



THE NE-ATLANTIC SYSTEM

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The NE-Atlantic system represents the northward propagation of the Atlantic Ocean north of the Charly Gibbs Fracture Zone (Fig. 1). This region includes both continental and oceanic domains and experienced a long and complex tectonic evolution since the Caledonian orogen.

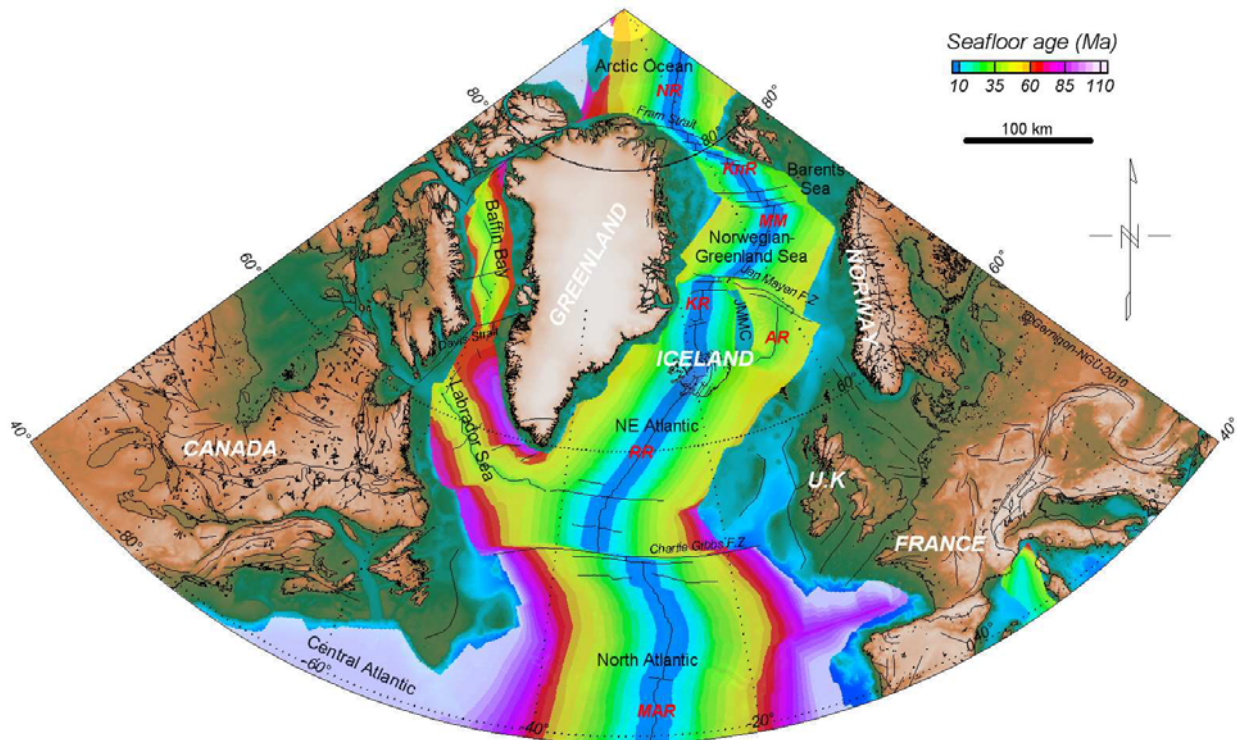


Figure 1: Main features of the NE Atlantic region. Seafloor ages after Müller et al. (2008), elevation grid after Sandwell and Smith (1997). AR: Aegir Ridge, JMMC: Jan Mayen microcontinent, KR: Kolbeinsey Ridge, KnR: Knipovich Ridge, MAR: Mid. Atlantic Ridge, MR: Mohn's Ridge, NR: Nansen Ridge, RR: Reykjanes Ridge.

During the Lower Palaeozoic, the Laurentia and Baltica continents progressively became a single continent (Laurussia) through subduction of the Iapetus oceanic lithosphere. The consecutive orogen formed the Caledonian fold belt extending from N-America to N-Europe by the end of the Silurian (Fig. 1). The Pangaea supercontinent was subsequently affected by the Variscan Carboniferous collision between Laurussia and Gondwana. These two orogens set the structural grain for later tectonic episodes and reactivation.

During the Devonian, the Caledonian belt collapsed under its own weight and initiated the earliest stages of a very long period of lithosphere extension between Greenland and Europe. This extension spanned, although episodically, until continental breakup in the Early Tertiary (Fig. 2).



