Imperial College London

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Upper mantle conditions during the opening of the North Atlantic Ocean

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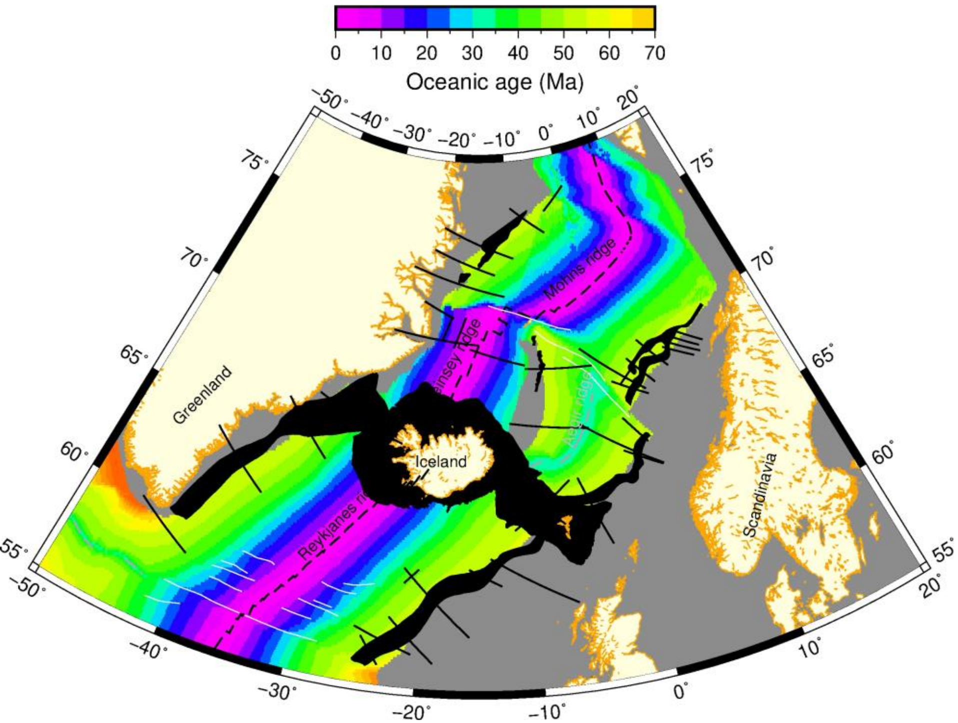
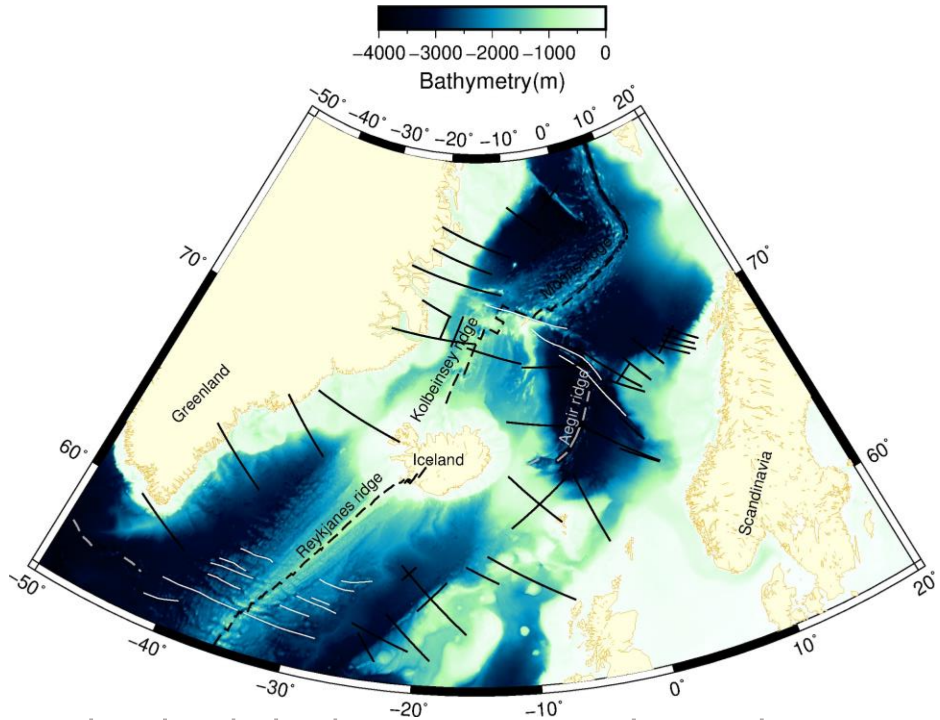
If you have any questions or want to talk in 'person', feel free to contact me: z.zalai18@ic.ac.uk

North Atlantic Ocean



North Atlantic oceanic age. Black denotes the North Atlantic Igneous Province.



