The influence of the Iceland plume on the development of the North Atlantic in the last 60 Ma.

P. Mihálffy(1) H. Schmeling(1) B. Steinberger(2)

(1)*Institut of Meteorology and Geophysics, Goethe University Frankfurt*
Feldbergstraße 47, Frankfurt am Main, D-60323, Germany; e-mail: mihalffy@geophysik.uni-frankfurt.de
(2) *Norges geologiske undersøkelse*
N-7491 Trondheim, Norway

J
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J.W. Goethe-Universität
Frankfurt am Main

Introduction

The development of the Iceland plume in the North Atlantic is investigated using different plume model assumptions: fixed hotspot hyphothesis, plume advected in the large-scale mantle flow field, plume-ridge interaction, whole mantle plume, upper mantle plume.

1 Modelling approach

The large-scale mantle flow field was calculated in a global model in the whole mantle. The flow was driven by prescribed surface plate velocities and internal density heterogeneities derived from different seismic tomography models. Using time dependent surface boundary conditions and advecting the density anomalies, a time dependent global mantle flow field was obtained for the last 60 Ma. An initially vertical, buoyant whole-mantle plume conduit was advected in this mantle flow field. (Steinberger (2000)).

The motion of a plume coming from the 660km was calculated in a 3D cartesian model of the upper mantle. In this regional model, the calculated global mantle flow field was used as a background flow. The coupling between the 2 models was achieved in terms of boundary conditions derived from the global model and prescribed in the regional model. These resulted in a similar flow pattern inside the regional model as in the global one. The plume was introduced by a perturbation of the thermal boundary condition on the bottom at 60Ma time. The plume source was kept fixed at the 660km, since the large-scale mantle flow field has a small horizontal component.

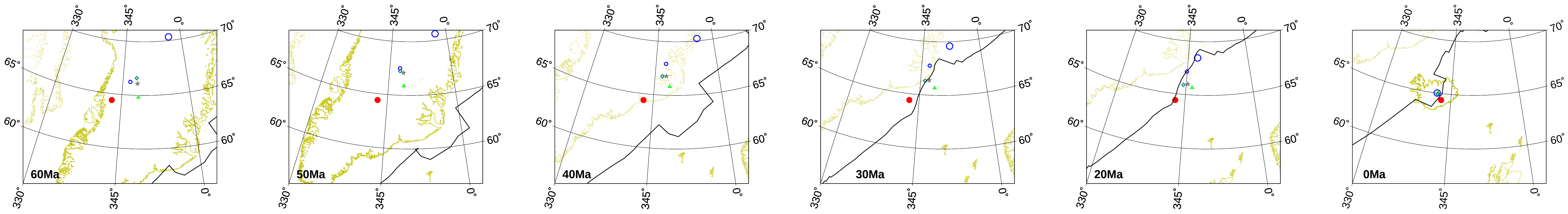
In both models surface boundary condition for the velocity was used for mimicking spreading and to kinematically drive the flow. Magnetic anomalies of the ocean floor were used to calculate detailed ridge geometry and to produce this surface velocity field with higher accuracy. In the global model density anomalies derived from tomography were used to introduce the dynamic flow. A summary of the modelling approach is given in the following table:

	GLOBAL MODEL (Hager and O'Connell (1981))	REGIONAL MODEL (Albers (2000))
1. Model domain	The whole mantle	660kmX1800kmX1800km model box
2. Viscosity	Layered viscosity	Temperature and depth dependent viscosity
4. Equations	incompressible mass, momentum equation + advecting densities backward in time	Mass, momentum, energy equation, Boussinesq, 1/Pr=0
5. Solving method	Propagator matrix technique	Finite volumes, multigrid
6. Boundary conditions	Time dependent surface plate velocity	**Velocity is prescribed on all sides of the box. Dirichlet velocity values are derived from the global model.**
7. Initial conditions	Density anomalies derived from seismic tomography	Temperature profile of a 200km thick lithosphere
8. Plume	Plume is an initially (60 Ma time) vertical conduit, which buoyantly rises and is (passively) advected in the mantle flow field.	Plume is a perturbation of the temperature and velocity boundary condition causing a hot inflow with a volume flux B=54 m^3 /s and excess temperature dT=200K

2 Whole mantle plume

Figure 1: Motion of the surface position of whole-mantle plume models. Red full circle: fixed hotspot; blue circle, green triangle, star and diamond: moving plume advected in large-scale mantle flow fields driven by different tomography models; big empty circle: moving hotspot in a mantle flow field, in which the lithosphere has no net rotation.

