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HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

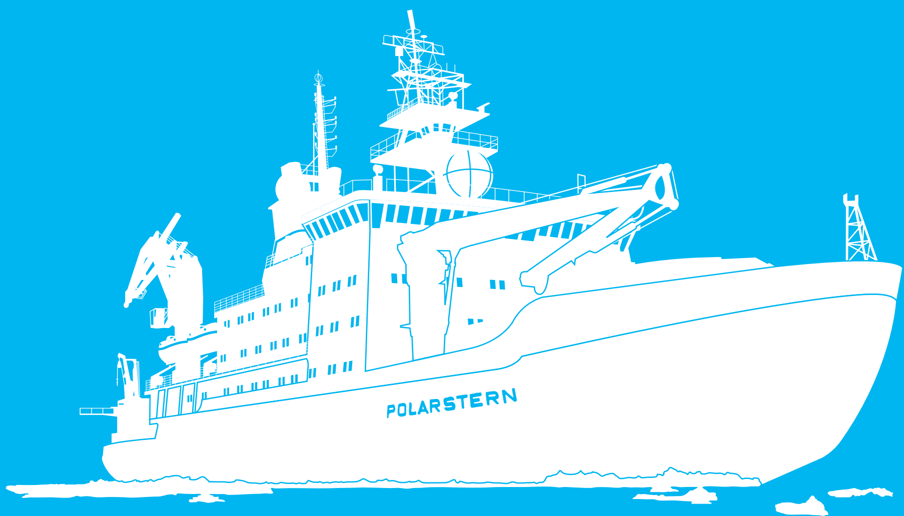
EXPEDITION PROGRAMME PS140

Polarstern

PS140
Cape Town - Hobart
25 November 2023 - 01 February 2024

Coordinator: Ingo Schewe

Chief Scientist: Marcus Gutjahr



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Contents

1. ÜBERBLICK UND EXPEDITIONSVERLAUF

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Die Expedition EASI-2 (Instabilität des Ostantarktischen Eisschildes) ist die zweite von drei geplanten *Polarstern*-Expeditionen, die die Geschichte der Instabilität des Ostantarktischen Eisschildes (EAIS) und ihre Wechselwirkung mit Veränderungen in der Zirkulation des Südozeans (SO) untersuchen werden. Während die erste der drei Expeditionen (EASI-1) bereits vom 6. Januar bis 28. Februar 2022 stattfand, wird die dritte (EASI-3) unmittelbar nach EASI-2 folgen. Jede der drei koordinierten Expeditionen hat einen eigenen Forschungsschwerpunkt im Zusammenhang mit der potenziellen Instabilität des EAIS während aktueller und vergangener Klimaveränderungen. Im Vergleich zu den beiden anderen Expeditionen konzentriert sich EASI-2 am stärksten auf aktuelle Prozesse in der Wassersäule des Südpolarmeeres, die beobachtbare moderne Nährstoffverfügbarkeit mit besonderem Augenmerk auf die Lieferung essenzieller Mikronährstoffe vom Meeresboden und der Ostantarktis. Die Durchführung von zwei Transekten der Wassersäule im offenen Ozean sind geplant, um die Struktur, die chemische Zusammensetzung sowie den aktuellen Zirkulationszustand im Untersuchungsgebiet darzustellen. Analoge Arbeiten auf dem ostantarktischen Schelf werden die proximale antarktische Perspektive auf sowohl physikalische wie auch chemische ozeanografische Trends liefern, die heute in Zeiten allgemein steigender Meerestemperaturen, abnehmender Meereisausdehnung und einer Abnahme des Salzgehalts verschiedener Wassermassen im SO wie dem Antarktischen Bodenwasser (AABW) zu beobachten sind. An jeder Station der beiden Transekte wird die komplementäre Beprobung tiefmariner Sedimente von bis zu 25 Metern Tiefe unter dem Meeresboden die Rückverfolgung von Veränderungen in den Eigenschaften der Wassersäule über mehr als die letzten 500 Tausend Jahre ermöglichen. Im Fokus stehen die pleistozäne Dynamik ozeanischer Fronten des Antarktischen Zirkumpolarstroms, Veränderungen der Meeresoberflächenwassertemperaturen und die vergangene Meereisausdehnung. Auf dem Antarktischen Schelf werden kombinierte Parasound-Profile und Sedimentprobennahme die Beantwortung von Fragen zur Geschichte des quartären Eisschildes und zur vergangenen Tiefenwasserbildung ermöglichen.

Das wohl herausragendste Merkmal dieser Expedition ist das Bestreben, moderne Beobachtungen aus der Wassersäulenarbeit eng mit früheren Zuständen der SO-Zirkulationsmodi zu verknüpfen, indem eine Vielzahl modernster Methoden und/oder Proxies sowie Probenahmestrategien verwendet werden. Beispielsweise werden wir diagenetische Prozesse an vielen Probenahmestellen quantifizieren, parallel zur Anwendung paläozeanographischer Proxies, wie z. B. der Gewinnung authigener (aus dem Meerwasser ausgefallene) Spurenmetalle (z.B. Nd und Pb). Temperatur (z. B. Mg/Ca, $\delta^{18}O$, Transferfunktionen) und Karbonatsystem-bezogene Proxies (B/Ca, $\delta^{11}B$), die an Planktonproben und Mikrofossilien im Sediment gemessen werden, können direkt mit den Parametern des Karbonatsystems (TA, DIC) der heutigen Wassersäule verglichen werden, die wir gleichermaßen erhalten werden. Darüber hinaus werden Proxies für die Meereisausdehnung in der Vergangenheit (z.B. PIPSO25, Diatomeen-Transferfunktionen) Fragen zur Meereisdynamik im Pleistozän beantworten. Dank der Verwendung eines spurenmetallsauberem Wasserschöpfers sind wir in der einmaligen Lage, qualitativ hochwertige Daten zu heutigen Austauschprozessen verschiedenster Spurenmetalle zwischen (i) dem Meeresboden und dem Bodenwasser sowie (ii) verschiedenen Wassermassen in der offenen Wassersäule des Südlichen Ozeans zu messen. Dies erstreckt sich auch auf die Quantifizierung des subglazialen Eintrags von Übergangsmetallen und anderen analytisch anspruchsvollen Spurenmetallen, für die bislang kaum Daten aus der Antarktis vorliegen. Gemessen werden auch der Radiokohlenstoffgehalt der heutigen Wassersäule sowie die Methankonzentrationen in den antarktischen Gewässern und der Atmosphäre. An praktisch allen geplanten Stationen während EASI-2 wird ein erweitertes Spektrum an Probenahmestrategien verfolgt:

1. Durch den Einsatz eines normalen Wasserschöpfers wird zuerst die Struktur der Wassersäule ermittelt
2. Durch die Verwendung eines spurenmetallsauberen Wasserschöpfers werden Wasserproben für die zuverlässige Bestimmung verschiedener kontaminations-anfälliger Neben- und Spurenmetalle gewonnen
3. Die obersten Zentimeter des Meeresbodens werden mithilfe eines Multi-Corers oder Box-Corers beprobt
4. Je nach Standort werden Sedimentkerne mit einer Länge von bis zu 25 Metern entweder mit einem Kolben-, Schwere- oder Kastenlot beprobt
5. Die obersten 500 Meter der Wassersäule werden abschließend mithilfe eines Multinetzes und/oder eines Einzelplanktonnetzes auf Plankton beprobt

Im offenen Ozean entlang der EASI-2-Fahrtstrecke wird dies zu längeren Stationszeiten führen, weshalb eine gute Kommunikation mit den DWD-Meteorologen von entscheidender Bedeutung ist. Vorhersehbar schlechte Wetterbedingungen werden zu Anpassungen des Stationsplans führen, um sicherzustellen, dass jede Station vollständig durchgeführt werden kann.

Das Landgeologieteam wird hauptsächlich während einer dreiwöchigen Feldkampagne im Gebiet Vestfold Hills (östliche Prydz-Bucht) und bei Tagesausflügen in der Nähe von Gaussberg entlang der Davis-Küste arbeiten.

Die EASI-2-Expedition unterstützt die Ziele der Programmorientierten Förderung (PoF) der Helmholtz-Gemeinschaft, dem Forschungsprogramm „Changing Earth – Sustaining our Future“. Die behandelten Themen fallen vor allem in Thema 2 (Ozean und Kryosphäre im Klima) und decken alle vier Unterbereiche ab. Innerhalb von Thema 6 (Meeres- und Polarleben) erstrecken sich die durchzuführenden Forschungsarbeiten auf die Unterthemen 6.1 bis 6.3. Die Forschung dieser beiden PoFs der Helmholtz-Gemeinschaft wird sowohl am AWI Bremerhaven als auch am GEOMAR Kiel durchgeführt.

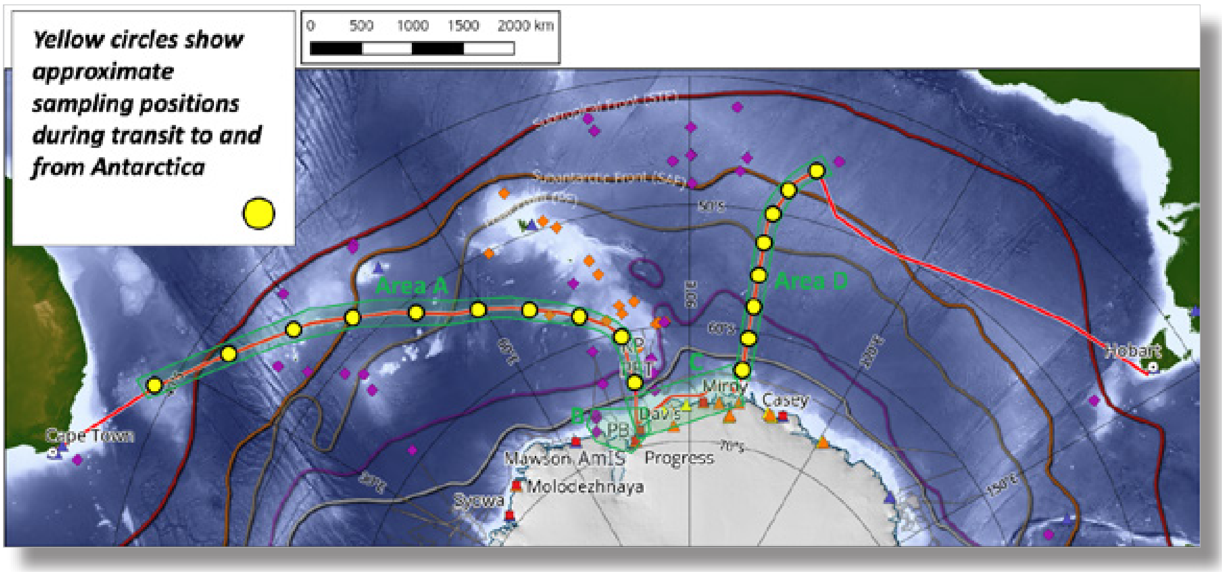

Abb. 1.1: Übersicht des geplanten EASI-2 /PS140 Fahrtverlaufs. Die Ausfahrt wird in Kapstadt starten, sich auf den indischen Sektor des Südozeans konzentrieren, umfasst sowohl offen-marine als auch Stationen auf dem Ostantarktischen Schelf, und nach 69 Tagen in Hobart enden. Gelbe Kreise zeigen ungefähre geplante Beprobungsstationen für Meerwasser, Sedimente und Multinetzproben. Arbeitsgebiete auf dem Ostantarktischen Schelf sind in Abb. 1.2 detaillierter dargestellt.

