Evolution of Labrador Sea–Baffin Bay: Plate or plume processes?

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SUMMARY

Breakup between Greenland and Canada resulted in oceanic spreading in the Labrador Sea and Baffin Bay. These ocean basins are connected through the Davis Strait, a bathymetric high comprising primarily continental lithosphere, and the focus of the West Greenland Tertiary volcanic province. It has been suggested that a mantle plume facilitated this breakup and generated the associated magmatism. Plume-driven breakup predicts that the earliest, most extensive rifting, magmatism and initial seafloor spreading starts in the same locality, where the postulated plume impinged. Observations from the Labrador Sea–Baffin Bay area do not accord with these predictions. Thus, the plume hypothesis is not confirmed at this locality unless major *ad hoc* variants are accepted. A model that fits the observations better involves a thick continental lithospheric keel of orogenic origin beneath the Davis Strait that blocked the northward-propagating Labrador Sea rift resulting in locally enhanced magmatism. The Davis Strait lithosphere was thicker and more resilient to rifting because the adjacent Paleoproterozoic Nagssugtoqidian and Torngat orogenic belts contain structures unfavourably orientated with respect to the extensional stress field at the time.

INTRODUCTION

Although many continental rifts and passive margins are magma-rich (Skogseid 2001; Geoffroy 2005; Thybo and Artemieva 2013; Geoffroy et al. 2015), such as the Norwegian margin (e.g. Gernigon et al. 2015), others are relatively magma-poor (Boillot and Froitzheim 2001; Wilson et al. 2001), such as the Newfoundland margin (e.g. Eddy et al. 2017). This has led to polarization of proposed causal mechanisms into views of magma-rich or 'active' rifts (postulated to be driven by deep mantle plumes, e.g. Morgan 1971; Sengör and Burke 1978), and magma-poor or 'passive' rifts (postulated to be driven by stretching of the lithosphere by far-field plate forces, e.g. McKenzie 1978; Fig. 1). However, magmatism occurs even on margins categorized as 'non-volcanic' or 'magma poor' (e.g. the U-reflector offshore Newfoundland; Deemer et al. 2010; Peace et al. 2017) because magmatism to some extent invariably accompanies continental breakup (White, 1992). This suggests that 'magma-rich' and 'magma-poor' margins are extremes that represent end-members only in a continuous spectrum (Geoffroy 2005; Franke 2013). For this reason the role of the mantle and its relationship with magmatism during continental breakup remains a subject of debate (e.g. Anderson 2000; van Wijk et al. 2001; Foulger 2002; Campbell 2007; Calvès et al. 2008; Foulger et al. 2015; Shellnutt et al. 2017). Furthermore, an unequivocal detection of a Morgan-type mantle plume (i.e. a thermal rising from the deep lower mantle) has yet to be made, using either geochemical or geophysical tools (Hwang et al. 2011; Foulger et al. 2013; Lustrino and Anderson 2015).

In this contribution we discuss, using observations from West Greenland and northeastern Canada, the predictions of the mantle plume hypothesis as the mechanism facilitating continental breakup and magmatism (Gill et al. 1992; Gerlings et al. 2009). We find that few of the predictions are confirmed. We suggest that breakup was, instead, predominantly driven by plate tectonic processes and that lithospheric structure in the neighbourhood of the Davis Strait was responsible for the excess Tertiary magmatism there that has traditionally been interpreted as the product of a mantle plume.

CONTINENTAL BREAKUP AND MAGMATISM BETWEEN GREENLAND AND CANADA

The Labrador Sea and Baffin Bay (Fig. 2) opened as a result of divergent motion between Greenland and Canada (Srivastava 1978; Chalmers and Pulvertaft 2001; Abdelmalak et al. 2012;

Hosseinpour et al. 2013; Delescluse et al. 2015; Alsulami et al. 2015; Peace et al. 2016). This separation occurred in three stages (Oakey and Chalmers, 2012): 1) Paleocene separation between North America and Greenland while the latter was still attached to Eurasia, 2) continued Eocene separation between Greenland and North America as separation between Eurasia and Greenland (Greenland moving as an independent plate) began, and 3) since the Oligocene continued separation between Eurasia and Greenland, which again was attached to North America. Extension between Greenland and Canada resulted in oceanic spreading in the Labrador Sea (Chalmers and Laursen, 1995) and most likely in Baffin Bay (Suckro et al., 2012) but not at the Davis Strait (Funck et al., 2012).

The earliest rifting, (possibly Triassic; Larsen et al. 2009) and the oldest and most extensive oceanic crust in the Labrador Sea–Baffin Bay area, occurs in the southern Labrador Sea (mid-Paleocene; Srivastava 1978; Chalmers and Pulvertaft 2001). The spatial and temporal extent of oceanic crust in Baffin Bay (Suckro et al., 2012) is less than in the Labrador Sea (Srivastava 1978). The Davis Strait is a bathymetric high linking the Labrador Sea to Baffin Bay and it is primarily underlain by continental lithosphere (Dalhoff et al., 2006) up to 20 km thick (Funck et al., 2012). The Ungava Transform Fault System (Suckro et al., 2013), a 'leaky' transform system where small amounts of oceanic crust may have been produced in the absence of fully developed oceanic spreading (Funck et al., 2012), traverses the Davis Strait.

The earliest magmatism related to the opening of the Labrador Sea is possibly Late Triassic in age (ca. 220 Ma; Larsen et al. 2009). However, it is not until the Early Cretaceous that a strong extensional stress field is evidenced by the intrusion of coast-parallel dykes in West Greenland (ca. 150 Ma; Larsen et al. 2009) and possibly some debated equivalent dykes in Labrador (Tappe et al. 2007; Peace et al. 2016) along with a Mesozoic diatreme (King and McMillan 1975; Wilton et al. 2002; Wilton et al. 2016). Breakup occurred in the Paleocene (Chalmers et al., 1995), in addition to the eruption of flood basalt around the Davis Strait as four region-wide formations: the 62.5–61 Ma Vaigat Formation picrite, the 61–60 Ma Maligât Formation depleted basalt (also in the Hellefisk-1 offshore well), the 60–58 Ma Svartenhuk Formation less-depleted basalt and the Naqerloq Formation 56–54 Ma enriched basalt (Larsen et al., 2016). Furthermore, two less widespread basalt sequences include the 53.5 Ma Erqua Formation alkali basalt and the 38.7 Ma Talerua Member transitional basalt (Larsen et al., 2016).

