



Deposited via The University of Leeds.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/id/eprint/85531/>

Version: Accepted Version

Article:

Alsulami, S, Paton, DA and Cornwell, DG (2015) Tectonic variation and structural evolution of the West Greenland continental margin. *AAPG Bulletin*, 99 (9). 1689 - 1711. ISSN: 0149-1423

<https://doi.org/10.1306/03021514023>

Reuse

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

1 **Tectonic Variation and Structural Evolution of the West Greenland Continental**
2 **Margin**

3

4 S. Alsulami*, D. A. Paton*, D. G., Cornwell**

5

6 * Basin Structure Group, Institute of Applied Geosciences, School of Earth and Environment,
7 University of Leeds, Leeds, UK

8 **School of Geosciences, University of Aberdeen, King's College, Aberdeen, UK

9

10 **Abstract**

11 Due to its geographic extent of over 2500 km, the West Greenland margin provides a much
12 understudied example of a divergent continental margin, both with respect to hydrocarbon
13 exploration and academic studies. A seismic interpretation study of representative 2D
14 reflection profiles from the Labrador Sea, Davis Strait and Baffin Bay was undertaken to
15 identify sedimentary and structural components to elucidate the tectonic development of the
16 margin. Nine horizons were interpreted from six representative seismic lines in the area.
17 Margin-scale tectono-stratigraphy was derived from isochron maps, the geometry of
18 mappable faults and their associated stratal architecture.

19

20 Rifting began in Early to Late Cretaceous at c.145 -130 Ma, which was followed by two
21 pulses of volcanism in Eocene and Palaeocene ages. The transition to the drift stage includes
22 a typical subsidence phase but also erosion, uplift and deposition of Neogene postrift
23 packages. The shift in the position of depocentres in the Davis Strait and the Labrador Sea
24 during Palaeocene and Miocene times is evidence for structural modification of the basin
25 bounding faults. Drift stage deformation suggests a possible anticlockwise rotation in the
26 orientation of the spreading axis in Baffin Bay culminating in an ultraslow seafloor
27 spreading.

28

29 Seafloor spreading on the West Greenland margin started in the south at 70 Ma in the
30 Labrador Sea and propagated northward into the Baffin Bay by 60 Ma. Prospective petroleum
31 systems include thick Cretaceous age strata, with structural traps provided by grabens and
32 inversion structures. Our structural model provides insight into margin that is highly variable
33 in its structural configuration, further modified by other processes such as magma-assisted
34 rifting which may result in elevated regional heat flow which has considerable impact on
35 hydrocarbon maturation. Further constraining the implications of heat flow associated with
36 volcanic activities in comparison to that associated with lithospheric stretching will be critical
37 in future exploration.

38

39 **Keywords: Seismic Interpretation, Tectonic, Basin Architectures, West Greenland,**
40 **rifting, magmatism**

41

42 **1.0 Introduction**

43 Although there has been considerable interest, over a number of decades, in the evolution of
44 sedimentary basins associated with lithospheric stretching (e.g. McKenzie, 1978; Wernicke,
45 1985; Lister, 1986), recent studies have made significant advances in our understanding of
46 the processes involved. These studies have greatly expanded our understanding on the
47 variability of margins, in particular: the differences between volcanic and non-volcanic
48 margins (e.g. Reston and Perez-Gussinye, 2007; Franke, 2013); the role of depth dependent
49 stretching and multiple rift stages (e.g. Huisman & Beaumont, 2011; Soares et al., 2012);
50 and the influence of mantle plumes (White and McKenzie, 1989; Clift and Turner, 1995;
51 Corti, 2009; Lundin and Doré, 2011). These studies commonly focus on portions of margins,
52 or their equivalents on the conjugate margins. The aim of this study is to consider the lateral

53 variability of a single margin. We chose the West Greenland Margin because of the interplay
54 amongst a number of the key factors including: the presence of a mantle plume; the existence
55 of volcanic and non-volcanic areas on the margin; and changes in extension orientations.
56 Furthermore, the absence of salt enables us to understand margin architecture without the
57 limitations of either sub-salt imaging or salt tectonics.

58

59 The West Greenland Margin includes the Labrador Sea, Davis Strait and Baffin Bay (Figure
60 1). The margin is considered to have formed by the northward propagation of continental
61 rifting and seafloor spreading associated with the breakup of North America from Europe
62 during the Late Cretaceous and Early Paleocene periods (Balkwill et al., 1990; Chalmers,
63 1991, 2000, 2012; Chalmers and Pulvertaft, 2001; Chalmers et al., 1993; Nielsen et al., 2002;
64 Roest and Srivastava, 1989; Rowley and Lottes, 1988; Schenk, 2011).

65

66 The aim of this study is to consider the interplay amongst processes involved along an entire
67 margin during lithospheric rifting and drifting. We describe the basin development along the
68 West Greenland continental margin and consider the implication of this on hydrocarbon
69 exploration. By doing so, we quantify the overall basin fill and architecture during the
70 different phases of basin growth. We demonstrate that the timing of initiation and cessation
71 of rifting together with the duration of sea floor spreading are critical to improving the
72 evolutionary models for the West Greenland margin.

73

74 **1.1 Tectonic and Geological settings of the West Greenland basin**

75 The earliest rifting event probably occurred in the Early Cretaceous (c.145 -130 Ma) or Late
76 Jurassic periods (Schenk, 2011; Harrison et al., 1999). A second rifting event of Late

77 Cretaceous and Early Palaeogene age culminated in thermal subsidence and subsequent
78 passive margin sedimentation at ~ 60 Ma (Dam et al., 2000).

79

80 The Early Cretaceous rifting event is evidenced by deposition of clastics rocks in half grabens
81 and graben basins, such as the Kitsissut and Appat sequences (Chalmers and Pulvertaft,
82 2001). Sedimentary facies within this area includes alluvial fan, fluvial, fan-delta, deltaic and
83 shallow lacustrine sandstones and mudstones of the Kome and Atane Formations from
84 Nuussuaq basin (Balkwill et al., 1990; Chalmers and Pulvertaft, 2001; Dam et al., 2000;
85 Figure 2).

86

87 A Late Cretaceous unconformity separates deltaic deposits of the upper Albian Atane
88 Formation from fully marine deposits of the lower Campanian Itilli formation (Dam et al.,
89 2000). This Campanian Formation is equivalent to the marine deposits at Fylla Structure
90 Complex Area (FSCA), which is overlain by Kangeq Formation offshore West Greenland.
91 The Kangeq seismic sequences in West Greenland basins were probably deposited into
92 thermally subsiding basins (Chalmers et al., 1993; Chalmers and Pulvertaft 2001). The oldest
93 Mesozoic clastics rocks in the Baffin Bay region are Aptian to lower Albian sandstones of the
94 Quqaluit Formation, described by (Burden and Langille, 1990; Figure 2).

95

96 The Aptian-Albian mudstones of the upper Bjarni Formation on the Canadian Labrador shelf
97 are equivalent to the Appat Formation of Greenland. Similarly, the lower Bjarni Formation is
98 equivalent to the Kitsissut Formation of West Greenland (Chalmers et al. 1993, 2012). An
99 unconformity is present between the Cretaceous and Early Paleocene mudstones (Nøhr-
100 Hansen and Dam, 1997). Early Palaeocene mudstones were deposited above the Kangeq
101 Formation (Chalmers and Pulvertaft 2001).The onset of the second rifting event took place in

102 the middle of Paleocene (61 Ma) and was probably associated with seafloor spreading along
103 the West Greenland margin (Oakey and Chalmers, 2012). Extrusion of plateau basalts in both
104 offshore and onshore West Greenland took place in the Late Paleocene and Eocene and is
105 overlain by the fluvio-deltaic and marine deposits of Early Palaeogene age (Chalmers, 2012).
106 Offshore basalts drilled in the Hellefisk-1 and Nukik-2 wells have been interpreted in the
107 Hecla and Maniitsoq Highs (Chalmers et al., 1993, Rolle, 1985). Basalt layers in the southern
108 part of Baffin Bay represent the northernmost extension of the volcanic rocks found in the
109 Davis Strait and were possibly expanded equivalents of sea-floor spreading in Baffin Bay
110 (Whittaker, 1997; Rolle, 1985).

111

112 The Labrador Sea and Baffin Bay regions are connected by the Ungava Transform Fault
113 Zone (UTFZ) in the Davis Strait area (Figure 1). The (UTFZ) is characterized by complex
114 structures that were initially extensional. These structures were subsequently affected by both
115 transtension and transpression processes as the (UTFZ) evolved into a transform zone
116 (Skaarup et al., 2006; Sørensen, 2006). A Mid-Eocene unconformity was then developed
117 (Nøhr-Hansen and Dam, 1997) as a result of strike slip movement across the margin as well
118 as the Ikermiut flower structure (Chalmers et al., 1999).

119

120 From Mid-Miocene time, the West Greenland basins subsided without further obvious
121 evidence of tectonism, until Late Neogene times (Chalmers and Pulvertaft 2001; Green et al.,
122 2011). Strata of largely fine-medium grained sandstones of slope and fan were deposited as
123 as a result of the second postrift subsidence phase (Dalhoff et al., 2003; Schenk, 2011)

124

125 Neogene uplift in the central part of the West Greenland margin is recorded by 2-3 km uplift
126 in the Nuussuaq basin (Chalmers, 2000, Chalmers and Pulvertaft, 2001). Offshore evidence

127 on seismic can be seen in the uplift of the eastern Sisimiut basin (Dalhoff et al., 2003). In the
128 northwest end of Baffin Bay channel erosion is observed which is probably related to
129 Neogene uplift in the Jones Sound, southern Nares Strait and Lancaster Sound (Harrison et
130 al., 2011). The cause of Neogene uplift is still unknown. Although, subsidence analysis of
131 the margin reveals that Neogene uplift is unrelated to subsidence in offshore areas (McGregor
132 et al., 2012).

133

134 **2.0 Materials and methods**

135 Hydrocarbon exploration started in the Arctic region in the Late sixties with the collection of
136 gravity, magnetic, seismic and drilled borehole data. During the last 50 years existing
137 information has been substantially enriched by a series of completed 3D seismic surveys and
138 a significant amount of 2D seismic data. No major hydrocarbon discoveries, however, have
139 yet been made. Access to ~ 65,000 km of 2D processed and stacked seismic reflection data
140 was provided by the Geological Survey of Denmark and Greenland (GEUS) and the TGS-
141 NOPEC Geophysical Company (TGS) for this study. In addition, information from seven
142 published wells (Dalhoff et al., 2003) was used to create synthetic seismograms to tie well
143 data with intersecting seismic sections. The well ties were used to constrain both the age and
144 the lithology of the interpreted horizons. Since the wells are located farther from the seismic
145 lines, extrapolation of the stratigraphic interpretation away from the wells was carried out by
146 following key stratigraphic horizons where possible (Sørensen, 2006).

147

148 A seismic-stratigraphic approach was used (Figure 3) to interpret the seismic data (Badley,
149 1985). Reflection terminations (e.g. onlap, down lap, erosional truncation) were used to
150 identify major sequence boundaries /unconformities on seismic sections. Reflection packages
151 were categorised as prerift, synrift, and postrift (Figure 3). Furthermore, seismic facies used

152 to discriminate megasequences include high amplitude reflections, continuity, frequency
153 variation and lap geometries (e.g. Mitchum Jr et al., 1977).

154

155 Faults were manually mapped from seismic reflection then displayed as lines in map-view
156 (Figure 1). Even with relatively large spacing between 2D seismic lines (8 km in Nuuk West
157 Province, 50 km in Cape Farewell, and 20 to 25 km in Disko West and Baffin Bay
158 respectively), it was possible to recognize and link major faults based on their geometries, dip
159 direction and the amount of displacement. Multiple lines were used to connect the faults in
160 order to create fault array maps and constrain the geological sense of regional faults trends
161 along the margin.

162

163 Having correlated the key seismic reflections across the basins, surfaces were generated that
164 accounted for picked faults and areas of erosion or non-deposition. Two way travel time
165 (TWTT) thickness maps were used to establish 1) relative stratigraphic thickness trends, 2)
166 zones affected by faulting, and 3) the overall basin architecture.

167

168 **3.0 Tectonostratigraphy**

169 The nine horizons interpreted include Sea Bed (SB); base Quaternary (BQ); Mid-Miocene
170 Unconformity (MMU); Mid-Eocene Unconformity (MEU); Top Palaeocene (TP); Palaeocene
171 Basalt (PB); Top Cretaceous (TC); Mid-Lower Cretaceous (MLC); and Acoustic Basement
172 (Bs). The high amplitude (peak) and continuous nature of the SB, MMU, MEU, TP, and
173 MEC reflections provided a high confidence interpretation whereas the moderate to
174 discontinuous (trough) reflector character of TC, PB, BQ and Bs reflections resulted in some
175 uncertainty in the interpretation. The Acoustic Basement (Bs), Mid-Lower Cretaceous (MLC)

176 and Top Cretaceous (TC) reflectors were not mapped in Disko West as they have been
177 masked by the overlying Palaeocene basalt (PB) (Figure 1).

178

179 The main structural domains of the margin are Baffin Bay, Davis Strait and the Labrador Sea.
180 These major regions define the West Greenland margin and are characterized by a large
181 variety of complex structures including grabens, half-grabens, horsts, flower structures, and
182 thrust faults. These structures, and the associated sedimentary packages within the basin fill,
183 represent a multi-phase evolution of the margin. At the margin scale, this complex evolution
184 can be simplified into four phases of deformation rifting, transition, seafloor spreading and
185 Neogene uplift. The pre-rift strata are characterized by parallel reflectors that can extend
186 down to the acoustic basement.

187

188 Synrift sediments have wedge shaped seismic reflector packages and thickness increased
189 towards the fault plane. The earliest rift phase is of Lower Cretaceous to Late Cretaceous in
190 age and defines the main graben structures. The transition period from rifting to drift stage is
191 interpreted to be of Early Palaeocene to Mid-Eocene age. Postrift phase, in which no fault
192 controlled thickening is observed occur above the Mid-Miocene unconformity. There is
193 significant erosional truncation and uplift in a number of areas of the West Greenland margin
194 in particular at Mid-Eocene and Mid-Miocene level. Neogene uplift also affected the margin.

195

196

197

198 **3.1 Structure and history of the individual basins in West Greenland**

199 Recent studies have sub-divided the margin into four structural provinces namely, Cape
200 Farewell, Nuuk West, Disko West and Baffin Bay basins (e.g. Knutsen et al., 2012; Figure 1).

