Iron transport by subglacial meltwater indicated by $\delta^{56}Fe$ in coastal sediments of King George Island, Antarctica

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Introduction

Iron input from glaciated coasts and shelf areas in Antarctica is known to stimulate the primary production in the overall Fe-limited Southern Ocean [1]. The distinct Fe transport and reaction pathways are, however, not well quantified yet [e.g. 2, 3, 4]. The potentially most relevant Fe sources are benthic fluxes and subglacial meltwater discharge, but estimates (Fig. 1) vary over several orders of magnitude. Since these two sources are related to microbial Fe reduction [e.g. 5, 6] which is known to cause isotope fractionation, stable Fe isotope geochemisty might be a suitable tool to identify and quantify these contributions. Iron delivered by meltwater is largely deposited proximal to the place of discharge due to oxidation and flocculation [7]. There, it is assumed to control early diagenetic processes and, thus, benthic Fe^{2+} release.
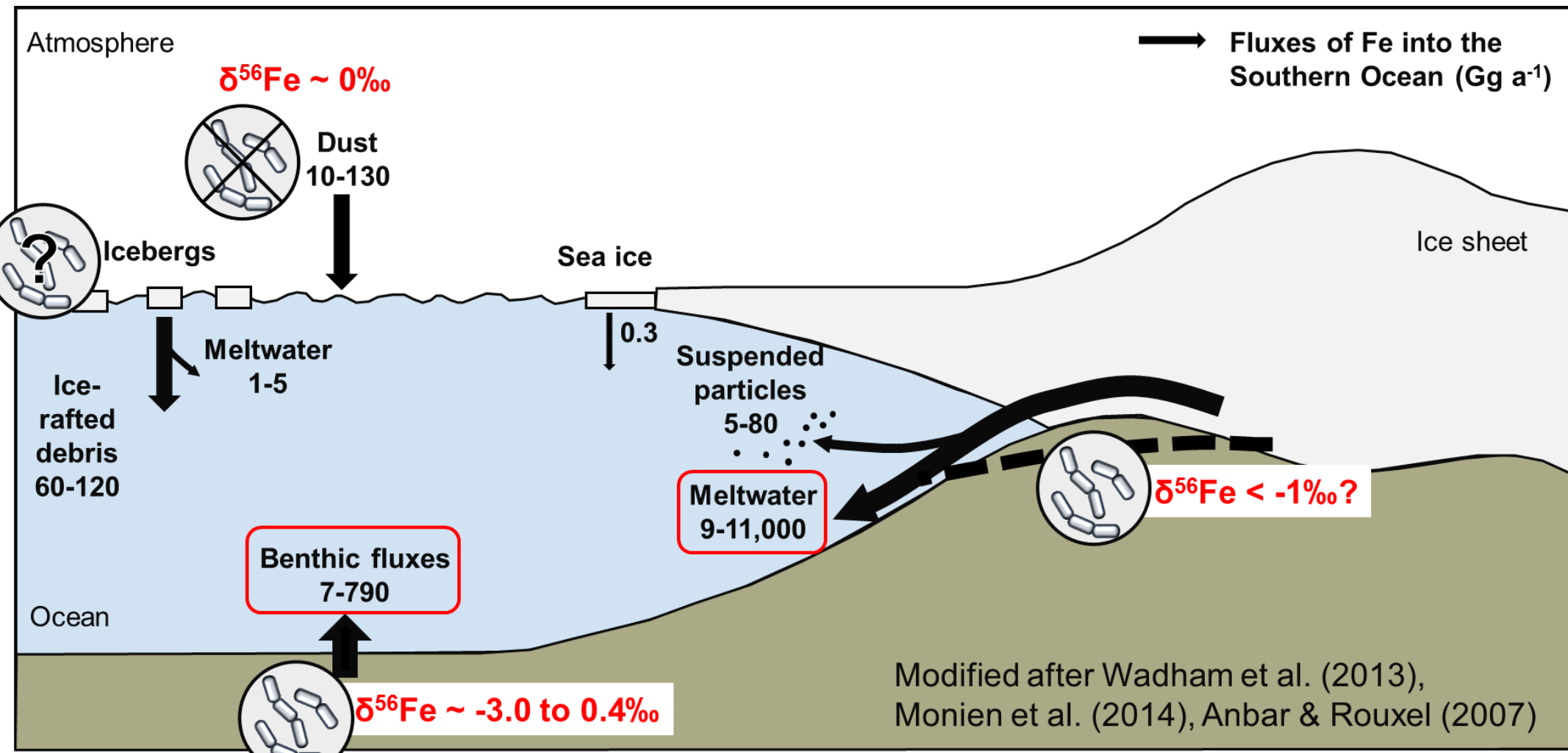

