Deep-crustal seismic study of continental rifting in the Newfoundland Basin

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The generation, timing and manifestation of magmatism are key factors controlling the development of both rifted continental margins and seafloor spreading systems, yet the evolution of the magmatic system during the transition from rifting to mature seafloor spreading remains one of the least-studied problems in plate tectonics. A type example of a magma-poor rifted margin, where a seafloor spreading system was slow to develop [*Jagoutz et al.*, 2007], is the Newfoundland rifted margin. We suggest that characterizing the crust and mantle on the outer part of this slow, magma-poor system would illuminate the magmatic and deformational processes associated the transition from late-stage rifting to mature seafloor spreading. New studies should include 1) very long-offset seismic refraction data and/or passive seismic data to constrain deeper lithospheric structure, and 2) coverage of the oceanic crust produced by the earliest oceanic spreading center with active and passive seismic data. Magnetotelluric and deep-tow magnetic data may also provide critical constraints on these processes.

The magma-poor rifted margin of Newfoundland was the target of the deep-seismic SCREECH study in 2000 and ODP Leg 210 in 2003. As a result, the basement morphology and seismic velocity structure are constrained along three dip lines by deep-penetration multi-channel seismic reflection data and wide-angle seismic reflection-refraction data. The SCREECH project resulted in three deep-seismic transect across the Newfoundland margin. Whereas the northern line (SCREECH 1) crossed the edge of Flemish Cap [*Funck et al.*, 2003; *Hopper et al.*, 2004], SCREECH 2 [*Shillington et al.*, 2006; *Van Avendonk et al.*, 2006] and SCREECH 3 [*Lau et al.*, 2006a; *Lau et al.*, 2006b] ran from the Grand Banks to the Newfoundland Basin (Figure 1a). SCREECH 2 and 3 both showed wide zones of thinned continental crust and a portion of exhumed continental mantle. It appeared that oceanic crust of normal thickness (~6 km) was not even found at the seaward end of these profiles [*Lau et al.*, 2006a; *Van Avendonk et al.*, 2006], which led *Tucholke et al.* [2007] to suggest that true oceanic crust was only produced here at the Aptian/Albian boundary, which lies seaward of SCREECH lines 2 and 3. The deep structure of SCREECH 1 appears quite different, with a shorter transition from thinned continental crust to normal oceanic crust [*Funck et al.*, 2003; *Hopper et al.*, 2004].

Recent work on the SCREECH data includes a new interpretation of strong laterally continuous seismic reflections in the deep sediments of the Newfoundland continent-ocean transition [*Peron-Pinvidic et al.*, 2010], which appear to be post-rift magmatic sills [*Karner and Shillington*, 2005] that represent a phase of late-stage magmatism in the Newfoundland basin. Unfortunately, these sills obscure seismic reflections from the basement beneath them [*Shillington et al.*, 2008], so the basement morphology is not very clear in the continent-ocean transition zone of SCREECH 2. Given that the basement appears relatively flat and void of prerift sediments along this transect, *Van Avendonk et al.* [2009] suggested that it was formed by a west-dipping detachment fault that exhumed deep-crustal rocks. An analysis of seismic converted waves [*Eddy et al.*, 2011, in prep] confirms that rocks from the continental crust and upper mantle are both exhumed in the continent-ocean transition zone of SCREECH Line 2.

The previous work conducted in the Newfoundland Basin forms a great foundation for future marine geophysical work on cold rifting. The along-strike change in structural style of the rifted margin between SCREECH 1 and SCREECH 2 may have its origin in preexisting structures and far-field stresses during the early phase of the rift [*Sibuet et al.*, 2007], but it is nonetheless surprising that normal oceanic crust appears to have formed sooner off Flemish Cap than off the Grand Banks [*Van Avendonk et al.*, 2006], while extension of the continental lithosphere appears to have commenced in the south, and propagated north [*Tucholke et al.*, 2007]. The contrast in structural style, and its apparent influence on the delivery of melts to the incipient spreading center, makes the area between SCREECH Lines 1 and 2 the best location for a comparative seismic study (Figure 1). This area was also the site of ODP Leg 210, during which Site 1276 and 1277 were drilled [*Tucholke et al.*, 2007].