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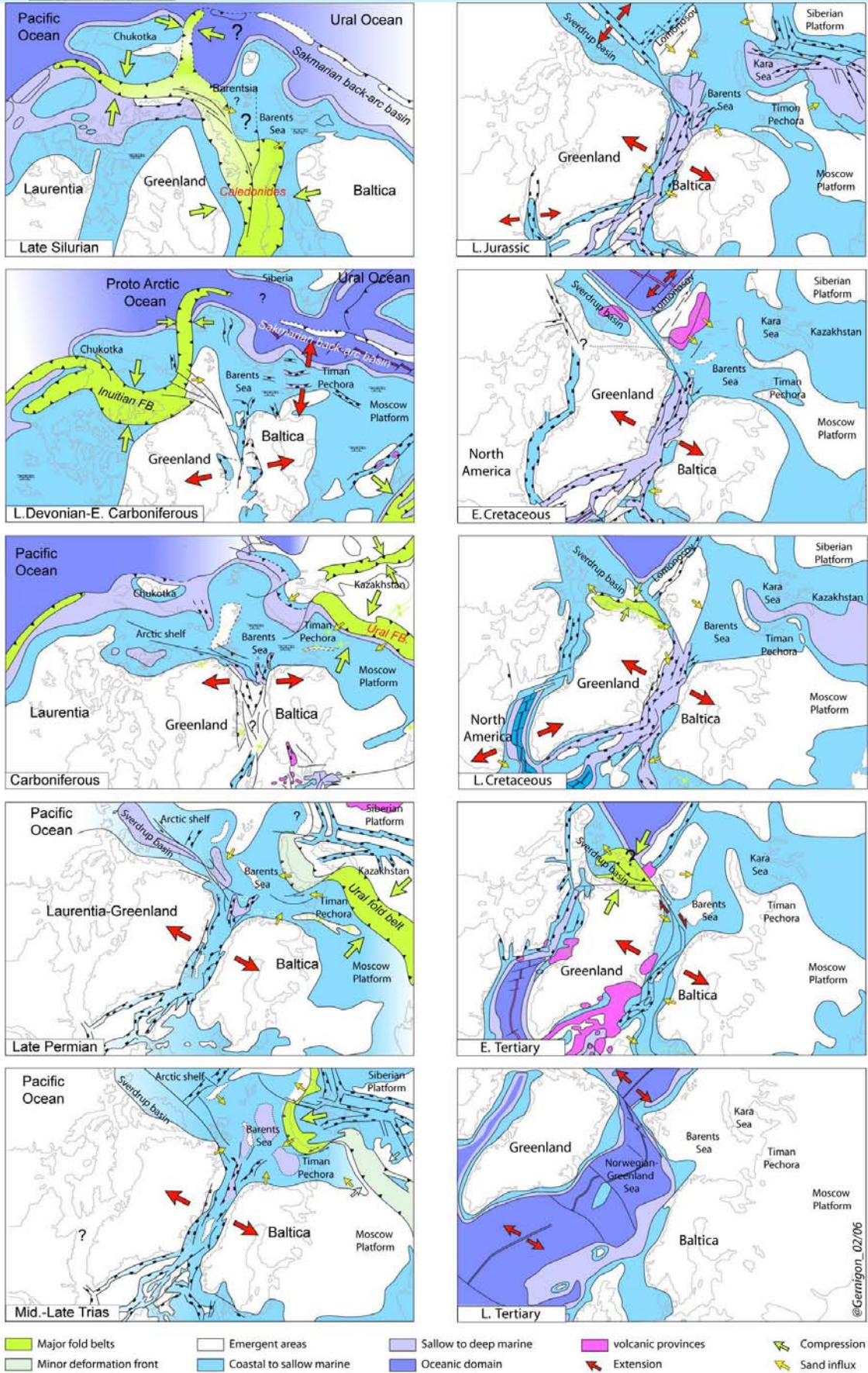


Figure 2: Schematic cartoon of the geodynamic evolution of the North Atlantic and Arctic Region (modified after Ziegler et al. 1999, Smelror et al., 2009)



Although it is unclear if the control is crustal or mantellic, crustal extension and the resulting formation of rift basins between Norway and Greenland attempted to fragment Pangaea along a weakness zone sub-parallel to the ancient Iapetus Ocean (Ziegler, 1999; Torsvik et al., 2002; Lundin and Doré, 2005, Faleide et al., 2008).

In the NE Atlantic, rift developed sporadically during the Late Permian and continued into the Early Triassic (Fig. 2). During Early and Middle Jurassic times, the rift axis propagated progressively northwards concomitantly with the formation of the Central Atlantic Ocean. Following the intense rift tectonics of the Permian and Triassic, areas between Scandinavia and East Greenland were, however, subject only to a period of reduced tectonic activity during this period.

