

2018-01-01

Processes influencing differences in Arctic and Antarctic Trough Mouth Fan sedimentology

Gales, Jenny

<http://hdl.handle.net/10026.1/10383>

10.1144/sp475.7

Geological Society Special Publication

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

1 **Processes influencing differences in Arctic and Antarctic Trough Mouth Fan** 2 **sedimentology**

3 Jenny Gales(1)*; Claus-Dieter Hillenbrand(2), Rob Larter(2), Jan Sverre Laberg(3), Martin Melles(4), Sara Benetti(5),
4 Sandra Passchier(6)

5
6 (1) University of Plymouth, School of Biological and Marine Sciences, Drake Circus, Plymouth, PL4 8AA

7 (2) British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK.

8 (3) UiT Arctic University of Norway, Postboks 6050 Langnes, 9037, Tromsø, Norway.

9 (4) University of Cologne, Zùlpicher Str. 49a/b, 50674 Cologne, Germany.

10 (5) University of Ulster, Coleraine Campus, Cromore Road, Coleraine, Co. Londonderry, BT52 1SA.

11 (6) Montclair State University, 1 Normal Ave, Montclair, New Jersey, 07043.

12 *Correspondence (jenny.gales@plymouth.ac.uk)

13

14 **Abstract**

15 Trough Mouth Fans (TMFs) are sediment depocentres that form along high-latitude
16 continental margins at the mouths of some cross-shelf troughs. They reflect the dynamics of
17 past ice sheets over multiple glacial cycles and processes operating on (formerly) glaciated
18 continental shelves and slopes, such as erosion, reworking, transport and deposition. The
19 similarities and differences in TMF morphology and formation processes of the Arctic and
20 Antarctic regions remain poorly constrained. Here, we analyse the dimensions and
21 geometries of 15 TMFs from Arctic and Antarctic margins and the grain-size distribution of
22 82 sediment cores centred on them. We compare the grain-size composition of sub- and
23 proglacial diamictos deposited on the shelves and glaciogenic-debris flows (GDFs) deposited
24 on the adjacent TMFs and find a significant difference between Arctic and Antarctic margins.
25 Antarctic margins show a coarser grain-size composition for both GDFs and shelf
26 diamictos. This significant difference provides insight into high-latitude sediment input,
27 transportation and glacial/interglacial regimes. We suggest that surface run-off and river
28 discharge are responsible for enhanced fine-grained sediment input in the Arctic compared to
29 in the Antarctic.

30 **Introduction**

31 Ice streams are the main drivers of erosion, transport and deposition along high-latitude
32 continental margins. Their past extent and dynamics control not only the volume, but also the
33 location and type of the deposited sediments. They ultimately shape how the continental
34 shelves and slopes have evolved during past glaciations, along with the tectonic history and
35 slope processes operating independently from climatic stages. Ice streams are thought to have

36 reached the shelf edge along much of the Arctic and Antarctic margins during the Quaternary
37 (e.g. Denton & Hughes, 1981; Laberg & Vorren, 1995; Anderson, 1999; Vorren & Plassen,
38 2002; Cooper et al., 2008; Ruther et al., 2013; Rydningen et al., 2013; Jakobsson et al., 2014;
39 The RAISED Consortium et al., 2014). This caused, or at least contributed to, the erosion of
40 large cross-shelf bathymetric troughs, the formation of subglacial and glacially-influenced
41 bedforms across the continental shelf and, at the mouths of some palaeo-ice stream troughs,
42 the deposition of large volumes of sediment at the shelf edge to form prograding Trough
43 Mouth Fans (TMFs) (Vorren et al., 1989).

44 The occurrences of TMFs are far fewer in the Antarctic compared to the Arctic (Figs.
45 1 and 2). In bathymetric profiles across polar continental margins, TMFs are identifiable by
46 distinctive convex-outward morphologies at the mouths of some cross-shelf troughs (Vorren
47 et al., 1998; Kuvaas & Kristoffersen, 1991; Dowdeswell et al., 2008; Livingstone et al., 2012;
48 Batchelor et al., 2014). They reflect the dynamics of past ice sheets over multiple glacial
49 cycles and thus are important palaeoclimate archives (Vorren and Laberg, 1997). TMFs are
50 mainly composed of poorly sorted and glacially-influenced sediments, predominantly
51 glacial debris flows (GDFs) formed of diamictons. These diamictons consist of
52 subglacially-eroded, unsorted debris that had been transported to the shelf edge as tills at the
53 base of a grounded ice stream or ice sheet. Additional sediments commonly found on TMFs
54 comprise glacial marine hemipelagic sediments and turbidites (Vorren et al., 1989; Laberg &
55 Vorren, 1995; Dowdeswell et al., 1996, 1997; King et al., 1996; Lucchi et al., 2013). The
56 composition of these sediments can be expected to provide insight into past ice advance and
57 retreat and may shed light on processes operating on high-latitude continental margins, for
58 example meltwater plume deposition. The main seismostratigraphic components of TMFs are
59 prograding outer shelf – upper slope strata which are constructed predominantly of foresets
60 comprising debris flow units and topsets commonly formed of subglacially-deposited tills
61 (Damuth, 1978). Gravitational downslope deposits, including submarine landslides and debris
62 lobes, as well as erosional bedforms, such as channel / levee systems and gullies, are also
63 common features of TMFs.

64 TMFs are of global significance in terms of sediment transport to the deep ocean,
65 carbon storage and evaluation of slope stability and resulting hazard risks (e.g. Elverhøi et al.,
66 1997; Mienert et al., 2002; Covault, 2011; Talling et al., 2015; Cartapanis et al., 2016). It
67 remains poorly constrained how Arctic and Antarctic TMFs differ in terms of sediment
68 composition, morphology and processes operating in these regions and the factors controlling
69 these differences. Despite a vast number of previous studies that investigated the local

70 morphology and sedimentology of TMFs, only a few studies focussed on differences between
71 Arctic and Antarctic margins (e.g. Ó Cofaigh et al., 2003; Nielsen et al., 2005; Gales et al.,
72 2013). These previous studies largely focussed on gross architecture, geometry and
73 geomorphology of the TMFs in comparison to portions of other polar margins, whereas here,
74 we focus on the differences in the grain-size composition of the TMF sediments.

75 In our study we address the following key questions:

76 1) How does the sedimentology of Arctic and Antarctic TMFs vary and differ?

77 2) What are the causes for the observed differences?

78 3) What can this tell us about processes operating on high-latitude continental
79 margins?

80

81 **Previous work: TMF formation and sedimentology**

82

83 TMFs on both Arctic and Antarctic margins have been studied in detail with 20 TMFs
84 identified on Arctic margins and three on Antarctic margins (Batchelor et al., 2014;
85 Livingstone et al., 2012; Table 1). TMF formation has been attributed to two major processes.

86 The first comprises erosion and remobilization of sediments deposited landward of and on the
87 shelf by ice streams and their subsequent redeposition as debris flows on the outer continental
88 shelf and upper slope (e.g. Vorren et al., 1989; Laberg & Vorren, 1995; Dowdeswell et al.,

89 1996, 1997; King et al., 1996). Seismic-reflection and sub-bottom profiler data show the
90 signature of these debris flow deposits as prograding sigmoidal / oblique reflections and
91 (stacked) semi-transparent lenses or opaque wedges (Damuth, 1978; Vorren et al., 1989;

92 King et al., 1996; Laberg and Vorren, 1995). On Arctic margins, the debris flows are
93 suggested to result from the intermittent failure of clay-rich, subglacial soft tills which were
94 deposited rapidly under full-glacial conditions at the shelf edge (Laberg & Vorren, 1995;

95 Dowdeswell et al., 1996; Elverhøi et al., 1997; Ó Cofaigh et al., 2003). The second
96 mechanism of TMF formation comprises deposition of mass flows and the suspension load of
97 turbid meltwater plumes (e.g. Ó Cofaigh et al., 2003; Lucchi et al., 2013; Rebesco et al.,

98 2013). Turbid meltwater plumes released at the grounding line of ice-sheets result in dense
99 flows of sediment-laden water across the outer shelf and down the continental slope.
100 Suspension settling from these flows enhances fan formation (Lucchi et al., 2013). This

101 process may occur alongside debris flow activity during glacial periods, or during
102 deglaciation/interglacials (Ó Cofaigh et al., 2003). These processes are modulated by

103 environmental factors such as the slope gradient, the underlying geological substrate and the
104 abundance of meltwater (Ó Cofaigh et al., 2003).

105 Sediment cores recovered from the outer shelf sections of palaeo-ice stream troughs
106 and the adjacent TMFs provide important insights into processes operating in these areas.
107 Diamictons on the shelf may have been formed by (1) subglacial deposition beneath
108 grounded ice (= till), (2) melt-out of glacial debris from the base of floating ice (=
109 glacimarine diamicton), either under an ice shelf proximal to the grounding line or from
110 debris-rich icebergs (= iceberg-rafted diamicton), (3) reworking of subglacial and/or glacial-
111 marine sediments by iceberg ploughing (= iceberg turbate), or (4) deposition of glacial
112 debris flows (= GDFs) (e.g. King et al., 1998; Anderson, 1999; Domack et al., 1999; Lowe
113 and Anderson, 2002; Hillenbrand et al., 2005;). Distinguishing the formation processes
114 usually takes into account factors including shear strength, density, porosity, water content as
115 well as the presence, preservation and composition of biogenic material, sedimentary
116 structures, grain-size distribution, and age constraints (e.g. Kurtz & Anderson, 1979; Laberg
117 & Vorren, 2000; Evans and Pudsey, 2002; Hillenbrand et al., 2005; Ó Cofaigh et al., 2005).
118 In contrast, diamictons on TMFs are likely to have been deposited as GDFs or glacimarine /
119 iceberg-rafted diamictons. The latter process is unlikely to play a significant role for
120 deposition on TMFs as embayments that are capable of trapping icebergs at an ice front can
121 be expected to form on a continental shelf but are less common above the continental slope.
122 In Antarctica, strong ocean currents flowing parallel to the shelf break (e.g. Antarctic
123 Circumpolar Current, Antarctic Coastal Current, Weddell Gyre) and the predominant
124 offshore wind direction due to katabatic winds (Turner et al., 2009) would have driven
125 icebergs quickly further seaward during times when the grounding line was located at, or near
126 to, the shelf edge.

127

128 **Study Areas**

129 The Antarctic study areas include the Belgica Trough Mouth Fan in the Bellingshausen Sea,
130 the Crary Trough Mouth Fan in the southern Weddell Sea, and the Prydz Channel Trough
131 Mouth Fan in the Cooperation Sea (Fig. 1; Table 1). TMFs analysed from margins in the
132 Arctic include the Vilkitsky-Khatanga Trough Mouth Fan, Voronin Trough Mouth Fan, St
133 Anna Trough Mouth Fan and Franz Victoria Trough Mouth Fan on the northern Barents-Kara
134 Sea margin, the Kongsfjorden Trough Mouth Fan, Isfjorden Trough Mouth Fan, Bellsund
135 Trough Mouth Fan, Storfjorden Trough Mouth Fan, Kveithola Trough Mouth Fan and Bear
136 Island Trough Mouth Fan on the western Barents Sea margin, the North Sea Trough Mouth
137 Fan, and the Scoresby Sund Trough Mouth Fan on the eastern Greenland margin (Fig. 2;
138 Table 1).

139 Extensive ice sheets advanced episodically across the continental shelves in East
140 Antarctica since 34 Ma and in West Antarctica since at least the Late Miocene (e.g. Florindo
141 & Siegert 2008; Barrett, 2008). Northern Hemisphere glaciation started during the middle to
142 late Miocene in Greenland, intensified around ~4 Ma and 2.6 Ma along the Norwegian
143 margin (Larsen et al., 1994; Thiede et al., 1998), and ice-sheets there are thought to have
144 reached their greatest extent around 1 Ma (Knies et al., 2009). Along many Antarctic and
145 Arctic margins grounded ice reached the shelf edge during glacial periods of the Late
146 Quaternary (e.g. Cooper et al., 2008; Mangerud et al., 2011; Jakobsson et al., 2014).