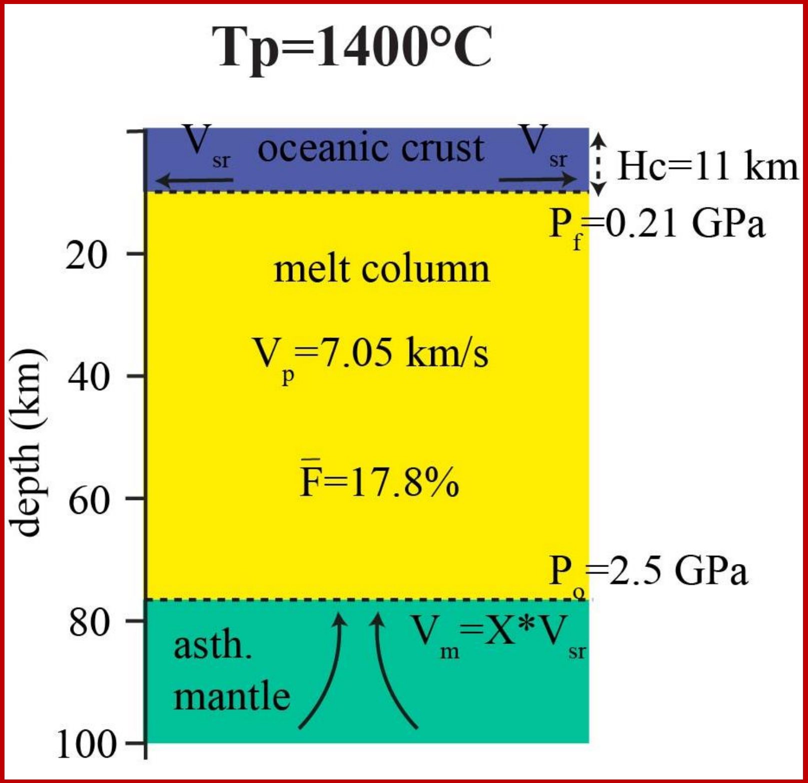
North Atlantic bathymetry. Note elevated bathymetry around Iceland and Greenland-Iceland-Faroes Ridge

- What causes continental break-up at magma-rich margins? Mantle convection or plate tectonics?
- Here we will use estimates of melt produced during continental break-up from seismic refraction profiles to determine mantle conditions from parametrized mantle melting models

Melting models

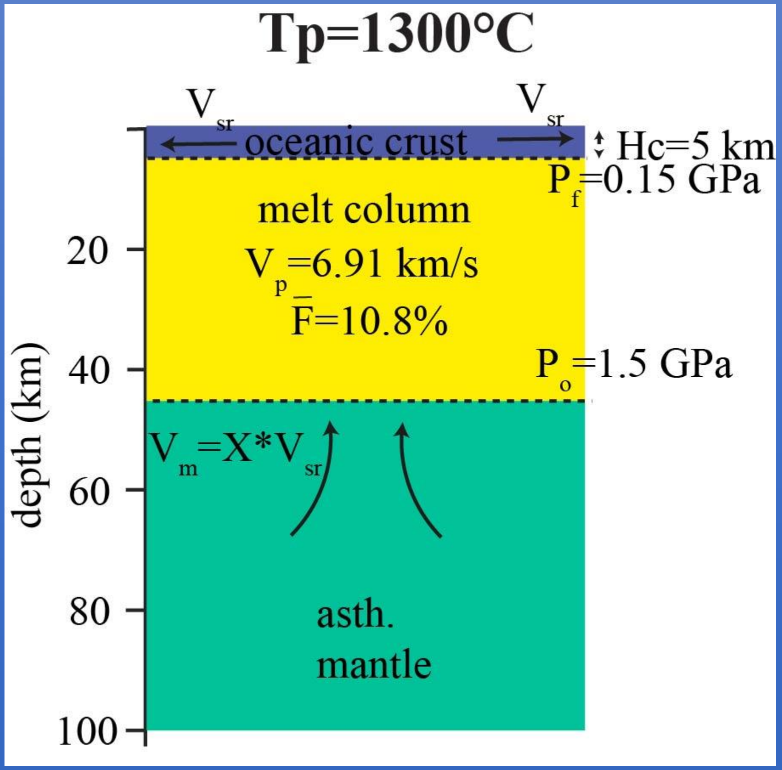
Diagnosing causes of melting in the mantle from geophysical observations

Hot model
e.g. mantle plume



Deeper solidus overstep: Thicker melt column, thicker crust (H_c), enriched MgO, high melt fraction (F), higher V_p.