201 We describe the main structures and basin fill within these provinces using interpreted 2D
202 seismic lines to compare and contrast the variation in stratigraphic and structural
203 configurations along the margin (Figure 2). We focus on the main basins in each province,
204 which include Kivioq and Melville Bays and the Upemavik basin in Baffin Bay Province, the
205 Aaisaa basin in the Disko West Province; the Lady Franklin, Kangamuit, Sisimuit and Fylla
206 Structures Complex basins in Nuuk West Province; the South Fylla Structures Complex basin
207 and the Cape Farewell basin in Cape Farewell Province (Figure 1).

208

209 **3.2 Baffin Bay Province (BBP)**

210 The structure of Baffin Bay Province is characterized by two NW-SE trending grabens
211 (Kivioq and Melville Bays) that are separated by the intervening Melville Ridge (Figure 1).
212 The two grabens, which are broadly asymmetric, comprise features that are approximately 50
213 km wide and over 310 km long with sedimentary rocks thickness of up to 5.0 second TWTT
214 in the Melville Bay area (Figure 4). The Kivioq basin is 200 km long and 25 km wide;
215 whereas the Umberk basin is 80 km long by 50 km wide (Table 1). The Melville Ridge has
216 minor sedimentary rockson top of it (~0.1 second or less) suggesting that it remained a
217 structural high throughout most of the evolution of the margin (Figure 4).

218

219 The graben-controlling faults are commonly planar structures with displacements of up to 4.5
220 second TWTT, and are correlatable along trend as a single fault (Figure 4) in excess of 310
221 km in length in the interior of the Baffin Bay basin (Figure 1). In addition to the graben
222 forming structures, a number of intra-basin faults with the same orientation as the basin
223 bounding faults are observed with displacements of up to 1.0 second TWTT (Figure 4). As
224 would be expected, these latter faults have shorter lengths compared to the boundary faults.

225

226 Despite the distance from Baffin Bay to the closest well tie-point of 800 km away from the
227 representative seismic line, the continuous nature of the principal megasequence reflections
228 allows the correlation of the packages into the province with some degree of confidence. The
229 rift phase in Baffin Bay Province is Lower Cretaceous and was controlled by many of the
230 main basin bounding faults, e.g. the Melville Platform fault (Figure 4). However, not all the
231 faults were active during the earliest stages of rifting, with much of the regional vertical
232 displacement being accommodated on a master fault that is now in the middle of the Kivioq
233 basin. These dominant faults became inactive before the cessation of rifting (Figure 4).
234 Instead, the majority of thickening (often sedimentary rocks thickness up to 0.5 second
235 TWTT) during the late stage of rifting is localised onto the graben bounding faults (Figure 4)
236 such as the northern Kivioq Ridge Fault, the northern and southern Melville Ridge Fault and
237 the southern Melville Platform fault (Figures 1 and 4).

238

239 During the transition phase from Early Palaeocene to Mid-Miocene sedimentary rocks are
240 characterized by wedging and thickening towards the faults plane, are truncated against
241 Kivioq Ridge fault and are thinner than Cretaceous synrift deposits. The postrift package
242 from mid Miocene to present thins towards the south which is likely to be a reflection of a
243 reduction in sediment supply from the margin towards the north and differential compaction
244 (See Figures 1 and 4).

245

246 As noted, the Baffin Bay Province is dominated by a series of grabens demarcated to the
247 south by the Kivioq Ridge (Figure 4). Across the ridge there is a rapid transition over 20 km
248 from continental crust across the gravity high and into a transition zone (Figure 4). The
249 continental region as a whole is characterized by large rotated basement blocks composed of
250 seaward dipping faults and deep synrift basins. The central area of Baffin Bay is bounded by

251 a collapsed structure created by an inclined West limb and a sub-horizontal to gently dipping
252 eastern limb (Figure 4). The transition zone is characterized by thinner synrift sedimentary
253 rocks, basalts and seaward dipping reflectors (SDRs) that separates rotated continental
254 basement faulted blocks from the oceanic crust. The oceanic crust is interpreted in the
255 southwest part of Baffin Bay and evident as a chaotic reflection occurring at depth of ~4800
256 ms TWTT.

257

258 The most common fault geometry observed includes horst and graben structures resulting
259 from NW-SE normal faults that divide the Baffin Bay basin into NW-SE structural domains.
260 A NE-SW fault also divides the Kivioq basin from the Upemavik basin (Figure 1). These NE-
261 SW faults, ridges and basins were initiated during the earliest phases of rifting (Figure 4).
262 Deposition of Cretaceous sedimentary rocks in Baffin Bay was into extensive basins in
263 Kivioq and Melville Bay basin (Figure 4) which is at least 5.0 second TWTT thick. The
264 Melville Ridge is a subsurface high on the NE part of the bay (Figure 4). The total
265 thicknesses in Melville and Kivioq basins are approximately 5.0 second to 4 seconds TWTT
266 respectively (Figure 4).

267

268 **3.3 Disko West Province (DWP)**

269 The deepest reflection that is imaged in the Disko West Province is the Paleocene Basalt
270 (PB), which is identified as a high-amplitude reflection and is mappable both across the
271 margin and along the Aasiaa basin. The Aasiaa basin is 350 km long and 30 to 110 km wide
272 and the Disko High is 280 km long and 40 to 60 km wide (Figure 1). The Nussuaq basin is
273 130 km long and 60 km wide (Table 1). This indicates that the volcanic rocks cover an area
274 of ~150,000 km² (Figure 1). Evidence from boreholes, seismic reflection and refraction data
275 located both west and east of Disko Island indicate the presence of thick clastics rocks of

276 Cretaceous age (Chalmers et al., 1999; Dam et al., 2009, Funck et al., 2012; Suckro et al.,
277 2013 and 2012). This is supported by the presence of similarly aged stratigraphy that is found
278 in the east of the Disko West Province that has not been covered by basalt (Figure 1).
279 Although the basalt geometry is not imaged, the basalt reflection package is remarkably
280 continuous.

281

282 In Disko West Province, the faults are dominated by steeply dipping normal faults with a
283 series of half grabens with lengths of up to 350 km and widths of 110 km (Figures 1 and 5).
284 The faults show clear thickening of up to 0.6 second TWTT during the Top Cretaceous-Top
285 Paleocene package (Figure 5). In contrast to the basin bounding faults in Baffin Bay, these
286 faults (N-S and NW-SE) are present in sigmoidal plan view geometry and most likely
287 resembles fault within a pull-apart basin (Figures 1 and 5). This is supported by the presence
288 of strike-slip faults within the area. Towards the southwest, postbasalt faulting is very limited.
289 The exception is a few relatively small normal faults on the eastern flank and a normal fault
290 on the northern edge of the Davis Strait High (Figure 1). However, mapping of gravity and
291 magnetic anomalies suggest that oceanic crust is present with a probably age of 60 Ma
292 (Oakey and Chalmers, 2012). Reflections above the oceanic crust clearly show significant
293 thickening of postrift wedge (Figure 5) from approximately 0.1 second TWTT in the
294 northeast nearshore to 1.5 second TWTT in the southwest. This thickening is most evident in
295 the Mid-Miocene to Quaternary packages (Figure 5). The thickness variation is unrelated to
296 rifting but deposition of postrift packages into topography created by the emplacement of the
297 basalt.

298

299 **3.4 Nuuk West Province (NWP)**

300 The Nuuk West Province has a number of strike-slip structures that trend broadly in a NE-
301 SW orientation and are associated with the Ungava transform fault (Figure 1). In terms of this
302 province length, the Nuuk West Province is about 550 km long from the Fylla complex
303 structure to the Sisimut basin and has a width of 150 km in the north and 260 km in the south
304 (Table 1). The geometry in the south of the Nuuk West Province is remarkably different from
305 that to the north. Instead of a relatively unfaulted flexure, the south is dominated by a number
306 of basement highs (Hecla, Manlitsoq, Kangamuit, Fylla) separated by grabens and half-
307 grabens, different from the faulted north.

308

309 The absence of the Paleocene Basalt (PB) in this area (except on the Hecla and Maniisok
310 High) allows the identification of Top Acoustic Basement (Bs) with greater certainty.
311 Cretaceous rifting is again interpreted in this region and the interpretation in this work
312 suggests a series of isolated, large (> 7 km) rift basins during this phase (Figure 6). The Late
313 Cretaceous package is more uniformly distributed and is mappable across at least some of the
314 basement highs suggesting postrift sedimentation in most of the margin (Figure 6). The nature of
315 this unit however is rather variable. Within the Lady Franklin and Nuuk (Figure 6); Sisimiut
316 (Figure 7); and South Fylla Structures Complex (Figure 8) basins there is demonstrable
317 thickening of strata into rift faults typical of synrift intervals. In contrast, many of the basin
318 faults within the Cretaceous grabens (e.g. Cape Farewell) show no thickening (Figure 8). This
319 may be an indication of how extension was progressively localised onto a limited number of
320 faults during the rift episode. Thick basalts are deposited on both flank of the Hecla High
321 (Figure 6) and a flower structure is interpreted within the Sisimiut basin (Figure 7).
322 Sediments of postrift package were probably deposited during thermal subsidence resulting in
323 onlapping of sediments onto the topography highs. In the Hecla High, postrift strata are thin
324 and post Mid- Miocene in age in contrast to the thick (~1.0 second TWTT) postrift packages

325 of the Fylla Structures Complex Area (Figure 6). The postrift sedimentary succession are
326 thicker (~2.0 second TWTT) in the Sisimiut and Kangamiut basins than in the (FSCA) and
327 Hecla basins (Gregersen and Skaarup, 2007). In addition, the eastern side of Sisimiut basin is
328 characterized by non-deposition of sediment resulting in the absence of Mid-Miocene to
329 present day (Figure 8).

330

331 **3.5 Cape Farewell Province (CFP)**

332 The Cape Farewell Province shows faults up to 200-400 km in length and typical throws of
333 0.5 seconds TWTT (Figures 1 and 8). The (SFSCA) is 400 km long and 100 km wide,
334 whereas the Cape Farewell is approximately 400 km long and 200 km wide (Table 1). One of
335 the faults has a throw of 1.5 second TWTT that may be the result of reactivation during the
336 late stage of rifting in Late Cretaceous (Figure 8). The Cape Farewell Province also marks a
337 significant narrowing in the width of the continental margin as the transition from attenuated
338 continental crust into full oceanic crust occurs over ~80 km (rather than >250 km as is the
339 case further north. On the continental crust the rifting geometry is dominated by relatively
340 planar faults and rotated faults blocks (Figures 1 and 8). The imaging of the footwall cut-offs
341 suggest faults remain planar and show no evidence of a listric geometry with depth. From
342 stratal thickening it is evident that the faults were active during the Cretaceous, similarly to
343 basins in the north. However, the fault throws are significantly smaller (maximum observed
344 throws are <0.5 second TWTT) in contrast to reactivated faults with throws of 1.5 second
345 TWTT. This difference in fault geometry is also reflected in a change of fault orientation.
346 Faults in the southern Nuuk West Province are dominated by a broadly north-south
347 orientation whereas in Cape Farewell they have a NW-SE orientation.

348

349 In the more distal portion of the basin, the lower section is characterized by low amplitude
350 reflectivity suggestive of oceanic crust at ~ 8 seconds TWTT (Figure 8). In addition, the
351 presence of ~ 80 km wide magnetic (70 Ma) and (60 Ma) at the south and north respectively
352 further justifies the presence of the oceanic crust (*cf.* Chalmers and Laursen 1995; Figures 1
353 and 8). The seismic character of the area between the attenuated continental crust containing
354 the rift faults and the oceanic crust is rather enigmatic and may be either Seaward Dipping
355 Reflector (SDR), basaltic intrusions; this is interpreted as the transition zone (Figure 8). It is
356 onlapped by the Upper Cretaceous unit and then overlain by Paleocene basalts that are
357 attributed to break-up related magmatism. These volcanic rocks appear to mask all internal
358 reflections at a transition zone of c. 80 km observed between the oceanic and continental
359 crust. The west section of the transition zone has high amplitude reflectors that may be
360 seaward dipping reflections (Figure 8), and this, coupled to a positive gravity anomaly above
361 it, suggests that it is a late stage volcanic event that may have been the pre-cursor to break-up.
362 Overlying the entire section (Figure 8), including the oceanic and continental crust, is a
363 postrift sequence with a rather constant thickness of ~1.3 second TWTT, reflecting a uniform
364 subsidence across the margin. The exceptions are postrift packages of Palaeocene to Eocene
365 ages, which show local onlap onto both the margin to the east and a volcanic edifice on the
366 ocean crust.

367

368 **4.0 Discussion.**

369 **4.1 Models of the Tectonic Development of the West Greenland margin**

370 The development of the West Greenland margin involved deposition of thick sediment
371 wedges during rifting, faulting of the rift sequence, and erosion of fault scarps that formed
372 during early lithospheric extension by postrift sedimentation. The regional erosion during the
373 latter stage is revealed by Mid-Eocene and Early Miocene unconformities. The rift event

374 interpreted in this study area occurred intermittently with the emplacement of volcanic rocks
375 during the Palaeocene and Eocene. Categorically, the pre-rift packages are flanked by an
376 irregular dome structure in Cape Farewell; the dome is interpreted as a remnant of the
377 oceanic crust or serpentine zone (Figure 9), and it is shown as chaotic and high-amplitude
378 reflection at a deeper stratigraphic level on the seismic data (Figure 8). Furthermore, we
379 surmise that the boundaries of the oceanic crust are delimited by a probably zone of SDRs
380 developed prior the initial opening of the oceanic crust. Neogene uplift, post seafloor
381 spreading are dated ~11-10 Ma and 7-2 Ma (cf. Chalmers, 2000; Green et al., 2011; Japsen et
382 al., 2006). These observations all suggest a rather complex and variable margin evolution.

383

384 We propose a tectonic model that integrates the seismic interpreted faulting and overall basin
385 geometry with the key stage of tectonic development (Figure 9):

386 I. Rifting stage (145-130 Ma): NE-SW extension across the West Greenland margin.
387 This rift produced rotated fault blocks that formed horsts and grabens in the Cape
388 Farewell, Baffin Bay and Nuuk West Provinces. The basin geometry in Disko West
389 Province at this stage is not covered by the available seismic data. However,
390 deposition of Cretaceous age strata onshore suggests that the province was affected by
391 this rift stage. Late stage rifting comprises an early magmatic pulse during which the
392 margin was intruded by dykes in Nuuk West and probably Disko West.

