Fourth North East Atlantic Meeting, Durham, 27-28 September, 2018

Venue: 83 New Elvet, Elvet Riverside 1, room ER154

Agenda

Wednesday, 26th of September

19.30 Dinner in local restaurant (self-pay). Venue: Tapas Factory, 14 Elvet Bridge, DH1 3AA

Thursday, 27th September

08.45-9.00	Welcome/Introduction	Gillian Foulger
09:00-09:20	Summary of our current working hypothesis for formation of the Greenland-Iceland-Faroe Ridge	Gillian Foulger
09:20-09:50	What are the oceans made of?	Laurent Geoffroy
09:50-10:10	Temperature & what we need to do next	Malcolm Hole
10:10-10:30	Iceland - What lies Beneath?	Jim Natland
10:30-10:50	North Atlantic orogenic belts and inheritance	Ken McCaffrey
10:50-11:10	Intraplate deformation	Randell Stephenson
11:10-11:30	*Break*	
11:30-11:50	Formation and elimination of transform faults and fracture zones on the Reykjanes Ridge: Implications for hotspot models	Fernando Martinez
11:50-12:10	Where we currently stand and future research	Christian Schiffer
12:10-12:40	Thermo-mechanical Wilson Cycle models of the North East Atlantic	Kenni Petersen
12:40-13:00	Questions to a continental margin	Dieter Franke
13:00-14:00	*Lunch*	
14:00-15:30	Planning of future research & proposals	Chair: Gillian Foulger
15:30-16:00	*Break*	
16:00-17:30	Planning of future research & proposals	Chair: *to be decided*
19.00	*Workshop dinner (complimentary). Venue: Restaurant 17, 17 Elvet Bridge.*	

Friday, 28th September

09:00-09:15	Structural elements on the Faroe Platform area	Jana Olavsdottir
09:15-09:30	Fingerprinting structural inheritance: styles and expression in rift systems	Thomas Phillips
09:30-09:45	Title to be announced	Scott Jess
09:45-10:00	Discussion of presentations	Christian Schiffer

10:00-11:00	Planning of future research & proposals	Chair: *to be decided*
11:00-11:30	*Break*	
11:30-13:00	Planning of future research & proposals	Chair: *to be decided*
13:00-14:00	*Lunch*	
14:00-	Free discussion	

List of participants

Foulger	Gillian	g.r.foulger@durham.ac.uk
Franke	Dieter	Dieter.Franke@bgr.de
Geoffroy	Laurent	laurent.geoffroy@univ-brest.fr
Hole	Malcolm	m.j.hole@abdn.ac.uk
Jess	Scott	r01sj14@abdn.ac.uk
Martinez	Fernando	fernando@hawaii.edu
McCaffrey	Ken	k.j.w.mccaffrey@durham.ac.uk
Natland	James	jnatland@rsmas.miami.edu
Olavsdottir	Jana	jana.olavsdottir@jardfeingi.fo
Petersen	Kenni	kenni@geo.au.dk
Phillips	Thomas	t.phillips13@imperial.ac.uk
Schiffer	Christian	christian.schiffer@durham.ac.uk
Stephenson	Randell	r.stephenson@abdn.ac.uk

Possible future avenues of research (circulated before the meeting)

Marine work

1. Seismic surveying on the GIFR to look for any embryonic axes of seafloor spreading.

   There is need for a deep-penetration seismic reflection survey from Shetland to Greenland all along the GIFR before any drilling, as well as one line from Hatton to SE Greenland across the whole oceanic domain. Unfortunately, the ION-GXT NE Atlantic project is more focused on sub-basalt imaging for petroleum exploration

   https://www.iongeo.com/Data_Library/Europe_and_Middle_East/Northeast_AtlanticSPAN/

   Do we have the technology to do this via academic channels?

   Some companies such as *Geology Without Limits* propose technology to get good crustal models and they will work on scientific projects for a reasonable price.

   What about the BGR?

2. New aeromagnetic data all around the GIFR and south Jan Mayen are needed.

3. Some seismic lines SW of the Faroe Plateau are missing.

4. Magnetic and seismic surveying of the areas between Rockall Bank and the Faroe Islands, and at the west end of the IFR is poor. New data and surveys are required to investigate whether the magnetic lineations represent true oceanic chrons or rifted continental crust and basin, affected by magmatism.

Numerical modeling

5. Vertical motions. Kenni's model implies that recent melt formation should be near the continental margins on either side of the basin and not beneath Iceland. What isostatic uplift is predicted by this model as the old lithosphere is removed but the crust is thinned very little. Uplift should be quite large.

   Areas beneath Greenland and Scotland should be undergoing significant subsidence due to outflow of continental crust. Should be possible to do a rough estimate by simple volume conservation of continental crust needed to supply the GIFR and subtracting this from the Greenland and Scotland margins.