Fig. 1.1: Overview of the planned EASI-2 / PS140 cruise track. The expedition will start in Cape Town, cover the Indian sector of the Southern Ocean, cover both open ocean and East Antarctic shelf work areas, and terminate after 69 days in Hobart. Yellow circles indicate approximate positions for seawater, sediment and multi net sampling. Working areas on the East Antarctic shelf are shown in Fig. 1.2.

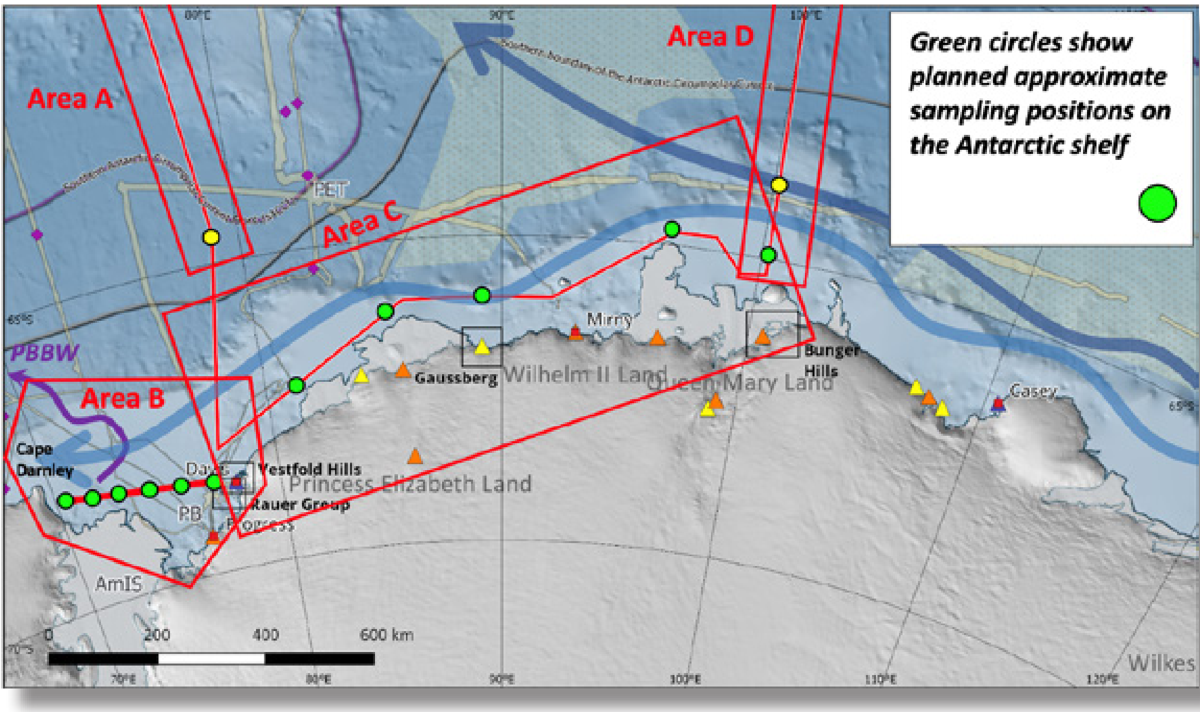

Abb. 1.2: Geplante Arbeitsgebiete auf dem Ostantarktischen Schelf während EASI-2 / PS140. Nach dem Abschluss der Stationen auf dem Weg in die Prydz-Bucht (Area A) wird das Team der Landgeologen in der Nähe der Vestfold Hills nahe der australischen Forschungsstation Davis für ihre etwa dreiwöchige Feldarbeit abgesetzt. Während dieser Zeit werden die anderen Teams an Bord vor allem in der Prydz-Bucht und in der Nähe von Cape Darnley arbeiten. Nach Abschluss der Landarbeiten wird die Expedition Richtung Osten fortgesetzt. Grüne Kreise zeigen ungefähre geplante Beprobungsstationen für Meerwasser, Sedimente und Multinetzproben auf dem Ostantarktischen Schelf.

Fig. 1.2: Planned working areas on the East Antarctic shelf during EASI-2 / PS140. After finalisation of the stations during transect to Prydz Bay (Area A) the land geology team will be dropped off in the Vestfold Hills area near the Australian Davis Station for their three-weeks field work campaign. The other teams onboard Polarstern will mainly be working in Prydz Bay and the adjacent Cape Darnley area. The expedition will continue towards the east after the end of the field campaign of the land geology team. Green circles show approximate sampling stations for seawater, sediments and multi net samples while working on the East Antarctic shelf.

SUMMARY AND ITINERARY

Expedition EASI-2 (East Antarctic Ice Sheet Instability) is the second of three scheduled expeditions that will examine the history of East Antarctic Ice Sheet (EAIS) Instability and its interaction with changes in Southern Ocean (SO) circulation. While the first of the three expeditions (EASI-1) already took place from 6 January until 28 February 2022, the third (EASI-3) will follow immediately after EASI-2. Each of the three coordinated expeditions has a unique research focus related to the potential instability of the EAIS during current and past climatic transitions. Compared with the other two expeditions, EASI-2 has the strongest focus on present-day processes in the Southern Ocean water column, observable modern nutrient availability with particular attention to delivery of essential micro-nutrients from the seafloor and East Antarctica. Two open-ocean water column transects are planned, aimed to resolve the structure, chemical composition, as well as present-day circulation state in the study area. Analogous work on the East Antarctic shelf will provide the proximal Antarctic perspective on both physical and chemical oceanographic trends seen today during times of generally increasing ocean temperatures, decreasing sea ice-extent, and freshening of various water masses in the SO such as Antarctic Bottom Water (AABW). At each station of the two transects, complementary collection of sea floor sediments and sediment archives of up to 25 metres depth below the sea floor will allow tracing changes in water column characteristics back to more than 0.5 million years. In focus are the Pleistocene oceanic frontal dynamics of the Antarctic Circumpolar Current, changes in sea surface water temperatures and past sea ice-extent. On the Antarctic shelf, combined parasound profiling and sediment sampling will allow to address questions regarding Quaternary ice sheet history and past bottom water formation.

The arguable most outstanding feature of this cruise is the ambition to tightly connect modern observations derived from the water column work with past states of SO circulation modes using a variety of state-of-the-art methods and/or proxies, and sampling strategies. For example, we will assess and quantify diagenetic processes at many sampling sites in parallel to the application of paleoceanographic proxies such as the extraction of authigenic past seawater-sourced trace metals (e.g. Nd and Pb). Temperature (e.g. Mg/Ca, $\delta^{18}O$, transfer functions) and carbonate system-related proxies (B/Ca, $\delta^{11}B$) applied on plankton samples and sedimentary microfossils can be directly compared to modern water column carbonate system parameters (TA, DIC), which we will equally obtain. Additionally, proxies for past sea ice-extent (e.g. PIPSO25, diatom transfer functions) will address questions regarding Pleistocene sea ice-dynamics. Thanks to the use of a trace metal clean seawater sampling system, we will be in a unique position to provide high-quality data on current transition metal cycling between (i) the seafloor and bottom water, as well as (ii) various water masses in the open Southern Ocean water column. This also extends to the quantification of sub-glacial delivery of transition metals and other analytically challenging trace metals for which hardly any data from Antarctic settings exist. The radiocarbon budget of the present-day water column will be assessed, as well as methane concentrations in Antarctic waters and the atmosphere. At virtually all planned stations during EASI-2, an extended range of sampling strategies will be followed:

1. Descent of a regular water sampler will resolve the structure of the water column
2. Use of a trace metal clean water sampler will recover water samples of sufficient quality for the reliable measurement of various contamination-prone minor- and trace metals
3. Sampling of the seafloor will provide surface sediments using a multi corer or box corer
4. Depending on location, sediment cores of up to 25 metres length will be targeted using either a piston, gravity, or kasten corer
5. The upper 500 metres of the water column will finally be sampled for plankton using a multi net and a single plankton net

In open ocean settings along the EASI-2 cruise track this will lead to extensive individual station times, for which reason good communication with the DWD meteorologists is key. Predictably poor weather conditions will lead to adjustments of the station plan in order to ensure each station can be fully occupied.

The land geology team will dominantly work during a three-week field campaign in the Vestfold Hills area (eastern Prydz Bay) and in day trips in proximity to Gaussberg along the Davis coast.

The EASI-2 expedition supports the goals of the Helmholtz Association's Programme-oriented Funding (PoF), the research programme "Changing Earth – Sustaining our Future". Topic covered fall most prominently into Topic 2 (Ocean and Cryosphere in Climate), covering all four sub-soptic. Within Topic 6 (Marine and Polar Life), research to be conducted extends to sub-topics 6.1 to 6.3. Research falling into these two Helmholtz Associaton'S PoF will be carried out both at AWI Bremerhaven and GEOMAR Kiel.

2. MARINE (GEO-)CHEMISTRY AND PHYSICAL OCEANOGRAPHY: COMPREHENSIVE SAMPLING OF THE WATER COLUMN, BOTTOM WATER AND SEDIMENTARY POREWATER

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Objectives

One of the major aims of EASI-2 comprises water sampling for a geochemical characterisation of the modern water column in the Indian sector of the SO for trace metal and micronutrient availability, hydrographic properties, dissolved silica and carbonate system parameters. This not only includes major and trace metal concentration work and isotope analyses that can be pursued following standard seawater sampling, but also collection of contamination-prone transition metals and other heavy trace metals such as lead (Pb) that were to date virtually not sampled in abyssal water depths of this part of the Southern Ocean. This approach can only be realised since a special trace metal clean water sampler and clean room laboratory can be used during EASI-2 (the Titan sampling system for trace metals from NIOZ). We expect a wide range of novel chemical insights into water column processes. Chemical exchange reactions between the seafloor and bottom water will equally be key given that various trace metals are supplied to the water column from marine sediments.