147 The underlying geology and tectonic history of our study areas have been well
148 documented (e.g. Kenyon, 1987; Larter & Barker, 1991; Kuvaas and Kristofferson, 1991;
149 Nitsche et al., 1997; Cunningham et al., 2002; Eagles et al., 2004, 2009; Stoker et al., 2005;
150 Faleide et al., 2008). The Belgica Fan is situated above a relict subduction zone which has
151 been inactive since 55 Ma (Cunningham et al., 2002). The Crary Fan margin has been a
152 passive margin since the Jurassic period (Jokat et al., 1996; Bart et al., 1999). Offshore Prydz
153 Bay, sediments include pre-Cenozoic non-marine sedimentary rocks and Cenozoic
154 diamictons (Hambrey et al., 1991). The location is a passive margin on the boundary between
155 between where India rifted away from Antarctica in the Early Cretaceous and where
156 Australia rifted away in the Late Cretaceous. The geological setting of the NW European
157 margin reflects a passive margin, which during the Cenozoic underwent various tectonic
158 movements resulting in variations from a classic post-rift development (STRATEGEM
159 Partners, 2003). Early Pliocene uplift and basin subsidence resulted in a significant shift in
160 the depositional style, from sedimentation controlled by ocean current-induced erosion and
161 transport to sedimentation dominated by shelf progradation (STRATEGEM Partners, 2003).

162

163 **Materials and methods**

164 Examination of Arctic and Antarctic TMFs included morphometric analysis (e.g. TMF
165 geometry and dimensions) from regional bathymetric data and grain-size analysis. Grain-size
166 data of individual sediment samples taken from 76 gravity cores and six drill sites from the
167 outer shelf and upper slope of Arctic and Antarctic TMFs and the surrounding areas were
168 investigated (Table 2). Cores were selected based on their vicinity to the shelf edge and only
169 cores recovered from GDFs deposited on the slope or diamictons deposited on the shelf are
170 considered here. The core locations are shown in Figures 1 and 2.. Average grain sizes for
171 gravel (> 2mm), sand (63 μ m - 2 mm), silt (2 μ m - 63 μ m) and clay (< 2 μ m) from the

172 GDF/diamicton section of each core were either measured for this study (most cores from
173 Belgica TMF; Fig. 3a), or the data were taken from the published literature. Where no
174 published grain-size data could be obtained from the authors, grain-size composition (gravel-
175 sand-silt-clay) was estimated for the diamicton section of a core by measuring the percentage
176 of a grain-size fraction as displayed in high resolution figures of the source publications (Fig.
177 3b; Table 2). The approach used for each core is detailed in Table 2. This approach may give
178 rise to an error of $\leq 3\%$ percent. Grain-size data are expressed either as sand-silt-clay or as
179 gravel-sand-mud (with mud= silt+clay).

180 Although the exact methods of grain-size analyses may differ between the various
181 studies, the techniques predominantly followed the same standard procedures: subsamples
182 were treated with 3% hydrogen peroxide solution and 10% acetic acid to remove total organic
183 carbon (TOC) and CaCO_3 and gravel, sand and mud (silt and clay) fractions were separated
184 by wet sieving (e.g. Hillenbrand et al., 2005). In some cores from the Belgica TMF, Crary
185 TMF and Prydz TMF (e.g. Passchier et al., 2003) biogenic material had not been removed by
186 chemical treatment before the grain-size analysis, but this should not have affected the results
187 of our comparison because diamictons from the Antarctic shelf and slope have been shown to
188 consist almost entirely of terrigenous detritus (e.g. Kurtz & Anderson, 1979; Anderson et al.,
189 1980; Hillenbrand et al., 2005; Licht et al., 1999). The silt and clay fractions were either
190 separated using settling tubes, or their contents were measured with a particle size analyser,
191 such as Sedigraph, laser particle analyser or Coulter Counter. Although the use of different
192 techniques and instruments for measuring the grain-size distribution in the fine fraction < 63
193 μm may result in different silt and clay contents (e.g. Konert & Vandenberghe 1997;
194 Beuselinck et al., 1998; Bianchi et al., 1999; Molinaroli et al., 2000; McCave et al., 2006),
195 this will not affect our comparison of gravel, sand and mud contents.

196 International Bathymetric Chart of the Arctic Ocean (IBCAO) and International
197 Bathymetric Chart of the Southern Ocean (IBCSO) data were used to quantify TMF
198 morphometrics including slope gradient, geometry, trough length and TMF area. Trough
199 length is measured from modern ice shelf limits to the continental shelf edge. Data on
200 drainage basin sizes for palaeo-ice streams were either taken from the literature (Table 1) or,
201 if unavailable, estimated from published palaeo-ice divide data (Table 1). The statistical
202 significance of the results were tested using regression analysis. Standard deviation
203 calculations were used to identify whether the variances between Arctic and Antarctic TMFs
204 were greater than within the datasets.

205

206 **Results**

207 ***Geometry and dimensions of TMFs***

208 The locations and parameters of many Arctic and Antarctic TMFs have been described
 209 previously (Table 1). Figure 4A shows clear relationships between some TMF parameters,
 210 including trough length, trough relief at the shelf edge, slope gradient, fan area and palaeo-
 211 drainage basin size. Bear Island Fan and the North Sea Fan are clear outliers due to the very
 212 large fan areas (215,000 km² and 142,000 km² respectively). These data were therefore
 213 excluded in regression calculations for correlations.

214 The matrix plot of the 15 measured TMF parameters (Fig. 4A, Table 1) shows a
 215 strong positive correlation between trough length and fan area ($r^2 = 78\%$). Fan area also
 216 increases with paleo-drainage basin size for both Arctic and Antarctic TMFs. For Arctic
 217 TMFs, this correlation is very strong ($r^2 = 89\%$). The correlation decreases with the addition
 218 of Antarctic TMFs, although this may be affected by errors introduced by estimating palaeo-
 219 drainage basin sizes. There is a strong positive correlation between trough relief and fan area,
 220 with fan area increasing with cross-shelf trough relief ($r^2 = 61\%$). There are weak negative
 221 correlations between slope gradient and trough length ($r^2 < 47\%$) and between slope gradient
 222 and palaeo-ice stream drainage basin size ($r^2 = 43\%$) for both Arctic and Antarctic TMFs.
 223 There is also a weak negative relationship between cross-shelf trough relief and slope
 224 gradient ($r^2 = 37\%$).

225 The geometry and gradients of the TMFs show generally low gradient ($< 4^\circ$) (Fig. 4B).
 226 Antarctic TMFs on average typically show the lowest slope gradients ($< 1.5^\circ$). Slope
 227 geometries generally show concave profiles with gradients that decrease with distance down-
 228 slope.

229

230 ***Grain-size distribution of GDFs from TMFs and shelf diamictos in adjacent palaeo-ice***
 231 ***stream troughs***

232 The grain-size distributions in GDFs and shelf diamictos were analysed from 82
 233 cores from Arctic and Antarctic TMFs and adjacent palaeo-ice stream troughs (Fig. 5). The
 234 results show that Arctic GDFs and shelf diamictos are characterised by generally finer
 235 grain-size composition compared to their Antarctic counterparts (Fig. 5C, D). Within the
 236 shelf diamictos and GDFs of the 39 sediment cores from the Antarctic margin (Fig. 5C; 15
 237 cores from the slope; 24 cores from the outer shelf), the grain-size distribution is relatively

238 constant and shows an average sand content of 43%, average silt content of 36% and average
239 clay content of 21%. Antarctic diamictos were significantly coarser than those from the
240 Arctic margins (Fig. 5D; 32 from the slope; 11 from the outer shelf). Within the 43 Arctic
241 GDFs and shelf diamictos, the average sand content is 17%, average silt content is 43% and
242 average clay content is 40% (Fig. 5). Average grain sizes for the analysed diamictos were
243 generally coarser on the shelf compared to the slope for both the Arctic and the Antarctic. For
244 the Antarctic diamictos, the average sand content varies from 47% on the shelf to 39% on
245 the slope. For the Arctic diamictos, the average sand content is 18% on the shelf and 17%
246 on the slope. Where gravel (>2 mm grain-size) data were available (Fig. 5B),
247 GDFs/diamictos also show a coarser grain-size composition on the shelf in the Antarctic.
248 The standard deviations for both Arctic and Antarctic GDFs/diamictos were less than the
249 difference between the mean Arctic and Antarctic values. This indicates that the difference in
250 grain-size composition between Arctic and Antarctic GDFs/diamictos are significant as
251 these are greater than the variances within the datasets.

252

253 **Discussion**

254 Analysis of the grain-size distributions of GDFs and shelf diamictos recovered in 82
255 sediment cores from 15 TMFs and the adjacent palaeo-ice stream troughs show distinct
256 differences between the Arctic and the Antarctic. Antarctic diamictos from both the shelf
257 and the slope are significantly coarser grained (average sand content of 43%) than their
258 counterparts from the Arctic margin (average sand content of 17%). The coarse fraction
259 content in diamictos from the slope is lower than in diamictos from the shelf for both the
260 Arctic and the Antarctic margin, although for the Arctic the difference is small (~1%).

261 These differences have important implications for the processes operating on the
262 continental shelves and at the mouths of cross-shelf troughs and the factors controlling TMF
263 sedimentation and evolution. In the following section we discuss three possibilities causing
264 the differences between Arctic and Antarctic TMFs: (1) mechanisms for the enrichment of
265 coarse-grained detritus in diamictos from the Antarctic shelf and slope; (2) mechanisms for
266 the depletion of fine-grained material in diamictos from the Antarctic shelf and slope; and
267 (3) mechanisms for the enrichment of fine-grained detritus in diamictos from the Arctic
268 shelf and slope. Mechanisms that may have depleted coarse-grained detritus in Arctic
269 diamictos cannot be identified.

270 ***Mechanisms causing the enrichment of coarse-grained detritus in Antarctic diamictos***

271 The composition of bedrock on the shelf may influence the rate and volume of sediment
272 eroded by over-riding ice and thus may influence the character of sediment transported to the
273 slope (Solheim et al., 1998; Ó Cofaigh et al., 2004). This may also influence the observed
274 difference in grain-size composition between Arctic and Antarctic margins. Till composition
275 is largely influenced by the subglacial relief and the subglacial substrate, i.e. hinterland
276 geology, initial sediment concentration and lithology, and physical properties of the
277 subglacial debris, as well as the mode of glacial erosion, comminution and transport (Clark,
278 1987). The difference in source rock type between Arctic and Antarctic margins does not
279 appear to influence grain-size distribution on the outer shelf and slope. For example, the
280 diamicton composition in Belgica Trough is influenced by reworking and recycling of older
281 sediments, as well as debris from different sedimentary and crystalline source areas in the
282 West Antarctic hinterland (Hillenbrand et al., 2009). Diamictons from the western Barents
283 Sea margin are also suggested to consist largely of eroded sedimentary substrate (e.g.
284 Elverhøi et al., 1998), however display significantly finer grain-size distributions. Diamictons
285 in Prydz Bay are sourced from crystalline and sedimentary rocks which vary depending on the
286 source area (Forsberg et al., 2008) similar to diamictons recovered from Filchner Trough,
287 adjacent to Crary Fan (Michels et al., 2002), resulting in a coarser grained composition
288 compared to tills from mainly sedimentary source areas such as the Belgica Trough (Fig. 4a).
289 The north east Greenland shelf has an igneous substrate (Escher & Pulvertaft, 1995), however
290 the observed grain-size distributions of GDF/diamicts are fine-grained.

291 Subglacial sediment transport distances may also influence grain-size distribution on
292 the outer shelf and slope due to erosion, subglacial deformation and comminution (Anderson
293 et al., 1980; Domack et al., 1980; Menzies, 1996; Evans et al., 2006). On Antarctic margins,
294 dispersal distances of a hundred to 100s of km are assumed based on trough length,
295 topography and presence of subglacial bedforms (e.g. Ó Cofaigh et al. 2005; Hillenbrand et
296 al., 2009). Trough length (or shelf width) can be used to infer transport distance, with studies
297 suggesting that ice reached the shelf edge around many parts of the Arctic and Antarctic
298 during the Quaternary (e.g. Denton & Hughes, 1981; Anderson, 1999; Cooper et al., 2008;
299 The RAISED Consortium et al., 2014). For both Arctic and Antarctic margins, no significant
300 variation in grain-size distribution with trough length was observed. Most troughs on Arctic
301 margins show a fine-grained grain-size distribution, independent of trough length. Troughs of
302 various lengths (e.g. Bear Island Trough, 700 km; Scoresby Sound Trough, 480 km, and
303 Isfjorden Trough, 180 km) have similar average sand contents. In contrast, troughs of similar
304 lengths on Arctic and Antarctic margins (e.g. Belgica Trough, 490 km; Scoresby Sund

305 Trough, 480 km) display significant differences in grain-size distribution suggesting that
306 transport distance has little overall influence on grain-size distribution in shelf diamictons and
307 GDFs.

