



1           **Inputs and processes affecting the distribution of**  
2           **particulate iron in the North Atlantic along the GEOVIDE**  
3           **(GEOTRACES GA01) section**

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6   Arthur Gourain<sup>1,2</sup>, H el ene Planquette<sup>1</sup>, Marie Cheize<sup>1,3</sup>, Nolwenn Lemaitre<sup>1,4</sup>, Jan-Lukas  
7   Menzel Barraqueta<sup>5</sup>, Rachel Shelley<sup>1,6</sup>, Pascale Lherminier<sup>7</sup> and G eraldine Sarthou<sup>1</sup>

8  
9   1-UMR 6539/LEMAR/IUEM, Technop ole Brest Iroise, Place Nicolas Copernic, 29280 Plouzan e, France

10   2- now at Ocean Sciences Department, School of Environmental Sciences, University of Liverpool, Liverpool,  
11   L69 3GP, United Kingdom

12   3- now at Ifremer, Centre de Brest, G eosciences Marines, Laboratoire des Cycles G eochimiques (LCG), 29280  
13   Plouzan e, France

14   4- now at Department of Earth Sciences, Institute of Geochemistry and Petrology, ETH-Z urich, Z urich,  
15   Switzerland

16   5- GEOMAR, Helmholtz Centre for Ocean Research Kiel, Wischhofstra e 1-3, 24148 Kiel, Germany

17   6- now at Earth, Ocean and Atmospheric Science, Florida State University, Tallahassee, Florida, 32310, USA

18   7- Ifremer, LPO, UMR 6523 CNRS/Ifremer/IRD/UBO, Ifremer Centre de Brest, CS 10070, Plouzan e, France

19  
20   *Correspondence to: [helene.planquette@univ-brest.fr](mailto:helene.planquette@univ-brest.fr)*

21  
22   **Abstract**

23   The GEOVIDE cruise (May-June 2014, R/V Pourquoi Pas?) aimed to provide a better understanding on trace  
24   metal biogeochemical cycles in the North Atlantic. As particles play a key role in the global biogeochemical  
25   cycle of trace elements in the ocean, we discuss the distribution of particulate iron (PFe), in light of particulate  
26   aluminium (PAI), manganese (PMn) and phosphorus (PP) distributions. Overall, 32 full vertical profiles were  
27   collected for trace metal analyses, representing more than 500 samples. This resolution provides a solid basis for  
28   assessing concentration distributions, elemental ratios, size-fractionation, or adsorptive scavenging processes in  
29   key areas of the thermohaline circulation. Total particulate iron (PFe) concentrations ranged from as low as 9  
30   pmol L<sup>-1</sup> in surface Labrador Sea waters to 304 nmol L<sup>-1</sup> near the Iberian margin, while median PFe  
31   concentrations of 1.15 nmol L<sup>-1</sup> were measured over the sub-euphotic ocean interior.

32   At most stations over the Western, the relative concentrations of total PFe and aluminium (PAI) showed the  
33   near-ubiquitous influence of crustal particles in the water column. Overall, the lithogenic component explained  
34   more than 87% of PFe variance along the section. Within the Irminger and Labrador basins, the formation of  
35   biogenic particles led to an increase of the PFe/PAI ratio (up to 0.7 mol mol<sup>-1</sup>) compared to the continental crust  
36   ratio (0.21 mol mol<sup>-1</sup>), Margins provide important quantities of particulate trace elements (up to 10 nmol L<sup>-1</sup> of  
37   PFe) to the open ocean, and in the case of the Iberian margin, advection of PFe was visible more than 250km



38 away from the margin. Additionally, several benthic nepheloid layers spreading over 200m above the seafloor  
39 were encountered along the transect, especially in the Icelandic, Irminger and Labrador basins, delivering  
40 particles with high PFe content, up to 89 nmol L<sup>-1</sup> of PFe. Finally, remineralisation processes are also discussed,  
41 and showed different patterns among basins and elements.

42

### 43 **1. Introduction**

44 Particles play a key role in the ocean where they drive the residence time of most elements (Jeandel et al., 2015),  
45 and strongly influence the global biogeochemistry of macro and micro-nutrients including iron (Milne et al.,  
46 2017). In the surface ocean, biological activity produces biogenic suspended matter through planktonic  
47 organisms, while atmospheric deposition (Baker et al., 2013; Jickells et al., 2005), riverine discharge (Aguilar-  
48 Islas et al., 2013; Berger et al., 2008; Ussher et al., 2004) or ice-melting (Hawkings et al., 2014; Lannuzel et al.,  
49 2011, 2014) bring mostly lithogenic derived particles to surface waters. These particulate inputs highly vary,  
50 both spatially and seasonally, around the world's oceans. At depth, benthic and shelf sediment resuspension  
51 (e.g. Aguilar-Islas et al., 2013; Cullen et al., 2009; Elrod et al., 2004; Fitzwater et al., 2000; Hwang et al., 2010;  
52 Lam et al., 2015; Lam and Bishop, 2008; McCave and Hall, 2002), and hydrothermal activity (Elderfield and  
53 Schultz, 1996; Lam et al., 2012; Tagliabue et al., 2010, 2017; Trefry et al., 1985), provides important amounts  
54 of particles to the water column. Moreover, authigenic particles can be produced *in-situ* by aggregation of  
55 colloids (Bergquist et al., 2007) or oxidation processes (Bishop and Fleisher, 1987; Collier and Edmond, 1984).  
56 Thus, oceanic particles result from a complex combination of these different sources and processes (Lam et al.,  
57 2015).

58 Particles represent the main part of the total iron pool in the upper water column (Radic et al., 2011), and  
59 strongly interact with the dissolved pool (e.g. Ellwood et al., 2014). Indeed, dissolved iron can be scavenged  
60 onto particles (Gerringa et al., 2015; Rijkenberg et al., 2014), incorporated into biogenic particles (Berger et al.,  
61 2008) or remineralised (Dehairs et al., 2008; Sarthou et al., 2008). Interestingly, the concept of “reversible  
62 scavenging” (i.e. release at depth of dissolved iron previously scavenged onto particles) has been advocated  
63 recently (Dutay et al., 2015; Jeandel and Oelkers, 2015; Labatut et al., 2014), while other studies reveal distinct  
64 dissolution processes (e.g. Oelkers et al., 2012; Cheize et al., submitted to Chemical Geology). Slow dissolution  
65 of particulate iron at margins has also been evoked as a continuous fertilizer of primary production and should  
66 be considered as a source of dissolved iron (e.g. Jeandel et al., 2011; Jeandel and Oelkers, 2015; Lam and  
67 Bishop, 2008). Within or below the mixed layer, the rates of regeneration processes can also impact the  
68 bioavailable pool of iron, among other trace metals (e.g. Ellwood et al., 2014; Nuester et al., 2014). However,  
69 the rates of these processes are not yet fully constrained. The study of particulate iron is thus essential to better  
70 constrain the global biogeochemical cycle of iron in the ocean. This subject received a growing interest over the  
71 last 10 years in particular (e.g. Bishop and Biscaye, 1982; Collier and Edmond, 1984; Frew et al., 2006; Lam et  
72 al., 2012; Milne et al., 2017; Planquette et al., 2011, 2013; Sherrell et al., 1998) and, to our knowledge, only two  
73 have been performed at an ocean-wide scale and published so far: the GA03 GEOTRACES North Atlantic  
74 Zonal Transect (Lam et al., 2015; Ohnemus and Lam, 2015) and the GP16 GEOTRACES Pacific Transect (Lam  
75 et al., 2017; Lee et al., 2017).

76 In this context, this paper presents the particulate iron distribution in the North Atlantic Ocean, along the  
77 GEOTRACES GA01 section (GEOVIDE), and discusses the various sources and processes affecting its



78 distribution, using the distribution of other trace elements, more particularly particulate aluminium, phosphorus  
79 or manganese, to further our understanding of this important pool of iron.

80

## 81 2. Methods

### 82 2.1. Study area

83 Particulate samples were collected at 32 stations during the GEOVIDE (GEOTRACES GA01 section) campaign  
84 between May and June 2014 aboard the R/V *Pourquoi Pas?* in the North Atlantic. The sampling spanned  
85 several biogeochemical provinces (Figure 1): the Iberian margin (IM, Stations 2, 1 and 4), the Iberian Abyssal  
86 Plain (IAP, Stations 11 to 17), the Western European Basin (WEB, Station 19 to Station 29), the Icelandic Basin  
87 (IcB, Stations 32 to 36), above the Reykjanes Ridge (RR, Station 38), the Irminger Basin (IrB, Stations 40 to  
88 60), the Greenland shelf (GS, Stations 53 and 61), the Labrador Basin (LB, Stations 63 to 77) and finally the  
89 Newfoundland shelf (NS, Station 78) (Figure 1).

90 The North Atlantic is characterized by a complex circulation (briefly described in section 2.1 and in detail by  
91 Zunino et al. (2017) and García-Ibáñez et al. (2015) and is one of the most productive regions of the global  
92 ocean (Martin et al., 1993; Sanders et al., 2014), with a complex phytoplankton community structure composed  
93 of diverse taxa (Tonnard et al., in prep.).

94

95

### 96 2.2. Sampling

97 Samples were collected using the French GEOTRACES clean rosette, equipped with twenty-two 12L GO-FLO  
98 bottles (two bottles were leaking and were never deployed during the cruise). GO-FLO bottles were initially  
99 cleaned in the home laboratory (LEMAR) following the GEOTRACES procedures (Cutter and Bruland, 2012).  
100 The rosette was deployed on a 6mm Kevlar cable with a dedicated, custom-designed clean winch. Immediately  
101 after recovery, the GO-FLO bottles were individually covered at each end with plastic bags to minimize  
102 contamination. They were then transferred into a clean container (class-100) for sampling, and the filters  
103 processed under a laminar flow unit. On each cast, nutrient and/or salinity samples were taken to check potential  
104 leakage of the GO-FLO bottles.

105 Prior to filtration, the GO-FLO bottles were shaken three times, as recommended in the GEOTRACES  
106 cookbook to avoid settling of particles in the lower part of the bottle. GO-FLO bottles were pressurized to <8 psi  
107 with 0.2 µm filtered dinitrogen (N<sub>2</sub>, Air Liquide). Seawater was then filtered directly through paired filters (Pall  
108 Gelman Supor™ 0.45 µm polyetersulfone, and Millipore mixed ester cellulose MF 5 µm) mounted in Swinnex  
109 polypropylene filter holders (Millipore), following Planquette and Sherrell (2012) inside the clean container.  
110 Filtration was operated until the bottle was empty or until the filter clogged; volume filtered ranged from 2  
111 liters for surface samples to 11L within the water column. Filters were cleaned following the protocol described  
112 in Planquette and Sherrell (2012) and kept in acid-cleaned 1 L LDPE bottles (Nalgene) filled with ultrapure  
113 water (Milli-Q, resistivity of 18.2 MΩ cm<sup>-1</sup>) until use. All filters were 25 mm diameter in order to optimize  
114 signal over the filter blank except at the surface depth where 47 mm diameter filters mounted on acid-cleaned  
115 polysulfone filter holders (Nalgene™) were used. After filtration, filter holders were disconnected from the GO-  
116 FLO bottles and a gentle vacuum was applied using a syringe in order to remove any residual water under a



117 laminar flow hood. Filters were then removed from the filter holders with plastic tweezers that were rinsed with  
118 Milli-Q between samples. Most of the remaining seawater was ‘sipped’ by capillary action, when placing the  
119 non-sampled side of the filter onto a clean 47 mm supor filter. Then, each filter pair was placed in an acid-  
120 cleaned polystyrene Petri slide (Millipore), double bagged, and finally stored at  $-20^{\circ}\text{C}$  until analysis at LEMAR.  
121 Between casts, filter holders were thoroughly rinsed with Milli-Q, placed in an acid bath (5% HCl) for 24 hours,  
122 then rinsed with Milli-Q.

123 At each station, process blanks were collected as follows: 2L of a deep (1000 m) and a shallow (40 m) seawater  
124 samples were first filtered through a  $0.2\ \mu\text{m}$  pore size capsule filter (Pall Gelman Acropak 200) mounted on the  
125 outlet of the GO-FLO bottle before to pass through the particle sampling filter, which was attached directly to  
126 the swinnex filter holder.

127

### 128 2.3. Analytical methods

129 Back in the home laboratory, sample handling was performed inside a clean room (Class 100). All solutions  
130 were prepared using ultrapure water (Milli-Q) and all plasticware had been acid-cleaned before use. Frozen  
131 filters, collected within the mixed layer depth or within nepheloid layers, were first cut in half using a ceramic  
132 blade: one filter half was dedicated to total digestion (see below), while the other half was archived at  $-20^{\circ}\text{C}$  for  
133 SEM analyses or acid leaching of “labile” metals (Berger et al., 2008; to be published separately).

134 Filters were digested following the method described in Planquette and Sherrell (2012). Filter were placed on  
135 the inner wall of acid-clean 15mL PFA vials (Savillex<sup>TM</sup>), and 2 mL of a solution containing  $2.9\ \text{mol L}^{-1}$   
136 hydrofluoric acid (HF, suprapur grade, Merck) and  $8\ \text{mol L}^{-1}$  nitric acid ( $\text{HNO}_3$ , Ultrapur grade, Merck) was  
137 added to each vial. Vials were then closed and refluxed at  $130^{\circ}\text{C}$  on a hot plate for 4 hours. After cooling, the  
138 digest solution was evaporated at  $110^{\circ}\text{C}$  until near dryness. Then,  $400\ \mu\text{L}$  of concentrated  $\text{HNO}_3$  (Ultrapur  
139 grade, Merck) was added, and the solution was re-evaporated at  $110^{\circ}\text{C}$ . Finally, the obtained residue was  
140 dissolved with 3mL of a  $0.8\ \text{mol L}^{-1}$   $\text{HNO}_3$  (Ultrapure grade, Merck). This archive solution was transferred to an  
141 acid cleaned 15 mL polypropylene centrifuge tube (Corning®) and stored at  $4^{\circ}\text{C}$  until analyses.