393

394 II. Magma-poor phase (80-70 Ma): recorded as the development of a continental-ocean
395 transition zone that presumably includes attenuated continental crust in the Cape
396 Farewell and Baffin Bay provinces or serpentinised zone. Possible thermal subsidence
397 occurs on other areas across the West Greenland margin. The margin underwent
398 postrift thermal subsidence as materialised by the marine mudstones of Kangeq

399 sequence, which show little evidence of extension prior to the onset of seafloor
400 spreading at 60 Ma (Chalmers 2012).

401 III. Seafloor spreading (70-60 Ma): Seafloor spreading started in the south of Cape
402 Farewell Province (70 Ma) and is likely to have propagated to the northwest of Cape
403 Farewell Province (61 Ma) and then transferred to Baffin Bay via the Ungava fault
404 zone to form oceanic crust at (60 Ma) (See figure 9). The presence of a Magnetic high
405 suggests uniform stretching of the lithosphere in Cape Farewell. Disko West and
406 Baffin Bay showed magnetic low implying slow seafloor spreading on an underlying
407 strongly extended continental crust and/or serpentinised mantle (Reid and Jackson,
408 1997). We propose that the cessation of seafloor spreading occurred during (48 Ma)
409 and at (33 Ma) in Cape Farewell and Baffin Bay Provinces respectively, corroborating
410 the works of Chalmers and Pulvertaft (2001) and Oakey and Chalmers (2012). The
411 shift in spreading axis was from NNE in Palaeocene to NNW in Eocene in Baffin Bay
412 (See also Oakey and Chalmers, 2012). This is attributed to an anticlockwise rotation
413 of spreading axis by the oceanic crust or a shift in magmatic intrusion from West to
414 East Greenland. Hence, the margin subsided after the breakup in the Davis Strait in
415 Palaeocene to Late Eocene times, supporting the model of postrift subsidence reported
416 onshore Disko and Nuussuaq basins (cf. Green et al., 2011).

417

418 **4.2 Magmatism and influence of the mantle plume**

419 For the study area, there continues to be a debate whether the Eocene and Palaeocene
420 volcanism events are the product of multiple mantle plumes or a single mantle plume. The
421 separation and movement of the Greenland and Canada cratons were probably influenced by
422 the migration of a mantle plume that may have caused transient thermal uplift, extension and
423 subsequent plate movements (Harrison et al., 1999). Several authors favoured a single plume

424 hypothesis for the emplacement of all the volcanic provinces (Larsen et al., 1999; Nielsen et
425 al., 2002; Storey et al., 1998; Torsvik et al., 2001). The geochemistry of early picrites of West
426 Greenland are similar to subaerial Icelandic basalts and are formed by similar greater degrees
427 of melting of their source mantle than their Icelandic counterparts (Holm et al., 1993). The
428 volcanic eruption of the West Greenland picrites occurred ~5-6 Ma earlier than the start of
429 volcanism in eastern Greenland (Gill et al., 1995). A possible scenario describing the plume
430 dynamics under West Greenland is that the ~ 60 Ma events involves volcanism from a fast
431 moving upper mantle plume that rapidly spreads out horizontally on encountering the base of
432 the lithosphere (*cf.* Larsen et al., 1999; Nielsen et al., 2002). Palaeomagnetic reconstructions
433 show that mantle and crust processes are linked via complex and enigmatic cause-and-effect
434 relationships (Torsvik et al., 2001).

435

436 Our data analysis supports the notion that the West Greenland plume formed at ~60 Ma as
437 suggested by earlier workers (e.g. Storey et al, 1998). Critically, there was early rifting along
438 the whole margin during a magma-poor phase with more extension recorded in the south. The
439 evidence is for a plume that is present at the transfer zone rather than at the area of greatest
440 extension. Subsequently, the plume played a minor role in rift initiation and development.
441 Therefore, we suggest that the role of the plume was less significant than proposed by
442 previous authors. The plume may have contributed to the cessation of rifting in the study
443 area. Our model proposes that the West-Greenland volcanic margin developed after a period
444 of amagmatic extension during the Cretaceous in accord with the work of Abdelmalak et al.
445 (2012). Consequently, the area was subjected to regional uplift in the Danian (65–60Ma)
446 before the extrusion of pre-breakup magmatic rocks.

447

448 **4.3 Contribution to understanding of lithospheric stretching**

449 Based on the model defined in section 4.1, we propose a) multiphase extension and
450 continental breakup for the West Greenland margin and that b) individual basins within West
451 Greenland comprise both magma-poor and rich basins. The seismic stratigraphic division
452 from this work is consistent with the classification of Schenk (2011). As the transition from
453 rifting to drifting is marked by the breakup unconformity (BU) of Falvey (1974) and Franke
454 (2013); the BU in this study is the mid-Miocene horizon. Angular unconformities with
455 erosional truncation on seismic profiles were interpreted as the Rift Onset Unconformity
456 (ROU) in line with the definition of Falvey, (1974). In the study area, the ROU is the Top
457 Cretaceous Horizon. The nature and position of the Ocean-Continent Transition (OCT) is
458 marked by the presence of Seward Dipping Reflectors (SDR). Structurally, the interpretation
459 of compressional and inversion structures accompanied by strike-slip faulting and local
460 transtensional faults and flexures are expression of the Eurekan orogeny (Gregersen et al.,
461 2013). However, the identification of the transition between synrift and postrift settings may
462 not always be reflected by a simple breakup unconformity (Alves et al., 2009; Soares et al.,
463 2012). These authors show that the “breakup unconformity” is a Lithospheric Breakup
464 Surface (LBS) that is not always developed as an unconformity and that the entire lithosphere
465 is involved in the breakup process, not only the continental crust. The complex nature of the
466 transition phase, which is stratigraphically between the demonstrable synrift and postrift
467 phases, in this study is a reflection that the simple concept of the breakup unconformity is not
468 applicable. Hence, the mid-Miocene (BU) may only indicate basinward shift of the
469 extensional locus and not the end of rifting processes along West Greenland margins (Falvey
470 1974; Soares et al., 2012).

471

472 Our model offers supporting evidence for the occurrence of a passive continental margin
473 comprised of both magma-rich and magma-poor lithospheric extension. Since most passive

474 margins develop in response to lithospheric extension, passive margins can be classified into
475 two end-members depending on the volume of extension-related magmatism (Franke, 2013).
476 Baffin Bay and Labrador Sea are magma-rich margins characterized by SDRs at their ocean-
477 continent transition. Keen et al (2012) showed that the Labrador Sea is exemplified by the
478 presence of excess magmatism, SDRs, and volcanic plateau and thick igneous crust. This
479 agrees with the classification of Funck et al (2007) and Gerlings et al (2009). In contrast,
480 Skaarup et al (2000) proposed that the Labrador Sea is a non-volcanic margin. From this
481 work, the Davis Strait is interpreted as a magma-poor margin that is defined by a wide area of
482 highly attenuated crust where the upper crust is deformed by planar faults. Unlike other
483 magma-poor passive margins, the detachment over which the fault soles was not interpreted.
484 Therefore, the West Greenland to the north and south are magma-rich margins while centrally
485 it is magma-poor margin. This highlights that single margins can be highly variable and these
486 simple end members are not always applicable.

487

488 The role of mantle plumes in the evolution of magma-rich margins has been a subject of
489 debate. Crustal rifting can evolve in conjunction with a plume head as: a) where the plume
490 head triggers the rift evolution by a circular uplift in which the earliest and widest rift is
491 expected to be close to the plume head and the width of the rift decreases away from the
492 plume; and b) where the rift starts farther from the plume with a consistently decreasing
493 width of the rift toward the plume (Franke, 2013). Examples include Iberia–Newfoundland,
494 the Equatorial Atlantic Ocean, and East Antarctica–Australia. We have shown that extension
495 along the West Greenland was less dependent on the mantle plume and that continental
496 extension and break-up is not always associated with large amounts of volcanism.

497

498 The evolutionary model presented in this paper has implications for all aspects of
499 hydrocarbon prospectivity in West Greenland. Reservoir intervals are likely to be present in
500 synrift strata deposited in the observed half grabens of substantial size as well as postrift
501 clastic deposits (Table 1). These intervals include the fluvio-deltaic sandstones of the
502 Cretaceous Atane Formation in the Nuussuaq basin, the mid-Cretaceous to Paleocene marine
503 slope channel sandstones and the marine canyon sandstones equivalent to the incised valley
504 fill sandstones of the Paleocene Quikavsak Member (Dam et al., 2009; Dam et al., 1998). The
505 deposition of these intervals, and the facies variations within them, will be intimately
506 controlled by the basin and fault architecture that we have presented (Figure 9). Of equal
507 importance as reservoir distribution is the trapping mechanisms, which within our
508 interpretation are likely to include both structural and stratigraphic plays. Early rotated faults
509 blocks, grabens and their horsts are important structural trap forming three-way closure.
510 Additional trapping mechanism may include Upper Cretaceous compressional structures and
511 rollover four-way closures formed by synrift packages (Figure 6).

512

513 The Paleocene was a time of widespread volcanic activity in the central part of the Davis
514 Strait (Larsen and Pulvertaft, 2000; Pedersen and Larsen, 2006), when several kilometres of
515 plume-related volcanic rocks were extruded regionally. Consequently, basalts extruded into
516 Cretaceous strata are going to alter both reservoir and basin scale heat flow scenarios. The
517 synvolcanic strata of the Baffin Bay Province may be of interest for hydrocarbon exploration
518 activity (Pedersen et al., 2002) with the stratigraphic position of volcanic rocks is playing a
519 role on reservoir scale source rock maturation. The Neogene was a time of widespread clastic
520 input along north Atlantic passive margins, indicative of Neogene uplift that has been
521 documented from many onshore locations around the Arctic and north Atlantic (Japsen et al.,
522 2005; Japsen and Chalmers, 2000). The implications of such uplift are poorly constrained on

523 other margins but are likely to influence sediment supply, geometry of stratigraphic traps and
524 may also alter regional heat flows (Paton et al., 2008).

525

526 **5.0 Conclusion**

527 We present a new structural framework for the West Greenland margin. This reveals a long
528 and complex evolution, and in particular demonstrates:

- 529 • Rifting margin in Early Cretaceous with synrift packages intercalated with volcanic
530 sills. The Palaeocene basalt occurred in the Disko West, south Baffin Bay and the
531 north Cape Farewell Provinces. These extrusive rocks are connected with the breakup
532 stage during the development of the West Greenland margin.
- 533 • The architecture of faults in the Davis Strait High suggests continuity between the
534 structures of Labrador Sea and Baffin Bay. Strike-slip faults in the Davis Strait acted
535 as transfer zones for displacement during seafloor spreading during and after volcanic
536 activity.
- 537 • Incipient rifting on the West Greenland margin was unaffected by the mantle plume.
538 Seafloor spreading started in the Cape Farewell, propagated to the north West and
539 later slowly to Baffin Bay where the underlying continental crust is strongly extended
540 over a probable serpentinised mantle.
- 541 • The basins on the West Greenland margin such as the Sisimiut, Kangamiut and
542 Melville Bay Graben have significant potential for hydrocarbon reservoir and seal in
543 thick Cretaceous strata. Structural traps include half grabens and grabens with further
544 potential in possibly inverted structures.
- 545 • The West Greenland margin is characterized by magma-rich and poor basins.

546

547 In conclusion, tectono- stratigraphic packages studied from seismic reflection and borehole
548 data interpretation has permitted the basin architecture to be established and allowed us to
549 construct a model for the tectonic development of West Greenland basins. The West
550 Greenland margin shows complex tectono-stratigraphy and the along margin variability, in
551 particular the variation of magma-poor to magma-rich margin, the relatively small influence
552 of plume emplacement, and the significant variation in rift architecture along the margin has
553 a significant impact on the hydrocarbon potential resources. Hence, the boarder basin
554 geometry have more accommodation space for sediments and higher potential for
555 hydrocarbon accommodation than their narrow counterparts.

556

557

558 Acknowledgement

559 We would like to thank GEUS and TGS for data. Saudi Aramco for funding, and also
560 reviewers; Tiago Alves and Chris Jackson for their every constructive comments

561 **References**

562 Abdelmalak, M. M., L. Geoffroy, J. Angelier, B. Bonin, J. P. Callot, J. P. Gélard, and C.
563 Aubourg, 2012, Stress fields acting during lithosphere breakup above a melting mantle: A
564 case example in West Greenland: Tectonophysics, v. 581, p. 132-143. doi:
565 <http://dx.doi.org/10.1016/j.tecto.2011.11.020>

566 Alves, T. M., C. Moita, T. Cunha, M. Ullnaess, R. Myklebust, J. H. Monteiro, and G.
567 Manuppella, 2009, Diachronous evolution of Late Jurassic–Cretaceous continental rifting in
568 the northeast Atlantic (west Iberian margin): *Tectonics*, v. 28, p. TC4003. doi:
569 10.1029/2008tc002337

570 Badley, M. E., 1985, *Practical seismic interpretation*, Medium: X; Size: Pages: 265 p.

571 Balkwill, H. R., N. J. McMillan, B. MacLean, G. L. Williams, and S. P. Srivastava, 1990,
572 *Geology of the continental margin of Eastern Canada / edited by M.J. Keen and G.L.*
573 *Williams*, v. 2: Ottawa :, Canadian Government Publishing Center.

574 Bojesen-Koefoed, J. A., F. G. Christiansen, H. P. Nytoft, and A. K. Pedersen, 1999, Oil
575 seepage onshore West Greenland: evidence of multiple source rocks and oil mixing:
576 *Geological Society, London, Petroleum Geology Conference series*, v. 5, p. 305-314. doi:
577 10.1144/0050305

578 Bojesen-Koefoed, J. A., H. P. Nytoft, and F. G. Christiansen, 2004, Age of oils in West
579 Greenland: Was there a Mesozoic seaway between Greenland and Canada: *Geological*
580 *Survey of Denmark and Greenland Bulletin*, v. 4, p. 49-52.

581 Burden, E. T., and A. B. Langille, 1990, Stratigraphy and sedimentology of Cretaceous and
582 Paleocene strata in half-grabens on the southeast coast of Baffin Island, Northwest
583 Territories: *Bulletin of Canadian Petroleum Geology*, v. 38, p. 185-196.