308 Ice stream characteristics, such as the basal properties (warm-based or cold-based
309 ice), palaeo-drainage basin size, roughness, till coverage and basal hydrological system may
310 influence the volume, erosion and average grain size of detritus transported from the
311 hinterland towards the outer shelf and shelf edge. We identify no significant relationship
312 observed between palaeo-drainage basin size and grain-size distribution, with areas of
313 significantly different drainage basin sizes (e.g. Bear Island Fan, 500000 km²; Isfjorden,
314 14000 km²) showing similar grain-size compositions along the Arctic margin. Antarctic
315 palaeo-drainage basin sizes are generally larger (up to 1600000 km²) than in the Arctic (<150
316 000 km²), with the Bear Island Fan and the St Anna Fan being exceptions. Antarctica
317 experienced a more extensive and prolonged glaciation, i.e. here ice streams eroded and
318 reworked older sedimentary strata and bedrock substrate over tens of millions of years. It
319 follows that greater erosion, reworking and comminution under prolonged glacial conditions,
320 as can be expected for Antarctic margins, would result in a finer grain-size composition of the
321 diamictons. However, coarser grained GDFs and tills are observed on Antarctic margins (Fig.
322 5), suggesting that palaeo-ice sheet drainage basin size (and trough length) has little influence
323 on overall grain-size distribution.

324 The depth of the cross-shelf troughs at the shelf edge, with respect to the surrounding
325 shelf, may give an indication of the amount of erosion the shelf has undergone over
326 progressive glacial cycles where ice streams have formed in the same locations over several
327 glacial cycles. Some of the relief, however, is likely to be due to aggradation of the adjacent
328 banks during the Quaternary. With increased palaeo-drainage basin size, trough relief at the
329 shelf edge increases, indicating the shelf has undergone prolonged erosion over time.
330 However, under more unstable ice sheet configurations over repeated glacial cycles, flow
331 switching may occur leading to erosion of a particular trough that is not that pronounced.
332 There is a strong correlation between fan gradient and drainage basin size, and trough length
333 and fan area increase with both of these parameters (Fig. 4). This indicates that a greater
334 volume of sediment was transported toward the shelf edge under ice sheets with larger
335 drainage basin sizes/longer troughs (or wider shelves), leading to a reduction of slope
336 gradient. However, our results suggest that grain size was not significantly influenced by
337 these factors. No correlation between trough relief at the shelf edge and grain-size
338 composition is observed.

339

340 ***Mechanisms causing the depletion of fine-grained material in Antarctic diamictos***

341 Winnowing by along-slope currents, or cascading flows of dense water formed during sea-ice
342 formation through brine rejection, may influence grain-size composition on the shelf and
343 slope of polar margins during glacial and interglacial periods. This may lead to erosion along
344 some parts of the shelf and slope and deposition of mud in other areas. Strong bottom
345 currents are observed on both Arctic and Antarctic margins (e.g. Camerlenghi et al., 1997;
346 Heathershaw et al., 1998; Giorgetti et al., 2003; Foldvik et al., 2004; Ivanov & Shapiro, 2005;
347 Bøe et al., 2009) with current velocities $>0.06 \text{ m s}^{-1}$ measured using current metres and
348 inferred from modelling along both margins. These currents are able to erode and remove at
349 least silt- and clay-sized particles from interglacial sediments (Young and Southard, 1978).
350 Subglacial reworking of these interglacial sediments during subsequent glacial periods may
351 have caused a coarser grain size of the tills deposited by the ice. However, strong bottom
352 currents are only observed near the outer Antarctic shelf and slope (e.g. Melles et al., 1994;
353 Hillenbrand et al., 2010) suggesting that a difference in the bottom current strength between
354 Arctic and Antarctic margins cannot explain the grain-size differences observed between
355 shelf diamictos. Cascading flows of cold, dense water are only known to influence the
356 seafloor sediments in the outer Filchner Trough, on the Crary Fan, and episodically on the
357 East Antarctic shelf (Harris et al., 2000) but not from regions surrounding the Belgica Fan,
358 which displays similar grain-size distributions to the Crary Fan. This suggests that cascading
359 flows of dense water do not have a significant influence on the grain-size differences
360 observed between GDFs on Arctic and Antarctic margins.

361 Ice sheet drainage basin size presumably influences the abundance and volume of
362 subglacial meltwater released from beneath an ice sheet. Meltwater may winnow fine-grained
363 particles from shelf and slope sediments and initiate turbidity currents when released at the
364 grounding line of an ice stream. In areas of greater meltwater, processes such as turbidity
365 current activity would increase, which could increase the coarse fraction on the fan,
366 depositing finer sediment further down-slope, although other processes such as slope by-pass
367 or erosion may occur at times. Plumites, or finer material, may also be deposited by settling
368 from meltwater and deposited close to the shelf edge (Lucchi et al., 2013). This would
369 contribute fine-grained material to the TMF and that material may later be incorporated in
370 GDFs. The volume and abundance of subglacial meltwater is largely controlled by strain
371 heating and the geothermal heat flux beneath the ice sheet (Joughin et al., 2004; Pattyn,

2010). The volume of palaeo-meltwater discharge for individual ice streams is difficult to quantify although there are numerous examples of bedforms formed by subglacial meltwater erosion on the inner parts of Antarctic palaeo-ice stream troughs (Lowe & Anderson, 2003; Ó Cofaigh et al., 2005, Anderson & Oakes Fretwell, 2008; Graham et al., 2009). Studies of modern systems have shown that basal meltwater production is usually millimetres per year (e.g. Beem et al., 2010; Pattyn, 2010). Meltwater released from the generally larger Antarctic palaeo-ice sheets may have resulted in increased winnowing of fine-grained sediments, thus leading to coarser-grained deposits. However, this can explain neither the average coarse grain-size composition of an Antarctic GDF, which consists of an unsorted diamicton deposited as a cohesive unit, nor the coarse-grained composition of an Antarctic shelf diamicton. The latter could have inherited its coarser grain size only by the incorporation of meltwater-winnowed interglacial sediments into the subglacial till. Subglacial meltwater release at grounding lines on the modern Antarctic shelf, however, has been shown to result in sediment deposition rather than winnowing, with the resulting sediments being enriched in terrigenous silt (e.g. Hass et al. 2010).

Mechanisms causing the enrichment of fine-grained detritus in Arctic diamictons

The difference in the onset, duration and timing of glacial-interglacial cycles between the Arctic and Antarctic may have influenced the supply of fine-grained detritus to the margins in both regions, with the supply of such material being higher in the Arctic during interglacial or deglacial periods. The fine-grained fraction of interglacial sediments in both regions consists largely of ice rafted debris, volcanic ash particles, eolian dust, hemipelagic detritus and microfossils, with modern hemipelagic sediments commonly being characterised by <6% sand content (e.g. Laberg & Vorren, 1995; Laberg et al., 2000; Lucchi et al., 2013). A significant difference between the Antarctic and Arctic margins is the interglacial supply of fluvial detritus to the latter, which plays no role in the Antarctic. Interglacial hemipelagic sediments are more abundant, or were deposited over prolonged time periods, on Arctic margins due to the shorter duration of glaciations and more rapid deglaciations (Nielson et al., 2005). Deposition of biogenic matter, resulting in the sedimentation of foraminifera- and diatom-bearing muds and oozes, also plays a greater role for the interglacial sedimentation on Arctic margins due to more favourable conditions for primary production, although this would not have affected the GDFs, which have a negligible biogenic component (Marchal et al., 2000). Therefore, a prolonged interglacial period would enhance deposition of fine-grained material on Arctic margins. The higher amount of interglacial hemipelagic deposits

405 probably also influenced the composition of the tills on the continental shelves that
406 incorporated this material during subsequent glacial periods and supplied it to the slope as
407 GDFs.

408 The difference in dust (<100 micron) input between Arctic and Antarctic margins may
409 contribute to the increased input of fine-grained detritus to the former during interglacials,
410 although determining the exact input is a major challenge (e.g. Albani et al., 2014). Estimated
411 modern bulk dust fluxes are 0-3 mg/m²/yr for Antarctica but ~10-2080 mg/m²/yr for Arctic
412 margins (Cambray et al., 1979; Steffensen, 1997; Zdanowicz et al., 1998; Albani et al., 2014).
413 Particle size was found to decrease with distance down-wind, with sand-sized grains being
414 deposited within 5 km from the dust source and silt-clay sized grains being deposited up to
415 >100 km down-wind of the source (Atkins & Dunbar, 2009; Chewings et al., 2014). The
416 potential local dust sources for Antarctica are significantly smaller compared to the Arctic,
417 with the potential source areas covering only ~2% (4,800 km²) of the Antarctic continent
418 today (and likely being significantly smaller during glacial periods). However, ice core
419 records document that dust is supplied to Antarctica also from distal sources, such as
420 Australia and South America (Li et al., 2008), and that this supply from distal sources had
421 increased during Late Quaternary glacial maxima by a factor of ≤ 25 (e.g. Lambert et al.,
422 2008). Dust production along the Greenland, Norwegian and Barents Sea margins was likely
423 higher during both interglacials and glacials due to smaller ice sheets and shorter glaciations
424 that resulted in larger land areas being exposed to erosion by wind, which would have caused
425 a higher supply of fine grained dust input to the margins.

426 The difference in fluvial input to the Arctic and Antarctic margins is likely to be a
427 dominant factor controlling the composition of glacial diamictos and GDFs on both
428 margins. This is reflected by the total suspended matter flux, which is estimated to be
429 227×10^6 t/year (1% of the global flux) in the Arctic Ocean (Gordeev, 2006) whereas it is
430 probably far less in the Antarctic due to the extensive ice cover. Fjords (e.g. observed along
431 coastal Norway, Greenland and Svalbard), however, may limit the transport of sediment to
432 the shelf by acting as efficient sediment traps during interglacials. In contrast to the Arctic,
433 land surface is seldom exposed in Antarctica and fluvial transport to the Antarctic margin is
434 negligible even during interglacial periods. Thus, surface run-off and river discharge are the
435 most likely explanation for the fine-grained shelf diamictos and slope GDFs characterising
436 the Arctic margins.

437

438 Conclusions

439 Analysis of the grain-size composition of GDFs and shelf diamictons from 82 sediment cores
440 recovered from Arctic and Antarctic TMFs and outer shelf parts of adjacent palaeo-ice stream
441 troughs revealed a distinct coarser-grained composition for the Antarctic margin. A
442 significant difference in grain-size composition is observed between diamictons recovered on
443 the Arctic and Antarctic outer-shelves, indicating that the origin of the differences in grain-
444 size distribution lies on the shelf. Palaeo-environmental conditions, such as palaeo-ice sheet
445 drainage basin size, subglacial sediment transport distance and size of the palaeo-ice sheets,
446 do not appear to influence grain-size distribution of the shelf diamictons and GDFs.
447 Similarly, the hinterland geology does not influence the grain-size compositions of the TMFs
448 on the continental slopes. The significant difference between the Arctic and Antarctic
449 margins is attributed to the differences in environmental conditions between the two regions
450 during interglacial periods. The duration of interglacial periods is recognized to control the
451 supply of fine-grained detritus to the margins. The volume and composition of interglacial
452 sediments has the greatest influence on the grain-size composition of the glacial sediments.
453 Input of fluvial detritus, greater dust production and supply resulting from greater land
454 exposure in combination with enhanced surface weathering, and prolonged high biological
455 productivity in response to longer interglacial conditions, are responsible for a higher
456 accumulation of fine-grained sediment on Northern hemisphere shelves during interglacials.
457 This fine-grained sediment is eroded and reworked into tills by grounded ice advancing to the
458 shelf edge during subsequent glacial periods. The till is then redeposited downslope as GDFs
459 to form TMFs. We suggest that the observed difference in grain-size composition between
460 Antarctic and Arctic shelf diamictons and GDFs originates from the fundamental difference
461 in the composition of shelf sediments deposited during interglacials.

462 Acknowledgements

463 We thank Kelly Hogan and Denise R  ther for their advice and comments during the review
464 process.

465

466

467 References

468 Albani, S., Mahowald, N.M., Perry, A.T., Scanza, R.A., Zender, C.S., Heavens, N.G., Maggi, V., Kok, J.F.,
469 Otto-Bliesner, B.L. 2014. Improved dust representation in the Community Atmosphere Model. *Journal of*
470 *Advances in Modelling Earth Systems* 6, 541-570.