The remote yet hydrologically highly dynamic Indian Ocean sector of the Southern Ocean (SO) is dominated by the eastward flowing and vertically well mixed Antarctic Circumpolar Current (ACC). Its deeper portions are occupied by Antarctic Bottom Water, dominantly but likely not exclusively sourced from the Weddell Sea. Bathymetric highs such as the Kerguelen Plateau form topographic barriers around which deep water masses have to circulate on their way east. To the south of the ACC, the presence of the westward flowing Antarctic Slope Current (Williams et al., 2010) forms a thermal buffer zone around the East Antarctic Ice Sheet (EAIS) with near-freezing temperatures, preventing substantial submarine basal melting at present. The formation of new Antarctic Bottom Water (AABW) in front of the marine-based EAIS is a further important process in Antarctic waters. While the most important Antarctic Deep Water formation areas have long been known to lie in the southern Weddell and Ross Sea (e.g. Orsi et al., 1999; Purkey et al., 2018), more recently other locations of AABW formations have been identified such as the Cape Darnley region (Ohshima et al., 2013; Meijers et al., 2010; Solodoch et al., 2022; Williams et al., 2016; Williams et al., 2010). Generally speaking, AABW has warmed, declined in volume and freshened in recent decades, which likely will have consequences for the global sea level rise and heat budgets (Purkey et al., 2018). In this context, water column work in Antarctic waters particularly in the Prydz Bay region will serve as an important assessment of the current state of regional AABW formation as well as regional circulation patterns of other water masses along the studied sector of the EAIS. Hydrographic work in this area will also evaluate whether a southward displacement of the southern boundary of the ACC is already taking place, including the potential upwelling of relatively warm Circumpolar Deep Water onto the Antarctic shelf in eastern portions of the Prydz Bay that may lead to accelerated sub-glacial melting of the EAIS (Herraiz-Borreguero and Naveira Garabato, 2022).

The CTD (standard water sampler and Titan water sampler) and MUC water sampling work will further be complemented by the extraction of local marine porewaters that we will separate from multi cores at selected sites that will be obtained in close cooperation with the Marine Geology group (Chapter 4) and the determination of benthic release of trace metals and nutrients by the used of a benthic lander. Last but not least, the water column and benthic porewater work will be further extended by the sampling of sediment-containing continental ice (containing Antarctic rock debris) that PI M. Gutjahr is carrying out in cooperation with the land geology group onboard PS140 (Chapter 5).

Lead input and its dispersal in the Southern Ocean

The human impact on the marine environment is extreme and mankind already altered natural biogeochemical cycles substantially (Hader et al., 2020; Mahowald et al., 2018), even though the impact on the Antarctic ecosystem via pollution seemingly is as yet not as dramatic when compared to other regions (Clarke and Harris, 2003). Atmospheric emissions of lead (Pb) are a prime example for man made heavy metal pollution and transient atmospheric fluxes of Pb have long been monitored (Duce et al., 1991; Schaule and Patterson, 1981). During the late 1980s, the global total Pb flux to the oceans was on the order of 0.24 mg per square metre and year (Duce et al., 1991). The majority was deposited in the North Atlantic, while dust fluxes in the South Indian Ocean were estimated at 0.05 mg/m^2yr. This Pb flux led to a Pb deposition budget of 89 x 109 g/yr globally and 2.4 x109 g/yr in the South Indian Ocean. These numbers comprise both natural and anthropogenically sourced Pb but are clearly dominated by anthropogenic Pb sourcing. The phasing out of leaded gasoline between 1975 and 1995 resulted in remarkable modern-day water column Pb concentration gradients in the North Atlantic, where at present highest dissolved Pb concentrations are observed in the intermediate depth water column (Noble et al., 2015). These are water masses enriched in Pb that were in contact with the atmosphere decades ago when anthropogenic Pb emissions from Northern Hemisphere sources were still substantially higher than today. This North Atlantic subsurface concentration maximum equally highlights the transient behaviour of anthropogenic and natural Pb sourcing and its short residence time in seawater. The intermediate water Pb concentration peak in the North Atlantic also demonstrates that anthropogenic Pb emissions to the atmosphere have been decreasing in circum-North Atlantic areas, in contrast to other parts of the world such as the North Indian Ocean where surface water Pb concentrations define maxima because of continuously increasing Pb emissions in India, China and South Africa (Echegoyen et al., 2014; Lee et al., 2014).

While the generally lower Pb emissions in the Southern Ocean are more difficult to detect, these can be sensitively traced in Antarctic snow and ice. Antarctic snow deposited in the Hercules Névé plateau in Victoria Land (Antarctica) between 2012-15 still contained more than 90 % Pb of noncrustal origin (Han et al., 2022). Combining these recent observations with previous data, the authors suggested that Pb pollution in Antarctica has not significantly decreased until recently, despite continued international efforts to reduce Pb emissions in the

Southern Hemisphere during the corresponding period (see also Bertinetti et al., 2020). The Pb isotopic fingerprints in Victoria Land point to major Pb sourcing from South America, and particularly Brazil and Chile have become major sources of anthropogenic Pb in East Antarctic areas bordering the Pacific sector of the Southern Ocean (Han et al., 2022). Conversely, anthropogenic Pb in the Indian sector of the Southern Ocean is dominantly of South African origin (Boye et al., 2012; Lee et al., 2015; Schlosser et al., 2019).

Lead is a very particle-reactive element with an associated short residence time in seawater. According to a study using ^{210}Pb, the average residence time within the upper 2,000 m is on the order of 48 years, yet with large differences between high- and low-productivity regions (Henderson and Maier-Reimer, 2002). The residence time of Pb in the surface Indian Ocean is shorter than one year, while dissolved Pb in the deep Northern Indian Ocean has a residence time of 6-10 years (Sarin et al., 1994). Given that anthropogenic Pb sourcing also generate a regional water mass sourcing signal, it should be possible to distinguish anthropogenic Pb sourcing from major input sources such as India, China, or South Africa (Bollhöfer and Rosman, 2000, 2001; Flament et al., 2002). All these anthropogenic Pb isotope signatures will equally be substantially different compared with regional natural (Antarctic) Pb isotope source signatures.

In terms of ocean current and water mass configuration, the Southern Ocean presents an ideal laboratory to study how anthropogenic Pb sourced from the lower latitudes is transferred southward and eastward within various water masses. Given that anthropogenic sourcing of Pb is a very regional phenomenon, we should be able to sensitively trace the continental sources of Pb in each part of the Southern Ocean, particularly given the short residence time on the order of only a few years to decades. In order to resolve water mass sourcing by means of Pb, it is essential to study its isotopic composition and not only the dissolved Pb concentration. Lee et al. (2015) who presented the first in-depth study of natural and anthropogenic Pb distribution in the Indian Ocean demonstrated that while Pb isotopic compositions measured at the deepest water depths of the most southern station contained compositions closest to natural Fe-Mn crust compositions, these still contained an anthropogenic component.

Over the past decades the southern hemisphere westerlies intensified (Boning et al., 2008). This, in turn, led to stronger vertical mixing, and as a result, also more efficient entrainment of atmospherically deposited anthropogenic Pb into intermediate water depths of the ACC within the Southern Ocean (Schlosser et al., 2019). This also coincided with a southerly displacement of the southern hemisphere westerly wind belt at least in the Pacific sector of the Southern Ocean, while displacements in the ACC frontal system in the Indian sector seem to be more strongly controlled by regional changes in ocean circulation (Kim and Orsi, 2014). Overall, the strengthening of the westerly wind belt alongside its displacement to higher southern latitudes will lead to accelerated Pb transfer to the Antarctic zone of the Southern Ocean.

The last point that will be investigated is the generally poorly understood benthic Pb cycling in the marine environment. Some elements such as neodymium were shown to be released from marine sediments to overlying bottom water (Abbott et al., 2015; Du et al., 2022). While such a scenario is less likely important for Pb because of its higher particle reactivity, potential exchange of Pb between dissolved and particulate phase has been mentioned (Lee et al., 2015). While this aspect may seem less important to readers outside the paleoceanographic community, it indeed is a crucial process since exchange between particulate and dissolved Pb in sedimentary porewaters could in the worst-case lead to alteration of originally precipitated seawater-sourced Pb isotope signatures. A previous record published from the last two glacial terminations suggest that the authigenic Pb isotope signature in Southern Ocean sediments is immune to such authigenic diagenesis (Huang et al., 2020, 2021), yet this urgently needs further proof from modern meaningful case studies. And such case studies can only be realised in remote sub-glacial settings such as proposed here. This research objective is targeted with continental ice sampling containing detrital sediments that is presented in Chapter 5.

Tracing water mass sourcing with neodymium isotopes

A secondary major target for PS140 is the study of neodymium (Nd) isotope systematics within the water column. Neodymium isotopes are among the best provenance markers for individual water masses. Neodymium belongs to the group of Rare Earth Elements (REE) and is systematically incorporated in continental and oceanic crust with unique isotopic signatures. Neodymium isotopes are also an increasingly employed tool to investigate the origin and flow path of water masses in the oceans today and in the past. Analogously to Pb, this trace metal is supplied to the oceans via physico-chemical weathering on land and at the seafloor in shallow marine and continental rise settings. A latest modelling study reported that the relative contributions of Nd to seawater are ~60 % via boundary/benthic additions (i.e., from the sediments to bottom water), ~32 % through riverine inputs, and ~9 % from partial dissolution of dust in the water column (Pöppelmeier et al., 2020). The Nd isotope signature is thereby reflecting the isotopic signal of the material dissolving on land, within the water column (dust), or at the seafloor. As a consequence, water masses in contact with the ocean margin often successively change their isotopic composition along their flow path, but in the open ocean Nd isotopic compositions remain constant unless a parcel of water is mixed with another parcel of water with a different isotopic composition. Neodymium can hence be categorized as behaving semi-conservatively in seawater with a mean global residence time of about 690 years (Pöppelmeier et al., 2020).

The AABW exported into deep Atlantic and Indian Ocean today are predominatedly sourced from the areas in the southwest Weddell Sea and Prydz Bay regions (Solodoch et al., 2022). The PIs have sampled seawater in the southern and northwestern Weddell Sea and in the western flank of Prydz Bay during previous cruises for analyses of Nd isotopes and its concentration during PS111 in 2018, PS118 in 2019 and PS128 in 2022. Prelimilary Nd data have already provided insights into the Nd isotopic and concentration behaviours in these areas, also highlighting discrete hotspots of Nd addition to bottom waters, most clearly resolvable along the margins of eastern Antarctic Peninsula and East Antarctica within the Indian sector. The work to be realised during PS140 will extend the Nd database to the key unsampled East Antarctic areas, e.g., east of Prydz Bay, for a comprehensive understanding of the quasi-conservative behaviour of Nd isotope in the SO.