142

143 All analyses were performed on a sector field inductively coupled plasma mass spectrometer (SF-ICP-MS  
144 Element2, Thermo-Fisher Scientific). Samples were diluted by a factor of 7 on the day of analysis in acid-  
145 washed 13 mm (outer diameter) rounded bottom, polypropylene centrifuge tubes (VWR) with  $0.8\ \text{mol L}^{-1}$   $\text{HNO}_3$   
146 (Ultrapur grade, Merck) spiked with  $1\ \mu\text{g L}^{-1}$  of Indium ( $^{115}\text{In}$ ) solution in order to monitor the instrument drift.  
147 Samples were introduced with a PFA-ST nebulizer connected to a quartz cyclonic spray chamber (Elemental  
148 Scientific Incorporated, Omaha, NE) via a modified SC-Fast introduction system consisting of an SC-2  
149 autosampler, a six-port valve and a vacuum-rinsing pump. The autosampler was contained under a HEPA  
150 filtered unit (Elemental Scientific). Two 6-points, matrix-matched multi-element standard curves with  
151 concentrations bracketing the range of the samples were run at the beginning, the middle and the end of each  
152 analytical run. Analytical replicates were made every 10 samples, while accuracy was determined by performing  
153 digestions of the certified reference material BCR-414 (plankton, Community Bureau of Reference,  
154 Commission of the European Communities), PACS-3 and MESS-4 (marine sediments, National Research  
155 Council Canada), following the same protocol as for samples. Recoveries were typically within 10% of the  
156 certified values (and within the error of the data, taken from replicate measurements, Table 1).



157

158

159 Once all data were normalized to an  $^{115}\text{In}$  internal standard and quantified using an external standard curve, the  
160 dilution factor of the total digestion was accounted for. Obtained element concentrations per filter (pmol/filter)  
161 were then corrected by the process blanks described above. Finally, pmol/filter values were divided by the  
162 volume of water filtered through stacked filters.

163 Total concentrations (sum of small size fraction (0.45-5  $\mu\text{m}$ ) and large (>5  $\mu\text{m}$ ) size fraction) of particulate trace  
164 elements are reported in Table S1 (supplementary data).

165

166

#### 2.4. Ancillary data:

167 Particulate barium (Ba) concentrations were determined in samples collected using a standard CTD rosette  
168 equipped with 12 L Niskin bottles. Typically, 18 samples were collected at each station within the first 1000 m.  
169 Details on analytical procedures are given in Lemaitre et al. (in press, 2018a). Briefly, particulate biogenic  
170 Barium, or excess Barium ( $\text{Ba}_{\text{ex}}$ ), were calculated by subtracting the particulate lithogenic barium (PBa-litho)  
171 from the total particulate barium (PBa). The PBa-litho was determined by multiplying the particulate aluminium  
172 (PAI) concentration by the upper continental crust (UCC) Ba: Al molar ratio (0.00135 mol mol $^{-1}$ ; Taylor and  
173 McLennan, 1985). Potential temperature ( $\theta$ ), salinity (S), and transmissometry data were retrieved from the CTD  
174 sensors (CTD SBE911 equipped with a SBE43).

175

176

### **3. Results**

177

#### 3.1. Hydrography and biological setting

178 Here, we briefly describe the hydrography encountered during the GEOVIDE section (Figure 2), as a thorough  
179 description is available in García-Ibáñez et al. (2015). The warm and salty Mediterranean Water (MW,  $S=36.50$ ,  
180  $\theta=11.7^\circ\text{C}$ ) was sampled between 600 and 1700 m in the Iberian Abyssal Plain (IAP). MW resulted from the  
181 mixing between the Mediterranean Overflow Water plume coming from the Mediterranean Sea and local  
182 waters. Surface water above the Iberian Shelf was characterised by low salinity ( $S=34.95$ ) at station 2 and 4  
183 compared to surrounding water masses. Close to the floor of the Iberian Abyssal Basin, the North East Atlantic  
184 Deep Water (NEADW,  $S=34.89$ ,  $\theta=2.0^\circ\text{C}$ ) spread southward. The East North Atlantic Central Water  
185 (ENACW,  $S>35.60$ ,  $\theta>12.3^\circ\text{C}$ ) was the warmest water mass of the transect and was observed in the subsurface  
186 layer of the Western European Basin and Iberian Abyssal Plain. An old Labrador Sea Water (LSW,  $S=34.87$ ,  
187  $\theta=3.0^\circ\text{C}$ ) flowed inside the Western European and Icelandic Basins, between 1000 and 2500m depth. In the  
188 Icelandic Basin, below the old LSW, the Iceland-Scotland Overflow Water (ISOW,  $S=34.98$ ,  $\theta=2.6^\circ\text{C}$ ) spread  
189 along the Reykjanes Ridge slope. This cold water, originating from the Arctic, led to the formation of NEADW  
190 after mixing with surrounding waters. North Atlantic hydrography was impacted by the northward flowing of  
191 the North Atlantic Current (NAC), which carried up warm and salty waters from the subtropical area. When  
192 NAC crossed the Mid-Atlantic ridge through the Charlie-Gibbs Fracture Zone (CGFZ), it created the Subpolar  
193 Mode Water (SPMW). The recirculation of SPMW inside the Icelandic and Irminger Basins led to the formation  
194 of regional modal waters: the Iceland Subpolar Mode Water (IcSPMW,  $S=35.2$ ,  $\theta=8.0^\circ\text{C}$ ) and the Irminger



195 Subpolar Mode Water (IrSPMW,  $S=35.01$ ,  $\theta=5.0^{\circ}\text{C}$ ) respectively. IcSPMW was a relatively warm water mass  
196 with potential temperature up to  $7^{\circ}\text{C}$  (García-Ibáñez et al., 2015). Another branch of the NAC mixed with  
197 Labrador Current waters to form the relatively fresh SubArctic Intermediate Water (SAIW,  $S<34.8$ ,  
198  $4.5^{\circ}\text{C}<\theta<6^{\circ}\text{C}$ ). The Irminger Basin is a really complex area with a multitude of water masses. In the middle of  
199 the basin, an old LSW, formed one year before (Straneo et al., 2003), spread between 500 and 1200 m depth.  
200 Close to the bottom, the Denmark Strait Overflow Water (DSOW,  $S=34.91$ ) flowed across the basin. Greenland  
201 coastal waters were characterised by low salinity values, down to  $S=33$ . The strong East Greenland Current  
202 (EGC) flowed southward along the Greenland shelf in the Irminger Basin. When reaching the southern tip of  
203 Greenland, this current entered the Labrador Basin along the west coast of Greenland and followed the outskirts  
204 of the basin until the Newfoundland shelf. In the Labrador Basin, the deep convection of SPMW at 2000 m was  
205 involved in the formation of the LSW ( $S=34.9$ ,  $\theta=3.0^{\circ}\text{C}$ ) (García-Ibáñez et al., 2015; Yashayaev and Loder,  
206 2009). Above the Newfoundland Shelf, surface waters were affected by discharge from rivers and ice-melting  
207 and characterised by extreme low salinity for open ocean waters, below 32 in the first 15 meters.

208

209 During GEOVIDE, diatoms and type 6-haptophytes dominated the bloom close to the IM, while type-6-  
210 haptophytes and dinophytes were dominant in the WEB province (Tonnard et al., in prep.). The IB bloom was  
211 dominated by type-6-haptophytes and the IrB was dominated by diatoms. GS and NS coastal stations were  
212 almost exclusively composed of large diatoms. Finally, the LB was dominated by diatoms and type 6 and 8-  
213 haptophytes. The NS, LB, GS and IrB provinces (stations 44 to 77) were sampled just after the bloom peak. The  
214 LB was characterized by an intense particulate organic carbon (POC) export and high remineralization activity  
215 (Lemaitre et al., 2018a). In contrast, low remineralization fluxes and high POC exports were determined within  
216 the IB and WEB provinces, where the bloom was still active (Lemaitre et al, 2018a, b).

217

### 3.2. Section overview

218 Total particulate iron (PFe), aluminium (PAI), manganese (PMn) and phosphorus (PP) concentrations spanned a  
219 large range of concentrations from below detection to 304, 1544, 21.5, 3.5 and 402  $\text{nmol L}^{-1}$  respectively.  
220 Moreover, PFe, PAI, and PMn were predominantly found (>90%) in particles larger than 5  $\mu\text{m}$ , except in  
221 surface waters, where 20% of PFe, 30% of PP, 35% of PAI and up to 60% of PMn were hosted by smaller  
222 particles (0.45-5  $\mu\text{m}$ ). The ranges of concentrations are comparable to other studies recently published (Table 2).  
223 Data are shown in Figure 3.

224

225

### 3.3. Iberian Margin (stations 1 to 4)

226 The Iberian margin was characterised by low beam transmissometry values at station 2 (88% at 140 m)  
227 suggesting significant particle concentrations. Particulate iron concentrations varied between  $0.02 \text{ nmol L}^{-1}$  (20  
228 m) to  $304 \text{ nmol L}^{-1}$  (138 m) in this area. Above the Iberian Shelf, high PFe concentrations were measured in  
229 surface (Station 2,  $2.53 \text{ nmol L}^{-1}$ ); then, on the shelf break, surface concentrations dropped down to  $0.8 \text{ nmol L}^{-1}$   
230 (Station 1 at 20 m depth). PFe concentrations increased with depth at all three stations and reached a maximum  
231 at the bottom of station 2 (138.5 m) with more than  $300 \text{ nmol L}^{-1}$  of PFe. Lithogenic tracers, such as PAI or



232 PMn, presented similar profiles to PFe with concentrations ranging between 0.11 and 1544 nmol L<sup>-1</sup>, and from  
233 below detection to 2.51 nmol L<sup>-1</sup> respectively. The highest concentrations were also measured at the bottom of  
234 station 2 (138.5 m). Total particulate phosphorus (PP) concentrations were relatively low in this area ranging  
235 from undetectable values to 38 nmol L<sup>-1</sup>. Maximum PP was measured in surface at Station 1 (20 m depth), then  
236 concentrations decreased with depth and were less than 0.7 nmol L<sup>-1</sup> below 1000 m depth.

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#### 3.4. Iberian Abyssal Plain (stations 11 to 17) and Western European Basin (stations 19 to 29)

240 In the Iberian Abyssal Plain (IAP) and the Western European Basin (WEB), particulate iron concentration  
241 vertical profiles were similar (Figure 4); median PFe concentrations were 0.18 nmol L<sup>-1</sup> in the first 100 m and  
242 steadily increased with depth. Close to the seafloor, concentrations of PFe were up to 1.4 nmol L<sup>-1</sup> at every  
243 station and reached values superior to 8 nmol L<sup>-1</sup> at stations 26 and 29, with low beam transmissometry  
244 (<98%). Particulate aluminium profiles matched the PFe profiles, with low median concentrations within the  
245 first 100m of 1.77 nmol L<sup>-1</sup> and 26 pmol L<sup>-1</sup> respectively. Then, concentrations increased with depth to reach a  
246 maximum close to the oceanic floor. At stations 26 and 29, total PAI concentrations reached high values, up to  
247 42 nmol L<sup>-1</sup>. In the Western European Basin, PMn concentrations ranged from below detection to 0.36 nmol L<sup>-1</sup>,  
248 except close to the bottom of stations 26 and 29, where high concentrations of 0.91 and 1.31 nmol L<sup>-1</sup> were  
249 measured, respectively. Particulate phosphorus profiles, while similar between stations of this basin, differed a  
250 lot from the other element profiles. In the WEB, surface median PP concentration was two times higher than in  
251 the Iberian margin (60 nmol L<sup>-1</sup> against 28 nmol L<sup>-1</sup> in the first 50 m with a maximum of 162 nmol L<sup>-1</sup> (station  
252 21). Concentrations dropped drastically with depth and remained under 10 pmol L<sup>-1</sup> below 100 m.

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#### 3.5. Icelandic Basin (stations 32 to 36)

256 Concentrations of PFe were in a similar range and displayed analogous profiles to the ones collected in the  
257 Western European Basin (figure 4), from below detection to 40.6 nmol L<sup>-1</sup>; with low values at the surface (<1  
258 nmol L<sup>-1</sup>) and a progressive increase with depth. Close to the basin seafloor, low beam transmissometry (97.4%)  
259 measurements were associated with high PFe concentrations of 40.6 nmol L<sup>-1</sup> at 3271 m of station 32.  
260 Particulate aluminium vertical profiles were similar to those in the WEB but with extremely low surface  
261 concentrations below 0.6 nmol L<sup>-1</sup>; PAI then increased steadily with depth, reaching values up to 2 nmol L<sup>-1</sup>  
262 below 500 m. As previously observed for PFe, PAI concentrations were higher close to the seafloor, from 29  
263 nmol L<sup>-1</sup> at station 34 to 101 nmol L<sup>-1</sup> at station 32. PMn also presented similar distributions than PFe and PAI.  
264 Median surface concentrations were low within the first 100 m, 31 pmol L<sup>-1</sup> and 35 pmol L<sup>-1</sup>, respectively, and  
265 increased in the deep ocean to reach a maximum of 2.98 nmol L<sup>-1</sup> close to the seafloor. The Icelandic Basin had  
266 a typical vertical profile for PP, with high concentrations at the surface, reaching 129 nmol L<sup>-1</sup> at station 32 and  
267 really low concentrations below 150 m, inferior to 20 nmol L<sup>-1</sup>.