THE MANTLE PLUME HYPOTHESIS AND BREAKUP BETWEEN GREENLAND AND CANADA

A mantle plume (Morgan, 1971) has been proposed as the causal mechanism for continental breakup and magmatism between Greenland and Canada (e.g. Storey et al. 1998; Courtillot et al. 1999; Nielsen et al. 2002; Funck et al. 2007; Gerlings et al. 2009; Altenbernd et al. 2015). It is postulated that initial rifting was relatively amagmatic (Nielsen et al. 2002; Altenbernd et al. 2015) and that the arrival of a mantle plume at ca. 62–60 Ma (Storey et al. 1998) led to the onset of seafloor spreading in the Labrador Sea (Gerlings et al., 2009) and widespread magmatism around the Davis Strait (Holm et al. 1993; Storey et al. 1998). The postulated plume is claimed to underlie Iceland presently (Tegner et al., 1998), and to have remained fixed with respect to other mantle plumes throughout its existence. This is suggested by various authors to have existed since ca. 250 Ma, depending on what basalt units are considered to comprise its associated 'plume-head' volcanic rocks (e.g. Lawver and Müller 1994). Figure 2 depicts three postulated plume tracks that are commonly cited as explanations for breakup and magmatism in West Greenland (Forsyth et al. 1986; Lawver and Müller 1994; Lawver et al. 2002). In this paper we primarily discuss the Lawver and Müller (1994) plume track as this is most complete and the one that approaches most closely the Davis Strait.

Observations in the Labrador Sea–Baffin Bay rift system that have been attributed to a mantle plume include:

1) The onset of seafloor spreading in the Labrador Sea (Gerlings et al. 2009);

2) Movement on the Ungava fault system (Storey et al., 1998);

3) Volcanism in West Greenland and Baffin Island (Chalmers et al. 1995; Larsen et al. 2016)

4) Interpreted underplating beneath the Davis Strait (Gerlings et al., 2009);

5) High $^{3}He/^{4}He$ (Graham et al. 1998; Dale et al. 2009);

6) Regional uplift patterns (Dam et al. 1998; Japsen et al. 2006); and

7) High melting temperatures estimated for picrite cumulates (Gill et al., 1992).

Despite this there are first-order disparities between the predictions of the mantle plume model and regional observations (Nielsen et al. 2007; McGregor et al. 2014; Peace et al. 2014). The mantle plume hypothesis requires that the earliest and most extensive uplift, magmatism and rifting occurred closest to the plume centre (e.g. Franke 2013; Fig. 3). However, this did not occur in the Labrador Sea-Baffin Bay rift system if the plume track of Lawver and Müller (1994) is assumed, as exemplified by the following:

1) Seafloor spreading started in the southern Labrador Sea before the north (Roest and Srivastava, 1989);
2) Seafloor spreading was delayed and developed poorly in Baffin Bay (Suckro et al., 2012);
3) Seafloor spreading did not develop at all in the Davis Strait (Suckro et al., 2013), the location of the plume centre predicted by Lawver and Müller (1994), and;
4) The predicted kilometre-scale uplift at the centre of the arriving plume did not occur (Redfield 2010; McGregor et al. 2013).

These points are discussed in more detail in the following subsections.

The Labrador Sea

The Labrador Sea progressively opened from south to north (Oakey and Chalmers 2012; Delescluse et al. 2015), and although there is a consensus that spreading started no later than Chron 27 (Paleocene; Chalmers and Laursen 1995; Oakey and Chalmers 2012) some work suggests that spreading may have started as early as Chron 33 (Roest and Srivastava 1989; Srivastava and Roest 1999). Despite this debate it is clear that seafloor spreading started in the southern Labrador Sea considerably before the north (Roest and Srivastava 1989). This does not fit a model whereby a plume located to the north (Lawver and Müller, 1994) initiated seafloor spreading (Storey et al. 1998; Gerlings et al. 2009). If seafloor spreading was initiated by mantle plume arrival it would be expected to start nearest to the plume and to propagate away from it (Fig. 3).

Baffin Bay

The nature of seafloor spreading in Baffin Bay is contrary to plume hypothesis predictions. First, it has been proposed that Baffin Bay is either entirely underlain by continental crust (Kerr 1967; Van der Linden 1975) or that if oceanic crust is present it is less extensive than in the Labrador Sea (Jackson et al. 1979; Gerlings et al. 2009; Suckro et al. 2012; Hosseinpour et al. 2013). Baffin Bay is proposed to have been much closer to the plume (Lawver and Müller, 1994) and so the reverse would be expected.

The Davis Strait

In the Davis Strait seafloor spreading was never fully initiated as it was in the Labrador Sea (Srivastava 1978) and probably Baffin Bay (Suckro et al., 2012). Instead, a ‘leaky transform’ system developed (Funck et al., 2007). It is again not clear why a mantle plume should cause seafloor spreading in the Labrador Sea to the south (Gerlings et al. 2009; Storey et al. 1998) but not in the much closer Davis Strait. The Davis Strait is the focus of the West Greenland Tertiary volcanic province (Fig. 2; Storey et al. 1998; Gerlings et al. 2009; Larsen et al. 2016) and, although volcanic rocks are observed on Baffin Island (Clarke and Upton 1971; Geoffroy et al. 2001), rift-related dykes are also documented to the south on the margins of the Labrador Sea (Larsen et al., 2009). This disparity between a predicted time-progressive volcanic track as a result of plume passage (Lawver and Müller, 1994) and the observations provides further evidence against a fixed mantle plume as the primary cause of the magmatism.