584 Chalmers, J. A., 1991, New evidence on the structure of the Labrador Sea/Greenland
585 continental margin: *Journal of the Geological Society*, v. 148, p. 899-908. doi:
586 10.1144/gsjgs.148.5.0899

587 Chalmers, J. A., 2000, Offshore evidence for Neogene uplift in central West Greenland:
588 *Global and Planetary Change*, v. 24, p. 311-318. doi: 10.1016/s0921-8181(00)00015-1

589 Chalmers, J. A., 2012, 11 - Labrador Sea, Davis Strait, and Baffin Bay, in D. G. Roberts, and
590 A. W. Bally, eds., *Regional Geology and Tectonics: Phanerozoic Passive Margins, Cratonic*
591 *Basins and Global Tectonic Maps*: Boston, Elsevier, p. 384-435.

592 Chalmers, J. A., and K. H. Laursen, 1995, Labrador Sea: the extent of continental and
593 oceanic crust and the timing of the onset of seafloor spreading: *Marine and Petroleum*
594 *Geology*, v. 12, p. 205-206. doi: 10.1016/0264-8172(95)92840-s

595 Chalmers, J. A., and T. C. R. Pulvertaft, 2001, Development of the continental margins of the
596 Labrador Sea: a review: *Geological Society, London, Special Publications*, v. 187, p. 77-105.
597 doi: 10.1144/gsl.sp.2001.187.01.05

598 Chalmers, J. A., T. C. R. Pulvertaft, F. G. Christiansen, H. C. Larsen, K. H. Laursen, and T.
599 G. Ottesen, 1993, The southern West Greenland continental margin: rifting history, basin
600 development, and petroleum potential: *Geological Society, London, Petroleum Geology*
601 *Conference series*, v. 4, p. 915-931. doi: 10.1144/0040915

602 Chalmers, J. A., T. C. R. Pulvertaft, C. Marcussen, and A. K. Pedersen, 1999, New insight
603 into the structure of the Nuussuaq Basin, central West Greenland: *Marine and Petroleum*
604 *Geology*, v. 16, p. 197-211, 213-224. doi: 10.1016/s0264-8172(98)00077-4

605 Clift, P. D., and J. Turner, 1995, Dynamic support by the Icelandic plume and vertical
606 tectonics of the northeast Atlantic continental margins: *Journal of Geophysical Research:*
607 *Solid Earth*, v. 100, p. 24473-24486. doi: 10.1029/95jb02511

608 Corti, G., 2009, Continental rift evolution: From rift initiation to incipient break-up in the
609 Main Ethiopian Rift, East Africa: *Earth-Science Reviews*, v. 96, p. 1-53. doi:
610 <http://dx.doi.org/10.1016/j.earscirev.2009.06.005>

611 Dalhoff, F., J. A. Chalmers, U. Gregersen, H. Nøhr-Hansen, J. Audun Rasmussen, and E.
612 Sheldon, 2003, Mapping and facies analysis of Paleocene–Mid-Eocene seismic sequences,
613 offshore southern West Greenland: *Marine and Petroleum Geology*, v. 20, p. 935-986. doi:
614 10.1016/j.marpetgeo.2003.09.004

615 Dam, G., M. Larsen, and M. Sønderholm, 1998, Sedimentary response to mantle plumes:
616 Implications from Paleocene onshore successions, West and East Greenland: *Geology*, v. 26,
617 p. 207-210. doi: 10.1130/0091-7613(1998)026<0207:srtmpi>2.3.co;2

618 Dam, G., H. Nøhr-Hansen, G. K. Pedersen, and M. Sønderholm, 2000, Sedimentary and
619 structural evidence of a new early Campanian rift phase in the Nuussuaq Basin, West
620 Greenland: *Cretaceous Research*, v. 21, p. 127-154. doi: 10.1006/cres.2000.0202

621 Dam, G., G. K. Pedersen, M. Sønderholm, H. H. Midtgaard, L. M. Larsen, H. Nøhr-Hansen,
622 and A. K. Pedersen, 2009, Lithostratigraphy of the Cretaceous–Paleocene Nuussuaq Group,
623 Nuussuaq Basin, West Greenland: *Geological Survey of Denmark and Greenland Bulletin*, v.
624 19, p. 1-171.

625 Davies, G., 1998, A channelled plume under Africa: *Nature*, v. 395, p. 743-744. doi:
626 10.1038/27320

627 Falvey, D. A., 1974, The development of continental margins in plate tectonic theory: *APEA*
628 *J*, v. 14, p. 95-106.

629 Franke, D., 2013, Rifting, lithosphere breakup and volcanism: Comparison of magma-poor
630 and volcanic rifted margins: *Marine and Petroleum Geology*, v. 43, p. 63-87. doi:
631 <http://dx.doi.org/10.1016/j.marpetgeo.2012.11.003>

632 Funck, T., K. Gohl, V. Damm, and I. Heyde, 2012, Tectonic evolution of southern Baffin
633 Bay and Davis Strait: Results from a seismic refraction transect between Canada and
634 Greenland: *J. Geophys. Res.*, v. 117, p. B04107. doi: 10.1029/2011jb009110

635 Funck, T., H. R. Jackson, K. E. Loudon, and F. Klingelhöfer, 2007, Seismic study of the
636 transform-rifted margin in Davis Strait between Baffin Island (Canada) and Greenland: What
637 happens when a plume meets a transform: *Journal of Geophysical Research: Solid Earth*, v.
638 112, p. n/a-n/a. doi: 10.1029/2006jb004308

639 Gerlings, J., T. Funck, H. R. Jackson, K. E. Loudon, and F. Klingelhoefer, 2009, Seismic
640 evidence for plume-derived volcanism during formation of the continental margin in southern
641 Davis Strait and northern Labrador Sea: *Geophysical Journal International*, v. 176, p. 980-
642 994. doi: 10.1111/j.1365-246X.2008.04021.x

643 Gill, R. C. O., P. M. Holm, and T. F. D. Nielsen, 1995, Was a short-lived Baffin Bay plume
644 active prior to initiation of the present Icelandic plume? Clues from the high-Mg picrites of
645 West Greenland: *Lithos*, v. 34, p. 27-39. doi: 10.1016/0024-4937(95)90007-1

646 Green, P. F., P. Japsen, J. A. Chalmers, and J. M. Bonow, 2011, Thermochronology, erosion
647 surfaces and missing section in West Greenland: *Journal of the Geological Society*, v. 168, p.
648 817-830. doi: 10.1144/0016-76492010-124

649 Gregersen, U., and T. Bidstrup, 2008, Structures and hydrocarbon prospectivity in the
650 northern Davis Strait area, offshore West Greenland: *Petroleum Geoscience*, v. 14, p. 151-
651 166. doi: 10.1144/1354-079308-752

652 Gregersen, U., J. R. Hopper, and P. C. Knutz, 2013, Basin seismic stratigraphy and aspects of
653 prospectivity in the NE Baffin Bay, Northwest Greenland: *Marine and Petroleum Geology*, v.
654 46, p. 1-18. doi: <http://dx.doi.org/10.1016/j.marpetgeo.2013.05.013>

655 Gregersen, U., and N. Skaarup, 2007, A mid-Cretaceous prograding sedimentary complex in
656 the Sisimiut Basin, offshore West Greenland—stratigraphy and hydrocarbon potential:
657 *Marine and Petroleum Geology*, v. 24, p. 15-28. doi:
658 <http://dx.doi.org/10.1016/j.marpetgeo.2006.10.005>

659 Griffiths, R. W., and I. H. Campbell, 1990, Stirring and structure in mantle starting plumes:
660 *Earth and Planetary Science Letters*, v. 99, p. 66-78. doi: [http://dx.doi.org/10.1016/0012-821X\(90\)90071-5](http://dx.doi.org/10.1016/0012-821X(90)90071-5)

662 Harrison, J. C., T. A. Brent, and G. N. Oakey, 2011, Chapter 40 Baffin Fan and its inverted
663 rift system of Arctic eastern Canada: stratigraphy, tectonics and petroleum resource potential:
664 *Geological Society, London, Memoirs*, v. 35, p. 595-626. doi: 10.1144/m35.40

665 Harrison, J. C., U. Mayr, D. H. McNeil, A. R. Sweet, J. J. Eberle, D. J. McIntyre, C. R.
666 Harington, J. A. Chalmers, G. Dam, and H. Nohr-Hansen, 1999, Correlation of Cenozoic
667 sequences of the Canadian Arctic region and Greenland; implications for the tectonic history
668 of northern North America: *Bulletin of Canadian Petroleum Geology*, v. 47, p. 223-254.

669 Holm, P. M., R. C. O. Gill, A. K. Pedersen, J. G. Larsen, N. Hald, T. F. D. Nielsen, and M. F.
670 Thirlwall, 1993, the tertiary picrites of west greenland - contributions from icelandic and
671 other sources: *Earth and Planetary Science Letters*, v. 115, p. 227-244. doi: 10.1016/0012-
672 821x(93)90224-w

673 Huisman, R., and C. Beaumont, 2011, Depth-dependent extension, two-stage breakup and
674 cratonic underplating at rifted margins: *Nature*, v. 473, p. 74-78. doi:

675 [http://www.nature.com/nature/journal/v473/n7345/abs/10.1038-nature09988-](http://www.nature.com/nature/journal/v473/n7345/abs/10.1038-nature09988-unlocked.html#supplementary-information)
676 [unlocked.html#supplementary-information](http://www.nature.com/nature/journal/v473/n7345/abs/10.1038-nature09988-unlocked.html#supplementary-information)

677 Japsen, P., J. M. Bonow, P. F. Green, J. A. Chalmers, and K. Lidmar-Bergström, 2006,
678 Elevated, passive continental margins: Long-term highs or Neogene uplifts? New evidence
679 from West Greenland: *Earth and Planetary Science Letters*, v. 248, p. 330-339. doi:
680 <http://dx.doi.org/10.1016/j.epsl.2006.05.036>

681 Japsen, P., and J. A. Chalmers, 2000, Neogene uplift and tectonics around the North Atlantic:
682 overview: *Global and Planetary Change*, v. 24, p. 165-173. doi:
683 [http://dx.doi.org/10.1016/S0921-8181\(00\)00006-0](http://dx.doi.org/10.1016/S0921-8181(00)00006-0)

684 Japsen, P., P. F. Green, and J. A. Chalmers, 2005, Separation of Palaeogene and Neogene
685 uplift on Nuussuaq, West Greenland: *Journal of the Geological Society*, v. 162, p. 299-314.
686 doi: 10.1144/0016-764904-038

687 Keen, C. E., K. Dickie, and S. A. Dehler, 2012, The volcanic margins of the northern
688 Labrador Sea: Insights to the rifting process: *Tectonics*, v. 31, p. n/a-n/a. doi:
689 10.1029/2011tc002985

690 Knutsen, S. M., N. P. Arendt, M. K. Runge, J. Stilling, and M. P. Brandt, 2012, Structural
691 provinces offshore West Greenland and key geological variations influencing play
692 assessment: *First Break* v. 30, p. 43-55. doi: 10.3997/1365-2397.2012021

693 Larsen, J. G., and T. C. R. Pulvertaft, 2000, The structure of the Cretaceous-Palaeogene
694 sedimentary-volcanic area of Svartehuk Halvø, central West Greenland, v. 188, *Geological*
695 *Survey of Denmark and Greenland, Ministry of Environment and Energy.*

696 Larsen, T. B., D. A. Yuen, and M. Storey, 1999a, Ultrafast mantle plumes and implications
697 for flood basalt volcanism in the Northern Atlantic Region: *Tectonophysics*, v. 311, p. 31-43.
698 doi: 10.1016/s0040-1951(99)00163-8

699 Lister, G. S., M. A. Etheridge, and P. A. Symonds, 1986, Detachment faulting and the
700 evolution of passive continental margins: *Geology*, v. 14, p. 246-250. doi: 10.1130/0091-
701 7613(1986)14<246:dfateo>2.0.co;2

702 Lundin, E. R., and A. G. Doré, 2011, Hyperextension, serpentinization, and weakening: A
703 new paradigm for rifted margin compressional deformation: *Geology*, v. 39, p. 347-350. doi:
704 10.1130/g31499.1

705 McGregor, E. D., S. B. Nielsen, R. A. Stephenson, O. R. Clausen, K. D. Petersen, and D. I.
706 M. Macdonald, 2012, Evolution of the west Greenland margin: offshore thermostratigraphic
707 data and modelling: *Journal of the Geological Society*, v. 169, p. 515-530. doi: 10.1144/0016-
708 76492011-139

709 McKenzie, D., 1978, Some remarks on the development of sedimentary basins: *Earth and*
710 *Planetary Science Letters*, v. 40, p. 25-32. doi: [http://dx.doi.org/10.1016/0012-](http://dx.doi.org/10.1016/0012-821X(78)90071-7)
711 [821X\(78\)90071-7](http://dx.doi.org/10.1016/0012-821X(78)90071-7)