According to the global mantle flow model there is a regional upwelling and a general northeastward mantle flow in the North Atlantic (fig. 3) at a depth of 250 km. In contrary, there is a southward mantle flow in the lower mantle in the direction of the Great African Plume. This results in a southward motion of the surface position of the plume between 30Ma and 0Ma times.



3 Upper mantle plume

Figure 2: Plume motion and ridge positions in a cartesian box model of the upper mantle

Due to the northward mantle wind the plume becomes tilted to the north. The plume source is fixed on the bottom of the box (660km). Since initially there is a long distance between the plume and the ridge, no significant ridge feeding developes.

4 Hotspot motion and lithospheric tracks

The hotspots first move to the north due to the northward mantle wind in the upper mantle, and then move to the south due to southward flow in the lower mantle (fig. 4). This southward motion causes, that the track of the moving hotspot is situated north of that of the fixed hotspot (fig. 5). The latter fits better the orientation of the Faeroe-Iceland ridge. In case of an upper mantle plume the track is similar as in case of the fixed plume. In both cases movement also lacks a southward motion, because the lower mantle southward flow does not influence hotspot motion. Thus, an upper mantle plume fits better the surface observables, than a whole mantle plume.

Figure 4: Motion of the whole-mantle plume conduit at 660km (green) and on the surface (blue) in case of 2 different tomography. Blue circle and triangle: starting position of the plume models with different tomography.

