Discussion of

Mechanisms of crustal growth in large igneous provinces: the North-Atlantic Province as a case study

by

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The data presented in the paper by Geoffory et al. (this volume) suggest that a significant part of the magmas forming the central North Atlantic Igneous Province (NAIP) were injected in a limited number of igneous centers, feeding dikes (sub-horizontally) over (sometimes) large distances. More work is needed, but if the suggested pattern of the calculated dike flow vectors as presented in this study is correct, existing models for emplacement processes may need to be re-evaluated.

Prior work on emplacement processes often assumed that magma is transferred vertically, and that therefore the surface extent of flood basalts gives a good indication of the extent of mantle melting at depth. Geoffroy and coworkers however find that magma feeds a limited number of igneous centers, and then travels from these centers outward, sub-horizontally. They propose, for example, that seaward dipping magmatic reflector sequences could be fed laterally from central crustal reservoirs, instead of vertically as initially thought. This conclusion confirms an earlier discussion advanced by Klausen and Larsen (2002) on the East Greenland coast parallel dike swarm. Geoffroy et al. (this volume) provide new quantitative results and show that this lateral feeding model proves to be valid for other areas in the North Atlantic as well.

The authors propose that no direct relation needs to exist between the magma distribution at the surface of the Earth and the extent of mantle melting at depth. The distribution of igneous centers in the crust is more indicative of the extent of mantle melting. Several lines of arguments exist on how melt accumulates in igneous centers, and the authors favor a process in which melt migration horizontally in the mantle over large distances is unlikely, such that the igneous centers thus form above or close to the location of mantle melting. To explain the distribution of igneous centers, small-scale convection-induced magmatism just below the lithosphere is proposed. Geoffroy et al. (this volume) do not support diapiric structures inside the continental lithosphere to explain the igneous feeding systems. Nevertheless, other studies have supported such a mechanism for different study areas and under specific conditions; Gerya et al. (2004), for example, describe and model diapiric features in the Bushveld complex explained by the temporal inversion of a vertical temperature gradient due to the emplacement of large quantities of hot and mafic magma onto cold material. Drury et al. (2001) simulate diapiric intrusions inside a cold cratonic area.

If the melting region in the mantle is indeed reflected by the distribution of igneous centers, a large, quite uniformly thermal plume head is not supported by these observations, according to the authors.

The suggested link between these sub-lithospheric instabilities (small scale convection) and the igneous centers is clearly at a developing stage at this moment, and there exists no geophysical evidence yet that allows us to prove the presence of these mantle instabilities during Paleocene time. Emplacement and formation of huge igneous complexes at depth is far from being well understood. Recent potential-field investigations in the Rockall-UK area (Edwards, 2002) for example, suggest that massive high-density igneous complexes vary in shape, can be present deep in the crust, or restricted only to the upper part of the crust. We cannot exclude that different modes of emplacement may exist (Edwards, 2002). More geophysical data are needed to detect and investigate igneous intrusions in other parts of the NAIP as well.

The authors discuss about three dozen igneous centers, located in the central NAIP. Most of them are Paleocene in age, but some remain undated and some datings are not well constrained (e.g. Hitchen, 2004; Meyer et al., this volume). To our knowledge, these magmatic features far from the breakup axis have not been recognized in the rest of the NAIP area to the same extent (Figure 1). This could change in the future when more datasets are processed, but for now it is unknown whether the Rockall-UK area style of massive igneous accumulation is representative for the entire NAIP. On the Norwegian margin for example, Berndt et al. (2000) identified the Hel Graben Sill Complex, but this feeder system does not seem similar to the feeders investigated by Geoffroy et al. (this volume).

Along-margin variations in melt accumulation could be expected, as the tectonic evolution (and stress field) of different margin segments has varied during the long rifting history that ultimately resulted in breakup. Lithosphere-scale processes (such as the regional stress field, as mentioned by Geoffroy et al., this volume), affected by inherited structures, play a role in how magma transfer and accumulation will develop. Deep shear zones like the Great Glen Fault can probably affect the upper mantle as suggested by deep seismic data cutting the Moho (e.g. Klemperer and Hobbs, 1991) or/and act as conduits for melt transport. Figure 1 illustrates the distribution of major (recognized) fracture and shear zones in the North Atlantic, suggesting a geographical and structural relation with breakup related intrusions.

At this point, many open questions remain, including:

1. How has melt accumulated in the NAIP? Are there regional variations?
2. Does the suggested sub-horizontal melt transfer mechanism, proposed by Geoffroy et al. (this volume) apply to the entire NAIP?
3. If there indeed exists a dense concentration of igneous feeding centers in the Rockall-UK area, how can this be explained? Why are similar features not clearly observed north of the Faeroes-Shetland Basin?
4. In general, how does melt migration and accumulation work in continental lithosphere, and what is the relation/connection with mantle melting?