- 712 Merle, O., 2011, A simple continental rift classification: *Tectonophysics*, v. 513, p. 88-95.
713 doi: <http://dx.doi.org/10.1016/j.tecto.2011.10.004>
- 714 Mitchum Jr, R. M., P. R. VAIL, and J. B. SANGREE, 1977, Seismic stratigraphy and global
715 changes of sea level, part 11: Stratigraphic Interpretation of Seismic Reflection Patterns in
716 Depositional Sequences: *AAPG Bulletin*, v. Memoir 26, p. 117-133.
- 717 Müller, R. D., M. Sdrolias, C. Gaina, and W. R. Roest, 2008, Age, spreading rates, and
718 spreading asymmetry of the world's ocean crust: *Geochem. Geophys. Geosyst.*, v. 9, p.
719 Q04006. doi: 10.1029/2007gc001743
- 720 Nielsen, T. K., H. C. Larsen, and J. R. Hopper, 2002, Contrasting rifted margin styles south
721 of Greenland: implications for mantle plume dynamics: *Earth and Planetary Science Letters*,
722 v. 200, p. 271-286. doi: 10.1016/s0012-821x(02)00616-7
- 723 Nøhr-Hansen, H., and G. Dam, 1997, Palynology and sedimentology across a new marine
724 Cretaceous-Tertiary boundary section on Nuussuaq, West Greenland: *Geology*, v. 25, p. 851-
725 854. doi: 10.1130/0091-7613(1997)025<0851:pasaan>2.3.co;2
- 726 Oakey, G. N., and J. A. Chalmers, 2012, A new model for the Paleogene motion of
727 Greenland relative to North America: Plate reconstructions of the Davis Strait and Nares
728 Strait regions between Canada and Greenland: *J. Geophys. Res.*, v. 117, p. B10401. doi:
729 10.1029/2011jb008942
- 730 Paton, D. A., D. van der Spuy, R. di Primio, and B. Horsfield, 2008, Tectonically induced
731 adjustment of passive-margin accommodation space; influence on the hydrocarbon potential
732 of the Orange Basin, South Africa: *AAPG Bulletin*, v. 92, p. 589-609
- 733 Pedersen, A. K., and L. M. Larsen, 2006, The Ilugissoq graphite andesite volcano, Nuussuaq,
734 central West Greenland: *Lithos*, v. 92, p. 1-19. doi:
735 <http://dx.doi.org/10.1016/j.lithos.2006.03.027>
- 736 Pedersen, A. K., L. M. Larsen, P. Riisager, and K. S. Dueholm, 2002, Rates of volcanic
737 deposition, facies changes and movements in a dynamic basin: the Nuussuaq Basin, West
738 Greenland, around the C27n-C26r transition: *Geological Society, London, Special
739 Publications*, v. 197, p. 157-181. doi: 10.1144/gsl.sp.2002.197.01.07
- 740 Pik, R., B. Marty, and D. R. Hilton, 2006, How many mantle plumes in Africa? The
741 geochemical point of view: *Chemical Geology*, v. 226, p. 100-114. doi:
742 <http://dx.doi.org/10.1016/j.chemgeo.2005.09.016>
- 743 Reid, I., and H. R. Jackson, 1997, Crustal structure of northern Baffin Bay: Seismic refraction
744 results and tectonic implications: *J. Geophys. Res.*, v. 102, p. 523-542. doi:
745 10.1029/96jb02656
- 746 Reston T.J and M. Pérez-Gussinyé, 2007. Lithospheric extension from rifting to continental
747 break-up at magma-poor margins: rheology, serpentinisation and symmetry. *Int. J. Earth Sci.*,
748 doi:10.1007/s00531-006-0161-z

749 Rolle, F., 1985, Late Cretaceous – Tertiary sediments offshore central West Greenland:
750 lithostratigraphy, sedimentary evolution, and petroleum potential: *Canadian Journal of Earth*
751 *Sciences*, v. 22, p. 1001-1019. doi: doi:10.1139/e85-105

752 Rowley, D. B., and A. L. Lottes, 1988, Plate-kinematic reconstructions of the North Atlantic
753 and Arctic: Late Jurassic to Present: *Tectonophysics*, v. 155, p. 73-120. doi: 10.1016/0040-
754 1951(88)90261-2

755 Schenk, C. J., 2011, Chapter 41 Geology and petroleum potential of the West Greenland–East
756 Canada Province: *Geological Society, London, Memoirs*, v. 35, p. 627-645. doi:
757 10.1144/m35.41

758 Skaarup, N., J. A. Chalmers, and D. White, 2000, An AVO study of a possible new
759 hydrocarbon play, offshore central West Greenland: *AAPG Bulletin*, v. 84, p. 174-182.

760 Skaarup, N., H. Jackson, and G. Oakey, 2006, Margin segmentation of Baffin Bay/Davis
761 Strait, eastern Canada based on seismic reflection and potential field data: *Marine and*
762 *Petroleum Geology*, v. 23, p. 127-144. doi: 10.1016/j.marpetgeo.2005.06.002

763 Soares, D. M., T. M. Alves, and P. Terrinha, 2012, The breakup sequence and associated
764 lithospheric breakup surface: Their significance in the context of rifted continental margins
765 (West Iberia and Newfoundland margins, North Atlantic): *Earth and Planetary Science*
766 *Letters*, v. 355–356, p. 311-326. doi: <http://dx.doi.org/10.1016/j.epsl.2012.08.036>

767 Sørensen, A. B., 2006, Stratigraphy, structure and petroleum potential of the Lady Franklin
768 and Maniitsoq Basins, offshore southern West Greenland: *Petroleum Geoscience*, v. 12, p.
769 221-234. doi: 10.1144/1354-079305-692

770 Storey, M., R. A. Duncan, A. K. Pedersen, L. M. Larsen, and H. C. Larsen, 1998, ⁴⁰Ar/³⁹Ar
771 geochronology of the West Greenland Tertiary volcanic province: *Earth and Planetary*
772 *Science Letters*, v. 160, p. 569-586. doi: 10.1016/s0012-821x(98)00112-5

773 Suckro, S. K., K. Gohl, T. Funck, I. Heyde, A. Ehrhardt, B. Schreckenberger, J. Gerlings, V.
774 Damm, and W. Jokat, 2012, The crustal structure of southern Baffin Bay: implications from a
775 seismic refraction experiment: *Geophysical Journal International*.

776 Suckro, S. K., K. Gohl, T. Funck, I. Heyde, B. Schreckenberger, J. Gerlings, and V. Damm,
777 2013, The Davis Strait crust—a transform margin between two oceanic basins: *Geophysical*
778 *Journal International*. doi: 10.1093/gji/ggs126

779 Torsvik, T. H., J. Mosar, and E. A. Eide, 2001, Cretaceous-Tertiary geodynamics: a North
780 Atlantic exercise: *Geophysical Journal International*, v. 146, p. 850-866. doi: 10.1046/j.0956-
781 540x.2001.01511.x

782 Wernicke, B., 1985, Uniform-sense normal simple shear of the continental lithosphere:
783 *Canadian Journal of Earth Sciences*, v. 22, p. 108-125. doi: 10.1139/e85-009

784 White, R., and D. McKenzie, 1989, Magmatism at Rift Zones: The Generation of Volcanic
785 Continental Margins and Flood Basalts: *J. Geophys. Res.*, v. 94, p. 7685-7729. doi:
786 10.1029/JB094iB06p07685

787 Whittaker, R. C., N. E. Hamann, and T. C. R. Pulvertaft, 1997, A new frontier province
788 offshore northwest Greenland: Structure, basin development, and petroleum potential of the
789 Melville Bay area: *Aapg Bulletin-American Association of Petroleum Geologists*, v. 81, p.
790 978-998.

791

792

793

794

795

796

797

798 **Figure 1:** Regional tectonic framework map of the West Greenland study area at Top
799 Cretaceous level. Generated by data integration of, 2D seismic data (GEUS and TGS),
800 Structural Provinces after Knutsen et al., (2012). Global Seafloor Fabric and Magnetic chrons
801 from Roest & Srivastava 1989 (dotted dark blue lines; C21-C33); and Chalmers and Laursen
802 1995 (dotted red lines; C27). Seafloor from Müller 2008 which has been modified to fit data
803 seismic. Continental-Oceanic Transition zone (COT) has been characterized by Seaward
804 Dipping Reflectors (SDRs), basalts and dikes. Ungava Transform Fault Zone (UTFZ), Fylla
805 Structures Complex Area (FSCA) and South Fylla Structures Complex Area (SFSCA)
806 **Figure 2:** Generalized stratigraphic column of the West Greenland margin (this paper)
807 differential subsidence and uplift among these basins have been established.

808 **Figure 3:** (a) Reflection terminations used for the seismic interpretation in this study. (b)
809 Interpreted seismic examples from the study area showing applied reflection termination on a
810 sequence boundary showing onlap, toplap, downlap and erosional truncation. (c)
811 Chronostratigraphic interpretation in this study.

812 **Figure 4:** Seismic profile line 1 (line position in Figure 1) showing the interpreted
813 sedimentary units in north Baffin Bay Province. Synrift sediments of lower and upper
814 Cretaceous are in Melville Bay and Kivioq basins. Transition time include the Paleocene and
815 Eocene sediments and postrift sediments from Mid-Miocene to present. The oceanic crust
816 exposed at c. (6.0 second TWTT) southwest of Kivioq ridge. A Continental-Oceanic
817 Transition (COT) zone is at c. (4.5 Second TWTT) and characterized by SDRs and basalt.
818 Half right part is Kan92 of (GEUS) seismic data and other half on the right is reprocessed
819 BB08RE11 (TGS) seismic data.

820 **Figure 5:** Seismic profile line 2 (line position in Figure 1) showing the interpreted
821 sedimentary units of synrift in the Disko West Province including Paleocene Basalt and early
822 Eocene sediments. Postrift from Mid- Miocene to present sediments. Cretaceous synrift
823 sediments masked by a basalt layer. The approximate position of (COT) zone occurs at c. (4.5
824 second TWTT). The oceanic crust exposed at c. (3.8 second TWTT) southwest of Aaisaa
825 basin.

826 **Figure 6:** Seismic profile line 3 (line position in Figure 1) showing the interpreted
827 sedimentary units in the Nuuk West Province. Synrift sediments of lower and upper
828 Cretaceous in Sisimint Basin. Transition time includes the Paleocene and early Eocene
829 sediments and postrift sediments from Mid- Miocene to present. The basin characterized by
830 flower structures as part of the (UTFZ) and Paleocene dikes in the lower Cretaceous
831 sediment.

832 **Figure 7:** Seismic profile line 4 (line position in Figure 1) showing the interpreted
 833 sedimentary units in the Nuuk West Province. Synrift sediments of lower and upper
 834 Cretaceous in Nuuk and Lady Franklin Basins. Transition time includes the Paleocene to
 835 Mid-Miocene sediments. Postrift sediments from Mid- Miocene to present. Paleocene dikes
 836 in the lower cretaceous sediment.

837 **Figure 8:** Seismic profile line 5 (line position in Figure 1) showing the interpreted
 838 sedimentary units in Cape Farewell Province. Synrift sediments of lower and upper
 839 Cretaceous in (SFSCA). Transition time includes the basalt of Early Paleocene to Mid-
 840 Miocene. Postrift sediments from Mid- Miocene to present as well as oceanic crust
 841 formation. The oceanic crust is flanked by high-amplitude reflections which might be a
 842 (COT) zone. This (COT) zone occurs at c. (6.0 second TWTT).

843 **Figure 9:** West Greenland basin evolution model.

844 **Table 1:** Summarizing the major basins geometries and thicknesses of west Greenland
 845 continental margin

Table 1: Summarising the major basins geometries and thicknesses of west Greenland continental margin

West Greenland provinces	Basins geometry			Synrift sediment thicknesses	Transition sediment thicknesses	Postrift sediment thicknesses
	Basin Name	Length Km	Width Km	TWTT, Second	TWTT, Second	TWTT, Second
Baffin Bay Province	Melville	310	50	2.50	1.35	1.00
	Kivioq	200	25	1.41	1.00	2.00
	Upemavik	80	50	0.98	1.00	2.15
Disko West	Aasiaa	30-100	350	n	1.60	2.00

Province	Disko high	40-60	280	n	0.50	0.14
	Nuussuaq	130	60	1.0	n	n
Nuuk West Province	Sisimiut	120	100	2.40	1.30	1.10
	Ikimurt	120	40	2.12	1.04	1.00
	Kangamuit	110	50	2.14	1.1	1.20
	Maniisoq high	80	60	1.02	0.22	0.75
	Nuuk west	200	80	2.53	0.8	1.21
	Lady franklin	180	80	3.67	1.2	1.00
	Fylla Structures Complex	110	100	1.55	0.80	1.5
	Helca high	120	55	1.87	0.5	1.06
Cape Farewell Province	South Fylla Structures Complex	400	100	1.05	0.75	0.95
	Cape Fairwell	400	200	0.80	0.96	1.5