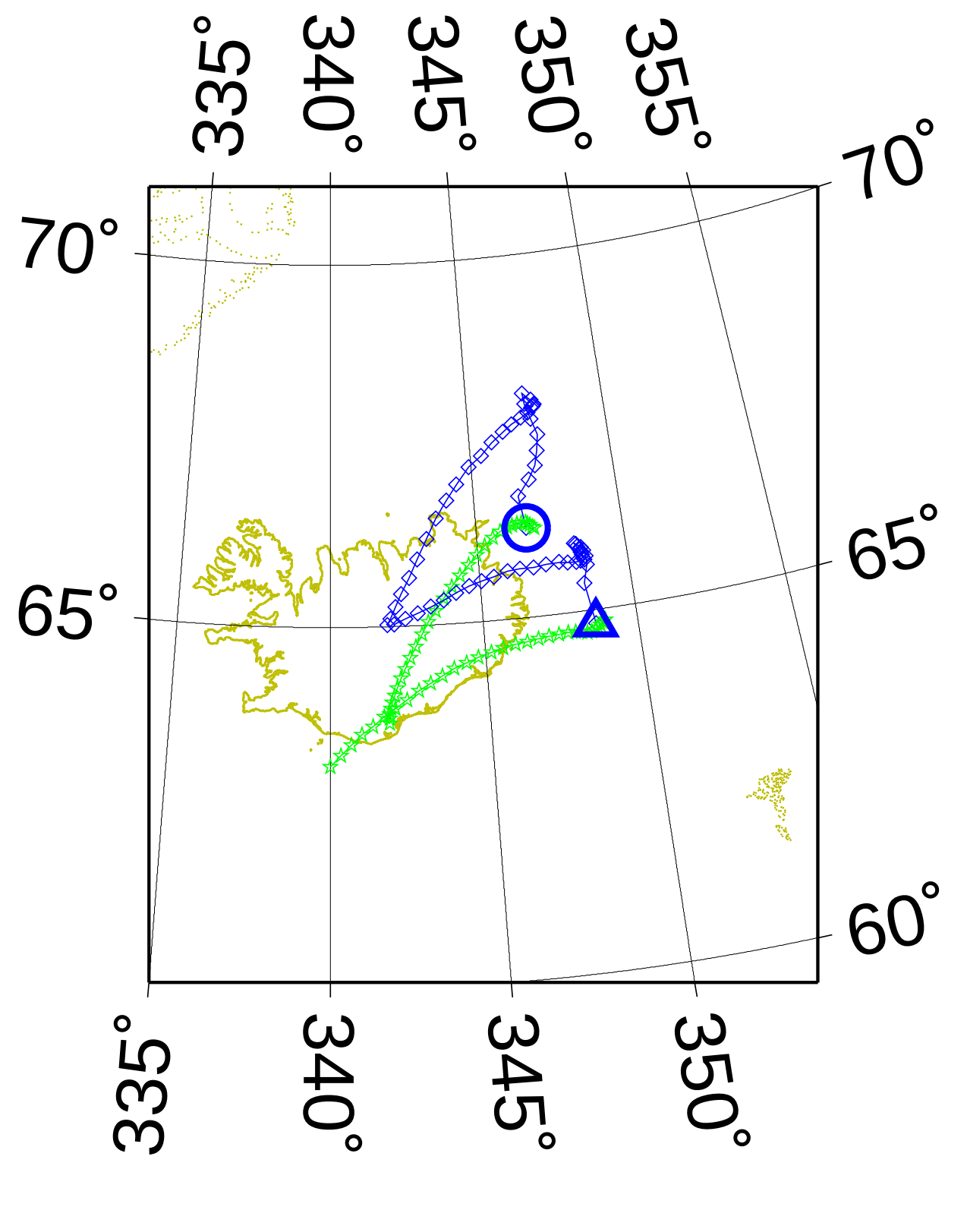
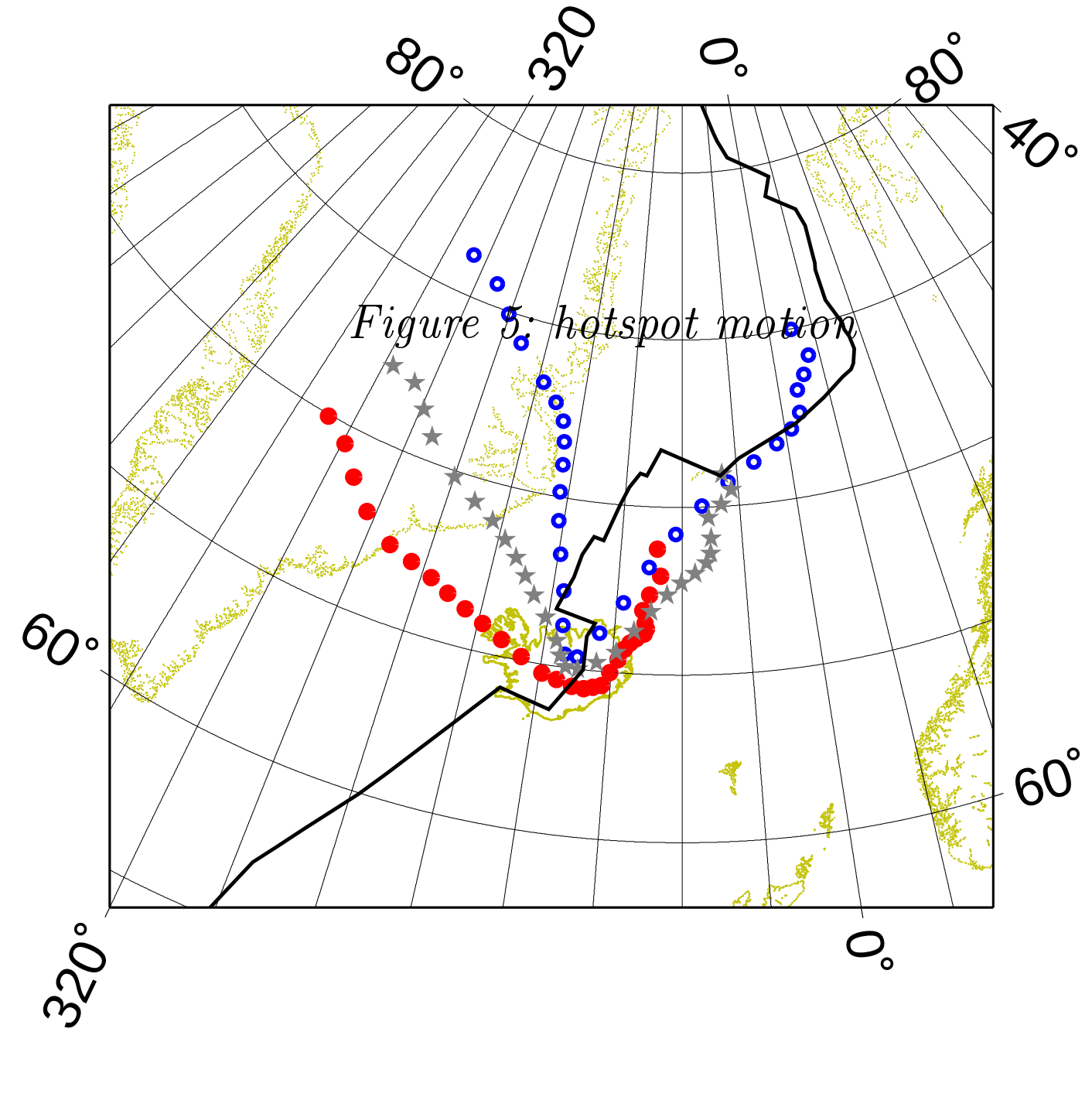


