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1 **Volcanic record of continental thinning in Baffin Bay**  
2 **margins: insights from Svartenhuk Halvø Peninsula basalts,**  
3 **West Greenland**

4

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17

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25

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27

28 **Abstract**

29

30 We report major, trace elements and Pb, Hf, Nd and Sr isotopes in 61-54 Ma old basalts  
31 from Svartenhuk Halvø Peninsula (Greenland). This area corresponds to the  
32 northernmost exposure of the West Greenland volcanic province, of which the  
33 emplacement marks the continental thinning and breakup process leading to the opening

34 of Baffin Bay during the Eocene. Its wedge structure displays typical characteristics of  
35 inner seaward-dipping-reflectors (SDR) with an exposed volcanic sequence thicker than  
36 7 km. Our results cover the entire volcanic sequence starting with an earliest V1 unit  
37 reflecting rather low degree partial melts (transitional basalts), which are geochemically  
38 imprinted by continental crust contamination. This unit is followed by much thicker and  
39 mainly tholeiitic V2 and V3 basaltic lava piles, and ends with a rather thin V4 unit,  
40 consisting of alkali basalts and associated trachytes. Pressures and temperatures of melt  
41 extraction were estimated based on major element concentrations and rare earth  
42 elements patterns. Our results suggest that melts were extracted from the garnet-spinel  
43 transition zone at greater depths for the initial V1 and the final V4 lavas (alkali to  
44 transitional basaltic compositions) than for the main V2 and V3 mostly tholeiitic lava  
45 piles (at  $2 \pm 0.5$  GPa and  $1350 \pm 100^\circ\text{C}$ ). Isotope signatures suggest that mantle sources  
46 of the melts were controlled by the mixing of ambient upper mantle and Icelandic  
47 plume-type materials. The proportion of ambient upper mantle involved in the lava  
48 source appears to increase together with melting rates and the upward propagation of  
49 melting zone during V3 emplacement, suggesting that melting in this area progressed as  
50 follows: 1. Initiation of partial melting (low degrees) of deep-seated Icelandic plume-  
51 type material (V1 and V2); 2. Upward propagation of the melting area within the  
52 shallower mixed upper mantle (V3); 3. Progressive decrease of “ambient upper mantle”  
53 involvement, deepening of magma extraction and decrease of partial melting associated  
54 with the emplacement of V4 lavas. We show that these changes are consistent with the  
55 tectonic stages of continental thinning that preceded the Eocene breakup in Baffin Bay.

56

## 57 **1. Introduction**

58 Volcanic passive margins (VPM) characterize continental breakup associated with  
59 the emplacement of large igneous provinces (White and McKenzie, 1989; Coffin and  
60 Eldholm, 1994). In detail, initial mantle melting is thought to start prior to significant  
61 lithosphere extension (Courtilot et al., 1999), leading to the eruption of voluminous  
62 flood basalts. Then, focusing of mantle melting combined with lithosphere extension  
63 and consecutive syn-magmatic break-up leads to the formation of volcanic passive  
64 margins (Geoffroy et al., 2015). The corresponding volcanic sequences, although  
65 emplaced subaerially, are usually found as immersed seaward-dipping reflectors (SDR)  
66 sequences beneath post-rift sediments, a common occurrence throughout the North  
67 Atlantic Igneous Province (NAIP; Saunders et al., 1997). Such sequences, linked to the

68 opening of the Baffin Bay oceanic basin, are exceptionally well-exposed along the West  
69 Greenland coast, where they are of Paleocene-Eocene age and up to 5-7 km thick  
70 (Larsen and Pulvertaft, 2000; Larsen and Pedersen, 2009; Larsen et al., 2015; Chauvet  
71 et al., accepted). Petrologic and geochemical studies of these volcanic successions as  
72 well as those of similar sequences exposed in the East Greenland margin raise several  
73 important (and still debated) petrogenetic and tectono-magmatic questions, e.g. (1) do  
74 the considerable volumes of erupted picrites indicate abnormally high temperatures of  
75 partial melting of plume-related materials (Francis, 1985; Larsen and Pedersen, 2000,  
76 2009; Hole and Millett, 2016); (2) does the heterogeneity of the mantle sources of  
77 Paleocene-Eocene mafic magmas foreshadow that of the present-day Icelandic hotspot  
78 (Holm et al., 1993; Peate and Stecher, 2003; Barker et al., 2006); and finally (3) does  
79 the temporal evolution of melting rates and depths record the successive stages of  
80 continental extension and rupture in the East (Larsen and Saunders, 1998; Abdelmalak  
81 et al., 2012, 2018) and West Greenland (Tegner et al., 1998; Barker et al., 2006)  
82 margins as well as in other parts of the NAIP (Kerr, 1994; Geoffroy, 2005; Meyer et al.,  
83 2007; Saunders et al., 2007)?

84 Svartenhuk Halvø Peninsula represents the northernmost exposure of the West  
85 Greenland Volcanic Province. The Svartenhuk wedge typically displays the structural  
86 and stratigraphic characteristics of inner-SDR wedges observed on deep seismic  
87 reflection profiles from VPM worldwide (e.g. Planke et al. 2000; Stica et al., 2014;  
88 Geoffroy et al., 2015). The thickness of the exposed volcanic sequence may reach up to  
89 7 km and at least one third of it is made of picrites (Larsen and Pulvertaft, 2000). The  
90 aims of the present study are (1) to analyze magmatic processes such as mantle source  
91 heterogeneity, depths and rates of partial melting, and crustal contamination that  
92 occurred during the c. 10 m.y. of its emplacement (i.e. from 62.5-61 Ma to 54-53 Ma;  
93 Larsen et al., 2015; Chauvet et al., accepted), and (2) to discuss their temporal evolution  
94 during the successive stages of the continental stretching and thinning margin system  
95 related to the opening of the Baffin Bay oceanic basin.

96  
97

## 98 **2. Geological setting**

99

### 100 *2.1. The Labrador-Baffin oceanic domain and West Greenland Volcanic Province*

101 The Labrador-Baffin axis is part of a wider Phanerozoic divergent system  
102 including the NE-Atlantic area between Eurasia and Greenland (Fig. 1). A continental  
103 and diachronous rift system developed between Greenland and Canada during the  
104 Cretaceous. This a-magmatic extension led to continental breakup with mantle  
105 exhumation in the southern Labrador Sea. A now extinct oceanic spreading axis in the  
106 Labrador Sea led to the drifting apart of Greenland from North America since the Late  
107 Cretaceous (Roest and Srivastava, 1989) or Paleocene (Chalmers and Laursen, 1995)  
108 and ceased to operate during the Oligocene (~ magnetochron C13, Roest and Srivastava,  
109 1989). The SW-NE-trending left-lateral Ungava transform-fault system (UFS)  
110 connected the Labrador Sea to Baffin Bay farther North (Fig. 1).

111 In the northern Labrador Sea, the oldest undisputed oceanic magnetic anomaly has  
112 a mid-Paleocene age (Chalmers and Laursen, 1995), i.e. C27n (62.2 – 62.5 Ma,  
113 according to Ogg, 2012). During the Paleocene, the spreading directions were oriented  
114 ~N060E, i.e. sub-orthogonal to earlier rifted structures on the conjugate margins. Both  
115 the oceanic fracture zones and magnetic anomalies in the Labrador Sea indicate that a  
116 major shift in kinematics occurred during the Early Eocene, between C25 and C24,  
117 when spreading directions rotated from N060E to N010E (Roest and Srivastava, 1989;  
118 Geoffroy et al., 2001; Fig. 1).

119 In Baffin Bay, the age of the earliest accretion is still debated since no obvious  
120 linear magnetic anomalies can be identified on its floor, although there is a consensus  
121 for the cessation of spreading during the Oligocene (Roest and Srivastava, 1989; Oakey  
122 and Chalmers, 2012). Two major N-S-trending fracture zones in the central part of the  
123 Baffin Bay (Fig. 1) suggest that oceanic spreading may have been coeval with the ~N-S  
124 reorientation of the kinematic trend in the Labrador Sea during Eocene (Chalmers and  
125 Pulvertaft, 2001; Geoffroy et al., 2001; Suckro et al., 2012; Funck et al., 2012). Other  
126 authors (Oakey and Chalmers, 2012; Suckro et al., 2012; Hosseinpour et al., 2013)  
127 consider that earlier oceanic-type crust of mid-Paleocene age could exist within Baffin  
128 Bay. However, none of these studies took into account the age of continental stretching  
129 and thinning recorded along the Baffin Bay continental passive margins.

130 The conjugate passive margins in Baffin Bay (Fig. 1) are clearly of volcanic type  
131 in the South of the basin (Geoffroy et al., 2001; Skaarup et al., 2006; Block et al., 2012).  
132 The inner part of the SE-Baffin volcanic passive margin (VPM) is largely exposed from  
133 latitudes 69°N to 72°N in the Disko-Svartenhuk area (Fig. 1). An inner-SDR (Planke et  
134 al., 2000) developed orthogonally to the regional stretching direction during the

135 Paleogene (Geoffroy et al., 2001; Abdelmalak et al., 2012) and is fully exposed at  
136 Svartenhuk where its total thickness reaches up to 7 km. Recently published Ar-Ar ages  
137 (Larsen et al., 2015; Chauvet et al., accepted) that range from 62.5-61 Ma to 54-53 Ma  
138 for Svartenhuk basalts provide new constraints for the tectono-magmatic evolution of  
139 the Baffin Bay margin system.

140

## 141 2.2. *The Svartenhuk Halvø Peninsula*

142 The tectonics of the Svartenhuk SDR has already been investigated (Larsen and  
143 Pulvertaft, 2000; Geoffroy et al., 2001; Abdelmalak et al., 2012). Until recently, the age  
144 of the regional strain remained a matter of debate due to the lack of age determinations  
145 on lavas in this area (see discussion in Larsen and Pulvertaft, 2000). However, new sets  
146 of  $^{40}\text{Ar}/^{39}\text{Ar}$  ages recently published by Larsen et al. (2015) and Chauvet et al.  
147 (accepted) provide new constraints on the timing of melting processes at the scale of the  
148 NAIP. In Svartenhuk Peninsula, the thickness of the exposed volcanic sequence may  
149 reach up to 7 km (Larsen and Pulvertaft, 2000). Its dense fault network results from a  
150 seaward-migrating strain (Geoffroy et al., 2001). The Arfertuarssuk Fault represents the  
151 exposed master fault bounding and controlling the development of the Svartenhuk  
152 wedge (Fig. 2).

153 In the present study and in the companion paper by Chauvet et al. (accepted)  
154 dealing with the same sample set, the volcanic formations making up the SDR wedge in  
155 Svartenhuk Halvø have been subdivided into four successive sequences (labeled V1 to  
156 V4 upwards; Fig. 2) (Fig. 2). The boundaries between these sequences are consistent  
157 with the geological and petrographic distinctions of Larsen (1983) and Larsen and  
158 Grocott (1992).

159 Coeval volcanics crop out on Disko Island, Nuussuaq Peninsula and Ubekendt  
160 Ejland Island, where they form a plurikilometric pile of ultramafic to mafic Paleogene  
161 lavas crosscut by sheeted intrusions (e.g. Pedersen et al., 2002). The stratigraphy and  
162 age of the W-Greenland basalts were defined in these areas as follows (Storey et al.,  
163 1998 and references therein). The Vaigat Fm. consists of a lower sequence dominated  
164 by hyaloclastites and pillow lavas overlain by picrites and Mg-rich subaerial basalts.  
165 The earliest subaqueous volcanics unconformably overlie the remnants of an Early  
166 Cretaceous to Paleogene paleobasin (Fig. 2). The overlying Maligât Fm. is dominated  
167 by feldspar-phyric and aphyric basalts associated with a sharp change in lava chemistry  
168 (Larsen and Pedersen, 2009). Larsen and Pulvertaft (2000) suggested that the lava

169 stratigraphy established in the Disko-Nuussuaq area could be applied to the Svartenhuk  
170 area. As such, the V1 and V2 formations correlate with the southern Vaigat Formation,  
171 while the “Svartenhuk Fm.” (V3 in Fig. 2) would be equivalent to the Maligât Fm. (Fig.  
172 3). In Svartenhuk Halvø, a 1-2 km thick succession of transitional to alkaline basalts  
173 (V4 unit) lies above the V3 unit. A stratiform sill-like trachytic body marks the  
174 boundary between the V3 and V4 units. Larsen and Grocott (1992) considered these  
175 basalts and trachyte as the uppermost part of the Svartenhuk Fm. According to Larsen et  
176 al. (2015), this succession belongs to a newly introduced Naqerloq Fm. (Fig. 2),  
177 dominated by transitional light rare Earth element (LREE) enriched basalts.

178 From observations on the Disko and Nuussuaq areas, two main volcanic pulses  
179 have been identified and further correlated by radiometric dating and paleomagnetic  
180 data (Storey et al., 1998; Riisager and Abrahamsen, 1999; Riisager et al., 2003). The  
181 earliest pulse was mid-Paleocene in age and spans chrons 27n and 26r (62.5-59.2 Ma  
182 after Ogg, 2012). The second pulse occurred during the early Eocene at C24r (54-  
183 57 Ma), i.e., after a hiatus of 2 m.y. or more. An Early Eocene age was obtained from  
184 the basaltic succession of the Kanísut Mb. (Storey et al., 1998), that crops out  
185 exclusively West of the Itilli fault, and which is seaward tilted at about 15° (Fig. 2,  
186 Riisager et al., 2003). These basalts lie unconformably above the Vaigat-Maligat  
187 basalts, which are in turn deeply down-faulted westward (Larsen et al., 2015). It is  
188 noteworthy that early Eocene ages were also obtained for dykes crosscutting the  
189 Paleocene-related series in Disko and Nuussuaq (Storey et al., 1998) and also in the  
190 Svartenhuk Peninsula (Geoffroy et al., 2001). Larsen et al. (2015) proposed that the  
191 Paleocene magmatic pulse in West Greenland spans not only C27n-C26r but also up to  
192 chron C25r (59-57.7 Ma), based on four  $^{40}\text{Ar}/^{39}\text{Ar}$  ages ranging from  $60.3 \pm 1.4$  Ma to  
193  $58.0 \pm 0.6$  Ma on Svartenhuk Fm. basalts from the northern part of the Svartenhuk  
194 peninsula. This implies that the Svartenhuk Fm. was mostly contemporaneous with the  
195 Maligât Fm. but that its upper part was younger. These authors also outlined that the  
196 transitional to alkaline basaltic successions exposed along the Arfertuarssuk Fault in  
197 Svartenhuk Halvø (V4 unit) and on the western parts of the Ubekendt Ejland, Nuussuaq  
198 peninsula and Hareøen are all early Eocene in age (Naqerloq and Erqa Fms). Chauvet et  
199 al. (accepted) point out that both in W-Nuussuaq and Svartenhuk the Eocene lavas are  
200 part of the syn-extension inner SDR, i.e. that continental crust thinning and stretching  
201 still occurred during the Eocene (fig. 2).

202

203 2.3. *Svartenhuk volcanic facies*

204 We investigated and sampled 45 sites mostly located along the coastal cross-  
205 section of the Svartenhuk volcanic margin (Fig. 1). Hyaloclastic sub-aquatic breccias  
206 and associated pillowed lavas formed in a lacustrine environment (Escher and  
207 Pulvertaft, 1995) are characteristic of the lower member of the Vaigat Fm (V1 unit,  
208 sampling sites 40 and 38). They are up to 200 m thick and dip 20-30° westwards. These  
209 dips are mostly of tectonic origin but may also be due to dipping prograding foresets  
210 (Jerram, 2002), which have been identified for instance in the Naajaat syn-volcanic  
211 lake, Nuussuaq Basin (Pedersen et al., 1998). Svartenhuk hyaloclastic breccias consist  
212 of basaltic glassy clasts and pillow fragments, usually of centimeter- to decimeter-size,  
213 set in a matrix of yellowish glass particles altered to clays and palagonite. Locally,  
214 preserved pillow piles form cliffs up to 10-15 m high which delineate small high points  
215 on the shoreline. Individual basaltic pillows, 10 cm to 1 m large, display typical glassy  
216 margins and radial fractures together with flow features consistent with their  
217 emplacement over moderate slopes. Attempts to recover geochemically fresh glassy  
218 basaltic rims were unsuccessful, but the cores of large pillows proved to be rather well  
219 preserved from post-magmatic alteration.

220 Lava flows from V2, V3 and V4 units were exclusively emplaced in subaerial  
221 environments as suggested by lack of pillow lavas and hyaloclastites and common  
222 occurrence of pahoehoe surface features. Their most common facies, especially in V3  
223 and V4 units, is that of individual tabular flows, 1 to 10 m thick. They generally show a  
224 basal scoriaceous autoclastic breccia, which overlies a reddish thermal metamorphic  
225 sole. These breccias are, in turn, overlain by a massive basaltic part often displaying  
226 rough columnar-jointing patterns, and less frequently sheet flow patterns. The rather  
227 common occurrence, in these massive levels, of subvertical vesicle pipes, sometimes  
228 feeding horizontal vesicle sheets (Caroff et al., 2000), suggests that the Svartenhuk  
229 Peninsula basaltic magmas were water-rich at the time of their emplacement. Tuff  
230 horizons usually less than 50 cm thick are occasionally interbedded between these  
231 tabular flows, and probably correspond to subaerial ash and/or lapilli fall deposits.  
232 Intercalated reworked (volcanic-sedimentary) deposits are much less common than in  
233 Disko and Nuussuaq (Larsen and Pedersen, 2000). They correspond to basaltic pebble  
234 conglomerates of probable laharic origin, filling local topographic channels. Their  
235 maximal thickness is less than 10 m (sites 44 and 45), and they are sometimes overlain  
236 by layered clay horizons less than 1 m thick.



237 Vaigat Fm picrites (V2 unit) and less commonly Vaigat and Svartenhuk Fms  
238 tholeiitic basalts (V2 and V3) display a more specific emplacement facies, i.e. a  
239 compound-braided flow facies (Jerram, 2002). The corresponding lava piles, up to 30 m  
240 thick (site 39), have a typical grayish color also characteristic of Disko and Nuussuaq  
241 picrites, (Larsen and Pedersen (2009), and are usually deeply altered and converted into  
242 assemblages of post-magmatic minerals (mostly zeolites and carbonates). They consist  
243 of thin (usually less than 50 cm thick) anastomosed individual layers emplaced as sheets  
244 and lobes of pahoehoe lava breakouts. These individual lobes are elongated (up to  
245 several meters) and usually hollow; all the transitions are observed between meter-size  
246 lobes and typical lava tubes. Well preserved small pahoehoe ropy lava “tongues” often  
247 occur within the central cavity of these lobes or tubes, and provide good markers of  
248 flow emplacement patterns. In V2 and V3 units they point usually upwards due to the  
249 tectonic tilting of these sequences. Massive (and geochemically better preserved)  
250 porphyritic layers 50 cm to 2-3 m thick are common within the lobe/tube piles. They  
251 display intrusive relationships with respect to them (locally chilled margins) and are  
252 thought to result from inflation processes within the pahoehoe compound flow  
253 sequences (Jerram, 2002; Self et al., 1997). In the studied picritic lava sequences, both  
254 pahoehoe lobes/tubes and intrusive (inflation-related) sheets commonly contain large  
255 vesicles and vesicle pipes typical of water-rich magma emplacement features (Caroff et  
256 al., 2000). These facies are often ascribed to relatively low volume, low viscosity  
257 eruptions occurring during early stages of emplacement of continental flood basalts  
258 (Jerram, 2002).

259 Most dykes range in width from 10-20 cm to 2-3 m, and display characteristic  
260 jointing patterns perpendicular to their chilled margins (which are glassy to microlitic)  
261 and have coarser-grained, often porphyritic, vesicle-rich central parts. These dykes tend  
262 to form swarms associated with fracture zones, and composite (multiple) dykes are  
263 common. Sills are usually easily distinguished from lava flows by their larger and more  
264 regular columnar jointing patterns. The thickest ones (> 10 m) display evidence for  
265 gravitational settling of olivine phenocrysts, which accumulate above their lower chilled  
266 margin.

267

### 268 **3. Sampling and analytical methods**

269

#### 270 *3.1. Sampling strategy*

271           Sampling was conducted in 45 sites mostly located along the coastal cross-section  
272 of the volcanic margin (Table 1 and Fig. 2), from the basal lacustrine hyaloclastites and  
273 pillow basalts of the Vaigat Fm (labelled V1 in the geochemical discussion below; sites  
274 40 and 38) towards successively: the subaerial picritic and basaltic flows of the main  
275 Vaigat Fm (labelled V2; sites 37, 39, 41, 42, 20, 43, 45, 44, 5, 3, 6, 7, 1, 27, 25, 28);  
276 then those of the overlying Svartenhuk Fm (labelled V3; sites 4, 2, 36, 35, 8, 31, 32, 11,  
277 10, 34, 12, 9, 33); and finally the trachytic intrusion (site 29) and the subaerial alkali  
278 basaltic lava flows from the top of the Svartenhuk Fm, recently attributed to the  
279 Naqerloq Fm by Larsen et al. (2015) (site 30, labelled V4 below). Additional samplings  
280 were done for V2 (sites 19, 22, 23, 16, 14, 15, 13), V3 (site 26) and V4 (site 21). Major,  
281 trace element and isotopic measurements were only carried out on samples from lava  
282 flows, dykes and sills which were relatively fresh based on their macroscopic and  
283 microscopic features, and from which zeolite- and carbonate-bearing vesicles were  
284 removed by handpicking. The corresponding analytical database includes 5 samples  
285 from V1, 53 from V2, 28 from V3 and 5 from V4 lava flows, together with 47 intrusive  
286 (sills, dikes) samples (Tables 1, 2, 3 and 4). Most of the pillow fragments collected from  
287 V1 are altered (Loss on Ignition higher than 1.9 wt%), and a number of compound-  
288 braided basaltic flows (pahoehoe lobes and lava tube piles, see below), especially from  
289 V2, are too rich in secondary minerals (zeolites and carbonates) to have retained their  
290 primary magmatic features. Such samples were primarily collected to investigate these  
291 post-magmatic mineral associations found as vesicle fillings and vein/fracture deposits  
292 (57 samples from V2 and V3).

293

### 294 *3.2. Analytical methods*

295           All samples were subsequently crushed in stainless steel and agate mortars. Major  
296 element concentrations were obtained using an ICP-AES Jobin Yvon Ultima 2 at the  
297 University of Brest, after a HF-HNO<sub>3</sub> digestion, boric acid neutralization and dilution in  
298 nitric acid, as described in Cotten et al. (1995). Trace element concentrations were  
299 measured with a Thermo® Element2 HR-ICP-MS in Brest. 15 mg of samples were  
300 repeatedly (twice) dissolved at 120°C in 2 mL Teflon Savilex® beakers using in 1mL  
301 HF + 0.5 mL HClO<sub>4</sub>. After total evaporation, samples were diluted 10000 times using  
302 0.5N HNO<sub>3</sub> and analyzed using both medium and low resolution on the Thermo®  
303 Element2 as discribed by Mougél et al. (2014). All samples were externally calibrated  
304 using international standards BCR2, BHVO2 and BIR-1 (Li and Lee, 2006). These

305 standards demonstrated external reproducibilities better than 5–10% depending on the  
306 element and concentration as documented in Supplementary Table 1. Pb, Hf, Sr and Nd  
307 isotope compositions were obtained on single fractions (0.5-1 g of samples) leached for  
308 one hour at 100°C in 6mL of 6N HCl, and subsequently dissolved in 3mL HF + 1mL  
309 HNO<sub>3</sub> following the protocol described by Mougél et al. (2014). Hf, Nd and Pb were  
310 purified following the protocol of Blichert-Toft et al. (2005) (fluoride centrifugation,  
311 and column chromatography). Sr was separated from the Nd fraction using Eichrom Sr-  
312 specific resin following the protocol by Moynier et al. (2010), adapted from Fietzke and  
313 Eisenhauer (2006). Pb, Hf and Nd isotopes were analysed using a Thermo® Neptune  
314 MC-ICP-MS at Ifremer-Brest. Sr isotopes were obtained using a Thermo Triton TIMS  
315 at the University of Brest. 2σ internal errors for Hf and Nd are reported in Table 4 and  
316 never exceed the last significant digit (1E-5) in each analysis. External reproducibility  
317 of Pb isotopes is estimated based on the repeated measurements since 2008 of a mixed  
318 standard solution and never exceeded 60 ppm for <sup>206</sup>Pb/<sup>204</sup>Pb, 150 ppm for <sup>207</sup>Pb/<sup>204</sup>Pb  
319 and 300 ppm for <sup>208</sup>Pb/<sup>204</sup>Pb. Measured values were compared with repeatedly analyzed  
320 international standards NBS981 (Todt et al., 1996), JMC475 (Blichert-Toft et al., 1997)  
321 and La Jolla48 (Tanaka et al., 2000) shown in Supplementary Table 2. Duplicated Sr,  
322 Nd, Hf, Pb isotope analyses of one of our samples (S39E1) are shown in Supplementary  
323 Table 3.