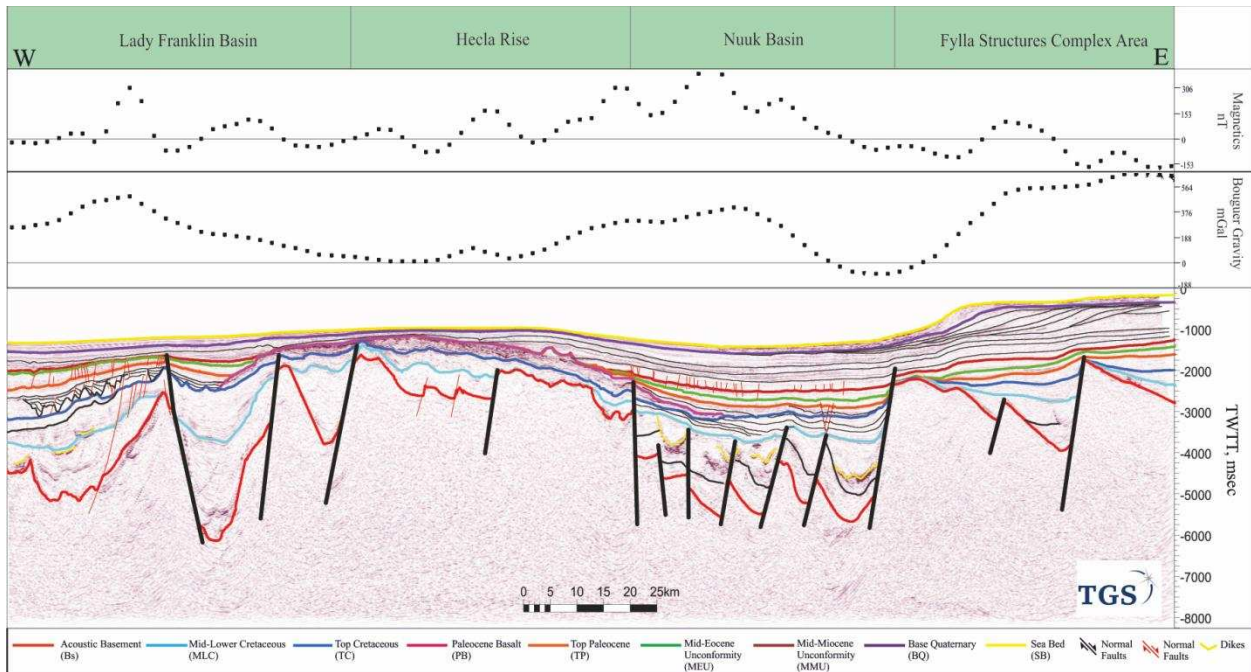


Fig 7

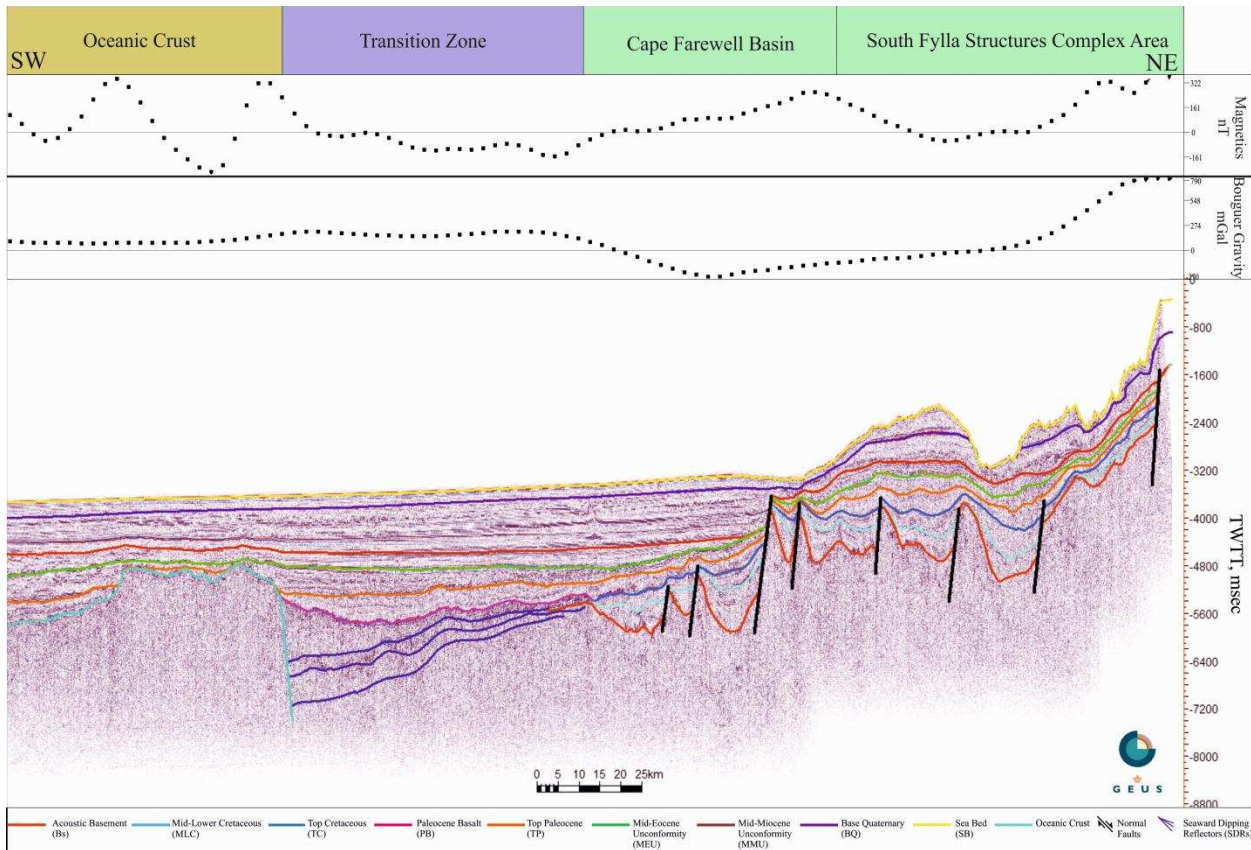


Fig 8

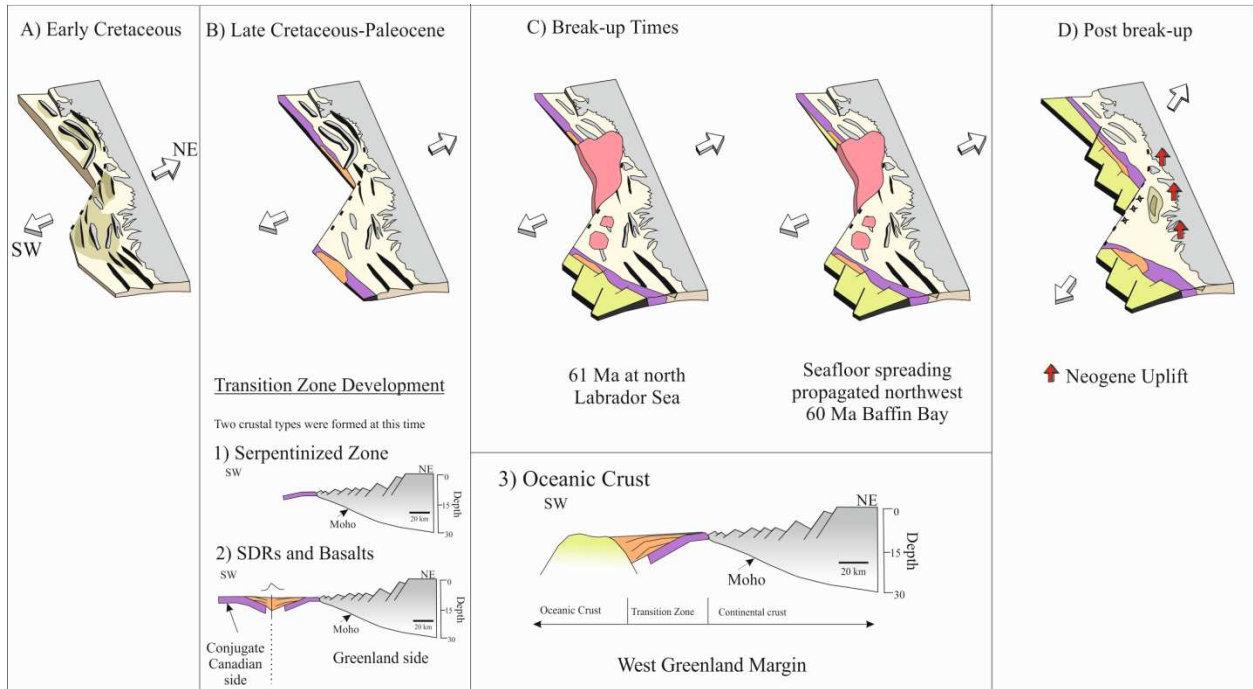


Fig 9

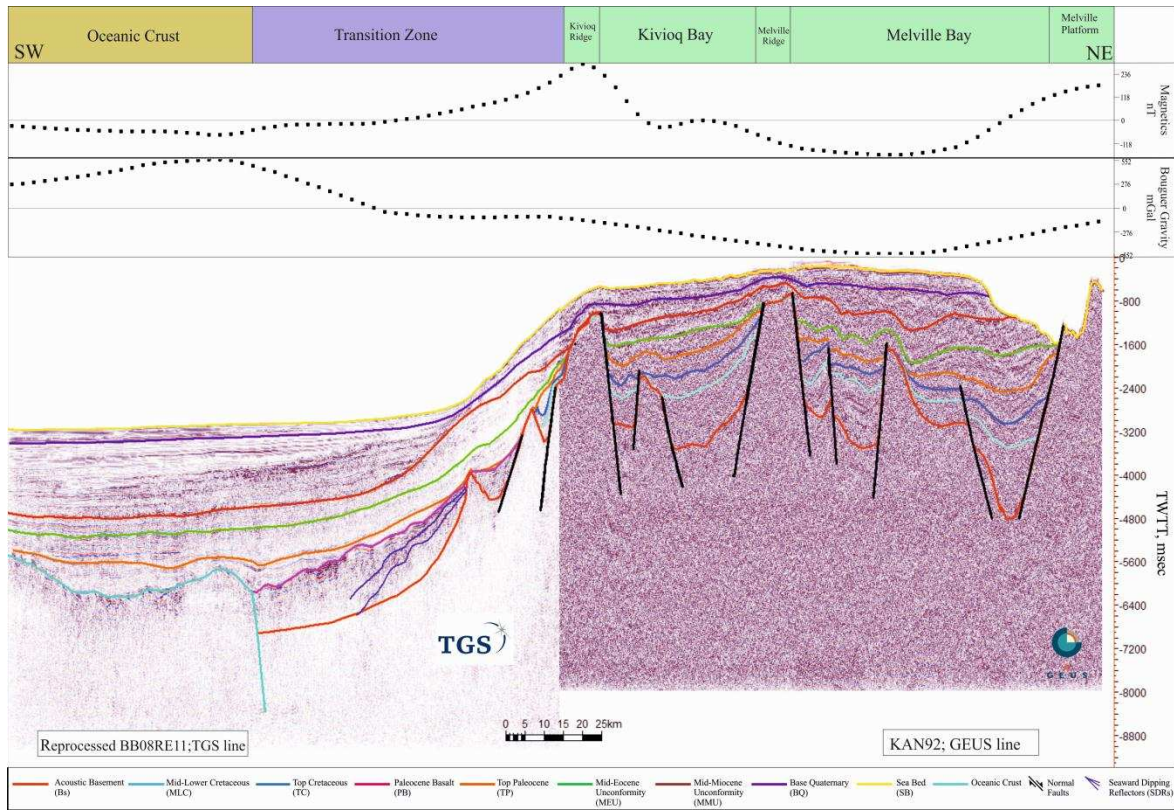


Fig 4

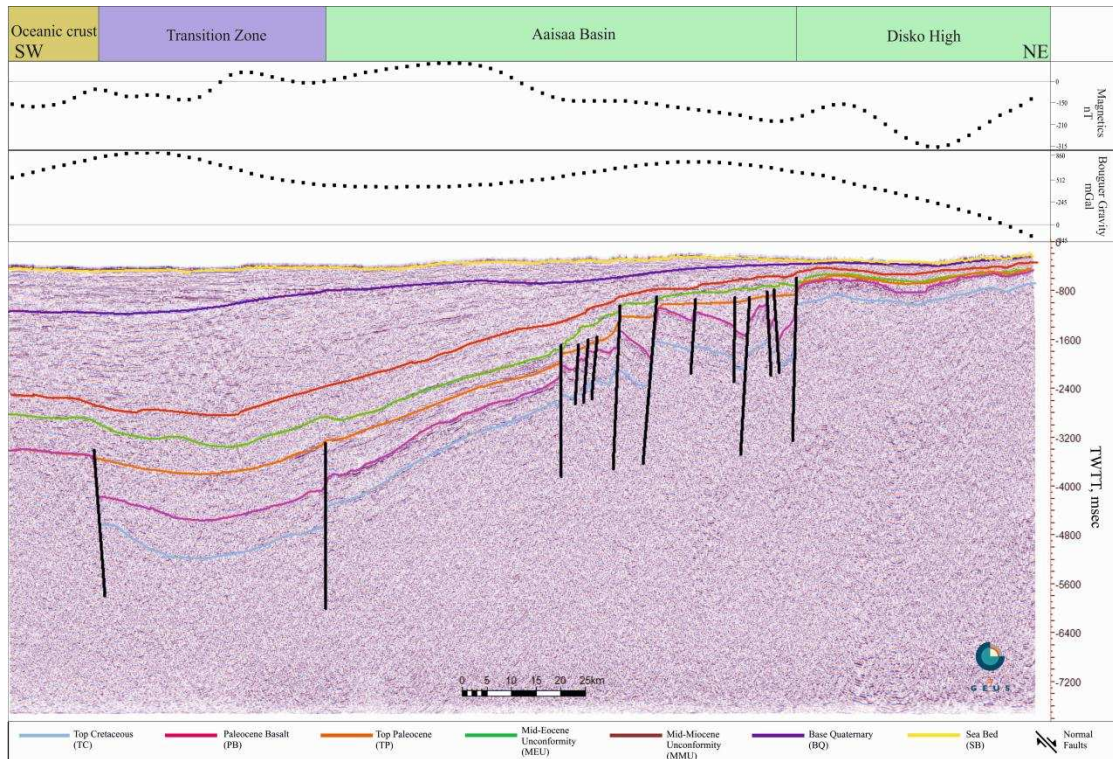


Fig 5