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269

#### 3.6. Reykjanes Ridge (station 38)



270 Surface concentrations of particulate Fe, Al, and Mn above the Reykjanes Ridge (RR) were similar to the  
271 Icelandic Basin (Figure 3). However, close to the seafloor, high concentrations were measured, with PFe, PAI,  
272 and PMn reaching  $16.2 \text{ nmol L}^{-1}$ ,  $28.8 \text{ nmol L}^{-1}$ , and  $0.51 \text{ nmol L}^{-1}$  at 1354 m, respectively. Low concentrations  
273 of PP were measured in surface waters, with a median value of  $24.8 \text{ nmol L}^{-1}$  in the top 100 m and a maximum  
274 of only  $72.6 \text{ nmol L}^{-1}$  at 20 m.

275

### 276 3.7. Irminger Basin (stations 40 to 60; except Stations 53 and 56)

277 Particulate Iron, Aluminium and Manganese distributions were similar to stations sampled in the WEB, IcB and  
278 IAP provinces (Figure 3). Surface concentrations of these elements were lower than  $1.1 \text{ nmol L}^{-1}$ ,  $3.4 \text{ nmol L}^{-1}$ ,  
279 and  $0.4 \text{ nmol L}^{-1}$ , respectively. Then, below 50 m depth, concentrations of PFe, PAI, and PMn increased and  
280 reached high values close to the seafloor, especially at stations 42 and 44; reaching up to  $40 \text{ nmol L}^{-1}$ ,  $90 \text{ nmol}$   
281  $\text{L}^{-1}$ , and  $1.5 \text{ nmol L}^{-1}$  respectively. Close to the Greenland margin, at the bottom of stations 49 and 60,  
282 concentrations of particulate trace metals were also elevated with PFe greater than  $10 \text{ nmol L}^{-1}$ . Particulate  
283 phosphorus concentrations were relatively high in surface waters, of the Irminger Basin, with a median value of  
284  $127 \text{ nmol L}^{-1}$  within the first 50 m. Particulate phosphorus decreased with depth and remained constant below  
285 500 m with concentration below  $10 \text{ nmol L}^{-1}$ .

286

### 287 3.8. Greenland coast (stations 53, 56 and 61)

288 Particulate Fe concentrations in the vicinity of the Greenland shelf had a high median concentration of  $10.8$   
289  $\text{nmol L}^{-1}$ , while PAI and PMn also had high median concentration of  $32.3 \text{ nmol L}^{-1}$  and  $0.44 \text{ nmol L}^{-1}$ ,  
290 respectively. Concentrations of PP were maximum at the surface with a value of  $197 \text{ nmol L}^{-1}$  at 25 m of station  
291 61. Then, PP concentrations decreased strongly with depth with values below  $30 \text{ nmol L}^{-1}$  below 100 meters  
292 depth. Furthermore, beam transmissometry values in surface waters at these two stations, were the lowest of the  
293 entire section, with values below 85 %.

294

### 295 3.9. Labrador Basin (stations 63 to 77)

296 In the Labrador Basin, median concentrations of PFe within the first 100 m were low, with a median value of  
297  $0.9 \text{ nmol L}^{-1}$  ( $n=30$ ). However, at two stations, elevated concentrations were determined, up to  $4.4 \text{ nmol L}^{-1}$  at  
298 station 77 at 40 m and  $7 \text{ nmol L}^{-1}$  at station 63 between 70 and 100 m depth. Below the surface waters, PFe  
299 remained constant with depth until in proximity of the seafloor (Fig. 3). Between stations 64 and 71, the median  
300 concentration between 100 m and 200 m above the seafloor was  $2.0 \text{ nmol L}^{-1}$  ( $n=39$ ). Particulate Fe  
301 concentration at station 63, close to the Greenland margin, remained constant below 100 m depth, with a high  
302 median value of  $5.7 \text{ nmol L}^{-1}$ . On the other side of the Labrador Basin, station 77, close to the Newfoundland  
303 margin, constant PFe values of  $3 \text{ nmol L}^{-1}$  between the surface and 200 m above bottom depth were observed.  
304 As previously described, PFe concentration increased close to the seafloor to  $88 \text{ nmol L}^{-1}$  at station 71 at 3736  
305 m. Particulate Al and Mn displayed similar characteristics to PFe, with low median concentrations at the surface  
306 of  $3.37 \text{ nmol L}^{-1}$  and  $90 \text{ pmol L}^{-1}$  respectively. Close to the seafloor of Station 71, at 3736 m depth, PAI, and





307 PMn reached high concentrations of 264 and 3.5 nmol L<sup>-1</sup>. Particulate Phosphorus distribution was no different  
308 than in the eastern basins, with 71 nmol L<sup>-1</sup> median PP within the first 50 m. Then below 50 m, the  
309 concentration dropped off quickly to a median PP of 3 nmol L<sup>-1</sup>.

310

### 311 3.10. Newfoundland Shelf (station78)

312 Close to the Newfoundland margin, surface waters displayed a small load of particulate trace metals as PFe,  
313 PAI, and PMn were below 0.8 nmol L<sup>-1</sup>, 2 nmol L<sup>-1</sup>, and 0.15 nmol L<sup>-1</sup> respectively. Then close to the bottom, at  
314 371 m, beam transmissometry values dropped to 94% and were associated with extremely high  
315 concentrations of lithogenic elements: PFe=168 nmol L<sup>-1</sup>, PAI=559 nmol L<sup>-1</sup>, and PMn=2 nmol L<sup>-1</sup>. Total PP  
316 concentrations in the first 50 m ranged from 35 to 97 nmol L<sup>-1</sup>. Below the surface, PP remained relatively high  
317 with values up to 16 nmol L<sup>-1</sup> throughout the water column.

318

## 319 **4. Discussion**

320 Our goal in this work was to investigate mechanisms that drive the distribution of PFe in the North Atlantic, in  
321 particular the different routes of supply and removal.

322 Possible candidate sources of PFe include lateral mixing from the different margins, atmospheric inputs,  
323 recently melted sea ice, melting ice shelves and icebergs, resuspended sediments or hydrothermal inputs and  
324 biological pool. Removal processes include remineralization and dissolution processes.

325 In the following sections, we examine each of these sources and processes, explore the evidence for their  
326 relative importance, and use compositional data to estimate the particle types and host phases for iron and  
327 associated elements.

### 328 4.1. Analysis of the principal factors controlling variance: near-ubiquitous influence of 329 crustal particles in the water column

330 Positive Matrix Factorisation (PMF) was run to characterise the main factors influencing the particulate trace  
331 elements variances along the GEOVIDE section. In addition to PFe, PAI, PMn, and PP, nine additional  
332 elements were included in the PMF: Y, Ba, Pb, Th, Ti, V, Co, Cu and Zn. The analysis has been conducted on  
333 samples where all the 13 elements previously cited are above the detection limits; after selection, 445 of the 549  
334 existing data points were used. Analyses were performed using the PMF software, EPA PMF 5.0, developed by  
335 the USA Environmental Protection Agency (EPA). Models have been tested with several factors number (from  
336 3 to 6), after full error estimation of each model, we decide to use the configuration providing the lowest errors  
337 estimations and in consequence the most reliable.

338 In consequence, models were set up with four factors and were run 100 times to observe the stability of the  
339 obtained results. After displacement, error estimations and bootstraps error estimations, the model was  
340 recognised as stable. Results are shown in Figure 5.

341 The first factor is characterised by lithogenic elements, representing 86.8% of the variance of PFe, 75.8% of PAI  
342 and 90.5% of PTi. The second factor is correlated with both Mn and Pb and explains no less than 76.5% and  
343 77.0% of their respective variances. Ohnemus and Lam (2015) observed this co-relation between manganese



344 and lead particles and explained it by the co-transport on Mn-oxides (Boyle et al., 2005). The formation of barite  
345 is causing the third factor constraining 87.7% of the Ba variance in the studied regions. A biogenic component is  
346 the fourth factor and explained most of particulate phosphorus variance, 83.7%. The micronutrient trace metals,  
347 copper, cobalt and zinc, had more than a quarter of their variances influenced by this factor.

348

349

350 Along the GA01 section, PFe distributions were predominantly controlled by lithogenic material, and to a  
351 smaller extent by remineralisation processes (as seen by a Factor 3 contribution of 4.1%). These inputs and  
352 processes are discussed below.

353 To further investigate the influence of crustal material on the distribution of PFe, it is instructive to examine the  
354 distribution of the molar ratio of PFe/PAI along the section as a way to assess the lithogenic inputs (Lannuzel et  
355 al., 2014; Ohnemus and Lam, 2015; Planquette et al., 2009) (Figure 6) along the section.

356

357 The PFe/PAI ratio can be used to estimate the proportion of lithogenic particles within the bulk particulate  
358 material. A comparison with the Upper Continental Crust (UCC) ratio of Taylor and McLennan (1995), 0.21,  
359 was used to calculate the lithogenic components of particles ( $PFe_{litho}$ ) following Eq. (1):

360

$$361 \quad \%PFe_{litho} = 100 * \left( \frac{PAI}{PFe} \right)_{sample} * \left( \frac{PFe}{PAI} \right)_{UCC \text{ ratio}} \quad (1)$$

362

363 Then the non-lithogenic PFe is simply obtained using Eq. (2):

364

$$365 \quad \%PFe_{non-litho} = 100 * \%PFe_{litho} \quad (2)$$

366

367 Overall, the lithogenic contribution to PFe varies from 24% (station 60, 950 m) to 100% at stations located  
368 within the Western European Basin. The most striking feature is the almost exclusive lithogenic nature of PFe  
369 from stations 1 to 26 throughout the water column, except between 1000 and 3000 m at stations 21 to 26 (Figure  
370 6 and 7). This feature could be linked to the fact that atmospheric inputs generally dominate the supply of PFe -  
371 deposited from Saharan dust and transported via the Gulf Stream and North Atlantic Current to the WEB  
372 (Shelley et al., 2017; Garcia-Ibanez et al. (2015)), even if low atmospheric fluxes were reported during our  
373 cruise.

374

375 This feature at 1000 and 2500 m between stations 21 and 26 is likely be associated to the presence of the Sub-  
376 Arctic Front, located between 49.5 and 51°N latitude and 23.5 and 22°W longitude (Zunino et al., 2017).  
377 Indeed, this front which separates cold and fresh water of subpolar origin from warm and salty water of  
378 subtropical origin was clearly identifiable at station 26 by the steep gradient of the isotherms and isohalines. The  
379 fact that the WEB was sampled close to but just after the bloom maximum is limiting any higher PFe/PAI  
380 signatures (see also section 3.3.4). The intrusion of an old LSW at stations 21 to 26 between 1000 and 2500 m



381 with a different PFe/PAI signature could explain the smaller contribution of lithogenic PFe in this depth range as  
382 atmospheric inputs to the Labrador Sea region are relatively small (Shelley et al., 2017).

383

#### 384 4.2. Fingerprinting watermasses

385 The GEOVIDE section crossed several distinct water masses along the North Atlantic, each of them being  
386 distinguishable by their salinity and potential temperature signatures (García-Ibáñez et al., 2015; Figure 2).  
387 Based on this study, we applied a Kruskal-Wallis test on molar PFe/PAI ratios of nine water masses (Figure 8)  
388 in order to test the presence of significant differences. Water masses for which we had less than 5 data points for  
389 PFe/PAI were excluded from this test.

390 As previously seen, the lithogenic inprint is dominant in the WEB, with MW and NEADW showing PFe/PAI  
391 values close to the UCC value of  $0.21 \text{ mol mol}^{-1}$ . Interestingly, the PFe/PAI signature of  $0.36 \text{ mol mol}^{-1}$  within  
392 the old LSW<sub>WEB</sub> is probably due to the effect of biologic inputs associated with the strong bloom encountered in  
393 the Irminger Sea than in the WEB (see section 4.3.5).

394 While it appears that lithogenic particles are dominating the water column in the WEB, and that some water  
395 masses have a clear PFe/PAI fingerprint, it is important to discuss the origin of these signatures, which is the  
396 purpose of the following sections.

397

#### 398 4.3. Tracking the different inputs of particulate iron

##### 399 4.3.1. Inputs at margins: Iberian, Greenland and Newfoundland

400 Inputs from continental shelves and margins have been demonstrated to support high productivity in shallow  
401 coastal areas. Inputs of iron from continental margin sediments supporting the high productivity found in  
402 shallow coastal regions have been demonstrated in the past (e.g. Cullen et al. (2009), Elrod et al. (2004), Jeandel  
403 et al. (2011), Ussher et al. (2007)) and sometimes, were shown to be advected at great distances from the coast  
404 (e.g. Lam et al., 2008). Moreover, freshwater inputs that are usually present in these regions can also play a key  
405 role in the global biogeochemical cycling of trace metals (Blain and Tagliabue, 2016; Guieu et al., 1991; Martin  
406 and Meybeck, 1979). Rivers, runoff and continental glacial melt and/or sea-ice melt can also supply dissolved  
407 and particulate iron to coastal waters, thus sustaining important phytoplankton production (Fung, 2000).

