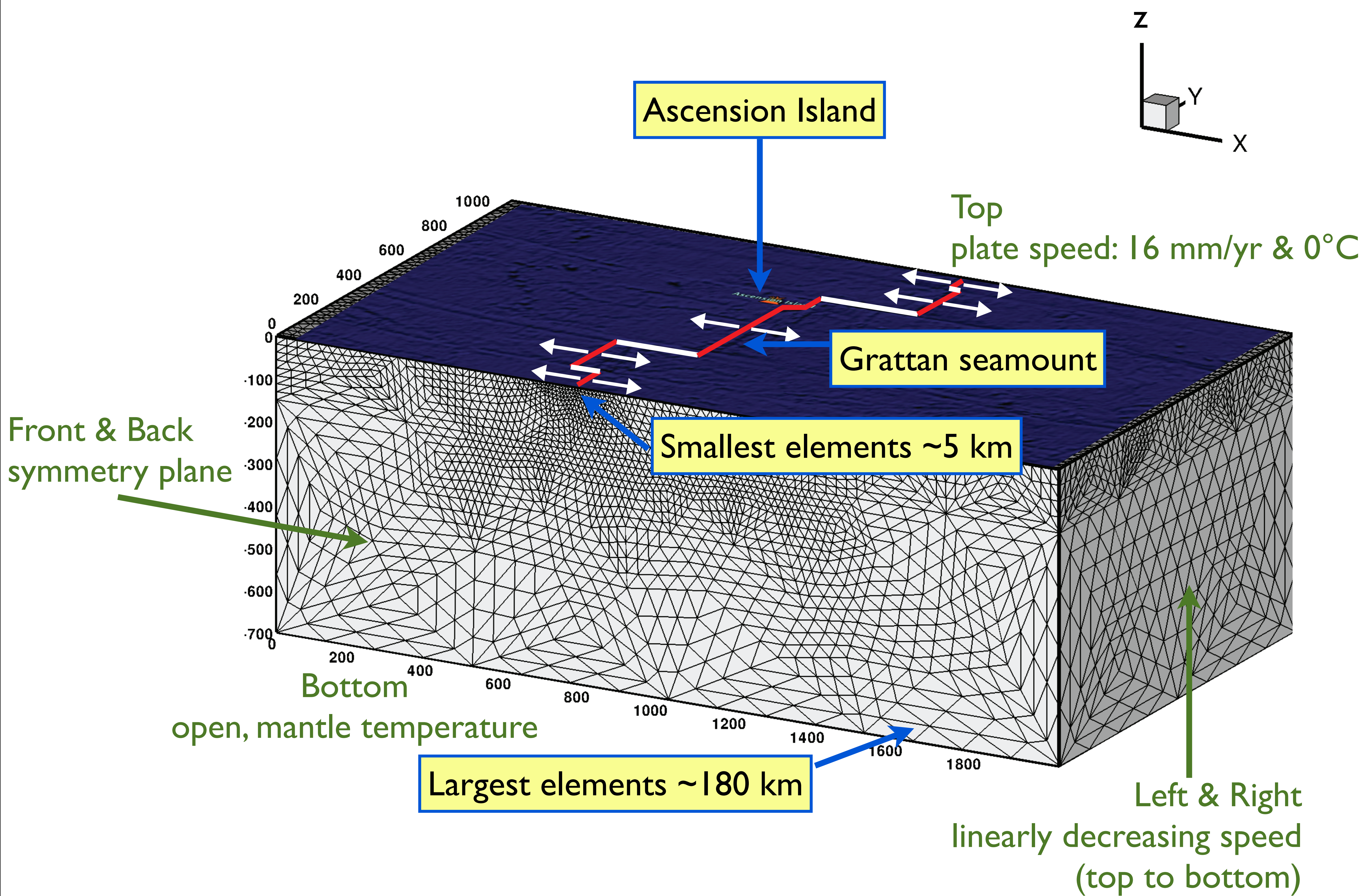
- Vectorizing!
  re-write loops as vector (matrix) operations

- Avoid operations with small matrices!