Vertical motion studies

Low-temperature thermochronological studies (e.g. apatite fission track dating – AFT), helium isotopes and vitrinite reflectance) may be used to date vertical motions including possible plume-related exhumation. Results from West Greenland linking apparent uplift to presumed plume activity (Japsen et al., 2006) are controversial (Redfield, 2010). Furthermore, results from Baffin Island suggest a slow and long-lived exhumation since the Late Proterozoic while Cenozoic uplift is not detected (Yaehne 2008; McGregor et al. 2013; Creason 2015). The Torngat Mountains in Labrador experienced rapid uplift in the latest Jurassic–earliest Cretaceous, but this is inferred to be rift-flank uplift (Centeno, 2005). AFT ages from Ellesmere Island and along the

Nares Strait show peaks in the Paleogene and Permo-Triassic, reflecting the complex tectonic evolution of the region (Arne et al. 2002; Grist and Zentilli 2005; Hansen et al. 2011). However, this is not when the postulated plume is predicted to have underlain the area (approx. 120–90 Ma). Apparent vertical motions along the West Greenland–East Canada margin are thus not consistent with the spatial and temporal pattern of vertical motions predicted for plume head impingement and a migrating plume tail.

Plume Variants

Several variants of the plume hypothesis have been proposed to account for the mismatches between predictions and observations by Gill et al. (1992). These include: 1) a 'doughnut-shaped' plume; 2) a shift in relative plume position (migrating plume); 3) multiple, separate plumes; and 4) a non-axisymmetric plume head. Numerical modelling of the South Atlantic has been used to support the suggestion that plume-driven rift initiation may be offset from the proposed plume impingement location (Beniest et al., 2017), and that mantle contamination in combination with elevated temperatures near Iceland may explain igneous crustal thickness (Shorttle et al., 2014), concepts that may be applicable in the Labrador Sea–Baffin Bay area. Variants of the standard plume model are, however, not useful unless they make predictions of their own that can be tested – arbitrary *ad hoc* adjustments introduced merely to explain *a posteriori* observations that do not fit the simple model do not progress understanding of causative processes. It is clear that non-plume mechanisms for the Labrador Sea–Davis Strait–Baffin Bay region must be considered.

THE ROLE OF LITHOSPHERIC STRUCTURE AND PROCESSES IN THE TECTONO-MAGMATIC EVOLUTION

Plate-related mechanisms provide candidate mechanisms for breakup and magmatism between Greenland and Canada (Foulger 2002; Nielsen et al. 2007; Peace et al. 2014; Foulger et al. 2015). In this section we discuss the role of lithospheric architecture in controlling breakup and associated magmatism between Greenland and Canada.

Beneath the Davis Strait (Fig. 2) the crust (Fig. 4 and 5A) is thicker than elsewhere in the Baffin Bay–Labrador Sea rift system (Laske et al. 2012; Welford and Hall 2013;). According to a model of the depth of the lithosphere–asthenosphere boundary (LAB) (Schaeffer and Lebedev 2015; Schiffer et al. 2017; Lebedev et al. 2017) the lithosphere is also thicker (Fig. 5B). According to this LAB model the Davis Strait may be underlain by lithosphere c. 150 km thick compared to the Labrador Sea and Baffin Bay which may have lithosphere as thin as c. 50 km (Fig. 5).

Local mantle convection patterns may have been influenced by a lithospheric keel protruding into the asthenosphere (Fig. 6). Regions of thick lithosphere have been inferred to influence asthenospheric flow elsewhere, e.g. in southeast Brazil (Assumpção et al. 2006). Such structures may induce lateral thermal gradients leading to initiation of small-scale convection cells that boost adiabatic melting (Simon et al. 2009; Ballmer et al. 2010). Lateral temperature gradients beneath the Davis Strait may have varied, both spatially and temporally, because of variable crustal and lithospheric thinning (Suckro et al., 2013). Such lateral temperature gradients are expected particularly if small amounts of oceanic crust were produced along 'leaky' transform faults (Funck et al., 2007).

Thicker Davis Strait lithosphere (Fig. 5) could have had an insulating effect, causing large asthenosphere temperature gradients from north (Baffin Bay) to south (Labrador Sea) (Lenardic et al. 2005; Whittington et al. 2009; Heron and Lowman 2011) and therefore enhancing melting caused by other mechanisms such as edge-driven convection (e.g. Ghods 2002; van Wijk et al. 2008; Simon et al. 2009). Continental lithosphere persisted in the Davis Strait longer than elsewhere (Srivastava and Roest, 1999). The Davis Strait is a considerably smaller region than others where insulation by continental lithosphere has been inferred to be influential, e.g. supercontinents (Lenardic et al. 2011), so this is likely to have been a minor effect.

The thickness of the pre-rift continental crust has also been shown to be capable of exerting a significant influence on thinning and magmatic evolution during rifting and continental breakup (Audet and Bürgmann 2011; Petersen and Schiffer 2016). Previous work has shown that thick, warm, weak initial crust promotes dislocated extension and continental, pre-breakup melting whereas extension of thinner, colder, more brittle crust tends to be more localized, leading to quicker continental breakup in the absence of pre-breakup melting (Petersen and Schiffer, 2016). The predictions of this model appear to be supported by observations of rifting in the Davis Strait as well as its location as the focus of the West Greenland Tertiary volcanic province.

The most important factor that boosted melt production at the Davis Strait region is probably the role the region played as a barrier to the propagating rift (Koopmann et al., 2014). Recent modelling suggests that such structural barriers retard rifting and enhance local melt production by restricting the area over which it can escape (Koopmann et al., 2014). Systematic variations in the abundance of magmatism are reported along the margins of the North and South Atlantic (Chalmers 1997; Franke et al. 2007; Skaarup et al. 2006; Elliott and Parson 2008; Blaich et al. 2009; Koopmann et al. 2016) with more abundant magmatism near 'transfer zones', interpreted to have comprised barriers to rift propagation (Koopmann et al., 2014).

Numerical modelling shows that stress concentrations that encourage adiabatic melting can occur at ridge–transform intersections (Beutel, 2005). This effect may explain instances of excess volcanism where ridge segments terminate at transform faults (Beutel, 2005). Examples of volcanism produced in such a tectonic environment include the Foundation Seamounts (Hekinian et al., 1999), the Amsterdam and St. Paul Islands (Graham et al., 1999) and the Galapagos Islands. Two such ridge–transform intersections occur in the Davis Strait (Suckro et al., 2013) where two spreading centres terminate and melt produced will have found ready pathways to the surface through the transtensional segments.