324

#### 325 **4. Petrographic and geochemical results**

326

##### 327 *4.1. Petrographic features and lava classification*

328 Lava samples were classified according to their position in the Total Alkali-Silica  
329 plot (TAS; Le Bas et al., 1986; Fig 3a). With the exception of a trachytic intrusion from  
330 V4 (site 29), all of them plot within or near the fields of microbasalts and basalts (SiO<sub>2</sub>=  
331 43-53 wt%, K<sub>2</sub>O+Na<sub>2</sub>O=0.1-5 wt%). A large majority of them are silica-saturated or -  
332 oversaturated, and plot below the alkaline-subalkaline boundary of Macdonald and  
333 Katsura (1964). Therefore, these samples, which include all the massive or pillowed  
334 flows of units V1, V2 and V3, the sills and about half the population of dykes can be  
335 termed as tholeiitic or transitional picrites and basalts. Alkali basalts plotting above this  
336 boundary include the V4 basaltic flows (site 30) and the other half of the analyzed  
337 dykes. Some V3 basalts plot near or slightly above Macdonald and Katsura's (1964)

338 boundary (Fig. 3a) and can be considered as transitional, as well as V1 basalts which  
339 plot definitively below this limit but display strong enrichments in highly incompatible  
340 elements (see below).

341 Pillowed tholeiitic basalts from V1 unit display groundmass textures ranging from  
342 glassy (devitrified) rims to microlitic cores. They are subaphyric, with 4-8 modal%  
343 phenocrysts and microphenocrysts of olivine (mostly altered to smectite and chlorite)  
344 and fresh plagioclase ranging in size from 0.1 to 0.5 mm. Their groundmass is variably  
345 altered into clays and palagonite-type mineral aggregates. Zeolites and carbonates are  
346 found as vesicle- and vein-filling materials.

347 Picrites and picritic basalts (microbasalts in Fig. 3a) are much more common in  
348 subaerial Vaigat Fm flows (V2) than in the overlying main unit of Svartenhuk Fm (V3).  
349 They are highly porphyritic, with up to 60 modal% centimeter- to millimeter-size  
350 olivine phenocrysts, containing occasional magnesiochromite inclusions, and  
351 subordinate (and smaller) plagioclase phenocrysts and microphenocrysts. The  
352 percentage of olivine phenocrysts and their size tend to decrease together with  
353 decreasing MgO contents of bulk rocks, while the relative abundance of plagioclase  
354 increases. Clinopyroxene microphenocrysts are uncommon in picrites, and this mineral  
355 follows plagioclase in the crystallization sequence of V2 and V3 lavas. The picritic  
356 basalts from these two units are rather similar in thin section. Their groundmass is  
357 usually intergranular or microlitic. Neither native iron, nor graphite has been identified  
358 in the studied picrites. This suggests a weaker contamination in these samples  
359 (originally selected for their primitive features) than that described for some more acidic  
360 samples from Disko and Nuussuaq (Larsen and Pedersen, 2009).

361 Tholeiitic basalts from V2 and V3 are the most common petrographic type  
362 encountered in the studied sequences. Their phenocryst contents are highly variable and  
363 decrease together with MgO contents of bulk rocks, from 25-20 modal% (porphyritic  
364 basalts) to less than 5 modal% (subaphyric basalts). Olivine is followed by calcic  
365 plagioclase, and then sometimes by minor amounts of augitic clinopyroxene in their  
366 crystallization sequence. Plagioclase phenocrysts dominate over olivine in the most  
367 evolved (silica-rich) samples, which are especially common in the Svartenhuk Fm main  
368 unit (V3). Clinopyroxene phenocrysts mostly occur in this V3 unit, and are uncommon  
369 in V2 basalts. The groundmass of tholeiitic basalts usually display microlitic to  
370 intergranular textures. Subdoleritic textures occur in sills and in the cores of thick flows  
371 and dykes.

372 Post-magmatic mineral associations are commonly found in V2 and V3 tholeiitic  
373 picrites and basalts. They occur as vesicle- and vein-fillings, and include a variety of  
374 zeolites, carbonates (calcite, Mg-calcite, aragonite, dolomite), and clays (smectites,  
375 chlorites).

376 Alkali basalts from Naqerloq Fm. (V4) and from a number of dykes display  
377 microlitic to intergranular groundmass textures. They contain about 10 to 15 modal%  
378 phenocrysts, which are, by order of decreasing abundance, calcic plagioclase (up to 0.5  
379 cm large), diopsidic clinopyroxene and magnesian olivine. They contain significantly  
380 smaller amounts of post-magmatic minerals than V1, V2 and V3 lavas.

381 The fresh alkali trachyte collected at site 29 (V4 unit) is highly porphyritic, with  
382 ~40 modal% centimeter-size sanidine phenocrysts, and lesser amounts of smaller  
383 titanomagnetite, olivine and green clinopyroxene phenocrysts. Its groundmass, almost  
384 exclusively made of alkali feldspar laths, displays a fluidal texture.

385

#### 386 *4.2. Major element trends*

387 The Loss on Ignition (LOI) values (Table 2) range from 0.58 wt% to 10 wt%,  
388 with an average of 2.8 wt%. These rather high values are accounted for by the common  
389 occurrence of post-magmatic water-rich minerals (zeolites and clays) and of carbonates  
390 in the studied lavas. The variations of SiO<sub>2</sub> and MgO in the studied basaltic flows (V1  
391 to V4) are plotted against their Ni, CaO and alkali element contents. The higher MgO  
392 contents of V2 lavas (Table 2) evidence the dominance of picrites (MgO > 12 wt%) and  
393 Mg-rich basalts in the Vaigat subaerial flows. An upward increase of TiO<sub>2</sub> is also  
394 observed in the stratigraphic pile: contents higher than 2 wt%, usually considered  
395 typical of High-Ti basalts from Large Igneous Provinces (Pik et al., 1998; Shellnutt and  
396 Jahn, 2011), are only observed in some V3 evolved tholeiitic and transitional basalts  
397 and in V4 alkali basalts (Table 2). Conversely, all V1 and V2 basalts and a majority of  
398 V3 tholeiites are typical Low-Ti basalts (TiO<sub>2</sub> < 2 wt%, Table 2). Similar features have  
399 been reported by (Larsen and Pedersen, 2009) for the Disko and Nuussuaq areas, where  
400 the lower Vaigat Fm is exclusively made of Low-Ti basalts while High-Ti lavas occur  
401 within the overlying Maligât Fm (lateral equivalent of Svartenhuk Fm according to  
402 Escher and Pulvertaft (1995).

403 Major element variations in the studied sequence are dominated (and largely  
404 overprinted) by processes linked to accumulation or removal/fractionation of olivine  
405 phenocrysts. Indeed, as shown in Figure 3B, addition or removal of magnesian olivine

406 are consistent with the covariation of CaO and MgO: olivine-rich picritic basalts are  
407 CaO-poor while evolved basalts are CaO-rich. These variations are partly accounted for  
408 by local gravitational settling effects involving olivine phenocrysts in thick lava flows  
409 or sills. However, such shallow processes during and after emplacement are unlikely to  
410 occur in thin pahoehoe units and meter-thick tabular flows which make up most of the  
411 Vaigat and Svartenhuk Fms sequences. Therefore, fractional crystallization involving  
412 olivine separation/accumulation must have occurred at depth, possibly within thick sills  
413 or genuine underlying magma chambers. In addition, the least Mg-rich basalts, mostly  
414 sampled from dykes, display a co-linear decrease of CaO and MgO (Fig. 3B), that is  
415 consistent with concomitant removal/ fractionation of olivine plus augite and/or calcic  
416 plagioclase. Such variations might result from differential motions of crystal-rich and  
417 crystal-poor liquids during dyke emplacement (“Bagnold effect”, e.g. Komar, 1972),  
418 and thus cannot be taken as evidence for deep-seated fractional crystallization involving  
419 olivine, augite and plagioclase.

420

#### 421 *4.3. Trace element variations*

422 Compatible trace elements Ni, Co and Cr, which are hosted by olivine and  
423 magnesiochromite, display positive correlations with MgO contents (Fig. 3B). Their  
424 contents decrease from picrites to evolved basalts, and their behaviors are mainly  
425 controlled by olivine removal/accumulation processes.

426 Incompatible element concentrations vary in a more complex fashion, as  
427 illustrated by Rare Earth Element (REE) plots normalized to CI chondrite (Fig. 4). V1  
428 transitional basalts display the most fractionated REE patterns and the highest contents  
429 in Light REE (LREE; e.g. La, Ce), up to 80 times the primitive mantle (PM). V4 alkali  
430 basalts also display fractionated REE patterns, although their LREE enrichment remains  
431 lower than that of V1 lavas. V2 and V3 REE patterns are fan-shaped, and display  
432 variable enrichments in LREE, those of picritic samples being the lowest. The REE  
433 patterns of dykes are also fan-shaped, and they encompass the variability found within  
434 lava flows (Fig. 4). Alkali basaltic dykes show fractionated patterns and LREE  
435 enrichments similar to those observed for V4 alkali basaltic flows. A second family of  
436 dykes (and the analyzed sills) has rather flat patterns which resemble those of picrites;  
437 and a third dyke family shows moderately LREE enriched patterns similar to those of  
438 V2 and V3 evolved tholeiitic basalts. Large Ion Lithophile Elements (LILE: Cs, Rb, Ba,  
439 Sr) display somewhat erratic behaviors, with highly variable enrichments or depletions

440 generating positive or negative spikes in incompatible multi-element patterns  
441 normalized to the primitive mantle (Figure 4B). Given the high solubility of these  
442 elements into water, such variations can be considered as post-magmatic and attributed  
443 to alteration by surface waters and/or percolation of hydrothermal fluids through the  
444 studied lava piles. The elements less affected by post-magmatic processes (ie rare earth  
445 elements, high field strength elements...) define patterns similar to that of typical OIB  
446 (Fig. 5).

447 Highly incompatible elements (e.g. Th and La) versus MgO (not shown) in V2  
448 and V3 lavas define a rough negative correlation (not shown) consistent with the  
449 “dilution” of incompatible elements in bulk rocks as a result of accumulation of  
450 incompatible element-poor olivine phenocrysts in picritic and Mg-rich lavas. Compared  
451 to V2 and V3, V4 alkali basalts and alkaline dykes display higher Th and La contents  
452 (Fig. 4) consistent with their more fractionated REE and multi-element patterns, as well  
453 as higher Nb/La ratios (Fig. 5). These features might indicate either lower degrees of  
454 partial melting, or a more incompatible element enriched source (with respect to V2 and  
455 V3 ones), or a combination of both. Finally, despite their transitional character, some  
456 V1 pillowed lavas (together with a few dykes) show the highest La, Th and Pb contents  
457 found in the studied lava sequence (Figs. 4 and 5), and consistent with their highly  
458 fractionated REE and multi-element patterns. Once again, these features could be  
459 attributed to a more enriched source, lower degrees of melting, or both.

460

#### 461 *4.4. Sr, Nd, Pb and Hf isotopes*

462 Lead isotopes define two distinct trends (Figs. 6 and 7).  $^{208}\text{Pb}/^{204}\text{Pb}$  range from  
463 36.7 to 39,  $^{207}\text{Pb}/^{204}\text{Pb}$  from 15 to 15.5 and  $^{206}\text{Pb}/^{204}\text{Pb}$  from 16.13 to 19.26. A principal  
464 component analysis calculated on these Pb isotopes reveals the existence of only two  
465 significant principal components (the first one accounting for 94.2% of the total  
466 variability, principal component 2 for about 5.3%, and principal component 3 is  
467 insignificant). This result indicates that a mixture of three end-members is sufficient to  
468 explain the isotope variability in this area (Blichert-Toft et al., 2005). Hafnium isotopes  
469 are scattered as well, and feature both radiogenic and unradiogenic signatures  
470 ( $^{176}\text{Hf}/^{177}\text{Hf}$  from 0.28247 to 0.2832;  $\epsilon_{\text{Hf}} = -10.81$  to  $+15.95$ ). They also define a three  
471 end-members-pattern corresponding to two distinct mixing trends (Fig. 6). Nd isotopes  
472 correlate with Hf data ranging from  $^{143}\text{Nd}/^{144}\text{Nd} = 0.51222$  ( $\epsilon_{\text{Nd}} = -8.15$ ) to

473  $^{143}\text{Nd}/^{144}\text{Nd}=0.51309$  ( $\epsilon_{\text{Nd}}=8.9$ ). Even if most of the samples have “mantle-like” Sr  
474 isotopic compositions ( $^{87}\text{Sr}/^{86}\text{Sr} < 0.704$ ), 16 of them display significantly more  
475 radiogenic Sr signatures (up to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.708$ ). Ten out of those 16 samples also have  
476 unradiogenic Pb ( $^{206}\text{Pb}/^{204}\text{Pb} < 17$ ), and trace element patterns (low Nb, Ta and high Pb  
477 contents, Fig. 5) typical of continental crust contamination (Rudnick and Fountain,  
478 1995; Rudnick and Gao, 2003). These samples include all of those collected from the  
479 basal unit V1.

480 The two mixing trends identified in Sr, Pb and Hf isotope spaces, are also visible  
481 on diagrams using isotopic and REE ratios (e.g.,  $^{206}\text{Pb}/^{204}\text{Pb}$ , La/Sm, Sm/Yb and La/Yb,  
482 Fig. 8). They are also related to the stratigraphic position of the samples, i.e. their height  
483 within the lava pile. Indeed, all the samples from basal units V1 and V2 lie within the  
484 same trend (Figs. 6 and 7) connecting a component “Sk1” (with low  $^{207}\text{Pb}/^{204}\text{Pb}$  and  
485 “intermediate”  $^{208}\text{Pb}/^{204}\text{Pb}$ ) to a moderately high  $^{208}\text{Pb}/^{204}\text{Pb}$  and  $^{206}\text{Pb}/^{204}\text{Pb}$  component  
486 “Sk2”. Complementarily, all samples from units V3 and V4, together with those from  
487 sills and dykes, plot along a trend connecting “Sk2” to a component “Sk3” (with high  
488  $^{208}\text{Pb}/^{204}\text{Pb}$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{206}\text{Pb}/^{204}\text{Pb}$ ).

489

## 490 **5. Discussion**

491

### 492 *5.1. Trace element and isotopic evidence for a minor role of crustal contamination*

493 The highly incompatible elements Nb and Ta display positive or negative peaks in  
494 multi-element patterns (Fig. 4B) which are unlikely of post-magmatic origin  
495 considering the insoluble character of these High Field Strength Elements (HFSE).  
496 Nb/La ratios show a tentative negative correlation with  $\text{SiO}_2$ , whereas Pb contents are  
497 positively correlated with silica for V1 and V2 lavas (Fig. 5). These features likely  
498 reflect crustal contamination effects in these two lowermost units, since silica-rich  
499 continental crust is selectively depleted in Nb and Ta and enriched in Pb with respect to  
500 elements of similar incompatibility, e.g. La (Tang et al, 2019 and references therein)..

501 Component Sk1 is clearly distinct from either “typical” mantle-reservoirs (Hart  
502 et al., 1992), or any North Atlantic volcanic rocks. Its radiogenic Sr, unradiogenic Hf  
503 and Nd, as well as the low Nb, Ta, and high Pb contents (Fig. 5) of lavas plotting close  
504 to it (Figs. 6 and 7) suggest that the origin of this component is related to continental  
505 crust contamination of mantle-derived melts by materials similar in composition to



506 Greenland basement late Archean orthogneisses and granodiorites analyzed by Larsen  
507 and Pedersen (2009). The fact that these contamination effects are limited to the oldest  
508 units V1 and V2 is consistent with the hypothesis of an uprise of the younger melts  
509 (constituting units V3 and V4) through a plumbing system coated with earlier basaltic  
510 lavas (e.g. Arndt and Christensen, 1992) or exhausted of fertile material by previous  
511 melting events (e.g. Meade et al, 2014).

512

### 513 *5.2. Partial melting conditions*

514 Si and Mg contents can be used as proxies in order to estimate pressure and  
515 temperature of melt extraction in the mantle (Lee et al., 2009). Only a limited number of  
516 samples are “primitive enough” (i.e. experienced only olivine fractionation), to  
517 adequately estimate their pristine major element concentrations by simple olivine  
518 addition (Albarède, 1992; Lee et al., 2009). Moreover, some of them, with MgO  
519 contents >15 wt%, need to be afterwards corrected for olivine accumulation (back to  
520 equilibrium with their olivine phenocrysts Mg#~0.83, Supplementary Table 4) and  
521 olivine fractionation (back to equilibrium with olivine of mantle-like composition  
522 Mg#~0.89). Thermobarometric estimates thus obtained on ten samples from units V2  
523 and V3 suggest temperatures and pressures of  $\sim 1350 \pm 100$  °C and  $2.5 \pm 0.5$  GPa,  
524 respectively. These results, although consistent with those recently reported by Hole and  
525 Natland (2019), need to be considered with caution, given the number of  
526 approximations in the thermobarometric approach, as well as uncertainties concerning  
527 the precise geological setting at that time (crustal thickness). The estimated temperature  
528 range suggests that the mantle beneath Svartenhuk was not very hot compared with  
529 other published evaluations for the NAIP (e.g. 1480-1550 °C, Hole and Millett, 2016;  
530 see also Herzberg et al. 2007 and references therein). Our estimated P-T conditions  
531 overlap the spinel/garnet transition zone in the mantle (2.2 GPa at 1300 °C, O’Neill,  
532 1981; Robinson and Wood, 1998), and it is therefore probable that Svartenhuk Fm.  
533 lavas were extracted from melting columns involving both garnet- and spinel-bearing  
534 peridotites, as often proposed for NAIP magmas (Kerr, 1994; Kerr et al, 1999; Saunders  
535 et al., 2007; Hole and Millett, 2016).

536 Even if the “fan-shaped” rare earth elements (REE) patterns observed on figure 4  
537 are partly the result of different rates of partial melting, LREE/HREE fractionation can  
538 also be accounted for by the presence of residual garnet in the source (e.g. Frey et al.  
539 1978, Thirlwall et al., 1994). In figure 8 plots, Pb isotopes, La/Sm and Sm/Yb ratios are

540 compared with the average slope of REE spectra quantified by La/Yb ratios. The upper  
541 diagram ( $^{206}\text{Pb}/^{204}\text{Pb}$  vs La/Yb) reflects the effects of crustal contamination (units V1  
542 and V2) on geochemical compositions (see section 5.1). The middle diagram documents  
543 the concomitant effects of crustal contamination and degrees of partial melting on  
544 LREE/intermediate REE relative abundances. The lower plot provides insights  
545 concerning the amount of garnet-bearing peridotites involved in the melting column.  
546 Altogether, these three diagrams suggest that:

547 i/ Lavas derived from rather high degrees of partial melting all belong to units V2  
548 and V3. Basalts from units V1 and V4 were generated by smaller degrees of  
549 mantle melting (as suggested by their alkali to transitional signatures in Figs. 4  
550 and 5). Precise amounts of melting are difficult to assert considering the  
551 uncertainties concerning the initial composition(s) of mantle source(s).  
552 Nevertheless, models of garnet- (shown in red) and spinel-bearing (shown in  
553 green) batch lherzolite melting (see Gurenko and Chaussidon, 1995 for details on  
554 initial compositions, McKenzy and O'nion, 1991 for partition coefficients; and  
555 Thirlwall et al.1993 for mineral proportions in the melting) show that V1 and V4  
556 lavas would be derived from melting degrees lower than 5%, and most V2 and  
557 V3 lavas from clearly higher ones (Fig. 8).

558 ii/ On average, basalts from units V2 and V3 feature Sm/Yb ratios 50% lower  
559 than those of samples from units V1 and V4. This stronger fractionation between  
560 intermediate and heavy REE in V1 and V4 suggests a larger involvement of  
561 garnet peridotites (and therefore greater melting depths) at the beginning and the  
562 end of the magmatic history than during the emplacement of the main V2-V3  
563 volcanic sequences. These results are in agreement with previous petrogenetic  
564 studies of West Greenland picritic and Mg-rich basalts demonstrating that their  
565 main sequences derived predominantly from spinel-bearing peridotites (Gill et al.,  
566 1991; Ryabchikov et al., 1998; Larsen and Pedersen, 2000, 2009).

567 Therefore, we propose that small degrees of melting leading to V1 lavas were  
568 initiated at depths greater than 75 km below a relatively thick lithosphere. Subsequently,  
569 these melts propagated upwards into the spinel peridotite zone in connection with  
570 lithospheric thinning. The melting rates increased consistently during this process,  
571 forming V2 and V3 lavas. Finally, the melting zone deepened again, and melting rates  
572 decreased, thereby generating V4 alkali basalts.

573

574 *5.3. Mantle source heterogeneity and its temporal evolution*

575 The isotope diversity reported in this study covers a range similar to that  
576 previously reported for the neighboring Disko Island (Larsen and Pedersen, 2009) and  
577 the only differences concern the extent of crustal contamination (Fig. 5). The least  
578 contaminated samples (identified on Figs. 5 and 8) also largely overlap with samples  
579 from Iceland and the adjacent ridges, as well as with those from East Greenland (figs. 6  
580 and 7). The isotopic diversity within the Iceland plume has been widely discussed  
581 (Chauvel and Hémond, 2000; Thirlwall et al., 2004; Kokfelt et al., 2006; Maclennan,  
582 2008; Kitawaga et al., 2008) and is denoted in figure 7 by both depleted (D, Kitawaga et  
583 al., 2008; ID-1 and ID-2, Thirlwall et al., 2004), and enriched (E-1 and E-2, Kitawaga et  
584 al., 2008; IE-1 and IE-2, Thirlwall et al., 2004) Icelandic internal components (Fig. 7).  
585 In figures 6 and 7, Hf, Sr and Pb compositions of component “Sk2” are very similar to  
586 those of OIB and E-MORB related to the Iceland hotspot, and more especially to a  
587 mixture of the Icelandic inner components “D” (for depleted) and “E-1” (for Enriched  
588 1) of Kitawaga et al. (2008) or “ID1” – “ID2” (for Iceland Depleted 1 and 2) and “IE1”  
589 (for Iceland enriched 1) of Thirlwall et al. (2004).