6. Why does the GIFR sit at the apex of a ~ 3000-km-long bathymetric/geoid high that stretches from the Azores to the JMFZ? Does this correspond to Caledonian, and possibly Hercynian, slabs? Can this be investigated?

7. Three-dimensional thermo-mechanical modeling of breakup across the Caledonian western frontal thrust and formation of the GIFR (Kenni/Christian?).

8. Finite-element modeling of stress associated with the rifting history of the GIFR and ridges to the N and S (Beutel/Foulger).

Tectonic studies & analogous areas

9. Development of a region-wide tectono-magmatic comparison through time is the next step for understanding the coupling of different sub-regions. A follow-up paper utilizing the ideas developed in the ESR papers as a basis for analyzing the sedimentary response around the margins of the NGS is a natural way forward. Study how diachroneity in the breakup process is reflected along the ocean margins including analysis and comparison of which unconformities reflect regional events and which local, thus casting light on details of the diachronous breakup (LGon/Martyn).

   Assuming that breakup is not instantaneous can help to understand basin evolution. Can be done between Norway and Faroe Islands but the conjugate aspect is more difficult to constrain due to lack of data or difficulty accessing existing data.

10. Re-interpret the Davis Strait and JMFZ in terms of the new GIFR model.

11. Conducting more comparisons between the NE Atlantic region with other regions worldwide? This could justify field trips to analogue locations including Italy and Greenland.

12. Study the magmatism and extension rates at rifted margins: An extraordinary injection of hot magma into a rift at the time of break-up is not necessary to form a magmatic margin, or to cause fast break-up. However, such arguments are hampered by missing data. The collection and presentation of well-constrained age data from conjugate margins remains one of the most important future goals for extended margin studies (Lundin et al., 2018).

13. We have to find a link between break-up related Blosseville Kyst inner-SDRs (and probable outer SDRs) and the initial Kolbeinsey events (LGof).

Volcanic margins

14. New estimates of magma volumes are required, or at least the error bounds estimated.

Iceland

15. Age dating in Iceland to look for old crust.

16. Geodetic work: Possible geodetic studies to look for diffuse stretching of Iceland overall, beyond the rift zones and intervening areas that are likely deforming by distributed bookshelf faulting.

17. The hypothesis that continental crust underlies the GIFR needs to be tested further. How can this be done?

    a. Drilling in Iceland?
    b. Drilling on the IFR?
    c. More seismic work?
    d. Other marine geophysical work?
    e. Targeted geochemical or petrological work? Is there any way of mapping lower-crustal petrology from the geochemistry of surface lavas? What about the "NS geochemical asymmetry" of Iceland? There are plenty of data available but we have a new theory and maybe no-one has looked at the data to see how it fits with this.
    f. Resurrection of the zircon work in Iceland?
    g. Comparison of Iceland geochemistry with other basalts that have erupted through continental crust.
    h. Potential field modeling.

18. Can a more detailed correlation of tectonic shifts/ridge jumps in Iceland with RR propagators be achieved, e.g., by more structural geology work in Iceland?

    This can be done locally. However, most of the upper crustal structure of Iceland is hampered by the covering of recent lavas. This gives the impression of a poorly tectonized area whereas windows in the deepest valleys show a quite different history

19. Are the reported Archaean and Mesozoic zircons found in Iceland real? This result has been reported in several conference abstracts but verification of the results, and possible mapping of the distribution of such zircons throughout Iceland has frustratingly not been forthcoming now for over a decade. Verifying or negating these findings could contribute to mapping the distribution of continental lithosphere beneath the GIFR.

    Onshore drilling is an option but where and how deep would be necessary to reach continental material?

<u>Reykjanes Ridge</u>

20. Why did the region south of the GIFR start off with orthogonal spreading, change to stair-step at about the same time as a major counter-clockwise rotation in the direction of extension, and "iron out" the transforms by small propagators within the plate boundary zone that take off from Iceland at the same time as major rift relocations there? The passage of those rift tips are associated with transient formation of slightly thickened crust, resulting in a pattern of chevron ridges and troughs about the RR.

    It is difficult to avoid the fact that initiation of these propagators was closely associated with tectonic reorganizations on the GIFR. Fernando's paper proposes solutions that need to be tested somehow. The times of the reorganizations need to be pinpointed. Randell is working on this by using inversion structures to pinpoint

reorganizations.

Need to define precisely what magmato-tectonic processes control the functioning of such propagators in slow-spreading environments.