Overall, a thicker continental lithosphere may have been conducive to enhanced melt production for a number of reasons including: 1) influencing asthenospheric flow; 2) providing additional insulation and thus enhancing other mechanisms; 3) comprising a barrier to rift propagation that was conducive to melt generation, 4) necessitating the development of a transform fault against which melt accumulated, increasing the magmatic volume locally, and 5) promoting dislocation extension with associated volcanism rather than abrupt breakup. Several crust and lithosphere-related effects thus predisposed the Davis Strait region to enhanced magmatism. The unusual magmatism there, traditionally attributed to mantle plume activity, may thus be explained by the interaction of a propagating rift and pre-existing lithosphere architecture.

Preservation of thicker continental-type crust and lithosphere in the Davis Strait

Integral to the mechanisms we propose is the persistence of lithosphere near the Davis Strait that is thicker than Baffin Bay and the Labrador Sea. However, whether the crust and lithosphere in the Davis Strait and slightly farther north (Fig. 5) was thicker than the surrounding areas prior to rifting or only after preferential thinning in the Labrador Sea and Baffin Bay areas is relevant because this affects the feasibility of the mechanisms discussed above. The potential contribution of underplating (Gerlings et al., 2009) is also relevant.

The Davis Strait lies adjacent to the Paleoproterozoic Nagssugtoqidian (Connelly and Mengel 2000; Van Gool et al. 2002; Kolb 2014; Engström and Klint 2014) and Torngat (Funck and Louden 1999; Funck et al. 2000) orogenic belts (Fig. 4I) and thus the crust and lithosphere were almost certainly thickened prior to Mesozoic rifting. This suggests that the thick lithospheric keel we postulate was long-established prior to the onset of rifting.

Major structures in those terranes (Wilson et al., 2006) lay approximately perpendicular to the rift axis (e.g. Srivastava and Keen 1995; Abdelmalak et al. 2012) and may have thus resisted northward rift propagation (Fig. 4I) resulting in the reactivation of structures oblique to the extension direction (Peace et al. in press). The unfavourable orientation of pre-existing terranes may explain the failure of complete continental breakup locally between Greenland and Canada and have encouraged the transfer of opening to the Northeast Atlantic between Greenland and Eurasia. That rifting exploited more favourable Caledonian structures to the east of Greenland (Doré et al. 1997; Schiffer et al. 2015a, 2015b; Mjelde et al. 2016; Schiffer et al. in press).

The large-scale geometry of the Labrador Sea–Baffin Bay rift system, that is a right-lateral step through the Davis Strait, may be a direct consequence of the presence of the Paleoproterozoic Nagssugtoqidian and Torngat orogens. This right-lateral step in the plate boundary geometry would have resulted in compression in the Davis Strait (Chalmers et al. 1993; Gregersen and Bidstrup 2008; Peace et al. in press) during later stages when Greenland moved north (magnetic Chron 24-13; Abdelmalak et al. 2012; Oakey and Chalmers 2012). This in turn would have allowed continued extension in the Labrador Sea and (probably) Baffin Bay but minimal thinning in the Davis Strait where transform tectonics continued to dominate.

Overall, the preservation of thicker continental-type crust and lithosphere in the Davis Strait is likely a combination of: 1) initial excess thickness, and 2) rifting not manifesting there as a result of the pre-existing orogenic belts that hindered rift propagation.

CONCLUDING REMARKS

A suite of observations in the Labrador Sea–Baffin Bay rift system related to the geometry, spatial and temporal extent of rifting, seafloor spreading, rift-related magmatism and uplift do not fit the predictions of a model of breakup in response to the arrival of a mantle plume. This conclusion accords with the suggestion by Alsulami et al. (2015) that the role of a mantle plume has been overstated and that of Armitage et al. (2009; 2010) that elevated mantle temperatures alone cannot explain North Atlantic magmatism and rifting without the inheritance of previous structures.

The history of rifting, magmatism and seafloor spreading in the region are consistent with reaction to changing far-field stresses associated with plate tectonics. The observations can be explained without invoking a mantle plume. Tertiary volcanism in the Davis Strait results from local lithospheric structure. A thick lithospheric keel enhanced convection and comprised a barrier to the northerly propagating Labrador Sea rift, resulting in enhanced magmatism. This lithospheric keel is likely related to large-scale, pre-existing structures associated with the Paleoproterozoic Nagssugtoqidian and Torngat orogens. Pre-existing orogenic belts in the disintegrating continental lithosphere had first-order influences on the large-scale mode, timing and geometry of breakup across the entire North Atlantic region.