590 Alternatively, Sk3 seems to correspond to the Iceland E-2 enriched component of  
591 Kitawaga et al. (2008) (or “IE-1” of Thirlwall et al., 2004) that point toward the  
592 common component C (Hanan and Graham, 1996) in all isotope spaces. This enriched  
593 component has been proposed to be intrinsic to the Icelandic hotspot (Hanan and  
594 Schilling, 1997; Kitawaga et al., 2008; Thirlwall et al., 2004; Peate et al., 2010). The  
595 presence of distinct Icelandic isotopic components has also been described in Eastern  
596 Greenland (Barker et al., 2006). Nevertheless, in that region, the different signatures  
597 appear in separate areas (Milne, Rømer and Skræterne), located hundreds of kilometers  
598 away from each other. In the present study, we report distinct signatures on samples all  
599 coming from a restricted segment (<40 km along the coast) and covering a time span  
600 shorter than 8 m.y. Such diversity can therefore hardly be imagined as the result of the  
601 tapping of distinct parts of an Iceland type mantle plume. Instead, we suggest that the  
602 Sk3 signature in our dataset corresponds to a trend toward the C component of Hanan  
603 and Graham (1996). This component has been recognized as being widely disseminated  
604 within the upper mantle feeding the Arctic segments of the mid-Atlantic ridges and is  
605 therefore believed to correspond to an ubiquitous ingredient of the North Atlantic upper  
606 mantle (Blichert-Toft et al., 2005).

607 Nb, Zr and Y concentrations also suggest consistency between uncontaminated  
608 Svartenhuk samples and Iceland plume geochemical signatures. Indeed, Fitton et al.  
609 (1997) used the comparison of Nb/Y and Zr/Y in order to decipher whether the  
610 magmatic sources of basalts are more likely related to the Iceland plume or to the  
611 neighboring MORB mantle. They proposed a  $\Delta\text{Nb}$  index  $= 1.72 + \log(\text{Nb}/\text{Y}) -$   
612  $1.92\log(\text{Zr}/\text{Y})$ ; where  $\Delta\text{Nb}$  is negative in MORB samples, but positive in Iceland  
613 plume-derived material. Even if this approach has been criticized as possibly biased by  
614 differences in pressures of melting (Hanan et al., 2000; Stracke et al., 2003), it is worth  
615 noting that most samples from this study feature positive  $\Delta\text{Nb}$  values. Indeed, in Figure  
616 9, only some samples from units V2 and V3 display negative  $\Delta\text{Nb}$  (Fig. 9), suggesting  
617 that the contribution of Icelandic material in lava sources was lower during these  
618 intermediate stages than during the emplacement of the earliest and latest V1 and V4  
619 units. Moreover, a plume imprint on geochemical signatures of Svartenhuk lavas is also  
620 consistent with the extremely primitive helium isotopic compositions recently published  
621 by Péron et al. (2018) for olivines from our V3 samples S33E7 and S35E7 ( $R/R_a=31.0$   
622 and 34.9, respectively), similar to those previously reported for samples from Disko  
623 Island and Baffin Island (Graham et al., 1998; Jackson et al., 2010).

624 Altogether, these features suggest that the Sk2-Sk3 trend (common to both V3 and  
625 V4 units) could be accounted for by a mixture of Icelandic-type material (Sk2) and a  
626 mixed ambient upper mantle reservoir (Sk3). The respective proportions of these two  
627 components appear to evolve through time, since only samples coming from unit V3  
628 carry isotope signatures suggesting the involvement of significant amounts of C-like  
629 material, whereas the uppermost V4 lavas seem to tap preferentially Iceland hotspot  
630 material. Furthermore, even if geochemical signatures of V1 and V2 are partly  
631 controlled by crustal contamination, they also point solely toward the Iceland-like  
632 signature. This sequence of magmatic events is summarized in figures 10 (petrogenetic  
633 constraints) and 11 (speculative tectonic interpretation). During the emplacements of  
634 basal units V1 and V2 (61 to 59.5 Ma old, Chauvet et al., accepted), initially low, but  
635 temporally increasing degrees of melting of enriched Icelandic plume material  
636 (displaying Sk2 isotopic signatures) generated basaltic melts at depths starting beneath  
637 75 km, and these magmas were contaminated during their ascent through the continental  
638 crust. During V3 emplacement (59.5-57.7 Ma), the melting process affected a wider  
639 range of lithologies in the spinel stability field and propagated to neighboring

640 (shallower) materials from the upper mantle (involving material displaying component  
641 Sk3 isotope signatures), with little or undetectable crustal contamination. Finally, during  
642 V4 emplacement, i.e. between 57.7 and 53.3 Ma (Chauvet et al., accepted), the melting  
643 zone deepened again and was once more mostly restricted to the enriched mantle  
644 material (Figs. 10 and 11).

645

#### 646 *5.4. Baffin Bay breakup and tectonic controls of mantle melting*

647 This sequence of events as reported by combining geochemical and tectonic data can  
648 be interpreted as the progressive initiation of decompression melting of an upwelling  
649 mantle below a progressively thinning lithosphere in a continental extension setting  
650 (Fig. 11). The thinning observed between the emplacement of V1 and V2-V3 lavas  
651 likely results from a combination of the tectonic stretching of the upper part of the  
652 lithosphere and of the thermal erosion of its base by convecting hot mantle (Fig. 11).  
653 Such a combination has been proposed as an explanation of the magmatic history of  
654 Mull and Skye islands (Kerr, 1994; Kerr et al., 1999; Saunders et al., 1997). In these  
655 islands, as well as in Giant's Causeway basalts (Barrat and Nesbitt, 1996), temporally  
656 increasing melting rates and decreasing melting pressures similar to those described  
657 in Svartenhuk are observed, despite rather different tectonic contexts characterized by  
658 lower extension rates (Meyer et al., 2007). A temporal decrease of lithospheric  
659 thickness seems the most likely factor controlling such changes in NAIP basaltic  
660 magma compositions (Ellam, 1992; Kerr, 1994).

661 The decreasing involvement of the ambient mantle (component Sk3) contribution from  
662 V3 to V4 (Fig. 10), and the concomitant deepening and decrease of partial melting rates  
663 (back to alkali basaltic compositions) in this most proximal part of the volcanic margin,  
664 may be (at least partly) attributed to the gradual westward shift of extension with time  
665 (Geoffroy et al., 2015; Chauvet et al., accepted). Indeed, the innermost Svartenhuk  
666 margin progressively became passive although extension still continued (as attested by  
667 syn-tectonic control of V4 emplacement), albeit at lower rates (Chauvet et al, accepted).  
668 It is also possible that the accumulation beneath the lithosphere of refractory mantle  
669 residues left after melt extraction blocked the ascent of hot and fertile mantle sources  
670 and resulted in deeper, lower-degree melting as previously suggested for East Greenland  
671 flood basalts (Fram and Leshner, 1993, 1997).

672

## 673 **6. Conclusions**

674           Geochemical data obtained on 93 samples of basaltic to trachytic rocks from the  
675 Svartenhuk peninsula allow us to document the c. 7 m.y. long volcanic activity  
676 accompanying the continental thinning process that preceded the Eocene opening of  
677 Baffin Bay, the chronological and tectonic aspects of which are discussed in a  
678 companion paper (Chauvet et al., accepted). The sequence of magmatic events started  
679 with (i) the deep (>75 km) low degree partial melting of an Iceland plume-like source,  
680 followed by (ii) shallower and higher degrees of melting of a mixture of Iceland hotspot  
681 and “ambient upper mantle” materials, and finally ended with (iii) lower degrees of  
682 melting of a deeper source dominated again by Icelandic-type signatures. The first  
683 melting event could have been triggered by the adiabatic ascent of the Iceland plume  
684 below a ~75-km-thick lithosphere, inherited from the previous Mesozoic extension. The  
685 OIB-type signature of V1 lavas is clear despite the crustal contamination processes that  
686 they experienced during their ascent. The following melting events (V2 to V3 lavas)  
687 occurred at decreasing pressures and were coeval with syn-magmatic extension in the  
688 upper crust (Chauvet et al., accepted) and therefore a subsequent reduction in  
689 lithosphere thickness (Figs. 10 and 11). Thus, V2-V3 melts were a direct consequence  
690 of the convective upwelling of Icelandic OIB-type mantle in the necked sub-lithospheric  
691 area (Boutiller and Keen, 1999), associated with lithospheric thinning resulting from a  
692 combination of tectonic stretching and thermal erosion of the Svartenhuk lithosphere.  
693 The later decrease in magmatic activity (emplacement of V4 lavas) was concomitant  
694 with a progressive focusing of syn-magmatic strain towards the central axis of the  
695 proto-Baffin Bay during the Eocene. This shift in extension was likely accompanied by  
696 a progressive cooling (and thus, thickening) of the proximal W-Greenland lithosphere  
697 over a still convecting asthenosphere. The combined decrease in melting rates and the  
698 return to enriched source materials suggest a further deepening of the melting zone,  
699 possibly linked to the accumulation beneath the lithosphere of refractory mantle  
700 residues.

701

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715

## 716 **References**

- 717 Abdelmalak, M.M, Geoffroy, L., Angelier, J., Bonin, B., Callot, J.P., Gelard, J.P.,  
718 Aubourg, C., 2012. Stress fields acting during lithosphere breakup above a  
719 melting mantle: A case example in West Greenland. *Tectonophysics* 581, 132-  
720 143.
- 721 Abdelmalak, M.M, Planke, S., Polteau, S., Hartz, E.H., Faleide, J.I., Tegner, C.,  
722 Jerram, D.A., Millett, J.M., Myklebust, R., 2018. Breakup volcanism and plate  
723 tectonics in the NW Atlantic. *Tectonophysics* in press,  
724 doi.org/10.1016/j.tecto.2018.08.002
- 725 Agranier, A., Blichert-Toft, J., Graham, D., Debaille, V., Schiano, P., Albarede, F.,  
726 2005. The spectra of isotopic heterogeneities along the mid-Atlantic Ridge.  
727 *Earth Planet. Sci. Lett.* 238, 96–109.
- 728 Albarède, F., 1992. How deep do common basaltic magmas form and differentiate. *J.*  
729 *Geophys. Res.-Solid Earth* 97, 10997–11009.
- 730 Arndt, N., Christensen, U., 1992. The role of lithospheric mantle in continental flood  
731 volcanism - thermal and geochemical constraints. *J. Geophys. Res.-Solid Earth*  
732 97, 10967–10981.
- 733 Barrat, J.A., Nesbitt, R.W., 1996. Geochemistry of the tertiary volcanism of Northern  
734 Ireland. *Chem. Geol.* 129, 1-2, 15-38.
- 735 Barrat, J. A., Yamaguchi, A., Greenwood, R. C., Bohn, M., Cotten, J., Benoit, M.,  
736 Franchi, I.A., 2007. The Stannern trend eucrites: Contamination of main group  
737 eucritic magmas by crustal partial melts. *Geochim. Cosmochim. Acta*, 71, 16,  
738 4108-4124
- 739 Barker, A. K., Baker, J. A., Peate, D., W., 2006. Interaction of the rifting East  
740 Greenland margin with a zoned ancestral Iceland plume. *Geology* 34, 481–484.
- 741 Blichert-Toft, J., Agranier, A., Andres, M., Kingsley, R., Schilling, J., Albarède, F.,  
742 2005. Geochemical segmentation of the Mid-Atlantic Ridge north of Iceland  
743 and ridge-hot spot interaction in the North Atlantic. *Geochem. Geophys.*  
744 *Geosystems* 6. <https://doi.org/10.1029/2004GC000788>
- 745 Blichert-Toft, J., Chauvel, C., Albarede, F., 1997. Separation of Hf and Lu for high-  
746 precision isotope analysis of rock samples by magnetic sector multiple collector  
747 ICP-MS. *Contrib. Mineral. Petrol.* 127, 248–260.
- 748 Block, M., Damm, V., Ehrhardt, A., Berglar, K., Schnabel, M., Altenbernd, T., 2012.  
749 Characteristics of the West Greenland Margin in the Southern Baffin Bay. 74th  
750 EAGE Conference & Exhibition, Abstract, 10.3997/2214 4609.20148225.
- 751 Boutiller, R.R., Keen, C.E., 1999. Small-scale convection and divergent plate  
752 boundaries. *J. Geophys. Res.-Solid Earth* 104, B4, 7389–7403.

753 Breddam, K., 2002. Kistufell: Primitive melt from the Iceland mantle plume. *Journal*  
754 *of Petrology* 43, 2, 345–373.

755 Callot, J.-P., 2002. Origine, structure et développement des marges volcaniques:  
756 l'exemple du Groenland. Université Paris 6, Ecole Normale Supérieure.

757 Caroff, M., Maury, R.C., Cotten, J., Clément, J.P., 2000. Segregation structures in  
758 vapor-differentiated basaltic flows. *Bull. Volcanol.* 62, 171–187.

759 Chalmers, J.A. and Laursen, K.H., 1995. Labrador Sea – the extent of continental and  
760 oceanic-crust and the timing of the onset of sea-floor spreading. *Marine*  
761 *Petroleum Geology* 12, 2, 205-217.

762 Chalmers, J.A. and Puvertaft, T.C.R., 2001. Development of the continental margins  
763 of the Labrador Sea: a review. *Geol. Soc. Special Pub.* 187, 77-105.

764 Chauvel, C., Hemond, C., 2000. Melting of a complete section of recycled oceanic  
765 crust: Trace element and Pb isotopic evidence from Iceland. *Geochem.*  
766 *Geophys. Geosystems* 1, 1001. <https://doi.org/10.1029/1999GC000002>

767 Chauvet, F., Geoffroy, L., Guillou, H., Maury, R.C., Le Gall, B., Agranier, A.,  
768 Aviana, A., accepted. Eocene continental breakup in Baffin Bay.  
769 *Tectonophysics*

770 Coffin, M.F., Eldholm, O., 1994. Large Igneous provinces – crustal structure,  
771 dimensions, and external consequences. *Reviews Geophysics* 32, 1-36.

772 Cotten, J., Le Dez, A., Bau, M., Caroff, M., Maury, R., Dulski, P., Fourcade, S.,  
773 Bohn, M., Brousse, R., 1995. Origin of anomalous rare-Earth element and  
774 Yttrium enrichments in subaerially exposed basalts, evidence from French  
775 Polynesia. *Chem. Geol.* 119, 115–138.

776 Courtillot, V., Jaupart, C., Manighetti, I., Tapponnier, P., Besse, J., 1999. On causal  
777 links between flood basalts and continental breakup. *Earth Planet. Sci. Lett.*  
778 166, 3-4, 177-195.

779 Eggins, S.M., Woodhead, J.D., Kinsley, L.P.J., Mortimer, G.E., Sylvester, P.,  
780 McCulloch, M.T., Hergt, J.M., Handler, M.R., 1997. A simple method for the  
781 precise determination of  $\geq 40$  trace elements in geological samples by ICPMS  
782 using enriched isotope internal standardisation. *Chem. Geol.* 134, 4, 311-326.

783 Ellam, R.M., 1992. Lithospheric thickness as a control on basalt geochemistry.  
784 *Geology*, 20, 2, 153-156.

785 Escher, J.C., Pulvertaft, T.C.R., 1995. Geological map of Greenland, 1:2 500 000.  
786 *Geol. Surv. Greenl.*

787 Fietzke, J., Eisenhauer, A., 2006. Determination of temperature-dependent stable  
788 strontium isotope (Sr-88/Sr-86) fractionation via bracketing standard MC-ICP-  
789 MS. *Geochem. Geophys. Geosystems* 7, Q08009.  
790 <https://doi.org/10.1029/2006GC001243>

791 Fitton, J.G., Saunders, A.D., Norry, M.J., Hardason, B.S., Taylor, R.N., 1997.  
792 Thermal and chemical structure of the Iceland plume. *Earth Planet. Sci. Lett.*  
793 153, 3-4, 197–208.

794 Francis, D., 1985. The Baffin-Bay lavas and the value of picrites as analogs of primary  
795 magmas. *Contrib. Mineral. Petrol.*, 89, 2-3, 144-154.

796 Fram, M.S., Leshner, C.E., 1993. Geochemical constraints on mantle melting during  
797 creation of the North-Atlantic basin. *Nature* 363, 6431, 712-715.

798 Fram, M.S., Leshner, C.E., 1997. Generation and polybaric differentiation of East  
799 Greenland early tertiary flood basalts. *Journal of Petrology* 38, 2, 231-275.

800 Frey, F.A., Green, D.H., Roy, S.D., 1978. Integrated models of basalt petrogenesis: a  
801 study of quartz tholeiites to olivine melilites from south eastern Australia



802 utilizing geochemical and experimental petrological data. *Journal of Petrology*  
803 19, 463-513.

804 Funck, T., Gohl, K., Damm, V., Heyde, I., 2012. Tectonic evolution of southern  
805 Baffin Bay and Davis Strait: Results from a seismic refraction transect between  
806 Canada and Greenland. *J. Geophys. Res.* 117, B04107.

807 Geoffroy, L., 2005. Volcanic passive margins. *C. R. Geoscience* 337, 1395–1408.

808 Geoffroy L., Burov, E.B., Werner, P., 2015. Volcanic passive margins: another way to  
809 break up continents. *Scientific Reports* 5, 14828, DOI: 10.1038/srep14828.

810 Geoffroy, L., Callot, J.P., Scaillet, S., Skuce, A.S., Gélard, J.-P., Ravilly, M.,  
811 Angelier, J., Bonin, B., Cayet, C., Perrot-Galmiche, K., Lepvrier, C., 2001.  
812 Southeast Baffin volcanic margin and the North American–Greenland plate  
813 separation. *Tectonics* 20, 566–584.

814 Gill, R.C.O., Pedersen, A.K., Larsen, J.G., 1991. Tertiary picrites in West Greenland:  
815 Melting at the periphery of a plume?, in: *Magmatism and the Causes of*  
816 *Continental Break-Up. Programme and Abstracts.* p. 13.

817 Gurenko, A.A., Chaussidon, M., 1995. Enriched and depleted primitive melts  
818 included in olivine from Icelandic tholeiites – origin by continuous melting of a  
819 single Mantle column. *Geochim. Cosmochim. Acta* 59, 14, 2905-2917.

820 Graham, D.W., Larsen, L.M., Hanan, B.B., Storey, M., Pedersen, A.K., Lupton, J.E.,  
821 1998. Helium isotope composition of the early Iceland mantle plume inferred  
822 from the Tertiary picrites of West Greenland. *Earth Planet. Sci. Lett.* 160, 241-  
823 255.

824 Hanan, B.B., Blichert-Toft, J., Kingsley, R., Schilling, J.G., 2000. Depleted Iceland  
825 mantle plume geochemical signature: artifact of multicomponent mixing?  
826 *Geochem. Geophys. Geosystems* 1, 1003, <http://doi:10.1029/1999GC000009>.

827 Hanan, B.B., Graham, D.W., 1996. Lead and helium isotope evidence from oceanic  
828 basalts for a common deep source of mantle plumes. *Science* 272, 991–995.

829 Hanan, B.B., Schilling, J.G., 1997. The dynamic evolution of the Iceland mantle  
830 plume: the lead isotope perspective. *Earth Planet. Sci. Lett.* 151, 43–60.

831 Hart, S., Hauri, E., Oschmann, L., Whitehead, J., 1992. Mantle plumes and  
832 entrainment - isotopic evidence. *Science* 256, 517–520.

833 Herzberg, C., Asimow, P.D., Arndt, N., Niu, Y.L., Leshner, C.M., Fitton, J.G.,  
834 Cheadle, M.J., Saunders, A.D., 2007. Temperatures in ambient mantle and  
835 plumes: Constraints from basalts, picrites, and komatiites. *Geochem. Geophys.*  
836 *Geosystems* 8, Q02006. <https://doi.org/10.1029/2006GC001390>

837 Hole, M.J., Millett, J.M., 2016. Controls of Mantle Potential Temperature and  
838 Lithospheric Thickness on Magmatism in the North Atlantic Igneous Province.  
839 *Journal of Petrology* 57, 2, 417-436.

840 Hole, M.J., Natland, J.H., 2019. Magmatism in the North Atlantic Igneous Province;  
841 mantle temperatures, rifting and geodynamics. *Earth-Science Reviews*, in press,  
842 <https://doi.org/10.1016/j.earscirev.2019.02.011>

843 Holm, P.M., Gill, R.C.O., Pedersen, A.K., Larsen, J.G., Hald, N., Nielsen, T.F.D.,  
844 Thirlwall, M.F., 1993. The Tertiary picrites of West Greenland – contribution  
845 from Icelandic and other sources. *Earth Planet. Sci. Lett.* 115, 1-4, 227-244.

846 Hosseinpour, M., Müller, R.D., Williams, S.E., Whittaker J.M., 2013. Full-fit  
847 reconstruction of the Labrador Sea and Baffin Bay. *J. Geophys. Res. -Solid*  
848 *Earth* 4, 461–479.

849 Jackson, M.G., Carlson, R.W., Kurtz, M.D., Kempton, P.D., Francis, D., Blusztajn, J.,  
850 2010. Evidence for survival of the oldest terrestrial mantle reservoir. *Nature*  
851 466, 853-856, doi:1.138/nature09287.

- 852 Jerram, D.A., 2002. Volcanology and facies architecture of flood basalts. Geological  
853 Society of America Special Papers 362, 119-132 .
- 854 Kerr, A.C. 1994, Lithospheric thinning during the evolution of continental large  
855 igneous provinces – a case study from the North-Atlantic Tertiary province.  
856 *Geology* 22, 11, 1027-1030.
- 857 Kerr, A.C., Kent, R.W., Thomson, B.A., Seedhouse, J.K., Donaldson, C.H., 1999.  
858 Geochemical evolution of the Tertiary Mull volcano, Western Scotland. *Journal*  
859 *of Petrology* 40, 6, 873-908.
- 860 Kitawaga, H., Kobayashi, K., Makishima, A., Nakamura, E., 2008. Multiple pulses  
861 of the mantle plume: evidence from tertiary Icelandic lavas. *Journal of*  
862 *Petrology* 49, 7, 1365–1396.
- 863 Kokfelt, T.F., Hoernle, K., Hauff, F., Fiebig, J., Werner, R., Garbe-Schonberg, D.,  
864 2006. Combined trace element and Pb, Nd, Sr, O isotope evidence for recycled  
865 oceanic crust (upper and lower) in the Iceland mantle plume. *Journal of*  
866 *Petrology* 47, 9, 1705–1749.
- 867 Kokfelt, T.F., Hoernle, K., Lundstrom, C., Hauff, F., Van den Bogaard, C., 2009.  
868 Time-scales for magmatic differentiation at the Snaefellsjokull central volcano,  
869 western Iceland: Constraints from U-Th-Pa-Ra disequilibria in post-glacial  
870 lavas. *Geochim. Cosmochim. Acta* 73, 4, 1120–1144.
- 871 Komar, P.D. 1972. Mechanical interactions of phenocrysts and flow differentiation of  
872 igneous dikes and sills. *Geol. Soc. Am. Bull.* 83, 973-988
- 873 Kuritani, T., Yokohama, T., Kitawaga, H., Kobayashi, K., Nakamura, E., 2011.  
874 Geochemical evolution of historical lavas from Askja Volcano, Iceland:  
875 Implications for mechanisms and timescales of magmatic differentiation.  
876 *Geochim. Cosmochim. Acta* 75, 2, 570–587.
- 877 Larsen, J.G., 1983. *Geologisk kort over Grønland, 1:100 000, Igdlorssuit, 71 V.1 Syd.*  
878 *København: Grønlands Geologiske Undersøgelse (English legend).*
- 879 Larsen, J.G., Grocott, J., 1992. *Geologisk kort over Grønland, 1:100 000, Svartenhuk,*  
880 *71 V.1 Nord. København: Grønlands Geologiske Undersøgelse (English*  
881 *legend).*
- 882 Larsen, L.M., Pedersen, A.K., 2000. Processes in high-Mg, high-T magmas: Evidence  
883 from olivine, chromite and glass in palaeogene picrites from West Greenland.  
884 *Journal of Petrology* 41, 1071–1098.
- 885 Larsen, L.M., Pedersen, A.K., 2009. Petrology of the Paleocene Picrites and Flood  
886 Basalts on Disko and Nuussuaq, West Greenland. *Journal of Petrology* 50,  
887 1667–1711.
- 888 Larsen L.M., Pedersen, A.K., Tegner, C., Duncan, R.A., Hald, N., Larsen, J.G., 2015.  
889 Age of Tertiary volcanic rocks on the West Greenland continental margin:  
890 volcanic evolution and event correlation to other parts of the North Atlantic  
891 Igneous Province. *Geol. Mag.* 153, 487-511.
- 892 Larsen, J.G., Pulvertaft, T.C.R. 2000. The structure of the Cretaceous-Palaeogene  
893 sedimentary-volcanic area of Svartenhuk Halvø, central West Greenland.  
894 *Geology of Greenland Survey Bulletin*, 188, 1-40.
- 895 Larsen, H.C., Saunders, A.D., 1998. Tectonism and volcanism at the southeast  
896 Greenland rifted margin: a record of plume impact and later continental rapture.  
897 *Proc. Ocean Drill. Program Sci. Results* 152, 503-533.
- 898 Le Bas, M., Le Maitre, R., Streckeisen, A., Zanettin, B., 1986. A chemical  
899 classification of volcanic rocks based on the total alkali silica diagram. *Journal*  
900 *of Petrology* 27, 745–750.