The late Jurassic-Early Cretaceous period probably represents the most important rift episode in terms of lithospheric stretching and thinning. A new extensional axis propagated northward between Greenland and Canada and was superimposed on the older rift structure. Breakup and early oceanic accretion occurred along this axis in the Labrador Sea at Chron 33 or Chron 27 (a debated issue) whereas continental extension propagated in the Baffin Bay (Geoffroy et al., 2001). In the NE-Atlantic this period clearly individualized a hyper-extended rift axis from Rockall Trough to the south to the Lofoten to the north (Fig. 2). Nowhere did true oceanic crust formed between Greenland and Europe but serpentinized peridotites are thought to nearly floor part of the major rift basins (e.g Rockall Trough, Møre Basin ?).

Regional extension continued during Cretaceous but the last rift climax developed in the very Late Cretaceous (Campanian)-Paleocene before the onset of a major regional uplift observed from West-Greenland to Europe in latest Maastrichtian-Early Paleocene (Gernigon et al., 2004). This uplift was followed in Late Paleocene-Early Eocene by a significant volcanic event leading to the formation of the so-called "North Atlantic Large Igneous Province". The averaged rate of magma extrusion was in the range of 1-2 cubic kilometres a year at that time. This transient magmatic episode has long-time been interpreted as reflecting the impact and spreading of the Icelandic "mantle plume" head beneath the thinned NE-Atlantic lithosphere (White and McKenzie, 1989). It should however be noticed that other interpretations challenge this hypothesis now (Lundin and Doré, 2005; Meyer et al., 2007).

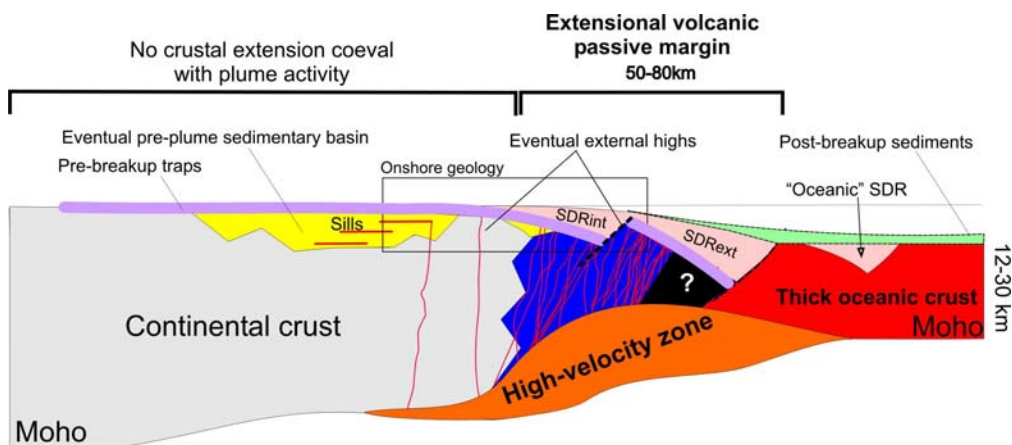


Figure 3: Simplified structure of a volcanic passive margin (Geoffroy, 2005)

A very important event, associated with the North Atlantic Large Igneous Province is the breakup of the continental lithosphere and the onset of oceanic accretion in the NE-Atlantic Ocean and Baffin Bay, respectively. The first magnetic chron in the NE-Atlantic is recorded at 24n (Early Eocene age ~53 Ma). In these regions, the lithospheric rupture was accompanied by punctual mantle melting and consecutive increase in melting rates along the proto-breakup axis. Association between huge mantle melting and fast-rate lithosphere extension gave birth to a particular type of passive margins. The so-called volcanic passive



margins are mostly characterised by magma emplaced in the crust as intrusions (underplated mafic bodies, dyke swarms, sills) and important lava flows forming the Seaward Dipping Reflectors (SDRs) developed along the proto-breakup axis (Fig. 2).