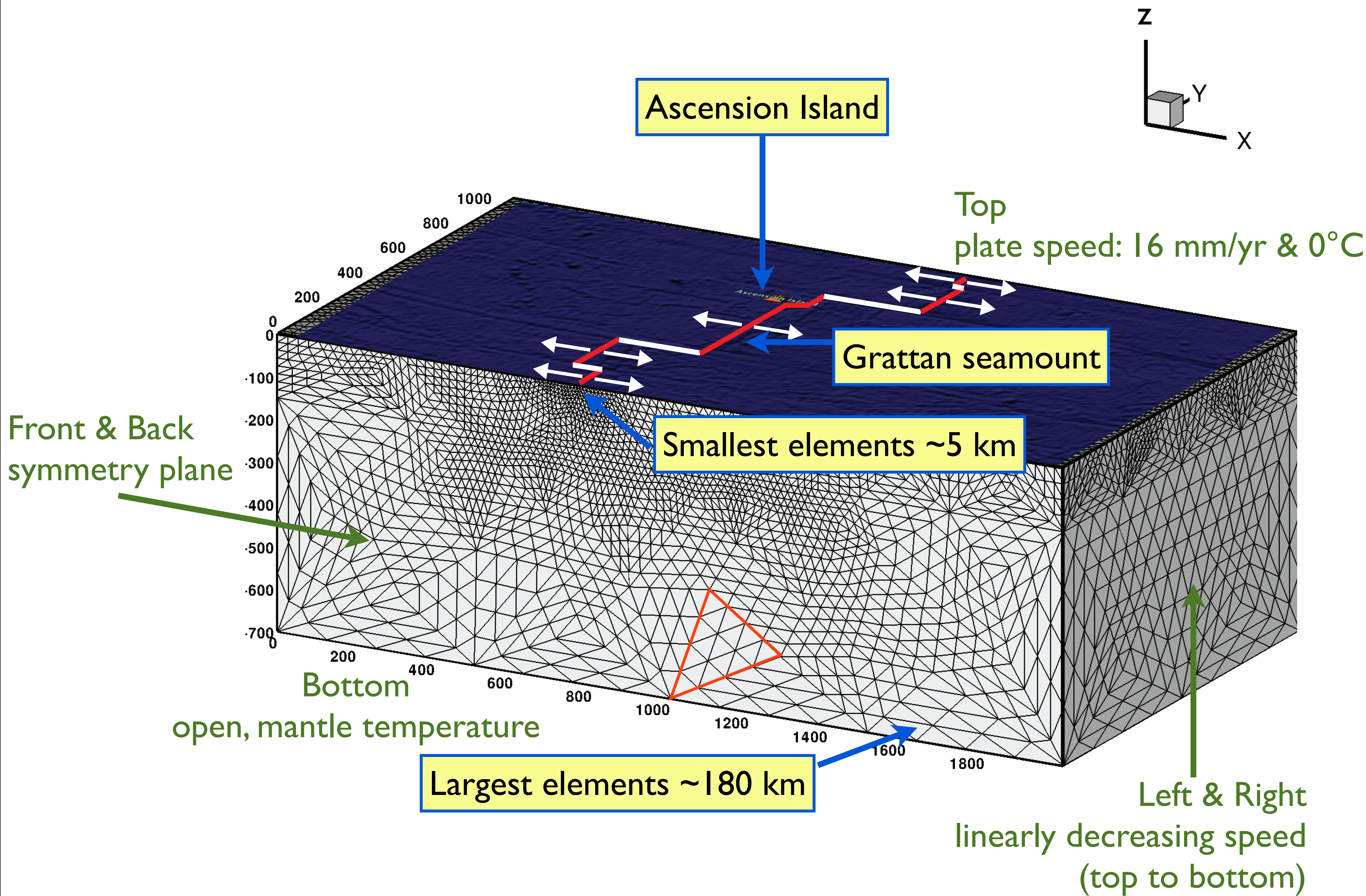
  - resort and merge small matrices for fewer operations

  - "MILAMIN" paper by Dabrowski et al. (G-cubed, 2008)
    (element integration/assembly in blocks of ~500 elements for a 2MB fast cache)