Cold model



Shallower solidus: thinner melt column, thin crust crust (H_c), , lower melt fraction (F), lower Vp

Diagnosing causes of mantle melting from geophysical observations

Hc-Vp plots - simple ‘rules of thumb’:

- Positive correlation between crustal thickness and Vp = increased mantle potential temperature
- No correlation = active upwelling (i.e. high melt flux)

Formal melting model (Korenaga et al. 2002)

- Crustal thickness, H_c, depends on active upwelling ratio (X), pressures at top and bottom of melting column (P_f, P_o) and mean melt fraction (F)

$$H_c = 30X\left(P_0 - P_f\right)\bar{F}$$

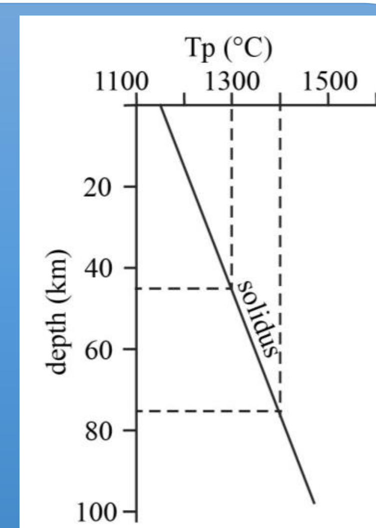
F depends on change in melting with change in pressure (assume constant entropy)

$$\bar{F} = 0.5\left(\frac{\partial F}{\partial P}\right)_S (P_0 - P_f)$$

- H_c calculated for mantle potential temperatures 1200-1650^{o}C and $1 \leq X \leq 8$.

Assumptions & Uncertainties

- 1D model; instantaneous rifting; pyrolitic mantle source composition; no melt retention; melt fraction linearly dependent on pressure; linear solidus (see figure).
- Oceanic crust igneous in nature (i.e. no serpentinised mantle present)

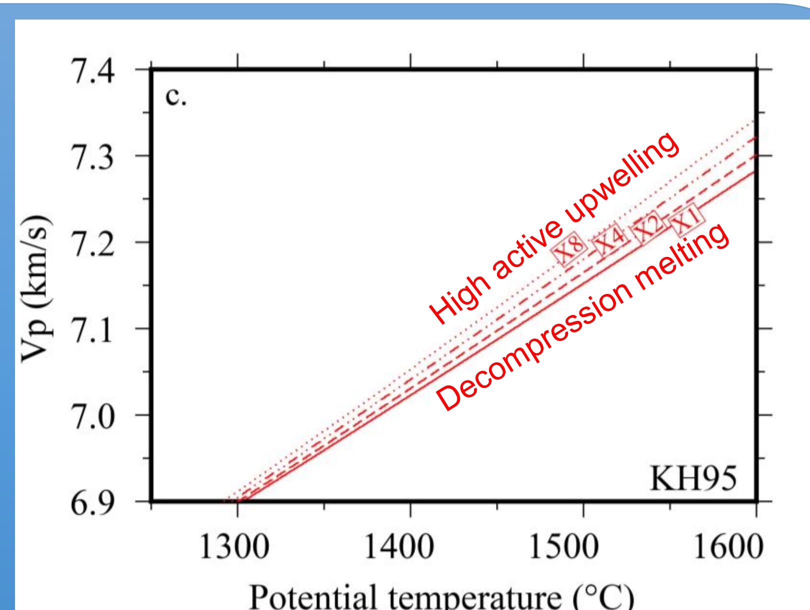


Model Parameterization

- Empirical relationship between V_p and melt fraction (F) and pressure (P)

$$V_p = 6.712 + 0.16P + 0.661F$$

- V_p and H_c from wide-angle seismic data



V_p increase with increasing mantle potential temperature and active upwelling.