21. Investigation: the spreading segments and transform offsets were smaller to the north, approaching the GIFR–part of Fernando's upcoming cruise. The plate motion change was essentially uniform along the previous linear axis but how this change was accommodated varied systematically with distance to Iceland. Why transform faults and ridge segments become shorter toward Iceland and why they were more quickly eliminated near Iceland are two issues the cruise will be looking into. Gravity and depth (multibeam) measurements will be used to estimate crustal thickness changes along the "mantle gradient" away from Iceland.

22. There is no well-resolved evidence for slow rotation of the Euler pole of RR motion at present, as a possible explanation for the oblique Reykjanes Ridge. This will be investigated as part of Fernando's cruise next year by fully and accurately mapping the Bight Fracture Zone from its inception when Labrador Sea spreading ceased. This should well-constrain the subsequent plate motions and determine if there are "leaky" sections.

Passive seismology

23. Passive seismology in northwestern Scotland (proposals in development) – with Christian and Aberdeen to reveal upper mantle dipping structures.

Drilling

24. Deep sea drilling on the outermost part of the insular shelf, east and west of Iceland, to try and determine the age of the oldest igneous rocks associated with Iceland (Stoker/Lundin). Needs to be preceded with appropriate geophysical surveying, however.

25. Drilling in Iceland?

26. Drilling on the IFR?

Additional new work
Drilling on GIR?
Geophysics on region of tip of Aegir ridge.
Ken: Model inheritance when complicated not simple

Notes taken on talks and discussions

Gillian: The NA Workshop series at Durham was held to bring together the latest knowledge and assemble it in a holistic model for the tectonics and volcanism of NA which the attendees felt was lacking. As a result of these workshops, an ESR special issue of papers was invited.

The 4th NA Workshop was held 27th - 28th September, 2018, at Durham. The purpose of this workshop was a) to recap on the contents of the ESR Special Issue papers, which were shaped by the earlier cross-disciplinary workshops and discussions, and b) to develop conceptual future projects and research proposals that will fill in gaps in our knowledge and data and test our new paradigm.

At the time of the meeting, 3 papers had been submitted to ESR and 4 or 5 are shortly to be submitted. The deadline for submissions is 30th November, 2018.

Gillian talk: Gillian summarised the content of the ESR Overview paper, which had been submitted the day before.

Laurent talk: Access to deep seismic from companies and fieldwork in Greenland. UCC on margin east of Greenland. Close to normal thickness Greenland crust but still see huge magma invasion. Precambrian with 40-50% mafic dykes. Very confident remnant of CC under GIFR. Must distinguish the continent ocean transition and the CO boundary. Transition is wide, extended area between unextended CL and OL. COB is precise limit. Peron Pinvidic 2013 paper shows HVLC interpretation. Magnetic anomalies are not diagnostic of oceanic crust. Can have accretion type behaviour under outer SDRs but only in upper crust. C21 is OK in Atlantic but not earlier. Seismic anomalies cannot be proof for oceanic crust. What kind of crust beneath outer-SDRs? So how do we define OC? Linear anomalies? seismic velocities? constant thickness? chemistry? Sci Reps paper a few years ago. Exceptional situation offshore Brazil. huge thickness of inner SDRs with underlying LC1 and LC2. LC1 is very ductile. LC2 is deep lower crust with subhorizontal layers, probably mafic, jump in Vp from 7.4? to 7.6? across Moho. Rosetta stone for offshore passive margins - Laxmi basin. Pelotos basin Brazil? another example

Malcolm talk: problem finding samples with olivine and glass in equilibrium. If olivine on own get nice line in T/Fo space. If other phases crystallise becomes more complicated. W Greenland rocks have too much olivine for it to be in equilibrium with glass. Clear Iceland and Greenland picrite rocks not in equilibrium. Explanation of olivine control line modelling. There are a lot of T estimates published that are too high and should be rejected. Pillow basalts from Disko and Baffin. Olivines in equilibrium with plagioclase so are not giving reliable Ts. Bottom line. Disko - 1500, Iceland < 1450, probably nearer 1400. Ol-sp. Assume equilibrium between sp and olivine. but spinel often included with olivine. Tortugal Tp up to 1700! Al in olivine about 100 C higher than expected for composition of whole rock. Rates of magma generation i.e. crustal thickness and Tp. T required for 25 km, would need 1550 (dry). If more fusible, e.g. wet, can get lower Tp's. Looked at various lithologies. Damp peridotite pus pyroxenite, at 10-40% and 1450 get 25 km. Conclusion: can generate 25 km at 1450 but not more. So

must be pre-existing CC because crust is 40 km thick. Short bursts of high T magmatism, extending upper levels, then cooling. Fusible compositions melt first - recycled Caledonian slabs but need not be deep. After first burst of magmatism, through time T decreases and maybe can be seen in Prince of Wales Bjerge. Final slide. Generation of continental flood basalts by decompression melting of internally heated mantle Geology 43, 311-314. Suggests warm mantle because insulated for long time and then when. Christian: remarks Tps calculated are much lower than traditional estimates of 200-300 C.