Fig. 1: Iron sources into the Southern Ocean and related stable iron isotope signatures.

Objectives:
(1) Determine if/how glacier melt affects the sediment composition (Fe reactivity) and early diagenesis
(2) Assess how geochemical conditions and biogeochemical processes in the sediment affect pore water and sedimentary $\delta^{56}Fe$
(3) Assess whether the $\delta^{56}Fe$ of reactive Fe indicates distinct Fe sources/ whether $\delta^{56}Fe$ can track Fe transport pathways

Sampling & Methods

- Sampling in glaciated bays of King George Island (Antarctica) (Figs. 2, 3)
- Main study area: Potter Cove (characterized by fast glacier retreat) [8]
- Sites proximal to glacier fronts, surficial meltwater discharges and in the central area of the bay (Groups I to III, Fig. 3)
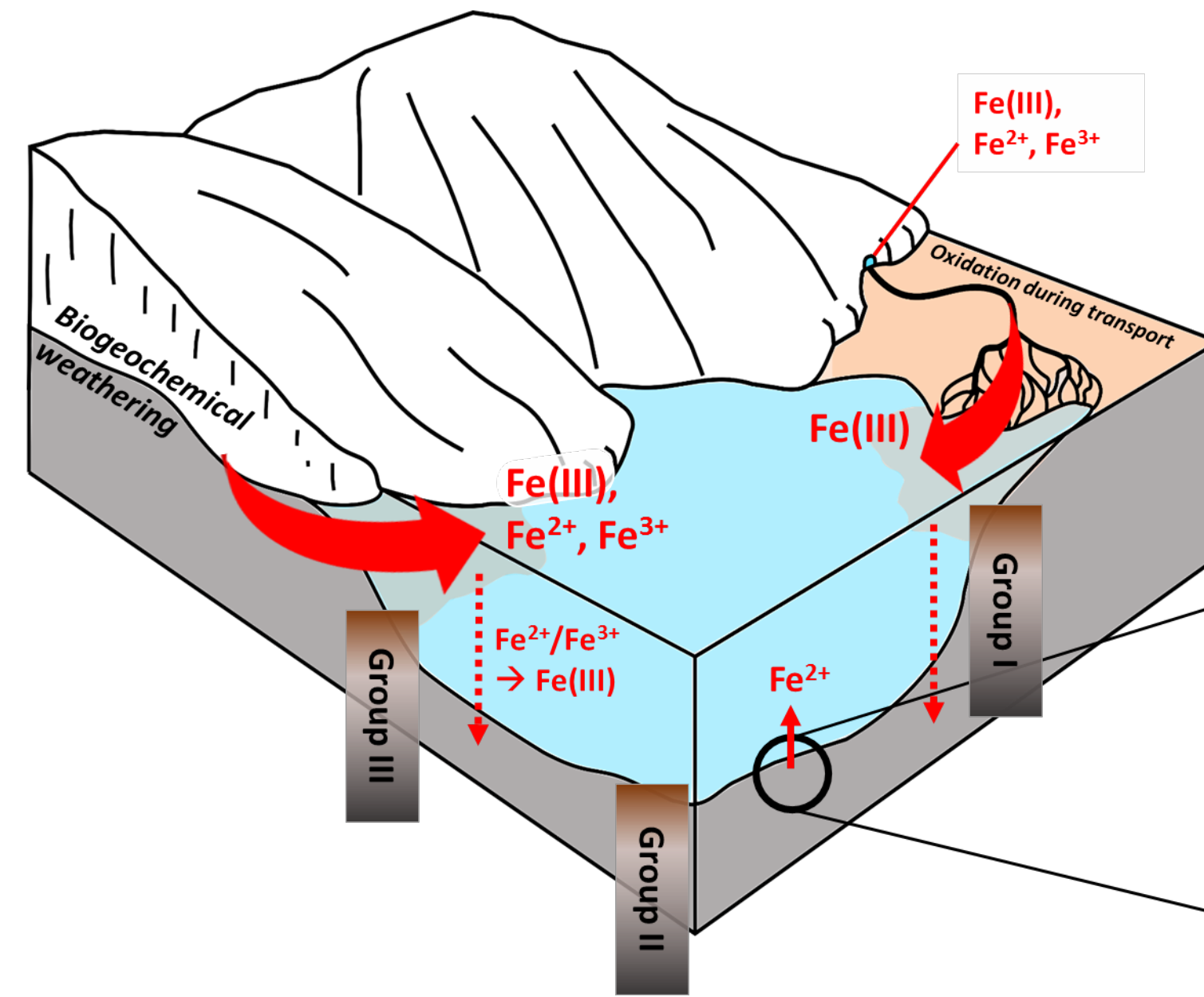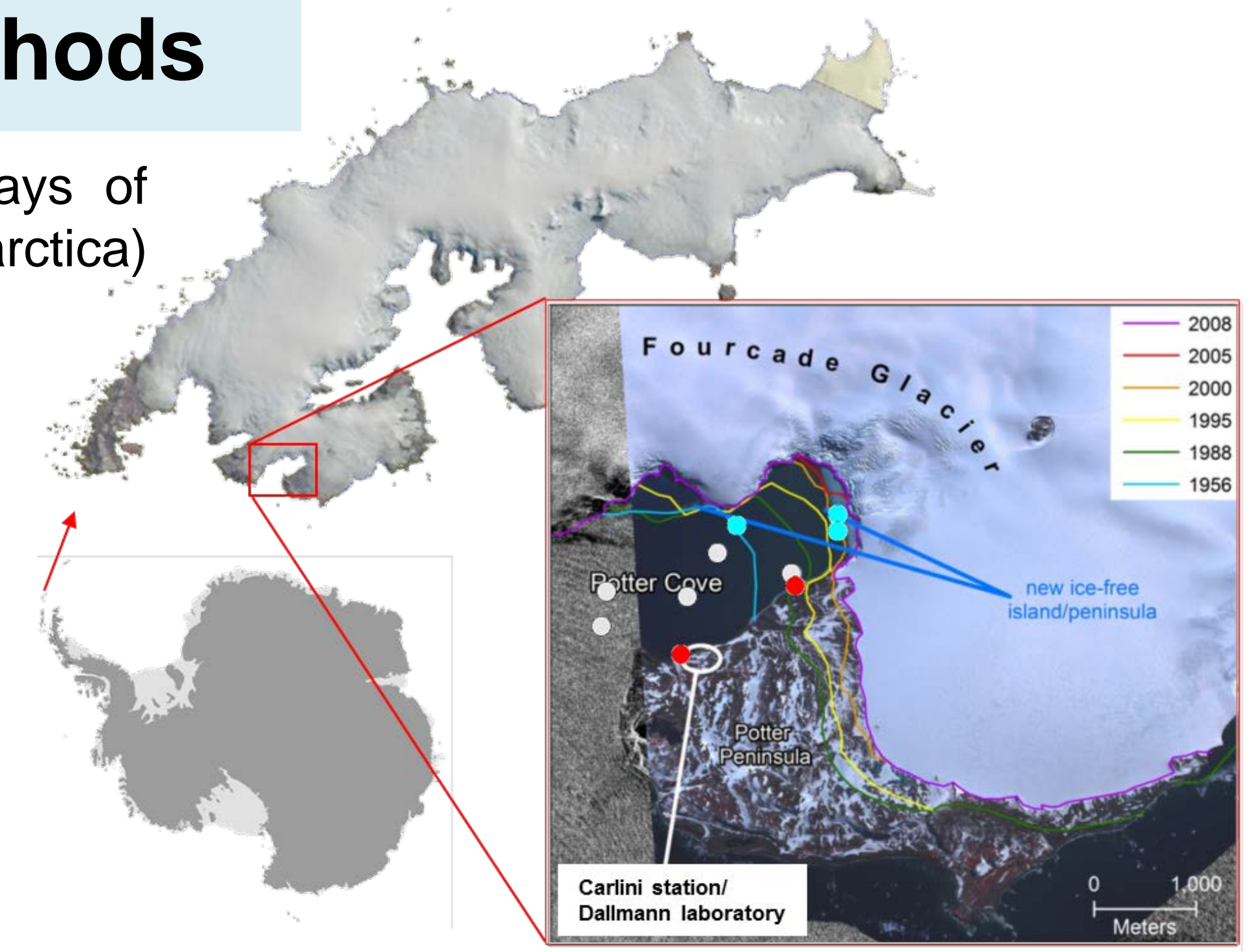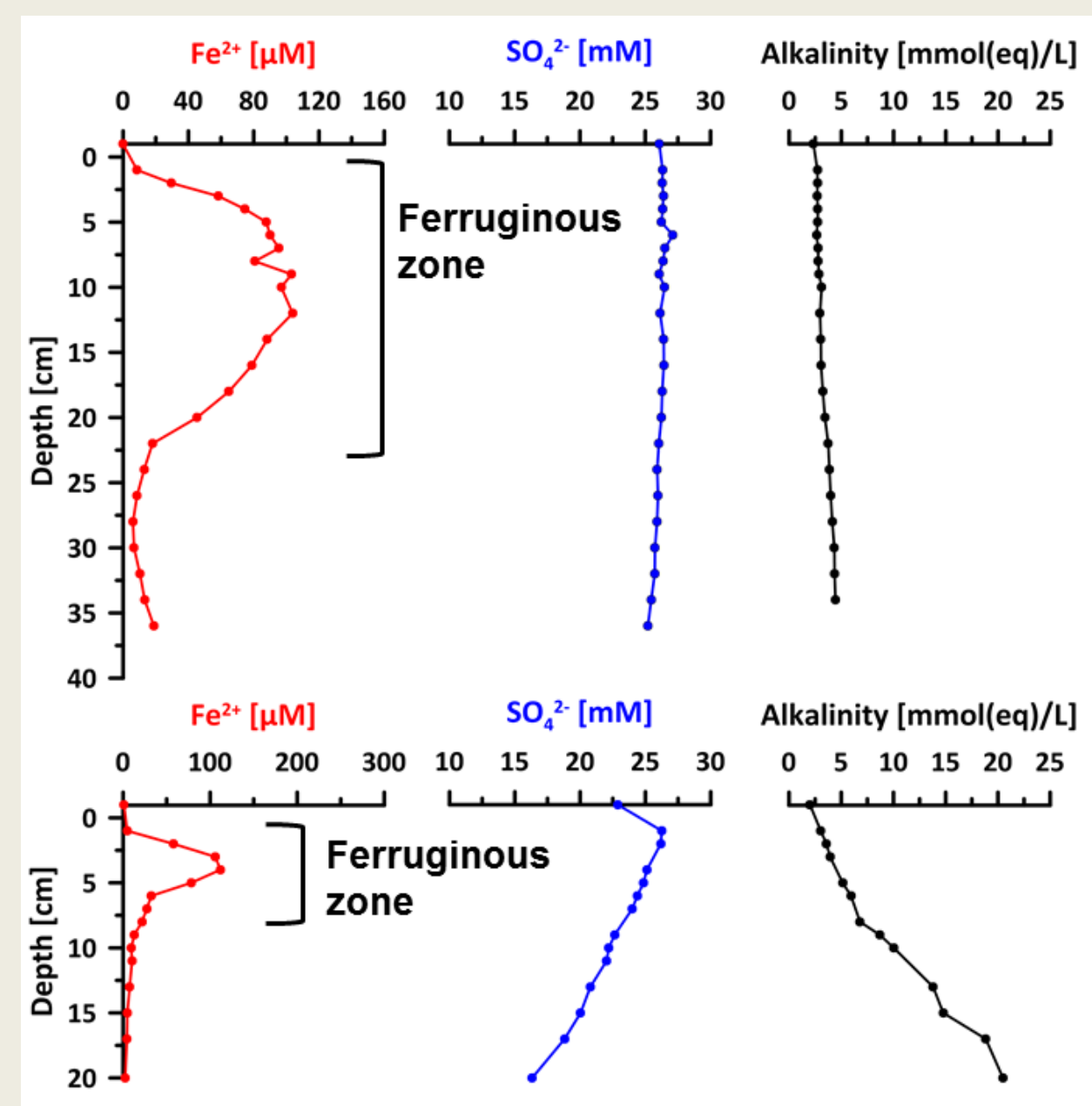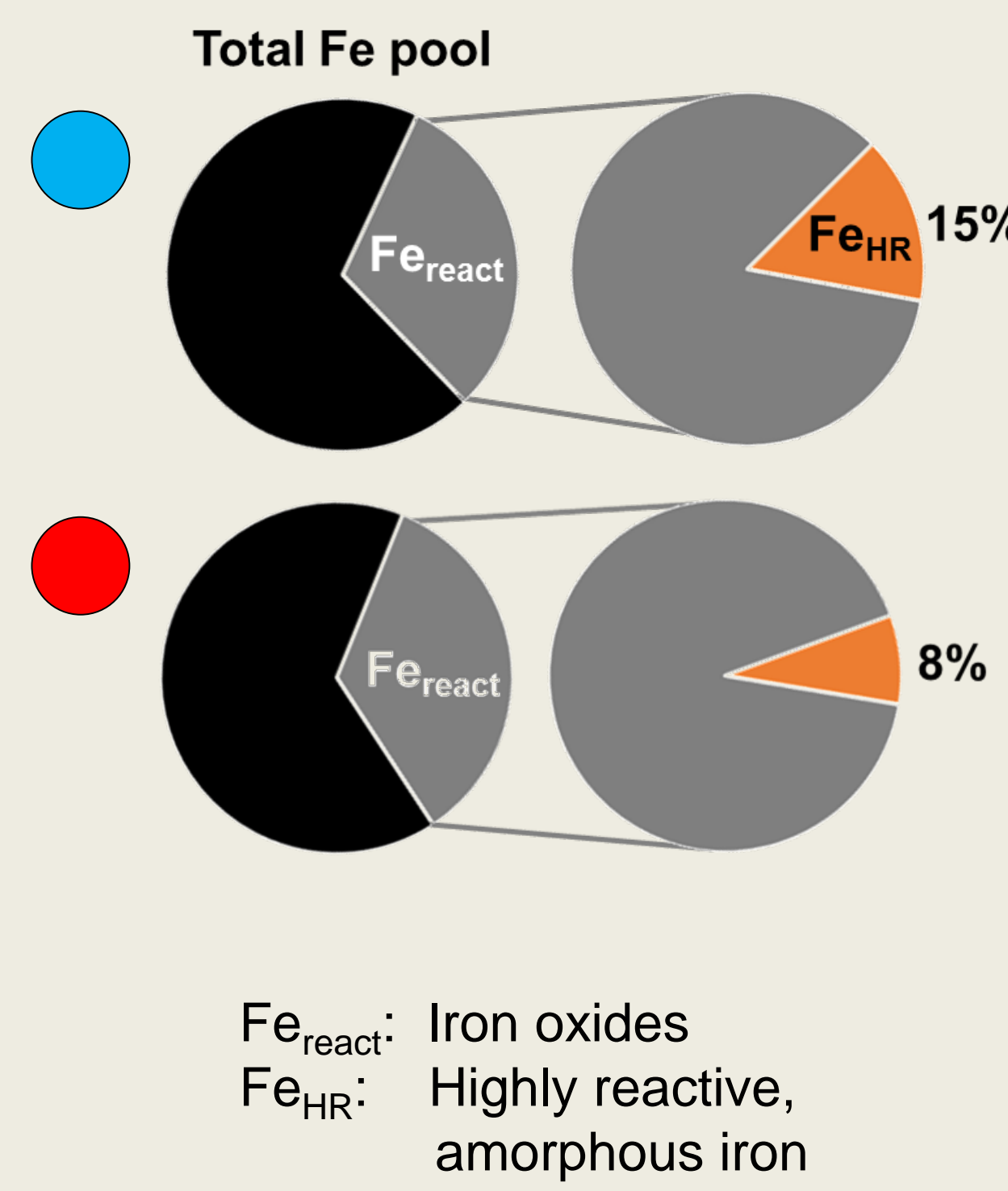