408 In the following section, we will investigate these possible candidate sources in proximity of the different  
409 margins encountered. Along the GEOVIDE section, sediments at margins were of various compositions  
410 (Dutkiewicz et al., 2015). Sediments originating from the Iberian margin were mainly constituted of silts and  
411 clays (Cacador et al., 1996; Duarte et al., 2014). East Greenland margin sediments were a mixture of sands and  
412 grey/green muds, while, sediments from the West Greenland margin were mainly composed of grey/green muds  
413 (Loring and Asmund, 1996). At the western end of the section, sediments from the Newfoundland margin were  
414 composed of gravelly and sandy muds (Mudie et al., 1984). The different sediment compositions of the three  
415 margins sampled during GEOVIDE have different mineralogy, which are reflected in their different PFe/PAI



416 ratios (Figure 9). While the Iberian Margin had a  $\overline{\text{PFe}}/\overline{\text{PAI}}$  close to  $\overline{\text{UCC}}$  ratio, mainly due to seasonal dust  
417 inputs from North Africa,(Shelley et al., 2017) the highest biogenic contribution could be seen at the East  
418 Greenland (stations 53 and 56) and West Greenland (station 61) Margins, with median  $\text{PFe}/\text{PAI}$  reaching 0.45  
419  $\text{mol mol}^{-1}$ . The Newfoundland margin displayed an intermediate behaviour, with  $\text{Fe}/\text{Al}$  ratios of  $0.35 \text{ mol mol}^{-1}$ .

420

421

422 In addition to PAI, PMn can be used as a tracer of inputs from shelf resuspension (Lam and Bishop, 2008).  
423 Indeed, Mn is really sensitive to oxidation mediated by bacteria (Tebo et al., 1984; Tebo and Emerson, 1985)  
424 and forms manganese oxides ( $\text{MnO}_2$ ). These authigenic particles lead to an enrichment of Mn in particle  
425 compositions. In order to track the influence of shelf resuspension, a percentage of sedimentary inputs “%bulk  
426 sediment inputs” can be calculated using PMn/PAI ratio from GEOVIDE samples and the PMn/PAI UCC value  
427 (0.0034; Taylor and McLennan, 1995) according to the following equation:

$$428 \quad \% \text{bulk sediment PMn} = 100 * \left( \frac{\text{PAI}}{\text{PMn}} \right)_{\text{sample}} * \left( \frac{\text{PMn}}{\text{PAI}} \right)_{\text{UCC ratio}} \quad (3)$$

429 This proxy is a good indicator of direct and recent sediment resuspension. We assume that particles newly  
430 resuspended in water column will have the same PMn/PAI ratio than the UCC ratio leading to a “%bulk  
431 sediment Mn” of 100%. This value will decrease by authigenic formation of Mn oxides. When a sample  
432 presents a “%bulk sediment Mn” greater than 100%, we assign a value of 100% to simplify the following  
433 discussion. As the Mn cycle can also be affected by biologic uptake (e.g. Peers and Price, 2004; Sunda and  
434 Huntsman, 1983), this proxy is only used at depths where biologic activity is negligible (i.e. below 150m depth).

435

#### 436 *The Iberian margin*

437 Coastal waters of the Iberian Shelf are impacted by the runoff for the Tagus River, which is characterised by  
438 high suspended matter discharges, ranging between  $0.4$  to  $1 \times 10^6 \text{ tons yr}^{-1}$ , and with a high anthropogenic  
439 signature (Jouanneau et al., 1998). During the GEOVIDE section, the freshwater input was observable at  
440 stations 1, 2 and 4 in the first 20 m; salinity was below 35.2 psu while surrounding waters masses had salinity  
441 up to 35.7 psu. Within the freshwater plume, particulate concentrations were important at station 2, at 20m, PFe  
442 was  $1.83 \text{ nmol L}^{-1}$ . Further away from the coast, the particulate concentrations remained low at 20m depth, with  
443 PFe, PAI, and PMn concentrations of  $0.77 \text{ nmol L}^{-1}$ ,  $3.5 \text{ nmol L}^{-1}$ , and  $0.04 \text{ nmol L}^{-1}$ , respectively at station 1.  
444 The low expansion of the Tagus plume is likely due to the rapid settling of suspended matter. Indeed, our coastal  
445 station 2 was already located at around 50 km of the Iberian coast and according to Jouanneau et al. (1998), the  
446 surface particle load can be observable at a maximum 30km of the Tagus estuary.

447 Besides, ADCP data acquired during GEOVIDE (Zunino et al., 2017) and several studies have reported an  
448 intense current spreading northward coming from Strait of Gibraltar and Mediterranean Sea, leading to a strong  
449 resuspension of benthic sediments above the Iberian Shelf e.g. Biscaye and Eittrheim (1977), Eittrheim et al.  
450 (1976), McCave and Hall (2002), Spinrad et al. (1983). The importance of the sediment resuspension was  
451 observable by low beam transmissometry value (87.6%) at the bottom of station 2. This important sediment  
452 resuspension led to an extensive input of lithogenic particles within the water column associated with high  
453 concentrations of PFe ( $304 \text{ nmol L}^{-1}$ ), PAI ( $1500 \text{ nmol L}^{-1}$ ), and PMn ( $2.5 \text{ nmol L}^{-1}$ ) (Figure 3, Table S1).



454 Moreover, one hundred percent of PFe is estimated to have a lithogenic origin (Figure 11) while 100% of the  
455 PMn was the result of a recent sediment resuspension according to the %Fe<sub>litho</sub> and “%bulk sediment Mn”  
456 proxies (Table S1), confirming the resuspended particle input.

457 At distance from the shelf, within the Iberian Abyssal Plain, an important lateral advection of PFe from the  
458 margin was observable (Figure 11). These lateral inputs occurred at two depth ranges: between 400 and 1000 m  
459 at seen at stations 4 and 1, with PFe concentrations reaching 4 nmol L<sup>-1</sup>, and between 2500 m and the bottom  
460 (3575 m) of station 1, with PFe concentrations reaching 3.5 nmol L<sup>-1</sup>. While 100% of PFe had a lithogenic  
461 origin, the sedimentary source input decreased, between 40% and 85% of the PMn (Figure 11). Transport of  
462 lithogenic particles was observable until station 11 (12.2°W) at 2500 m where PFe concentration was 7.74 nmol  
463 L<sup>-1</sup> and 60% of PMn had a sedimentary origin (Figure 10). Noteworthy, no particular increase in PFe, PMn or  
464 PAI was seen between 500 and 2000 m depth, where the MOW spreads, which is consistent with that was  
465 observed DFe concentrations (Tonnard et al., this issue), yet in contrast with the dissolved aluminium values  
466 (Menzel Barraqueta et al, subm., this issue) which were high in the MOW and with the study of Ohnemus and  
467 Lam (2015) that reported a maximum PFe concentration at 695 m depth associated with the particle-rich  
468 Mediterranean Overflow Water (Eittrheim et al., 1976) in the IAP. However, their station was located further  
469 south of our station 1. The shallower inputs observed at stations 1 and 4 could therefore be attributed to  
470 sediment resuspension from the Iberian margin and nepheloid layer at depth for station 1.

471 Therefore, the Iberian margin appears to be an important source of lithogenic-derived iron-rich particles in the  
472 Atlantic Ocean; shelf resuspension impact was perceptible until 280 km away from the margin (Station 11) in  
473 the Iberian Abyssal Plain.

474

#### 475 *South Greenland*

476 Several studies already demonstrated the importance of icebergs and sea ice as source of dissolved and  
477 particulate iron (e.g. van der Merwe et al., 2011a, 2011b; Planquette et al., 2011; Raiswell et al., 2008). The  
478 Greenland shelf is highly affected by external fresh water inputs as ice-melting or riverine runoff (Fragoso et al.,  
479 2016), that are important sources of iron to the Greenland Shelf (Bhatia et al., 2013; Hawkings et al., 2014;  
480 Statham et al., 2008).

481 Both East and West Greenland shelves (stations 53 and 60) had high concentration of particles (beam  
482 transmissometry of 83%) and particulate trace elements, reaching 22.1 nmol L<sup>-1</sup> and 18.7 nmol L<sup>-1</sup> of PFe,  
483 respectively (station 53 at 100m and station 61 at 136 m). During the cruise, the relative freshwater observed  
484 (S<33 psu) within the first 25 meters of stations 53 and 61 were associated with high PFe (19 nmol L<sup>-1</sup>), PAI (61  
485 nmol L<sup>-1</sup>), PMn (0.6 nmol L<sup>-1</sup>) and a low beam transmissometry (≤ 85%) (Figure 10 and Table S1). Particles  
486 associated were enriched in iron compared to aluminium, as PFe/PAI ratio was 0.3 within the meteoric water  
487 plume. High biological production, in agreement with PP concentrations reaching 197 nmol L<sup>-1</sup> induced by the  
488 supply of bioavailable dissolved iron from meteoric water (Raiswell et al., 2008; Statham et al., 2008.; Tonnard  
489 et al., submitted, this issue), led to a transfer of DFe to the particulate phase. This is in line with the fact that  
490 around 30% of the PFe had a non-lithogenic and likely biogenic origin. In addition, only 35% of the PMn  
491 originated from resuspended sediments. Interestingly, these two proxies remained constant from the seafloor to  
492 the surface (Station 49, Figure 11), with around 25% of the PMn of sedimentary origin, which could be due to



493 an important mixing happening on the shelf. The lithogenic PFe could result from the release of PFe from  
494 Greenland bedrock captured during the ice sheet formation on land.

495 The spatial extent of the off-shelf lateral transport of particles was not important on the east Greenland coast.  
496 Indeed, no visible increase of particulate trace metal concentrations was visible at the first station off-shelf,  
497 station 60 (Figure 11), except at 1000 m depth, where a strong increase (up to 89%) of sedimentary PMn was  
498 seen. This is probably due to the East Greenland Coastal Current (EGCC) that was located at station 53  
499 constrained these inputs while stations 56 and 60 were under the influence of another strong current, the East  
500 Greenland-Irminger current (EGIC) (Zunino et al., 2017).

501

502 To the west of the Greenland margin, lateral transport of particles was slightly more important. Noticeable  
503 concentrations of particulate lithogenic elements were observable until station 64 located 125 km away from  
504 shoreline. These particles had decreasing PFe lithogenic contribution (52%) with a similar (27%) sedimentary  
505 PMn content than closer to the margin. The increasing nature of non-lithogenic PFe is linked to the bloom in  
506 surface (associated with a PFe/PAI ratio of 0.30 mol mol<sup>-1</sup> and a PP of 197 nmol L<sup>-1</sup> at station 61), with the  
507 biogenic PFe settling down along the transport of particles.

508

509 Therefore, particles newly resuspended from Greenland sediments are an important source, representing around  
510 a third of the pMn pool, combined with surface inputs such as riverine runoff and/or ice-melting that are  
511 delivering particles on the shelf and biological production. Unlike the Iberian shelf, Greenland margin was not  
512 an important provider of particulate metals inside the Irminger and Labrador Basin, due to the circulation that  
513 constrained the extent of the margin plume.

514

#### 515 *The Newfoundland Shelf*

516 Previous studies already described the influence of fresh water on the Newfoundland shelf from the Hudson  
517 Strait and/or Canadian Arctic Archipelago (Fragoso et al., 2016; Yashayaev, 2007). Yashayaev (2007) also  
518 monitored strong resuspension of sediments associated with the spreading of Labrador Current along the West  
519 Labrador margin.

520 Close to the Newfoundland coastline, at station 78, high fresh water discharge ( $\leq 32$  psu) was observed in  
521 surface (Benetti et al., 2017). Interestingly, these freshwater signatures were not associated with elevated  
522 particulate trace metal concentrations. Distance of meteoric water sources implied a long travel time for the  
523 water to spread through the Labrador Basin to our sampling stations. Along the journey, particles present  
524 originally may have been removed from water column by gravitational settling.

525 The proportion of lithogenic PFe was relatively high and constant in the entire water column, with a median  
526 value of 67 %. At station 78, 95% of the PMn had a sedimentary origin close to the seafloor (371 m). The  
527 spreading of the recent sediment resuspension was observable until 140 m depth where the contribution of  
528 sedimentary Mn was still 51% (Figure 11, Table S2). This could correspond to an intense nepheloid layer as  
529 previously reported by Biscaye and Eitrem (1977) (see also section 3.3.2). The high PFe concentration (184  
530 nmol L<sup>-1</sup>, station 78, 371 m) associated with a high percentage of sedimentary PMn (95%) observed at the  
531 bottom of this station, was therefore the result of an important resuspension of shelf sediments. This was  
532 confirmed with low transmissometry values of 95%.



533 Despite the important phytoplanktonic community present (Tonnard et al., in prep), the PFe remained low at  
534  $0.79 \text{ nmol L}^{-1}$  at 10 m, but, the high PFe/PAI ratio, up to 0.4, and the PP concentration of  $97 \text{ nmol L}^{-1}$ , confirms  
535 the biogenic influence. Either the biogenic particles settled quickly, and/or they were quickly remineralized.  
536 Concerning this latter process, intense remineralization at station 77 has been reported by Lemaitre et al.  
537 (2018a), which could explain the low PFe values throughout the water column. That said, resuspended particles  
538 are still laterally transported off-shelf until station 71 (Figure 6) where PFe concentrations were higher  
539 than the background value, up to  $2 \text{ nmol L}^{-1}$  at depths greater than 100 m.

540

541 Along the GEOVIDE section, continental shelves provided an important load of particles within the surrounding  
542 water column. The three margins sampled during GEOVIDE behaved differently; the Iberian margin discharged  
543 high quantities of lithogenic particles far away from the coast while the Greenland and Newfoundland margins  
544 did not reveal important PFe concentrations. Spreading of particles is tightly linked to hydrodynamic conditions,  
545 which in the case of the Greenland margin, prevented long distance seeding of PFe. Moreover, each margin  
546 showed a specific PFe/PAI ratio (Figure 9) indicating different composition of the resuspended particles.  
547 Resuspended particles represent the composition of sediment at the margin if oxido-reductive transformation of  
548 iron and aluminium are considered negligible under these circumstances. Differences between margins were due  
549 to the presence of non-crustal particles. Biological production in surface waters produces particles with a higher  
550 PFe/PAI content and their export through the water column to the sediment increased the PFe/PAI ratio at depth.  
551 Regions where biological production is intense such as in the vicinity of Newfoundland presented higher  
552 PFe/PAI ratios of resuspended benthic particles. These results are in agreement with the study of Lam et al.  
553 (2017), which showed the different behaviour between margins are a function of several parameters such as  
554 boundary currents, internal waves and margin sediment composition.