Specifically, the marine geochemistry team onboard PS140 will assess the feasiblity of using seawater Nd isotope as a water mass tracer in the Indian Ocean sector of Southern Ocean. We will compare actual seawater Nd isotope data in the water column with the standard physical oceanographic parameters and oxygen concentrations. In order to better constrain the non-conservative behaviour of Nd, we will also target the seawater-sediment interface by collecting Nd isotope and REE concentration data in the porewater, authigenic and detrital fractions of the surface sediments. The benthic fluxes of Nd into the bottom water will be quantified by a combined water column and sedimentary data at various sites covering Antarctic continental shelf, Antarctic continental slope and seafloor in the open ocean. The results will largely improve our knowledge of Nd isotope geochemistry cycle in the Southern Ocean.

It is also worth noting that the Prydz Bay-sourced AABW is the last global deep water endmember of which the Nd isotope signature is still undetermined. Precise measurements of its Nd isotope signature implemented during PS140 will allow us to reconstruct the evolution of Prydz Bay-sourced AABW export back into the past several glacial cycle. Marine sediments contain an authigenic Fe-Mn oxyhydroxide fraction that preserves the bottom water Nd isotope signatures and we can extract this bottom water signature with a gentle reductive solution

(Huang et al., 2021). This objective will be realised by targeting marine sediments that will be obtained in close cooperation with the Marine Geology group during PS140 (Chapter 4). The reconstruction of Prydz Bay-sourced AABW variability will provide essential information into the interactive mechanisms between past East Antarctic Ice Sheet dynamics and the formation and export of AABW.

Transition metals

Marine primary productivity exerts a key control on global climate. Trace metal availability limits primary productivity in many ocean regions, influencing ecosystem dynamics and (anthropogenic) carbon sequestration. Specifically, Fe, Mn, Ni, Cu, Zn and Co, are key micro-nutrients for marine organisms. Notably in high latitude oceans, the availability of these bio-essential trace metals, and especially Fe and Mn, can limit phytoplankton productivity and control the microbial community composition (Finkel et al., 2010; Schoffman et al., 2016). This makes it critical to understand the key sources of trace metals to surface waters. Recent evidence suggests that, besides atmospheric input and upwelling, lateral transport of trace metals released from continental margin sediments and glacial melt is an important source of trace metals to the open ocean (Homoky et al., 2016; Lenstra et al., 2019; Lenstra et al., 2022; Seyitmuhammedov et al., 2021; Shi et al., 2019). For many marine areas, but especially in high-latitude regions where glaciers supply particulate trace metals to continental shelves (Raiswell et al., 2018; van Manen et al., 2022), insight in the sedimentary mobilization and its impact on the water column is still lacking. Consequently, current global scale models that are used to assess the potential impacts of climate change on ocean biogeochemistry, and vice versa, cannot reproduce present-day oceanic trace metal distributions and, hence, vary widely in their predictions (Tagliabue et al., 2016). Given ongoing rapid climate change at high latitudes, it is crucial to obtain a better predictive and quantitative insight into trace metal input from shelf sediments in these regions.

Specifically, we will characterize the water column using trace metal clean techniques (Middag et al., 2015; Rijkenberg et al., 2015), the clean sampling for the relevant water column parameters (including trace metals and lead isotopes), analysis of selected trace metal concentrations and isotopic compositions in the water column and near the sediment (e.g. Lenstra et al., 2019; van Manen et al., 2022). The ensuing data interpretations would not just be standalone research outcomes but are needed to successfully complete the overall mission of EASI-2, understanding the role of the EAIS and nearby seas and ocean in past, current and future climate scenarios.

Notably, we will assess the role of Antarctic shelf sediments and glacial melt as a source of bio-available Fe, Mn, Ni, Cu, Zn and Co to offshore waters. We will also compare this trace metal release from shelves to release from deep ocean sediments. The benthic fluxes of bioavailable trace metals and their controls will be quantified using a combination of the water column data from this project and sediment and porewater analyses and sediment incubations in project AWI_PS140_10, Biotrace. Overall, the research is expected to provide key novel insights into the processes that could make the EAIS a driver of future sea level rise. The results will greatly improve our knowledge of the trace metal fluxes of continental margin sediments to the ocean.

Physical oceanographic observations

Sparse observations suggest that the surface waters in Prydz Bay are accumulating CO_2 faster than the expected rate of increase in anthropogenic CO_2 in the atmosphere (Roden et al., 2013). This unexpectedly large change may be due to a change in local biological production, a change in the characteristics of the source waters, or a combination of the two. Herraiz-Borreguero and Naveira Garabato (2022) showed, for the first time, warm Circumpolar

Deep Water replacing cold Dense Shelf Water (DSW) in front of the Vanderford Glacier, in Vincennes Bay, explaining the rapid grounding line retreat of the Vanderford Glacier in the past two decades (Rignot et al., 2019).

DSW is a key ingredient in the formation of Antarctic Bottom Water. Antarctic Bottom Water (AABW) is a critical player in the distribution of heat, carbon, oxygen and nutrients around the world's oceans. Prydz Bay has several polynyas that are responsible for DSW production, and ultimately AABW offshore Cape Darnley (Williams et al., 2016). This project seeks to repeat a transect along the Amery ice shelf calving front and several temperature and salinity profiles within Prydz Bay that will allow us to study any changes within the Bay, with special emphasis into how DSW may have changed in the past decade and whether this can explain the large rate of CO_2 accumulation in the surfaces waters. The hydrographic data collected from this project will also be used to elucidate the forcing behind the extreme decline in sea ice extension observed this winter.

The Amery ice shelf also has a large marine ice layer. Melting of this layer is thought to be the primary source of iron that supports elevated productivity in Prydz Bay relative to neighbouring regions (Herraiz-Borreguero et al., 2016b). Potentially as a consequence of this glacial iron supply, Prydz Bay is the third most productive Antarctic polynya, with a total production of 4.8 Tg C y^{-1}, and second in the total biomass. The hydrographic sampling to take place during EASI-2 will help to explain the processes that transport Fe to the surface waters from the Amery ice shelf. Several Argo floats will also be deployed in the Bay, increasing the spatial and temporal resolution of the meltwater distribution and its influence over the primary productivity of the bay.

This project will build a baseline record of observations in Prydz by using a novel combination of mooring, Argo floats and shipboard sampling to quantify physical and biogeochemical variability on the shelf; and, near the West ice shelf and near the Denman glacier, to keep track of physical environmental change observed in the region and elucidate the forcing behind it. This will provide the foundation for a largely autonomous monitoring programmed to be implemented over subsequent field seasons. Given the importance of ice shelves and sea ice in the delivery of nutrients to support phytoplankton production and ultimately carbon uptake in Antarctic coastal regions, Prydz Bay and the neighbouring Amery Ice Shelf are an ideal environment to investigate the impacts of a changing climate on marine environment.

Assessing benthic fluxes for transition metals

Iron (Fe) and manganese (Mn), among other trace metals, are key micro-nutrients for marine phytoplankton. The availability of these bio-essential trace metals in oceanic surface waters can (co)-limit primary productivity (Moore et al., 2013; Browning et al., 2021). This makes it critical to understand the key sources of these trace metals to oceanic surface waters. Recent evidence points towards continental margin sediments as an important source of Fe and Mn to the surface ocean (Lam and Bishop, 2008; Tagliabue et al., 2009). It is therefore critical to understand the mechanisms that control the benthic supply of Fe and Mn to the ocean, especially at high latitude regions where Fe and Mn limit primary productivity.

We will collect sediment samples to determine the mechanisms that control the mobilization of Fe and Mn in the sediment. These samples will be analyzed for bio-available Fe and Mn oxides, using sequential extractions and X-ray spectroscopy and for organic carbon and solutes (e.g. NH_4^+, NO_x^-, SO_4^{2-}, H_2S, O_2, Fe, Mn(II/III)) to quantify sedimentary Fe and Mn cycling. Additionally, we will use a trace metal clean benthic lander to measure the benthic release of key trace metals, macro-nutrients and oxygen uptake. Overall the combination of sediment analysis and the determination of benthic fluxes is expected to greatly improve our mechanistic understanding of the supply of trace metals from the continental shelf to the Southern Ocean.

Uranium isotopes in Antarctic waters

Uranium (U) and its natural radioactive isotopes have been proposed as a tracer in oceanography for more than 60 years (Ku et al., 1977). Their utility stem from the ^{238}U decay into ^{234}U and ^{230}Th, providing measures of time for processes such as particle scavenging and continental weathering as well as carbonate formation in the recent geologic past (Bourdon et al., 2003). More recently, redox-driven $^{238}U/^{235}U$ isotope fractionation was recognized providing a potential proxy of ocean anoxia (Kipp et al., 2022). Note, U behaves conservatively in seawater with a mean residence time > 400 kyr in the ocean allowing inferences of global balances and regional processes. Also important is the potential strong regional influence on the ^{234}U - excess as demonstrated in studies of semi-closed ocean basins, yielding a visible signal of elevated ^{234}U-excess from river discharge or submerged groundwaters (Andersen et al., 2007; Border, 2020). Consequently, studies of the regional U isotopic composition of seawater regarding the $^{238}U/^{235}U$ ratio as well as the excess of ^{234}U can inform on ocean anoxia, weathering patterns, and freshwater discharge which gives the U proxy a new utility in paleoceanography. Here, we will collect samples representing the southern hemisphere balance of water injected in the Antarctic Circum polar current and its potentially visible influences from regional freshwater release and sedimentological isotope fractionation imprinted on the seawater $^{238}U/^{235}U$ ratio and ^{234}U-excess. This is of particular interest as the U isotope balance of the south polar Ocean has not been studied so far.

Radiocarbon in seawater

Global climate is critically sensitive to physical and biogeochemical dynamics in the subpolar Southern Ocean, since it is here that deep, carbon-rich layers of the world ocean outcrop and exchange carbon with the atmosphere (e.g., MacGilchrist et al., 2019). It is also here that much of anthropogenic carbon is taken up by the ocean, and glacial ocean carbon storage in the deep Southern Ocean is well established (e.g., Brovkin et al., 2012). Changes in Southern Ocean carbon uptake and its export to depth are thus strongly impacting the global carbon cycle. The Southern Ocean's role in anthropogenic carbon uptake has long been identified (Caldeira and Duffy, 2000), and it has been suspected that climate warming reduced the efficiency of this anthrogenic carbon uptake. More recently, the strength of this carbon sink has been described to have re-invigorated (Landschützer et al., 2015).