Figure 5: Lithospheric tracks of different hotspot models. Red circle: fixed hotspot; Stars: moving hotspots; Blue: moving hotspots with no net rotation of the lithosphere relative to mantle.



The development of the plume is controlled by the large-scale mantle flow field. The plume arrives under the lithosphere at 10 Ma time. At 30 Ma time it is slightly distorted to the northeast (fig. 2). Later, the northeastward (fig. 3) motion of the large-scale mantle flow field together with the sloping base of the lithoshere push the plume to the ridge.

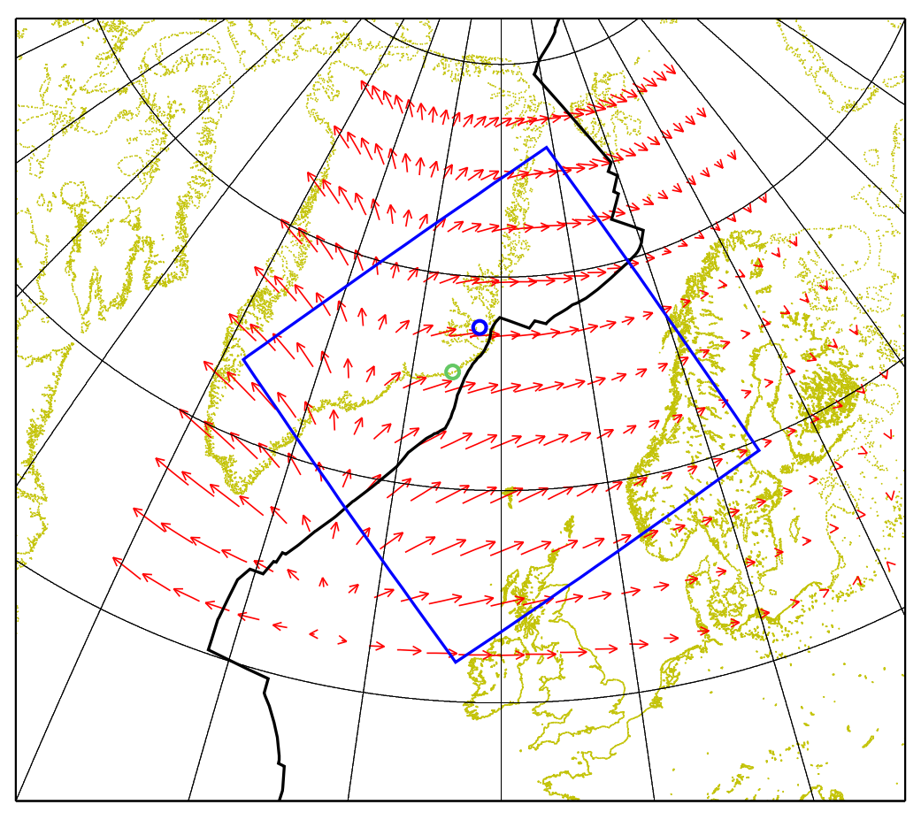


Figure 3: Horizontal velocities at 30Ma time in 250 km depth and plume positions at different times.

→ *2cm/yr*
○ *Plume position on the surface*
○ *Plume position at the 660km*

Between times 30Ma and 0Ma the plume remains approximately in the low viscosity zone defined by the ridge, and has a constant tilt over time.

Conclusions

1. The development of a plume conduit is controlled by the large-scale mantle flow field and the sloping base of the lithosphere.
2. An Iceland plume coming from the 660km fits better the orientation of the Greenland-Faeroe ridge, than a whole mantle plume.

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