555

556

#### 4.3.2 Benthic resuspended sediments

557 Benthic nepheloid layers (BNLs) can play a significative role in trace element distributions at depth as  
558 previously described (Dutay et al., 2015; Lam et al., 2015; Ohnemus et al., 2015; Revels et al., 2015). BNLs are  
559 important layers where local resuspension of sedimentary particles (Bishop and Biscaye, 1982; Eittrheim et al.,  
560 1976; Rutgers Van Der Loeff et al., 2002) occur due to strong hydrographic stresses interacting with the ocean  
561 floor (Gardner et al., 2017). In the North Atlantic, boundary currents were suspected to be the origin of these  
562 stresses (Biscaye and Eittrheim, 1977; Eittrheim et al., 1976) but more recent studies demonstrate the essential role  
563 of benthic storms and deep eddies (Gardner et al., 2018). Along the GA01 section, BNLs were observable in  
564 each province with different strengths (Figures 3 and 12).

565

566 In BNLs located within the WEB, PFe concentrations reached up to  $10 \text{ nmol L}^{-1}$  (stations 26 and 29). These  
567 concentrations were smaller than PFe concentrations encountered in BNL from the Icelandic, Irminger and  
568 Labrador Basins, where benthic resuspension led to PFe concentrations higher than  $40 \text{ nmol L}^{-1}$ , even reaching  
569  $89 \text{ nmol L}^{-1}$  at the bottom of station 71 (3736 m). Moreover, in the Irminger and Labrador Basins, PFe/PAI  
570 molar ratios within BNLs were higher than the ones measured within the WEB at station 26 and 29. In the  
571 Irminger Basin, PFe/PAI reached  $0.4 \text{ mol mol}^{-1}$ , which could reveal a mixture of lithogenic and biogenic matter



572 previously exported. This feature was also observed in the Labrador Basin, with PFe/PAI ratio ranging between  
573 0.34 and 0.44 mol mol<sup>-1</sup>. In contrast, BNLs sampled in the WEB have clearly a lithogenic imprint, with PFe/PAI  
574 molar ratios close to the crustal one. Resuspended sediments with a non-crustal contribution seem to hold a  
575 higher PFe content than sediments with a lithogenic characteristic. Nevertheless, interestingly all BNLs present  
576 during GEOVIDE were spreading identically, with impacts observable up to 200 meters above the oceanic  
577 seafloor (Figure 12), as reflected in beam transmissometry values, and PFe concentrations, that returned to a  
578 background level at 200 m above the seafloor. The presence of these BNLs has also been reported by Le Roy et  
579 al. (submitted, this issue).

580 Important differences of PFe intensities could also be due to different hydrographic components and  
581 topographic characteristics. As previously explained, two main triggers of BNLs are benthic storms and deep  
582 eddies; by definition these processes are highly variable geographically and temporally, but no physical data  
583 could allow us to investigate further this hypothesis.

584

585

#### 4.3.3. Reykjanes Ridge inputs

586 Recently, hydrothermal inputs of iron in the open ocean have been re-evaluated by (Fitzsimmons et al., 2017;  
587 Resing et al., 2015; Tagliabue et al., 2014). These studies demonstrated the importance of hydrothermal  
588 activities on the global iron biogeochemical cycle through particulate and dissolved iron fluxes. During the  
589 cruise, samples of station 38 have been collected above the Reykjanes Ridge, the upper section of the Mid-  
590 Atlantic Ridge in the North Atlantic, which has inferred hydrothermal sites from several studies conducted in  
591 the area (Baker and German, 2004). Above the ridge, high PFe concentrations were measured, reaching 16 nmol  
592 L<sup>-1</sup> just above the seafloor, while increased DFe concentrations were reported to the East of the ridge (Tonnard  
593 et al., this issue). The exact sources of iron-rich particles cannot be well constrained, as they could come from  
594 active hydrothermal vents or resuspension of particulate matter from new crustal matter produced at the ridge.  
595 According to the oceanic circulation (Zunino et al., 2017; Garcia-Ibanez et al., 2017), hydrothermal particles  
596 could have been seen in the ISOW within the Icelandic Basin. Nevertheless, at the vicinity of the ridge, scanning  
597 electron microscope (SEM) analyses of our samples did reveal a number of biological debris and clays but not  
598 the presence of iron (oxy-)hydroxide particles, which are known to be highly produced close to hydrothermal  
599 vents (Elderfield and Schultz, 1996). Their absence could thus indicate an absence of vents. However, other  
600 proxies, such as helium-3, are necessary to claim with more accuracy the presence or absence of an  
601 hydrothermal source close to station 38.

602 Alternatively, resuspended sediments transported with ISOW flowing across the Reykjanes Ridge could explain  
603 the high PFe concentrations below 1000 m depth at station 38. This feature was associated with lower median  
604 PFe concentrations and PFe/PAI ratios (Figure 7) at station 40 (2.2 nmol L<sup>-1</sup>, and 0.58 mol mol<sup>-1</sup> respectively)  
605 than at station 38 (6.8 nmol L<sup>-1</sup>, 0.48 mol mol<sup>-1</sup> respectively). Moreover, PMn had a 19% sedimentary origin,  
606 constant from the bottom to 1163 m depth, a contribution that is very low for the shallower water depths.  
607 Consequently, the increase in PFe within the ISOW<sub>west</sub> more likely came from sediment resuspension as the  
608 ISOW<sub>east</sub> flows through the Charlie Gibbs Bight Fracture Zones.

609

610

#### 4.3.4. Atmospheric inputs





611 Atmospheric deposition is an important input of trace elements in surface of the open ocean (e.g. (Jickells et al.,  
612 2005). Atmospheric inputs, both wet and dry, were reported to be low during the GEOVIDE cruise (Menzel-  
613 barraqueta et al., 2018, this issue; Shelley et al., 2017; 2018). In fact, oceanic particles measurements in surface  
614 waters along the section did not reveal high PFe or PAI concentrations, therefore, the surface composition of  
615 particles did not seem to be highly affected by atmospheric deposition at the time of the cruise. However,  
616 PFe/PAI ratio was closed to the UCC one, probably due to the overall influence of atmospheric deposition in  
617 this area. One pattern is also interesting to note: the surface waters of the Iberian Abyssal Plain and Western  
618 European Basin, between stations 11 and 23 presented a characteristic feature with really low PFe/PAI  
619 elemental ratios, of 0.11, smaller than the UCC ratio of 0.21 (Figure 6). Such low ratios have been reported in  
620 the same region by Barrett et al. (2012). One possible explanation is given by Buck et al. (2010) who described  
621 Fe-depleted aerosols in this area of the North Atlantic with PFe/PAI ratio below UCC ratio. However, Shelley et  
622 al. (2017) found a higher PFe/PAI ratio around 0.25 in this area (their sample geoa5-6). This result, highlights  
623 some of the difficulties that link atmospheric inputs to water column data (Baker et al., 2016), and implies a  
624 probable fractionation after aerosol deposition. In addition, there is high spatial and temporal variability of  
625 atmospheric deposition (Mahowald et al., 2005) and a certain degree of uncertainty about the dissolution  
626 processes of atmospherically-transported particles (Bonnet and Guieu, 2004).

627

#### 628 4.3.5. Influence of phytoplankton assemblages, remineralisation and scavenging in 629 the upper water column

630 Biological activity in surface waters impacts the particle composition in the upper water column. In bulk particle  
631 samples, direct measurement of the biogenic metal fraction is not possible due to the heterogeneity of particles,  
632 and in particular, the presence of lithogenic particles. It is however possible to estimate the  $\text{PFe}_{\text{nonlitho}}/\text{PP}$  molar  
633 ratios, based on Eq. (1) and (2), and assuming that most of the PP is of biogenic origin. As 100% of the PFe was  
634 estimated to be of lithogenic origin, stations 1 to 26 are excluded from the discussion below.

635 Overall, the median  $\text{PFe}_{\text{nonlitho}}/\text{PP}$  molar ratios varied from 1.0 (Irminger Basin) to  $38.7 \text{ mmol mol}^{-1}$  (Greenland  
636 margin) in the upper 50 m. These ratios are consistent with the few available bulk PFe/PP ratios available in the  
637 literature (Twining and Baines, 2013 and references therein), ranging from 1 to  $31 \text{ mmol mol}^{-1}$  and the  
638 phytoplankton assemblages encountered during GEOVIDE (Tonnard et al., in prep.). Indeed, the highest  
639  $\text{PFe}_{\text{nonlitho}}/\text{PP}$  molar ratio determined at stations 53 and 56 close to the South Greenland margin coincide with a  
640 bloom mostly composed of large diatoms, whereas, the smallest ratios were associated with a bloom mainly  
641 composed of cyanobacteria and haptophytes. The effect of biological uptake is also clearly visible when looking  
642 at PFe/PAI vertical variation, which increases from the surface to approximately 100m depth (Figure 13), except  
643 in the Iberian Margin, which is under the strong influence of lithogenic inputs.

644

645

646 At deeper depths, pelagic remineralisation processes influence the composition of particles (Barbeau et al.,  
647 1996, 2001; Boyd et al., 2010; Strzepek et al., 2005).

648 Close to the IM and within the IAP, no PFe/PAI decrease that could point to a preferential remineralisation of  
649 PFe over PAI could be observed within the remineralisation depth (200 to 400 m depth, Figure 13), whereas



650 preferential remineralisation of PP over PFe occurs, as reflected by increasing PFe/PP ratios (Figure 14). This is  
651 probably due to the fact that remineralisation rates were low (Lemaitre et al., 2018a), and that PFe was mostly of  
652 lithogenic origin, more difficult and slow to remineralize (Boyd et al., 2010). Below 600 m depth, scavenging  
653 processes could explain the increasing PFe:PP ratios, from 0.30 to 0.80 mol mol<sup>-1</sup> at station 13.

654 Within the WEB, between 200 and 500 m depth, remineralisation of PFe over PAI occurs, although reported to  
655 be small (Lemaitre et al., 2018a) as reflected by decreasing PFe:PAI ratios (Figure 13), while PFe:PP ratios  
656 remained constant, pointing out to similar remineralisation rates of PFe and PP. Below 600 m depth, a stronger  
657 scavenging of DFe onto particles than in IM and IAP is likely to explain the increasing ratios of PFe:PAI from  
658 0.18 to 0.30 mol mol<sup>-1</sup> and PFe:PP from 0.047 to 0.367 (Station 21), and from 0.16 to 1.05 (Station 26) mol mol<sup>-1</sup>.  
659 Similar patterns occur in IcB (station 32).

660  
661 Above the RR, at station 38, PFe is remineralized preferentially over PAI and PP, with decreasing PFe:PAI  
662 ratios from 0.46 to 0.19 mol mol<sup>-1</sup> and decreasing PFe:PP ratios from 0.24 to 0.04 mol mol<sup>-1</sup>. This interesting  
663 feature is associated with moderate POC remineralisation fluxes (Lemaitre et al., 2018a), and the fact that a  
664 stronger fraction of PFe was associated with biogenic material, easier to recycle.

665 In the IrB, PP is preferentially remineralized over PFe and PAI, as reflected by increasing PFe:PP ratios and  
666 constant PFe:PAI ratios within the remineralisation depth. This is associated with high POC remineralisation  
667 fluxes (Lemaitre et al., 2018a) and a high proportion of lithogenic PFe.

668 Finally, within the LB, PFe:PAI and PFe:PP remain constant within the deep remineralisation depth, extending  
669 from 200 to 1000 m depth due to the deep convection of the LSW (Lemaitre et al., 2018a). Below 1000 m,  
670 PFe:PP ratios increase from 0.29 to 0.85 mol mol<sup>-1</sup>, while PFe:PAI ratios still remain constant. This could be  
671 explained by the fact that most PP has been recycled due to the strongest remineralisation fluxes reported in this  
672 area (Lemaitre et al., 2018a).

673

## 674 5. Conclusions

675 This investigation of the PFe compositions of suspended particulate matter in the North Atlantic indicates the  
676 pervasive influence of crustal particles, augmented by sedimentary inputs at margins, and at depths, within  
677 benthic nepheloid layers.

678 Indeed, along the GEOVIDE section, continental shelves provided an important load of particles within the  
679 surrounding water column, with PFe mostly residing in non-biogenic particulate form. The Iberian margin  
680 discharged high quantities of lithogenic particles originating from riverine inputs far away from the coast while  
681 the Greenland margin did not reveal a long distance seeding of PFe, due to hydrodynamic conditions. Both  
682 Greenland and Newfoundland margins PFe resuspended particles were under a strong biogenic influence that  
683 were exported at depth. This resulted in different remineralisation fluxes among the different provinces.  
684 Scavenging processes could also be visible at depths greater than 1000 m, these effects being the most  
685 pronounced within the WEB.

686 Finally, resuspended sediments above the Reykjanes Ridge increased the PFe composition of the Iceland



687 Scottish Overflow Water. A similar feature occurs for the Labrador Sea Water, as it flows from the Irminger  
688 Basin to the Western European Basin.

