Supplementary Methods

Spatial patterns of nitrogen-transforming processes in the Southern Ocean: Potential role of Dissimilatory Nitrate Reduction (DNR)

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Identification of water masses

Water masses were identified at each station from the vertical profile of physical properties (see Fig 1b) (Table S1) and geographical considerations, in particular the location of main Southern Ocean fronts as determined by Park et al., 2019. The most abundant water masses of the Southern Ocean were identified from their neutral density, γ^n (Orsi et al., 1999, Bindoff and McDougall et al., 2000, Talley et al., 2011), with highest values in water masses close to the bottom decreasing upwards; Antarctic Bottom Water (AABW, $\gamma^n > 28.27$ kg m^{-3}), Lower Circumpolar Deep Water (LCDW, $\gamma^n > 27.8$), Upper Circumpolar Deep Water (UCDW, $\gamma^n > 27.5$) and Antarctic Intermediate Water (AAIW, $\gamma^n > 27.2$). Within the LCDW density range, the presence of North Atlantic Deep Water (NADW) was determined from the salinity criterion S> 34.8 (Park et al., 1993, 2001). In the Aghulas Current sector, Antarctic Intermediate Water (AAIW) was identified from the salinity minimum and the presence of mode waters (STMW) was assessed from the detection of a homogeneous low-potential vorticity layer in their corresponding density range.

Sample collection and analysis of environmental parameters

Concentration of trace metals. To sample seawater for trace metal determination, the trace metal clean rosette equipped with 24 GO-FLO bottles was deployed using a Kevlar wire. GO-FLO bottles and all sampling material were cleaned before the cruise following the GEOTRACES cookbook (Cutter et al., 2017). Immediately after recovery, the rosette was transferred into a clean container for sampling trace elements. Particle levels were controlled with a particle counter (Lighthouse HH3016) and when levels were adequate for ISO class 6 levels, sampling could begin. Bottles were pressurized with 0.2 µm-filtered nitrogen (Air Liquide®).

Samples dedicated to dissolved trace metal analyses were filtered on-line through a 0.45µm polyethersulfone filter (Supor®) and collected in duplicates in acid-cleaned 60mL LDPE bottles. All samples were acidified within 24h of collection with hydrochloric acid (HCl, ultrapure grade, Merck, final pH 1.8).

Concentrations of dissolved iron (dFe), manganese (dMn), copper (dCu), nickel (dNi) were analyzed using the preconcentration system seaFAST-pico™ coupled to a high-resolution magnetic sector field inductively-coupled plasma mass spectrometer (SF-ICP-MS, Element XR – Pôle Spectrométrie Ocean, Brest) following (Tonnard et al., 2020. Acidified MQ water with hydrochloric acid (HCl, ultrapure grade, Merck, 0.2‰, final pH 1.8) (n=9) was analyzed and used as the analytical blank (dFe=0.14±0.05 nmol L-1, dMn=0.08±0.04 nmol L-1, dCu=0.05±0.01 nmol L-1, dNi=0.06±0.01 nmol L-1). All trace metal data were above the detection limit (LOD), defined as three times the standard deviation (sd) of the blank. The reproducibility of our analyses has been verified with duplicat analyses (n=22). Reference seawater (NASS-7) and GEOTRACES consensus (GSC and GSP) seawaters were used to certify the accuracy of our analyses.

measured ***reference***	**dFe (nmol L^{-1})**	**dMn (nmol L^{-1})**	**dCu (nmol L^{-1})**	**dNi (nmol L^{-1})**
NASS 7 (n=10)	**5.87±0.62**	**12.52±0.87**	**2.60±0.16**	**3.74±0.16**
	6.23±0.46	*13.65±1.09*	*3.16±0.22*	*4.14±0.30*
GSC (n=15)	**1.76±0.35**	**1.87±0.31**	**1.08±0.19**	**3.81±0.66**
	1.53±0.12	*2.18±0.07*	*1.10±0.15*	*4.39±0.20*
GSP (n=2)	**0.18±0.02**	**0.65±0.04**	**0.55±0.08**	**2.77±0.06**
	0.16±0.04	*0.78±0.03*	*0.57±0.05*	*2.60±0.10*