The distributions of deep ocean $\Delta^{14}C$ data of dissolved inorganic carbon (DIC) are often used to illustrate the rate of deep ocean circulation, as radiocarbon is an invaluable tool to trace exchange processes in the carbon cycle and to estimate time in closed reservoirs. For instance, $\Delta^{14}C$ of DIC can be used to map the uptake of atmospheric CO_2 into the ocean, or reflect input of aged carbon from the sea floor originating, e.g., from geologic sources. Despite its usefulness, high-resolution profiles of $\Delta^{14}C$ of DIC in the water column are scarce, in particular for the Southern Ocean, and near the Antarctic continental margin, albeit the occurrence of deep-water formation at these locations. The current state of knowledge is based on a large international effort, the World Ocean Circulation Experiment conducted in the early 2000s. We will sample at all CTD stations to significantly expand the existing data base of DIC $\Delta^{14}C$ in the Southern Ocean, to detect deep-water formation and export and to investigate potential decadal-scale changes in carbon uptake.

The radiocarbon signature of pore water DIC has been used to infer the age of remineralized organic matter in sediment (Dumoulin et al., 2022) or dissolved carbonates (Martin et al., 2000), and it has been proposed that in extreme environments such as deep brine pools, inverse diffusion into the sediment might impact pore water ^{14}C (Sivan and Lazar, 2002). Gradients of DIC $\Delta^{14}C$ in the uppermost sediments and across the sediment-water interface will in any case have an impact on bottom water DIC $\Delta^{14}C$, which in turn will be incorporated by benthic foraminifera, commonly used as paleo-proxy carriers. In close collaboration with the marine geology group, we will study this system of complex interaction by sampling pore waters at selected sites and determining isotopic compositions and concentrations of DIC.

Carbonate System Parameters (TA and DIC), seawater $\delta^{13}C$ and $\delta^{18}O$

Any change in the marine carbon pool can be readily quantified via measurement of selected carbonate system parameters. At least two out of six carbonate system parametes are required in order to constrain all essential carbonate system variables (i.e. CO_2, HCO_3^-, CO_3^{2-}, H^+, DIC, TA). During PS140 we will determine total alkalinity (TA) either underway as well as in all individual bottled water samples. Seawater TA will be titrated onboard with help of a CONTROS HydroFIA™-TA, from 4H-JENA engineering. In addition to TA, discreted samples for Dissolved Inorganic Carbon (DIC) will be collected in order to provide the required second carbonate system parameter. Since planktic carbonates (e.g. foraminifera) are equally expected to be collected during the cruise, a direct assessment of seawater chemistry using for example the boron isotope proxy will be possible. The DIC budget will hence not only provide insights into current changes in the dissolved Southern Ocean carbon budget but also allow calibration of sedimentary carbonate system proxies, essential for any paleoceanographic applications following EASI-2. Moreover, TA will also be manually titrated onboard PS140 from extracted marine porewaters for the detection of diagenetic redox processes in surface sediments. Moreover, at each water sampling station additional aliquots will be taken for shore-based analyses of DIC $\delta^{13}C$, as well as seawater $\delta^{18}O$.

Methane and nitrous oxide in seawater

Following carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are the most important natural greenhouse gases (IPCC, 2021). Moreover, CH_4 and N_2O are involved in stratospheric ozone depletion (WMO, 2018). N_2O, in view of the ongoing atmospheric decrease of the chlorofluorocarbons, is expected to become the most important ozone-depleting compound of the 21st century (Ravishankara et al., 2009). When it comes to what we know of the ocean as a source of these gases, our knowledge is patchy and uncertainty ranges are significant. Estimates of oceanic CH_4 emissions suffer from significant uncertainties: although the ocean could contribute a minor, but still significant, 1 % of global CH_4 emissions, uncertainties are in the range of at least ± 50 % (IPCC, 2021). Oceanic N_2O emission estimates indicate that the open and coastal oceans may contribute between 13 % and 44 % of the natural and anthropogenic N_2O sources combined (IPCC, 2021). Oceanic emissions of both CH_4 and N_2O are largely determined by the balance of microbial production (i.e. nitrification, denitrification and methanogenesis) and consumption processes (denitrification and CH_4 oxidation) (Bakker et al., 2014). In the case of CH_4, microbial consumption is thought to be very effective and thus consumes a large fraction of the gas produced *in-situ* allowing only a small fraction to escape into the atmosphere. In contrast to the majority of the oceanic regions, the Southern Ocean is undersaturated with CH_4 and thus seems to act as a sink for atmospheric CH_4 (see e.g. Ye et al., 2023). However, only a few studies have addressed the distributions of CH_4 and N_2O in the water column of the Indian Ocean sector of the Southern Ocean and the Prydz Bay so far.

Work at sea

Up to 40 seawater stations will be targeted, which conform with the sediment sampling sites, providing the best possible reference frame for the sedimentary palaeo-seawater Nd and Pb isotope records to be generated alongside the seawater depth transect. Following GEOTRACES protocols (www.geotraces.org) and using the Titan trace metal clean seawater sampling system (De Baar et al., 2008) in conjunction with a regular water sampler, we will sample seawater throughout the water column for contamination-prone trace metals, which to date has hardly been done in Indian Ocean (sub-)Antarctic waters due to expensive and complex logistical requirements. Since 23 litre samples will be provided per depth and the seawater sampling will be carried out under trace metal clean conditions, obtained seawater samples will also be analysed for other key trace metals such as Zn, Fe, Cd. We will further measure $\delta^{14}C$, $\delta^{13}C$, $\delta^{18}O$, DIC, pH and Total Alkalinity at AWI and GEOMAR to provide the modern reference frame for our sediment-based proxy reconstructions. Small (few tens to hundreds of mL) aliquots will further be taken aside for the study of other isotope systems such as silicon (Grasse et al., 2017) and barium (Yu et al., 2022). Samples for DIC, $\Delta^{14}C$ and $\delta^{13}C$ analyses will be fixed with $HgCl_2$ and sealed without headspace in gas-tight sampling vials.

Water column sampling during EASI-2 will always be carried out in two steps. First, the regular water sampler / CTD with online communication with the winch control room will be used. Most parameters can already be covered using this device. Once the regular water sampler is back on board, the trace metal clean water sampler will be used. Since this water sampler is lowered over the 11 mm Dyneema rope, online communication with the ship is not possible and the bottles will have to be closed in pre-defined depths determined during the first standard water sampler descent. While the water samples of the standard sampling approach can be aliquoted in the bottling room II on E Deck, the trace metal clean water sampler will be immediately moved into a clean laboratory container that will be placed on the working deck. Samples for major nutrients, dissolved (0.2 µm filtered) and particulate (0.4 µm PES filter) trace metals will be collected over the water column. Samples for dissolved metals will be collected in clean LDPE bottles and acidified to 0.024 M HCl, which results in a pH of ~1.8, and stored at room temperature (Middag et al., 2023). Samples for particulate metals will be collected on PES filters and stored in clean centrifuge tubes at -20°C (Middag et al., 2023). The measured oxygen and salinity will be calibrated shipboard from discrete samples, all other samples will be analyzed in the home laboratory. Beside samples for analysis, water will be collected for bio-assay experiments (see Chapter 6 and 7).

Specifically, samples for metal concentrations, metal isotopes and biological variables are sampled from selected depths, whereby from at least one depth (deep chlorophyll maximum or mid mixed layer), all variables will be sampled. Transport of Fe requires stabilization with organic ligands, thus samples for the concentrations and nature of the ligands will be collected as well to assess the potential sources and interaction with the microbial community. Additional tracer information will come from stable and radiogenic isotopes including oxygen isotope ratio $\delta^{18}O$ and $\delta^{56}Fe$.

Water column samples for Nd isotopic and REE analyses will be collected by means of a regular CTD rosette, aiming to collect at least 10 litres per sample. For selected water depths seawater oxygen concentrations obtained using the oxygen sensor attached to the CTD rosette will be calibrated against discrete water samples onboard using standard procedures (Winkler titration). The locations of water sampling stations will be coordinated with Marine Geology stations (Chapter 4) in order to obtain a comprehensive picture from the sediments, across the sediment-bottom water interface into the open water column.

We will further separate sedimentary porewaters obtained from MUC sampling via centrifugation processed following trace metal clean sampling protocols in an oxygen-free atmosphere (using argon in glove bags) allowing for the reliable determination of contamination-prone trace metals and their isotopic compositions. Sampling of the MUCs (2 cm slices) will also be realised to analyse key geochemical porewater properties (alkalinity, sulphate, nitrate, NH_4^+, H_2S, various trace metal concentrations). A separate sample set for DIC and its carbon isotope analysis will be taken. These samples will be fixed with $HgCl_2$.

Water samples will be filtered on board, acidified and, in the case of samples for Nd isotope analyses, subsequently co-precipitated using dissolved Fe chloride. Subsequently, samples will be transferred into appropriate storage vials (1L HDPE flasks, head-space vials, or 50 mL centrifuge vials during the cruise). All sedimentary porewater samples will also already be sampled, centrifuged and filtered onboard. Filtered samples designated for nutrient and IC analyses at home laboratories at GEOMAR Kiel or NIOZ need to be stored frozen (-20°C), while porewater samples used for trace metal analyses will be further acidified to pH ~2 and taken home at ~4°C. Samples for seawater DIC analyses will be poisoned with $HgCl_2$ and stored at 4°C. Total Alkalinity of the water column will be measured on board using a Hydro FIA device, while TA of sedimentary porewater will be measured via manual titration.

Samples for the determination of CH_4 and N_2O concentrations will be sampled in triplicates from the CTD/Rosette at various water depths from the ocean surface to the bottom. The samples will be poisoned immediately after sampling with $HgCl_2$ for later analysis with GC-FID (CH_4) and GC-ECD (N_2O) in the GEOMAR laboratories in Kiel after the cruise.

Preliminary (expected) results

For Pb, we expect a gradient from anthropogenically sourced Pb isotope signals in seawater in the North to most pristine natural seawater Pb isotope compositions near Prydz Bay (cf. Lee et al., 2015). Further shallow water shelf sampling will be conducted on the East Antarctic shelf in the Prydz Bay area (Area B), during transit to Bunger Hills (Area C), as well as north of Bunger Hill (Area D). Neodymium isotopes in turn will reflect three major components, (i) an originally imparted Nd isotope signature from the area of Nd supply at the ocean margin, (ii) a mixing signature acquired when water masses meet in various parts of the SO, and (iii) the current Nd supply signature at the seafloor everywhere in the study area. This latter component will likely vary a lot in terms of magnitude and its variance is a major research question of this cruise.

Expected results for the shipboard work related to the transition metals work using Titan, include CTD data with corresponding the oxygen and salinity calibrations. Additional results will follow from analysis in the home laboratories (NIOZ, RU and UG) as described above and include bio-active metal concentrations, $\delta^{18}O$, phytoplankton community composition, particulate organic carbon / nitrogen and particulate metals.