Jim talk: MORB parental array can be explained by bulk lithological heterogeneity of the mantle plus a small range in melting temperature. Iceland - two or more different sources. Iceland blows apart at Iceland, any parameter you look at. map, Ti8 vs lat, Na8 vs Lat. Huge spot. Red high-Ti that have no counterpart in the MORB array. Subcontinental crust indicated. Sr, Nd, Pb, He no matter what you look at Iceland is crazy. Do not fit with MORB array. Pacific plateaus on the other hand, all show MORB array. Deccan, Karoo, all show same as Iceland. Summary, instead of one source, an array of peridotites and extends into the lower crust. If 1200 C melt enters crust, will remelt stuff in the LC. So do not need mantle heterogeneity to explain the heterogeneous source.

Main message. Iceland and WGreenland pet/geochem has been radically misunderstood for three reasons. Ignores magma mixing, assumption of uniform source became only way of understanding basalt petrology, and ignores transit through mantle and curst.

What lies beneath? Refractory SCLM beneath RR, KR, Iceland. At Iceland additionally some remnant of isotopically distinct CC probably gabbro/eclogite with (1) pre-existing gabbro and (2) Si rock. Melts from 1 invade 2 and produce partial melts of 2. Some mixed rocks erupt as ferrobasalts and ferroandesites and entrain rhyolites that form shallow composite dikes.

Discussion: mode of advection different under Iceland. Malc: Faroe, high-Ti, then break in magmatism and then low-Ti. In Iceland more of an overlap. Suggests different style of magmatism.

Ken talk: Imaging mantle scars Heron et al in prep. Set up model to understand bend in Nag orogen. If mantle scar that follows trend, how would that influence trend. Slabs embedded in crust and mantle scar. Result, using Aspect modelling software, shows rifted plate produces right step that replicates what is seen in DS. Ken has studied geology in Greenland for many years. Structure in crust not enough. Has to be in mantle lithosphere. In Peace et al, Basin Research. Last few days Nag/CFT confluence, and Nag/Rinkian confluence intersect. Further west in Laurentia crust v complicated mess of orogenic belts. Shows mantle scar e.g. Trans-Hudson Snyder et al recent paper. If we can see these mantle scars could cause stepping architecture. Separate work on Rinkian orogen. Many models, some think part of Nags but Ken current work suggests reactivated Paleoproterozoic reactivated in NeoProterozoic? Rinkian 1.9-Ga-ish. Grogott & McCaffrey (2017). Grogott honorary prof in Durham. New dates published suggest may be older. Now thought to be separate orogen from Nag. Moving N, same meta grade so possibly moving along Rinkian and not away from its source. could model two orogens - new work. What happens when parallel slabs. North China cratons can be very complicated. Windley et al 2010. Kenni/Christian paper Gondwana Research 2016.

Question: How do mantle slabs - scars - affect subsequent rifting. Where next? More mapping and modelling, do mantle scars focus or deflect lithospheric stress, investigate places where scars intersect at high angle or double up or en echelon, do they explain microcontinents? What happens when plate vectors change. Discussion: Hudson "scar" has been there for 2 billion years. How old is oldest? When did subductions start? Fernando - important point that slabs are in mantle lithosphere and thus can be transported. Has been a problem in the past that subducted slabs are though to be left behind by moving plates Malc - Also, eclogite which is fusible and changes whole T/melting profile. Eclogite reacts with peridotite forming pyroxenite so slab sill be preserved though altered. Christian: Tom: Free forming rift, not pinned. Laurent: Doesn't slab sink? Christian, once orogeny stalled, remnants left in lithosphere.