- 471 Anderson, J.B., 1999. *Antarctic Marine Geology*. Cambridge University Press.
- 472 Anderson, J.B., Kurtz, D.D., Domack, E.W., Balshaw, K.M., 1980. Glacial and glacialmarine sediments of the
473 Antarctic continental shelf. *J. Geol.* 27, 399– 414.
- 474 Anderson, J. B., Oakes-Fretwell, L., 2008. Geomorphology of the onset area of a palaeo-ice stream, Marguerite
475 Bay, Antarctic Peninsula. *Earth Surface Processes and Landforms* 33, 503-512.
- 476 Arndt, J.E., Schenke, H.W., Jakobsson, M., Nitsche, F.O., Buys, G., Goleby, B., Rebesco, M., Bohoyo, F.,
477 Hong, Jongkuk., Black, J., Greku, R., Udinstev, G., Barrios, F., Reynoso-Peralta, W., Taisei, M., Wigley, R.
478 2013. The International Bathymetric Chart of the Southern Ocean (IBCSO) Version 1.0—A new bathymetric
479 compilation covering circum-Antarctic waters. *Geophysical Research Letters* 40, 3111-3117.
- 480 Atkins, C.B., Dunbar, G.B. 2009. Aeolian sediment flux from sea ice into Southern McMurdo Sound,
481 Antarctica. *Global and Planetary Change* 69(3), 133-141.
- 482 Barrett, P., 2008. A history of Antarctic Cenozoic glaciation – view from the margin. In: Florindo, F., Siegert,
483 M., (Eds.), *Developments in Earth and Environmental Sciences* 8, 33-82.
- 484 Bart, P.J., De Batist, M., Jokat, W. 1999. Interglacial collapse of Crary trough-mouth fan, Weddell sea,
485 Antarctica: implications for Antarctic glacial history. *Journal of Sedimentary Research* 69, 1276-1289.
- 486 Batchelor, C.L., Dowdeswell, J.A. 2014. The physiography of High Arctic cross-shelf troughs. *Quaternary
487 Science Reviews* 92, 68-96.
- 488 Beem, L.H., Jezek, K.C., Van Der Veen, C.J., 2010. Basal melt rates beneath Whillans Ice Stream, West
489 Antarctica. *Journal of Glaciology* 56, 647-654.
- 490 Beuselinck, L., Govers, G., Poesen, J., Degraer, G. 1998. Grain-size analysis by laser diffractometry:
491 Comparison with sieve-pipette method. *Catena* 32, 193-208.
- 492 Bianchi, H., McCave, J. 1999. Measurement of the sortable silt current speed proxy using the Sedigraph 5100
493 and Coulter Multisizer II: precision and accuracy. *Sedimentology* 46, 1001-1014.
- 494 Bøe, R., Bellec, V.K., Dolan, M.F.J., Buhl-Mortensen, P., Buhl-Mortensen, L., Slagstad, D., Rise, L. 2009.
495 Giant sandwaves in the Høla glacial trough off Vesterålen, North Norway. *Marine Geology* 267, 36-54.
- 496 Butt, A.B., Elverhøi, A., Forsberg, C.F., Solheim, A. 2001. Evolution of the Scoresby Sund Fan, central East
497 Greenland – evidence from ODP Site 987. *Norsk Geologisk Tidsskrift* 81, 3-15. Trondheim 200 1. ISSN 0029-
498 196X.
- 499 Cambray, R.S., Jefferies, D.F., Topping, G. 1979. Atmospheric input of trace elements to the North Sea. *Mar.
500 Sci. Commun.* 5(2).
- 501 Camerlenghi, A., Crise, A., Pudsey, C.J., Accerboni, E., Laterza, R., Rebesco, M., 1997. Ten-month observation
502 of the bottom current regime across a sediment drift of the Pacific margin of the Antarctic Peninsula. *Antarctic
503 Science* 9 (4), 426-433.
- 504 Cartapanis, O., Bianchi, D., Jaccard, S.L., Galbraith, E.D. 2016. Global pulses of organic carbon burial in deep-
505 sea sediments during glacial maxima. *Nature Communications* 7,10796, DOI: 10.1038/ncomms10796.
- 506 Chewings, J.M., Atkins, C.B., Dunbar, G.B., Gollledge, N.R. 2014. Aeolian sediment transport and deposition
507 in a modern high latitude glacial marine environment. *Sedimentology*, doi:10.1111/sed.12108.
- 508 Clarke, G.K.C. 1987. Subglacial till: A physical framework for its properties and processes. *Journal of
509 Geophysical Research-Solid Earth* 92, 9023-9036.

- 510 Cooper, A.K., Barrett, P.J., Hinz, K., Traube, V., Leitchenkov, G., Stagg, H.M.J. 1991. Cenozoic prograding
511 sequences of the Antarctic continental margin: a record of glacio-eustatic and tectonic events. *Marine Geology*
512 102, 175-213.
- 513 Cooper, A.K., Brancolini, G., Escutia, C., Kristoffersen, Y., Larter, R., Leitchenkov, G., O'Brien, P., Jokat, W.,
514 2008. Cenozoic climate history from seismic-reflection and drilling studies on the Antarctic continental margin.
515 In: Florindo, F., Siegert, M., (Eds.), *Antarctic Climate Evolution, Developments in Earth and Environmental*
516 *Sciences* 8, Elsevier. 115-234.
- 517 Covault, J.A., Romans, B.W., Graham, S.A., Fildani, A., Hilley, G.E. 2011, Terrestrial source to deep-sea sink
518 sediment budgets at high and low sea levels: insights from tectonically active Southern California. *Geology* 39,
519 619–622.
- 520 Cunningham, A.P., Larter, R.D., Barker, P.F., Gohl, K., Nitsche, F.O. 2002. Tectonic evolution of the Pacific
521 margin of Antarctica 2. Structure of Late Cretaceous-early Tertiary plate boundaries in the Bellingshausen Sea
522 from seismic reflection and gravity data. *Journal of Geophysical Research- Solid Earth* 107 (B12), 2346.
523 Doi:10.1029/2002JB001897
- 524 Damuth, J.E., 1978. Echo character of the Norwegian-Greenland Sea: relationship to Quaternary sedimentation.
525 *Marine Geology* 28, 1-36.
- 526 Denton, G.H. & Hughes, T.J. 1981: The Arctic ice sheet: an outrageous hypothesis. In Denton, G. H. & Hughes,
527 T. J. (eds.): *The Last Great Ice Sheets*, 437–467. John Wiley & Sons, New York.
- 528 Domack, E.W., Fairchild, W.W., Anderson, J.B. 1980. Lower Cretaceous sediment from the East Antarctic
529 continental shelf. *Nature* 287, doi:10.1038/287625a0.
- 530 Domack, E.W., Jacobson, E.A., Shipp, S., Anderson, J.B., 1999. Late Pleistocene–Holocene retreat of the West
531 Antarctic Ice- Sheet system in the Ross Sea: Part 2. Sedimentologic and stratigraphic signature. *Geol. Soc.*
532 *Amer. Bull.* 111, 1517– 1536.
- 533 Dowdeswell, J.A., Kenyon, N., Elverhøi, A., Laberg, J.S., Mienert, J., Siegert, M.J., 1996. Large-scale
534 sedimentation on the glacier influenced Polar North Atlantic margins: long-range side-scan sonar evidence.
535 *Geophysical Research Letters* 23, 3535-3538.
- 536 Dowdeswell, J.A., Kenyon, N.H., Laberg, J.S., 1997. The glacier influenced Scoresby Sund fan, east Greenland
537 continental margin: evidence from GLORIA and 3.5 kHz records. *Marine Geology* 143, 207-221.
- 538 Dowdeswell, J.A., Ó Cofaigh, C., Noormets, R., Larter, R.D., Hillenbrand, C.-D., Benetti, S., Evans, J., Pudsey,
539 C.J. 2008. A major trough-mouth fan on the continental margin of the Bellingshausen Sea, West Antarctica:
540 Belgica Fan. *Marine Geology* 252, 129-140.
- 541 Dylmer, C.V. 2013. Paléohydrologie de surface des Mers Nordiques à l'Holocène Terminal (derniers 3000 ans):
542 le message du phytoplancton à squelette calcaire et organique (Thesis). University of Bordeaux, 354 pp.
- 543 Eagles, G., Gohl, K., Larter, R. D., 2004. High-resolution animated tectonic reconstruction of the South Pacific
544 and West Antarctic Margin. *Geochem. Geophys. Geosyst* 5, Q07002. Doi:10.1029/2003GC000657.
- 545 Eagles, G., Gohl, K., Larter, R. D., 2009. Animated tectonic reconstruction of the Southern Pacific and alkaline
546 volcanism at its convergent margins since Eocene times. *Tectonophysics* 464, 21-29.
- 547 Elverhøi, A., Hooke, R., Le, B., Solheim, A. 1998. Late Cenozoic erosion and sediment yield from the Svalbard-
548 Barents Sea region: implications for understanding erosion of glacierised basins. *Quaternary Science Reviews*
549 17, 209-242.

- 550 Elverhøi, A., Norem, H., Andersen, E.S., Dowdeswell, J.A., Fossen, I., Haflidason, H., Kenyon, N., Laberg,
551 J.S., King, E.L., Sejrup, H.P., Solheim, A., Vorren, T. 1997. On the origin and flow behaviour of submarine
552 slides on deep sea fans along the Norwegian-Barents Sea continental margin. *Geo-marine Letters* 17, 119-125.
- 553 Escher, J.C., Pulvertaft, T.C.R. 1995. Geological Map of Greenland, Scale 1:2.500.000. Geological Survey of
554 Greenland, Copenhagen.
- 555 Evans, J., Dowdeswell, J.A., Ó Cofaigh, C., Benham, T.J., Anderson, J.B. 2006. Extent and dynamics of the
556 West Antarctic Ice Sheet on the outer continental shelf of Pine Island bay during the last glaciations. *Marine*
557 *Geology* 230, 53-72.
- 558 Evans, D., King, E.L., Kenyon, N.H., Brett, C., Wallis, D. 1996. Evidence for long-term instability in the
559 Storegga Slide region off western Norway. *Marine Geology* 130, 281–292.
- 560 Evans, J., Pudsey, C.J. 2002. Sedimentation associated with Antarctic Peninsula ice shelves: implications for
561 paleoenvironmental reconstructions of glacial marine sediments. *J. Geol. Soc.* 159, 233–237.
- 562 Faleide, J. I., Tsikalas, F., Breivik, A.J., Mjelde, R., Ritzmann, O., Engen, Ø., Wilsen, J., Eldholm, O. 2008.
563 Structure and evolution of the continental margin off Norway and the Barents Sea. *Episodes* 31, 82-91.
- 564 Florindo, F., Siegert, M. 2008. *Antarctic Climate Evolution. – Developments in Earth and Environmental*
565 *Sciences* 8, Elsevier, The Netherlands, 606 pp.
- 566 Foldvik, A., Gammelsrød, T., Østerhus, S., Fahrbach, E., Rohardt, G., Schröder, M., Nicholls, K.W., Padman,
567 L., Woodgate, R. A. 2004. Ice shelf water overflow and bottom water formation in the southern Weddell Sea.
568 *Journal of Geophysical Research* 109, 1-15.
- 569 Forsberg, C.F., Florindo, F., Grutzner, J., Venuti, A. Solheim. 2008. Sedimentation and aspects of glacial
570 dynamics from physical properties, mineralogy and magnetic properties at ODP Sites 1166 and 1167, Prydz
571 Bay, Antarctica. *Palaeography, Palaeoclimatology, Palaeoecology* 260, 184-201.
- 572 Gales, J.A., Forwick, M., Laberg, J.S., Vorren, T.O., Larter, R.D., Graham, A.G.C., Baeten, N.J., Amundsen,
573 H.B. 2013. Arctic and Antarctic submarine gullies – a comparison of high latitude continental margins.
574 *Geomorphology* 201, 449-461.
- 575 Giorgetti, A., Crise, A., Laterza, R., Perini, L., Rebesco, M., Camerlenghi, A. 2003. Water masses and bottom
576 boundary layer dynamics above a sediment drift of the Antarctic Peninsula Pacific margin. *Antarctic Science* 15
577 (4), 537-546.
- 578 Gordeev, V.V. 2006. Fluvial sediment flux to the Arctic Ocean. *Geomorphology* 80, 94-104.
- 579 Graham, A.G.C., Larter, R.D., Gohl, K., Hillenbrand, C-D., Smith, J.A., Kuhn, G. 2009. Bedform signature of a
580 West Antarctic paleo-ice stream reveals a multi-temporal record of flow and substrate control. *Quaternary*
581 *Science Review* 28, 2774-2793.
- 582 Haas, H.C., Kuhn, G., Monien, P., Brumsack, H.-J., Forwick, M. 2010. Climate fluctuations during the past two
583 millennia as recorded in sediments from Maxwell Bay, South Shetland Islands, West Antarctica. *Geological*
584 *Society, London Special Publication* 344, 243-260.
- 585 Hambrey, M.J., Ehrmann, W.U., Larsen, B. 1991. Cenozoic glacial record of the Prydz bay continental shelf,
586 East Antarctica. *Proceedings of the Ocean Drilling Program, Scientific Results* 119, 77–132.
- 587 Harris, P.T. 2000. Ripple cross-laminated sediments on the East Antarctic Shelf: evidence for episodic bottom
588 water production during the Holocene. *Marine Geology* 170, 317-330.