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691

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701

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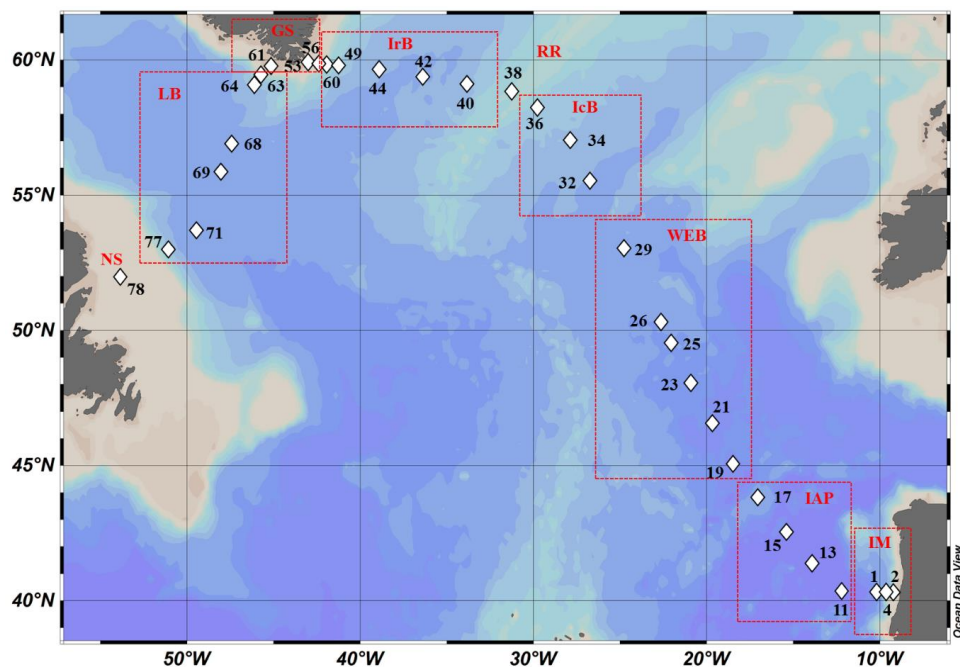
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1011 Figure 1: Map of stations where suspended particle samples were collected with GO-FLO bottles during the  
 1012 GEOVIDE cruise (GA01). Biogeochemical provinces are indicated by red squares, IM: Iberian Margin, IAP: Iberian  
 1013 Abyssal Plain, WEB: Western European Basin, IcB: Iceland Basin, RR: Reykjanes Ridge, IrB: Irminger Basin, GS:  
 1014 Greenland Shelf, LB: Labrador Basin, NS: Newfoundland Shelf. This figure was generated by Ocean Data View  
 1015 (Schlitzer, R., Ocean Data View, odv.awi.de, 2017).

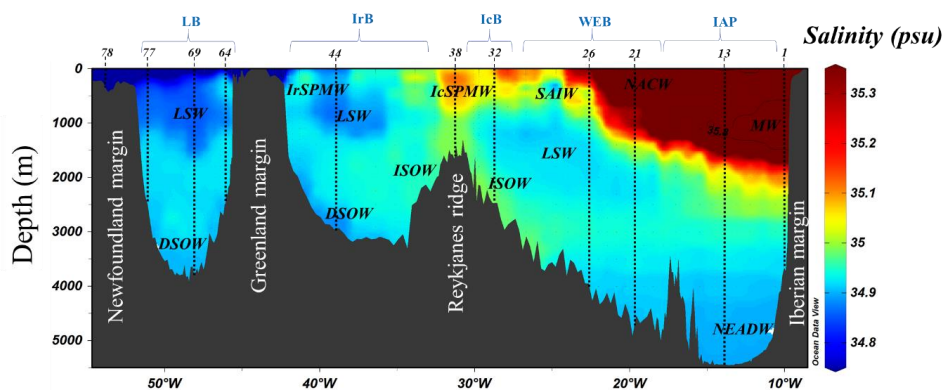


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1032 **Figure 2: Salinity section during the GEOVIDE cruise. Water masses are indicated in black, MW: Mediterranean**  
 1033 **Water; NACW: North Atlantic Central Water; NEADW: North East Atlantic Deep Water; LSW: Labrador Sea**  
 1034 **Water; ISOW: Iceland-Scotland Overflow Water; SAIW: Sub-Arctic Intermediate Water; IcSPMW: Iceland Sub-**  
 1035 **Polar Mode Water; IrSPMW: Irminger Sub-Polar Mode Water. Stations locations are indicated by the numbers.**  
 1036 **Biogeochemical provinces are indicated in blue font above station numbers. Contour of salinity = 35.8psu have been**  
 1037 **apply to identify the Mediterranean Water. This figure was generated by Ocean Data View (Schlitzer, R., Ocean Data**  
 1038 **View, odv.awi.de, 2017).**

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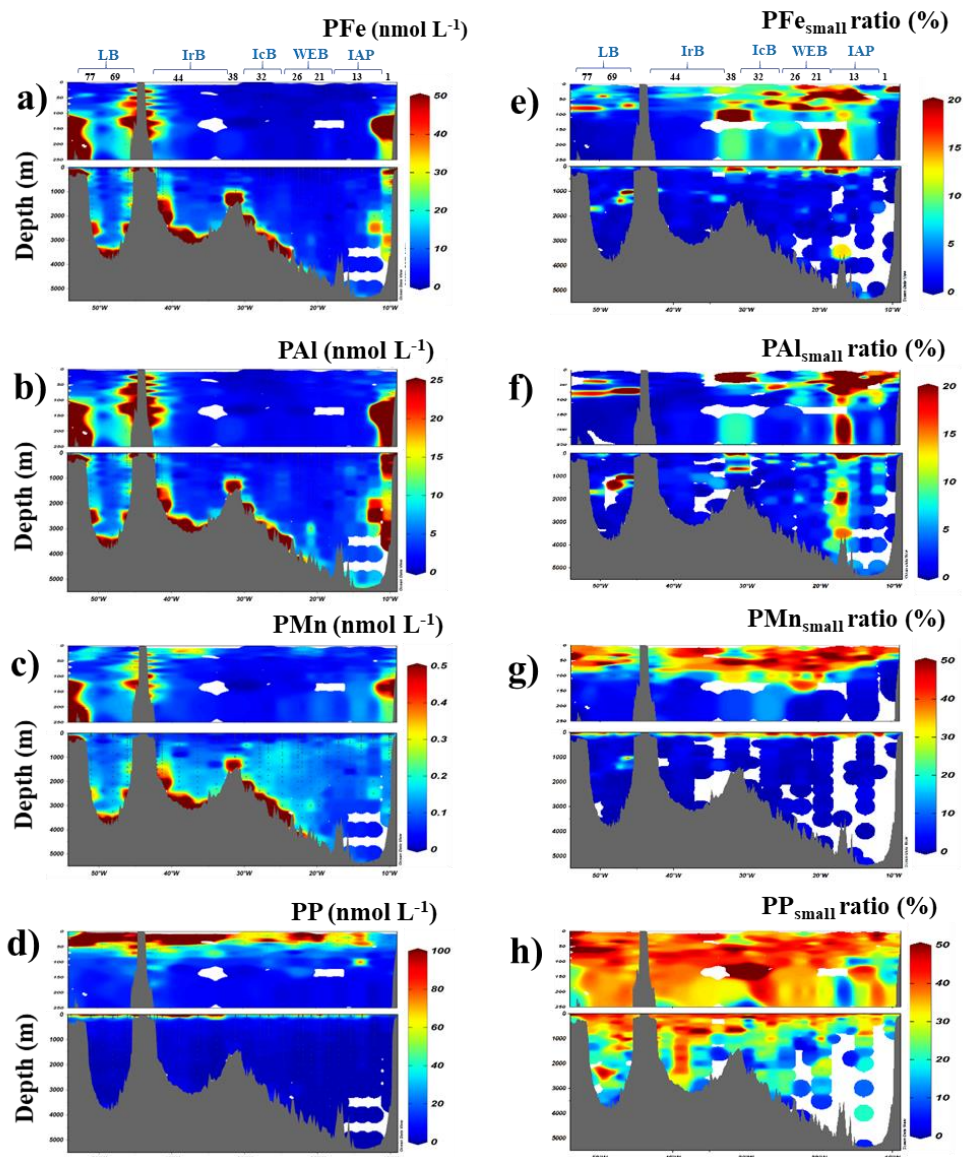
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1061 Figure 3: Left) Distribution of total particulate iron (a, PFe), aluminium (b, PAI), manganese (c, PMn) and  
1062 phosphorus (d, PP) concentrations (in  $\text{nmol L}^{-1}$ ) along the GEOVIDE section. Right) Contribution of small size  
1063 fraction (0,45-5  $\mu\text{m}$ ) expressed as percentage (%) of the total concentration of PFe (e), PAI (f), PMn (g) and PP (h).  
1064 Station IDs and biogeochemical region are indicated on top of section a. This figure was generated by Ocean Data  
1065 View (Schlitzer, R., Ocean Data View, odv.awi.de, 2017).



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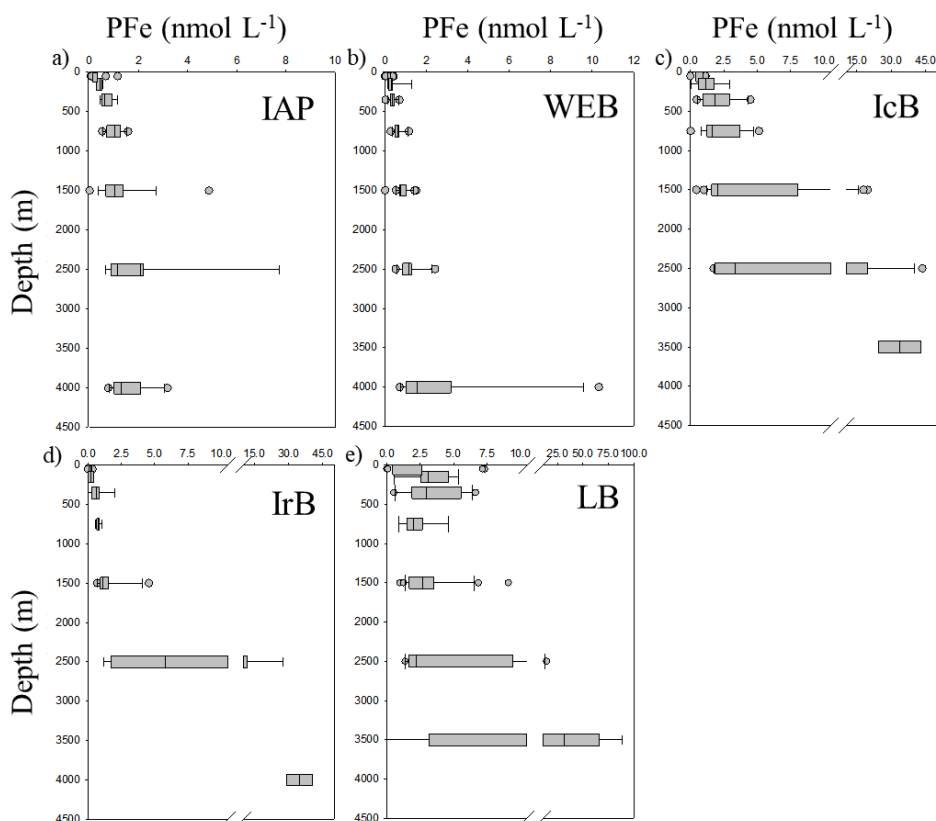
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1070 **Figure 4: Boxplot figure of the particulate iron vertical profile (in  $\text{nmol L}^{-1}$ ) in the a) Iberian abyssal plain (IAP), b)**  
 1071 **Western European basin (WEB), c) Icelandic basin (IcB), d) Irminger basin (IrB) and e) Labrador basins (LB). The**  
 1072 **left boundary of the box represents the 25<sup>th</sup> percentile while the right boundary represents the 75<sup>th</sup> percentile, the line**  
 1073 **within the box marks the median value. Whiskers represent the 90<sup>th</sup> and 10<sup>th</sup> percentiles and dots are the outlying**  
 1074 **data. Seven depth boxes have been used (0-100m, 100-200m, 200-500m, 500-1000m, 1000-2000m, 2000-3000m and**  
 1075 **3000m-bottom depth).**



