Unraveling the lithostratigraphy of the continental crust beneath the Faroe Islands

B. Dahrén[1], A.K. Barker[1], V.R. Troll[1], F.C. Meade[1,2], P.M. Holm[3]

[1] CEMPEG, Department of Earth Sciences, Uppsala University, Villavägen 16, Uppsala, Sweden.
[2] Dept. of Geographical and Earth Sciences, University of Glasgow, Scotland
[3] Dept. Of Geography and Geology, University of Copenhagen

Abstract

The Faroe islands CFB province is underlain by continental crust (Gariépy et al., 1983; Richardson et al., 1998), but access to this succession is severely limited simply due to the thickness of the basalts being in the order of 6 km (Passey and Bell, 2007). Therefore, we would like to gain access to the sedimentary rocks uncovered during Leg 152, Site 917, as these may be closely related to some of the lithologies underlaying the Faroese basalts. This will allow us to circumvent this problem by constructing 'virtual bore holes' into the sub-basalt lithology, employing in-situ isotope approaches, geochemical analyses and petrological HP-HT experiments.

Magmas traversing the Earth's crust to finally erupt at the surface will provide a record of the country rock it interacted with along the way. We will investigate partial melting behaviour and products of the country rocks, and compare this with geochemical signatures in the overlying volcanic rocks, enabling us to model crustal assimilation processes. This will be coupled with mineral-melt based geobarometers (Putirka, 2008) and existing seismic surveys (Richardson et al., 1998), to enable us not only to define the compositional character of the continental crust, but also approximate at what depths these are located, thereby allowing the construction of a lithostratigraphy of the continental crust underlying the flood basalt sequence of the Faroes.

This will have applications for e.g. petroleum exploration, with the possibility of identifying reservoir rocks hidden beneath the basalt, which has the potential for a massive impact on the economy of the region.

Background

It has long been realised that the composition of magmas change as they ascend through the lithosphere in response to differentiation processes such as crustal contamination, crystal fractionation and mixing of magmas. The eventual magmatic

rock analysed actually represent an accumulation of physio-chemical influences integrated over the time from original source to final solidification. Furthermore, the components that now constitute the rock – the various crystal phases and any residual glass or groundmass (liquid) – may not even share a common history. The crystals in particular may have formed at different times and places before being mechanically aggregated into a magma and eventually forming a solid rock. Recognising that the crystalline components within the rock preserve individual records of differentiation, we can apply modern geochemical analytical techniques to unravel a magma's integrated differentiation history (e.g. Chadwick et al., 2007; Charlier et al., 2008; Font et al., 2008; Troll et al., 2008). This not only gives us a means of accounting for the effects of differentiation and constraining the nature of the original source, but also allows us to quantify the mechanisms of differentiation and magma-crust interaction.

Geological setting

On a regional scale, volcanic rifted margins like Vøring and the Faroe-Shetland basin are major tectonic features of northern Europe and Scandinavia. However, these margins are submarine, and covered by a blanket of recent sediments. Our knowledge of these areas is therefore restricted to seismic studies, and the only real petrological information comes from drill cores of limited depth. The rocks of the Faroe Islands and the British and Irish Palaeogene Igneous Province provide an onshore analogue to areas such as the Vøring plateau (e.g. Meyer et al., 2009). In the Faroes, the influence of crustal rocks on the basalts can be studied by detailed petrology and geochemistry, within the context of well-constrained field relationships (e.g. Waagstein, 1988; Larsen et al., 1999; Passey and Bell, 2007). Crustal contamination has previously been identified in Faroese basaltic rocks (Gariepy et al., 1983; Holm et al., 2001), but was mainly considered an obstacle in elucidating mantle melting processes (e.g. Gariepy et al., 1983; Holm et al., 2001). The proposed study will provide targeted information on crustal interaction that can be tied back to field relations but concievably also to deeper crustal features identified in seismic sections (e.g. Bott et al. 1974; Richardson et al., 1998). The existing deep seismic profiling would thus be complemented with compositional information that will help subsequent modelling for research and exploration.