- 589 Heathershaw, A.D., Hall, P., Huthnance, J.M. 1998. Measurements of the slope current, tidal characteristics and
590 variability west of vestfjorden, Norway. *Continental Shelf Research* 18,1419-1453.
- 591 Hillenbrand, C.-D., Baesler, A., Grobe, H. 2005. The sedimentary record of the last glaciation in the western
592 Bellingshausen Sea (west Antarctica): implications for the interpretation of diamictons in a polar-marine setting.
593 *Marine Geology* 216, 191-204.
- 594 Hillenbrand, C.-D., Ehrmann, W., Larter, R.D., Benetti, S., Dowdeswell, J.A., Ó Cofaigh, C., Graham, A.G.C.,
595 Grobe, H. 2009. Clay mineral provenance of sediments in the southern Bellingshausen Sea reveals drainage
596 changes of the West Antarctic Ice Sheet during the Late Quaternary. *Marine Geology* 265, 1-18.
- 597 Hillenbrand, C.-D., Larter, R.D., Dowdeswell, J.A., Ehrmann, W. U., Ó Cofaigh, C., Benetti, S., Graham, A.G.
598 C., Grobe, H. 2010. The sedimentary legacy of a palaeo-ice stream on the shelf of the southern Bellingshausen
599 Sea: Clues to West Antarctic glacial history during the Late Quaternary. *Quaternary Science Reviews* 29, 2741-
600 2763.
- 601 Ivanov, W., Shapiro, G. I. 2005. Formation of a dense water cascade in the marginal ice zone in the Barents Sea.
602 *Deep Sea Research* 52, 1699-1717.
- 603 Imbo, Y., De Batist, M., Canals, M., Prieto, M.J., Baraza, J. 2003. The Gebra slide: a submarine slide on the
604 Trinity Peninsula margin, Antarctica. *Marine Geology* 193, 235-252.
- 605 Iverson, R.M., Vallance, J.W. 2001. New views of granular mass flows. *Geology* 29, 115-118.
- 606 Jakobsson, M., Ingolfsson, O., Long, A., Spielhagen, R. 2014. The dynamic Arctic. *Quaternary Science*
607 *Reviews* 92, 1-8.
- 608 Jakobsson, M., Mayer, L., Coakley, B., Dowdeswell, J.A., Forbes, S., Fridman, B., Hodnesdal, H., Noormets, R.,
609 Pedersen, R., Rebesco, M., Schenke, H.W., Zarayskaya, Y., Accettella, D., Armstrong, A., Anderson, R.M.,
610 Bienhoff, P., Camerlenghi, A., Church, I., Edwards, M., Gardner, J.V., Hall, J.K., Hell, B., Hestvik, O.,
611 Kristoffersen, Y., Marcussen, C., Mohammad, R., Mosher, D., Nghiem, S.V., Pedrosa, M.T., Travaglini, P.G.,
612 Weatherall, P. 2012. The International bathymetric Chart of the Arctic Ocean (IBCAO). Version 3.0.
613 *Geophysical Research Letters* 39, L12609.
- 614 Jamieson, S.S.R., Hulton, N.R.J., Dugden, D.E., Payne, A.J., Taylor, J. 2005. Cenozoic landscape evolution of
615 the Lambert basin, East Antarctica: the relative role of rivers and ice sheets. *Global and Planetary Change* 45,
616 35-49.
- 617 Jansen, E., Befring, S., Bugge, T., Eidvin, T., Holtedahl, H., Sejrup, H.P. 1987. Large submarine slides on the
618 Norwegian continental margin: sediments, transport and timing. *Marine Geology* 78, 77-107.
- 619 Jansen, E., Sejrup, H.P., Fjæran, T., Hald, M., Holtedahl, H., Skarbø, O. 1983. Late Weichselian
620 paleoceanography of the southeastern Norwegian Sea. *Nor. Geol. Tidsskr.* 63, 117-146.
- 621 Jokat, W., Hubscher, C., Meyer, U., Oszko, L., Schone, T., Versteeg, W., Miller, H. 1996. The continental
622 margin off East Antarctica between 10 W and 30 W in the Weddell Sea Tectonics and Gondwana Break up.
623 *Geological Society of London Special Publications* 108, 129-141.
- 624 Joughin, I., Tulaczyk, S., MacAyeal, D.R., Engelhardt, H. 2004. Melting and freezing beneath the Ross ice
625 streams, Antarctica. *Journal of Glaciology* 50, 96-108.
- 626 Kenyon, N.H., 1987. Mass-wasting features on the continental slope of northwest Europe. *Marine Geology* 74,
627 57-77.

- 628 King, E.L., Hafliðason, H., Sejrup, H.P., Løvlie, R. 1998. Glacigenic debris flows on the North Sea Trough
629 Mouth Fan during ice stream maxima. *Marine Geology* 152, 217-246.
- 630 King, E.L., Sejrup, H.P., Hafliðason, H., Elverhøi, A., Aarseth, I. 1996. Quaternary seismic stratigraphy of the
631 North Sea Fan: glacially fed gravity flow aprons, hemipelagic sediments, and large submarine slides. *Marine*
632 *Geology* 130, 293-315.
- 633 Kleiber, H.P., Knies, J., Niessen, F. 2000. The Late Weichselian glaciation of the Franz Victoria Trough,
634 northern Barents Sea: ice sheet extent and timing. *Marine Geology* 168, 25-44.
- 635 Kleiber, H.P., Niessen, F., Weiel, D. 2001. The Late Quaternary evolution of the western Laptev Sea continental
636 margin, Arctic Siberia e implications from subbottom profiling. *Global and Planetary Change* 31, 105-124.
- 637 Knies, J., Matthiessen, J., Vogt, C., Laberg, J.S., Hjelstuen, B.O., Smelror, M., Larsen, E., Andreassen, K.,
638 Eidvin, T., Vorren, T.O. 2009. The Plio-Pleistocene glaciation of the Barents Sea-Svalbard region: a new model
639 based on revised chronostratigraphy. *Quaternary Science Reviews* 28, 812-829.
- 640 Konert, M., Vandenberghe, J. 1997. Comparison of laser grain size analysis with pipette and sieve analysis: a
641 solution for the underestimation of the clay fraction. *Sedimentology* 44, 523-535.
- 642 Kurtz, D.D., Anderson, J.B. 1979. Recognition and sedimentologic description of recent debris flow deposits
643 from the Ross and Weddell seas, Antarctica. *J. Sediment. Petrol.* 49, 1159– 1170.
- 644 Kuvaas, B., Kristoffersen, Y. 1991. The Crary Fan, a trough-mouth fan on the Weddell Sea continental margin,
645 Antarctica. *Marine Geology* 97, 345-362.
- 646 Laberg, J.S., Vorren, T.O. 1995. Late Weichselian submarine debris flow deposits on Bear Island trough mouth
647 fan. *Marine Geology* 127, 45-72.
- 648 Laberg, J.S., Vorren, T.O. 2000. The Traenadjupet Slide, offshore Norway: morphology, evacuation and
649 triggering mechanisms. *Marine Geology* 171, 95-114.
- 650 Laberg, J.S., Vorren, T.O., Dowdeswell, J.A., Kenyon, N.H., Taylor, J. 2000. The Andøya Slide and the Andøya
651 Canyon, north - eastern Norwegian-Greenland Sea. *Marine Geology* 162, 259-275
- 652 Laberg, J.S., Vorren, T.O., Mienert, J., Evans, D., Lindberg, B., Ottesen, D., Kenyon, N.H., Henriksen, S. 2002.
653 Late Quaternary palaeoenvironment and chronology in the Traenadjupet Slide area offshore Norway. *Marine*
654 *Geology* 188, 35-60.
- 655 Lambert, F., Delmonte, B., Petit, J.R., Bigler, M., Kaufmann, P.R., Hutterli, M.A., Stocker, T.F., Ruth, U.,
656 Steffensen, J.P., Maggi, V. 2008. Dust-climate couplings over the past 800,000 years from the EPICA Dome C
657 ice core. *Nature* 452, 616-619.
- 658 Landvik, J.Y., Ingolfsson, Ó., Mienert, J., Lehman, S.J., Solheim, A., Elverhøi, A., Ottesen, D. 2005. Rethinking
659 late Weichselian ice sheet dynamics in coastal NW Svalbard. *Boreas* 34, 7-24.
- 660 Larsen, H.C., Saunders, A.D., Clift, P.D., Beget, J., Wei, W., Spezzaferri, S. 1994. SevenMillion years of
661 glaciation in Greenland. *Science* 244, 952e955.
- 662 Larter, R.D., Barker, P., 1991. Neogene interaction of tectonic and glacial processes at the Pacific margin of the
663 Antarctic Peninsula. In: Macdonald, D. I. M., (Eds.), *Sedimentation, Tectonics and Eustasy*. International
664 Association of Sedimentologists Special Publication 12, Blackwell, Oxford., 165–186.
- 665 Li, F., Ginoux, P., Ramaswamy, V. 2008. Distribution, transport, and deposition of mineral dust in the Southern
666 Ocean and Antarctica: Contribution of major sources. *Journal of Geophysical Research- Atmospheres* 113,
667 10.1029/2007JD009190.

- 668 Licht, K.J., Dunbar, N.W., Andrews, J.T., Jennings, A.E. 1999. Distinguishing subglacial till and glacial marine
669 diamictons in the western Ross Sea, Antarctica: implications for a Last Glacial Maximum grounding line. *Geol.*
670 *Soc. Amer. Bull.* 111, 91– 103.
- 671 Livingstone, S.J., Ó Cofaigh, C., Stokes, C.R., Hillenbrand, C.-D., Vieli, A., Jamieson, S.S.R. 2012. Antarctic
672 palaeo-ice streams. *Earth-Science Reviews* 111, 90-128.
- 673 Lowe, A.L., Anderson, J.B. 2002. Reconstruction of the West Antarctic ice sheet in Pine Island Bay during the
674 Last Glacial Maximum and its subsequent retreat history: a review. *Quaternary Science Review* 21, 1879-1897.
- 675 Lowe, A.L., Anderson, J.B. 2003. Evidence from abundant subglacial meltwater beneath the paleo-ice sheet in
676 Pine Island Bay, Antarctica. *Journal of Glaciology* 49, 125-138.
- 677 Lucchi, R.G., Camerlenghi, A., Rebesco, M., Colmenero-Hidalgo., Sjerro, F.J., Sagnotti, L., Urgeles, R., Melis,
678 R., Morigi, C., Barcena, M.-A., Giorgetti, G., Villa, G., Persico, D., Flores, J.-A., Rigual-Hernandez, A.S.,
679 Pedrosa, M.T., Macri, P., Caburlotto, A. 2013. Postglacial sedimentary processes on the Storfjorden and
680 Kveithola trough mouth fans: Significance of extreme glacimarine sedimentation. *Global and Planetary Change*
681 111, 309-326.
- 682 Mangerud, J., Gyllencreutz, R., Lohne, O., Svendsen, J.I. 2011. Glacial history of Norway. In: *Quaternary*
683 *Glaciations – Extent and Chronology*. Eds: Ehlers, J., Gibbard, P., Hughes, P. Elsevier, Amsterdam.
- 684 Marchal, O., Francois, R., Stocker, T.F., Joos, F. 2000. Ocean thermohaline circulation and sedimentary
685 $^{231}\text{Pa}/^{230}\text{Th}$ ratio. *Paleoceanography* 15, 625-641.
- 686 McCave, I.N., Hall, I.R., Bianchi, G.G. 2006. Laser vs. settling velocity differences in silt grain size
687 measurements: estimation of palaeocurrent vigour. *Sedimentology* 53, 919-928.
- 688 Melles M. 1987. Sedimentation in der Filchner-Depression, südöstlicher Weddellmeer-Schelf, Antarktis.
689 Unpubl. Diploma Thesis, University Göttingen, 180 pp.
- 690 Melles M. 1991. Paläoglazologie und Paläozeanographie im Spätquartär am Kontinentalrand des südlichen
691 Weddellmeeres, Antarktis. – Dissertation University Bremen, Reports on Polar Research, 81, 190 pp.
- 692 Melles M. & Kuhn G. 1993. Sub-bottom profiling and sedimentological studies in the southern Weddell Sea,
693 Antarctica: evidence for large-scale erosional/depositional processes. *Deep-Sea Research* 40(4), 739-760.
- 694 Melles, M., Kuhn, G., Fütterer, D.K., Meischner, D. 1994. Processes of modern sedimentation in the southern
695 Weddell Sea, Antarctica – evidence from surface sediments. *Polarforschung* 64 (2), 45-74.
- 696 Menzies, J. 1996. Past Glacial Environments. Sediments, Forms and Techniques. *Glacial Environments:*
697 *Volume 2*. Xxiv + 598 pp. Oxford.
- 698 Michels, K.H., Kuhn, G., Hillenbrand, C.-D., Diekmann, B., Fütterer, D.K., Grobe, H., Uenzelmann-Neben, G.
699 2002. The southern Weddell Sea: a combined contourite-turbidite sedimentation at the southeastern margin of
700 the Weddell Gyre. In: *Deep-water contourite systems: Modern drifts and ancient series, seismic and sedimentary*
701 *characteristics*. (Eds.) Stow, D. A. V. et al., Geological Society, London, Memoir 22, 305-323.
- 702 Mienert, J. 2002. Special Issue: European North Atlantic Margin (ENAM II): Quantification and modelling of
703 large-scale sedimentary processes. *Marine Geology* 188, 1-248.
- 704 Molinaroli, E., De Falco, G., Rabitti, S., Portaro, R.A. 2000. Stream-scanning laser system, electric sensing
705 counter and settling grain size analysis: a comparison using reference materials and marine sediments.
706 *Sedimentary Geology* 130, 269-281.