It is clear that more research is needed to establish the extent, style and distribution of igneous feeding centers along the margins of the NAIP. A more complete picture would enable testing the model proposed by Geoffroy et al. (this volume) for magma transfer in Large Igneous Provinces.

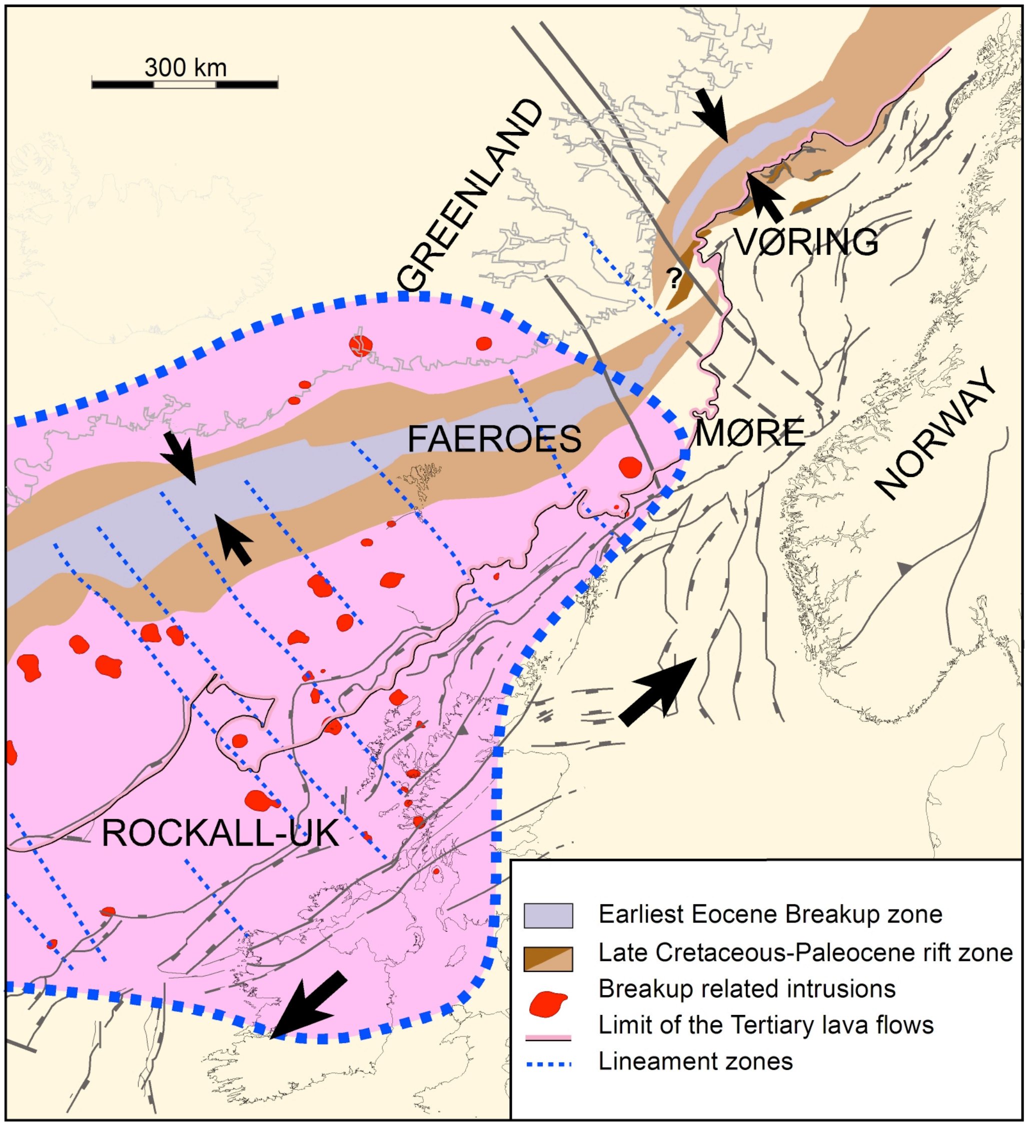

Figure 1. Distribution of breakup-related intrusions, major fracture systems and shear zones in the North Atlantic Igneous Province (NAIP). The regional pink surface represents the NAIP area with atypical? concentration of igneous centers. The major Paleocene intrusive complexes may be associated with old inherited structures and mostly focus in the Rockall-UK area. Map modified after Doré et al. (1999), Gernigon (2002) and Hitchen et al. (2004).

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