Dataset

40 Lines chosen from NAG-TEC dataset

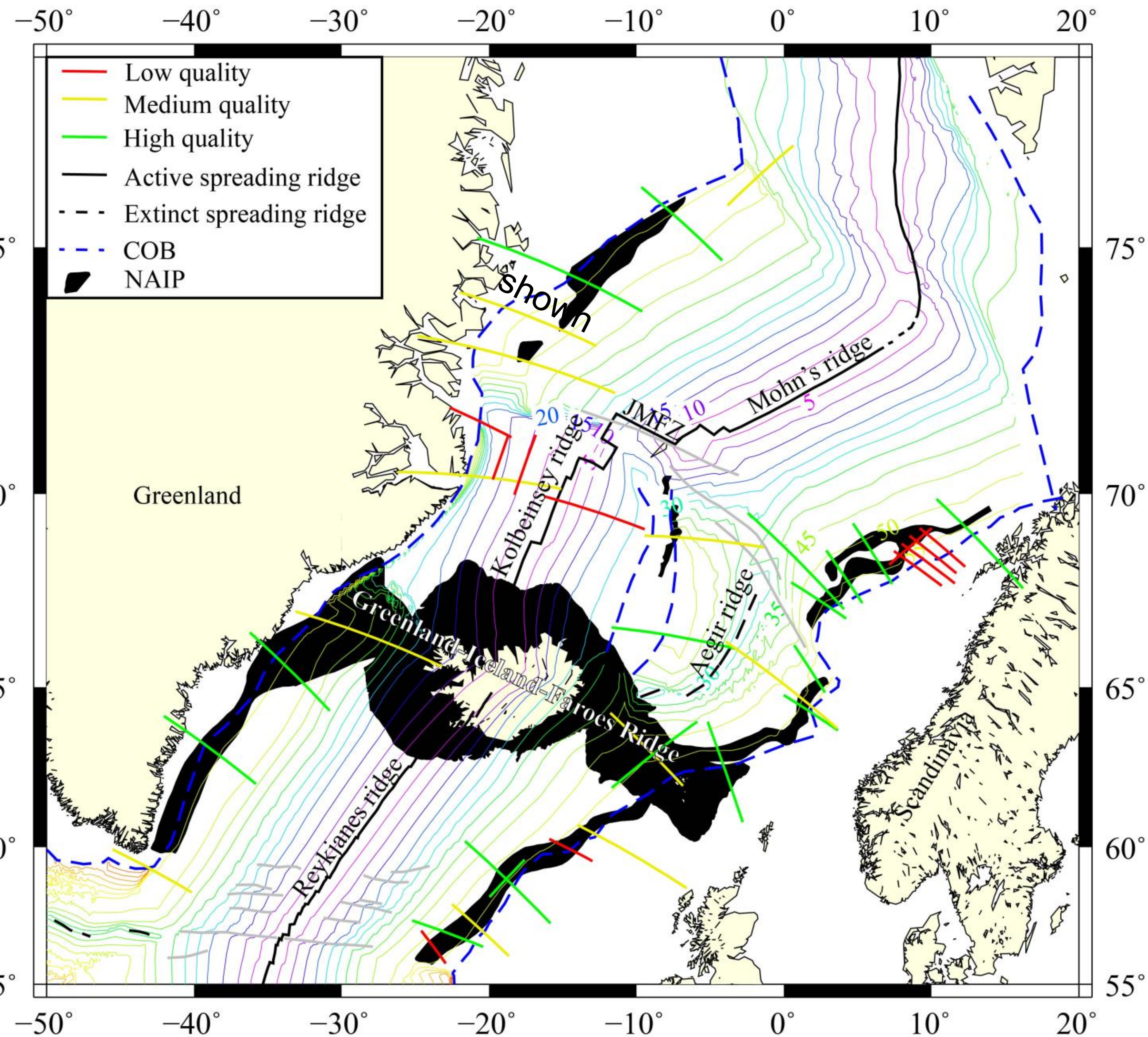
Labeled contours = Ocean age in Ma (Müller et al. 2019)

JMFZ = Jan Mayen Fracture Zone

NAIP = North Atlantic Igneous Province

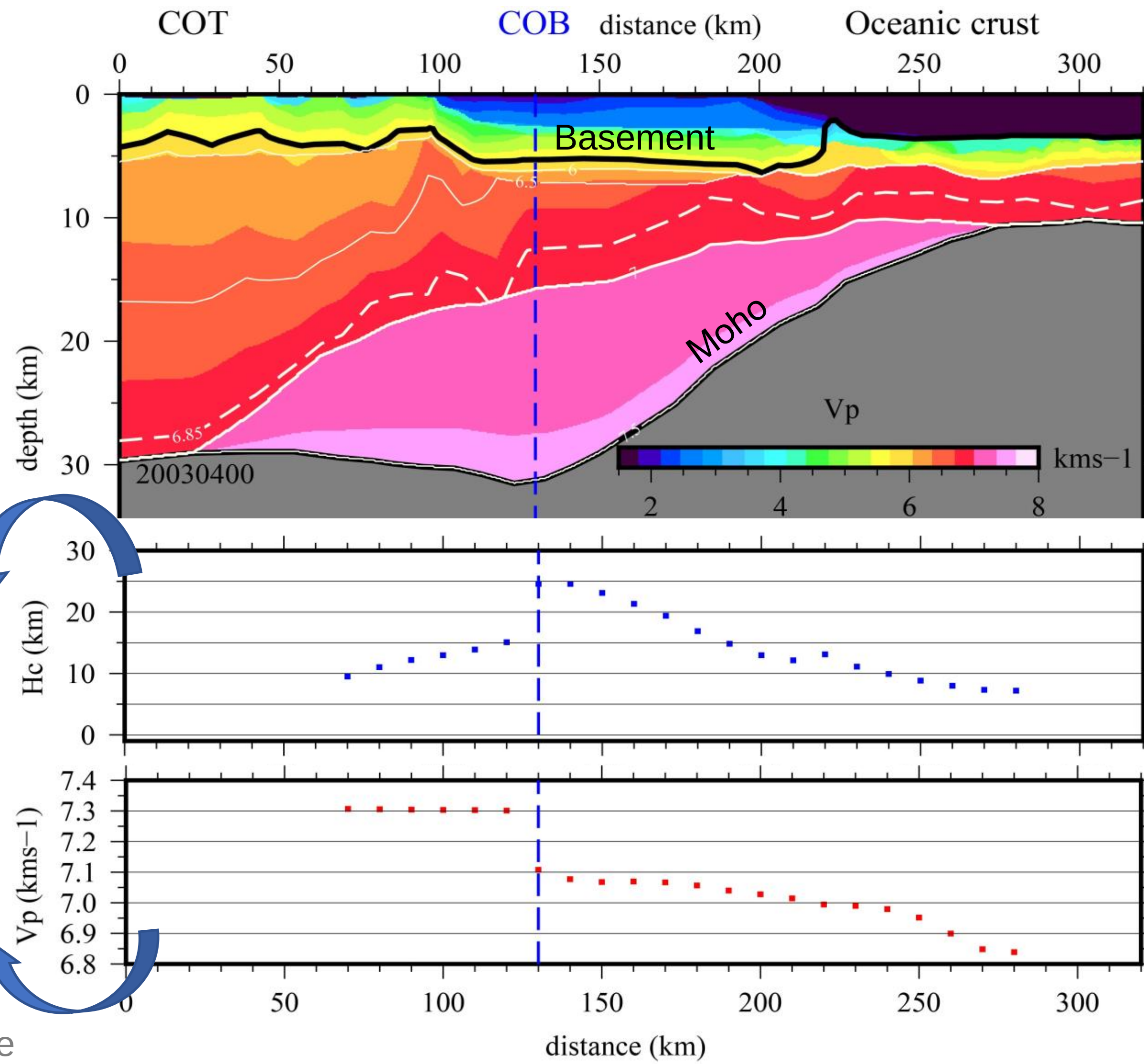
Coloured lines = Wide angle seismic data from NAG-TEC Dataset coloured according to quality