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FIGURE CAPTIONS

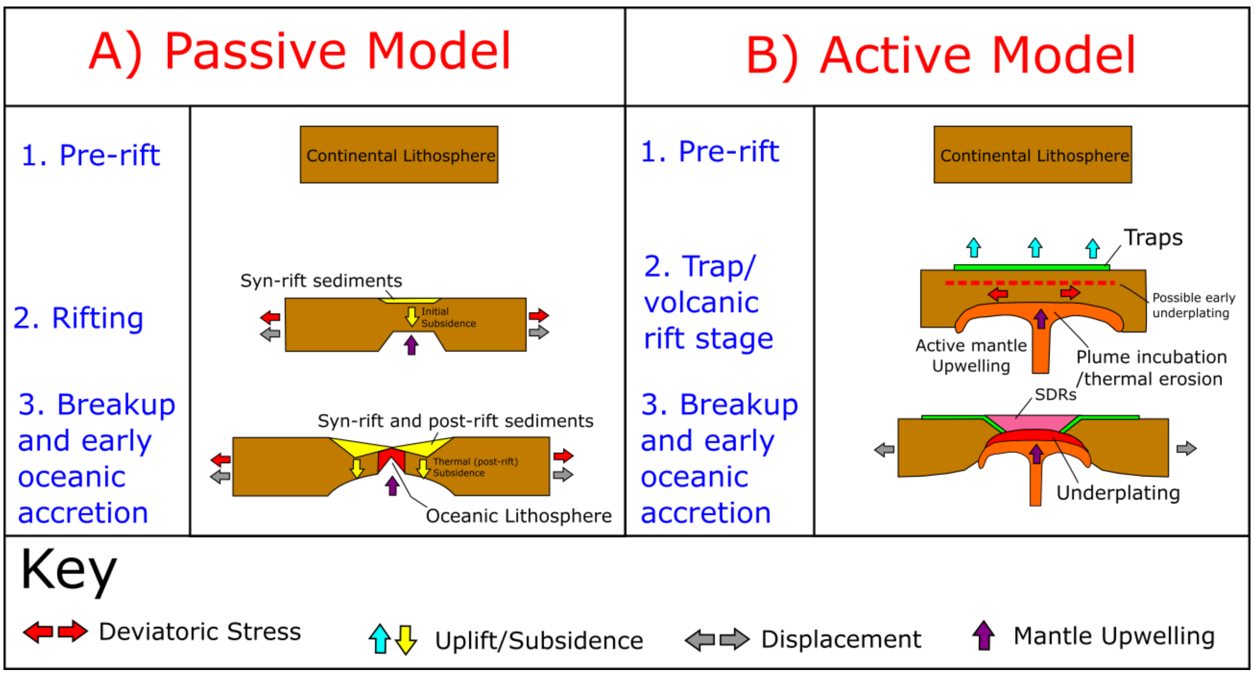


Figure 1

Comparison of A) the passive and B) active models of rifting and breakup. Modified from Geoffroy (2005) based on the concepts of Sengör and Burke (1978) and McKenzie (1978). SDRs = seaward-dipping reflectors (e.g. Mutter 1985; Paton et al. 2017; Buck 2017).

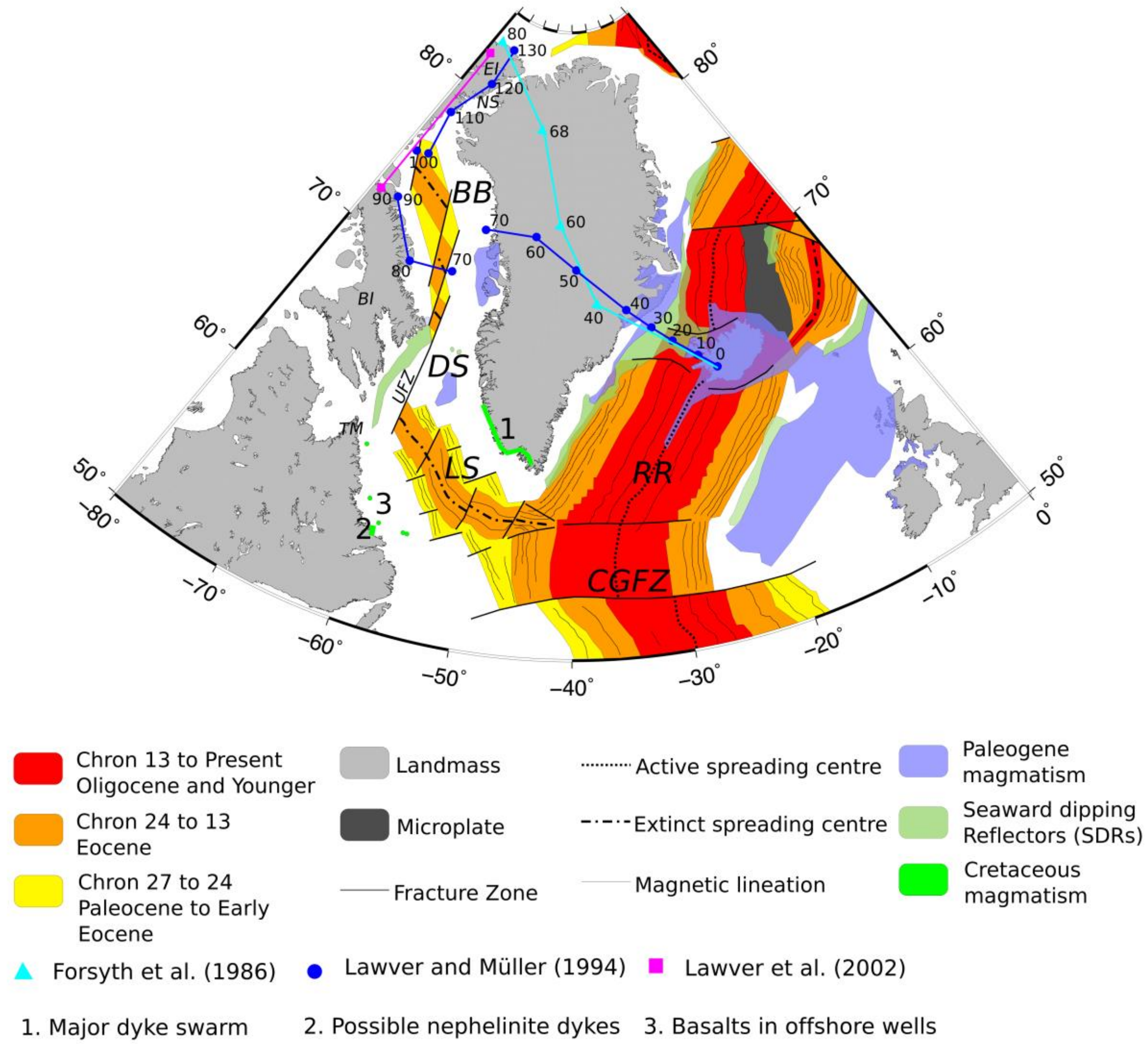


Figure 2

An overview of the North Atlantic oceanic spreading systems including the age of oceanic crust; major active and extinct spreading axes; oceanic fracture zones; proposed microplates; magnetic lineations and the spatial distribution of on- and off-shore flood basalts and seaward-dipping reflectors (SDRs) (Larsen and Saunders 1998; Upton 1988; Oakey and Chalmers 2012). The hotspot tracks of Lawver and Müller (1994) (dark blue), Lawver et al. (2002) (purple) and Forsyth et al. (1986) (light blue) are also included, along with magmatic events in the Labrador Sea pre-dating proposed plume arrival including: 1) onshore West Greenland (Larsen et al., 2009), 2) onshore Labrador (Tappe et al., 2007) but disputed by Peace et al. (2016) and 3) offshore Labrador (Umpleby, 1979). BB = Baffin Bay; BI = Baffin Island; EI = Ellesmere Island; DS = Davis Strait; LS = Labrador Sea; NS = Nares Strait; CGFZ = Charlie Gibbs Fracture Zone; RR = Reykjanes Ridge; CN = Canada; GR = Greenland; IL = Iceland; UK = United Kingdom; IR = Ireland.