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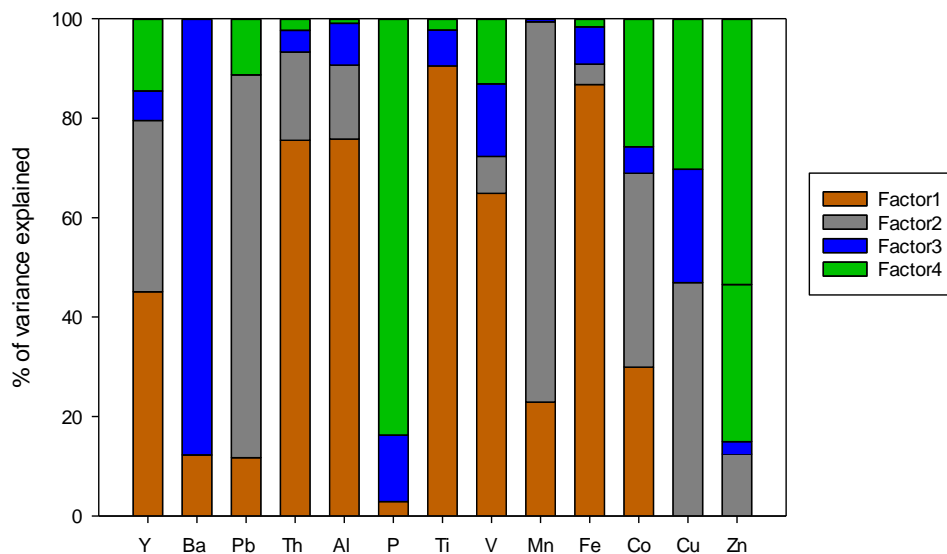
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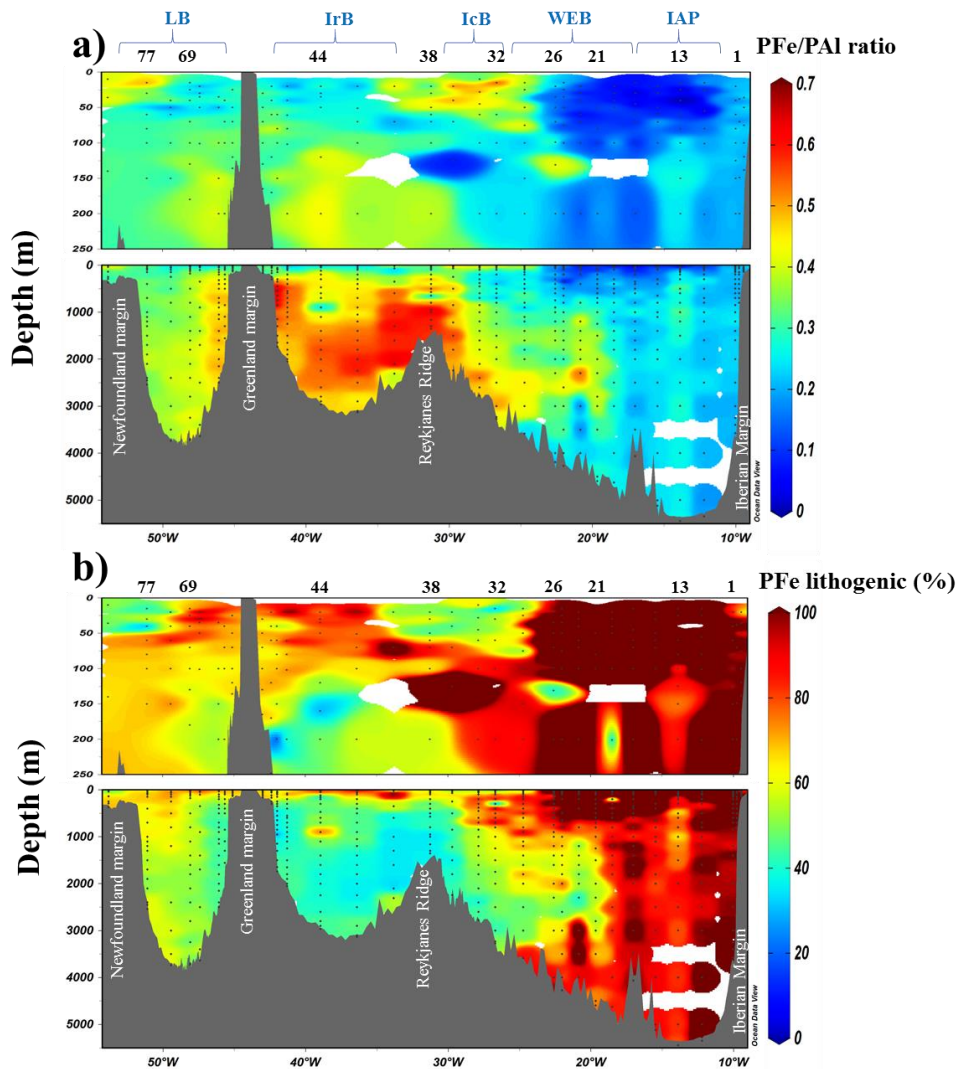
1086 **Figure 5: Factor fingerprint of the positive matrix factorisation. The four factors are represented in a stacked bar**  
1087 **chart of the percentage of variance explained per element.**



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1107 Figure 6: a) Section of the PFe to PAI molar ratio ( $\text{mol mol}^{-1}$ ); (b) contribution of lithogenic PFe (%) based on Eq. (1).  
 1108 Station IDs and biogeochemical provinces are indicated above each section. This figure was generated by Ocean Data  
 1109 View (Schlitzer, R., Ocean Data View, [odv.awi.de](http://odv.awi.de), 2017).



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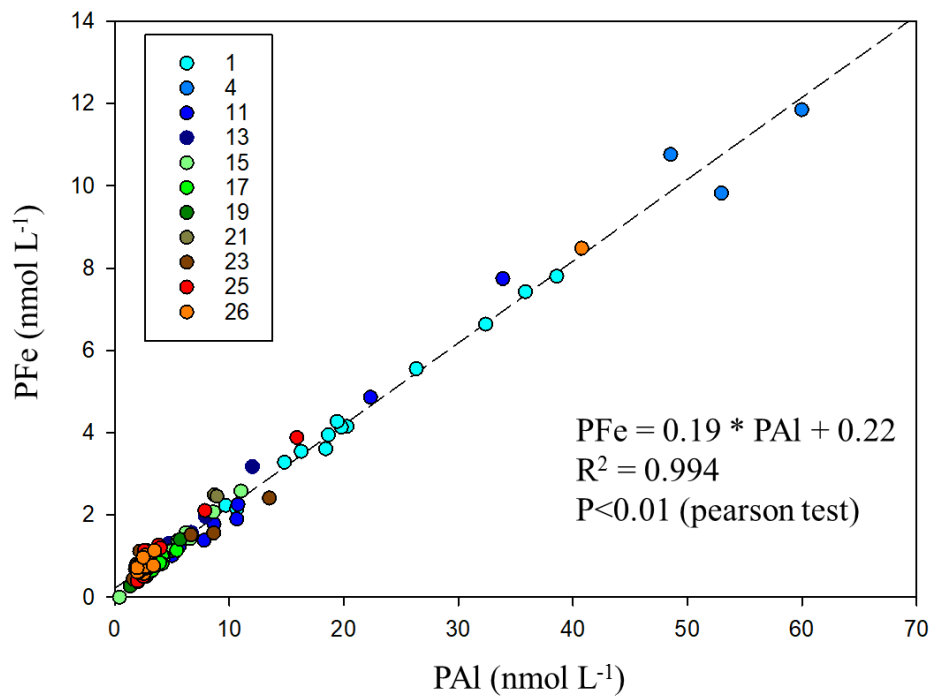
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1117 Figure 7: PFe over PAI concentrations ( $\text{nmol L}^{-1}$ ) for all stations located in the Iberian Abyssal Plain and Western  
1118 European Basin. Note that the total concentrations of the two elements covaried strongly.



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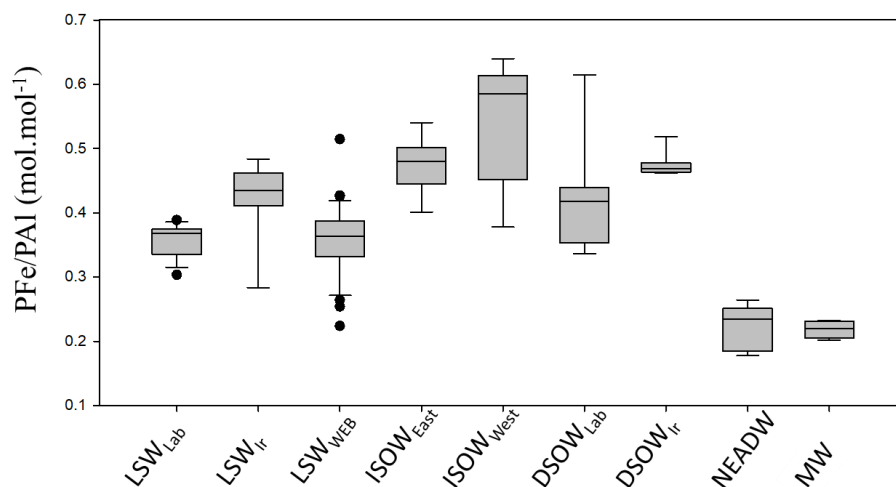
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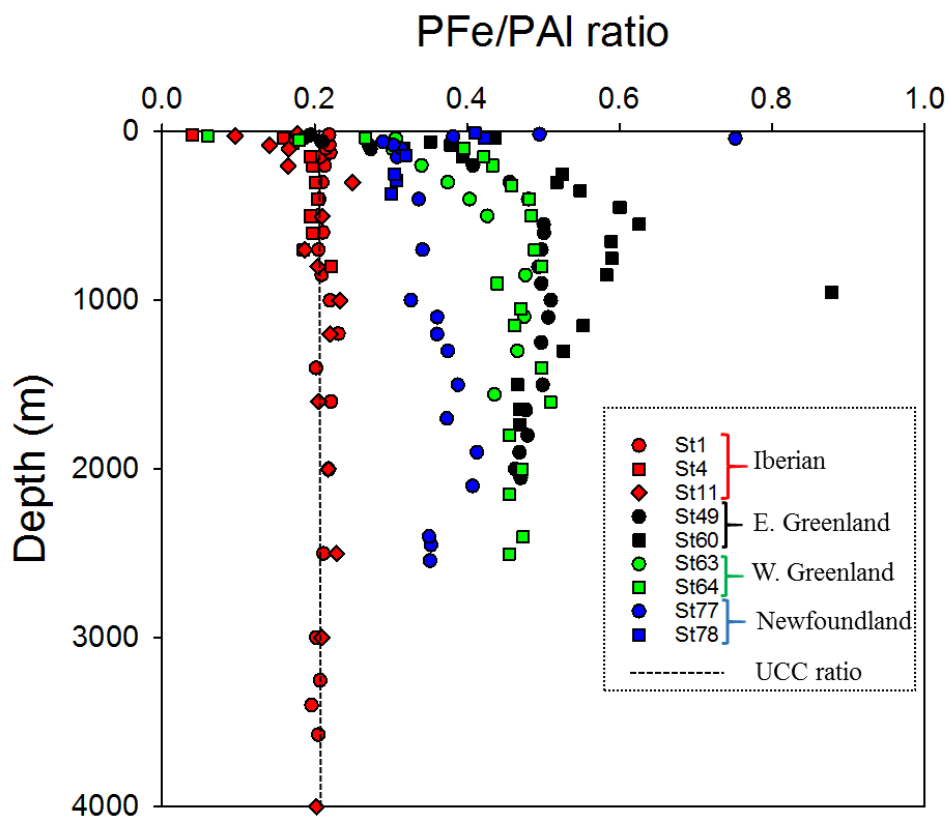
1132 **Figure 8: Whisker diagram of PFe/PAI molar ratio ( $\text{mol mol}^{-1}$ ) in the different water masses sampled along the GA01**  
 1133 **line. Median values for the water masses were as follows:  $\text{LSW}_{\text{lab}}=0.37$ ;  $\text{LSW}_{\text{Ir}}=0.44$ ;  $\text{LSW}_{\text{WEB}}=0.36$ ;  $\text{ISOW}_{\text{east}}=0.48$ ;**  
 1134  **$\text{ISOW}_{\text{west}}=0.58$ ;  $\text{DSOW}_{\text{lab}}=0.42$ ;  $\text{DSOW}_{\text{Ir}}=0.47$ ;  $\text{NEADW}=0.23$ ;  $\text{MW}=0.22 \text{ mol mol}^{-1}$ .**



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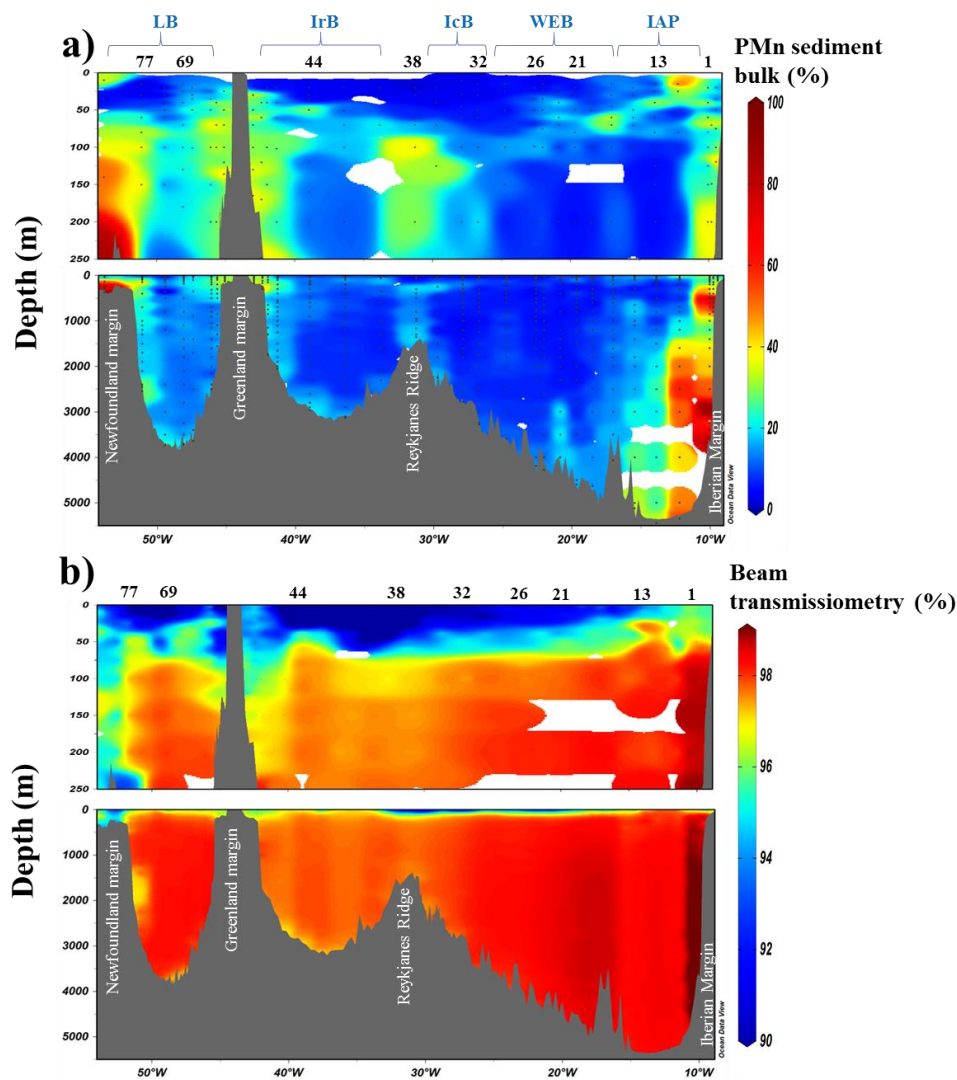
1155 Figure 9: Scatter of the PFe/PAI ratio at the Iberian (red dots), East Greenland (black dots), West Greenland (green  
1156 dots) and Newfoundland margins (blue dots). Dashed line indicate the UCC ratio (Taylor and McLennan, 1995).