Given the results from SCREECH, we would expect that the crustal and mantle structure varies both along margin dip lines and along-strike over distances of several 10s of kilometers. These length scales can be resolved most efficiently with regional 2-D seismic reflection and refraction lines, so we do not advocate a 3-D seismic reflection survey. In Figure 1 we illustrate a possible strategy (blue lines) for new marine seismic profiles that would target the structure of the margin in its rift-to-drift transition. Although the SCREECH project successfully imaged the crustal and uppermost mantle structure of the margin, the depth of serpentinization of the mantle in the continent-ocean transition zone is not always constrained. It is also possible that mantle-derived melts are not extruded to the surface during cold and slow rifting [*Bronner et al.*, 2011]. It is therefore an attractive option to acquire very long-offset seismic refraction data along dip lines over crust produced by the incipient seafloor spreading center in the Newfoundland Basin, in the same manner as during the FAIM experiment [*Gaherty et al.*, 2004; *Lizarralde et al.*, 2004]. Other key offshore data sets that could address these questions include passive seismic data, MT and deep-tow magnetics.

New studies of the rift-to-drift transition in the Newfoundland Basin would meet key objectives of the Geoprisms science plan. Mantle melts probably play a large role in the style of deformation. The process of continental breakup, and the role of mantle melts is still not well understood [*Tucholke et al.*, 2007]. The thermal state of the lithosphere during and after the rift-to-drift transition controls the subsidence of rifted margins, which creates the accommodation space for evaporates and sediments.

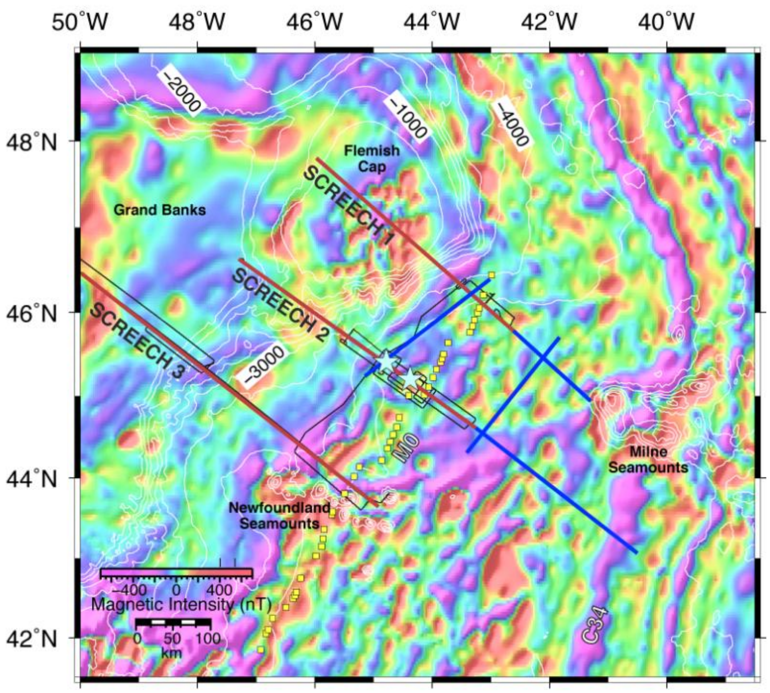

Figure 1. Magnetic map with existing (red) and proposed (blue) seismic lines at the Newfoundland margin. White contours represent depth intervals of 1000 m. White crosses mark ODP drill sites 1276 and 1277. Picks of magnetic anomaly M0, perhaps the oldest seafloor spreading anomaly in the Newfoundland Basin, are marked by yellow squares.

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