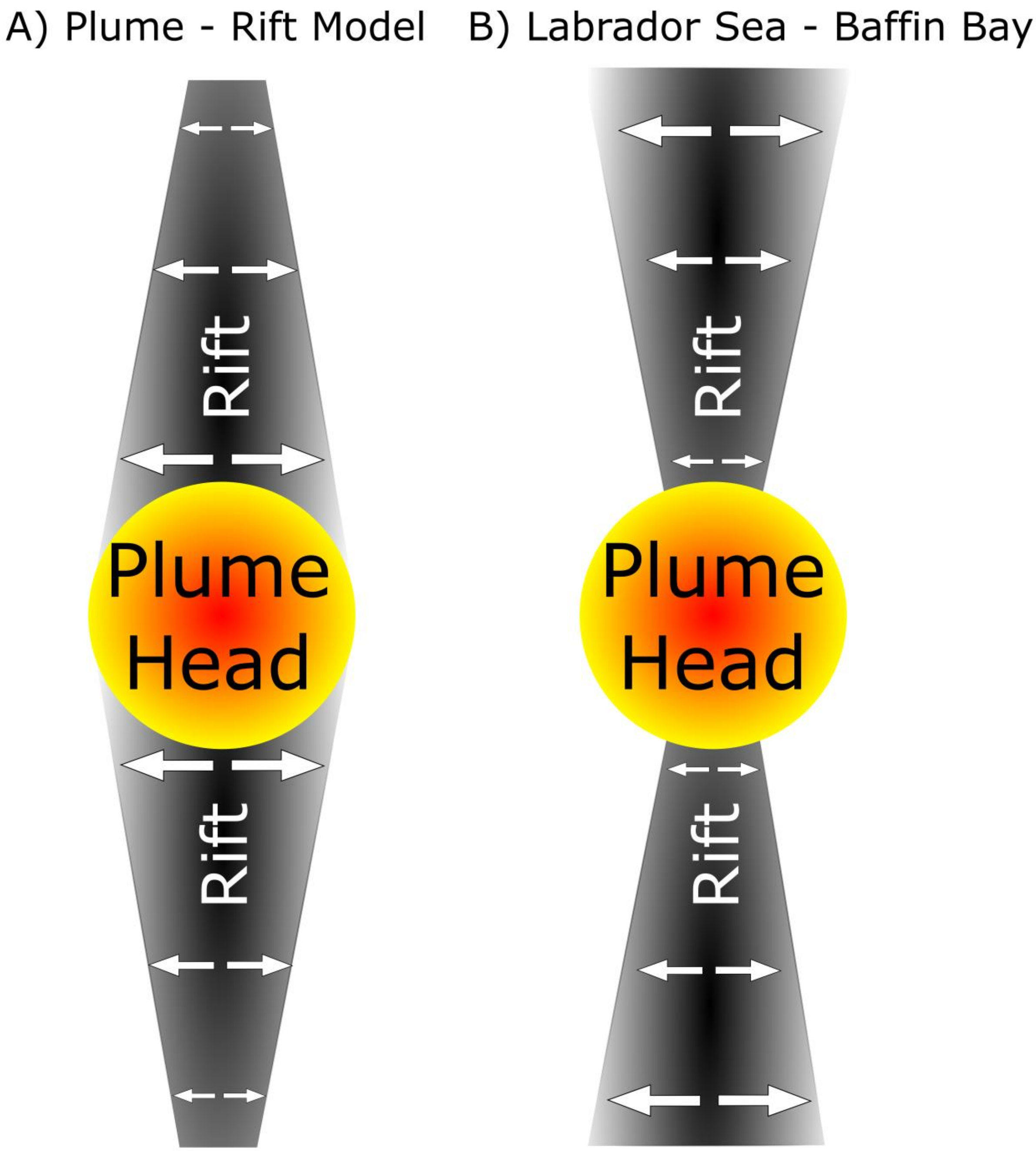
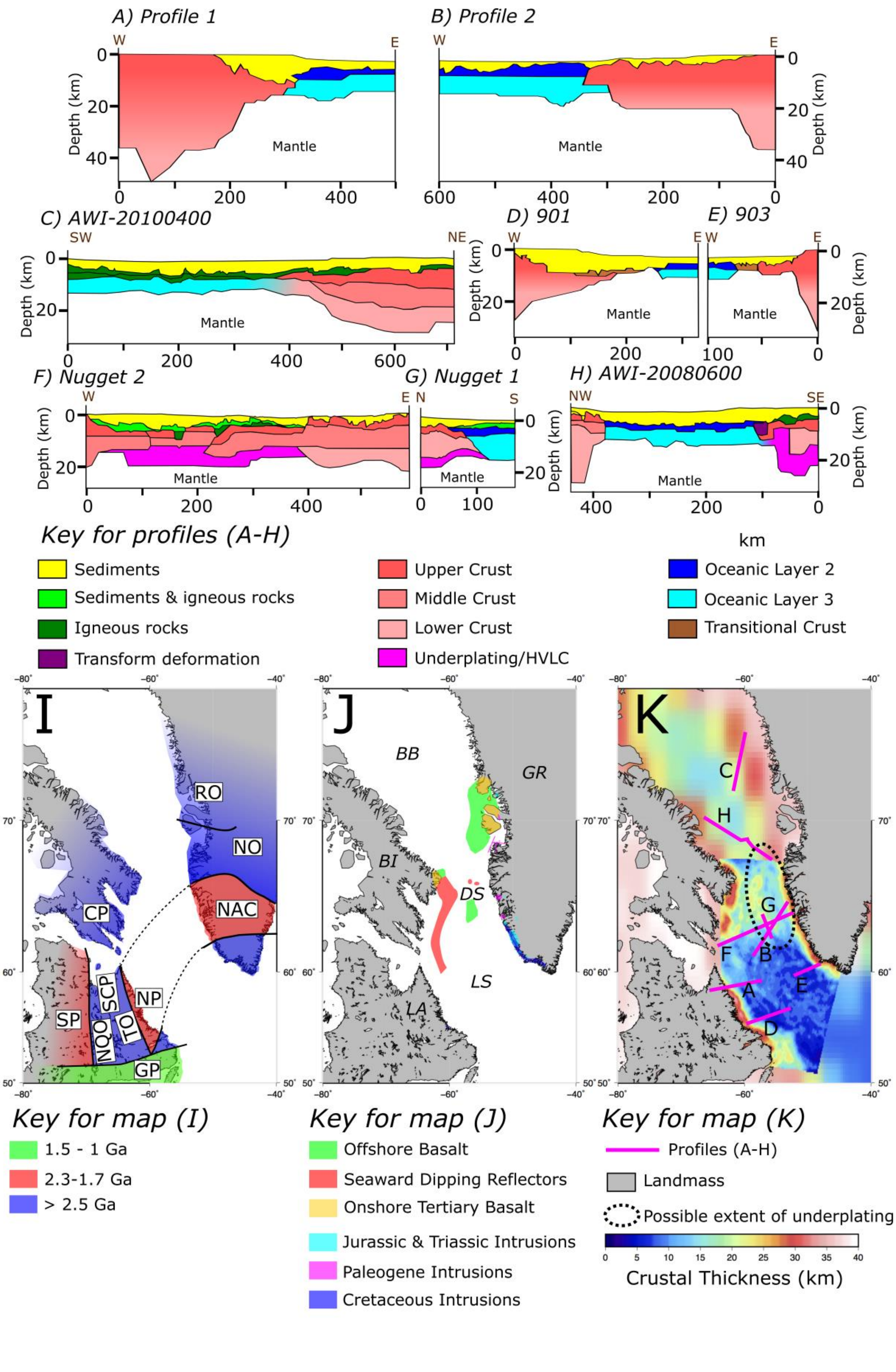