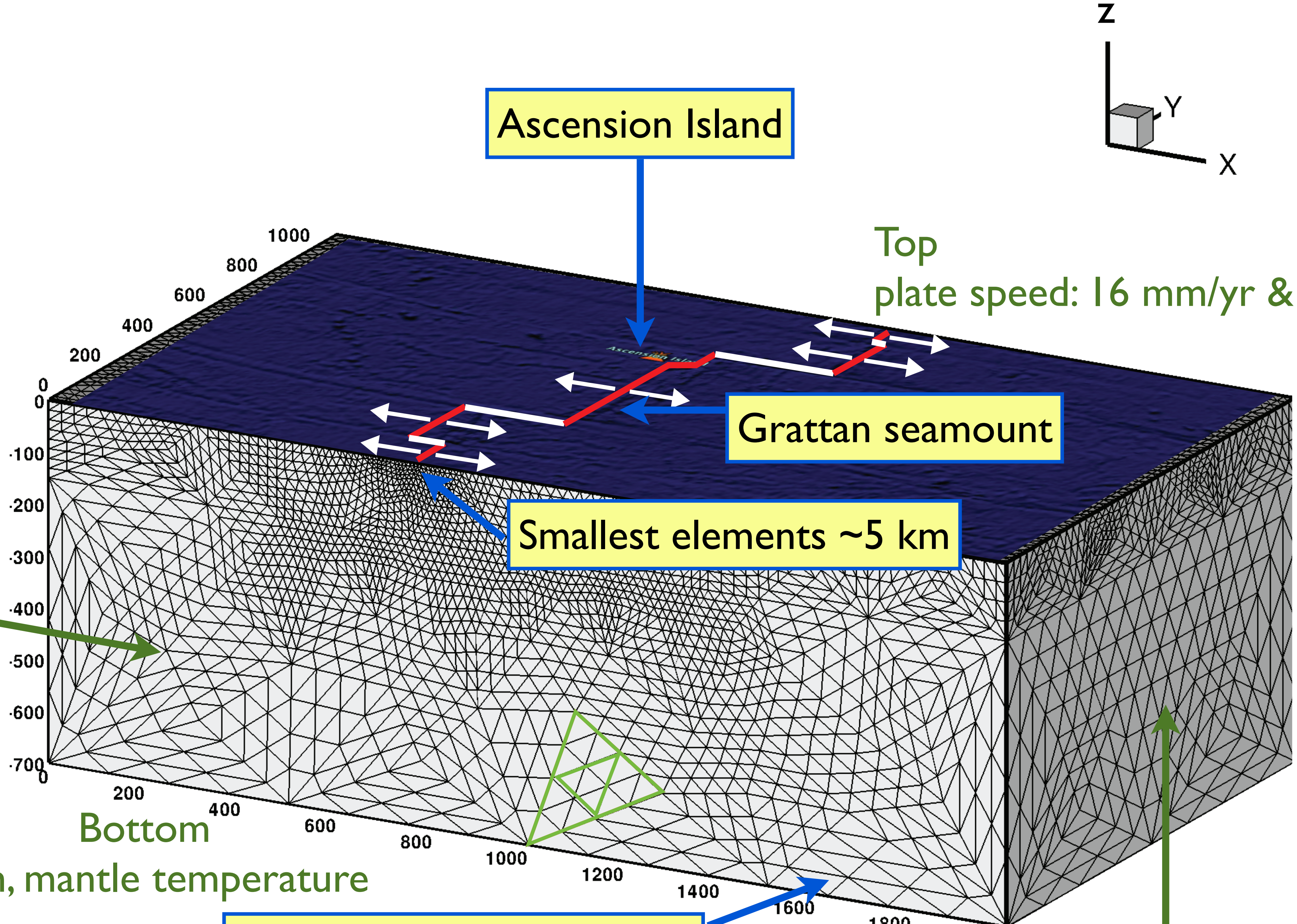
Boundary conditions and numerical resolution