- 707 Müller, C., Grobe, H., Ruediger, S. 2004. Sedimentology of core PS2118-2. doi: 10.1594/PANGAEA.135105. In
708 supplement to: Müller, C. 1995. Spätquartäre Sedimentationsprozesse in der östlichen Framstrasse. Diploma
709 Thesis, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven & Fachbereich
710 Geowissenschaften, Westfälische Wilhelms-Universität zu Münster, 84 pp, hdl:10013/epic.32119.d001
- 711 Nielsen, T., De Santis, L., Dahlgren, K.I.T., Kuijpers, A., Laberg, J.S., Nygård, A., Praeg, D., Stoker, M.S.
712 2005. A comparison of the NW European glaciated margin with other glaciated margins. *Marine and Petroleum*
713 *Geology* 22, 1149-1183.
- 714 Nitsche, F.O., Gohl, K., Vanneste, K., Miller, H. 1997. Seismic expression of glacially deposited sequences in
715 the Bellingshausen and Amundsen Seas, West Antarctica. *Antarctic Research Series* 71, 95-108.
- 716 Nygård, A., Sejrup, H. P., Haflidason, H. and Bryn, P. 2005. The glacial North Sea Fan, southern Norwegian
717 Margin: architecture and evolution from the upper continental slope to the deep-sea basin. *Marine and*
718 *Petroleum Geology* 22 (1-2): 71-84.
- 719 O'Brien P.E., Truswell E.M., Burton T. 1994. In *The Antarctic Continental Margin: Geophysical and Geological*
720 *Stratigraphic Records of Cenozoic Glaciation, Paleoenvironments and Sea-Level Change*. Terra Antarctica,
721 Morphology, seismic stratigraphy and sedimentation history of the Mac.Robertson Shelf, eds Cooper A. K.,
722 Barker P. F., Webb P-N., Brancolini G. 1, 407–408
- 723 Ó Cofaigh, C., Dowdeswell, J.A., Allen, C.S., Hiemstra, J., Pudsey, C.J., Evans, J., Evans, D.J.A. 2005. Flow
724 dynamics and till genesis associated with a marine-based Antarctic palaeo-ice stream. *Quaternary Science*
725 *Review* 24, 709-740.
- 726 Ó Cofaigh, C., Dowdeswell, J.A., Evans, J., Kenyon, N.H., Taylor, J., Mienert, J. & Wilken, M. 2004. Timing
727 and significance of glacially-influenced mass-wasting in the submarine channels of the Greenland Basin. *Marine*
728 *Geology* 207, 39-54
- 729 Ó Cofaigh, C., Taylor, J., Dowdeswell, J.A., Pudsey, C.J. 2003. Palaeo-ice streams, trough mouth fans and high-
730 latitude continental slope sedimentation. *BOREAS* 32, 37-55.
- 731 Ottesen, D., Dowdeswell, J.A., Landvik, J.Y., Mienert, J. 2007. Dynamics of the Late Weichselian ice sheet on
732 Svalbard inferred from high-resolution sea-floor morphology. *Boreas* 36, 286e306.
- 733 Passchier, S., O'Brien, P.E., Damuth, J.E., Januszczak, N., Handwerger, D.A., Whitehead, J.M. 2003. Pliocene-
734 Pleistocene glaciomarine sedimentation in eastern Prydz Bay and development of the Prydz trough mouth fan,
735 ODP Sites 1166 and 1167, East Antarctica. *Marine Geology* 199, 279–305.
- 736 Pattyn, F. 2010. Antarctic subglacial conditions inferred from a hybrid ice sheet/ice stream model. *Earth and*
737 *Planetary Science Letters* 295, 451-461.
- 738 Rebesco, M., Liu, Y., Camerlenghi, A., Winsborrow, M., Laberg, J.S., Caburlotto, A., Diviacco, P., Accettella,
739 D., Sauli, C., Wardell, N., Tomini, I. 2011. Deglaciation of the west margin of the Barents Sea Ice Sheet – a
740 swath bathymetric and subbottom seismic study from the Kveithola Trough. *Marine Geology* 279, 141-147.
- 741 Rebesco, M., Wåhlin, A., Laberg, J.S., Schauer, A., Brezcynska-Möller, A., Lucchi, R.G., Noormets, R.,
742 Accettella, D., Zarayskaya, Y., Diviacco, P., 2013. Quaternary contourite drifts of the Western Spitsbergen
743 margin. *Deep-Sea Research Part I: Oceanographic Research Papers* 79, 156–168.
- 744 Ruther, D.C., Andreassen, Spagnolo, M. 2013. Aligned glaciotectionic rafts on the central Barents Sea seafloor
745 revealing extensive glaciotectionic erosion during the last deglaciation. *Geophysical Research Letters* 40, 6351-
746 6355.

- 747 Ruther, D.C., Bjarnadottir, L.R., Junttila, J., Husum, K., Rasmussen, T.L. 2012. Pattern and timing of the
748 northwestern Barents Sea Ice Sheet deglaciation and indications of episodic Holocene deposition. *Boreas* 41,
749 494-512.
- 750 Rydningen, T.A., Vorren, T.O., Laberg, J.S., Kolstad, V. 2013. The marine-based NW Fennoscandian ice sheet:
751 glacial and deglacial dynamics as reconstructed from submarine landforms. *Quat. Sci. Rev.* 68, 126-141.
- 752 Saettem, J., Poole, D.A.R., Ellingsen, L., Sejrup, H.P. 1992. Glacial geology of outer Bjbrnbyrenna,
753 southwestern Barents Sea. *Mar. Geol.* 103, 15– 51.
- 754 Solheim, A., Faleide, J.I., Andersen, E.S., Elverhøi, A., Forsberg, C.F., Vanneste, K., Uenzelmann-Neben, G.,
755 Channell, J.E.T., 1998. Late Cenozoic seismic stratigraphy and glacial geological development of the East
756 Greenland and Svalbard-Barents sea continental margins. *Quaternary Science Reviews* 17, 155–184.
- 757 Steffensen, J.P. 1997. The size distribution of microparticles from selected segments of the Greenland Ice Core
758 Project ice core representing different climatic periods. *Journal of Geophysical Research* 102, 26,755-26,763.
- 759 Stoker, M.S., Hout, R.J., Nielsen, T., Hjelstuen, B.O., Laberg, J.S., Shannon, P.M., Praeg, D., Mathiesen, A.,
760 Van Weering, T.C.E., McDonnell, A. 2005. Sedimentary and oceanographic responses to early Neogene
761 compression on the NW European margin. *Marine and Petroleum Geology* 22, 1031-1044.
- 762 STRATAGEM Partners. Stoker, M.S. (Compiler), 2003. Neogene evolution of the glaciated European margin.
763 A product of the EC supported STRATAGEM Project (Svitzer:Gt. Yarmouth).
- 764 Svendsen, J.I., Mangerud, J., Elverhøi, A., Solheim, A., Schuttenhelm, R.T.E. 1992. The Late Weichselian
765 glacial maximum on western Spitsbergen inferred from offshore sediment cores. *Marine Geology* 104, 1-17.
- 766 Talling, P., Allin, J., Armitage, D., Arnott, R., Cartigny, M., Clare, M., Felletti, F., Covault, J., Girardclos, S.,
767 Ernst, H., Hill, P., Hiscott, R., Hogg, A., Hughes Clarke, J., Jobe, Z., Malgesini, G., Mozzato, A., Naruse, H.,
768 Parkinson, S., Peel, F., Piper, D., Pope, E., Postma, G., [Rowley, P.J.](#), Sguazzini, A., Stevenson, C., Sumner, E.,
769 Sylvester, Z., Watts, C., Xu, J. 2015. [Key future directions for research on turbidity currents and their deposits.](#)
770 *Journal of Sedimentary Research* 85, 153-169.
- 771 Taylor, J. 1999. Large-scale Sedimentation and Ice Sheet Dynamics in the Polar North Atlantic. Ph.D.
772 dissertation, University of Bristol, 310 pp.
- 773 The RAISED Consortium, Bentley, M.J., Ó Cofaigh, C., Anderson, J.B., Conway, H., Davies, B., Graham,
774 A.G.C., et al. 2014. A community-based geological reconstruction of Antarctic Ice Sheet deglaciation since the
775 Last Glacial Maximum. *Quaternary Science Reviews* 100, 1-9.
- 776 Thiede, J., Winkler, A., Wolf-Welling, T., Eldholm, O., Myhre, A. M., Baumann, K.-H., Henrich, R., Stein, R.
777 1998. Late Cenozoic history of the Polar North Atlantic: results from ocean drilling. *Quaternary Science*
778 *Reviews* 17, 185-208.
- 779 Turner, J., Bindschadler, R.A., Convey, P., di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D.A., Mayewski,
780 P.A., Summerhayes, C.P. 2009. Antarctic climate change and the environment. Cambridge, Scientific
781 Committee on Antarctic Research.
- 782 Vågnes, E. 1996. Cenozoic deposition in the Nansen Basin, a first-order estimate based on present-day
783 bathymetry. *Global and Planetary Change* 12, 149-157
- 784 Vogt, P.R., Crane, K., Sundvor, E. 1993. Glacigenic mudflows on the Bear Island submarine fan, *EOS Trans.*
785 *AGU* 74, 40, 449–453.

- 786 Vorren, T.O., Laberg, J.S. 1997. Trough mouth fans –palaeoclimate and ice-sheet monitors. *Quaternary Science*
787 *Reviews* 16, 865-881.
- 788 Vorren, T.O., Laberg, J.S., Blaume, F., Dowdeswell, J.A., Kenyon, N.H., Mienert, J., Rumohr, J., Werner, F.,
789 1998. The Norwegian-Greenland sea continental margins: Morphology and late Quaternary sedimentary
790 processes and environment. *Quaternary Science Reviews* 17, 273-302.
- 791 Vorren, T.O., Lebesbye, E., Andreassen, K., Larsen, K.B. 1989. Glacigenic sediments on a passive continental
792 margin as exemplified by the Barents Sea. *Marine Geology* 85, 251–272.
- 793 Vorren, T.O., Plassen, L. 2002. Deglaciation and palaeoclimate of the Andfjord-Vågsfjord area, north Norway.
794 *Boreas* 31, 97-125.
- 795 Weiel, D. 1997. Palaozeanographische Untersuchungen in der Vilkitsky Strasse und ostlich von Severnaya
796 Zemlya mit sedimentologischen und geophysikalischen Methoden. Ph.D. Thesis, Univ. Koln, 138 pp.
- 797 Young, R.N., Southard, J.B. 1978. Erosion of fine-grained marine sediments: sea-floor and laboratory
798 experiments. *Bulletin of the Geological Society of America* 89, 663-672.
- 799 Zdanowicz, C.M., Zielinski, G.A., Wake, C.P. 1998. Characteristics of modern atmospheric dust deposition in
800 snow on the Penny Ice Cap, Baffin Island, Arctic Canada. *Tellus* 50B, 506–520.