Fig. 2: Location of King George Island and Potter Cove (close-up). Colored lines indicate the glacier retreat [8]. Blue dots: coring sites close to the glacier terminus, red dots: sites proximal to surficial meltwater discharge, white dots: central basin stations.

Fig. 3: Iron transport and reaction pathways in polar coastal areas. Close-up shows early diagenetic cycling. Fe^{2+} and Fe^{3+} are dissolved, Fe(III) is the solid fraction. Sediment core classification (Group I, II, and III) as indicated in Fig. 2.

Methods:
- Pore water analyses (nutrients, alkalinity, $\delta^{56}Fe$)
- Total sediment composition
- Sequential Fe extraction [9] and processing for $\delta^{56}Fe$ analysis on a Neptune MC-ICP-MS [10, 11]

Results

- **Glacier front** (blue)
- **Surficial meltwater discharge** (red)

b) Pore water

c) Solid Fe

Fe_{react}: Iron oxides
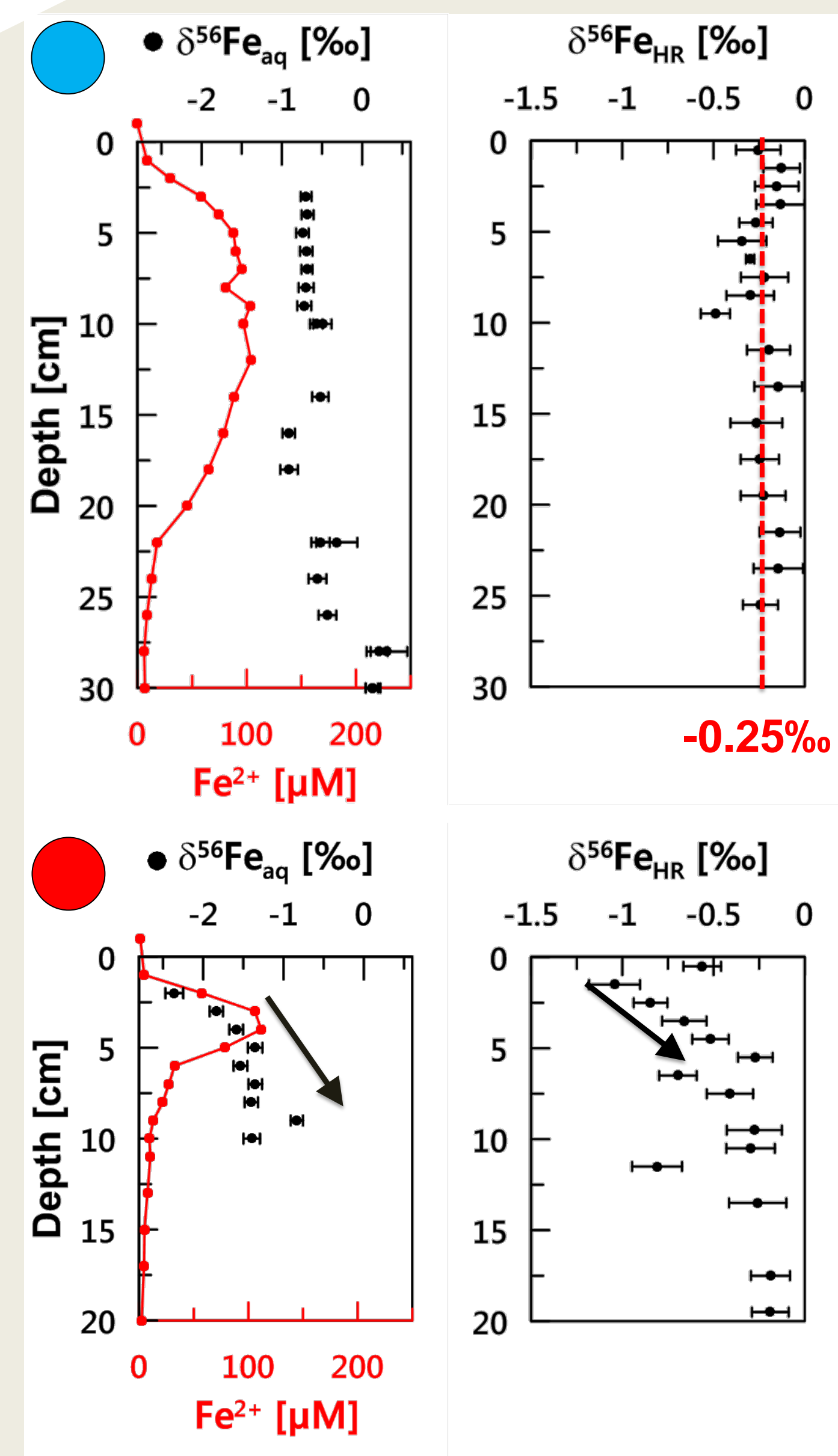Fe_{HR}: Highly reactive, amorphous iron