Randell talk: Basin inversion involves tectonic scale inversion. Try to time these suckers. Peter Ziegler with Shell support published atlas 1987 reconstruction with interplate inversion structures. Some info wrong e.g. timing of Eureken orogeny. Randall wants to make update including Alex using GPlates. More offshore mapping has been done. Interplate inversion been done. Peter did not look at Baffin, so room for updating. "Plate trauma". If we have scars must have trauma. Nielsen, Stephenson & Thomson 2008 Nature paper linked plate trauma in Tethys belt led to relaxation of stresses permitting Atlantic to open. Stresses predicted by plume impact inconsistent with observations. Figure of Christian/Soren in book "Intraplate Earthquakes" stress from potential energy variations. stresses from crust thickness variations from bathymetry and crust thickness variations. conclusion that stress related to thickness etc and slab effect relatively local and does not extend into plate. Intraplate stresses generated by plate scale potential energy effects rather than plate boundary effects. Where intraplate deformation occurs it is inferred that a. the plate boundary stresses constructively interfere with those from background potential energy variations and b. this net stress field must be favourably orientated wrt preexisting structure in the lithophere. Current paper. 3 musketeers - Alex, Christian and Scott.. End Palaeocene many things synchronised. Basin inversion, linked to alpine/Tethyan plate boundary, timing not compatible with plume. 40 Ma widespread teconic events throughout Europe. Eurekan orogeny Alpine-Tethys belt linked to Arabian plate-Eurasian collision. both Eurekan and greater Caucasus orogens are mega inversion zones. Early opening of ocean hapened at time of significant lithosphere shortening on both sides of the bounding continental plates. shortening to the point where core complexes exhumed. 15 Ma: synchronous but less well documented inversion in Miocene. Alpine Tethys plate boundary reorganisations linked to E European-S Eurasian region. Geopotential is dominant stress source in intraplate regions. Do not include superposed stress derived from convergence/collision processes. Trauma from plate boundary derived stresses geologically short lived and relaxed intraplate deformation. Final outcome. - to understand NA plate boundary evolution model tectonic evolution of the Alpine-Tethys plate boundary.

Fernando talk: recap of opening history and orthogonal/rift-transform/orthogonal story. How plume model explains this, "T only variable" story. Phipps Morgan and Forsyth 1988 JGR? modelling of horizontal mantle flow across ridge tips. Fernando modelling found 30% less effect per km. Less upwelling per km of ridge if there are en echelon segments and not continuous. Gripp and Gordon 2002 suggest W motion of plate boundary wrt underlying asthenosphere. TZs then ironed themselves out. Ridge is

now as if it were never segmented. V organised progressive reduction in TZ offsets with time. Very organised and regular and not consistent with a high-T theory. The bathymetric gradient from Bight to Iceland has always persisted. MAR bathymetry shows variations clearly related to local effects e.g. 10-30 deg N. In Iceland very large gradient in mantle properties e.g. water. How could the ridges form without a plume?

Christian talk: Overview of his inheritance paper. Exercise of writing review paper has been very good and helped understanding of NA. Because diverse co-authors, will only show most important take-home messages. Few examples. Map showing overview with exhumed mantle, SDRS. Suggests mantle shear fabric at 20 deg clockwise from Caledonian and controlled breakup. Early rifting topography driven, orogenic axis parallel. Later rifting, controlled by mantle oblique fabric.

Kenni talk: Laurent pointed out upper crust problem not continuous across ocean so how is that explained? Also need to put magma into system. Kenni: Need to add that. Can melt reach surface? Have tried that. EDGE convection: Can cratons extend to surface i.e. can it be recycled to underlie Iceland. Malc: 2 widely separated melt production areas in Kenni model. W Greenland Danian 62 Ma and over on E side conjugate melting. Could this be explained by dual melt zones in Kenni's modelling, which later focuses on one side. What would happen if box doubled in width?

Dieter talk: Questions:

1. What is breakup? It is not well defined. When rifting first started, or when it is 100% oceanic spreading all along the margin? Papers should clarify. Breakup of crust localised melt centers. Fernando: Lithosphere is constantly regenerating so are you talking about old or newly forming lithosphere? Christian: breakup = when 100% new section of lithosphere is formed. Laurent: when strength in the extending material drastically reduces. and CC disappears. Fernando: a diachronous process defined locally. Christian: continental breakup, lithospheric breakup,

2. The origin of volcanic rifted margins? Dore, Lundin showed VRMs not related to extension rate. Why no significant magmatism during Paleozoic/Mesozoic rifting phases? Scott: large volume magmatism in N Sea in Mesozoic?. Christian: recent paper Variscan involved. Lithosphere under Caledonides depleted but enriched under Variscan. Dieter: Why magmatic pulse then? Laurent: No strain rate info. Møre? Mesozoic strain rate v. small. During Tertiary higher rates and high thermal gradient. Fernando other explanations. How thick lithosphere? Thick lithosphere would take more extension. Thin would react quicker. Also rift width would affect thermal gradients. Laurent: Vøring basin very narrow. Jana: in some areas magmatism more voluminous than at breakup time. Hiatus of ~ 1 Myr.

Development of VRMs? One theory that extension stops once magma comes in. Gillian: suggested magmatism a passive reaction to lithosphere extension. Dieter: this is the opposite point of view from "theirs". Gillian: Who are "they"?

3. Post-breakup subsidence? Continental margins do not subside. Instead margins uplift.

4. What drives the plates? Why does Greenland move N in early Oligocene. If PT driven model, then Pacific subduction might be reason.