- 901 Le Breton, E., Cobbold, P.R., Dauteuil, O., Lewis, G., 2012. Variations in amount and  
902 direction of seafloor spreading along the northeast Atlantic Ocean and resulting  
903 deformation of the continental margin of northwest Europe. *Tectonics* 31,  
904 TC5006.
- 905 Lee, C.-T.A., Luffi, P., Plank, T., Dalton, H., Leeman, W.P., 2009. Constraints on the  
906 depths and temperatures of basaltic magma generation on Earth and other  
907 terrestrial planets using new thermobarometers for mafic magmas. *Earth Planet.  
908 Sci. Lett.* 279, 20–33.
- 909 Li, Z.X.A., Lee, C.-T.A., 2006. Geochemical investigation of serpentized oceanic  
910 lithospheric mantle in the Feather River Ophiolite, California: Implications for  
911 the recycling rate of water by subduction. *Chemical Geology* 235, 161-185.
- 912 Macdonald, G.A., Katsura, T., 1964. Chemical composition of Hawaii lavas. *Journal  
913 of Petrology* 5, 82-133.
- 914 MacLennan, J., 2008. Lead isotope variability in olivine-hosted melt inclusions from  
915 Iceland *Geochim. Cosmochim. Acta* 72 4159–4176.
- 916 McDonough, W.F., Sun, S.S., 1995. The composition of the Earth. *Chem. Geol.* 120,  
917 223–253.
- 918 McKenzie, D., O’Nions, R.K., 1991. Partial melt distribution from inversion of Rare  
919 Earth Element concentrations. *Journal of Petrology* 32, 5, 1021-1091.
- 920 Meade, F.C., Troll, V.R., Ellam, R.M., Freda, C., Font, L., Donaldson, C.H.,  
921 Klonowska, I., 2014. Bimodal magmatism produced by progressively inhibited  
922 crustal assimilation. *Nat. Commun.* 5, 4199, DOI: 10.1038/ncomms5199.
- 923 Meyer, R., Van Wijk, J., Gernigon, L., 2007. The North Atlantic Igneous Province: a  
924 review of models for its formation. *Geol. Soc. Amer., Special Paper* 430, 525-  
925 552.
- 926 Mougél, B., Agranier, A., Hemond, C., Gente, P., 2014. A highly unradiogenic lead  
927 isotopic signature revealed by volcanic rocks from the East Pacific Rise. *Nat.  
928 Commun.* 5, 4474. <https://doi.org/10.1038/ncomms5474>
- 929 Moynier, F., Agranier, A., Hezel, D.C., Bouvier, A., 2010. Sr stable isotope  
930 composition of Earth, the Moon, Mars, Vesta and meteorites. *Earth Planet. Sci.  
931 Lett.* 300, 359–366.
- 932 Oakey, G.N., Chalmers, J.A., 2012. A new model for the Paleogene motion of  
933 Greenland relative to North America: Plate reconstructions of the Davis Strait  
934 and Nares Strait regions between Canada and Greenland. *J. Geoph. Res. Solid  
935 Earth* 117, B10401.
- 936 Ogg, J.G., 2012. Geomagnetic Time Scale. In: Gradstein, F.M., Ogg, J.G., Schmitz,  
937 M., Ogg, G. (eds), *The Geologic Time Scale 2012*. Elsevier, Amsterdam, 85-113.
- 938 O’Neill, H.S.C., 1981. The transition between spinel lherzolite and garnet lherzolite,  
939 and its use as a geobarometer. *Contrib. Mineral. Petrol.* 77: 185–194.
- 940 Peate, D.W., Baker, J.A., Jakobsson, S.P., Waight, T.E., Kent, A.J.R., Grassineau,  
941 N.V., Skovgaard, A.C., 2009. Historic magmatism on the Reykjanes Peninsula,  
942 Iceland: a snap-shot of melt generation at a ridge segment. *Contrib. Mineral.  
943 Petrol.* 157, 3, 359–382.
- 944 Peate, D.W., Breddam, K., Baker, J.A., Kurtz, M., Barker, A.K., Prestvik, T.,  
945 Grassineau, N., Skovgaard, A.C., 2010. Compositional characteristics and  
946 spatial distribution of enriched Icelandic mantle components. *Journal of  
947 Petrology* 51, 7, 1447–1475.
- 948 Peate, D.W., Stecher, O., 2003. Pb isotope evidence for contributions from different  
949 Iceland mantle components to Palaeogene East Greenland flood basalts. *Lithos*  
950 67, 1-2, 39-52.

- 951 Pedersen, G.K., Larsen, L.M., Pedersen, A.K., Hjortkjaer, B.F., 1998. The syn-  
 952 volcanic Naajaat lake, Paleocene of West Greenland. *Palaeogeogr.*  
 953 *Palaeoclimatol. Palaeoecol.* 140, 271–287.
- 954 Pedersen, A.K., Larsen, L.M., Riisager, P., Dueholm, K.S., 2002. Rates of volcanic  
 955 deposition, facies changes and movements in a dynamic basin: the Nuussuaq  
 956 Basin, West Greenland, around the C27n-C26r transition. In: Jolley, D. W. and  
 957 Bell, B.R. (eds) *The North Atlantic Igneous Province: Stratigraphy, Tectonic,*  
 958 *Volcanic and Magmatic Processes.* Geological Society, London, Special  
 959 Publications 197, 157-181.
- 960 Péron, S., Moreira, M., Agranier, A., 2018. Origin of Light Noble Gases (He, Ne, and  
 961 Ar) on Earth: A Review. *Geochem. Geophys. Geosystems* 19, 4, 979-996,  
 962 <http://DOI: 10.1002/2017GC007388>.
- 963 Petersen, K.D., Schiffer, C., Nagel, T., 2018. LIP formation and protracted lower  
 964 mantle upwelling induced by rifting and delamination. *Scientific Reports* 8,  
 965 16578, DOI:10.1038/s41598-018-34194-0.
- 966 Pik, R., Deniel, C., Coulon, C., Yirgu, G., Hofmann, C., Dereje, A., 1998. The  
 967 Northwestern Ethiopian Plateau flood basalts : Classification and spatial  
 968 distribution of magma types. *J. Volcanol. Geotherm. Res.* 91–111.
- 969 Planke, S., Symonds, P.A., Avelstad, E., Skogseid, J., 2000. Seismic  
 970 volcanostratigraphy of large-volume basaltic extrusive complexes on rifted  
 971 margins. *J. Geophys. Res.* 105, 19333–19351.
- 972 Riisager, P., Abrahamsen, N., 1999. Magnetostratigraphy of Palaeocene basalts from  
 973 the Vaigat Formation of West Greenland. *Geophysical Journal International*  
 974 137, 774-782.
- 975 Riisager, J., Riisager, P., Pedersen, A.K., 2003. Paleomagnetism of large igneous  
 976 provinces: Case-study from West Greenland, North Atlantic igneous province,  
 977 *Earth Planet. Sci. Lett.* 214, 409–425.
- 978 Robinson, J.A.C., Wood, B.J., 1998. The depth of the spinel to garnet transition at the  
 979 peridotite solidus. *Earth Planet. Sci. Lett.* 164, 277–284.
- 980 Roest W. R., Srivastava, S.P., 1989. Sea-floor spreading in the labrador sea – a new  
 981 reconstruction. *Geology* 17, 11, 1000-1003.
- 982 Rudnick, R., Fountain, D., 1995. Nature and composition of the continental crust, a  
 983 lower crustal perspective. *Rev. Geophys.* 33, 267–309.
- 984 Rudnick, R., Gao, S., 2003. Composition of the continental crust, in: *The Crust.*  
 985 Elsevier, Oxford, pp. 1–64.
- 986 Ryabchikov, I., Brooks, C.K., Kogarko, L.N., Nielsen, T., Solovova, I.P., Turkov, V.,  
 987 1998. Tertiary picrites from Greenland: modelling sources and petrogenesis  
 988 from melt inclusion compositions. *Mineral. Mag.* 62A, 3, 1306-1307
- 989 Saunders, A.D., Fitton, J.G., Kerr, A.C., Norry, M.J., Kent, R.W., 1997. The North  
 990 Atlantic igneous province. In: Mahoney, J.J., Coffin, M.F. (Eds.), *Large Igneous*  
 991 *Provinces: Continental, Oceanic, and Planetary Flood Volcanism.* AGU  
 992 *Geophysical Monograph*, Washington, 45–93.
- 993 Saunders A.D., Jones, S.M., Morgan, L.A., 2007. Regional uplift associated with  
 994 continental large igneous provinces: The roles of mantle plumes and the  
 995 lithosphere. *Chem. Geol.* 241, 3-4, 282-318.
- 996 Self, S., Thordarson, T., Keszthelyi, L., 1997. Emplacement of continental flood  
 997 basalt lava flows. In: Mahoney, J.J., Coffin, M.F. (Eds.), *Large Igneous*  
 998 *Provinces: Continental, Oceanic, and Planetary Flood Volcanism.* AGU  
 999 *Geophysical Monograph*, Washington, 381–410.

- 1000 Shellnutt, J.G., Jahn, B.-M., 2011. Origin of Late Permian Emeishan basaltic rocks  
1001 from the Panxi region (SW China): Implications for the Ti-classification and  
1002 spatial-compositional distribution of the Emeishan flood basalts. *J. Volcanol.*  
1003 *Geotherm. Res.* 199, 85–95.
- 1004 Simon, K., Huismans, R.S., Beaumont, C., 2009. Dynamical modelling of lithospheric  
1005 extension and small-scale convection: Implications for magmatism during the  
1006 formation of volcanic rifted margins. *Geophys. J. Int.* 176, 1, 327–350.
- 1007 Sims, K.W.W., Maclennan, J., Blichert-Toft, J., Mervine, E.M., Blusztajn, J.,  
1008 Gronvold, K., 2013. Short length scale mantle heterogeneity beneath Iceland  
1009 probed by glacial modulation of melting. *Earth Planet. Sci. Lett.* 379, 146–157.
- 1010 Skaarup, N., Jackson, H.R., Oakey, G., 2006. Margin segmentation of Baffin  
1011 Bay/Davis Strait, eastern Canada, based on seismic reflection and potential field  
1012 data. *Marine Petroleum Geology* 23, 127–144.
- 1013 Stica, J.M., Zalan, P.V., Ferrari, A.L., The evolution of rifting on the volcanic margin  
1014 of the Pelotas Basin and the contextualization of the Parana-Etendeka LIP in the  
1015 separation of Gondwana in the South Atlantic. *Marine Petroleum Geology* 50,  
1016 1–21.
- 1017 Storey, M., Duncan, R.A., Pedersen, A.K., Larsen, L.M., Larsen, H.C., 1998.  
1018 <sup>40</sup>Ar/<sup>39</sup>Ar geochronology of the West Greenland Tertiary volcanic province.  
1019 *Earth and Planetary Science Letters* 160, 569–586.
- 1020 Stracke, A., Zindler, A., Salters, V.J.M., McKenzie, D., Blichert-Toft, J., Albarede,  
1021 F., Gronvold, K., 2003. Theistareykir revisited. *Geochem. Geophys.*  
1022 *Geosystems* 4, 8507. <https://doi.org/10.1029/2001GC000201>
- 1023 Suckro, S.K., Gohl, K., Funck, T., Heyde, I., Ehrhardt, A., Schreckenberger, B.,  
1024 Gerlings, J., Damm, V., Jokat, W., 2012. The crustal structure of southern  
1025 Baffin Bay: implications from a seismic refraction experiment. *Geophys. J.*  
1026 *International* 190, 1, 37–58.
- 1027 Tanaka, T., Togashi, S., Kamioka, H., Amakawa, H., Kagami, H., Hamamoto, T.,  
1028 Yuhara, M., Orihashi, Y., Yoneda, S., Shimizu, H., Kunimaru, T., Takahashi,  
1029 K., Yanagi, T., Nakano, T., Fujimaki, H., Shinjo, R., Asahara, Y., Tanimizu,  
1030 M., Dragusanu, C., 2000. JNdi-1: a neodymium isotopic reference in  
1031 consistency with LaJolla neodymium. *Chem. Geol.* 168, 279–281.
- 1032 Tang, M., Lee, C.T.A., Chen, K., Erdman, M., Costin, G., Jiang, H.H., 2019. Nb/Ta  
1033 systematics in arc magma differentiation and the role of arclogites in continent  
1034 formation. *Nat. Commun.*, 10, 235, DOI: 10.1038/s41467-018-08198-3.
- 1035 Tegner, C., Leshner, C.E., Larsen, L.M., Watt, W.S., 1998. Evidence from the rare-  
1036 earth-element record of mantle melting for cooling of the tertiary Iceland plume.  
1037 *Nature* 395, 6702, 591–594.
- 1038 Thirlwall, M.F., Gee, M.A.M., Taylor, R.N., Murton, B.J., 2004. Mantle components  
1039 in Iceland and adjacent ridges investigated using double-spike Pb isotope ratios.  
1040 *Geochim. Cosmochim. Acta* 68, 361–386.
- 1041 Thirlwall, M.F., Upton, B.G.J., Jenkins, C., 1993. Interaction between continental  
1042 lithosphere and the Iceland Plume – Sr, Nd, Pb, isotope geochemistry of  
1043 Tertiary basalts, NE Greenland. *Journal of Petrology* 35, 3, 839–879.
- 1044 Todt, W., Cliff, R.A., Hansen, A., Hofmann, A., 1996. Evaluation of a <sup>202</sup>Pb-<sup>205</sup>Pb  
1045 double spike for high-precision isotope analysis. In: *Earth Processes: Reading*  
1046 *the Isotopic Code* (Eds: A. Basu, S.R. Hart). *Am. Geophys. Union Geophysical*  
1047 *Monograph* 95, 429–437.

- 1048 Torsvik, T.H., Van der Voo, R., Meert, J.G., Mosar, J., Walderhaug, H.J., 2001.  
1049 Reconstructions of the continents around the North Atlantic at about the 60th  
1050 parallel. *Earth Planet. Sci. Lett.* 187, 55–69.  
1051 White, W., McKenzie, D., 1989. Magmatism at rift zones-the generation of volcanic  
1052 continental margins and flood basalts. *Journal of Geophys. Res.- Solid Earth* 94,  
1053 7685-7729.  
1054 Willbold, M., Hegner, E., Stracke, A., Rocholl, A., 2009. Continental geochemical  
1055 signatures in dacites from Iceland and implications for models of early  
1056 Archaean crust formation. *Earth Planet. Sci. Lett.* 279, 1-2, 44–52.  
1057 Wilson, S.A., 1997. The collection, preparation, and testing of USGS reference  
1058 material BCR-2, Columbia River, Basalt: U.S. Geological Survey Open-File  
1059 Report 98.

1060  
1061

### 1062 **Figure captions**

1063 Figure 1: Simplified structural map of Greenland and Northern Atlantic Igneous  
1064 Province, modified after Chauvet et al (accepted). The studied area (red square) is  
1065 located on the western volcanic margin of Greenland.

1066

1067 Figure 2: The 45 sampling sites (numbers) located on the simplified geological map  
1068 of Svartenhuk Peninsula (West Greenland), modified after Chauvet et al. (accepted).  
1069 Locations of cross sections AA', BB' and CC' are shown on the map.

1070

1071 Figure 3: Major element compositions of samples from units V1 (purple triangles),  
1072 V2 (beige circles), V3 (blue hexagons) and V4 (yellow triangles). A: Total alkali –  
1073 Silica plot (Le Bas et al., 1986). The thick black line (Macdonald and Katsura, 1964)  
1074 separates the fields of subalkaline basaltic series (below) from alkali basaltic series  
1075 (above).

1076 B: CaO vs SiO<sub>2</sub> and Ni vs SiO<sub>2</sub> plots. Compositions range from basaltic to trachytic  
1077 (the latter in V4 unit only) following olivine and plagioclase + pyroxene fractionation  
1078 trends. Dashed line identifies primitive Ni concentrations (higher than 400 ppm) and  
1079 dotted line denotes samples with MgO=12 wt%, consistent with olivine phenocryst  
1080 compositions (Mg#=0.83, supplementary table 1).

1081

1082 Figure 4: Multielement patterns of Svartenhuk samples. A: Rare earth element (REE)  
1083 patterns normalized to CI Chondrite (McDonough and Sun, 1995) for samples from  
1084 units V1 (pink), V2 (beige), V3 (blue) and V4 (yellow). Samples from V1 and V4  
1085 have comparable REE patterns with significant light REE enrichments compared with

1086 heavy REE, typical of alkali and transitional basaltic lavas. Samples from units V2  
1087 and V3 have more diverse signatures ranging from alkali to tholeiitic (LREE  
1088 depleted) patterns. B: Multielement plot normalized to Primitive mantle (McDonough  
1089 and Sun, 1995) compiling all samples (V1=purple lines, V2= beige lines, V3= blue  
1090 lines, V4= yellow lines) and the median compositions of each group (V1= purple  
1091 triangles, V2= beige circles, V3= blue hexagons, V4= yellow triangles).

1092

1093 Figure 5: Plot of SiO<sub>2</sub> vs Pb concentrations and Nb/La ratios. Continental crust  
1094 contamination typically generates SiO<sub>2</sub> and Pb enrichments (Rudnick and Fountain,  
1095 1995) associated with Nb depletions (Tang et al, 2019 and references therein)  
1096 illustrated here by low Nb/La ratios. Crustal contamination trends (black arrows) can  
1097 be identified within samples from units V1 and V2 only.

1098

1099 Figure 6: Pb, Hf, Sr and Nd isotopic data. Samples from units V1 to V4 (see figure 3  
1100 for color codes) are plotted together with basalts from the North Atlantic ridge : blue  
1101 crosses (Agranier et al., 2005; Blichert-Toft et al., 2005), Iceland : gray squares:  
1102 (Breddam, 2002; Chauvel and Hémond, 2000; Hanan and Schilling, 1997; Hanan et  
1103 al., 2000, Kitawaga et al., 2008; Kokfelt et al., 2009; Kuritani et al., 2011; Peate et al.,  
1104 2010, 2009; Sims et al., 2013; Stracke et al., 2003; Thirlwall et al., 2004; Willbold et  
1105 al., 2009) and East Greenland: orange crosses (Barker et al., 2006). Samples from this  
1106 study plot between three end-members materialized by letters Sk1, Sk2 and Sk3. The  
1107 Sk1-Sk2 trend can be accounted for by crustal contamination (Sk1 features radiogenic  
1108 Sr, and unradiogenic Pb, Hf and Nd); while Sk2-Sk3 largely overlaps with mantle like  
1109 signatures (Kitawaga et al. 2008) including North Mid-Atlantic Ridge and Iceland  
1110 basalts. Its trend in all diagrams appears to point toward the common component C of  
1111 Hanan and Graham (1996).

1112

1113 Figure 7: Pb isotopic data. Samples from this study are represented together with basalts  
1114 from Iceland (gray squares, see figure 6 for references) and East Greenland (Barker et  
1115 al., 2006) (orange crosses). The Iceland plume inner components: D, E-1 and E-2  
1116 (Kitawaga et al., 2008; Thirlwall et al., 2004) are also located in this diagram. Apart  
1117 from continental crust trend (segment Sk1-Sk2), all samples plot within in a triangle  
1118 delineated by D, E-1 and E-2.

1119

1120 Figure 8: Plots of  $^{206}\text{Pb}/^{204}\text{Pb}$ , La/Sm, Sm/Yb against La/Yb. Pb isotopes (upper  
1121 diagram) evidence crustal contamination for some V1 and V2 lavas and mantle-like  
1122 compositions for most of the sample set. La/Sm as well as Sm/Yb provide insights  
1123 about melting rates. On the Sm/Yb plot are reported for comparison the results of  
1124 simple batch melting models considering garnet bearing (red line) and spinel bearing  
1125 (green line) depleted lherzolite as proposed for Iceland by Gurenko and Chaussidon  
1126 (1995), partition coefficients by McKenzie and O’Nions (1991) and mineral  
1127 proportions by Thirlwall et al. (1993). Numbers from 0.02 to 0.1 denote F values. The  
1128 higher Sm/Yb values observed for most of V1 and V4 lavas suggest a stronger  
1129 involvement of garnet in their sources.

1130

1131 Figure 9: Plots of  $^{206}\text{Pb}/^{204}\text{Pb}$ , La/Sm and Sm/Yb against  $\Delta\text{Nb} = 1.74 + \log(\text{Nb}/\text{Y}) -$   
1132  $1.92 \log(\text{Zr}/\text{Y})$  (Fitton et al., 1997).  $\Delta\text{Nb}$  is considered as a bench marker of Iceland  
1133 plume affinity. Only samples from units V2 and V3 display negative  $\Delta\text{Nb}$ , indicative  
1134 of the contribution of “normal” upper mantle devoid of plume related enriched  
1135 component. The thick black arrows illustrate the temporal evolution of Icelandic  
1136 material contribution from V1 to V4.

1137

1138 Figure 10: Sketch summarizing the four main stages of Svartenhuk volcanism deduced  
1139 from geochemical and petrologic constraints. Sk1, Sk2 and Sk3 represent the three  
1140 geochemical reservoirs defined in figures 6 and 7. The tectonic evolution of the  
1141 lithosphere (crustal thinning) is more precisely depicted in figure 11. During V1 stage,  
1142 decompression melting affects Iceland plume-like material ascending through the  
1143 asthenosphere below an already thinned lithosphere. During V2, the ongoing crustal  
1144 thinning leads to an uprise of the isotherms and therefore to the upward propagation of  
1145 partial melting and to its increase. During the emplacement of these two first units,  
1146 geochemical signatures (benchmarked by Pb isotopes on the bottom diagram) can be  
1147 accounted for by the simple binary mixture of components Sk1 and Sk2. During V3, the  
1148 melting has propagated within Sk3 reservoir. Finally, during V4, the melting deepens  
1149 again and is once more mostly restricted to reservoir Sk2. See text for details.