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1168 Figure 10: Section of derived contribution of sedimentary inputs manganese bulk sediment proxy (a) and  
 1169 transmissometry (b) along the GA01 section. Station IDs and biogeochemical region are indicated above the section  
 1170 (a). This figure was generated by Ocean Data View (Schlitzer, R., Ocean Data View, odv.awi.de, 2017).



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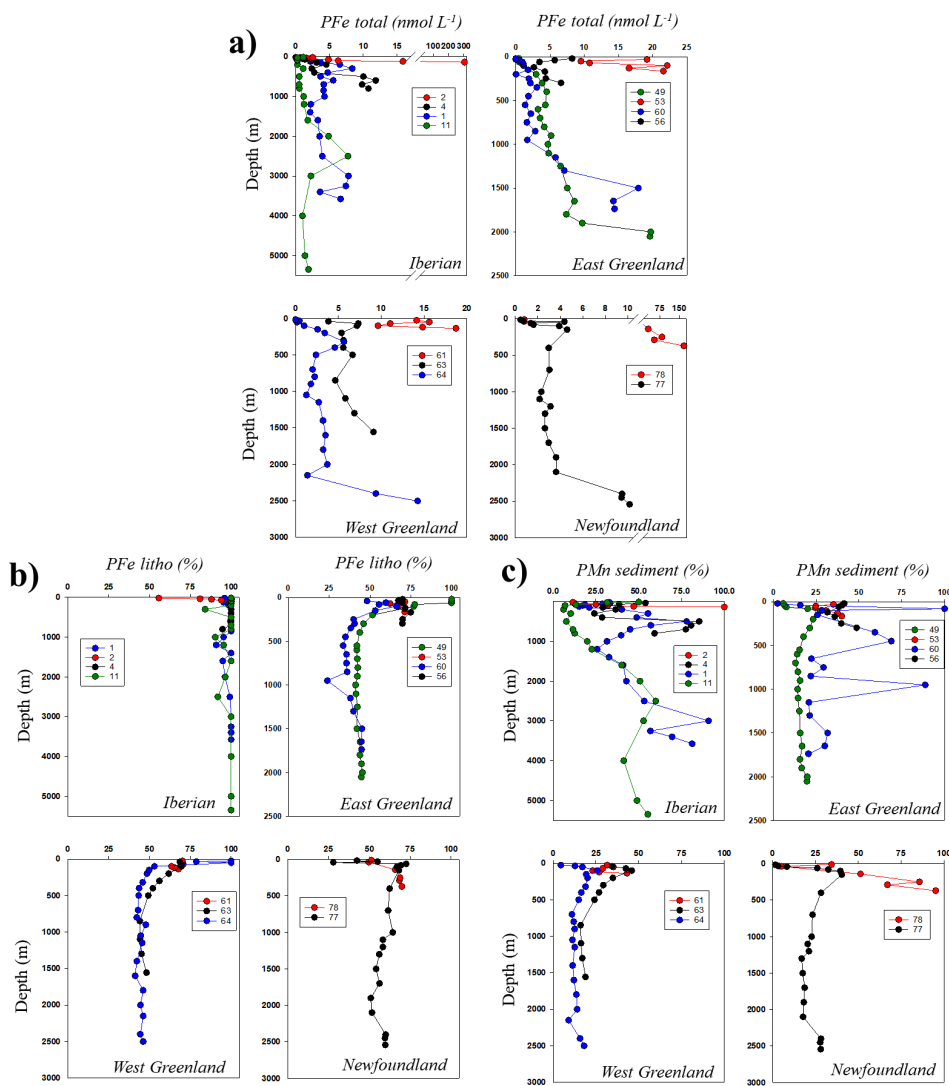
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1177 **Figure 11: Vertical profiles of PFe (nmol L<sup>-1</sup>, a), lithogenic proportion of particulate iron (%), b) and sedimentary**  
 1178 **proportion of particulate manganese (%), c) at the Iberian, East-West Greenland and Newfoundland margins.**



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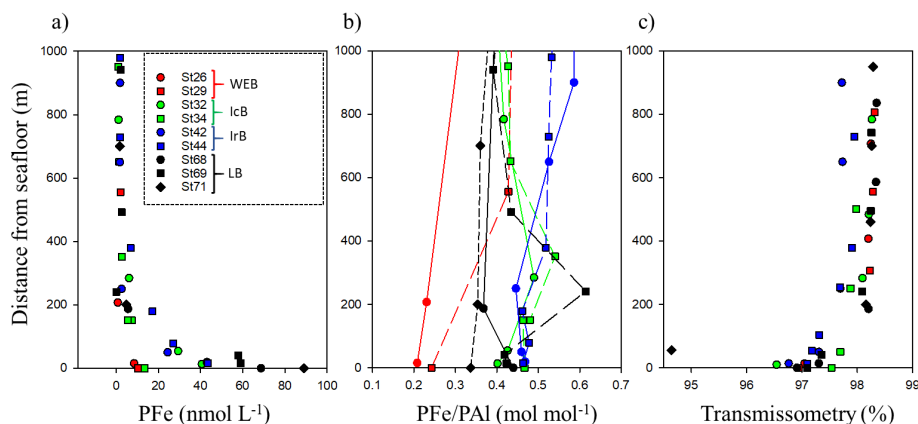
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1186 **Figure 12: PFe total (a); PFe/PAI ratio (b) and beam transmissometry (%) as a function of depth above the seafloor**  
 1187 **(m) at selected stations where a decrease in transmissometry was recorded.**



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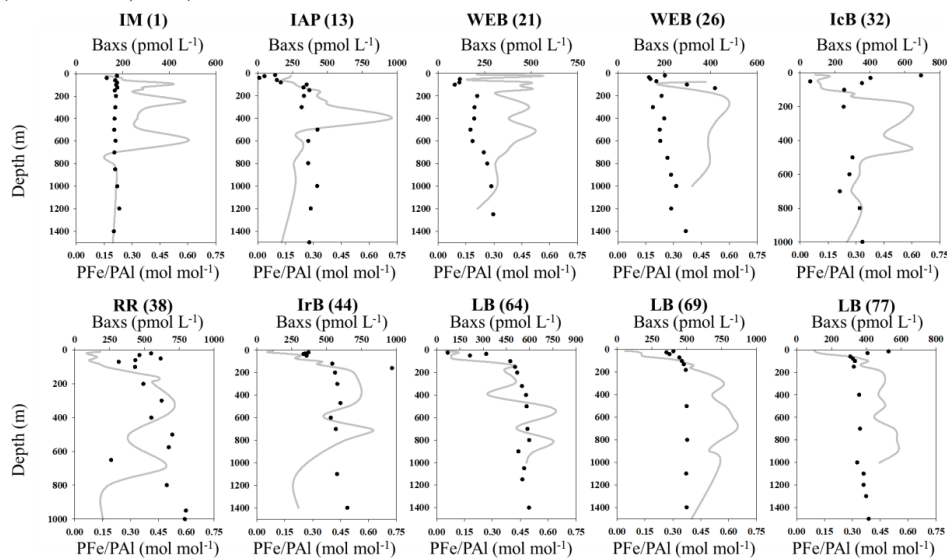
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1193 **Figure 13: Vertical profiles of Baxs (grey line, data from Lemaitre et al., 2018a) superimposed with PFe/PAI molar**  
 1194 **ratios (black dots) at stations sampled in the Iberian Margin (IM), Iberian Abyssal Plain (IAP), Western European**  
 1195 **Basin (WEB), Iceland Basin (IcB), above the Reykjanes Ridge (RR), Irminger Basin (IrB), and Labrador Basin (LB).**  
 1196 **Note that Baxs concentrations over the background level of 180 pmol L<sup>-1</sup> are indicative of remineralisation processes**  
 1197 **(Lemaitre et al., 2018a).**



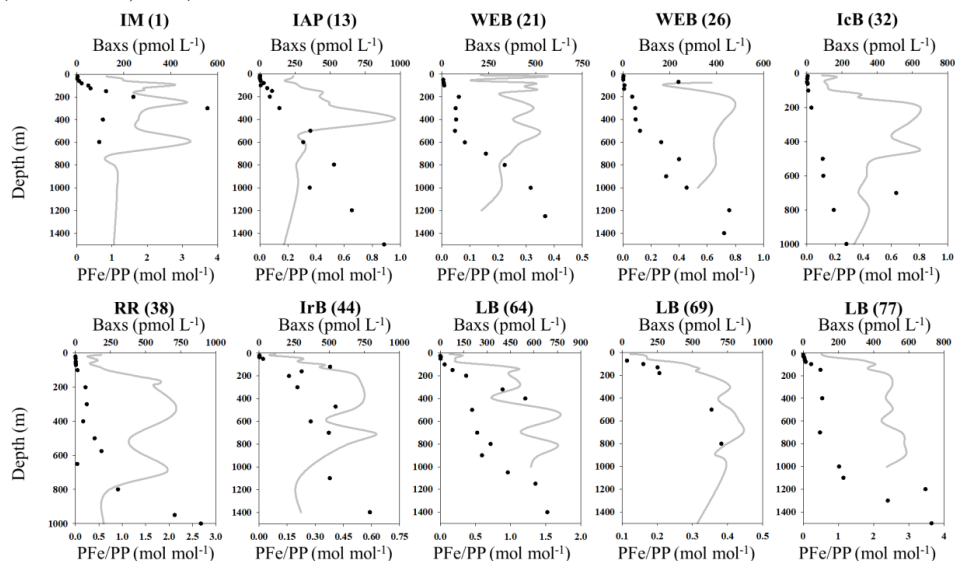
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1200 **Figure 14: Vertical profiles of Baxs (grey line, data from Lemaitre et al., 2018a) superimposed with PFe/PP molar**  
 1201 **ratios (black dots) at stations sampled in the Iberian Margin (IM), Iberian Abyssal Plain (IAP), Western European**  
 1202 **Basin (WEB), Iceland Basin (IcB), above the Reykjanes Ridge (RR), Irminger Basin (IrB), and Labrador Basin (LB).**  
 1203 **Note that Baxs concentrations over the background level of 180 pmol L<sup>-1</sup> are indicative of remineralisation processes**  
 1204 **(Lemaitre et al., 2018a).**



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% recovery	Ba	Al	P	Mn	Fe
BCR-414 (n=5)				93	94
MESS-4 (n=5)	110	111	53	104	106
PACS-3 (n=4)		136	104	134	130

1216 **Table 1: Certified reference material (CRM) recoveries during GEOVIDE suspended particle digestion.**

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Author	Year	Fraction	Location	Depth range	PFe	PAI	PMn	PP
This study		>0.45µm	N. Atlantic (>40°N)	All	bdl-304	bdl-1544	bdl-3.5	bdl-402
Barrett et al.	2012	0.4µm	N. Atlantic (25-60°N)	Upper 1000m	0.29-1.71	0.2-19.7		
Dammshauser et al.	2013	>0.2 µm	Eastern tropical N.A.	0-200		0.59-17.7		
Dammshauser et al.	2013	>0.2 µm	Meridional Atlantic	0-200		0.35-16.1		
Lam et al.	2012	1–51 µm	Eastern tropical N.A.	0-600	ND-12			
Lannuzel et al.	2011	>0.2 µm	East Antarctic	Surface		0.02-10.67	0.01-0.14	
Lannuzel et al.	2014	>0.2 µm	East Antarctic	Fast ice	43-10385	121-31372	1-307	
Lee et al.	2017	>0.8 µm	Eastern tropical S.Pacific	All	bdl-159	bdl-162	bdl-8.7	bdl-983
Marsay et al.	2017	>0.4 µm	Ross Sea	All	0.68-57.3	ND-185	ND-1.4	5.4-404
Milne et al.	2017	>0.45µm	Sub-tropical N.A.	All	ND-140	ND-800		
Ohnemus et al.	2015	0.8–51 µm	N. Atlantic	All	0-938	0-3600		
Planquette et al.	2009	>53 µm	Southern Ocean	30-340	0.15–13.2	0.11–25.5		
Schlosser et al.	2017	>1 µm	South Georgia Shelf	All	0.87-267	0.6-195	0.01-3.85	
Sherrell et al.	1998	1-53µm	Northeast Pacific	0-3557		0.0-54.2		
Weinstein et al.	2004	>53 µm	Labrador Sea	0-250	0.1-1.2	0.1-1.5		
Weinstein et al.	2004	0.4–10µm	Labrador Sea	0-250	2.5	3.6	0.05	
Weinstein et al.	2004	>0.4 µm	Gulf of Maine	0-300	34.8	109		

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1220 **Table 2: Concentration (in nmol L<sup>-1</sup>) of trace elements (PFe, PAI, PMn and PP) in suspended particles collected in**  
 1221 **diverse regions of the world's ocean. Bdl: below detection limit, ND: non-determined.**

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