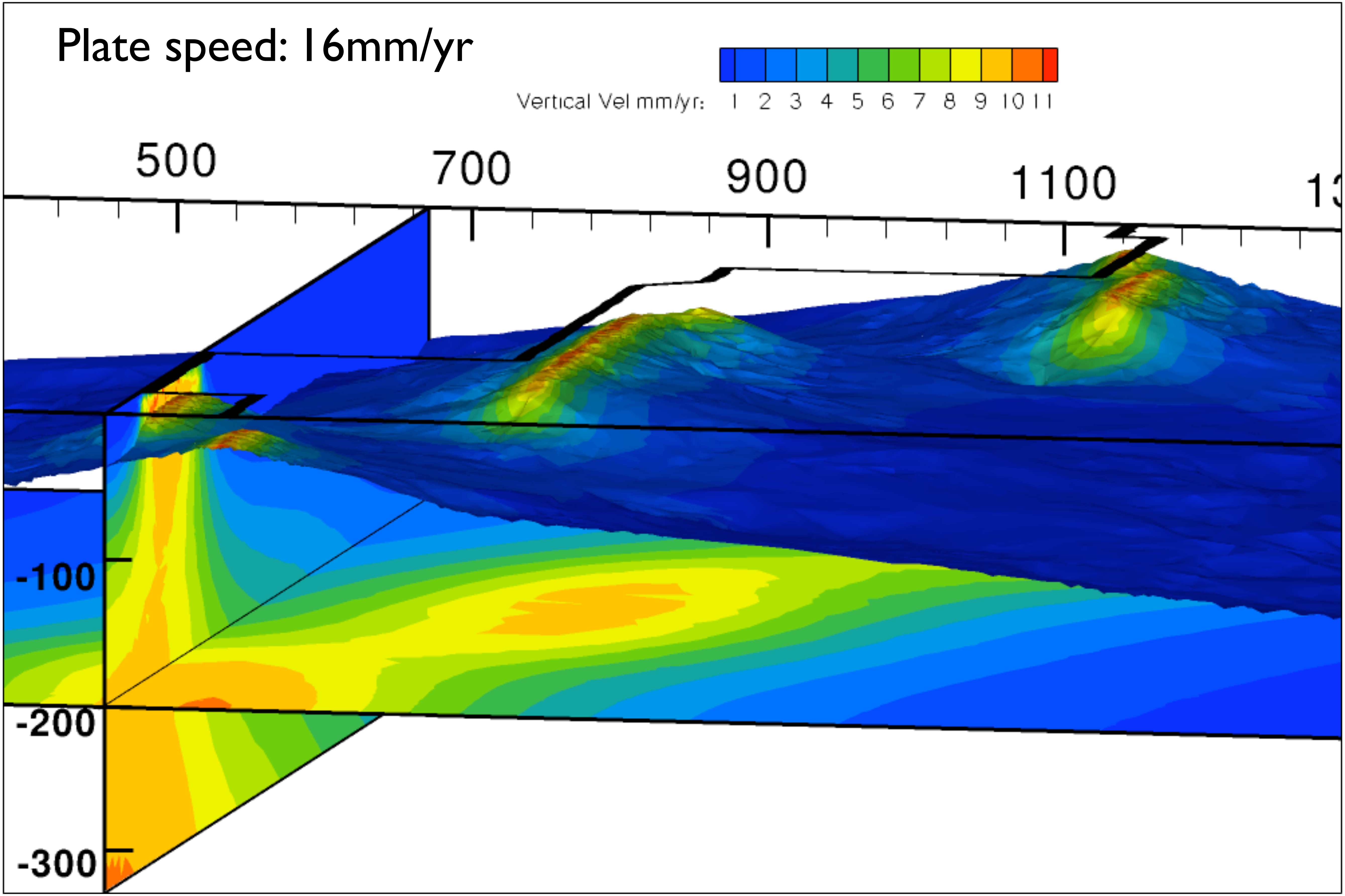
Boundary conditions and numerical resolution



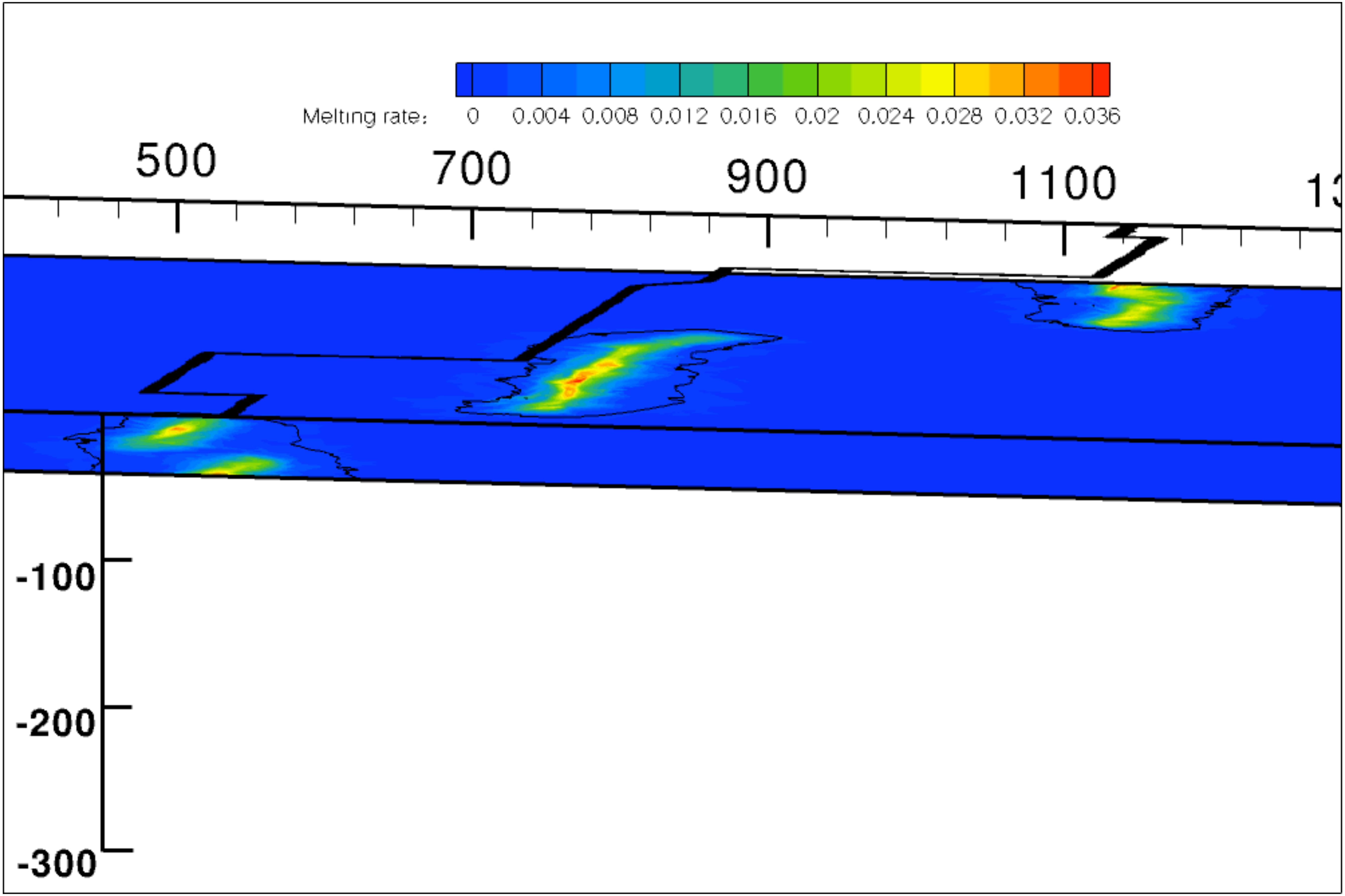
Boundary conditions and numerical resolution