Discussion of research proposals

Laurent up first because he has to leave by 10 am Friday. His research ideas:

1. Sigma profile showed some of best magnetic profiles WE Greenland, mag anomalies basement ridge covered with basalts, continuous S to N. Q Do we have continuous sliver all along Greenland ~ 150 km from coast? Is this continental? It corresponds to mag anomaly ? Sediment thickness ~ 800 m. Fernando - V-shaped ridges? So did they start early on in seafloor spreading? Were they then obscured by reorganization of ridge? So are they volcanic? Laurent: seems to be chaotic contact on flank of ridge. Apply for drilling in Atlantic - this would be good target. Dieter: Sigma lines - what is the result? What is below? This was sigma 2. That and sigma 1 are fully processed. Sigma 3 on the ridge is not. Can Jun do that? Gillian to email him. **[Note: Gill has emailed him]** Fernando: possible interpretation of ridge as V-shaped ridge they would have to be diachronous wrt anomalies. Is this ridge diachronous in this way? Need analog for GIFR and Iceland. This would be a good place to look
2. Back to profile from Brazil? showing inner/outer SDRs and continent-ward dipping fault along which decoupling can allow the upper layer to slide over the lower layer. The LC does not have to move in order for the UC to stretch. Can then just fill up the space produced with magma. One place E of Greenland like this with magma in the fault zone. There, friction does not apply. Large faults can move without seismic activity. Jim: What more to do? Laurent: Nothing - just taking more time to present research :-) Fernando: Normal interpretation = volcanic intrusive contact between SDRs and oceanic crust. To finish, figure of ocean off SW Africa. Laurent does not believe anomalies are oceanic crust.
3. Moving to the region E of Iceland, Basement ridge is NS extensive In Iceland need reworking of structure to better map flexures. Some faults are known. Need to reinterpret tectonics of Iceland.
4. LGon plan. long profiles along the GIR and IFR and two profiles to the south so oceanic and ridge structures can be compared. Two ESR projects already funded up to 5 million Euro. 2-ships. Dieter much experience in hiring Russian ships. Difficult process. hire Russian ships. SMRG hired to do seismics state of the art. Cost - varies each month depending on oil prices maybe 20,000 Euro/day or 50,000 Euro/day depending on oil price. Dieter from government organisation so cannot do exactly what likes. Must convince bosses. Could argue that could change view of N Atlantic. Possibly could do that by saying of interest to resources. Jana: Ridge/basin structure in Shetland basin likely continuous into Faroe Isl. and IFR. Jana Kimmeridge clay on land. Possibly FS basin and Rockall basin extended further NW than previously thought.
5. Dieter: Institute must do work relevant to resources but not directly commercial. Laurent: How much would work with Russian with everything hired cost. Do not have obs. Only streamer with everything provided. With 1 boat, 2nd one smaller with compressor and airgun rails. maybe cost another 20,000. Would 2 million be enough.
6. Jana: Also perpendicular line across ridge.
7. Should be multidisciplinary and also mention drilling. Must be different,
8. could do deep seismic reflection in Iceland. Already have older data. Petrobras did work in Djibouti but now collapsed because of political scandal.

9. Malc: if talk to right people in oil companies can get quick decisions on whether money available.
10. Talk with Dieter on bridge. German funding situation. They could provide all the geophysical equipment and ship but does not have OBS's. Dieter would need to convince his boss. 75% likelihood of getting support!!! He is optimistic he could sell it. Would not head up proposal himself but happy to contribute element. Would greatly help to have international collaborations and matching proposals from other sources.

first half of discussion I missed. Gillian recapped experiment - 2 seismic reflection lines along GIR and IFR and seismic reflection across all Iceland. 2 subsidiary lines in ocean to south. One transverse line across IFR. Laurent to lead. proposal to ESC. Should be interdisciplinary. Ask all colleagues for letter-type statement of support plums description of what they think is important and what they would do. Dieter can provide technical input. Laurent cannot. Laurent and Dieter to meet in twosome

Dieter separate experiment to run lines from known continental JMMC to Iceland platea . Can run seismics. would need others to do gravity, magnetics, OBSs

This is separate project, 75% chance of success. 32-berth ship, 14 berths needed for crew and technicians, rest for scientists. Volunteers please. Must be proposed by August 2019 and would be done in 2022?

Needs Sigma1 line fully interpreted. Aberdeen lots of masters students could do it. Gill to mobilise Jun. **[Note: done]** Maybe Aberdeen could provide students?

International continental drilling project, dredge samples along ridge, IFRMR next door to Laurent. Dieter: evidence for outcrops? Any high res bathymetry. Yes Iceland has good data down to CGFZ.

Everyone to write ½ page of support and suggest what they could bring to project.

Christian: Would more magnetics be useful? If grant big enough could aeromagnetics be done? Maybe LGon advise?