Yellow line north of Iceland = Data shown in following slide

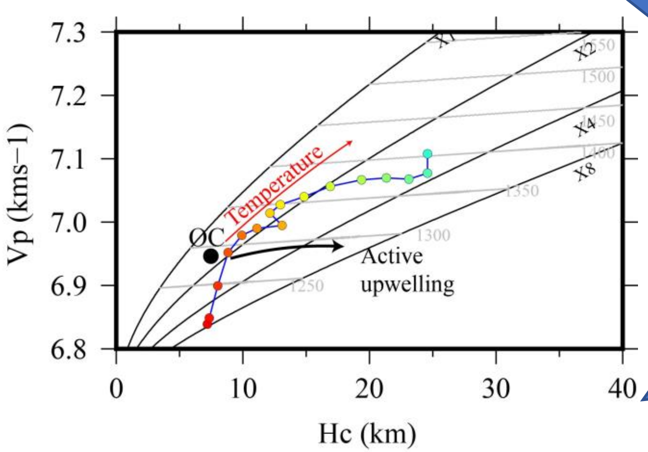


Example

- H_c=Moho-Basement
- V_p was corrected for the effect of porosity in the upper crust and effect of increasing pressure and temperture



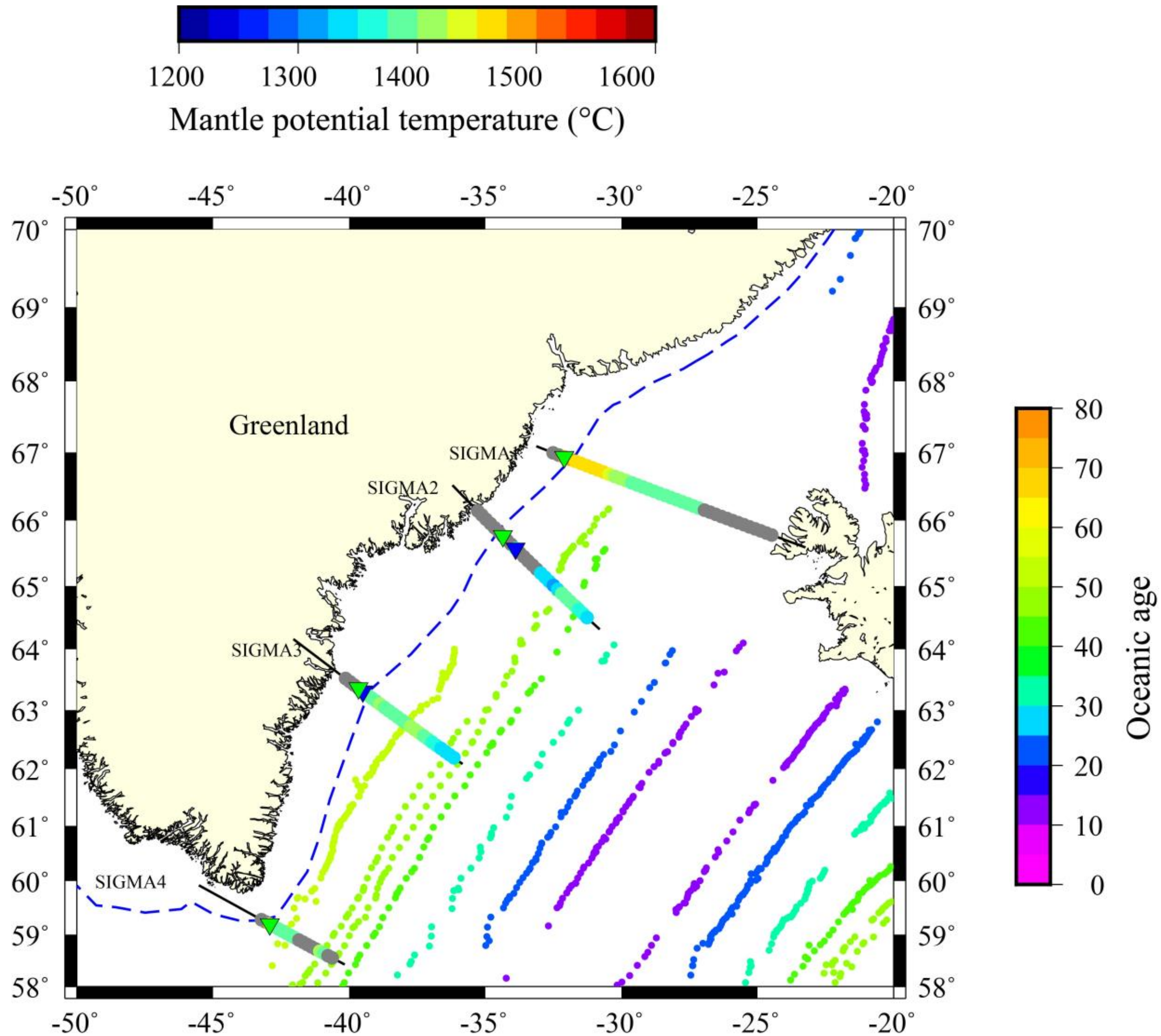
COT/COB = Continent-Ocean transition/boundary