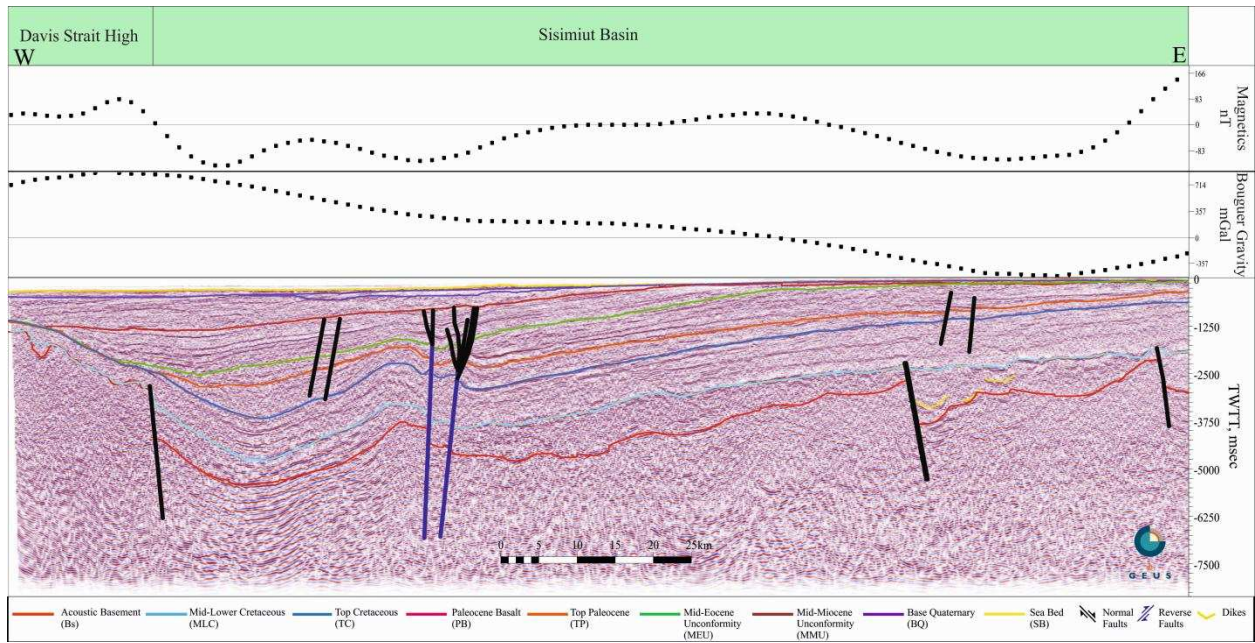


Fig 6

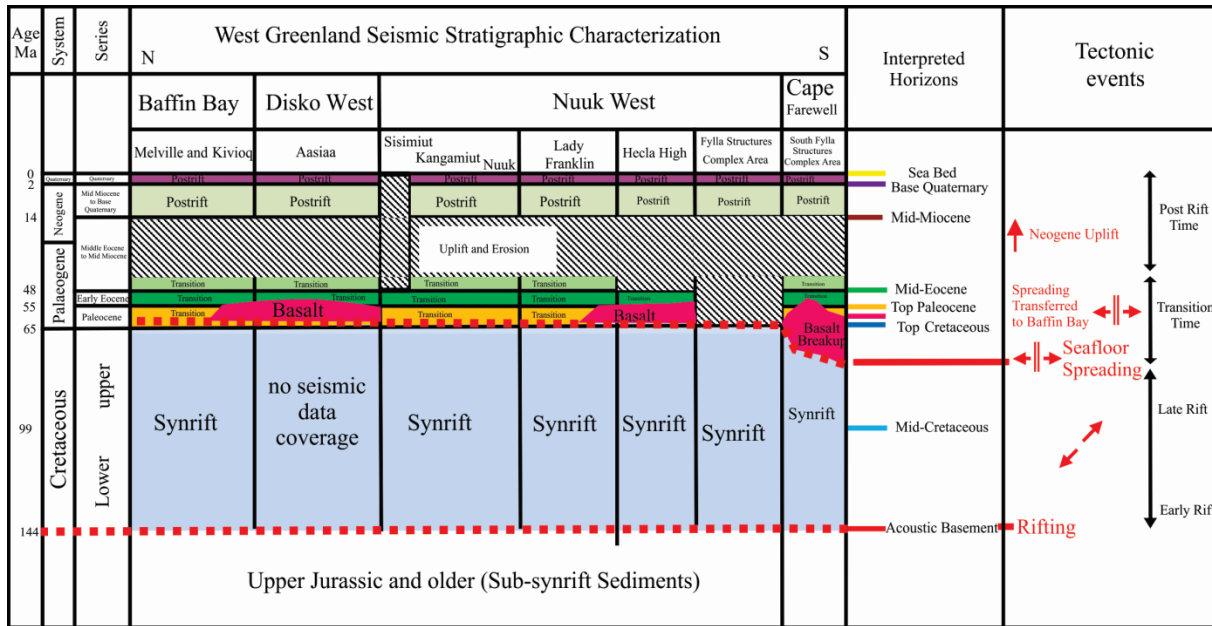


Fig 2

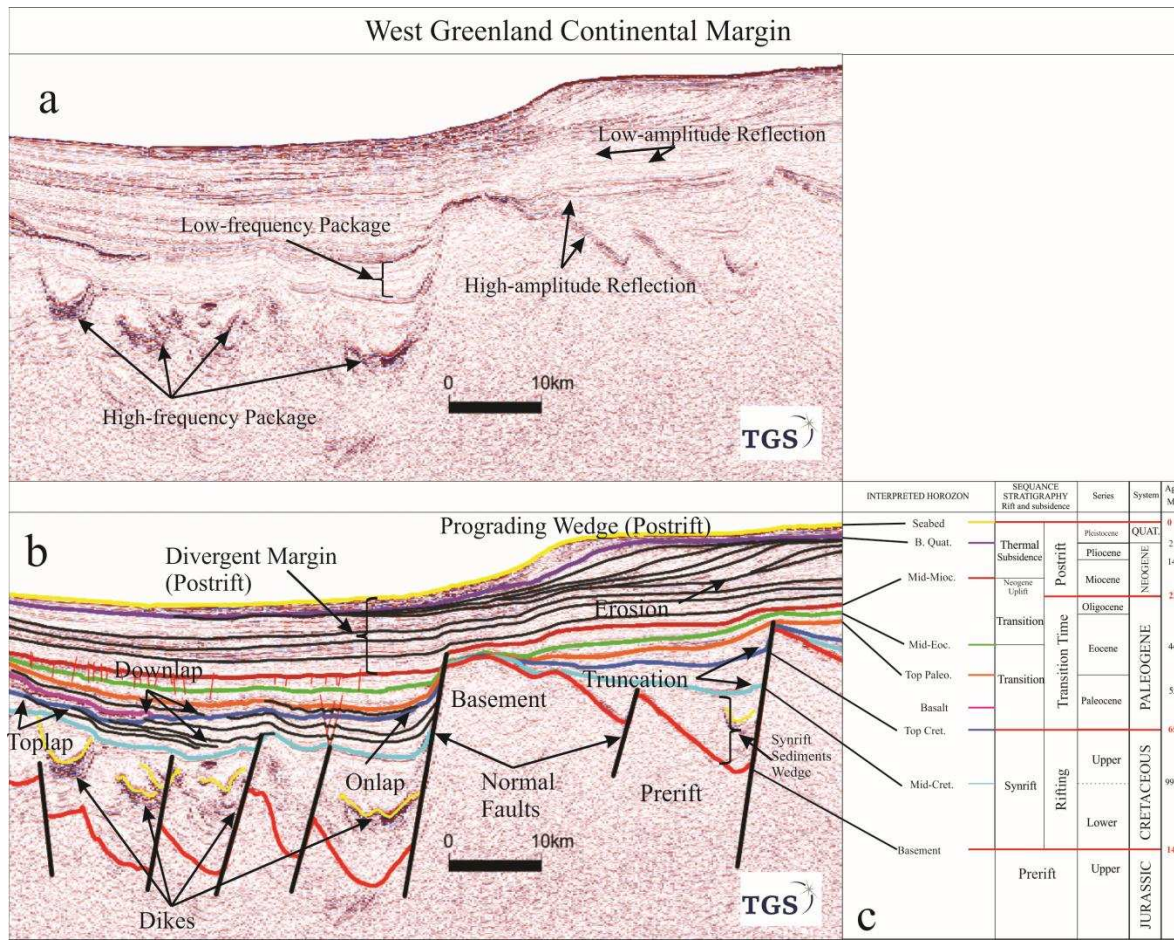


Fig 3

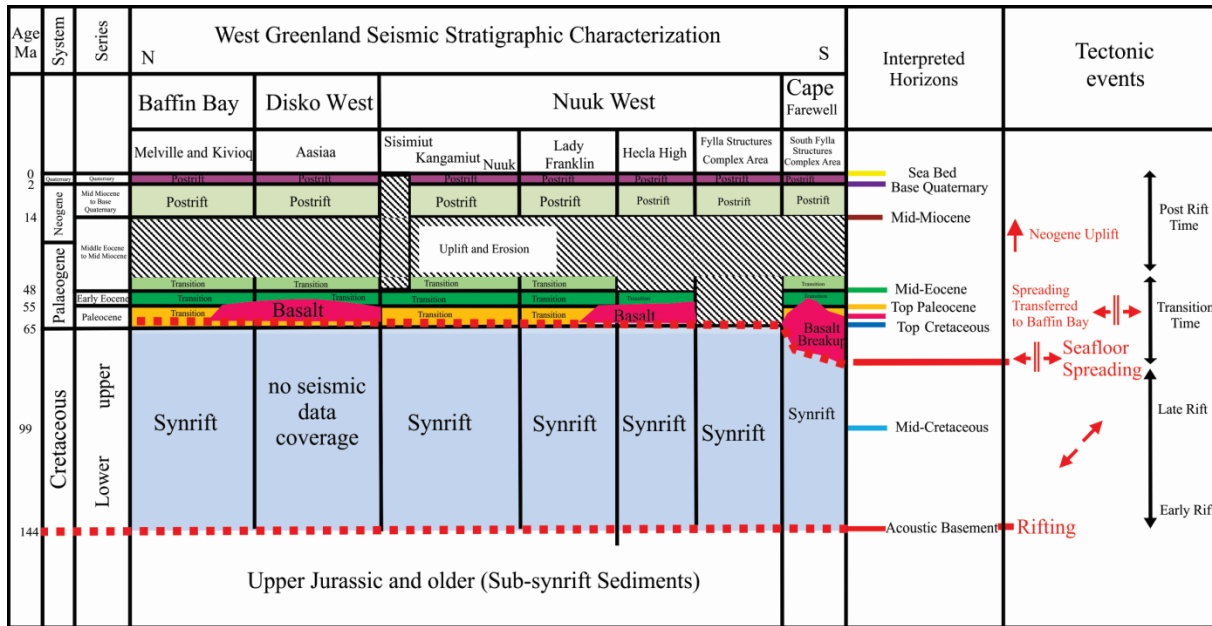


Fig 2

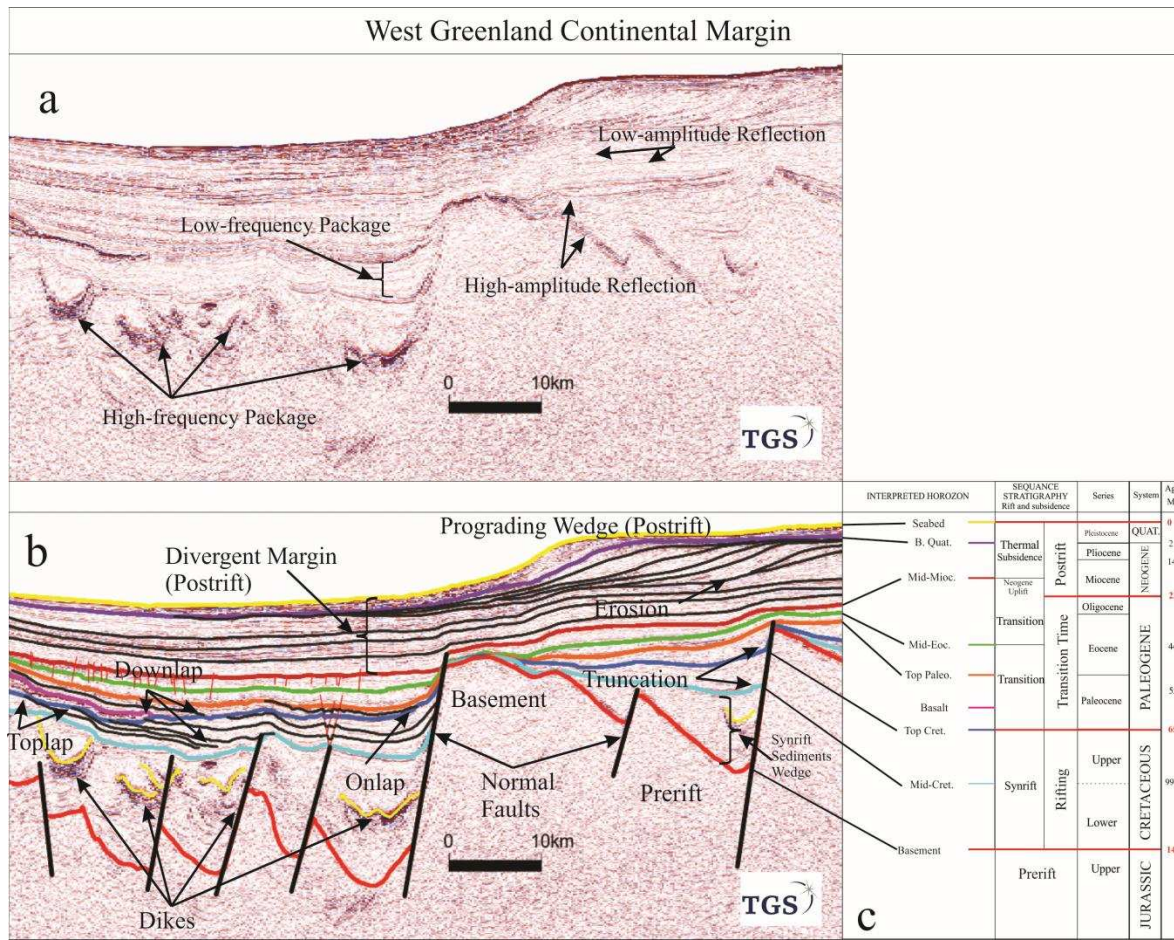


Fig 3

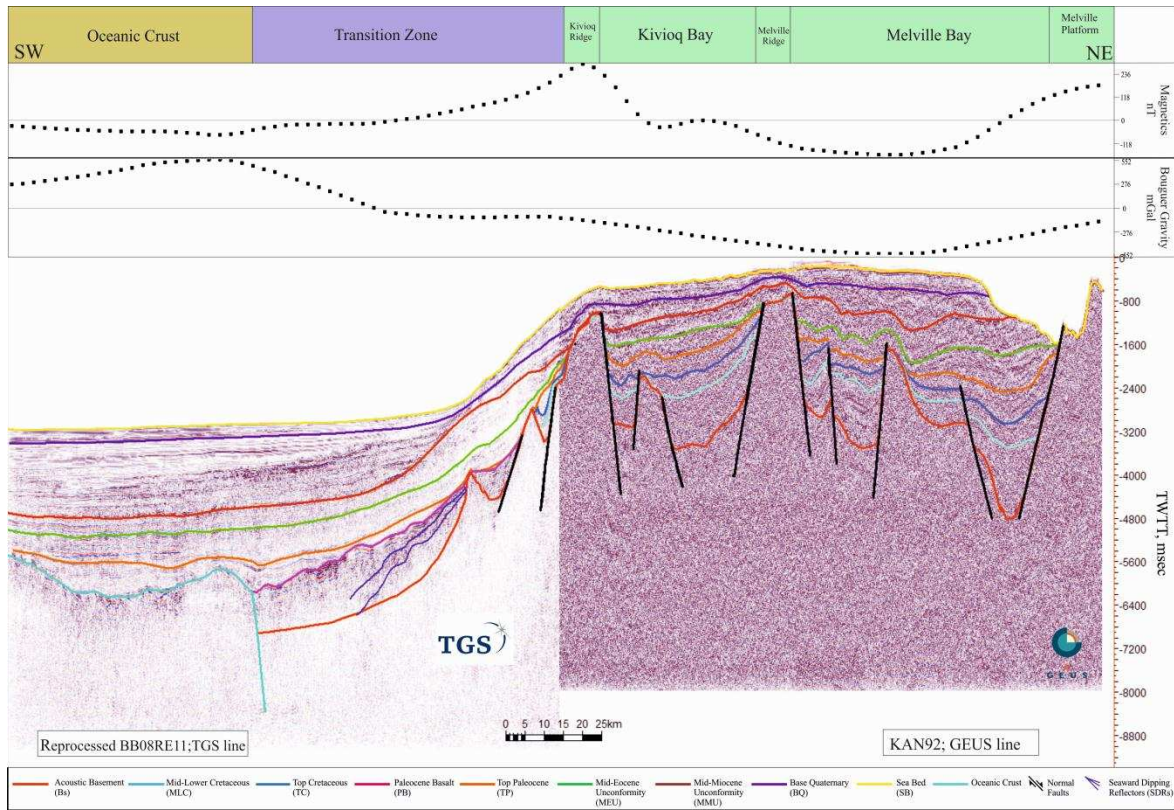