1150

1151 Figure 11: Tentative tectonic sketches depicting Svartenhuk magmatic evolution in  
1152 relation with the evolution of South Baffin Bay during the Paleogene, at the times of  
1153 V1, V2-V3 and V4 emplacements. Sk1, Sk2 and Sk3 refer to crustal and mantle



1154 reservoirs discussed in the text and shown in figure 10. Convection geometry is purely  
1155 conceptual, and based on small scale convection models (Petersen et al., 2018; Simon et  
1156 al., 2009). In the V1 sketch (top left), the occurrence of Cretaceous sediments, shown in  
1157 light green suggests that crustal thinning started during the Cretaceous. The melting  
1158 zones are indicated with coloured dots. Red boxes show the location of our field and  
1159 petrologic investigations. The shaded areas on the left of some diagrams underline the  
1160 speculative character of these interpretations when extrapolated to areas located away  
1161 from our study area.

1162

1163 Table 1: Sample locations. K/Ar and Ar/Ar ages are from Chauvet et al (accepted)

1164 Table 2: Major element data (oxide wt%, total iron as Fe<sub>2</sub>O<sub>3</sub>, LOI: Loss On Ignition).

1165 Analytical methods are presented in the text.

1166 Table 3: Trace element data (ppm). Analytical methods are presented in the text.

1167 Table 4: Pb, Hf, Sr and Nd isotopic data. Analytical methods are presented in the text.

1168

1169 Supplementary Table 1: ICP-MS repeated trace element analyses for standards BHVO2,  
1170 BCR-2 and BIR1.

1171 Supplementary Table 2: MC-ICP-MS repeated Nd, Hf and Pb isotope analyses of  
1172 standards JNDi-1, JMC475 and NIST981, respectively.

1173 Supplementary Table 3: Replicated analyses of Pb, Hf, Nd and Sr isotopic compositions  
1174 of sample S39E1.

1175 Supplementary Table 4: Olivine compositions obtained on Cameca SX100 electron  
1176 microprobe at Service Commun “Microsonde Ouest” (Plouzané), at 15 kV  
1177 accelerating voltage with a probe current of 12 nA.

1178

Figure 1

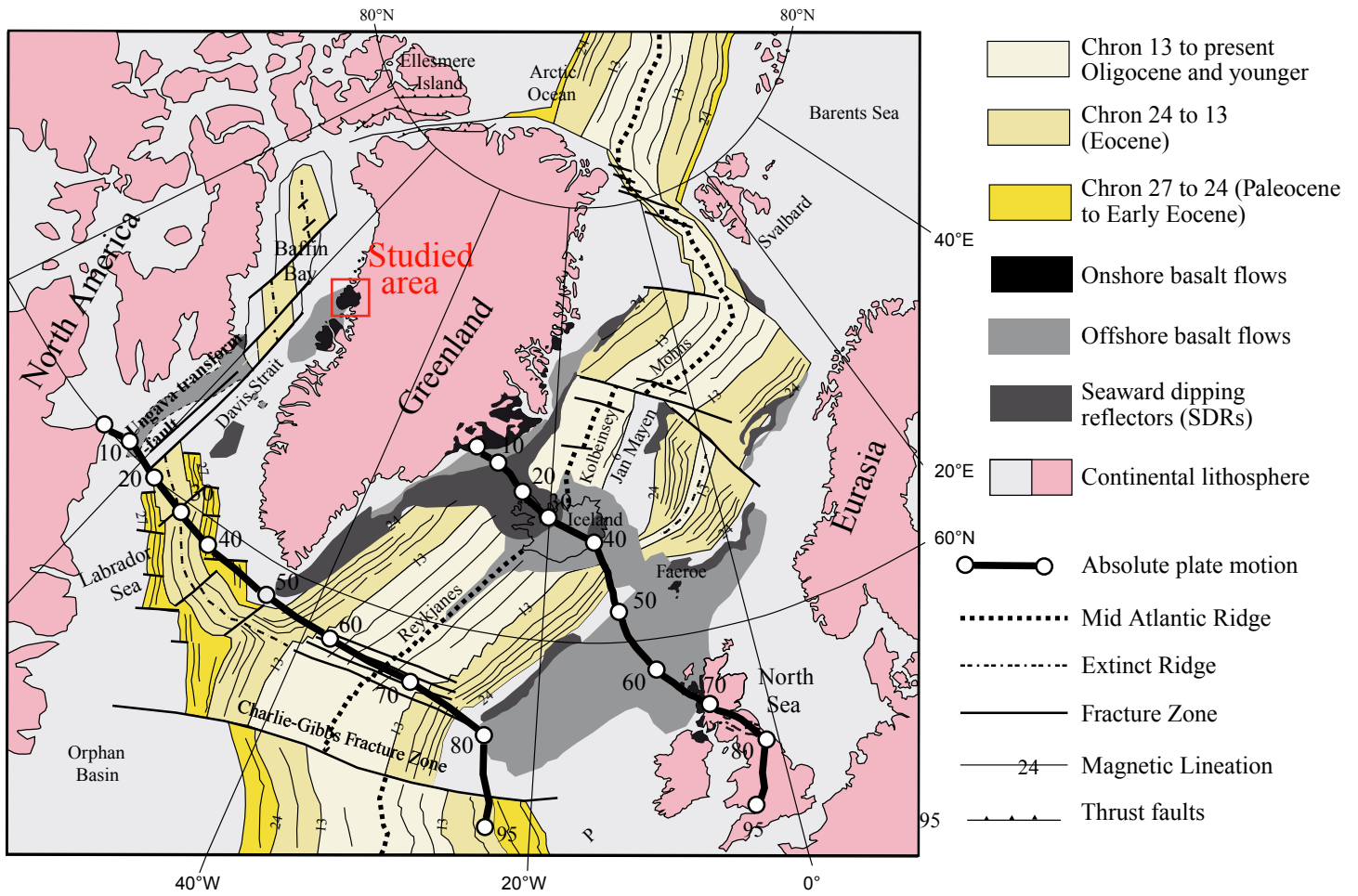
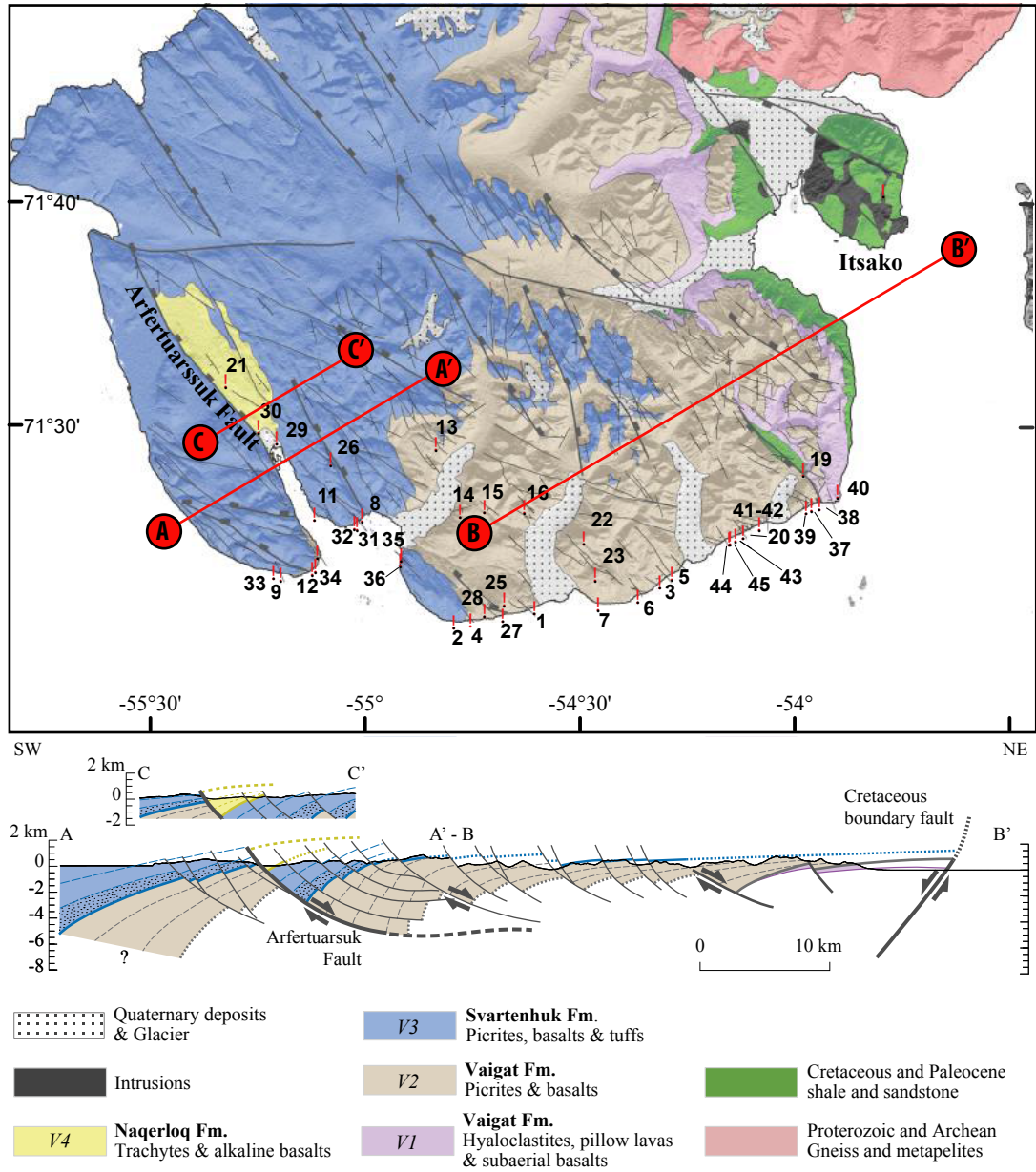
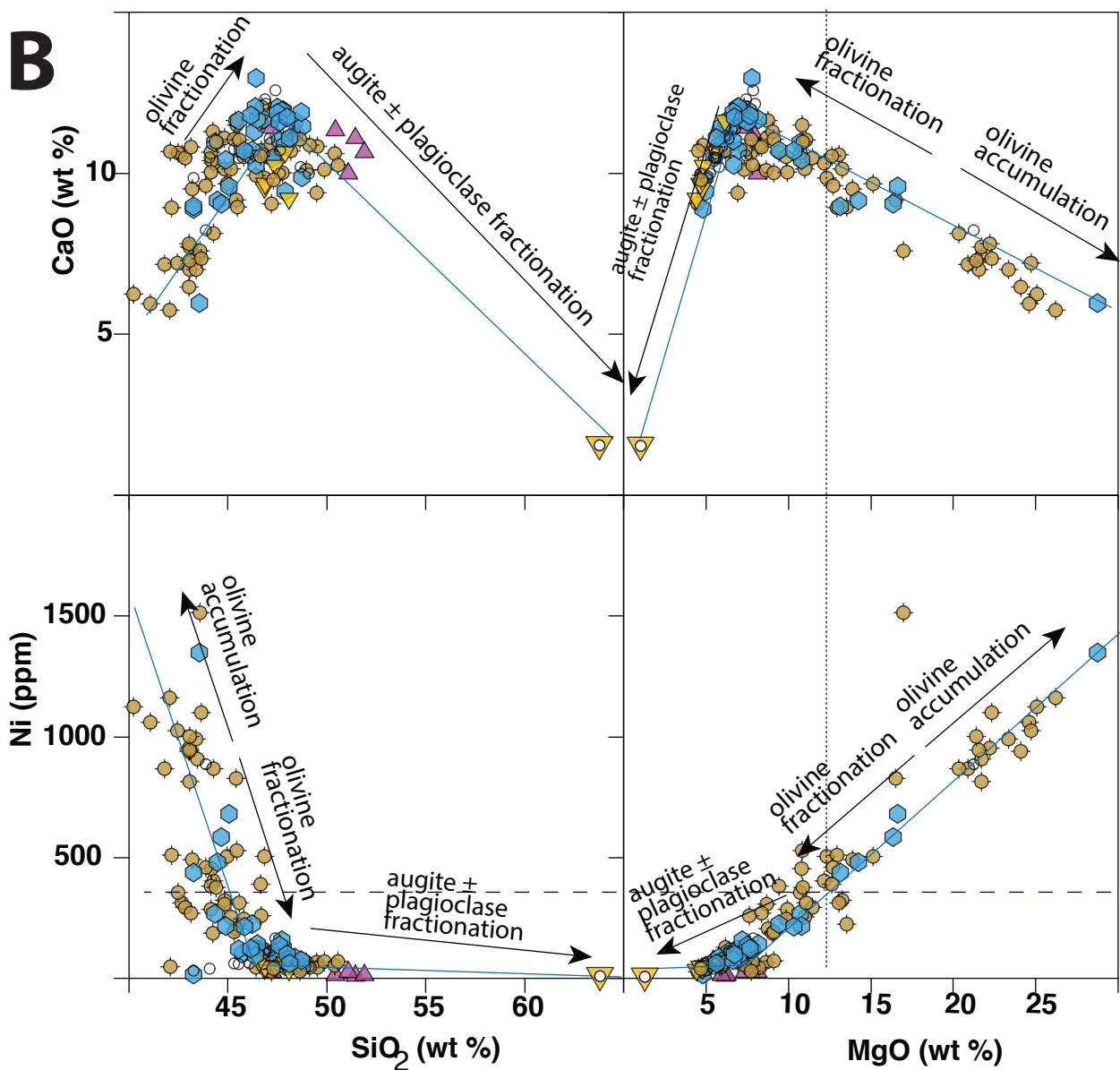
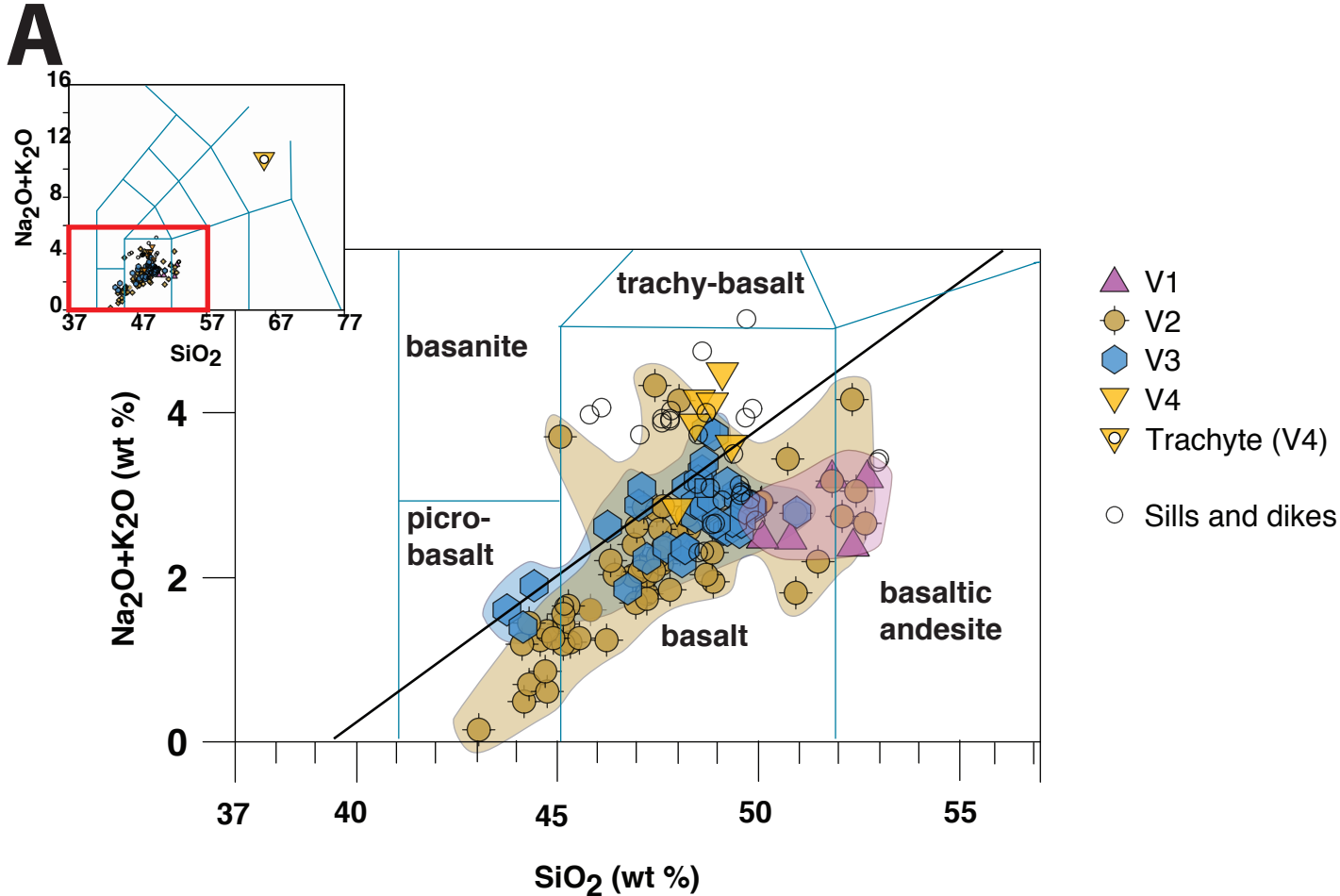
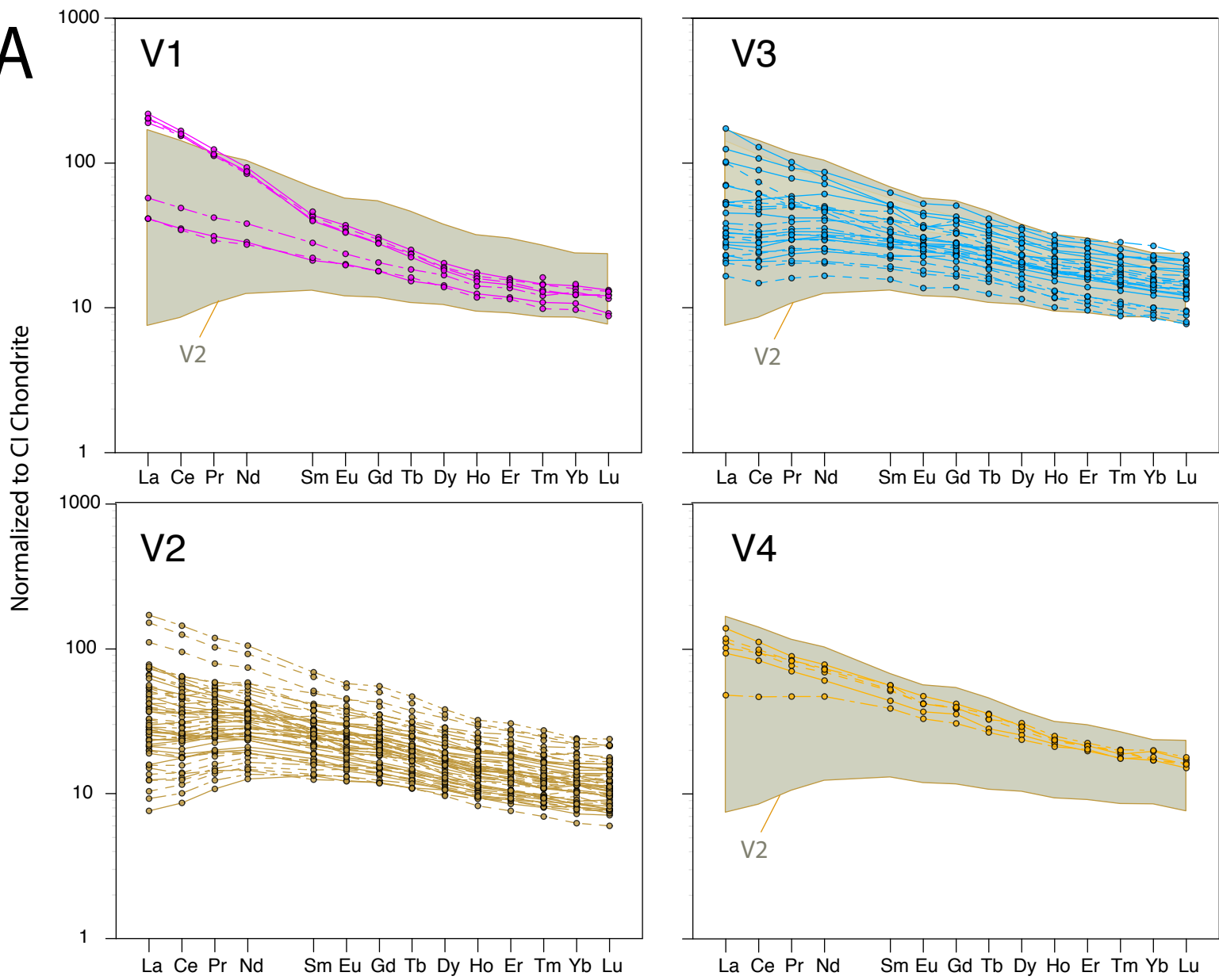
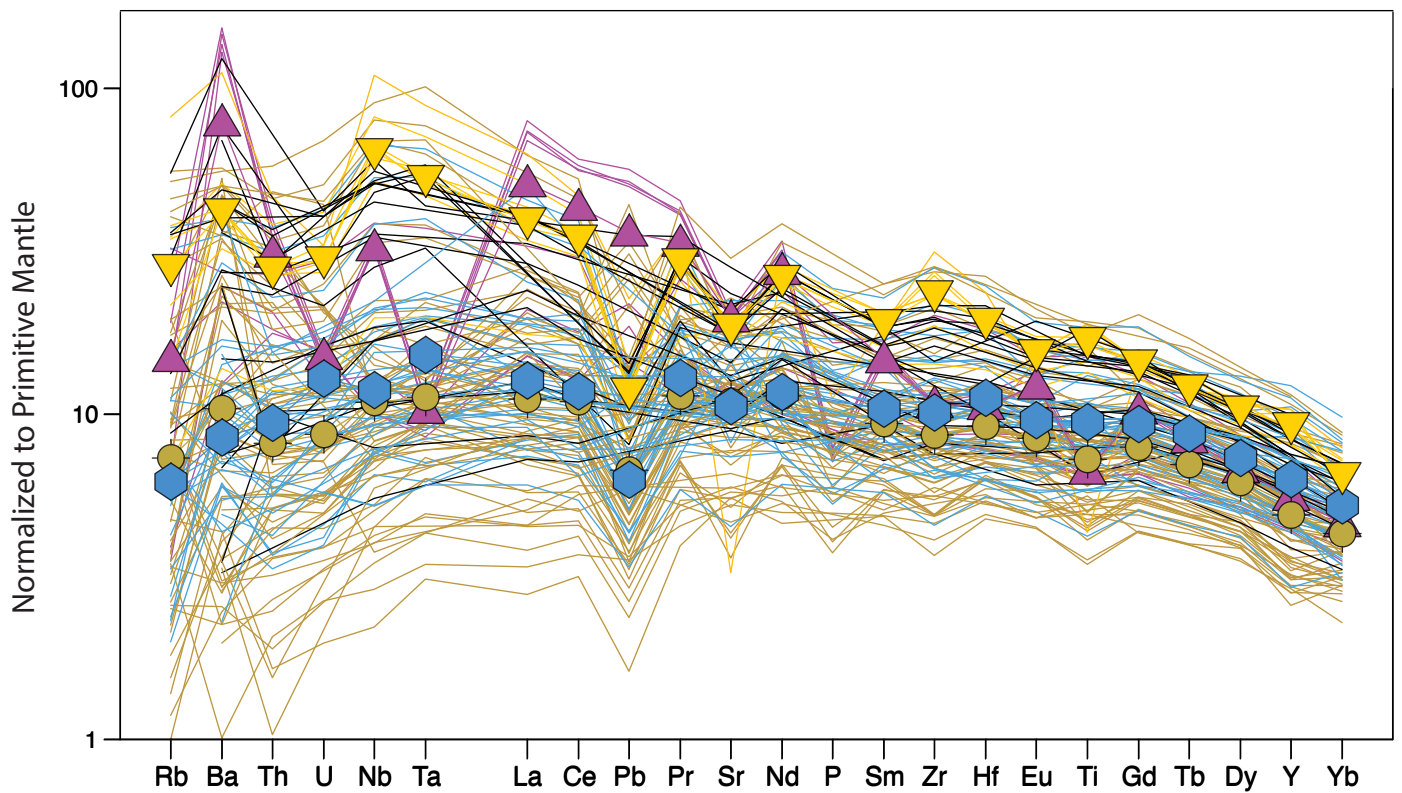
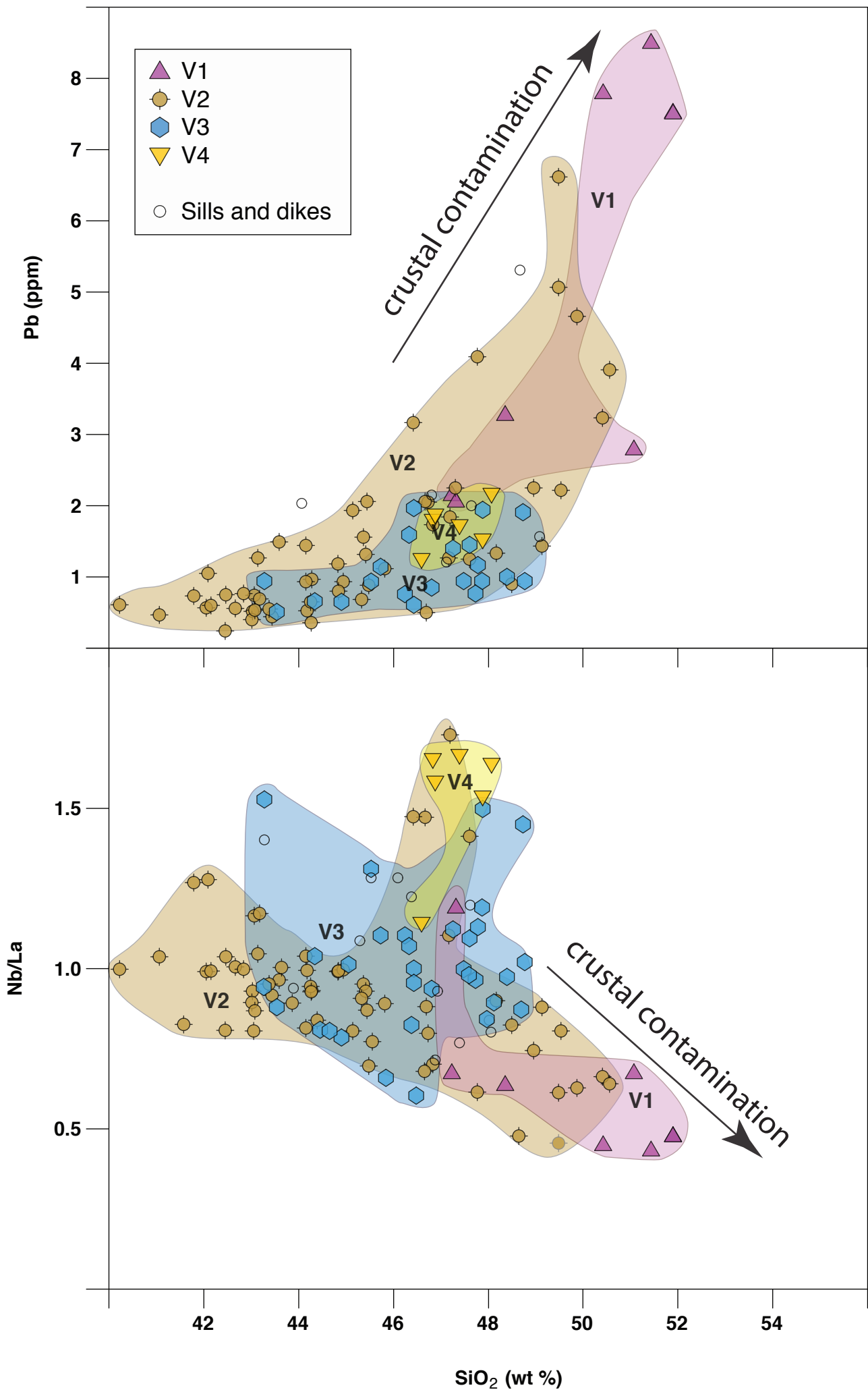