Work program and methodologies

A comprehensive set of rocks from the Faroes flood basalts is already available for analysis, and will be added to during a field trip in June 2011. However, in order to successfully model the crustal assimilation processes, we also need a handle on the sedimentary sequence underlying the basalts. However, these rocks are covered by several kilometres of basalts and are in principle inaccessible. Therefore, we have to circumvent this problem by sampling related rocks from more accessible locations. For this purpose we've acquired a suite of gneisses and sedimentary rocks from the mainland Scotland and Greenland that is thought to represent the pre-rift crust from before the opening of the North Atlantic (Larsen et al., 1999). Also, our industry collaborators have supplied us with a limited set of whole rock powders from boreholes in the continental shelf outside the Faroe islands. However, this collection is nowhere near complete and we are convinced that we need more samples order to achieve a realistic suite of rocks representing the sub-basalt succession. Therefore it would be of vital importance to the project to gain access to the sedimentary succession underlying the basalts on the seawards dipping reflector sequences (SDRS) southeast of Greenland, uncovered during Leg 152, Site 917 (Larsen et al., 1994). This would yield a much more extensive and spatially associated set of possible crustal components representing the bedrock prior to the rifting and eruption of the Faroe basalts, and thus the likely endmember compositions that can be expected to have interacted with the magmas as they traversed the crust.

The Faroese basalts will be subjected to an array of geochemical analyses including a) major, minor and trace elements in bulk rock and minerals (XRF and EMP), b) REE elements in bulk rocks (ICPMS), c) in-situ $^{87}Sr/^{86}Sr$ in plagioclase (Microdrill), d) Pb isotopes (TIMS) and e) $\delta^{18}O$ in plagioclase separates (conventional silicate line). These analyses will yield vital information with excellent spatial resolution on crustal contamination processes, as well as mineral and rock compositions

The sedimentary rocks will be subjected to a sequence of HP-HT experiments followed by in-situ analyses of major and minor elements (EMP) and radiogenic isotope (Micromill and LA-ICPMS) in order to eludicate partial melting behaviour, thereby providing endmember compositions for modelling of crustal contamination.

This dataset, will enable us to perform multi-parameter modelling of crustal contamination, which coupled with geobarometric calculations (Putirka 2008) will allow us to constrain composition and vertical location of the contaminant(s).

This qualitative and quantitative modelling of crustal contamination processes in the Faroes flood basalts will enable us to substantially refine current knowledge of crustal architecture beneath the Faroe Islands, knowledge that otherwise would only be available through exceedingly costly drilling of >5 km kilometres of basalt just to reach the top of the underlying crust.

Budget

To cover a series of different PT-X conditions, we propose to perform approximately 20 HP-HT experiments using the sedimentary rocks acquired from the drill cores from Leg 152, Site 917. The cost per experiment, including consumables and laboratory fees is 100 €, bringing the total cost to 2000 €

Description	**Total cost**
Experimental petrology, HP-HT experiments. 20 samples, 100 €/sample	2000 €

Schedule

After receiving the samples, we will need approximately 2 months for the initial thin section preparation and petrological description. The experiments will be carried out at the 'Istituto Nazionale di Geofisica e Vulcanologia' (INGV), Rome. Preparation of material for experiments and experimental procedures will take approximately 6 months. After this, another 4-6 months will be required for analysis of the experimental results, followed by conference presentations and manuscript preparations.

References

Bott, M.H.P., Sunderland, J. & Smith, P.J. (1974) Evidence for continental crust beneath the Faeroe Islands. *Nature*, 248:202-204

Chadwick, J.P., Troll, V.R., Ginibre, C., Morgan, D., Gertisser, R., Waight, T. & Davidson, J.P., (2007) Carbonate Assimilation at Merapi Volcano, Java, Indonesia: Insights from Crystal Isotope Stratigraphy, *J Petrol*, 48:1793-1812

Charlier B.L.A., Wilson C.J.N. & Davidson, J.P. (2008) Rapid open-system assembly of a large silicic magma body: time-resolved evidence from cored plagioclase crystals in the Oruanui eruption deposits, New Zealand, *Contrib Mineral Petrol*, 156:799-813

Font, L., Davidson, J.P., Pearson, D.G. Nowell, G.M., Jerram, & D.A., Ottley, C.J. (2008) Sr and Pb Isotope Micro-analysis of Plagioclase Crystals from Skye Lavas: an Insight into Open-system Processes in a Flood Basalt Province *J Petrol*, 49:1449-1471

Gariépy, C., Ludden, J. & Brooks, C. (1983) Isotopic and trace element constraints on the genesis of the Faeroe lava pile, *EPSL*, 63:257-272