H_c-V_p of profile 20030400. Solid lines are active upwelling contour lines, while dashed lines are mantle potential temperature contour lines for every 50°C.

Results: COB

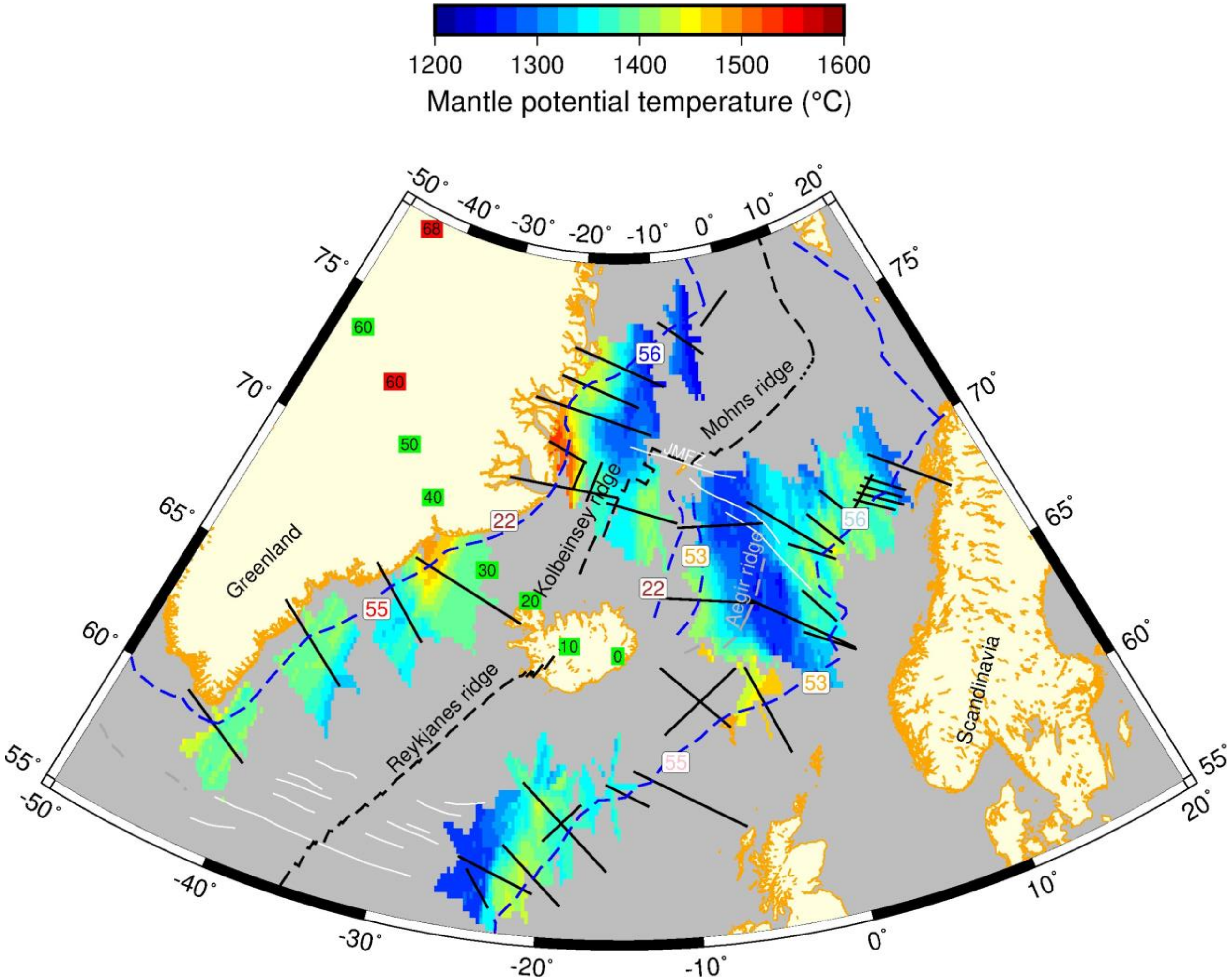
1. Mapping of COB based on Hc-Vp trends
2. T_p and X extracted along all lines from melting model: point outside melting model range – NaN value (grey)



Green & blue triangles = position of continent-ocean boundaries from Muller et al. (2014) & from this study.