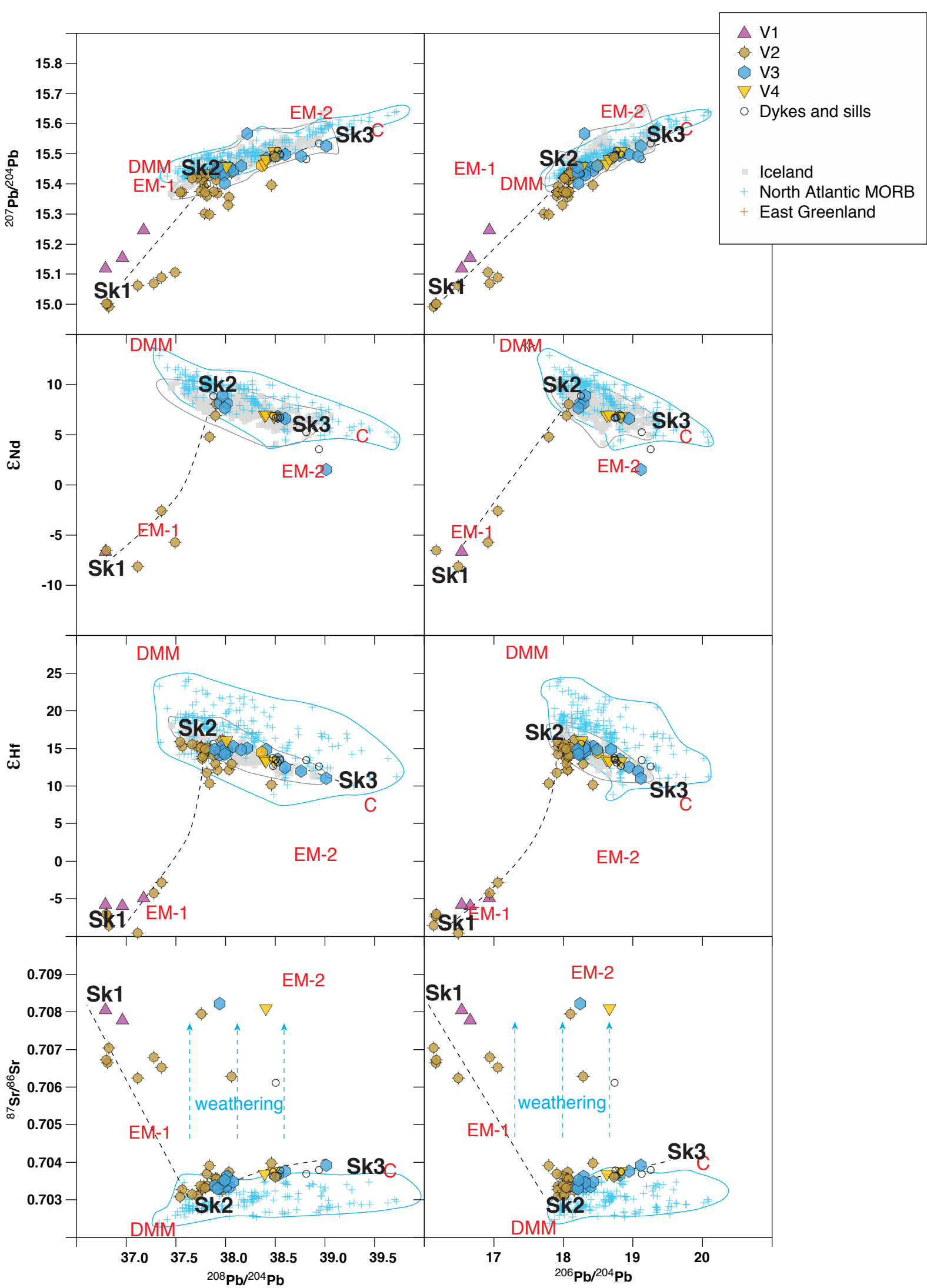
Figure 2

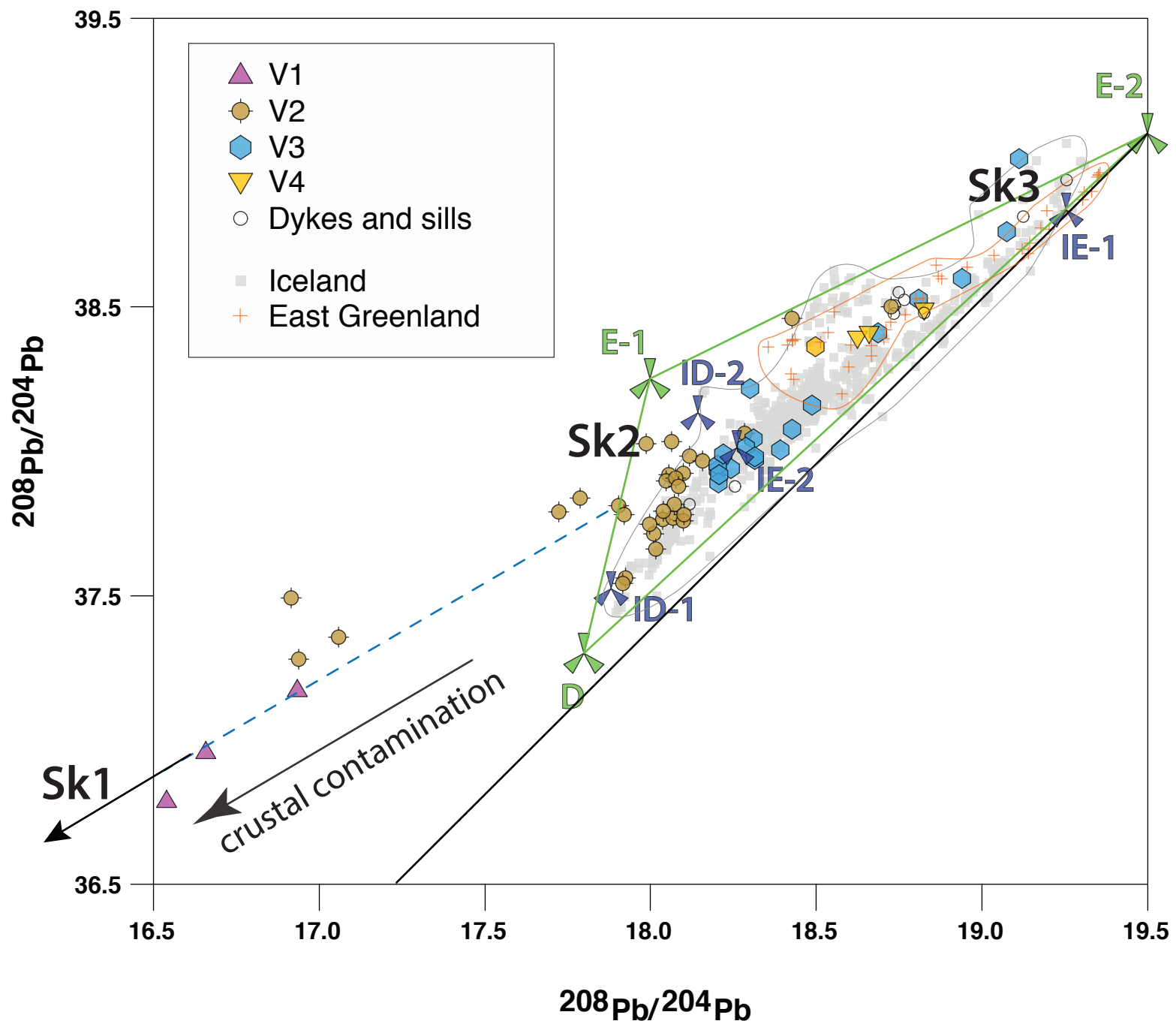




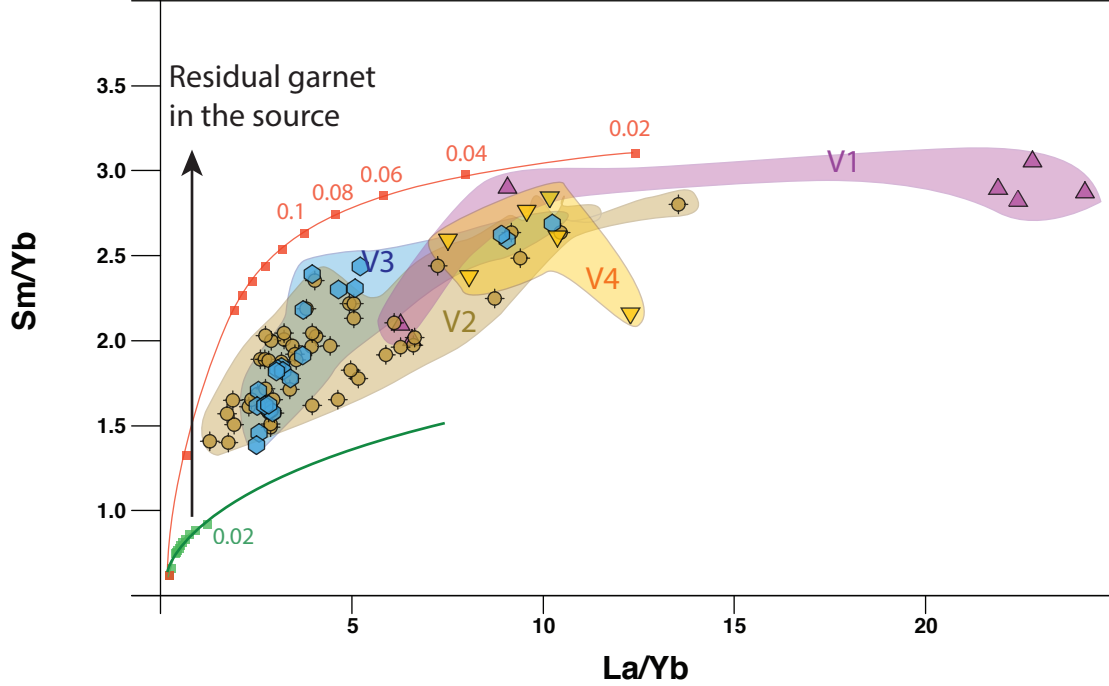
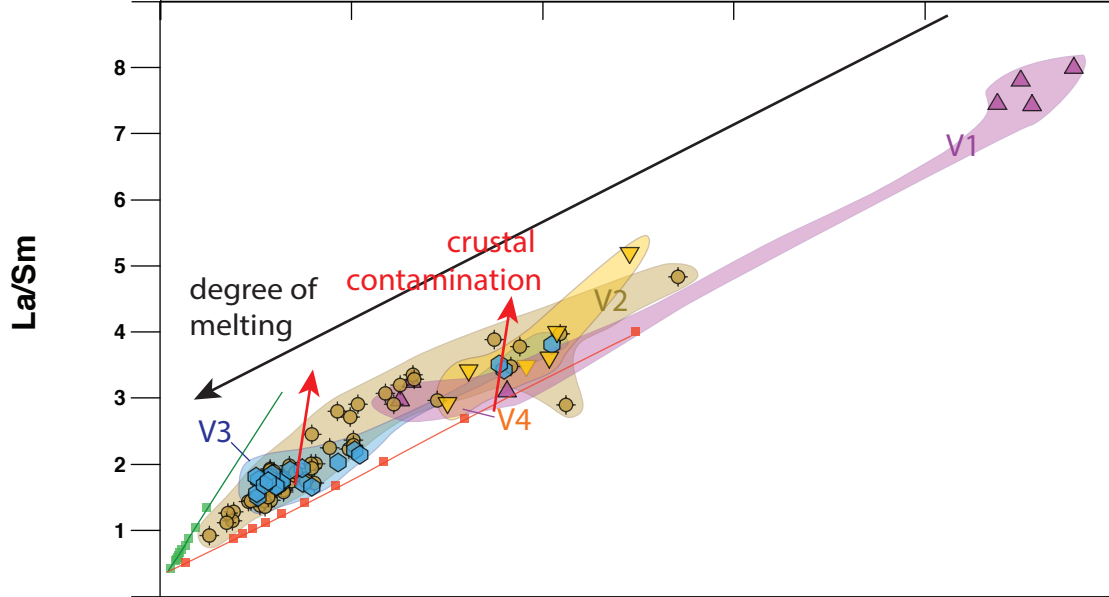
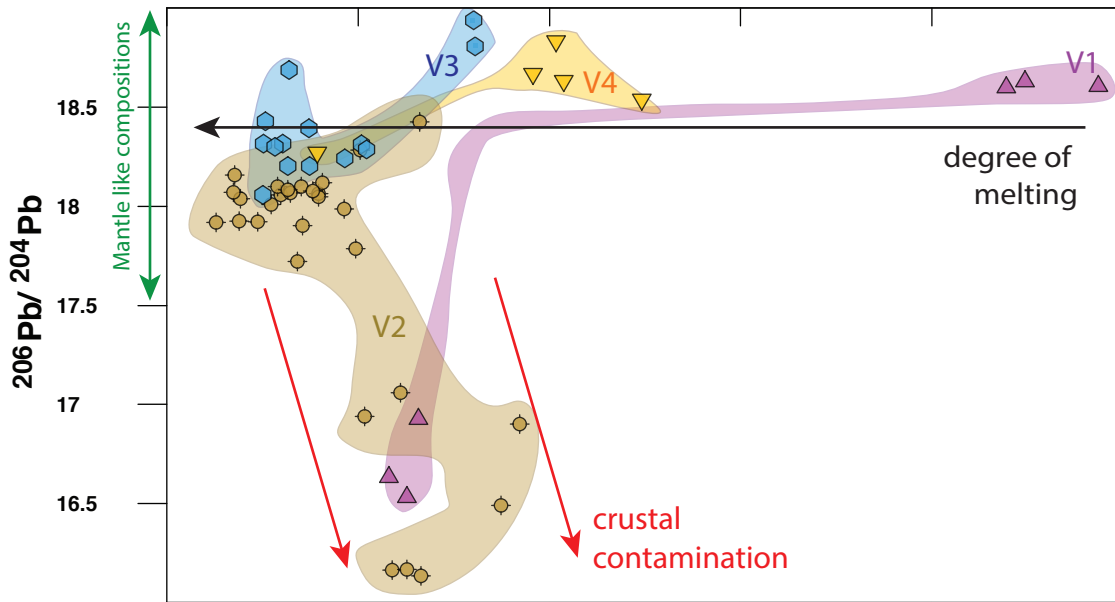
**A****B**