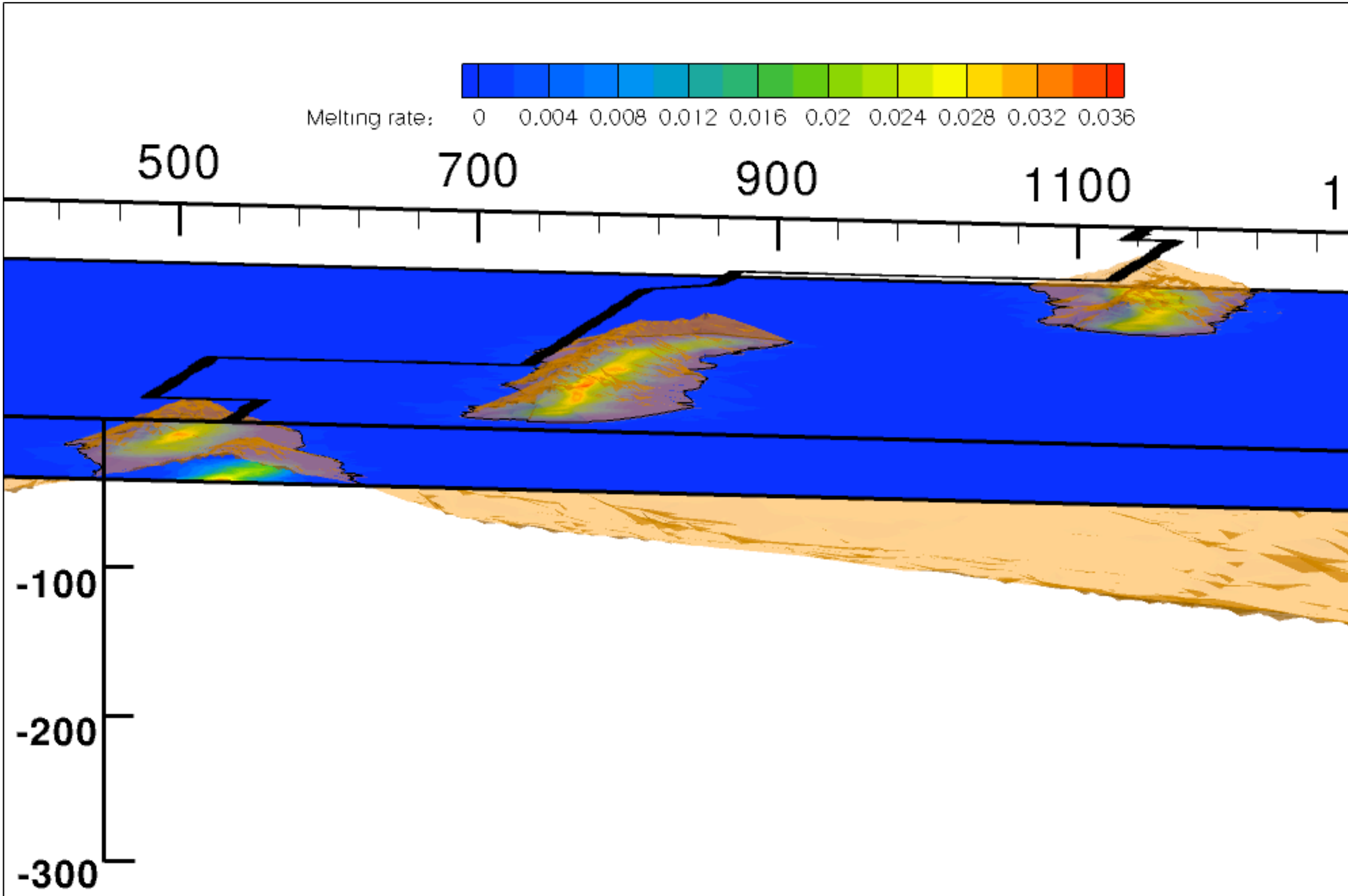
Vertical velocities and relief of 1200 °C isotherm