Concentrations of particulate iron (pFe), manganese (pMn), copper (pCu) and nickel (pNi) were determined following the protocol described by Planquette and Sherrell et al., 2012. Prior to use, 15 mL flat bottom vials (Savilex®) were filled with 6 mol L^{-1} HCl (Fisher Scientific - Merck Suprapur grade) and heated at 130°C for a minimum of 4 hours, then rinsed three times with Milli-Q water. Vials were then cleaned with 3 mL of a solution made of 1.45 mol L^{-1} HF (Fisher Scientific - Merck Suprapur grade) and 8 mol L^{-1} HNO_3 (Fisher Scientific - Merck Suprapur grade) for at least 4h at 130°C, then rinsed five times with Milli-Q water and dried under a laminar flow hood class ISO 3 (Planquette and Sherrell et al., 2012. All filters were digested with 3m mL of an acid mix of 8 mol L^{-1} of HNO_3 and 2.9 mol L^{-1} of HF (Fisher Scientific - Optima grade concentrated acids) for 4 hours at 130 °C. To ensure optimal reflux, filters were placed vertically against the wall of the vial while avoiding submersion in the digestion solution. Afterwards, vial lids were removed and vials were placed on a hot plate at 110°C until near dryness under a ISO 5 HEPA fume hood. Once the solution was evaporated, the residue was redissolved with 200 µL of concentrated $HN0_3$ (Fisher Scientific - Optima grade concentrated acids). Finally, the remaining residue was dissolved in 3 mL of 0.48 mol L^{-1} of HNO_3 (Fisher Scientific - Optima grade concentrated acids) before being archived into pre-cleaned 15 mL polypropylene tubes (Corning®) or 5mL cryotubes (Truecool®) until SF-ICP-MS analysis. All the analyses were performed using a magnetic sector inductively coupled plasma mass spectrometer (SF-ICP-MS, Element XR - Pôle Spectrométrie Océan, Brest) using low and medium resulution settings. Gravimetrically prepared in 3% (v/v) HNO_3 solution (spiked at 1 ppb of Indium), calibration solutions were analyzed at the beginning, middle and end of each analytical session.

A number of 21 process blank filters, i.e., 1 L of filtered seawater passing through a clean filter, were collected at all stations at several depths and were analyzed following the same protocols used for samples; Blank values were used to correct for filter contribution to the total concentration of the respective element. Then, the detection limit was calculated as 3 times the standard deviation of the process blank values, assuming that 10 liters of seawater were filtered, data point below this detection limit were not used in the analysis.

	pFe	**pMn**	**pCu**	**pNi**
Measured blank values (ng)	15.92 ± 7.17	0.42 ± 0.21	2.75 ± 1.51	0.89 ± 0.58
Detection Limit (nmol L^{-1})	0.04	0.001	0.007	0.003

To assess the method's accuracy, we relied on 3 certified reference material (CRM) of freeze-dried plankton (BCR-414, European Commission) and two marine sediments (PACS-3, NRC Canada and MESS-4, NRC Canada). They underwent the same digestion protocol as the marine particle samples, except that the digestion volume was 6mL for a mass of CRM digested comprised between 15 and 30 mg.

Measured (mg.kg^{-1}) Reference (mg.kg^{-1}) *Recovery (%)*	pFe	pMn	pCu	pNi
BCR-414	**1800.8 ± 119.6**	**270.9 ± 119.6**	**29 ± 3.2**	**18.9 ± 2.1**
	1850 ± 190	299 ± 13	29.5 ± 1.3	18.8 ± 0.8
	97 ± 5	*91 ± 4*	*98 ± 4*	*100 ± 5*
PACS-3	**39689 ± 4146**	**424.4 ± 32.1**	**314.1 ± 21.4**	**36.8 ± 2.9**
	41060 ± 640	432 ± 16	326 ± 10	39.5 ± 2.2
	97 ± 10	*98 ± 7*	*96 ± 7*	*93 ± 7*
MESS-4	**39945 ± 7101**	**336.2 ± 52.1**	**35.6 ± 7.8**	**46.3 ± 8.4**
	37900 ± 1600	298 ± 14	32.9 ± 1.8	42.8 ± 1.6
	105 ± 19	*113 ± 17*	*108 ± 24*	*108 ± 20*

Particulate Organic Carbon (POC) Analysis

Particulate organic carbon (POC) samples were collected by filtering seawater through pre-combusted (450 °C, 4 h) 0.3 µm GF/F filters. After filtration, filters were folded in half and stored in pre-combusted aluminum foil at −80 °C until analysis. Prior to measurement, filters were dried at 40 °C for 24 h and then encapsulated into 5 × 8 mm pre-cleaned tin capsules. POC concentrations were determined using a Flash EA 1112 Series elemental analyzer (Thermo Finnigan). To correct for background carbon, dry blanks consisting of pre-combusted GF/F filters were processed alongside the samples, typically every 12 samples, and their mean values were subtracted from sample measurements to obtain total POC concentrations. All procedures followed the JGOFS POC analytical protocols (Knapp et al., 1994).

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