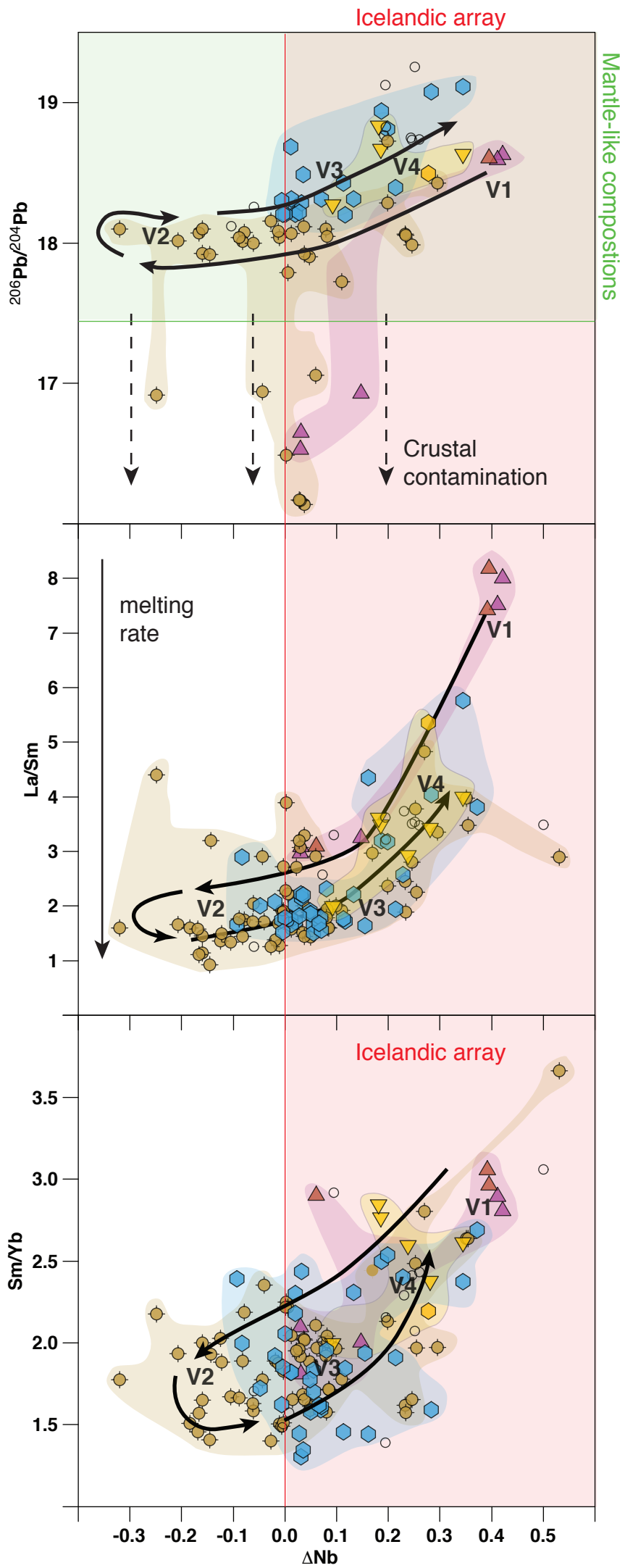


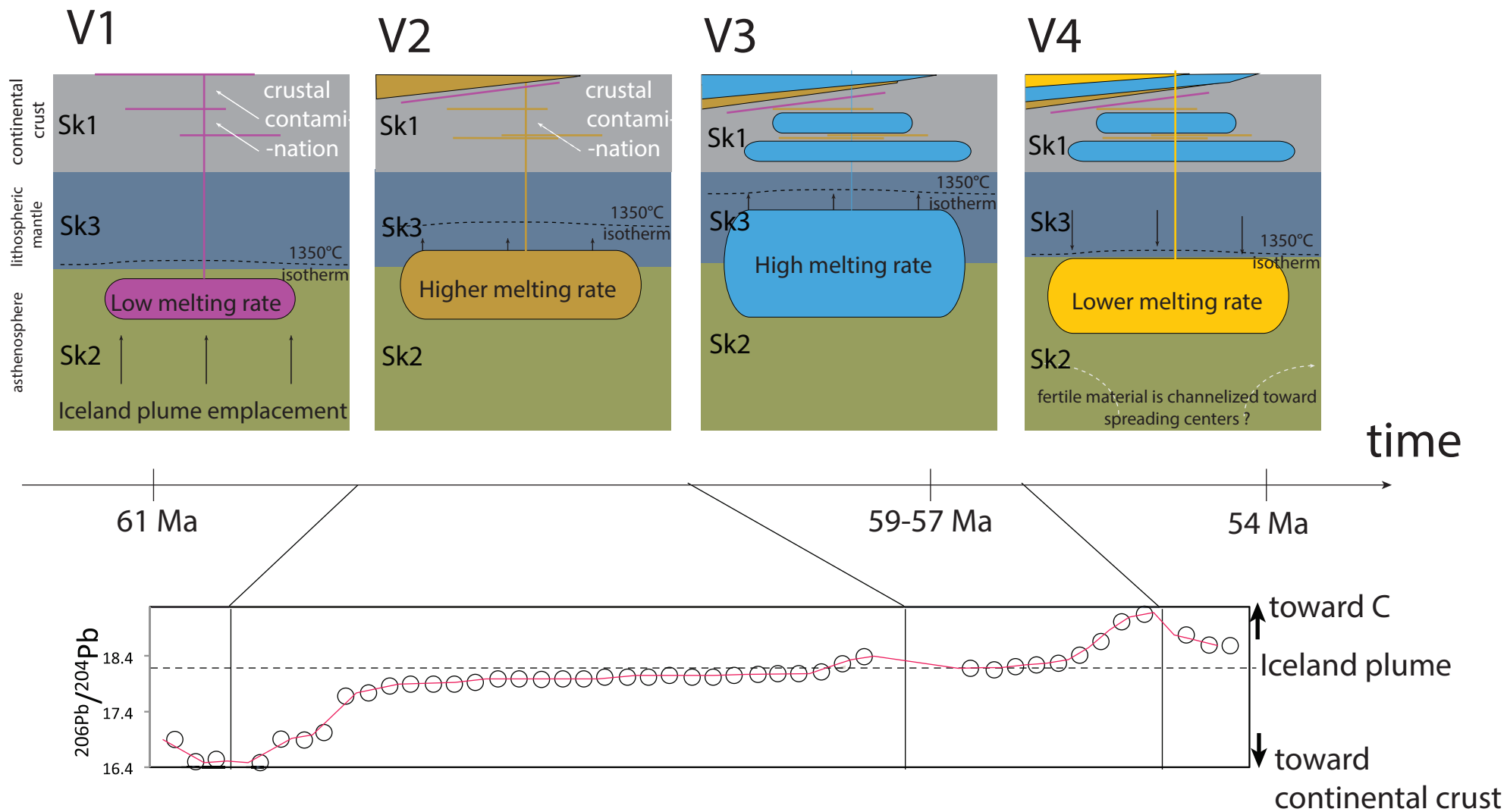


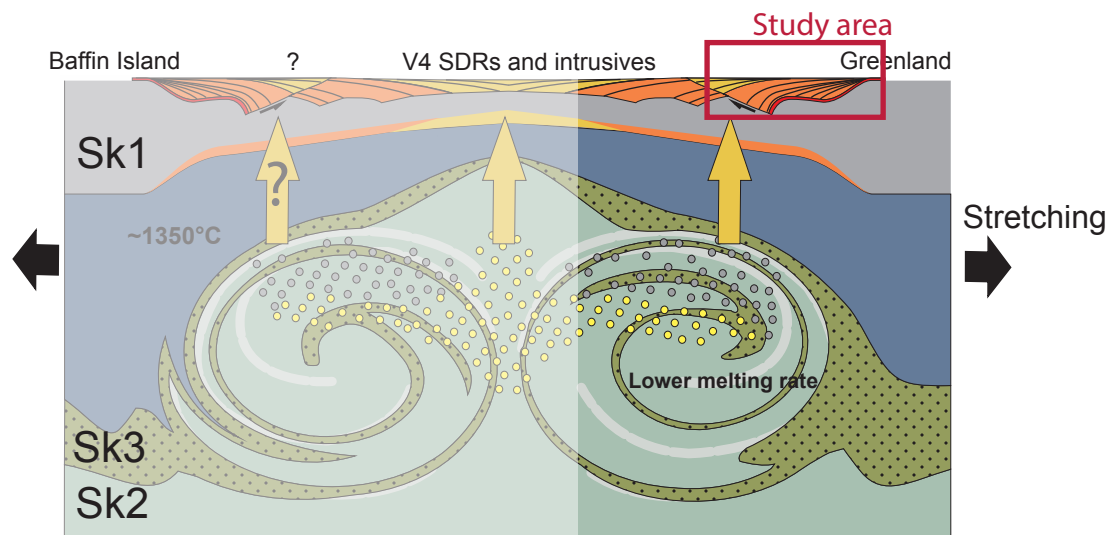
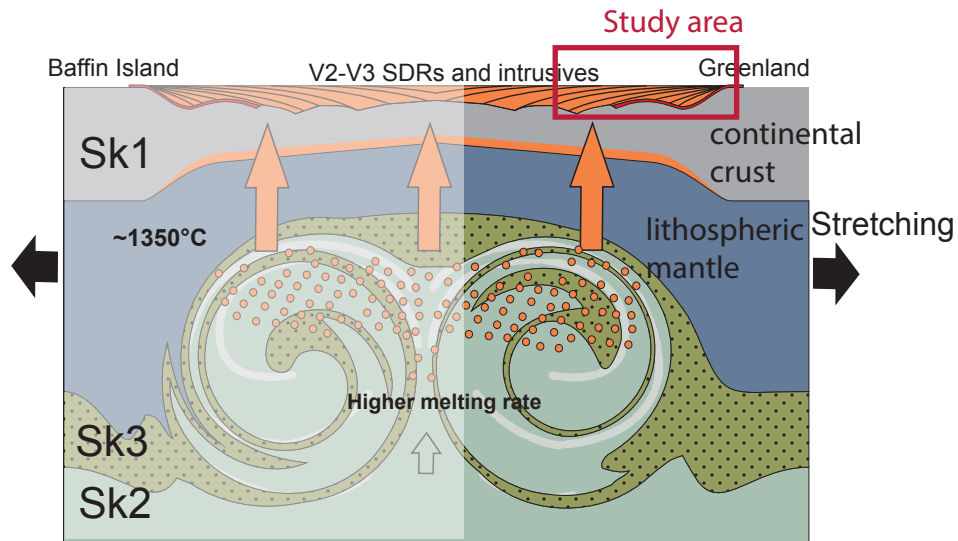
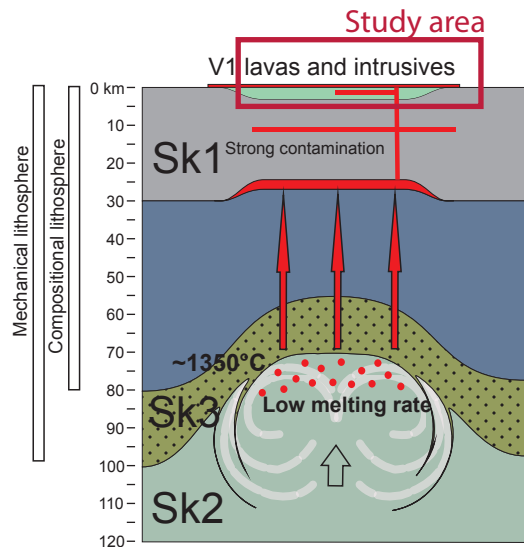




$\text{La}/\text{Yb}$







Sample names	longitude	latitude	Fm	<sup>39</sup> Ar- <sup>40</sup> Ar age	K-Ar age (My)
	Lon	lat			
S19E1	-53.974	71.470	V1		
S19E2	-53.974	71.470	V1		
S38E2	-53.936	71.446	V1		
S38E8	-53.936	71.446	V1		
S40E1	-53.899	71.455	V1		59.11 ± 0.83
S40E2	-53.899	71.455	V1		
S40E4	-53.893	71.453	V1		
S40E5	-53.893	71.453	V1		
S40E6	-54.067	71.426	V1		60.38 ± 1.34
S1E1	-54.605	71.370	V2		
S1E2	-54.605	71.370	V2		
S1E3	-54.605	71.370	V2		
S1E4	-54.606	71.370	V2		
S1E5	-54.604	71.368	V2		
S1E6	-54.607	71.369	V2		
S3E1	-54.300	71.386	V2		
S4E1	-54.679	71.363	V2		
S5E11	-54.282	71.395	V2		
S5E5	-54.288	71.394	V2		
S5E6	-54.287	71.394	V2		
S6E10	-54.359	71.374	V2		
S6E11	-54.367	71.378	V2		
S6E6	-54.364	71.378	V2		
S6E9	-54.366	71.378	V2		
S7E10	-54.458	71.371	V2		
S7E11	-54.457	71.371	V2		
S7E4	-54.461	71.372	V2		
S7E5	-54.461	71.372	V2		
S7E6	-54.456	71.370	V2		
S7E7	-54.459	71.371	V2		
S7E8	-54.455	71.370	V2		
S7E9	-54.459	71.371	V2		
S15H4	-54.719	71.438	V2		
S17H1	-54.218	71.835	V2		
S17H2	-54.224	71.834	V2		
S2014	-54.117	71.425	V2		
S20E10	-54.109	71.422	V2		
S20E15	-54.118	71.425	V2		
S20E17	-54.119	71.425	V2		
S20E7	-54.112	71.425	V2		
S22H3	-54.486	71.417	V2		
S27E10	-54.738	71.356	V2		
S27E12	-54.740	71.359	V2		
S27E13	-54.741	71.359	V2		
S27E15	-54.751	71.356	V2		
S27E17	-54.751	71.356	V2		
S27E18	-54.752	71.359	V2		
S27E20	-54.752	71.356	V2		
S37E1	-55.204	71.389	V2		
S38E10	-53.942	71.446	V2		
S38E6?	-53.936	71.446	V2		
S39E1	-53.974	71.449	V2		
S41E1	-54.066	71.432	V2		
S41E3	-54.066	71.432	V2		
S42E1	-54.074	71.432	V2		
S42E2	-54.074	71.432	V2		
S42E4	-54.082	71.431	V2		
S42E5	-54.082	71.431	V2		61.08 ± 0.56
S43E1	-54.133	71.423	V2		
S43E2	-54.134	71.423	V2		
S43E4	-54.136	71.423	V2		
S43E5	-54.136	71.423	V2		
S43E6	-54.139	71.422	V2		
S44E10	-54.163	71.419	V2		
S44E2	-54.154	71.420	V2		
S44E4	-54.156	71.420	V2		
S44E7	-54.157	71.420	V2		
S44E8	-54.159	71.420	V2		
S44E9	-54.160	71.419	V2		
S45E10	-54.151	71.420	V2		
S45E4	-54.150	71.421	V2		
S45E9	-54.151	71.420	V2		
S2E2	-54.791	71.358	V3		
S2E3	-54.792	71.358	V3		
S2E5	-54.793	71.358	V3		
S2E7	-54.791	71.355	V3		
S2E8	-54.791	71.355	V3		54.98 ± 1.16
S2E9	-54.796	71.358	V3		
S8E10	-55.006	71.437	V3		
S8E13	-55.013	71.437	V3		55.73 ± 2.49
S8E6	-55.004	71.438	V3		
S8E9	-55.003	71.436	V3		
S9E1	-55.201	71.399	V3		
S11E10	-55.102	71.436	V3		
S11E12	-55.104	71.437	V3		
S11E7	-55.110	71.435	V3		
S26H1	-55.086	71.479	V3		54.20 ± 2.88
S26H3	-55.088	71.479	V3		
S33E1	-55.206	71.393	V3		
S33E12	-55.219	71.393	V3		
S33E4	-55.206	71.393	V3		
S33E7	-55.208	71.393	V3		
S33E8	-55.210	71.393	V3		57.78 ± 1.88
S34E2	-55.118	71.401	V3		
S34E5	-55.117	71.403	V3		
S34E6	-55.120	71.399	V3		
S34E7	-55.120	71.399	V3		
S35E1	-54.920	71.408	V3		
S35E11	-54.916	71.410	V3		
S35E12	-54.916	71.410	V3		
S35E3	-54.919	71.408	V3		
S35E5	-54.918	71.409	V3		59.78 ± 0.41 59.15 ± 0.85
S35E7	-54.917	71.409	V3		
S35E8	-54.917	71.410	V3		
S36E1	-54.922	71.404	V3		
S36E4	-54.922	71.403	V3		
S36E5	-54.922	71.403	V3		
S21H1	-55.338	71.541	V4		55.20 ± 0.79 55.86 ± 1.25
S21H2	-55.340	71.541	V4		
S29E2	-55.218	71.495	V4		
S30E1	-55.249	71.502	V4		54.39 ± 0.60 59.07 ± 1.16
S30E2	-55.236	71.503	V4		
S30E3	-55.244	71.503	V4		57.96 ± 1.20
S30E4	-55.241	71.502	V4		58.73 ± 1.53
S11E9	-55.118	71.435	dike		
S13H1	-54.823	71.489	dike		
S13H5	-54.823	71.489	dike		
S14H1a	-54.773	71.438	dike		
S14H2	-54.773	71.438	dike		56.43 ± 1.06
S15H3	-54.719	71.438	dike		
S16H1	-54.635	71.441	dike		
S16H2	-54.635	71.441	dike		
S16H4	-54.635	71.441	dike		
S20E18	-54.108	71.422	dike		55.42 ± 1.91
S22H2	-54.491	71.423	sill		53.85 ± 2.84
S22H4	-54.486	71.417	dike		54.41 ± 0.99
S23H1	-54.456	71.390	dike		
S23H4	-54.456	71.390	dike V3		58.98 ± 0.93
S23H5	-54.456	71.390	dike		
S24H1	-53.783	71.679	Sill Itsako		55.31 ± 1.09
S27E4	-54.752	71.356	dike		55.95 ± 0.88
S27E8	-54.738	71.356	dike		
S41E2	-54.060	71.426	dike		

Sample names	Fm.	wt. %	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	FeO*	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	LOI	total
S19E1	V1	44.8	1.38	11.9	11.4	0.2	13.2	10.1	1.57	0.15	0.15	4.27	100.5	
S19E2	V1	31.1	1.41	11.1	0.17	21.6	7.0	1.15	0.05	0.12	3.87	99.7		
S38E2	V1	47.2	1.29	14.8	9.5	0.19	7.4	11.5	2.1	0.26	0.15	3.65	99.0	
S38E8	V1	51.1	1.29	14.5	9.9	0.16	8.2	10.0	2.13	0.21	0.15	2.03	100.7	
S40E1	V1	51.4	1.32	14.6	9.4	0.17	6.2	11.1	2.56	0.59	0.17	1.37	100.0	
S40E2	V1	50.4	1.33	14.9	9.4	0.21	6.3	11.4	2.63	0.51	0.17	1.94	100.3	
S40E4	V1	51.9	1.37	14.9	9.5	0.16	6.0	10.7	2.73	0.61	0.16	1.07	100.1	
S40E5	V1	47.3	1.4	13.7	12.7	0.2	5.4	10.5	2.83	0.16	0.36	0.91	99.5	
S40E6	V1	52.5	1.33	15.2	9.5	0.17	6.2	10.6	2.72	0.68	0.16	1.29	101.3	
S1E1	V2	43.9	1.45	11.6	10.7	0.16	12.7	9.6	1.93	0.15	0.17	1.1	94.6	
S1E2	V2	41.6	0.91	8.1	10.8	0.17	23.4	7.2	0.75	0.05	0.12	5.65	99.9	
S1E3	V2	43.1	1.01	9.4	11.1	0.17	21.6	7.0	1.15	0.05	0.12	3.87	99.7	
S1E4	V2	45.6	1.44	13.2	10.8	0.18	11.1	11.0	2.09	0.17	0.16	1.12	98.0	
S1E5	V2	46.7	1.82	15.6	10.3	0.19	7.3	12.1	2.3	0.37	0.22	2.63	100.7	
S1E6	V2	44.4	1.44	12.9	10.8	0.2	10.9	11.0	1.86	0.08	0.16	5.52	100.4	
S3E1	V2	47.3	4.11	12.6	15.1	0.25	4.7	9.8	2.91	1.18	0.54	-0.58	99.6	
S4E1	V2	45.3	1.66	13.9	11.0	0.18	9.1	11.1	2.49	0.24	0.14	3.63	100.0	
S5E11	V2	49.5	1.02	12.7	8.5	0.17	13.0	6.5	1.88	0.99	0.12	3.79	99.1	
S5E5	V2	49.0	1.37	13.9	10.1	0.26	8.7	10.1	2.13	0.54	0.15	2.46	99.7	
S5E6	V2	49.5	1.56	14.6	9.2	0.17	8.2	10.8	2.52	0.84	0.17	1.96	100.6	
S6E10	V2	42.1	3.8	13.0	13.5	0.21	5.9	10.7	2.74	0.72	0.71	2.69	97.6	
S6E11	V2	43.1	1.1	9.1	11.3	0.18	21.7	7.7	0.82	0.31	0.13	5.88	102.5	
S6E6	V2	44.6	1.04	9.5	11.4	0.17	21.7	7.4	1.24	0.14	0.11	3.02	100.5	
S6E9	V2	41.8	1.08	9.0	10.9	0.17	20.9	7.2	0.87	0.26	0.12	5.9	99.9	
S7E10	V2	42.7	1.52	11.7	11.3	0.19	13.1	10.6	1.09	0.06	0.16	7.47	101.0	
S7E11	V2	41.1	0.99	8.4	10.7	0.17	24.6	6.0	0.6	0.06	0.11	5.96	99.8	
S7E4	V2	44.2	1.58	12.4	12.2	0.25	10.8	10.4	2.14	0.12	0.17	4.85	100.4	
S7E5	V2	42.1	1.01	7.7	10.4	0.17	26.2	5.8	0.51	0.07	0.12	6.28	101.4	
S7E6	V2	44.9	1.51	11.3	11.2	0.19	15.1	9.7	1.4	0.22	0.15	4.36	101.3	
S7E7	V2	40.2	1.01	7.4	10.4	0.16	25.1	6.3	0.38	0.07	0.11	7.07	99.3	
S7E8	V2	46.4	4.11	12.9	14.8	0.25	4.7	9.9	2.79	1.46	0.59	0.5	100.0	
S7E9	V2	45.4	1.26	13.9	10.1	0.15	10.8	11.5	1.58	0.17	0.12	4.46	100.6	
S15H4	V2	42.5	0.84	8.5	11.0	0.18	24.7	7.2	1.01	0.13	0.11	3.32	100.7	
S17H1	V2	49.1	2.18	15.5	12.4	0.21	4.8	10.9	2.7	0.15	0.23	1.39	100.9	
S17H2	V2	48.2	2.16	15.1	12.3	0.2	4.6	10.7	2.59	0.22	0.23	1.83	99.4	
S20I4	V2	44.8	1.77	13.1	10.7	0.22	8.7	11.1	2.16	0.24	0.17	3.66	97.7	
S20E10	V2?	48.5	2.2	13.6	13.0	0.22	5.8	11.3	2.67	0.29	0.22	0.52	99.8	
S20E15	V2	45.4	1.43	10.8	11.3	0.18	16.5	9.2	1.68	0.28	0.16	2.06	100.2	
S20E17	V2	43.0	1.02	8.4	12.1	0.18	24.1	6.5	1.06	0.13	0.12	3.87	101.8	
S20E7	V2	45.4	1.61	13.9	10.6	0.18	8.8	11.6	2	0.21	0.18	3.64	99.2	
S22H3	V2	47.2	2.47	13.1	13.3	0.23	5.9	10.9	2.46	0.35	0.27	0.63	98.2	
S27E10	V2	46.7	2.53	14.8	11.3	0.19	6.2	10.7	2.69	0.9	0.35	0.82	98.3	
S27E12	V2	43.4	1.1	8.5	11.7	0.18	23.3	7.0	1.12	0.09	0.1	1.5	99.4	
S27E13	V2	46.7	1.72	12.9	11.2	0.17	12.6	10.5	2.01	0.12	0.16	1.61	100.9	
S27E15	V2	46.7	1.85	13.8	11.0	0.18	7.6	11.6	2.37	0.16	0.2	1.77	98.4	
S27E17	V2	47.2	1.35	13.7	14.1	0.23	4.5	9.0	3.44	1.17	0.4	1.05	99.7	
S27E18	V2	45.8	1.45	13.3	10.5	0.15	9.8	10.5	2	0.16	0.13	3.13	98.1	
S27E20	V2	47.6	2.62	13.5	12.2	0.2	7.4	10.7	2.41	0.6	0.31	0.98	99.9	
S37E1	V2	38.4	0.59	5.0	9.3	0.15	32.4	3.1	0.1	0.04	0.07	10.07	100.3	
S38E10	V2	44.3	1.37	12.5	11.0	0.19	12.2	10.3	1.68	0.21	0.13	2.67	97.7	
S38E6	V2	48.6	1.18	14.5	9.0	0.15	7.8	11.1	1.88	0.19	0.13	5.06	100.6	
S39E1	V2	49.6	1.35	14.1	9.1	0.15	6.9	9.4	2.8	0.65	0.16	4	99.6	
S41E1	V2	45.5	1.09	12.0	9.9	0.17	13.5	9.0	1.57	0.24	0.11	4.08	98.3	
S41E3	V2	49.9	1.32	14.1	9.2	0.16	7.3	10.1	2.1	0.41	0.15	2.64	98.4	
S42E1	V2	46.8	1.24	12.8	10.9	0.18	12.3	9.9	1.74	0.22	0.13	3.33	100.7	
S42E2	V2	50.4	1.36	14.3	9.5	0.17	7.7	10.6	2.4	0.25	0.15	2.32	100.2	
S42E4	V2	48.1	2.1	14.1	9.6	0.19	9.1	10.0	1.28	0.42	0.13	3.1	98.0	
S42E5	V2	50.6	1.38	14.4	9.7	0.17	7.8	10.3	2.67	0.42	0.16	1.89	100.5	
S43E1	V2	43.2	1.24	11.7	11.3	0.18	13.9	9.5	1.67	0.23	0.13	6.72	101.0	
S43E2	V2	42.2	1.2	11.3	11.0	0.16	12.9	8.9	1.43	0.12	0.12	7.91	98.4	
S43E4	V2	42.5	1.6	12.5	11.3	0.2	10.7	10.6	1.94	0.08	0.16	7.61	100.6	
S43E5	V2	42.8	1.3	12.7	9.9	0.2	11.5	10.5	1.81	0.13	0.13	7.01	99.0	
S43E6	V2	44.3	1.53	14.1	11.2	0.2	9.0	11.3	1.98	0.49	0.14	5.46	100.9	
S44E10	V2	43.7	1.11	9.1	11.3	0.18	22.3	7.4	1.39	0.11	0.15	3.2	101.1	
S44E2	V2	43.6	1.38	9.5	11.3	0.17	17.0	7.6	1.7	0.22	0.15	5.05	99.0	
S44E4	V2	43.1	1.94	12.3	11.9	0.2	8.4	10.8	2.45	0.16	0.22	5.63	98.5	
S44E7	V2	44.2	1.7	12.8	11.3	0.19	9.4	10.7	2.54	0.07	0.2	6	100.3	
S44E8	V2	44.3	1.12	10.1	10.8	0.16	20.3	8.1	1.46	0.09	0.14	2.74	100.6	
S44E9	V2	43.1	1.12	9.1	11.3	0.18	21.4	7.3	1.43	0.14	0.15	2.1	98.5	
S45E10	V2	44.2	1.74	12.3	12.0	0.18	9.9	10.0	2.09	0.3	0.19	5.97	100.2	
S45E4	V2	43.0	0.96	9.7	10.8	0.18	22.2	7.8	1.22	0.08	0.09	2.69	100.0	
S45E9	V2	45.1	1.69	12.0	11.4	0.18	11.0	10.1	2.11	0.27	0.18	4.39	99.8	
S2E2	V3	43.3	1.54	11.4	10.8	0.17	13.1	9.0	2.13	0.52	0.15	5.82	99.0	
S2E3	V3	45.7	2.28	13.5	10.8	0.19	7.0	10.7	3.31	0.25	0.24	2.83	98.0	
S2E5	V3	46.2	1.92	13.2	11.1	0.18	9.4	10.7	2.4	0.57	0.2	2.11	99.3	
S2E7	V3	47.9	3.97	12.7	14.6	0.23	5.0	9.4	2.63	1.02	0.52	0.34	99.9	
S2E8	V3	48.7	3.09	13.7	12.9	0.21	4.9	9.9	3.05	0.91	0.4	0.98	100.2	
S2E9	V3	46.4	2.7	13.6	12.3	0.22	6.7	10.3	2.87	0.28	0.25	2.17	99.1	
S8E10	V3	44.6	1.36	13.0	11.0	0.18	10.8	10.4	2.1	0.13	0.13	4.3	99.6	
S8E13	V3	48.0	1.9	13.5	12.0	0.2	6.7	11.7	2.35	0.24	0.18	0.6	98.7	
S8E6	V3	46.2	1.68	14.5	11.4	0.19	7.7	11.8	2.03	0.22	0.18	3.88	101.0	
S8E9	V3	43.3	3.72	12.7	14.4	0.21	4.8	8.9	2.39	1.04	0.47	4.71	98.3	
S9E1	V3	48.1	2.27	14.0	12.8	0.22	5.6	11.1	2.56	0.33	0.23	0.8	99.4	
S11E10	V3	48.4	1.79	13.9	10.0	0.18	6.2	11.6	2.46	0.19	0.17	1.83	97.9	
S11E12	V3	47.2	1.89	14.2	10.7	0.17	6.9	12.0	2.26	0.19	0.17	2.4	99.5	
S11E7	V3	48.7	1.72	14.0	11.6	0.19	6.6	11.9	2.64	0.16	0.16	2.61	101.7	
S26H1	V3	48.8	2.13	14.3	12.5	0.21	6.0	11.5	2.49	0.3	0.22	0.21	99.8	
S26H3	V3	47.9	2.58	13.2	12.5	0.22	5.8	10.9	2.41	0.32	0.28	3.09	100.5	
S33E1	V3	44.5	1.23	11.7	10.4	0.17	14.3	9.2	2.12	0.79	0.12	5.25	100.8	
S33E12	V3	44.7	1.31	13.5	10.7	0.17	10.7	11.0	1.92	0.18	0.12	5.02	100.1	
S33E4	V3	41.7	0.85	8.3	11.5	0.18	22.6	6.9	1.49	0.3	0.1	4.69	99.9	
S33E7	V3	44.7	1.23	11.2	11.3	0.19	16.4	9.1	2.08	0.45	0.14	2.26	100.1	
S33E8	V3	46.5	1.62	14.3	10.6	0.18	8.2	11.7	2.52	0.27	0.15	3.49	100.6	
S34E2	V3	45.1	1.18	11.5	10.3	0.17	16.6	9.6	1.62	0.17	0.12	2.44	100.0	
S34E5	V3	46.8	1.82	13.7	11.4	0.19	7.1	11.7	2.22	0.24	0.17	1.62	98.2	
S34E6	V3	46.4	1.8	14.0	10.8	0.18	7.8	13.0	2.06	0.2	0.13	2.37	100.0	
S34E7	V3	47.3	2.84	12.6	1									