We expect to quantitatively determine the supply of key trace metals from the continental shelf to the Southern Ocean and thereby identify hotspots for trace metal release (most likely in sediments that are rich in organic carbon). Additionally, we expect to mechanistically understand what controls this benthic trace metal supply and thereby constrain predictions of benthic trace metal supply to the ocean in the future. The radiocarbon data will be used to map the three-dimensional distribution of $\Delta^{14}C$ of DIC in the study area, thereby greatly increasing the existing data base for the Southern Ocean, and are expected to reveal deep-water formation rates and potential changes in uptake of anthropogenic CO_2 over the last decades.

In addition, we expect to quantitatively determine the supply of Fe from the cavity of the Amery ice shelf, and understand what controls the supply of Fe (and other trace metals) from the Amery ice shelf marine ice melt to the surface waters. This will also expand our knowledge of the impacts of meltwater addition to DSW formation, changes in ocean circulation and CO_2 uptake by the ocean, expected to increase under current emissions.

Repeat hydrographic sampling at key locations in this part of Antarctica, together with past and present observations from other platforms such as Argo floats, is expected to fill a key gap in knowledge on how the Antarctic Slope Current may have changed as a result of increased meltwater and warming of Circumpolar Deep Water, and whether this can explain any increased ocean heat supply towards the East Antarctic Ice Sheet.

The measurements of the CH_4 and N_2O concentrations in the Indian Ocean sector of the Southern Ocean and the Prydz Bay will significantly extend the existing data sets (mainly from various CHINARE campaigns during the last decade) and will thus allow to (i) improve the emissions estimates and (ii) gain further insights into the major production and consumption processes of CH_4 and N_2O in the water column.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

CH_4 and N_2O concentration data will be archived in MEMENTO (The MarinE MethanE and NiTrous Oxide database, https://memento.geomar.de)

All raw data for the transition metals will also be stored on the NIOZ-server for secured back-up and is available to collaborators upon completion of analysis. After suitable quality control, the metal data will be submitted in the final project year to the GEOTRACES International Data Management Centre (www.bodc.ac.uk/geotraces/) and the National Polar Data Centre (http://www.npdc.nl/) which is linked to other international databases. Two years after submission, data will become publicly available (www.bodc.ac.uk/geotraces/data/policy) and will also be incorporated in the next GEOTRACES Data Product. Additionally, all porewater and benthic flux data will be stored on the Radboud University server and portable hard drives.

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In all publications, based on this cruise, the one of the relevant Grant Numbers referring to the seawater work (i.e., AWI_PS140_01, AWI_PS140_02, AWI_PS140_10, AWI_PS140_11, AWI_PS140_12) will be quoted and the following Polarstern article will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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3. BATHYMETRY OF THE EAST ANTARCTIC SEA

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Objectives

Accurate knowledge of the seafloor topography, hence high-resolution bathymetry data, is key basic information necessary to understand many marine processes. It is of particular importance for the interpretation of scientific data in a spatial context. Bathymetry, hence geomorphology, is furthermore a basic parameter for the understanding of the general geological setting of an area and geological processes such as erosion, sediment transport and deposition. Even information on tectonic processes can be inferred from bathymetry.

While world bathymetric maps give the impression of a detailed knowledge of worldwide seafloor topography, most of the world's ocean floor remains unmapped by hydroacoustic systems. In these areas, bathymetry is modelled from satellite altimetry with a corresponding low resolution. Satellite-altimetry derived bathymetry therefore lack the resolution necessary to resolve small- to meso-scale geomorphological features (e.g. sediment waves, glaciogenic features and small seamounts). Ship-borne multibeam data provide bathymetry information in a resolution sufficient to resolve those features and for site selection for the other scientific working groups on board.

Glacigenic landforms preserved at the seafloor can form the basis for the reconstruction of the dynamic history of Antarctic Ice Sheets. In particular, these landforms can shed light on its retreat since its maximum extent during the Last Glacial Maximum. Understanding the processes that led to this ice sheet retreat in the past can provide important information for predicting future responses of Antarctic Ice Sheets to changing climate conditions and oceanographic settings. Glacigenic landforms can only be determined in high-resolution bathymetric data sets. These data are however sparse for the study areas of the EASI-2 expedition. Therefore, it is planned to acquire detailed bathymetric data of these areas with the ships hydroacoustic instruments.

Furthermore, the collection of underway data during PS140 will contribute to the bathymetry data archive at the AWI and thus to bathymetric world datasets such as GEBCO (General Bathymetric Chart of the Ocean).

Work at sea

Bathymetric data will be recorded with the hull-mounted multibeam echosounder Atlas Hydrosweep DS3. The main task of the bathymetry group is to plan and run bathymetric surveys in the study areas and during transit. The raw bathymetric data will be corrected for sound velocity changes in the water column, and will be further processed and cleaned for erroneous soundings and artefacts. Detailed seabed maps derived from the data will provide information on the general and local topographic setting in the study areas. High-resolution seabed data recorded during the survey will be made available for site selection and cruise planning. During the survey, the acoustic measurement will be carried out by three operators in a 24/7 shift mode (except for periods of stationary work).

Preliminary (expected) results

Expected results will consist of high-resolution seabed maps along the cruise track and from target research sites. The bathymetric data will be analyzed to provide geomorphological information of the research area. Expected outcomes aim towards a better understanding of the geological processes in the research area.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied. Furthermore, bathymetric data will be provided to the Nippon Foundation – GEBCO Seabed 2030 Project.

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In all publications based on this expedition, the **Grant No. AWI_PS140_05** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

4. MARINE GEOLOGY AND PALEOCEANOGRAPHY

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Objectives and scientific programme

The Antarctic Circumpolar Current (ACC) is the world's largest current system and connects all three major basins of the global ocean (i.e., the Pacific, Atlantic and Indian Ocean), and therefore integrates and responds to climate signals across the globe (e.g. Talley, 2013). Through upwelling and formation of new water masses, the ACC affects the global meridional overturning circulation (MOC) (Marshall and Speer, 2012) and the stability of Antarctica's ice sheets. Atmosphere-ocean-cryosphere interactions play an important role for understanding processes and feedbacks of past and future climate change, with the subantarctic SO providing the major link between Antarctica and the low latitudes. In the SO, these interactions are believed to control sea-ice cover, ice-sheet dynamics, upper ocean stratification, biological nutrient utilization, upwelling rates of deep-water, and to play a key role in explaining the variability in atmospheric CO_2 concentrations. A further major atmospheric forcing are the Southern Westerly Winds (SWW), which impact the upwelling of carbon-rich deep-water masses in the SO affecting atmospheric CO_2 (Anderson et al., 2009).

The East Antarctic Ice Sheet (EAIS) holds a potential contribution of 53 m to global sea level, of which currently 19 m form part of grounded continental ice below sea level (Fretwell et al., 2013). Past sea level estimates for the most recent warmer-than-present interglacials strongly suggest that parts of the EAIS are susceptible to enhanced melting under elevated radiative forcing (Wilson et al., 2018). The most important process leading to melting of marine based portions of both the EAIS and WAIS is submarine basal melting (Depoorter et al., 2013). At present the marine portions of the EAIS are largely shielded from basal melting through the presence of the westward flowing Antarctic Slope Current (Williams et al., 2010) forming a thermal buffer zone around most of the EAIS with near freezing temperatures (see also Fig. 2). The presence of this current prevents incursions of warmer Lower Circumpolar Deep Water (LCDW) diverted south from the eastward flowing Antarctic Circumpolar Current (ACC) that currently erodes large portions of the WAIS (Pritchard et al., 2012; Wåhlin et al., 2020).

Past changes in current strength and transport of the ACC are fragmentary reconstructed and only for limited late Pleistocene time intervals. In the Drake Passage (DP), a significant glacial decrease in DP throughflow combined with reduced current velocities has been identified (e.g., Lamy et al. ,2015), most likely regulated by variations in the SWW field over the subantarctic zone and changes in Antarctic sea ice extent. In contrast, a 500,000-year record from the Indian sector of the SO suggests that the ACC was weak during warm stages and strong during glacial epochs (Mazaud et al., 2010). The latitudinal positions of the oceanic fronts are not very well constrained in the Indian sector of the Southern Ocean during glacial/interglacial variations or even on millennial to centennial timescales during the last glacial to Holocene transition. This is largely due to the very remote locality of this part of the SO. However, like no other sector in the SO, the Indian sector offers a unique opportunity for reconstructing changes in SO circulation that responded to or have been forced by past variations in EAIS dynamics. This is because of bathymetric highs (shallow water depth), the Kerguelen Plateau and the Southeast Indian Ridge, covering a latitudinal range from 65° to 45°S, which allows for coring of carbonate-rich sediment cores. The application of carbonate-based proxies doubles the library of proxies that can be used to reconstruct climatic and oceanographic changes, e.g. latitudinal changes in the oceanic fronts as well as variations in deep water chemistry and circulation. This possibility would greatly improve the reliability of our reconstructions and statements.

The Subtropical Convergence (STC) has been found to have been located south of Tasmania during the last interglacials (Marine Isotope Stages: MIS 5, 7, 9, 11), while during glacial periods a northward movement of subantarctic water masses up to <44° S may have occurred (Nürnberg and Groeneveld, 2006). Chase et al. (2003), instead, concluded that a significant northward shift of the fronts in the SW Pacific during the last glacial is not feasible, as in particular the expected enhanced opal accumulation north of the glacial Polar Front (PF) is not documented. Whether this finding is also valid for the Indian sector of the SO, or whether there was a steepening of hydrographic gradients during the glacial period, can only be clarified by examining the sediment core transects requested here. The large majority of studies to date focused on the most extreme climatic transitions, most commonly the last (18–11 ka BP) or penultimate (137–129 ka BP) glacial terminations. The gradual oceanographic process of transitioning from an interglacial into a glacial circulation mode is much less well known, not to mention the detailed processes at work during re-partitioning of atmospheric carbon dioxide into a glacial abyssal ocean reservoir (Sigman et al., 2010).

The deep SO experienced major circulation changes on glacial/interglacial timescales, with significantly reduced overturning dynamics during peak glacial intervals (e.g. Adkins, 2013; Hasenfratz et al., 2019). A recent study presented evidence for cessation of Weddell Sea-sourced AABW export into the Atlantic sector of the SO (Huang et al., 2020) whereas AABW export into the Indian sector of the SO may still have been possible given the bathymetry of the Weddell-Enderby abyssal plane if AABW was indeed formed during extreme glacial climate. While AABW formation is generally assumed to take place in glacial climate, its presence has never been unambiguously proven apart from indirect evidence (Smith et al., 2010). The transect of sediment cores to be sampled during EASI-2 will allow a much better quantification of the export of AABW into the Indian Ocean and the import of CDW into the Southern Ocean during the last glacial cycles. In this context, geological work is intended in the Prydz Bay area, the Cape Darnley Polynya and along the Antarctic coasts of the Cooperation Sea, the Davis Sea and the Mawson Sea to reveal past geological processes in vicinity of the East Antarctic Ice Sheet (EAIS). Particular attention will be paid to processes that are related to basal ice shelf melting, including Warm Deep Water (WDW) intrusions into the ice shelf cavities and feedback mechanisms (e.g. freshening, sea ice cover) that control the formation and extent of Antarctic Bottom Water (AABW).