OBS. UK pool joint with Southampton and Durham. Christine Peirce still in charge. ~ 50 obs. Laurent has ~ 15, Dieter none, Danish pool ~ 15. LGon might want to do magnetic survey. NGU does not have money. Fernando: some seismic and multibeam survey surrounding Iceland platform from 10 years ago. Laurent: Is a map available? Ask Peter Vogt about US navy old magnetic data from RR **[Note: Gill has emailed him]**.

Malc: Many petrological issues, do not need more data but need to write. Need to re-evaluate Iceland petrology in terms of RR, isotopes, mixing models. Need to apply for student and post-docs. Dieter: Iceland data a problem need to re-interpret Sigma1 line. So that needs. Gill to inquire with Jun into re-processing these data **[Note: Gill has emailed him]**.

Ken could contribute modelling of deformation on GIFR. is also studying Rinkian. masters student are abundant. Malc can also propose masters students. Scottish student pay ½ fees in England and no fees in UK.

Kenni could support Laurent's project with inverse problem run model. Need to look how unique models are. What is meant by UC and LC? How can infer? What can be measured. What data can be got? If we need to propose an hypothesis, what data are needed to help modelling? What new info could help modelling? How can Vp Vs help? Kenni salary support needed - 3D models. Randell recommends driving toward what is known present-day. Christian: How important are lithospheric properties? Cannot model too much detail.

Laurent: 2 scales, mechanisms. What is observed is deformation with ballooning of the crust. This set properties of system. Maybe need higher resolution. May be good to stay in 2D.

Fernando: Diffuse deformation or propagating ridges. Are GIR and IFR deforming?

Dieter shows film. Hydrophones in yellow streamer. Can extend to 600 m. Airguns. New proposal. Kai Bergler will likely lead because need younger people to be inducted. A number of people needed on ship. 12-14 people manage multichannel. Page limit 20 pages for proposals. Have to explain why need lines, what each line will do.

Long term OBS's. If UK proposal to retrieve OBSs with small vessel and proposal would show international work and would greatly help. OBS deployment. Possibly surround Iceland with OBSs. Gillian: have to be sensible do-able objective. Teleseismic tomography if a flawed method and won't help much. Christian: surface waves and noise tomography. Gillian: That is more sensible approach.

Jana talk: Almost 99% of the Faroese area are covered with volcanic material and at present no well has manage to drill through the volcanic sequence in to the sub-non-volcanic (and basement) material, even though that was the purpose of wells. To drill a well that manages to drill through the volcanic cover and into the underlying non-volcanic strata and basement, an onshore well is the least expensive way forward. An onshore well will cost 1/20 of an offshore well. To prepare such an onshore well it is important to predict what kind of geology the well will drill through on its way down to basement at a particular location

A structural map exists over the Faroe-Shetland Basin (FSB), where the horsts generally are NE orientated. In the Faroese area of the FSB there are nine wells of approximately 3500-4500 m depth that do not penetrate through the volcanic sequence. At present no structural map exists of the Faroe Plateau, Munkagrunnur Ridge and Iceland-Faroe Ridge areas and there is only one deep well: the Lopra-1 well which drilled through 3500 m of volcanic material in 1981/1996 without penetrating through the sequence. Jana wonders why the structure of FSB does not extend onshore, but it is most likely a result of volcanics at the sea-bed making the reflection seismic data of poor quality. There are areas of uplift/inversion (of sub-basins? as in the FSB) to the NW and S on the islands and heavy erosion of these areas has occurred. Zeolite fission tracks and structural studies confirm this. The erosion products are deposited in the adjacent shelf areas.

At present the volcanic sequence is mapped in detailed onshore the Faroe Islands, with a total volcanic stratigraphic column of >6 km. Petersen et al. (2015) identified the onshore equivalent of the Prestfjall Formation (~boundary between pre- and syn-

breakup volcanic strata) on the seismic data in the FSB. Syn-breakup volcanic strata are located E and SE of the Faroe Platform. Pre-breakup volcanism lasted much longer than syn-breakup volcanism. Offshore FSB high gravity values are observed at ridges/horsts while low gravity value areas are identified at sub-basins. Efforts to extend this information onshore suggest the low gravity areas occur where refraction seismic data show large depths to basement and vice versa. Depth to basement on the Faroe Platform ranges from 2 to 8-9 km. The Icelandic rig Thor can at present drill to 6000 m depth.

Ken: what is basement? Prob crystalline - Lewisian gneiss. Ambient noise tomography publication by Samarco et al. (2017) show that the basement depths range from 3-9 km km in the Faroe Platform area. Interesting interpretation down to 10 km of the basement structures in the Faroe Platform area. Some strange artefacts but also some possible correlations with surface observations. Jana is trying to do structural interpretations to prepare for drilling to reach below the volcanic cover onshore. Structurally there seem to be 2 directions of extension, one NE-oriented and the other NW oriented. The NE one seems to have stopped at approximately breakup time. Maybe Faroe Islands are located where 2 structural directions meet.