Sample names	Frm.	ppm	Li	Be	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Tm	Yb	Lu	Hf	Ta	Pb	Th	U		
S1961	V1	4.24	0.42	32.4	7296	263	648	613	324	114	77.2	13.4	1.81	282	193	75.5	6.21	0.04	57.4	6.27	157	22.8	11.3	3.27	10.7	0.62	36.9	0.75	19.2	22.7	18.4	0.26	2.2	0.41	0.01	1.18	0.6	0.16		
S1962	V1	6.63	0.64	34.4	7518	288	448	423	45.1	41.9	87.3	23.4	1.74	2.12	238	216	90.8	6.88	163	13.6	30.389	17.4	4.16	13.6	0.57	40.9	4.13	7.17	2.19	0.3	2.07	0.28	0.47	0.08	3.28	1.64	0.25			
S3862	V1	6.69	0.72	34.4	7708	285	401	39.2	33.1	25.7	68.9	20.3	1.59	2.34	238	192	85.4	6.59	187	9.76	21.6	29	13	3.14	13.3	0.55	30.7	6.88	1.89	0.27	1.73	0.23	0.08	0.16	2.14	1.41	0.32			
S3868	V1	10.1	0.69	34.4	7862	283	422	39.3	30.9	25.5	76	18.7	1.56	9.38	250	189	85	6.61	0.26	146	97.9	21.2	27	12.5	3.28	11.1	0.59	35.6	3.42	6.05	1.84	0.24	1.56	0.22	0.21	0.32	0.22	1.84	1.45	0.31
S4061	V1	5.93	0.8	37	8142	279	463	41.5	38.1	55.1	91.8	20.6	2.03	8.36	245	209	91	6.51	0.01	96.5	20.6	21.5	23.5	2.55	3.36	2.21	0.56	2.36	2.24	0.33	0.36	0.41	0.24	8.4	3.18	0.32				
S4062	V1	7.4	0.78	37.4	8162	272	297	33.2	18.5	25.5	87.1	20.4	1.87	4.07	395	242	112	21.5	0.04	856	47.6	20.4	10.6	8.66	1.98	5.9	4.7	1.29	0.36	2.18	0.32	0.19	0.42	11.9	7.79	3	0.3			
S4064	V1	6.01	0.82	36.3	8279	276	284	31.7	17.4	25.4	88.4	20.3	1.94	1.15	390	239	114	21.5	0.27	905	44.9	94.6	10.4	38.4	6.03	1.89	8.64	5.6	4.61	0.87	2.4	0.33	1.97	0.3	3	0.38	0.2	7.52	2.78	0.28
S4065	V1	5.13	1.21	39.4	8260	402	98.8	41.4	77.3	23.4	11.1	23.4	20.1	1.94	390	315	211	25.4	0.23	800	21.3	50.6	6.62	30	6.83	2.31	1.07	7.18	5.81	1.09	2.92	0.4	2.35	0.32	5.16	1.38	0.37	2.04	0.6	
S4066	V1	9.82	0.79	36.5	7910	276	270	31.5	12.7	22.1	81.3	20.3	1.91	15.3	391	237	112	21.1	0.36	1017	48.2	97.5	107	39.9	5.88	1.86	0.81	5.52	4.46	0.83	2.31	0.27	1.98	0.3	0.37	0.38	0.18	7.63	2.8	0.29
S161	V2	31.81	304.93	411.77	62.86	458.99	210.39	19.53	82.26	4.88	1892	44.7	24.7	10.93	2.67	1.01	3.7	3.6	2.22	1.69																		0.35		
S162	V2	23.13	217.59	1226.42	88.54	1119.58	64.69	13.01	50.32	2.16	1.86	2.61	5.5	6.1	1.65	0.62	2.17	2.32	1.58	1.13																		0.25		
S163	V2	2.97	0.38	28.8	5935	221	1422	86.4	946	84.7	73	13.4	1.11	2.08	10.5	13.8	48.5	1.91	0.06	6.67	2.2	6.19	1.15	6.23	1.98	0.74	0.42	2.47	2.67	0.53	1.47	0.21	1.26	0.19	1.53	0.13	0.54	0.17	0.05	
S164	V2	7.92	1.32	26.9	6866	185	1124	51.3	279	43	67.7	17.2	1.04	24.3	157	101	71.8	0.57	233	15.7	33.3	4.1	18.6	3.5	0.41	16.6	3.63	0.67	1.83	0.27	1.64	0.24	0.45	0.41	6.62	0.83	0.88			
S165	V2	2.9	0.48	26.2	11020	272	392	41.1	55	42.5	82.1	18.1	1.58	5.44	320	245	85.1	14.7	0.07	17.5	18.4	36.8	4.52	19.6	3.81	1.53	0.61	3.97	3.31	0.63	1.69	0.23	1.36	0.19	2.33	0.83	0.31	2.05	1.14	0.33
S166	V2	36.13	342.99	793.46	59.71	376.77	186.68	21.05	79.51	4.25	1953	50.7	11.42	10.32	2.95	1.1	3.61	3.8	2.18	1.81																	0.3			
S361	V2	4.54	1.36	33.6	22770	413.69	36.46	46.17	40.5	24.1	149.9	23.9	2.52	34.47	48.62	289.09	45.03	0.28	93.14	9.38																		0.92		
S461	V2	3.75	0.77	42.5	10140	322	506	55.8	191	167	80.9	19	1.26	6.1	255	24	91.5	47.2	0.33	42.9	5.2	14.2	23.4	12.1	3.61	0.28	1.21	3.61	0.63	1.33	0.91	0.28	2.59	0.29	1.69	0.33	0.1			
S561	V2	3.88	0.36	28.4	5723	204	322	91.3	106.1	67.6	60.4	2.01	4.54	8.5	87.3	57.3	48.7	0.09	19.4	4.7	11.77	8.66	23.8	0.58	0.46	2.74	2.81	1.55	1.57	0.26	1.39	0.21	1.79	0.31	0.47	0.4	0.1			
S565	V2	6.29	0.81	40.4	8981	301	884	50.4	66.3	55.2	80.2	18.8	1.7	10.5	214	22.3	113	82.7	0.13	141	11.1	24.4	3.51	15.6	3.82	1.15	0.65	4.04	4.1	0.78	2.24	0.31	2.15	0.3	2.84	0.44	2.25	1.62	0.42	
S566	V2	5.95	1.09	43	9618	310	1210	28.4	44.9	53.3	76.9	20.4	1.05	1.71	234	23.7	112	97.5	0.16	229	12.1	27.5	38.5	17.1	4.17	3.8	1.74	4.49	4.37	0.85	2.3	0.33	1.98	0.29	3.04	0.48	2.22	1.69	0.43	
S6610	V2	4.28	0.65	30.1	19390	342	51	44.8	47.8	93.7	81.7	18.4	2.24	10.7	399	22.5	95	22.1	0.05	303	17.3	39.4	5.39	26.7	5.97	2.27	0.9	6.16	4.73	0.88	2.25	0.55	2.62	1.29	0.13	1.05	1.45	0.39		
S6611	V2	4.02	0.32	24.9	5458	206	1076	71.5	81.4	83.6	70.7	10.7	1.17	9.39	131	67.9	79.5	0.11	60.1	6.82	15.9	24.4	11.6	3.03	1.05	0.5	3.16	3.03	0.58	1.61	0.23	1.54	0.2	2.02	0.63	0.03	0.74	0.5	0.2	
S666	V2	2.99	0.24	24	5380	212	1231	78.8	907	88	74.3	12.2	1.57	5	109	142	51.2	2.96	0.05	210	32.3	85.9	14.9	8.12	2.53	0.85	0.49	3.34	3.16	0.21	1.29	1.63	0.23	1.8	0.23	0.04	0.29	0.08		
S669	V2	4.42	0.5	30.6	6455	216	1247	84.6	869	105	68.7	13.3	1.1	11.8	147	13.7	67.1	8.32	0.14	47.9	5.66	15.3	2.32	10.7	2.77	0.94	4.94	2.94	2.86	0.57	1.55	0.23	1.3	0.19	0.21	0.57	0.73	0.61	0.19	
S7610	V2	2.18	0.36	22.6	6574	203	711	48.2	31.2	85.9	36.7	12.2	1.33	0.51	169	151	64.9	5.67	0.01	281	5.64	14.2	2.24	10.7	2.81	0.97	0.51	3.18	3.03	0.65	1.65	0.24	1.43	0.22	2.02	0.38	0.01	0.56	0.51	0.13
S7611	V2	3.98	0.36	28.4	5723	204	322	91.3	106.1	67.6	60.4	2.01	4.54	8.5	87.3	57.3	48.7	0.09	19.4	4.7	11.77	8.66	23.8	0.58	0.46	2.74	2.81	1.55	1.57	0.26	1.39	0.21	1.79	0.31	0.47	0.4	0.1			
S764	V2	3.62	0.45	34.8	8725	305	983	73.2	45.4	97.5	90.8	16.1	1.73	0.83	196	20	77.8	5.98	15.9	6.01	14.8	2.35	12	3.73	11.8	0.66	4	3.84	0.72	2.04	1.63	0.26	2.33	0.39	0.01	0.57	0.47	0.13		
S765	V2	4.36	0.25	20.6	4957	174	998	76.1	1161	72.2	51.9	7.66	3.39	3.26	72	11.1	51.7	4.47	0.06	35.6	4.51	10.8	18.1	9.15	2.58	0.86	0.45	2.78	2.66	0.21	1.45	0.2	1.81	0.18	0.34	0.01	0.53	0.45	0.11	
S766	V2	5.14	0.42	31.5	8064	288	958	63.9	59.5	108	67.3	14.8	1.73	4.99	202	175	67.7	6.52	0.06	54.5	6.55	16.4	2.62	12.9	5.37	1.22	0.63	3.96	3.83	0.76	2.03	0.28	1.86	0.25	2.04	0.46	0.02	0.97	0.57	0.15
S767	V2	5.1	0.48	25.4	9339	189	2025	88.9	1123	82.8	61.3	9.29	0.98	4.34	82.8	127	58.6	7.4	0.07	14.9	7.75	11.6	1.83	8.77	3.37	0.81	0.44	2.66	2.62	0.51	1.38	0.17	1.17	0.77	0.03	0.52	0.61	0.12		
S7620	V2	5.13	0.58	29.9	21890	375	518	47.7	321	153	106	1.97	1.86	11.7	284	29.8	180	25.3	0.1	163	3.49	39.7	5.45	25.1	6.03	2.08	1.02	6.52	5.81	1.08	2.95	0.41	2.47	0.36	0.41	1.41	0.17	1.25	1.65	0.51
S769	V2	5.96	0.73	30.7	12460	480	1095	96.9	529	201	90.3	27.9	3.73	3.68	343	36.8	131	13.5	0.04	152	1.55	34.7	4.88	22.5	5.54	1.97	1.05	6.51	6.7	1.36	3.78	0.52	3.35	0.53	3.99	0.77	2.06	1.29	0.3	
S15H4	V2	2.22	0.19	23.1	4291	186	1501	83.1	1026	80.9	57	11	1.45	2.85	110	121	38.6	1.46	0.01	287	1.81	5.3	1	5.77	1.97	0.69	0.4	2.38	2.61	0.52	1.49	0.22	1.4	0.19	1.31	0.02	0.24	0.13	0.04	
S17H1	V2	3.73	0.77	36.5	12700	388	428	41	46.6	26.0	90.9	23.1	1.91	2.45	200	25	128	7.93	0.03	50.5	9.02	21.9	3.25	15.08	1.66	0.97	5.61	0.66	1.06	1.24	0.46	3.07	0.43	3.28	0.42	0.02	1.43	0.89	0.25	
S17H2	V2	3.38	0.22	24.9	6458	206	1076	71.5	81.4	83.6	70.7	10.7	1.17	9.39	131	67.9	79.5	0.11	60.1	6.82	15.9	24.4	11.6	3.03	1.05	0.5	3.16	3.03	0.58	1.61	0.23	1.54	0.2	2.02	0.63	0.03	0.74	0.5	0.2	
S20H4	V2	3.22	0.55	36.6	10440	369	564	51.4	306	148	72.1	19.5	1.72	1.22	250	22.7	88.8	4.43	39.4	54.7	15.3	25.4																		

Sample names	Fm.	<sup>208</sup> Pb/ <sup>204</sup> Pb	<sup>207</sup> Pb/ <sup>204</sup> Pb	<sup>206</sup> Pb/ <sup>204</sup> Pb	<sup>176</sup> Hf/ <sup>177</sup> Hf	2 σ	ε <sub>Hf</sub>	<sup>143</sup> Nd/ <sup>144</sup> Nd	2 σ	ε <sub>Nd</sub>	<sup>87</sup> Sr/ <sup>86</sup> Sr
S19E1	V1	37.7907	15.3018	17.7224			0.0000073				
S19E2	V1	37.1751	15.2492	16.9346	0.282636	0.0000048	-4.82				
S38E2	V1	36.9612	15.157	16.6579	0.282607	0.0000042	-5.84				0.70780
S38E8	V1	36.7908	15.1218	16.5386	0.282612	0.0000042	-5.65	0.512302	0.0000063	-6.56	0.70807
S40E1	V1	38.7418	15.4345	18.6374				0.512350	0.0000047	-5.62	0.70636
S40E2	V1	38.7234	15.4236	18.6007				0.511881	0.0000088	-14.76	0.70628
S1E1	V2	37.7479	15.3743	17.9969	0.283198	0.0000041	15.06				0.70338
S1E3	V2	37.8174	15.4329	18.0711	0.283198	0.0000034	15.08				0.70338
S1E4	V2	37.7933	15.3716	18.0389	0.283193	0.0000004	14.89				0.70332
S3E1	V2	38.5017	15.489	18.7265							0.70362
S4E1	V2	37.714	15.4216	18.0089	0.283203	0.0000079	15.23				0.70311
S5E11	V2	37.4929	15.1063	16.915		0.0000028		0.512345	0.0000047	-5.71	
S5E5	V2	37.2793	15.0701	16.9389	0.282652	0.0000036	-4.26				0.70679
S5E6	V2	37.3562	15.0888	17.0592	0.282692	0.0000003	-2.84	0.512506	0.0000044	-2.57	0.70652
S6E6	V2	37.7648	15.4218	18.037	0.283157	0.0000048	13.61				0.70330
S6E9	V2	38.0612	15.4362	18.2839	0.283138	0.0000049	12.94				0.70628
S7E6	V2	37.9231	15.443	18.098	0.283177	0.0000077	14.31				0.70338
S7E7	V2	37.9827	15.4257	18.1173	0.283173	0.0000036	14.19				0.70349
S7E9	V2	38.0256	15.3296	17.9856	0.283193	0.0000005	14.9				0.70363
S15H4	V2	37.5416	15.3724	17.9168	0.283220	0.0000034	15.85				0.70309
S20E15	V2	37.811	15.3603	17.9032	0.283104	0.0000043	11.74				0.70369
S20E7	V2	38.4594	15.3964	18.4259	0.283059	0.0000033	10.16				0.70398
S27E12	V2	37.7582	15.4339	18.099	0.283202	0.0000029	15.21				0.70794
S27E13	V2	37.6621	15.4177	18.0158	0.283211	0.0000044	15.52				0.70315
S27E18	V2	37.8792	15.3751	18.0833	0.283170	0.0000046	14.09				0.70335
S38E10	V2	38.0322	15.3567	18.0635	0.283115	0.0000034	12.12				0.70374
S39E1	V2	37.1137	15.0627	16.4893	0.282501	0.0000046	-9.58	0.512220	0.0000042	-8.15	0.70624
S41E3	V2	36.8255	14.9913	16.1358	0.282531	0.0000048	-8.51				0.70704
S42E2	V2	36.8122	15.0013	16.1661	0.282565	0.0000043	-7.31				0.70665
S42E5	V2	36.8	15.0014	16.1686	0.282574	0.0000027	-7.01	0.512303	0.0000006	-6.54	0.70673
S43E1	V2	37.9194	15.3688	18.0556	0.283116	0.0000061	12.15				0.70355
S43E4	V2	37.8974	15.4283	18.0467	0.283139	0.0000104	12.97	0.512992	0.0000052	6.9	0.70357
S43E6	V2	37.7803	15.3919	17.9208	0.283175	0.0000005	14.25				0.70337
S44E2	V2	37.7681	15.4128	18.0671	0.283165	0.0000053	13.89				0.70330
S44E7	V2	37.9074	15.4131	18.0767	0.283176	0.0000073	14.29	0.513050	0.0000083	8.05	0.70356
S44E8	V2	37.5621	15.3715	17.9248	0.283204	0.0000053	15.26				0.70328
S45E4	V2	37.9674	15.4621	18.1573	0.283230	0.0000005	16.18				0.70326
S45E9	V2	37.8374	15.2977	17.7873	0.283065	0.0000109	10.35	0.512883	0.0000061	4.78	0.70391
S2E2	V3	37.8894	15.4361	18.2036	0.283193	0.0000055	14.88				0.70338
S2E3	V3	38.042	15.4536	18.3113							0.70335
S2E5	V3	37.9368	15.4521	18.202							0.70331
S2E7	V3	38.5979	15.4975	18.94	0.283124	0.0000063	12.46	0.512977	0.0000069	6.62	0.70377
S2E8	V3	38.5267	15.4941	18.808	0.283155	0.0000048	13.56	0.512989	0.0000006	6.84	0.70366
S2E9	V3	37.9398	15.4554	18.2417	0.283172	0.0000045	14.14	0.513054	0.0000044	8.12	0.70822
S8E13	V3	37.9907	15.4015	18.2182	0.283174	0.0000046	14.22	0.513033	0.0000009	7.67	0.70353
S8E6	V3	39.0141	15.5255	19.112	0.283083	0.0000046	11	0.512719	0.0000065	1.54	0.70392
S9E1	V3	38.1598	15.4592	18.4869	0.283191	0.0000051	14.82				
S11E10	V3	38.0766	15.4443	18.4272	0.283203	0.0000004	15.23				0.70348
S26H1	V3	38.2176	15.5662	18.2994	0.283198	0.0000036	15.05				
S26H3	V3	37.9707	15.4411	18.3145	0.283205	0.0000043	15.3	0.513094	0.0000077	8.89	0.70345
S33E12	V3	38.4105	15.4844	18.6862	0.283192	0.0000074	14.86				
S33E7	V3	38.7609	15.4922	19.075	0.283111	0.0000074	11.97				
S35E11	V3				0.283171	0.0000005	14.1	0.513027	0.0000122	7.54	0.70354
S35E12	V3	38.0041	15.453	18.392							0.70336
S35E3	V3	37.9532	15.4402	18.2024	0.283188	0.0000049	14.7				
S35E5	V3	38.0145	15.4499	18.2868	0.283182	0.0000048	14.49	0.513055	0.0000098	8.13	0.70363
S35E8	V3	37.9179	15.4556	18.2058							0.70330
S36E5	V3	37.9807	15.4298	18.3146	0.283186	0.0000046	14.64				
S21H1	V4	38.3919	15.4636	18.6247	0.283150	0.0000035	13.36	0.512990	0.0000084	6.87	0.70367
S21H2	V4	38.0081	15.4547	18.2627	0.283223	0.0000039	15.95				
S29E2	V4	38.3614	15.4604	18.4962	0.283182	0.0000045	14.49				
S30E1	V4	38.4071	15.4795	18.6598	0.283145	0.0000023	13.19	0.512992	0.0000053	6.91	0.70806
S30E4	V4	38.4888	15.5065	18.8252	0.283146	0.0000025	13.23	0.512984	0.0000061	6.76	0.70376
S13H5	dike	37.8156	15.3998	18.1175							0.70332
S14H2	dike	38.5245	15.5106	18.765	0.283142	0.0000047	13.09	0.512985	0.0000009	6.73	0.70364
S15H3	dike	38.4756	15.4871	18.7332	0.283160	0.0000038	13.74				0.70364
S20E18	dike	38.5508	15.4971	18.7477	0.283154	0.0000057	13.52	0.512984	0.0000051	6.71	0.70379
S22H2	sill	37.8774	15.4337	18.2553	0.283213	0.0000047	15.6	0.513095	0.0000171	8.87	
S22H4	dike	38.5058	15.4949	18.7357	0.283153	0.0000048	13.48	0.512984	0.0000051	6.71	0.70611
S23H4	dike V3	38.9386	15.5336	19.2555	0.283128	0.0000052	12.6	0.512822	0.0000066	3.56	0.70380
S23H5	dike	38.812	15.4818	19.1238	0.283153	0.0000045	13.47	0.512909	0.0000007	5.24	0.70370
S24H1	Sill Itsako	37.8957	15.3504	18.0561	0.283164	0.0000037	13.85				
S27E4	dike	38.4799	15.4969	18.8261	0.283130	0.0000043	12.65	0.512994	0.0000071	6.91	0.70375