801

802

803

804

805

806

807

808

809

810

811

812

813

814

815

816

817

818 **Table 1.** *Physiography of high-latitude trough mouth fans used in analysis*

Location	Area (km ²)	Slope	Trough length (km)	Trough relief at shelf edge (m)	Palaeo-ice stream drainage basin area (km ²)	Reference
Belgica Fan, Antarctica	22,000	1–2	490 ¹	>250	217,000–256,000	Dowdeswell et al. (2008); Livingstone et al. (2012)
Crary Fan, Antarctica	34,300*	1	≤460	340	1,454,878	Kuvaas & Kristoffersen (1991); Melles & Kuhn (1993); Melles et al. (1994); Livingstone et al. (2012); Ó Cofaigh et al. (2003)
Prydz Channel Fan, Antarctica	9,200	0.6	220–350	>300	1,600,000	O'Brien (1994); Livingstone et al. (2012); Jamieson et al. (2005)
Vilkitsky-Khatanga	28,000	1.42	350	250	100,000	Kleiber et al. 2001; Batchelor et al. (2014)
Voronin	20,800*	1.55	450	240	130,000	Vågnes (1996); Batchelor et al. (2014)
St. Anna	48,200*	1.15	600	>440	300,000	Vågnes (1996); Batchelor et al. (2014)
Franz Victoria	21,000*	2.20	300	>420	170,000	Kleiber et al. (2000); Batchelor et al. (2014)
Kongsfjorden	2700	2.29	90	120	8000	Landvik et al. (2005); Batchelor et al. (2014)
Isfjorden	3700	3.60	180	135	14,000	Svendsen et al. (1992); Batchelor et al. (2014)
Belisund	3300	2.98	160	40	8000	Ottesen et al. (2007); Batchelor et al. (2014)
Storfjorden	11,200	1.68	250	140	60,000	Vorren et al. (1998); Batchelor et al. (2014)
Kveithola	2,600*	2.30	90	110	10,000	Rebesco et al. (2011); Batchelor et al. (2014)
Bear Island	215,000	0.74	700	>300	576,000	Vogt et al. (1993); Batchelor et al. (2014); Elverhoi et al. (1998)
North Sea Fan	142,000	0.5	800	300	x	King et al. (1996; 1998); Batchelor et al. (2014); Nygard et al. (2005)
Scoresby Sund	17,800	2.11	480	300	60,000	Mienert et al. (1992); Batchelor et al. (2014)

819 *Estimated from IBCSO and IBCAO dataset..

820

821 **Table 2.** *Cores used in sediment analysis*

Core	Location	Water depth (m)	Latitude	Longitude	Sample depth (cm)	Facies interpretation of sediments
GC357 ^a	Belgica shelf	565.0	-71.7667	-80.11	30-110	Hillenbrand et al. (2010)
GC359 ^a	Belgica shelf	685	-71.7183	-76.0383	70-160	Hillenbrand et al. (2010)
GC360 ^a	Belgica shelf	633	-71.995	-76.5517	40-170	Hillenbrand et al. (2010)
GC362 ^a	Belgica	845	-72.9833	-83.4433	140-190	Hillenbrand et al. (2010)

	shelf					
GC365 ^a	Belgica shelf	1011	-72.5967	-80.83	35-150	Hillenbrand et al. (2010)
GC366 ^a	Belgica shelf	617	-72.845	-82.615	34-140	Hillenbrand et al. (2010)
GC368 ^a	Belgica shelf	588	-71.5783	-82.86	40-80	Hillenbrand et al. (2010)
GC370 ^a	Belgica shelf	533	-71.65	-84.805	50-190	Hillenbrand et al. (2010)
GC371 ^a	Belgica shelf	595	-70.6533	-84.54	30-190	Hillenbrand et al. (2010)
GC372 ^a	Belgica shelf	676	-70.605	-86.2533	30-200	Hillenbrand et al. (2010)
GC374 ^a	Belgica shelf	650	-70.5	-86.2367	35-195	Hillenbrand et al. (2010)
PS2533-1 ^a	Belgica TMF slope	594	-71.02333	-85.89833	45-195	Hillenbrand et al. (2009)
PS2543-1 ^a	Belgica TMF slope	547	-70.94666	-89.34333	50-170	Hillenbrand et al. (2009)
PS2538-2 ^a	Belgica TMF slope	3238	-69.73	-88.921667	65-420	Hillenbrand et al. (2009)
PS2540-1 ^a	Belgica TMF slope	1822	-70.063333	-87.931667	35-414	Hillenbrand et al. (2009)
GC352 ^a	Belgica TMF slope	718	-70.2567	-86.365	30-150	Hillenbrand et al. (2009)
GC353 ^a	Belgica TMF slope	1041	-70.086667	-86.188333	44-290	This study
GC354 ^a	Belgica TMF slope	788	-70.005	-84.89	30-197	This study
GC375 ^a	Belgica TMF slope	877	-70.271667	-86.825	19-75	This study
GC376 ^a	Belgica TMF slope	1016	-70.221667	-86.905	49-260	This study
GC377 ^a	Belgica TMF slope	1608	-69.956667	-86.881667	60-326	This study
GC378 ^a	Belgica TMF slope	2182	-69.7667	-87.3617	51-220	This study
GC381 ^a	Belgica TMF slope	1953	-69.7217	-83.6983	38-105	This study
PS1494-2/3 ^a	Crary TMF slope	1942	-74.18183	-35.5005	50-340	Melles (1991)
PS1607-1/3 ^a	Crary TMF slope	1610	-74.106333	-33.648833	211-367	Melles (1991)
PS1606-1/3 ^a	Crary TMF slope	2933	-73.50216	-34.0335	108-426	Melles (1991)
PS1612-1/2 ^a	Crary TMF slope	815	-74.404667	-37.022333	49-213	Melles (1991)
PS1016-1 ^a	Weddell outer shelf	701	-77.284798	-40.832699	23-40	Melles (1987)
PS1017-1 ^a	Weddell outer shelf	874	-77.284798	-39.145	25-202	Melles (1987)
PS1018-	Weddell	1165	-77.589	-37.921	100-165	Melles (1987)

1 ^a	outer shelf					
PS1019-1 ^a	Weddell outer shelf	1095	-77.427	-37.876	21-172	Melles (1987)
PS1216-1 ^a	Weddell outer shelf	1091	-77.69	-37.065	34-36	Melles (1987)
PS1222-1 ^a	Weddell outer shelf	685	-75.8583	-34.3133	17-54	Melles (1987)
PS1223-1 ^a	Weddell outer shelf	772	-75.9832	-34.3133	31-52	Melles (1987)
PS1277-1 ^a	Weddell outer shelf	415	-77.53	-43.661701	11-22	Melles (1987)
PS1278-1 ^a	Weddell outer shelf	635	-77.540001	-42.126701	19-47	Melles (1987)
PS1279-1 ^a	Weddell outer shelf	729	-77.3133	-40.1367	34-35	Melles (1987)
PS1400-1/4 ^a	Weddell outer shelf	1058	-77.551	-36.403	60-306	Melles (1987)
PS1401-1/2 ^a	Weddell outer shelf	689	-77.6	-35.9	44-60	Melles (1987)
ODP Site 1167 ^a	Prydz TMF slope	1640	-66.400167	72.284167	80-440	Passchier et al. (2003)
92-T-2/1 ^b	Bear Island Fan (slope)	905	73.638611	14.901667	65-205	Laberg & Vorren (1995)
92-T-1/1 ^b	Bear Island Fan (slope)	1503	73.798333	13.927778	90-275	Laberg & Vorren (1995)
JM93-7/1 ^b	Bear Island Fan (slope)	2090	74.147222	12.108333	45-290	Laberg & Vorren (1995)
JM93-6/1 ^b	Bear Island Fan (slope)	2364	74.469444	10.7	90-290	Laberg & Vorren (1995)
7317/10-U-01 ^b	Bear Island (shelf)	465	73.149583	17.270278	0-150	Sættem et al. (1992)
7316/06-U-01 ^b	Bear Island (shelf)	428	73.554583	16.833222	0-30	Sættem et al. (1992)
7316/06-U-02 ^b	Bear Island (shelf)	421	73.568806	16.833583	0-65	Sættem et al. (1992)
7317/02-U-01 ^b	Bear Island (shelf)	297	73.8197	17.367925	0-45	Sættem et al. (1992)
88-01 ^b	Isfjorden (inner shelf)	270	78.035556	12.984167	200-470	Svendsen et al. (1992)
88-04 ^b	Isfjorden (inner shelf)	232	78.016667	11.665	120-250	Svendsen et al. (1992)
NP90-19/PC(1) ^b	Bear Island Fan (Isfjorden slope)	1427	78.236111	8.804722	20-850	Elverhøi et al. (1997)
JM95-2/1 ^b	Andøya Canyon (slope)	1975	69.583333	15.5	450-472	Laberg et al. (2000)
JM99-583 ^b	Kongsfjorden Trough, NW Svalbard (shelf)	308	78.721667	9.354333	0-95	Landvik et al. (2005)

JM99-591 ^b	Kongsfjorden Trough, NW Svalbard (shelf)	239	78.9765	9.864833	65-105	Landvik et al. (2005)
49-23 ^b	Storegga Slide (slope)	2842	64.69	1.636	30-60	Jansen et al. (1987)
49-24 ^b	Storegga Slide (slope)	2876	64.799833	1.773833	210-340	Jansen et al. (1987)
49-29 ^b	Storegga Slide (slope)	2758	64.658667	2.351	30-90	Jansen et al. (1987)
49-30 ^b	Storegga Slide (slope)	2372	64.536667	3.0585	55-220	Jansen et al. (1987)
49-31 ^b	Storegga Slide (slope)	2100	64.449833	3.685333	60-250	Jansen et al. (1987)
49-36 ^b	Storegga Slide (slope)	1581	63.922833	3.4845	70-130	Jansen et al. (1987)
49-38 ^b	Storegga Slide (slope)	1245	63.594167	3.042167	0-70	Jansen et al. (1987)
JM96-47/1 ^b	Trænadjupet Slide (slope)	945	67.333333	8.509	20-127	Laberg et al. (2002)
JM96-52/1 ^b	Trænadjupet Slide (slope)	649	67.295	8.703333	10-177	Laberg et al. (2002)
83-03 ^b	North Sea Fan (slope)	1615	62.926667	-0.8	268-290	King et al. (1998)
79-08 ^b	North Sea Fan (slope)	1327	62.873333	-0.03	225-270	King et al. (1998)
101-06 ^b	North Sea Fan (slope)	1006	62.746667	0.83	230-300	King et al. (1998)
79-20 ^b	North Sea Fan (slope)	2819	64.661667	-0.706667	90-250	King et al. (1998)
83-06 ^b	North Sea Fan (slope)	3002	64.28	-2.68	70-305	King et al. (1998)
31-38 ^b	North Sea Fan (slope)	1880	63.416667	0.383333	-	King et al. (1998)
31-41 ^b	North Sea Fan (slope)	810	62.616667	1.216667	-	King et al. (1998)
31-39 ^b	North Sea Fan (slope)	1309	63.033333	0.743333	190-520	Jansen et al. (1983); King et al. (1998)
31-37 ^b	North Sea Fan (slope)	2285	63.778333	0.0	50-510	Jansen et al. (1983); King et al. (1998)
ODP Site 987 ^b	Scoresby Sund TMF (slope)	1670	70.4966	-17.937383	560-660	Butt et al. (2001)
SV-03 ^b	Storfjorden fan	761	75.222533	14.620817	550-560	Lucchi et al. (2013)
EG-01 ^b	Storfjorden fan	1069	76.10335	13.627083	50-100	Lucchi et al. (2013)
SV-02 ^b	Storfjorden fan	743	75.22845	14.59933	400-640	Lucchi et al. (2013)

SV-05 ^b	Storfjorden fan	713	75.111716	15.221783	310-470	Lucchi et al. (2013)
SV-04 ^b	Kveithola / Storfjorden fan	1839	74.957083	13.899533	260-280	Lucchi et al. (2013)
JM09-KA11-GC ^b	Kveithola (shelf)	345	74.874667	16.484667	100-370	Ruther et al. (2012)
PS2118-2 ^b	Kongsfjorden fan	1306	79.0265	6.6165	0-630	Müller et al. (2004)
PS2121-4 ^b	Kongsfjorden trough (shelf)	339	79.0265	10.74933	0-620	Müller et al. (2004)
PS2782-1 ^b	Vilkitsky-Khatanga fan (shelf)	340	79.610000	103.355000	420-520	Weiel (1997)

822 ^aDirectly measured grain size data; ^bApproximate grain size data estimated from literature.