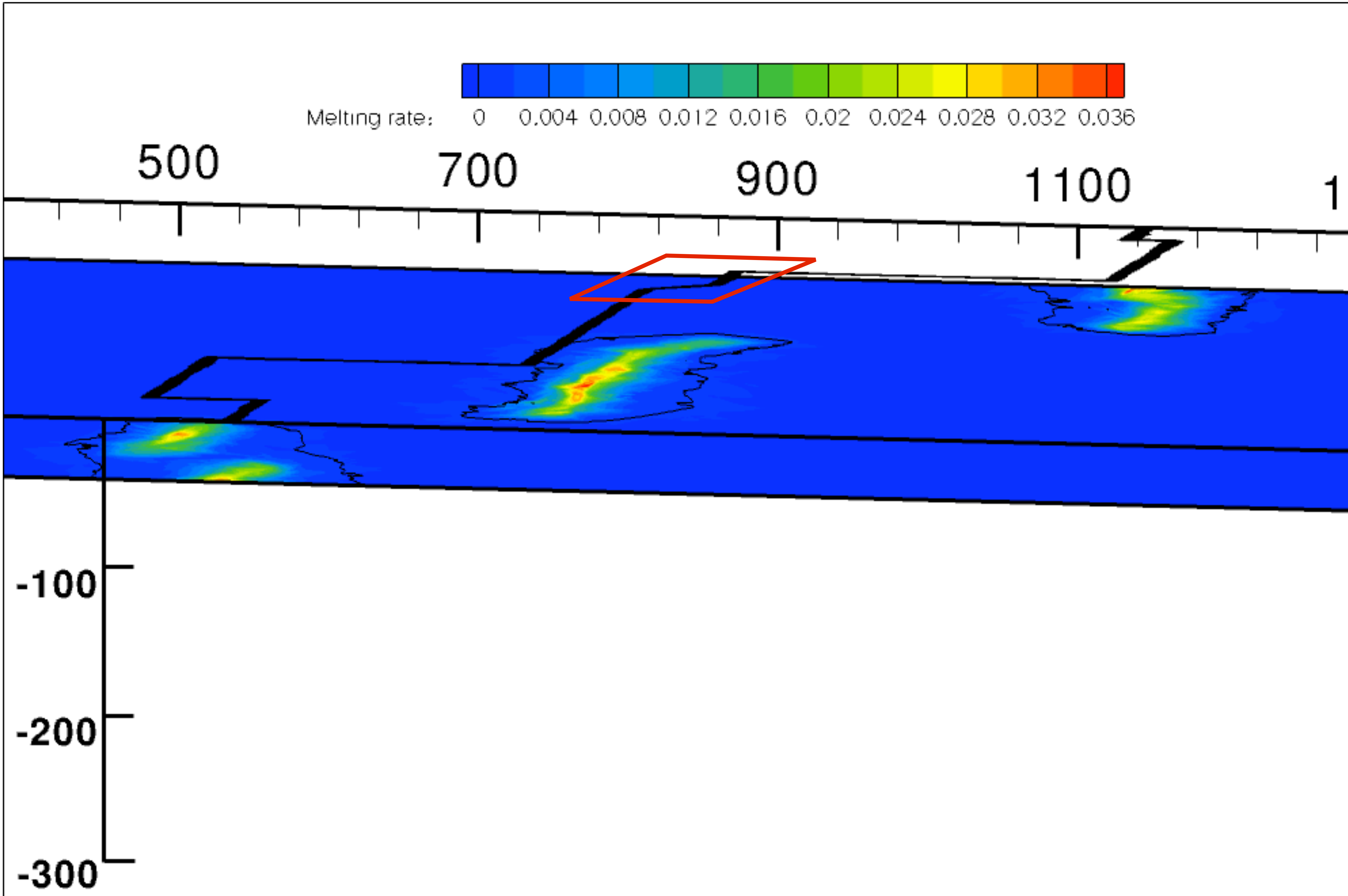
Melting rates at 40 km depth