Volcanic margins are specifically located immediately north of the Davis Strait in the Labrador-Baffin system and from the Charly Gibbs Fracture Zone to the Lofoten Margin in the NE-Atlantic (Fig. 1). It must also be noticed that the Arctic oceanic rift (Fig. 1) formed at the same time but no major magmatism occurred there during the breakup. From C24 to C13, the Reykjanes, Aegir and Nansen Ridges were active together but locally dislocated by major transform (e.g. Jan Mayen Fracture Zone) or megashear regions (e.g. Fram Strait) accommodating the Greenland-Europe divergence in the ~NW-SE trend (Engen et al., 2008; Gernigon et al., 2009; Gaina et al., 2009) (Fig. 2). The coeval functioning of two divergent axes from apart Greenland during the Early Palaeogene was associated with the northward drift of the new Greenland Plate to the N-NW leading to the formation of the Eurakan intraplate transpressional to collisional foldbelt NW of Greenland (notably in the Ellesmere, Axel Heiberg and Spitzbergen areas) (Fig. 4). North-East of Greenland, this northward displacement was guided by the pre-existing Fram Strait configuration (Fig. 4).

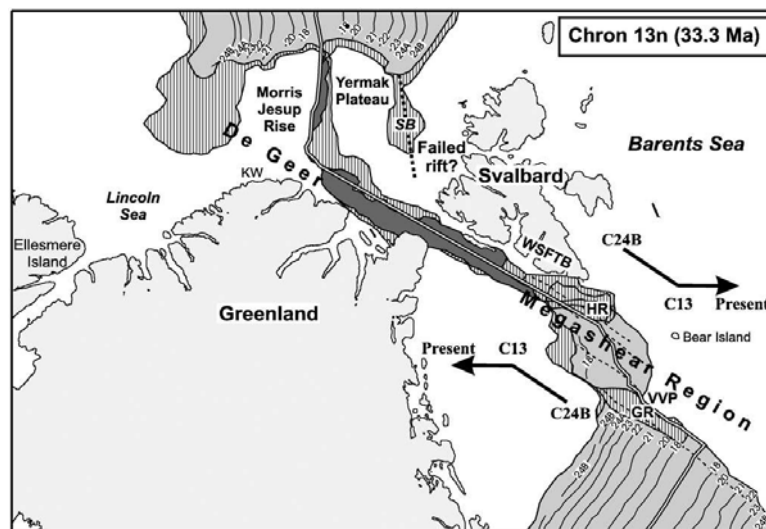


Figure 4: Plate tectonic reconstruction of the Fram Strait region to Chron 13 times (earliest Oligocene), when relative plate motion between Greenland and Eurasia changed from right-lateral shear to oblique divergence (arrows). Figure after Engen et al. (2008)

Major plate reorganization occurred during the earliest Oligocene (~C13, 33,3 Ma). Extinction of the Labrador-Baffin spreading axis was coeval with a major kinematic change within the NE-Atlantic (Skogseid et al., 2000; Gaina et al., 2009). The Aegir axis died and the creation of a new spreading axis east of Greenland along the Kolbeinsey Ridge, led to the insulation of the Jan Mayen microcontinent (Fig. 1). This was associated with a major change of the kinematic vector between North-America (including Greenland) and Eurasia. From C13, Greenland was no more a plate and no more compression acted in the Eurekan area and a transtensional oceanic opening progressively initiated within the Fram Strait (Engen et al., 2008; Døssing et al., 2010). Assuming that the onset of deep-water exchange depended on the formation of a narrow, oceanic corridor, the Fram Strait gateway between the Arctic and NE-Atlantic oceans probably formed during early Miocene times (20–15 Ma) (Engen et al., 2008).

Since the Eocene, mantle melting is locally in excess beneath the NE-Atlantic Reykjanes spreading axis as outlined by thicker-than-normal oceanic crust observed along the transverse Greenland-Iceland-Faeroe aseismic ridge (Fig. 2), where crust thickness is locally as high as 35-40 km. This ridge was long-time emerged (like the present-day Iceland) and displays similar tectonic features with the adjacent volcanic margins (such like oceanic SDRs, cf. Fig. 3). Like Iceland the high melting rates beneath the ridge is



interpreted as accretion over the residual tail of the Thulean mantle plume but its apparent symmetry is still problematic (Lundin and Doré, 2005; Meyer et al., 2007).

To conclude, the topography and bathymetry of the NE-Atlantic domain is strongly controlled by its past evolution and, notably, by abnormal mantle melting in the area since the Palaeocene. Because the crust is often thicker than normal (at both passive margins and in the oceanic domain), the lithosphere is lighter. This isostatic effect depends on the finite amount of past mantle melting. Because melting was heterogeneous (rate and/or duration), the bathymetry of the NE-Atlantic and the Labrador-Baffin is highly contrasted (Fig. 1). These lithospheric controls of the bathymetry are possibly combined with dynamical mantle uplift and low density of a hotter-than-normal asthenosphere, creating the net and large positive geoid anomaly over the area.