Figure 3

A) Predictions of rifting in response to a rising thermal anomaly in the mantle and B) observations in the Labrador Sea–Baffin Bay rift system. Modified from Franke (2013) whereby the original figure showed a similar example from the South Atlantic where observations of rifting and breakup again do not appear to fit the predictions of the mantle plume hypothesis.



A) Profile 1
B) Profile 2
W
E
Depth (km)
Mantle
C) AWI-20100400
SW
NE
D) 901
E) 903
F) Nugget 2
G) Nugget 1
N
S
H) AWI-20080600
NW
SE
km
Key for profiles (A-H)
Sediments
Sediments & igneous rocks
Igneous rocks
Transform deformation
Upper Crust
Middle Crust
Lower Crust
Underplating/HVLC
Oceanic Layer 2
Oceanic Layer 3
Transitional Crust
I
RO
NO
NAC
CP
SP
SCP
NQO
TO
NP
GP
J
BB
GR
BI
DS
LS
LA
K
C
H
G
F
B
A
E
D
Key for map (I)
1.5 - 1 Ga
2.3-1.7 Ga
> 2.5 Ga
Key for map (J)
Offshore Basalt
Seaward Dipping Reflectors
Onshore Tertiary Basalt
Jurassic & Triassic Intrusions
Paleogene Intrusions
Cretaceous Intrusions
Key for map (K)
Profiles (A-H)
Landmass
Possible extent of underplating
Crustal Thickness (km)

Figure 4

A compilation of crustal structure profiles (A-H) from the Labrador Sea–Baffin Bay rift system including: A) seismic reflection Profile 1 and B) and Profile 2 (Keen et al., 2012); C) seismic refraction line AWI-20100400 (Suckro et al., 2012); D) seismic reflection profiles 901 and E) 903 (Chian et al. 1995; Keen et al. 2012); F) seismic refraction NUGGET line 1 (Funck et al., 2007); G) Seismic refraction NUGGET line 2 (Gerlings et al., 2009) and H) seismic refraction line AWI-20080600 (Funck et al., 2012). Subfigure (I) depicts a simplified overview of basement units in northeastern Canada and Greenland modified from Kerr et al. (1997) and Van Gool et al. (2002). Subfigure (J) shows the distribution of magmatism from the Triassic to the Tertiary (Upton 1988; Park et al. 1971; Larsen et al. 1992; Tegner et al. 1998; Tappe et al. 2007; Larsen et al. 2009; Peace et al. 2016). Subfigure (K) shows the calculated offshore crustal thickness using the global CRUST1.0 model (Laske et al., 2013) except in the Labrador Sea where the model of Welford and Hall (2013) is used. RO = Rinkian Orogen, NO = Nagssugtoqidian, CP = Churchill Province, NQO = New Quebec Orogen, SCP = Southern Churchill Province, SP = Superior Craton, TO = Torngat Orogen, NP = Nain Province, GP = Grenville Province, NAC = North Atlantic Craton, BB = Baffin Bay, DS = Davis Strait, LS = Labrador Sea, GR = Greenland, BI = Baffin Island and LA = Labrador.