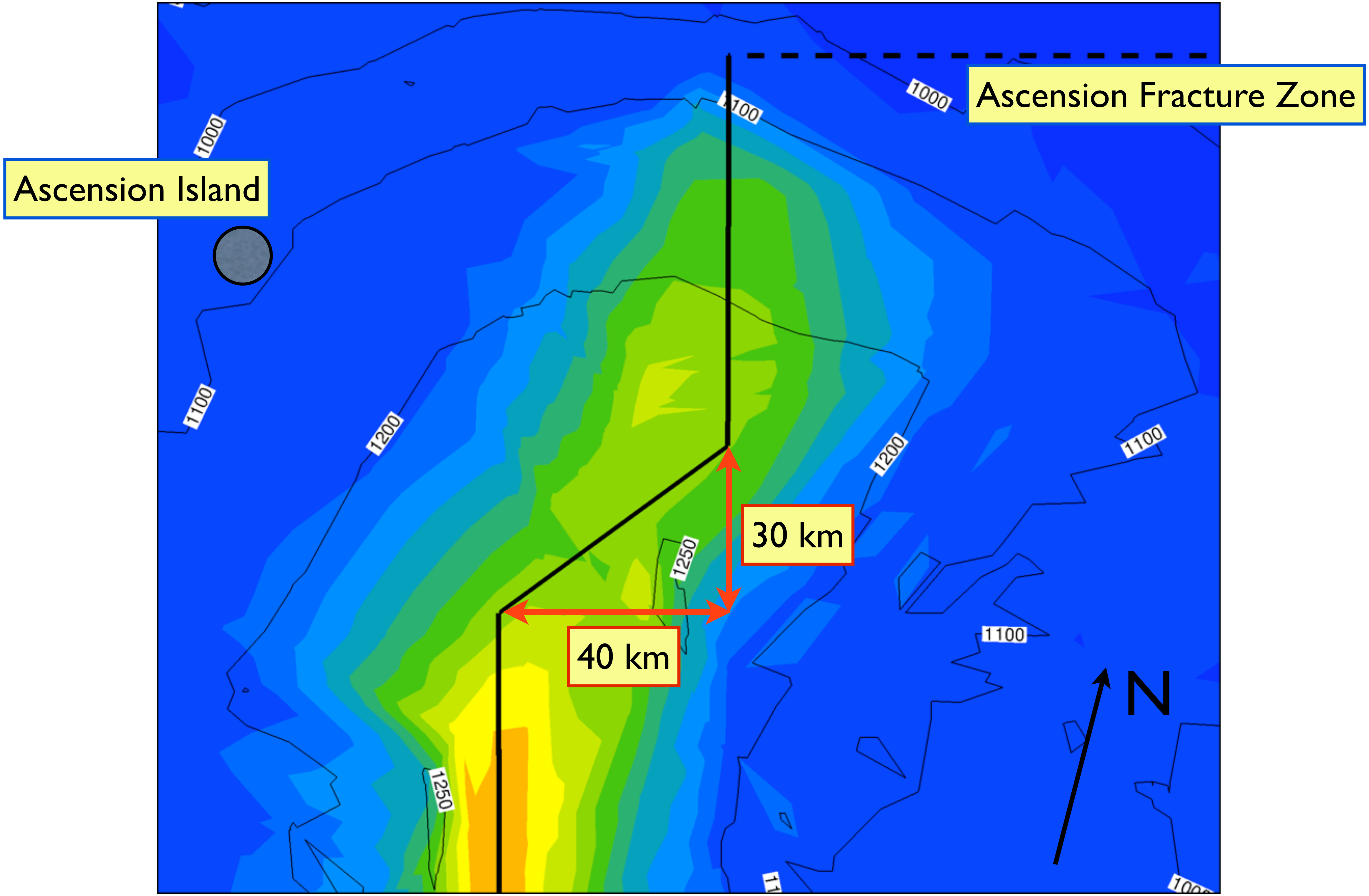
Melting rates at 40 km depth and relief of 1200 °C