Holm, P.M., Hald, N. & Waagstein, R. (2001) Geochemical and Pb–Sr–Nd isotopic evidence for separate hot depleted and Iceland plume mantle sources for the Paleogene basalts of the Faroe Islands, *Chem Geol*, 178:95-125

Larsen, L.M., Waagstein, R., Pedersen A.K. & Storey, M. (1999) Trans-Atlantic correlation of the Palaeogene volcanic successions in the Faroe Islands and East Greenland, *J Geol Soc London,* 156:1081-1095

Larsen, H.C., Saunders, A.D., Clift, P.D., et al., (1994) 13. Summary and Principal Results, *Proceedings of the Ocean Drilling Program, initial reports*, 152

Meyer, R., Nicoll, G.R., Hertogen, J., Troll, V.R., Ellam, R.M. & Emeleus, H. (2009) Trace element and isotope constraints on crustal anatexis by upwelling mantle melts in the North Atlantic Igneous Province: an example from the Isle of Rum, NW Scotland, *Geol Mag*, 146:382-399

Passey & Bell 2007, Morphologies and emplacement mechanisms of the lava flows of the Faroe Islands Basalt Group, Faroe Islands, NE Atlantic Ocean, *Bull Volcanol*, 70:139-156

Putirka, K.D. (2008) Thermometers and Barometers for Volcanic systems, *Rev Mineral Geochem*, 69:61-120

Richardson, K.R., Smallwood, J.R., White, R.S., Snyder, D.B. & Maguire, P.K.H. (1998) Crustal structure beneath the Faroe Islands and the Faroe–Iceland Ridge, *Tectonophysics*, 300:159-180

Troll, V.R., Nicoll, G.R., Donaldson, C.H., & Emeleus, H.C. (2008) Dating the onset of volcanism at the Rum Igneous Centre, NW Scotland, *J Geol Soc London*, 165:651-659

Vallier, T., Calk, L., Stax, R., and Demant, A., (1998) 10. Metamorphosed sedimentary (volcanoclastic?) rocks beneath Paleocene basalt in hole 917a, East Greenland Margin, *Proceedings of the Ocean Drilling Program, scientific results*, 152

Waagstein, R., (1988) Structure, composition and age of the Faeroe basalt plateau, *Geol Soc London, Special Publications*, 39:225-238

Yang, H.J., Kinzler, R.J. & Grove, T.L. (1996) Experiments and models of anhydrous, basaltic olivine-plagioclase-augite saturated melts from 0.001 to 10 kbar, *Contrib Mineral Petrol*, 124:1-18

ECORD
Science Support & Advisory Committee
ESSAC Office - Alfred Wegener Institute for Polar and Marine Research - Am Alten Hafen 26 - 27568 Bremerhaven, Germany
T +49 471 4831 2252 F +49 471 4831 2255 essac.office@awi.de www.essac.ecord.org

CV form

ECORD Research Grant

Affiliation: Dept. of Earth Sciences, CEMPEG, Uppsala University, Sweden

Personal Details:

First name: Börje
Surname: Dahrén
male/female: male
year of birth: 1984
Address: Rackarbergsgatan 11-120
City, Postcode, Country: SE-752 35 Uppsala, Sweden
Email: borje.dahren@geo.uu.se

Education (higher education, incl year PhD received/expected):

MSc. in Petrology and Geochemistry - May 2010.
PhD completion expected in 2014

current academic status: ☐ bachelor student ☐ master student ☑ phd student ☐ post-doc

Statement of interest:

Access to drill cores from the sedimentary succession underlying the basalts on the seawards dipping reflector sequences (SDRS) southeast of Greenland, uncovered during Leg 152, Site 917

Professional Experience:

Area of scientific interest (incl current research project):

Igneous petrology and geochemistry. Magma transport, storage and AFC processes in Continental Flood Basalt (North Atlantic Igneous Province) and Island Arc (Indonesia) settings

Prior involvement with IODP:

none

Publications:

Dahren et al., 2010, Geophys Res Abs, 12.
Dahren et al., 2011, Contrib Mineral Petrol, in revision.
Dzhaksybulatov et al., 2011, JVGR, in revision.