Fig 4

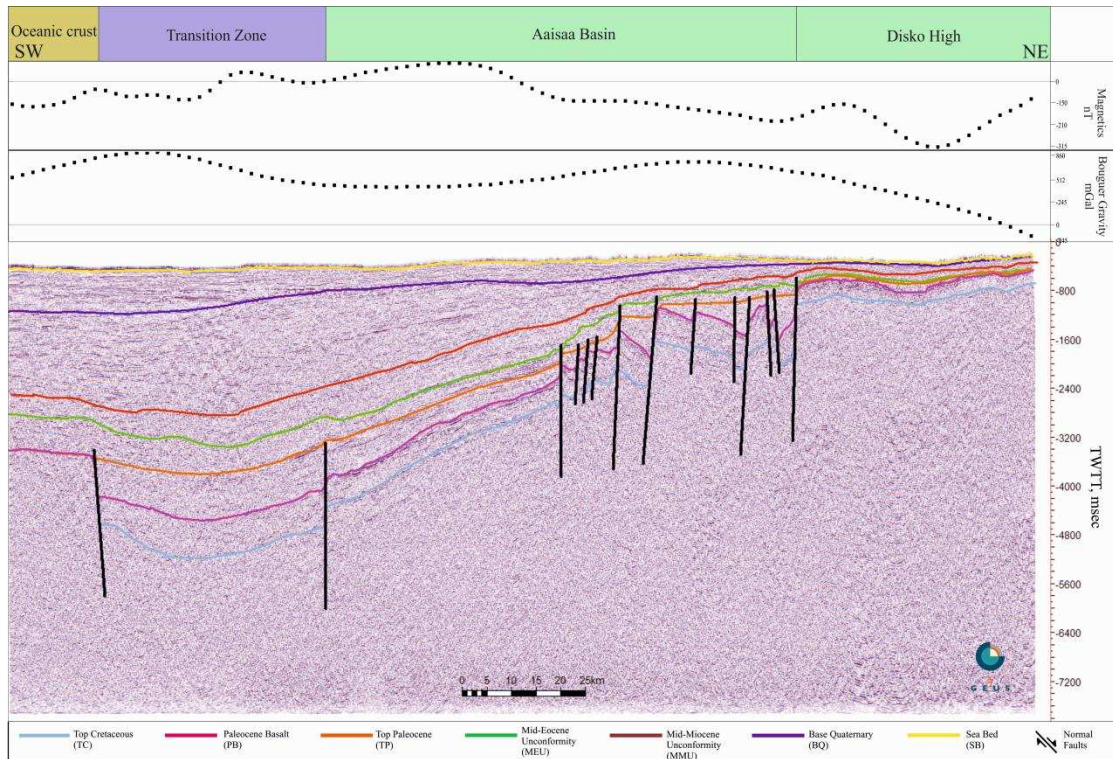


Fig 5

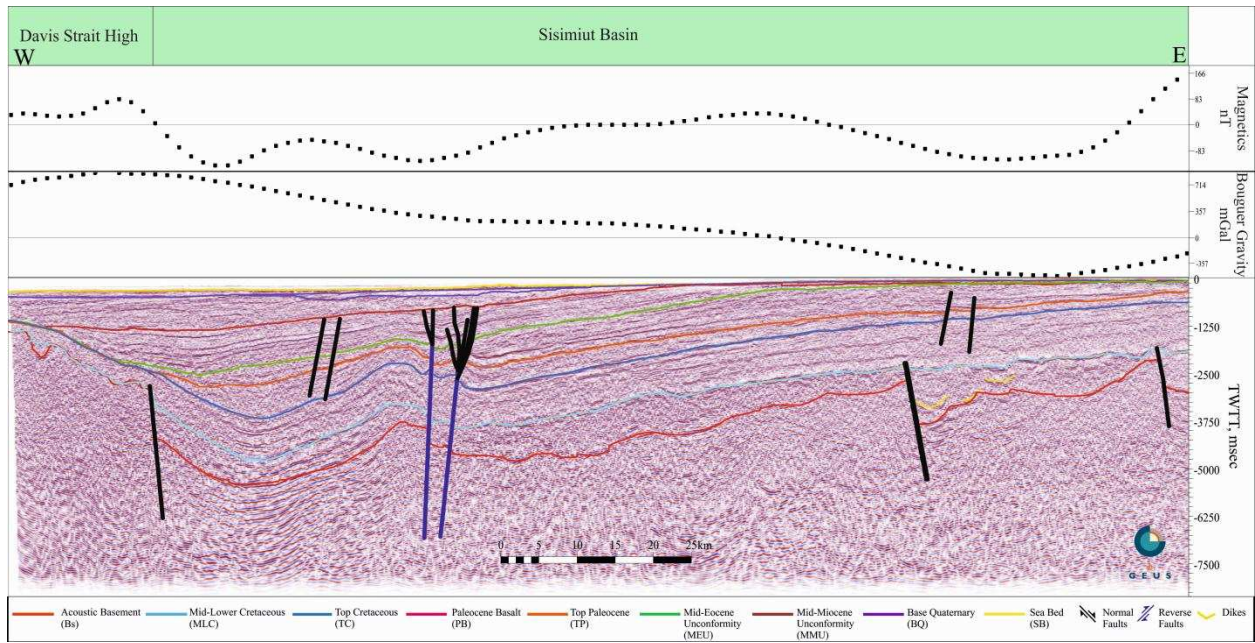


Fig 6

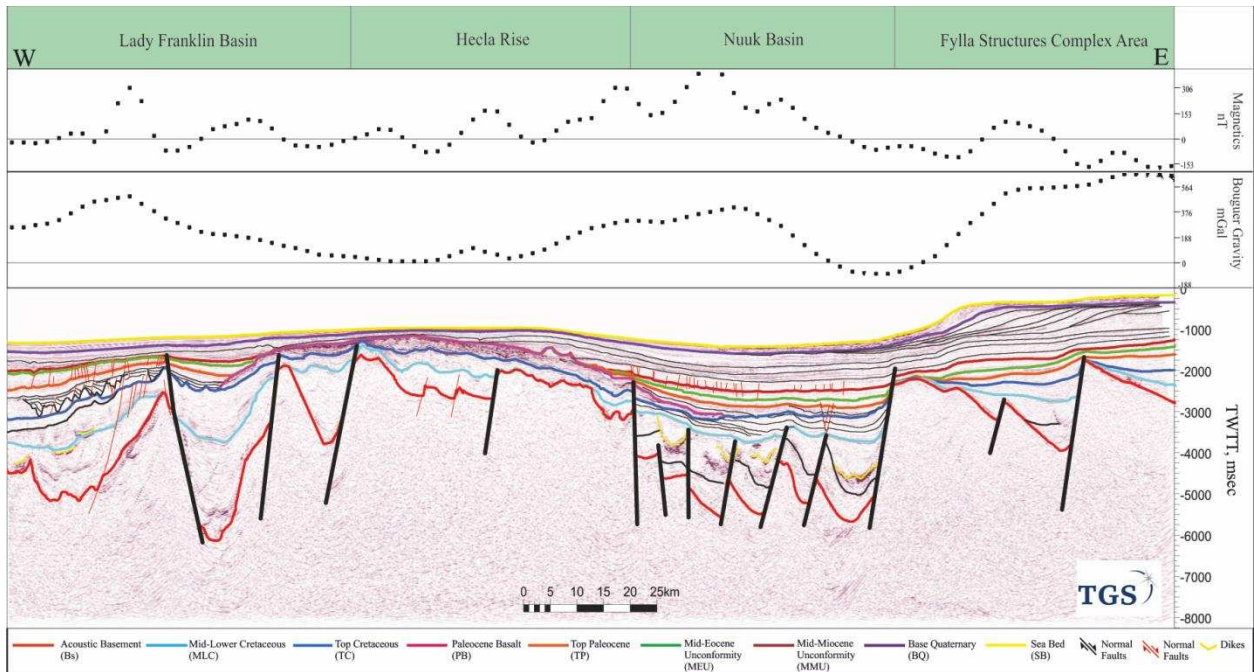


Fig 7

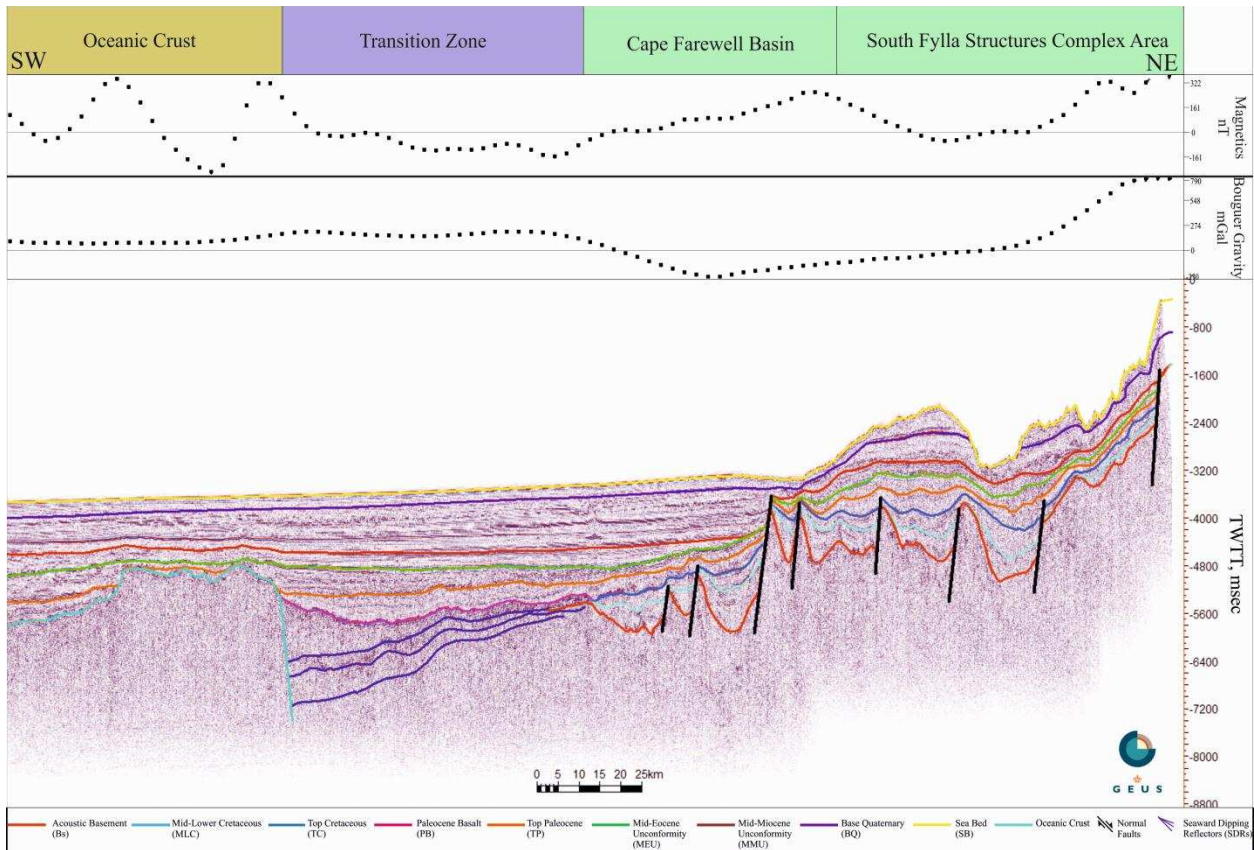


Fig 8

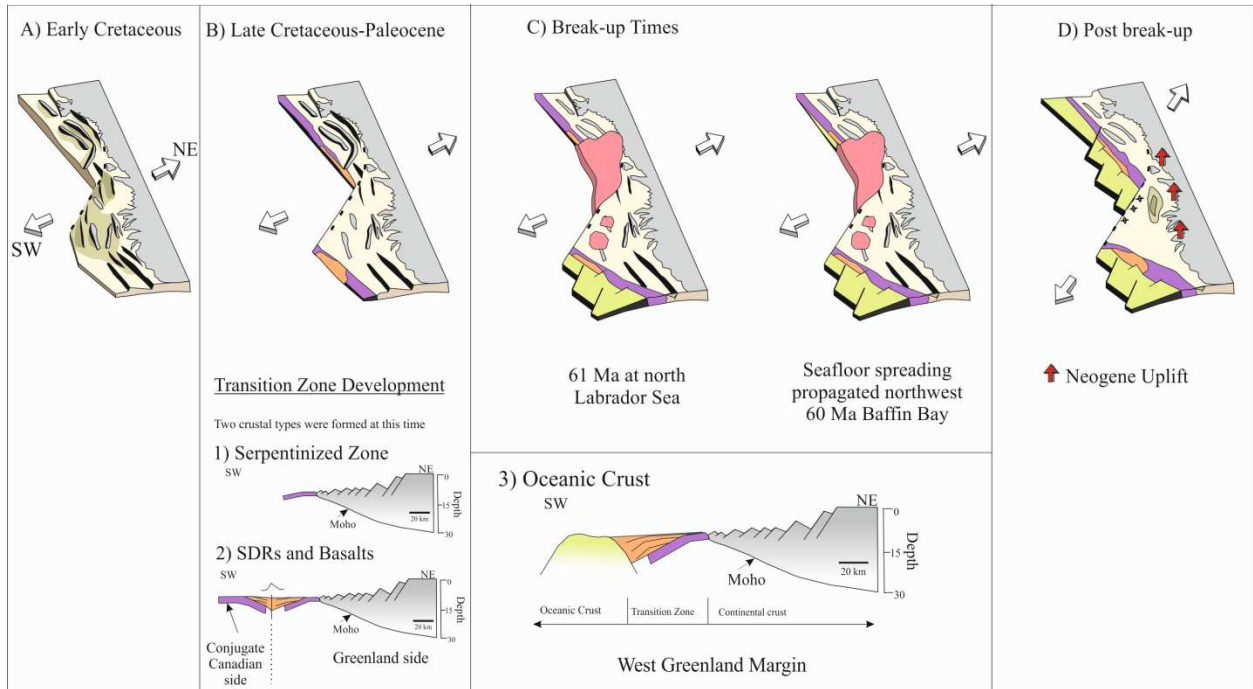


Fig 9