823

824 **Fig. 1. (a)** Location of Antarctic Trough Mouth Fans. Bathymetry is IBCSO v.1 Satellite data
825 is LIDAR. **(b)** Crary Trough Mouth Fan at mouth of the Filchner Trough, Weddell Sea. **(c)**
826 Belgica Fan at mouth of the Belgica Trough, Bellingshausen Sea. **(d)** Prydz Channel Fan at
827 mouth of the Prydz Channel. Multibeam is IBCSO v.1 Black dots are core locations used in
828 this paper. Black lines are long-profiles shown in Fig. 3B.

829

830 **Fig. 2. (a)** Location of Arctic Trough Mouth Fans used in analysis. **(b)**Vilkitsky-Khatanga
831 fan; **(c)** Voronin fan. **(d)** St Anna fan. **(e)** Franz Victoria Fan. **(f)** Kongsfjorden Fan. **(g)**
832 Isfjorden Fan. **(h)** Bellsund. **(i)** Scoresby Sund Fan. **(j)** Bear Island Fan. Bathymetry is
833 IBCAO v. Bathymetry is IBCAO v.3 Black dots are sediment core locations used in this
834 paper. Black lines are long-profiles shown in Fig. 4B.

835

836 **Fig. 3. (a).** Example for the homogenous grain-size distribution within diamictos interpreted
837 as glaciogenic debris flows (GDFs) recovered from trough-mouth fans (TMFs) on polar
838 continental margins. Core GC376 was recovered from Belgica TMF (West Antarctica), and
839 its GDF reveals hardly any variations in the contents of gravel, sand, silt and clay (silt +clay
840 = mud) and of sand, silt and clay (or mud), respectively, if the contents of the individual
841 grain-size fractions are calculated on a gravel-free basis. **(b)** Example for the estimation of
842 published gravel, sand, silt and clay contents in diamictos interpreted as GDFs, for which
843 the data were not available for this study in numerical form. We assume an uncertainty of ≤ 3
844 wt.% for the estimated contents of the individual grain-size fractions (estimated contents
845 here: 4 wt.% gravel, 16 wt.% sand, 40 wt.% silt and 40 wt.% clay). Core JM93 7/1 was
846 recovered from Bear Island TMF (Fig. 14b in Laberg & Vorren, 1995).

847

848 **Fig. 4. (a).** Arctic and Antarctic Trough Mouth Fan parameters including slope gradient, fan
849 area, trough length and paleo-ice stream drainage basin area and regression lines. Antarctic
850 TMF in blue; Arctic TMF in red. **(b)** Down-slope profiles for Arctic (dashed black) and
851 Antarctic (blue) TMF from IBSCO and IBCAO bathymetric data (located in Figures 1 and 2).

852

853 **Fig. 5.** Grain-size composition of sediment cores collected in diamictons on the shelf and
854 Glacial Debris Flows (GDFs) on the slope of trough mouth fans and surrounding areas. **(a)**
855 Arctic vs Antarctic grain-size composition (sand-silt-clay%). **(b)** Arctic vs Antarctic grain-
856 size composition (gravel-sand-mud%). **(c)** Antarctic grain-size composition (sand-silt-
857 clay%). **(d)** Arctic grain-size composition (sand-silt-clay%).

858

859

860

861

862

863

864

865

866

867

868

869

870

871

872

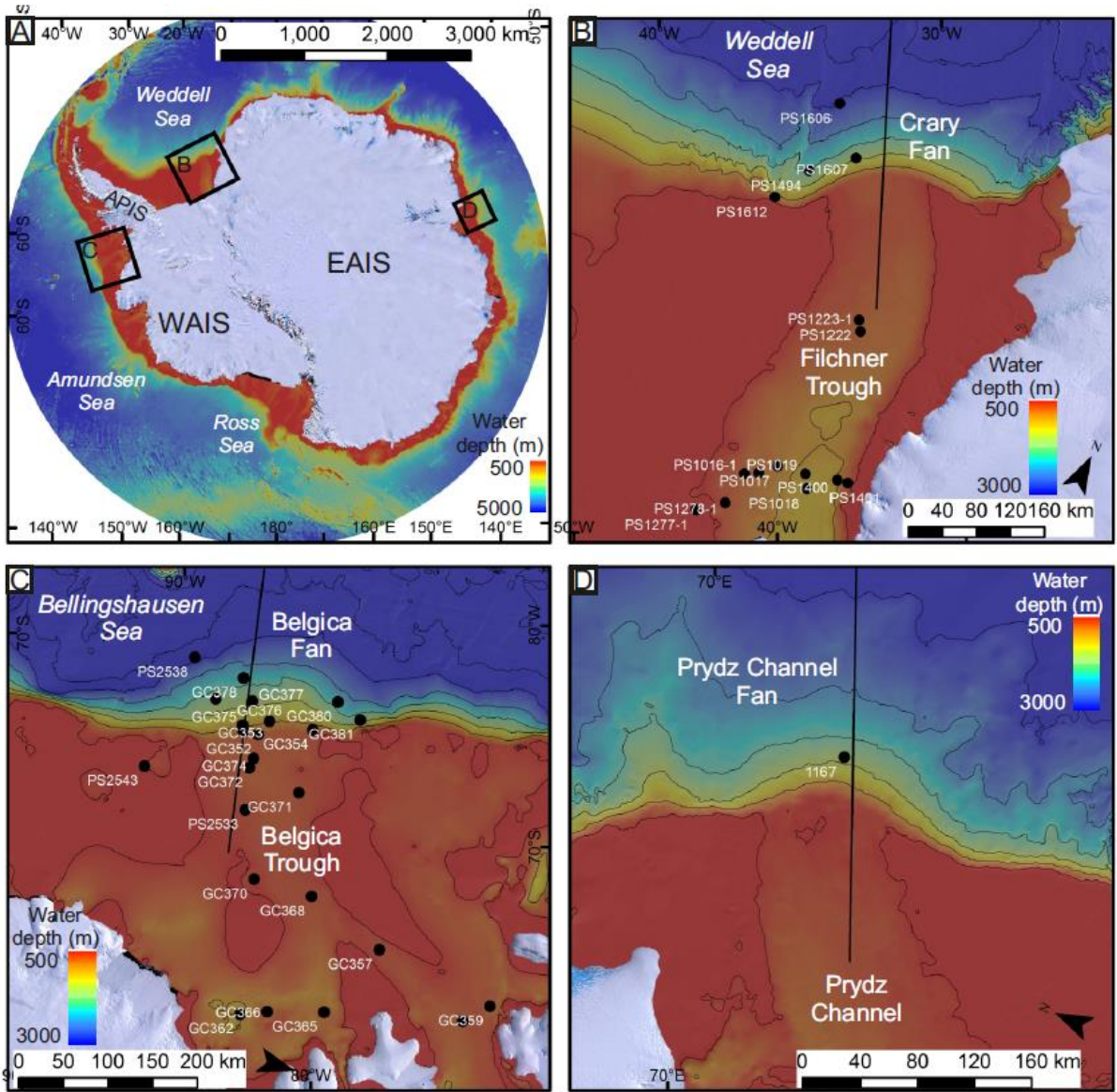
873

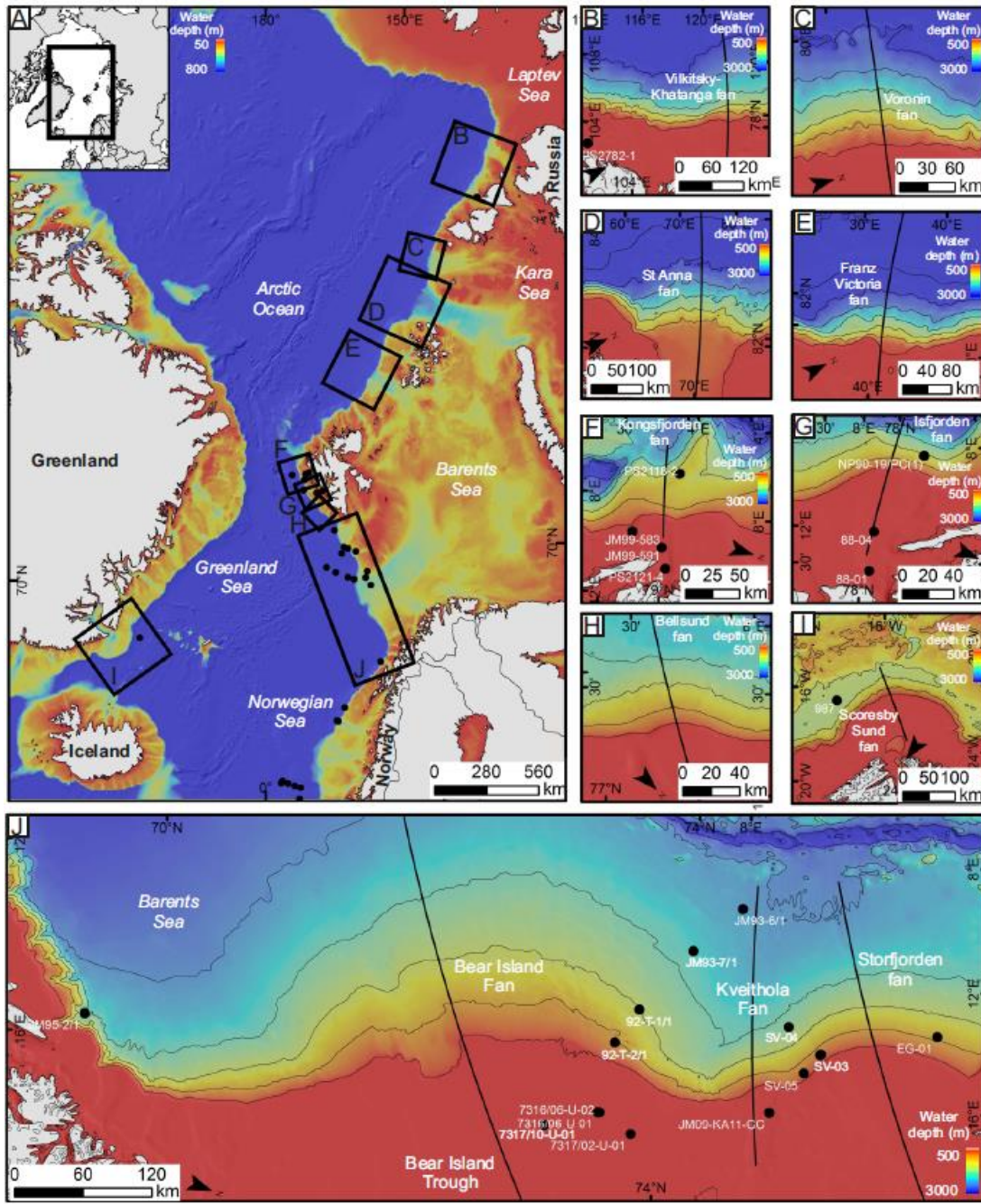
874

875

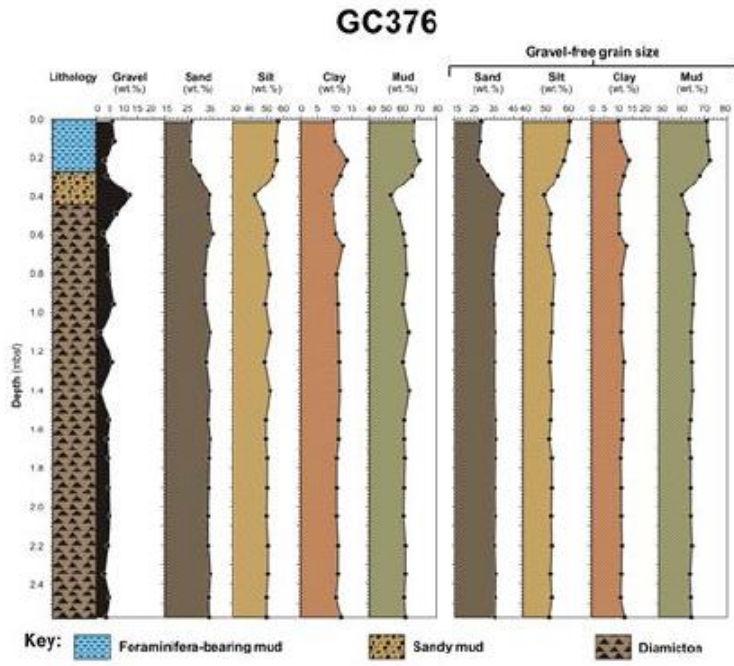
876

877





a)



b)