Awards:

References:

Prof. Valentin R. Troll, Department of Earth Sciences, CEMPEG, Uppsala University, Sweden

Dr. Abigail K. Barker, Department of Earth Sciences, CEMPEG, Uppsala University, Sweden

ECORD
Science Support & Advisory Committee
ESSAC Office - Alfred Wegener Institute for Polar and Marine Research - Am Alten Hafen 26 - 27568 Bremerhaven, Germany
T +49 471 4831 2252 F +49 471 4831 2255 essac.office@awi.de www.essac.ecord.org

Letter of Support

ECORD Grants

Full Name of Applicant Börje Dahrén

Instructions: This form consists of two parts. Both parts must be completed by a supervisor who is providing the reference. The completed report should be sent by the referee to the adress provided above by the deadline date. Personal information is requested in Section A. In section B the referee should comment on the candidate's skills, and on the importance of the ECORD Grant for their research.

A

Referee's name Dr. Abigail K Barker

Position Assistant Professor

Area of expertise Petrology and Geochemistry

Work address Dept of Earth Sciences, Uppsala University, Villavägen 16, 753 28 Uppsala, Sweden

B

1. Since when and in what capacity have you known the applicant?
January 2009 - when i moved to Uppsala, Börje was a MSc student in the petrology research group
September 2010 - PhD thesis supervisor

2. The applicant is/was among the best students/doctoral students (in %): ☒ 5% ☐ 10% ☐ 20% ☐ 30% ☐ no assessment possible

3. How does the applicant stand out in academic and personal terms and what is your assessment of his/her potential?
See attached letter.

4. Please comment on the overall standard,, feasibility, relevance and schedule of the project proposed by the candidate.
See attached letter.

5. Please provide any additional information that could be of importance to the ECORD Grant award decision:

6. Degree of approval ☑ Emphatic approval ☐ Approval ☐ Conditional approval (please specify)

Place, Date

Uppsala, 22nd March 2011

Referee's Signature, Stamp or Seal

AK Barker

CEMPEG Centre for Experimental Mineralogy Petrology & Geochemistry Uppsala University

UPPSALA
UNIVERSITET

Dr. Abigail K. Barker
Assistant Professor
Dept of Earth Sciences,
Uppsala University,
Villavägen 16
SE-752 36
Uppsala, Sweden

ECORD
Science Support & Advisory Committee
ESSAC Office
Alfred Wegener Institute for Polar and Marine Research
Am Alten Hafen 26
27568 Bremerhaven
Germany

22nd March 2011

Letter of support for Börje Dahrén

Dear Sir/Madam,

It is my pleasure to write to you in to recommend Börje Dahrén for an ECORD grant to support his research into the composition of the continental crust beneath the Faroe Islands. I first met Börje Dahrén on my interview visit to Uppsala University, where as a bachelor student he had shown great potential and was already integrated into the petrology research group. Börje continued to pursue his MSc research project with the petrology group and was awarded a PhD stipend to pursue research at Uppsala University with Prof. Valentin Troll and myself as supervisors, commencing in September 2010.

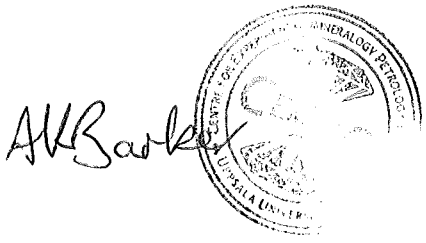
Börje's work as an MSc student continued to demonstrate his eagerness and ability to excel in his studies resulting in an outstanding thesis. His MSc thesis has led to two conference contributions and a manuscript that is currently in revision and expected to be published in "Contributions to Mineralogy and Petrology" in the near future. Furthermore, Börje's scientific

talents have been recognised by the award of three scholarships, one of which was a prestigious Uppsala University competition.

Samples of crustal lithologies below the oceanic basalts of the North Atlantic Igenous Province, from drill cores offshore East Greenland, will make a crucial contribution to the research project and success of Börje's PhD. The project combines the application of cutting edge petrological and geochemical methods with a novel approach to investigating crustal end-members. The outcome will be highly relevant to research in magmatic processes as well as understanding the sub-basalt structure of the Faroes continental crust, in which the hydrocarbon industry are interested. The goals are feasible and appropriate for the time schedule of the ECORD grant as well as the PhD research project.

Börje Dahrén has made a highly promising start to his PhD studies, and with an already emerging publication list, I expect Börje to be an excellent young researcher. Börje's application for an ECORD grant is supported by my highest recommendation.

Yours faithfully,



Abigail Barker, MSci, PhD
Assistant Professor, Uppsala University