Selected Bibliography

- Døssing, A., Stemmerik, L., Dahl-Jensen, T. & Schindwein, V. 2010: Segmentation of the eastern North Greenland oblique-shear margin — Regional plate tectonic implications. *Earth and Planetary Science Letters* 292, 239-253.
- Engen, O., Faleide, J.I. & Dyreng, T.K. 2008: Opening of the Fram Strait gateway: A review of plate tectonic constraints. *Tectonophysics* 450(1-4), 51-69.
- Faleide, J.I., Tsikalas, F., Breivik, A.J., Mjelde, R., Ritzmann, O., Engen, Ø., Wilson, J. & Eldholm, O. 2008: Structure and evolution of the continental margin off Norway and the Barents Sea. *Episodes* 31(1), 82-101.
- Gaina, C., Gernigon, L. & Ball, P. 2009: Paleocene-Recent plate boundaries in the NE Atlantic and the formation of the Jan Mayen microcontinent. *Journal of the Geological Society, London* 166, 1-16.
- Geoffroy, L., Callot, J.P., Scaillet, S., Skuce, A., Gelard, J.P., Ravilly, M., Angelier, J., Bonin, B., Cayet, C., Perrot, K. & Lepvrier, C. 2001: Southeast Baffin volcanic margin and the North American-Greenland plate separation. *Tectonics* 20(4), 566-584.
- Geoffroy, L. 2005: Volcanic passive margins. *Comptes Rendus Geoscience* 337(16), 1395-1408.
- Gernigon, L., Ringenbach, J.C., Planke, S. & Le Gall, B. 2004: Deep structures and breakup along volcanic rifted margins: Insights from integrated studies along the outer Vøring Basin (Norway). *Marine and Petroleum Geology* 21(3), 363-372.
- Gernigon, L., Olesen, O., Ebbing, J., Wienecke, S., Gaina, C., Mogaard, J.O., Sand, M. & Myklebust, R. 2009: Geophysical insights and early spreading history in the vicinity of the Jan Mayen Fracture Zone, Norwegian-Greenland Sea. *Tectonophysics* 468(1-4), 185-205.
- Lundin, E. & Doré, A.G. 2005: NE Atlantic break-up: a re-examination of the Iceland mantle plume model and the Atlantic-Arctic linkage. In Doré, A. G. & Vining, B. A. (eds.) *Petroleum geology: North-West Europe and Global perspectives-Proceedings of the 6th Petroleum Geology Conference*. Geological Society of London, 739-754.
- Meyer, R., van Wijk, J. & Gernigon, L. 2007: The North Atlantic Igneous Province: a review of models for its formation. In Foulger, G. R. & Jurdy, D. M. (eds.) *Plates, plumes and Planetary processes*. Geological Society of America Special paper 430, 525-552.
- Müller, R.D., Sdrolias, M., Gaina, C. & Roest, W.R. 2008: Age, spreading rates, and spreading asymmetry of the world's ocean crust. *Geochemistry Geophysics Geosystems* 9, Q04006, doi:10.1029/2007GC001743.
- Sandwell, D.T. & Smith, W.H.F. 1997: Marine gravity anomaly from Geosat and ERS1 satellite altimetry. *Journal of Geophysical Research* 102(B5), 10039-10054.
- Skogseid, J., Planke, S., Faleide, J.I., Pedersen, T., Eldholm, O. & Neverdal, F. 2000: NE Atlantic continental rifting and volcanic margin formation. In Nøttvedt, A. (eds.) *Dynamics of the Norwegian margin*. Geological Society Special Publications 167, 295-326.
- Smelror, M., Petrov, O., Larssen, G.B. & Werner, S.C. 2009: *ATLAS: Geological History of the Barents Sea*. Norges geologiske undersøkelse (Geological Survey of Norway, NGU), 135 pp.
- Torsvik, T.H., Carlos, D., Mosar, J., Cocks, R.M. & Malme, T.N. 2002: Global reconstructions and North Atlantic paleogeography 440 Ma to Recent. In Eide, E. & Coord. (eds.) *BATLAS: Mid Norway plate reconstructions atlas with global and Atlantic perspectives*. Geological Survey of Norway, 18-39.
- White, R.S. & McKenzie, D. 1989: Magmatism at rift zones: the generation of volcanic continental margins and flood basalts. *Journal of Geophysical Research* 94, 7685-7729.
- Ziegler, P.A. 1989: Evolution of the North Atlantic-An Overview. In Tankard, A. J. & Balkwill, H. R. (eds.) *Extensional Tectonics and Stratigraphy of the North Atlantic Margins*. American Association of Petroleum Geologists, 111-129.