Results: Mantle potential temperatures

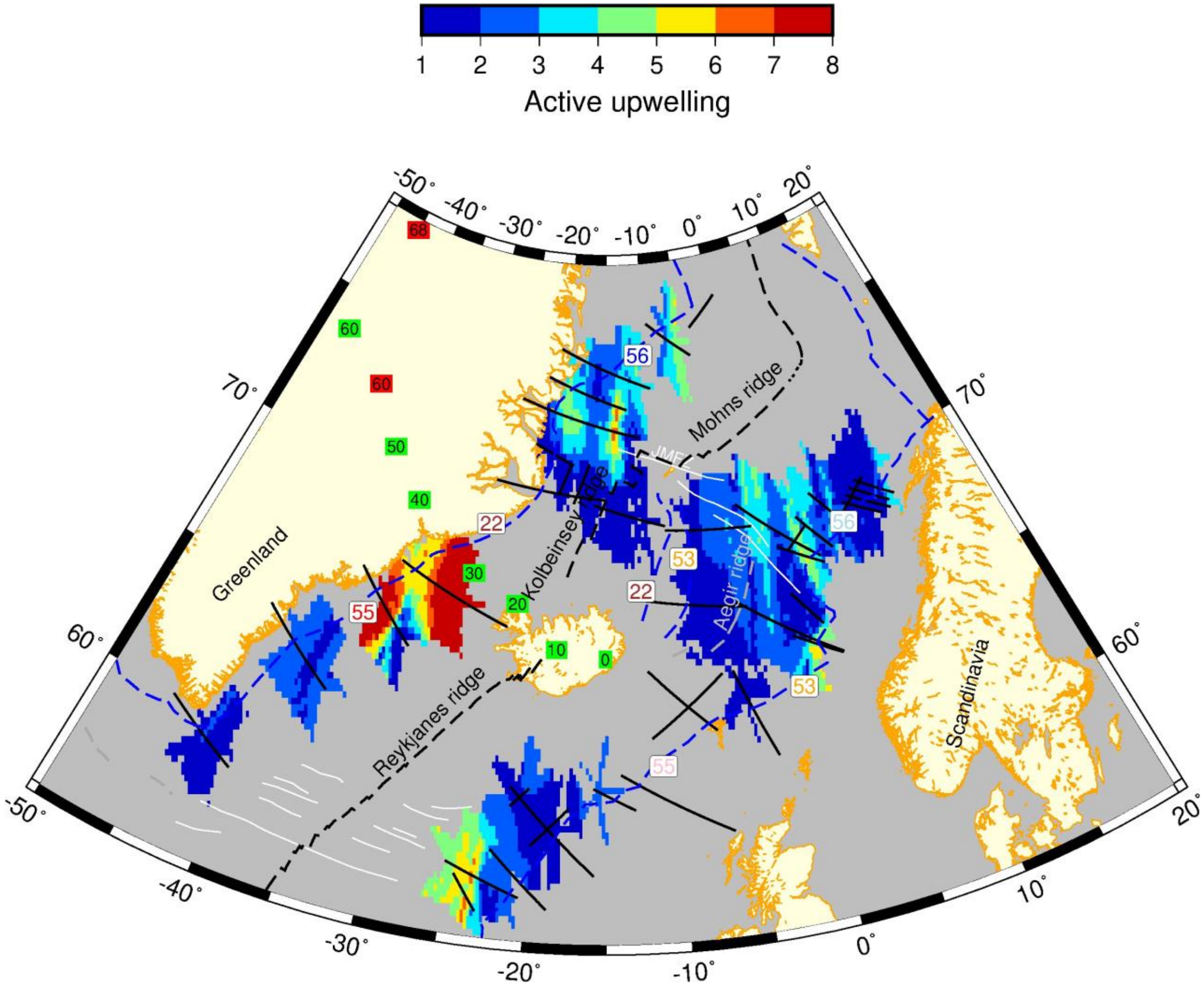
- All margins show generally higher temperatures, which decreases towards younger oceanic crust
- NE Greenland and GIFR are anomalously hot
- Extinct Ægir Ridge is anomalously cold (~1250°C)
- South of Iceland temperatures decrease