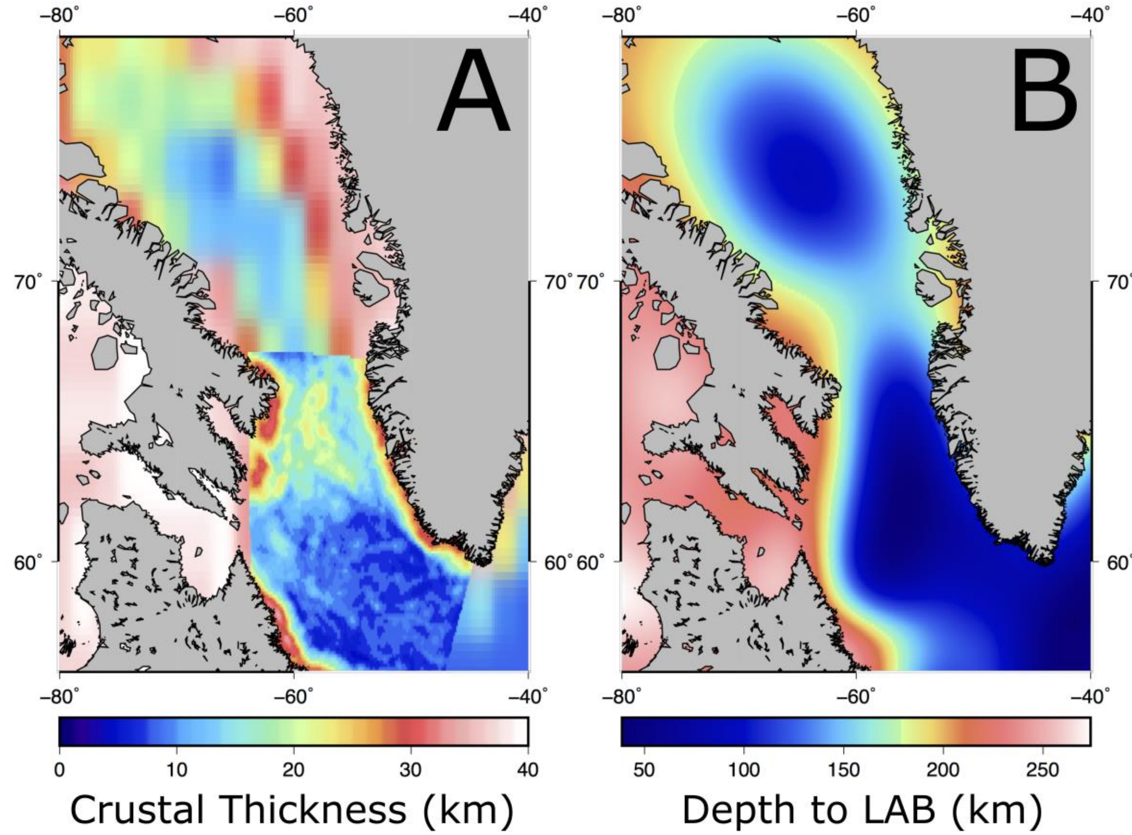


Figure 5

A) Calculated offshore crustal thickness using the global CRUST1.0 model (Laske et al., 2013) except in the Labrador Sea where the Welford and Hall (2013) grid is used. B) Depth to the lithosphere–asthenosphere boundary (LAB) using multimode waveform tomography (Schaeffer and Lebedev 2015; Schiffer et al. 2017).

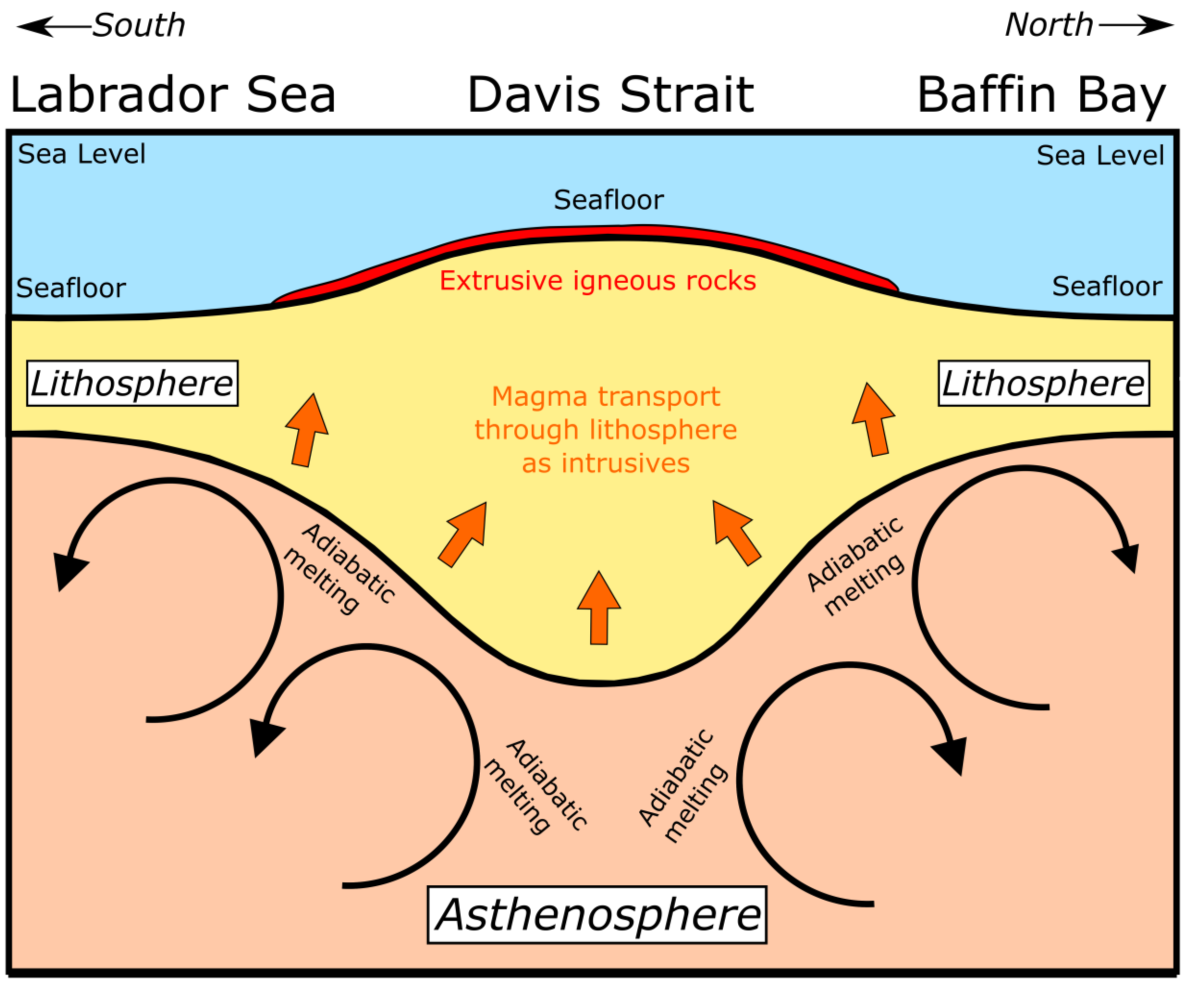


Figure 6

Schematic depiction of the model proposed herein. In this model the thicker crust and lithosphere in the Davis Strait, compared to the Labrador Sea and Baffin Bay (Fig. 5) where extensive thinning took place, could have induced small-scale convection (e.g. Simon et al. 2009). Small-scale convection in proximity to the Davis Strait could have resulted in adiabatic melting leading to the widespread magmatic rocks focused in this area. The reason lithospheric thinning in the Davis Strait was less than the Labrador Sea may have been due to the presence of pre-existing orogenic terranes that proved particularly resistant to thinning (Fig. 4I).