The overall goal is to enhance our understanding of Quaternary processes as well as the orbital to submillenial-scale evolution of ice-ocean-climate interactions during deglacial warming and climate intervals that were warmer than today. Therefore, we plan to probe Subantarctic and

Antarctic marine sediment archives along two latitudinal transects across the fronts of the ACC, one in the western Indian sector and one in the eastern Indian sector of the Southern Ocean. The coring sites for sampling of late Pleistocene sediments are chosen aiming to collect information on changes of the oceanic fronts and prevailing climate in response to ice sheet variability over the last glacial cycles. The palaeoceanographic approaches focus on sediment cores from the SO frontal system between Cape Town, Hobart, and Antarctica. Based on preliminary information from other sediment cores (e.g., *Marion Dufresne* expeditions in the 1980´s and 1990´s) we estimate that cores recovered at the proposed locations will document up to 300–700 kyr. Such material is crucial for addressing a number of current hypotheses regarding the importance of ocean-atmosphere-cryosphere dynamics in affecting global ocean circulation, CO_2, and climate. Pleistocene to Holocene variations ACC dynamics, near-surface temperatures salinity and nutrient concentrations, are to be determined with a multi-proxy approach. The regional changes in their gradients are intended to decipher fluctuations in heat and salt transfer, and provide additional information on the position of oceanic fronts and the wind field for certain time slices. Their vertical gradients are used to reconstruct the stratification of the upper ocean. These changes in stratification are the basis for understanding ocean-atmosphere gas exchange (CO_2) and for deciphering the Subantarctic intermediate and mode water formation. The boron isotopic and B/Ca application will be a powerful tool to gauge the SO carbon budget over the investigated timescales, most importantly with regard to the glacial sequestration of respired atmospheric carbon in the deep SO and subsequent release during glacial terminations (Martinez-Boti et al., 2015; Moy et al., 2019).

An important backbone to validate these hypotheses is the development of high-resolution age models. Precise timeframes are required to allow for comparisons with other existing high-resolution climate proxy records derived from sediment and ice cores. We will apply a variety of stratigraphic methods, including marine oxygen isotope stratigraphy, ^{14}C-dating techniques, $^{230}Th_{ex}$, methods, cross-correlation of proxy records with other well-dated records (e.g., ice-cores), paleomagnetics and tephrachronology.

ACC strength changes will be reconstructed by sedimentological and geochemical methods (sortable silt, XRF (e.g. Wu et al., 2020, 2021). Sea surface, intermediate and deep water temperatures will be based on Mg/Ca paleothermometry of planktic and benthic foraminifers (Nürnberg et al., 2000), the organic biomarker-based indices alkenones TEX^{L}_{86} and RI-OH’ (Ho et al. 2014; Lamping et al., 2021; Park et al., 2019) and diatom transfer functions (Esper & Gersonde, 2014a). Sea ice reconstructions will be based on analyses and intercomparisons of specific biomarker lipids (highly branched isoprenoids) and diatom assemblages (Esper & Gersonde, 2014b). These studies will allow to assess the role of “Warm Deep Water” in ice-shelf melting and the response of the Southern Ocean and sea ice to meltwater-induced freshening. The sediment archives proximal and distal to the Cape Darnley Polynya offer an excellent opportunity to assess past changes in Cape Darnley Bottom Water/AABW formation, which is of global significance. A multi-proxy approach is required to reconstruct and understand the system (Rickli et al., 2014; Borchers et al., 2016; Vorrath et al., 2019). We will reconstruct changes in sea ice production, biogenic productivity, Nd and Pb isotopes as well as Rare Earth Elements indicative of the provenance of current-derived and ice-transported material as well as past regional changes in overturning circulation. Changes in ocean stratification are the basis for understanding ocean-atmosphere gas exchange (CO_2) (e.g., based on multispecies foraminiferal oxygen, carbon and boron isotopes, B/Ca ratios) and for deciphering the subantarctic intermediate and mode water formation, complimenting the isotope geochemical approaches outlined above.

Our studies also aim to significantly improve our understanding of past EAIS extent, its flow and retreat patterns, and the related bed processes that controlled ice flow primarily since the last glacial to the Holocene (Klages et al., 2016; 2017). We will integrate and link bathymetric, seismic, marine geological, and modelling competence to map and document temporal changes in grounding line dynamics since the LGM.

Work at sea

Bathymetric and hydroacoustic surveys are used to identify (1.) core locations ideally containing undisturbed sediment sequences, (2.) sites with high sediment accumulation, (3.) sites that comprise the last 500 ka in the upper 20 m of the sediment archive and (4.) grounding lines, moraines and scour marks.

The standard coring program includes the operation of the multicorer (MUC) and the piston/gravity/box corer (PC/GC/BC). At selected stations, the sediment sampling will be complemented by multinet and plankton net hauls. In Area A (Fig. 4.1), along a NW-SE transect in the western Indian sector we plan to retrieve sediment records across the oceanic fronts to obtain material for applying proven analytical methods as well as to established new proxies. Sediment records from the deep-sea basin will be used to reconstruct changes in AABW dynamics and glacial/interglacial geographic shifts in the Southern Ocean frontal system. In Area B, we plan transects of sediment records in the Cape Darnley Polynya on the shelf and across the continental margin into Prydz Bay, particularly in the vicinity of the Amery Ice Shelf edge. In close proximity to the EAIS, we will complement previous shelf coring campaigns to define the extent and timing of grounded ice beneath and offshore the EAIS. This work to constrain the past extent and retreat pattern of grounded ice and its timing since the LGM will continue in Area C along the coast of the Davis and Mawson seas by combining information from multibeam and sediment echosounders with appropriate coring locations (KC and GC) on selected shelf sectors. In Areas D, along a S-N transect across the sea ice margin and the oceanic fronts of the eastern Pacific sector up to the Southeast Indian Ridge, we will perform an extensive sediment coring program, targeting sites distributed in water depth between 2,000 and 4,000 m to reconstruct the vertical water mass architecture and the different physical and chemical signatures of water masses. At foraminifer-bearing key stations, we will use the Kasten Corer (KC) and/or triple coring (PC/GC) to ensure that sufficient foraminifers are available for the application of certain paleoceanographic proxies and ^{14}C datings.

Sediment cores will be cut into 1 m sections and stored at 4°C. Prior to storage, all core sections will be analyzed for physical properties of the entire core using a Multi-Sensor-Core-Logger (MSCL-S, Geotek Ltd.). The MSCL device provides data at 1 cm depth intervals of wet-bulk density, porosity, p-wave velocity and magnetic susceptibility. Full processing of MSCL raw data will be carried out at sea, so that high resolution records of physical properties are available during the cruise. Selected sediment cores will be split onboard. Core images, descriptions of sediment properties and smear slide investigations of these cores allow an initial characterization of the sediments. However, some of the sediment cores remain unsplit until arrival at the home laboratories because the expected number of sediment cores is too high. Sampling of the Multi Corer sediment records (1 cm slices) into combusted glass vials (biomarker) and Whirlpack sampling bags will take place onboard. Samples designated for biomarker studies and ancient DNA analyses at home laboratories will to be stored frozen (–20°C). Water samples will be filtered on board, acidified and subsequently co-precipitated. At most sites MUC cores will equally be sampled for their trace metal and Pb isotope budget, both in porewaters as well as the particulate phase (see also Chapter 2).

Preliminary (expected) results

With sediment cores recovered during PS140, we aim to resolve glacial-interglacial, as well as millennial-scale variations in ACC dynamics, AABW formation and export, East Antarctic sea ice-extent, glacial deep SO carbon storage, as well as sediment sourcing and bottom-water oxygenation levels that include the most extreme late Pleistocene interglacials MIS 5e (Clark et al., 2020) and MIS 11 (Raymo and Mitrovica, 2012; Wilson et al. ,2018).

In general, our expedition will provide new data and samples from key regions of the Indian sector of the Southern Ocean and along the East Antarctic continental margin that will enhance our understanding of processes related to interactions in the ice-ocean-bedrock-climate system. This should improve our assessment of future ice sheet instability and associated changes in Southern Ocean circulation and ventilation.

On board, the combination of bathymetric and subsurface sediment features (parasound) in combination with core descriptions will already provide information on sedimentary structures and their morphological history in relation to former ice coverage, sub-ice hydrological conditions (sub-glacial lakes, meltwater channels), ice-flow dynamics and possible past natural collapses of ice shelves.

The transect of sediment cores to be sampled during EASI-2 will allow a much better quantification of the export of AABW into the Indian Ocean and the import of CDW into the Southern Ocean during the last glacial cycles.

We will address the following research questions:

We will address the following main research questions:

- **What is the state of AABW formation and export during Pleistocene glacial and extreme interglacial climate under elevated melting?** Given current knowledge, we predict that AABW will be severely reduced and possibly absent both during extreme glacial and interglacial boundary conditions (e.g. Huang et al., 2020).
- **Will a southward moving ACC eventually lead to cessation of AABW formation? Did this happen in the past and what were the consequences?** The ACC was tentatively moving south over the past decades (Chapman et al., 2020) yet results are in parts conflicting. We expect that such latitudinal shifts likewise occurred at glacial-interglacial and shorter centennial to millennial scale time frames.
- **How drastically shifted were SO fronts during glacial and interglacial climate in the Indian sector of the SO?** The absolute position of fronts is very likely to change depending on climate state (Fyfe and Saenko, 2006). However, this will vary spatially also as a function of bathymetry (Sokolov and Rintoul, 2009).
- **Which marine ecosystem responses are likely during AABW weakening due to elevated EAIS melting, lowered bottom-water ventilation and altered nutrient delivery to the SO?** The present-day micro-nutrient inventory of the water column can be set in context with past proxy records. We postulate that AABW weakening will have an effect on the marine ecosystem. However, the degree of which is largely unknown to date.
- **What is the offshore expression of chronological land-based deglacial EAIS retreat constraints?** The retreat of near-shore continental ice will take place during times of climatic warming that also involves palaeocirculation and palaeoproductivity changes. We will aim to link Antarctic shore- and shelf-based, as well as offshore records. How reliably can we use offshore records in older sedimentary sequences to reconstruct glacial processes on land preceding the LGM?

Sample and data management

The entire international community involved in the planned expedition will have immediate and preferential access to the cruise report, to shipboard data and samples retrieved. The availability of expedition data and samples may remain restricted to others not directly involved in the project. After a moratorium period that protects the interests of the project partners, the scientific community will have open access to data and samples.