Blue/black dashed lines = COB/Oceanic Ridges.
Labeled white rectangles = Time of break up (Ma). Lines = seismic data.
Colored grid = interpolated mantle potential temperatures from parameterized melting model.
Green/red labeled rectangles = Icelandic plume track (age in Ma) from Lawver & Muller (1994) and Martos et al. (2018)

Results: Active upwelling

- High upwelling ratios:
  - Greenland-Iceland-Faroe-Ridge
  - Voring Spur
  - NE Greenland
  - Oceanward of Rockall Plateau
- Highest values centered on GIFR consistent with proposed plume track



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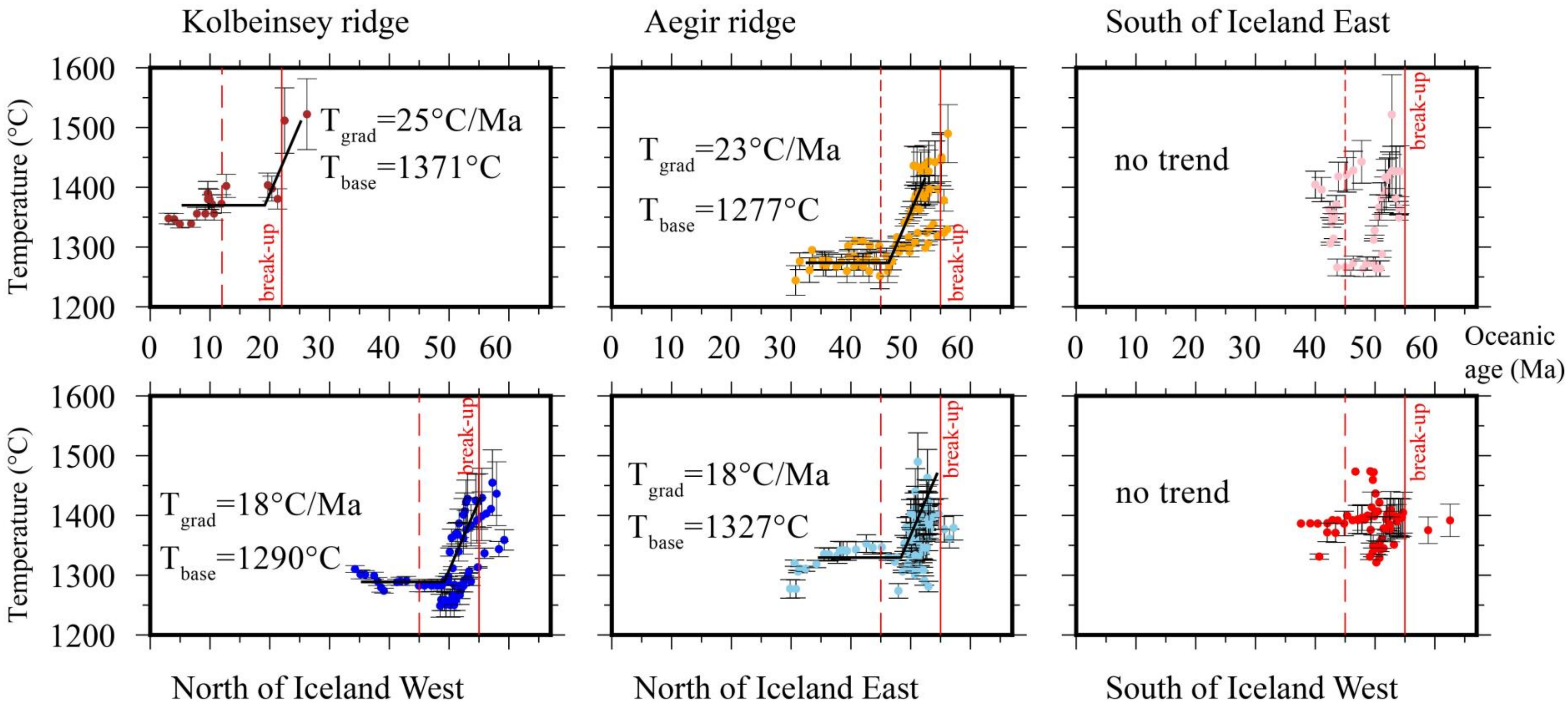
Temperature as a function of age



- "Hockey-stick trend": temperatures reach a steady state value 5-10 Ma after the start of seafloor spreading (dashed lines)
- Rate of temperature decrease is between 18 and 25°C/Ma
- The steady state value is between 1277°C and 1327°C before 50 Ma is 1353°C
- Kolbeinsey Ridge area has a higher steady state value around 1371°C

Conclusions

- Increased mantle potential temperature (1400–1450°C) at break-up (~55 Ma) in the North Atlantic Ocean
- Temperature reached steady state ~10 Ma after the start of seafloor spreading.
- Steady state temperatures are ~44°C higher in Kolbeinsey Ridge area than elsewhere
- Increased upwelling values coincide with proposed location of the Icelandic plume track
- Gradual decrease of temperature values with time could indicate complex pattern of mantle convection and/or continental insulation

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