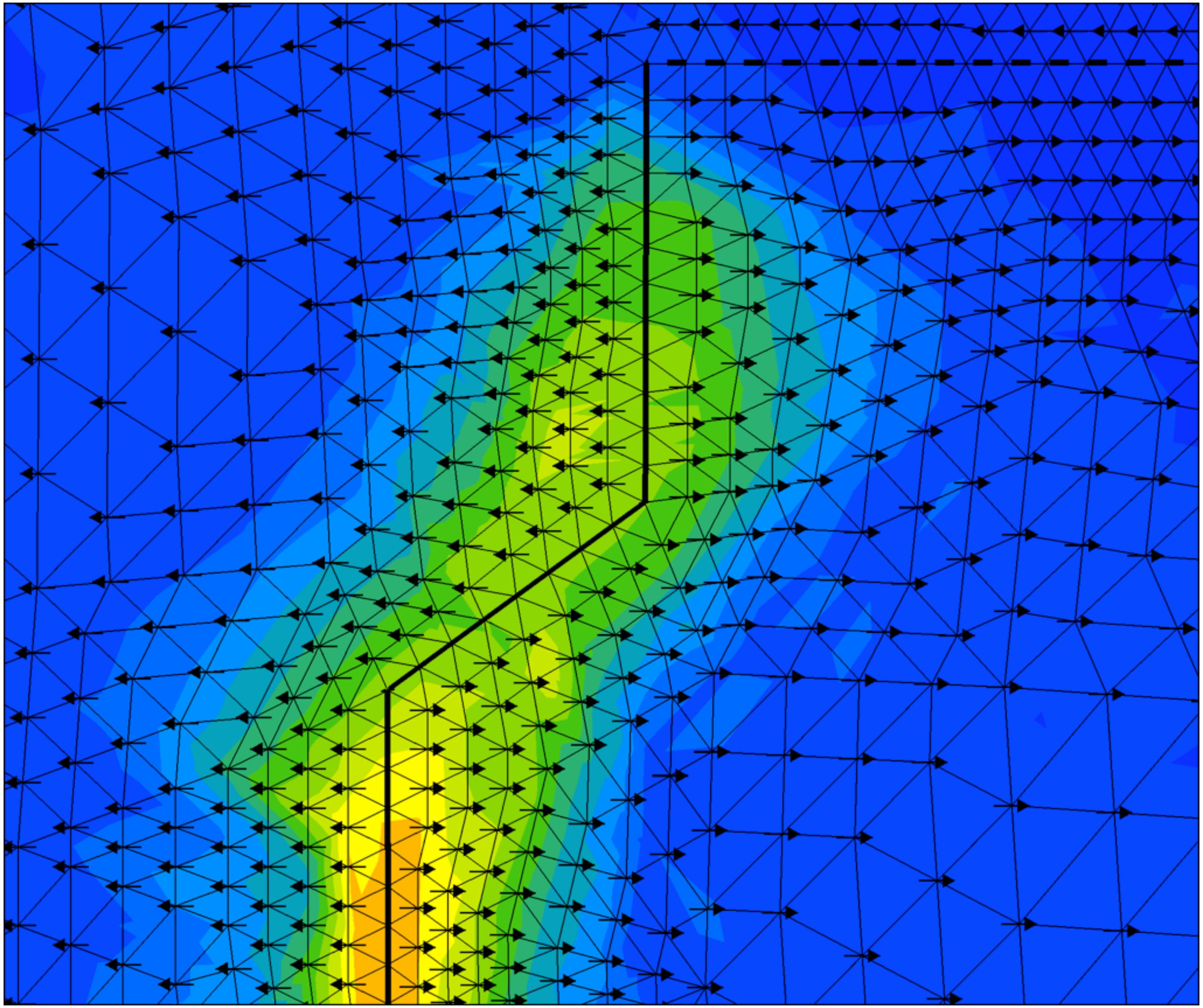
Location of zoomed plot



Isotherms & melting rates at 40 km depth



Numerical resolution at the top



First conclusions

- transform faults (TFs): colder regions, almost no mantle upwelling
- max melting at max distance from TFs
- even small ridge axis displacements hinder mantle upwelling, thus melt production

Work in progress & outlook

- feedback mechanisms between melting and mantle flow
(dehydration & melt effects on viscosity
depletion & melt effects on density)

- porous flow approximation for melt migration $\longrightarrow$ crustal thickness calculation

- more detailed 3D runs on our new cluster
(include thermal/compositional anomalies)

Thank you for your attention !