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Upper mantle conditions during the opening of the North Atlantic Ocean

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Mantle conditions during the opening of the North Atlantic Ocean and specifically the presence or otherwise of a deep mantle plume have been much debated. Current models fall into two groups: the plume impingement and the plate-driven models. The plume impingement model associates the arrival of the Icelandic plume with continental break-up of the North Atlantic and the observed excess magmatism is associated with passive upwelling and elevated mantle potential temperatures. However, the plate-driven model associates this excess magmatism with increased mantle fertility due to inherited lithospheric structure and/or small-scale convection induced by sub-lithospheric topography.

We examine the spatial and temporal variation of upper mantle conditions at the time of continental break-up using an inventory of 40 published seismic refraction velocity-depth profiles acquired between the Charlie Gibbs and the East Greenland Fracture Zones. We make use of the Hc-Vp method to estimate mantle potential temperature and the ratio of active to passive upwelling by extracting igneous crustal thickness, Hc, and its mean p-wave velocity, Vp. Finally, we compare the spatial and temporal patterns obtained to those predicted by previously proposed models of mantle conditions around the time of break-up.

Our results indicate an asymmetry in mantle potential temperature between the Greenland and the European side, the latter being 100°C hotter. The temperature anomaly also varies on a wavelength of 300-500 km along strike both margins. In most profiles, the mantle potential temperature decreases with time, with normal temperatures of 1300°C being reached 5-10 Ma after the onset of seafloor spreading at 55 Ma. This temperature appears to be “steady state” once reached. The exception to this is the Greenland-Iceland-Faroes Ridge where the “steady state” temperature is 100°C higher. However, the decreasing trend of mantle potential temperature with time is not uniform across the whole North Atlantic region: the temperature decreases by a 60°C/Ma rate at the Hatton margin, while at the Møre and Vøring margins it is considerably slower, at only 20°C/Ma. A 100°C lower than normal mantle potential temperature anomaly was found at the now extinct Aegir Ridge spreading centre even though it was located less than 300 km away from the proposed reconstructed position of the Icelandic plume. Nevertheless, the plume’s position coincides well with the highest calculated upwelling ratios. The NE Greenland margin is also characterised by moderate upwelling compared to the purely passive European side.

Overall the spatial distribution of high active upwelling ratios and widespread elevated mantle potential temperatures support the plume impingement model for the opening of the North Atlantic Ocean. This thermal anomaly was exhausted at a varying rate on the different margins in 5-10 Ma. Furthermore, the 300-500 km wide localised thermal anomalies and the proximity of the proposed plume location to a low temperature anomaly indicate moderation by local complexities that might be a manifestation of upper mantle flow induced by structural inheritance or plate tectonic processes.