Christian: If E Greenland reflector and Flannan joined up then would exactly go through Faroe Isl. on the NE trend. Ken: NE early extension direction which then changed to NW. Malc: full 3D seismics running down lone NE-oriented right across FSB. Maybe underlain by mafic continental crust. Paper in preparation will circulate when ready. Jana has also paper to be submitted regarding the volcanic coverage in the Faroese part FSB. Lavas from FSB like Iceland. Malc proposed melts drained through continental LC. maybe LGof's profile extend across FP and into FSB. Lots of data possibly available - masses of existing commercial data. Both pre- and syn-breakup material. Malc: geochemistry is a slam dunk for continental material in basement.

Thomas Phillips talk: PhD research Imperial. Was looking at how onshore structure was related to offshore structure off SW end of Norway. Can extend Devonian shear zones offshore. Extended dyke swarm and Tornquist zone. Dykes cross cut layers but do not offset. Talk on structural evolution of Tonquist zone. Links dykes to Scottish dyke swarms.

Scott Jess talk: Thermo-chronology. How surface rocks cool though time. Trying to collate all thermo-chronology data from N Atlantic. Lots from all around the margin of Norway, Britain, Greenland and Svalbard. Approach taken is to include sufficient thermal events to perfectly describe the data. Fission track dating does not give single event. Not true. FT data show the final result of whole thermal history, not particular events. Claims can "rule out yo yo model of Japsen" which involves exhumation in 3 phases, 34-Ma-ish, 11-Ma-ish and 4-Ma-ish Ma (??) Christian: What is your model? Monte-Carlo model by Kerry somebody(?). Looks for best fit modal. Christian: models should show what the data allow and what they exclude.

Dieter's proposal: Figure showing proposed lines. Start at S JM ridge to Iceland with NE orientated lines and some transverse lines. Limited to 32 days so limited number of lines. Need to place them optimally. Time frame. Could start application next year. Circulate 2-page starting proposal to those interested. Deadline August 2019. If missed, must go for 2020. If make Aug 2019, cruise possibly 2021, more likely 2022, possibly

2023. MCS-BGR 6-km streamer, 50 litre airgun array, navigation, processing. Industry normally 80 litre airgun so 50 litre is small.

Needs:

1. OBS's UK pool - GRF, needs to apply, and operate them. They can be deployed on Dieter ship.
2. Dredging probably cannot be done. Jim, Jana, Malc to check if already available.
3. Magnetics: ask LGon to do.
4. Gravity - will be taken but needs to be interpreted. Probably should be interpreted together with OBS data.
5. Proposal needs to tackle questions - dense sampling, multiple methods, S-waves, joint inversion, sub-basalt imaging.
6. Ideas from colleagues needed.
7. Where deploy OBSs, possibly from JMMC to Iceland, or across IFR. Location of lines open. Key point to start in known continental at the S tip of JMMC.
8. Max number of OBS's on ship - the current UK ones are quite small.
9. Integration in international/national projects - support letters can help.

Dieter: What contributions can colleagues make.

Gill, Randall: will help in any way able - writing, organizing, for example.

Christian: passive seismic element, possibly involving Danish instruments. Would need Danish person, e.g. Kenni, to PI the application. Christian will co-ordinate. Retrieval of long-term deployment OBS's needed. A UK/Danish ship could be helpful.

Data interpretation? Dieter institute - typically usually collaboration with German universities to interpret. Maybe go for Aberdeen, Christine Peirce (Durham), and possibly German Universities to interpret. A plan needed for ~ 2 Ph.D. studentships.

Permits from Iceland probably easy. Jana: No problem with seismic work in Faroese waters

Kenni: Can apply for career grants **[Note: He has now done this]**, can make focused modelling proposal and can say this research group backing it.

Christian talk: LGon slides. LGon wants data high resolution aeromag on IFR S of his high-resolution area. Such an experiment would tell us if lack of chrons on IFR are due to poor data or not. Christian key research areas for passive experiments. N Ireland through Scotland and S Scandinavia**,** GIFR swathe**,** E Greenland N of Blosseville Kyst**,** JMMC**,** N LS/DS/Baffin Bay.

Figs showing Scotland proposal, and E Greenland proposed profiles. Scotland trace Flannen reflector. In E Greenland only one line so desirable to have two more, N and S of existing one

Another - surrounding Iceland with OBSs from Bight up to JMFZ and coast to coast. Could cover margins with stations. This would cover an entire shear zone with Ireland-Scandinavia experiment. Could look at shear zones. Would be interesting to look at shear zones with anisotropy.

Gillian R. Foulger

Durham, 31st October, 2018