d) Fe isotopes

Fig. 4: Geochemical data are presented exemplarily for two contrasting sites in Potter Cove: a) proximal to the glacier front (20 m depth) and proximal to the discharge of surficial meltwater (11 m depth). Sites in the central bay show an intermediate situation between those shown here. b) Pore water data, c) sedimentary Fe data, d) $\delta^{56}Fe$ of dissolved and highly reactive (hydroxylamine-HCl leached) Fe. Error bars are 1SD.

- Strong diagenetic iron reduction (DIR) close to glacier terminus, strong sulfate reduction close to surficial meltwater discharge
- Sediments contain similar amounts of total and reactive Fe (6 wt% and 2 wt%, respectively); no decrease with depth
- Sediments **at glacier terminus contain significantly more highly reactive Fe** (ferrihydrite or lepidocrocite) compared to meltwater discharge site
- Total organic carbon contents comparably low (~0.2 wt%) [12].
→ **DIR at glacier terminus fueled by large supply with highly reactive Fe oxides**

- $\delta^{56}Fe_{aq}$ and $\delta^{56}Fe_{HR}$ **close to the meltwater discharge** show *in situ* DIR: negative $\delta^{56}Fe$ due to preferential release of ^{54}Fe and subsequent re-precipitation as amorphous Fe phase; more positive values with depth due to relative ^{56}Fe enrichment in substrate
- Despite intense *in situ* DIR, $\delta^{56}Fe_{aq}$ and $\delta^{56}Fe_{HR}$ don't show downcore trends **at glacier terminus** → easily reducible pool >> pool used by microbes
- Fe_{HR} generally enriched in ^{54}Fe at glacier terminus compared to more crystalline phases (data not shown) (-0.25 vs. +0.25‰)
→ **Microbial Fe cycling BEFORE accumulation; Subglacial environments are known to be microbial hotspots [13]!**

Conclusions

Sediments close to the glacier terminus contain significantly more highly reactive Fe fuelling the diagenetic Fe cycling than sediments close to surficial meltwater discharges. The pattern of $\delta^{56}Fe$ in pore water and solid phase indicates an isotopic alteration of Fe phases before sediment accumulation. We suggest discharge of Fe-rich meltwater from subglacial sources and subsequent precipitation of isotopically light amorphous Fe close to the glacier. A quantification of benthic Fe fluxes and subglacial Fe discharges based on stable Fe isotope geochemistry will be complicated because (1) diagenetic processes vary strongly at short lateral distances and (2) the variability of $\delta^{56}Fe$ in subglacial meltwater has not been sufficiently well investigated yet. However, isotope mass balance models that consider the current uncertainties could, in combination with the application of ancillary proxies, lead to a much better quantification of Fe inputs into polar marine waters than currently available.

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