AWI's research data policy follows the principles for the responsible handling of research data, which are based on the recommendations of the Helmholtz Association for guidelines on the management of research data, on the Guidelines of the European Commission on Data Management according to the FAIR principles and the guidelines of the Deutsche Forschungsgemeinschaft on handling research data.

AWI aims to publish at least the primary scientific data as soon as possible. The open-access cruise report will be published shortly after the cruise in the AWI series "Reports on Polar and Marine Research". It will contain detailed descriptions of the fieldwork conducted and initial results obtained along with lists of samples and data collected during the cruise. All data must be archived in a publicly accessible, citable long-term repository two years after collection. The archived data may be under moratorium for a maximum of two additional years. In addition, appropriate moratorium periods must be applied for and recorded in the data management plan. After the embargo periods have expired, the data must be made public immediately and actively using the FAIR principles. All data will be stored in international data bases (e.g., PANGAEA, DOD, SCAR SDLS), preferably in the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) operated as an open-access library by the AWI and the Center for Marine Environmental Sciences, University of Bremen (MARUM) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Sediment samples and cores collected during *Polarstern* expeditions are usually archived in the AWI Core Repository, which is operated by the marine geology department since 1983. Cores are stored in sealed D-tubes at 4° C and an air humidity limited at 35 %. The repository is open to the scientific community for sampling subject to ongoing work at AWI including national and international collaborations.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 1 Warming Climates.

In all publications, based on this cruise, the **Grant No. AWI_PS140_03** will be quoted and the following *Polarstern* article will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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5. CONTINENTAL GEOLOGY AND GEODESY

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Outline

Geoscientific research to be carried out on land during expedition PS140 will cover a variety of study areas (Fig. 5.1). Vestfold Hills, in Princess Elizabeth Land at the eastern margin of the Prydz Bay, will be the major target area, where comprehensive paleoenvironmental research will be conducted over several weeks from a field camp. In addition, geodetic-geophysical measurements and geological sampling will be carried out during short-term visits of a few hours at several land sites between Princess Elizabeth Land and Queen Mary Land (Fig. 5.1, Tab. 5.1).

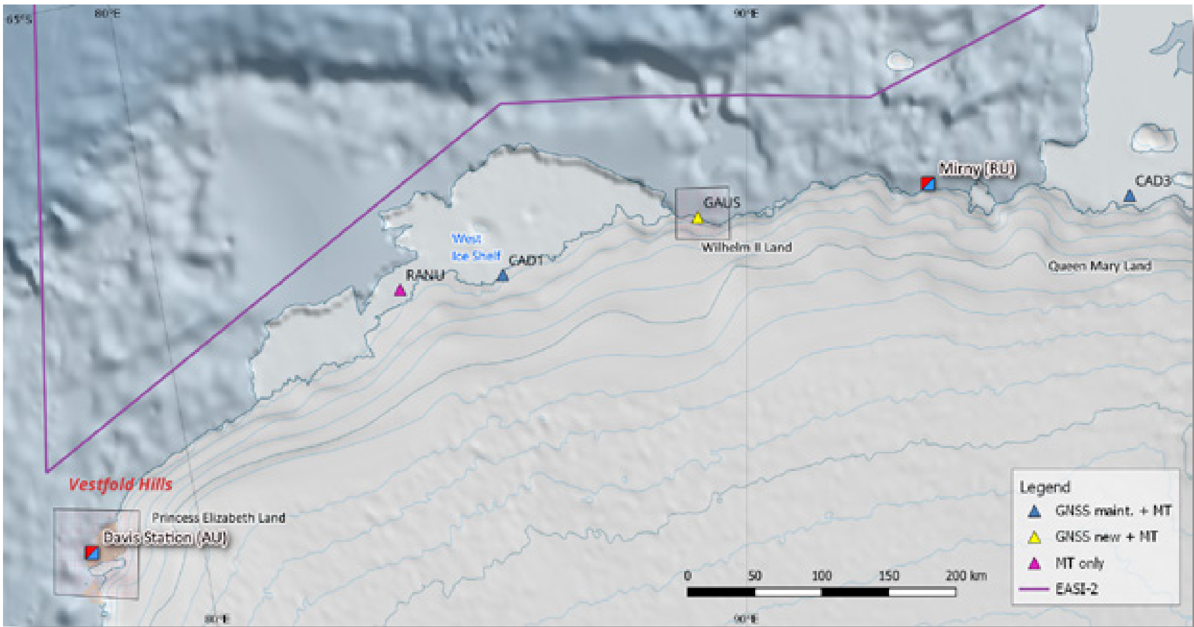

Fig. 5.1: Map of the East Antarctic coastal area between Princess Elizabeth Land and Queen Mary Land showing the general course track of Polarstern on PS140, Vestfold Hills (annotated rectangle) as the main work area on land for comprehensive paleoenvironmental research as well as further measurement sites (triangles; GNSS = Global Navigation Satellite Systems, MT = magnetotelluric) that are planned to be visited for short-term geoscientific work (day visits).

5.1. Ice sheet instability in Vestfold Hills – history and control

Objectives and scientific programme

The Prydz Bay (Fig. 5.1) is a key area to investigate the stability or instability of the East Antarctic Ice Sheet (EAIS). This bay forms the terminus of the Lambert Glacier-Amery Ice Shelf ice drainage system, which drains about 16 % of the grounded EAIS (Fricker et al., 2000). The topography of Prydz Bay is highly overdeepened, landward sloping and relatively smooth at 100 km scales, making the area particularly prone to marine ice sheet instability (White et al. 2022). Marine geological data and ice sheet models provide a basic understanding of the large-scale areal extent and flow pattern of the EAIS on the Prydz Bay shelf during the Last Glacial Maximum (LGM) and deglaciation (e.g., Domack et al., 1998; Golledge et al., 2012; Guitard et al., 2016). However, the data base still is rather poor with respect to the chronology of the reconstructed changes. Moreover, very little is known about past ice thicknesses, postglacial ice advances, and the regional climatic and sea-level changes that may have influenced the glacial history. This information can best be obtained by comprehensive paleoenvironmental investigations in currently ice-free areas along the Antarctic coastline, which are most proximal to the current ice edge. The largest of these so-called “oases” with currently 413 km^2 is Vestfold Hills (Fig. 5.2).

The fieldwork in Vestfold Hills on PS140 aims at a better understanding of the regional glacial history and the factors that have controlled past glaciological changes. They are driven by the hypotheses that the Late Quaternary ice sheet history of the oasis was more complex than indicated by the data as yet available and that the ice sheet dynamics were controlled by internal as well as external forcing mechanisms. The hypotheses shall be tested by answering the following central research questions.

Q1 *What was the maximum extent and thickness of the LGM ice coverage?* It is not yet clear, whether Vestfold Hills was entirely ice covered during the LGM (White et al., 2022). Gibson et al. (2009) deduced ice-free settings at the northwestern corner of the oases from presumed continuous sedimentation in a saline lake. This, however, has not yet been confirmed by geomorphological features or cosmogenic exposure ages in that area, and it is in conflict with an ice thickness of more than ~500 m that has been modelled based on relative uplift curves (e.g., Zwartz et al., 1998).

Q2 *When and how quick did deglaciation commence, how far did the ice retreat, and did ice re-advances take place?* The ice retreat over currently ice-free areas of Vestfold Hills is to some degree tracked by maximum ^{14}C ages of postglacial sediments and cosmogenic exposure ages (e.g., White et al., 2022). Very little, on the other hand, is known about potential ice sheet re-advances. The only one documented is the Chelnok Advance of the Sørsdal Glacier to the south of Vestfold, which probably had a minor lateral expansion and still is poorly dated (e.g., Kiernan et al., 2002). Ice retreats beyond the modern ice margin, which are known to have occurred in other East Antarctic oases (e.g., Goodwin, 1996), have not yet been detected in Vestfold Hills.

Q3 *Have unglaciated areas also existed during MIS 3 or earlier warm phases?* There is no evidence yet for the existence of ice-free areas in Vestfold Hills prior to the LGM. For Marine Isotope Stage (MIS) 3, ice sheet models hindcast an expanded EAIS, largely driven by lower sea levels and reduced rates of sub-ice shelf melt (e.g. Pollard & Deconto, 2009). However, this is in contrast to MIS 3 raised beaches in Lützow-Holm Bay (~40°E; Miura et al., 1998) and MIS 3 lake sediments in Rauer Group (to the west of Vestfold; Berg et al., 2016). Pre-LGM sediments were also cored in Windmill Islands (~110°E; Cremer et al., 2003), but their dating to MIS 3 or an earlier interglacial is ambiguous.

Q4 *Did local climatic changes initiate or follow ice retreats and advances?* The mid-Holocene ice margin retreat in Vestfold Hills correlates with increased temperatures, which are indicated in diatom assemblages and foraminifera concentrations (e.g., White et al., 2022, McMinn et al., 2001, Gibson et al., 2009). However, the age control is insufficient to identify leads or lags, i.e. it is not solved yet, whether the ice retreat was caused by the temperature rise, due to increasing melt rates, or has led to the temperature rise, due to additional exposure of dark land areas. Moreover, nothing is known about temperature changes during earlier movements of the ice margin and about potential influences of regional precipitation changes on the ice sheet behaviour.

Q5 *What do changes in relative sea level tell about the glacial history?* Changes in the relative sea level in coastal areas of Antarctica on the one hand provide information on former ice loads, due to glacial-isostatic adjustment (GIA) of the crust (e.g., Whitehouse et al., 2012), and on the other hand may influence the ice sheet behaviour by changing grounding line positions. In Vestfold Hills, relatively detailed information on past sea-level changes was already obtained from raised beaches and abandoned penguin colonies on land, as well as marine sediments in modern lakes and lacustrine sediments in modern marine basins (e.g., Zwartz et al., 1998, Hodgson et al., 2016). However, the available data still have larger gaps, in particular concerning the late glacial history, when sea level was below modern, and are not sufficiently well traced by the available GIA models.

Q6 *Did the sea-ice coverage and oceanic circulation on the shelf influence the ice sheet dynamics in Vestfold?* In difference to other oases such as Bunger Hills, the Vestfold Hills are in direct contact with the open ocean (Figs. 5.1 and 5.2). Nonetheless, it has never been investigated, which influence the oceanic properties had on the glacial history of the oasis. Possible impacts include warm-water intrusions with associated subaquatic ice melt (e.g., Pritchard et al., 2012) and the stabilization of the ice margin against calving by the sea-ice cover (Gomez-Fell et al., 2022).

Q7 *Which impacts did glaciological and morphological characteristics have on the glacial history?* Deglaciation and postglacial advances of the EAIS, as documented on the shelf and in ice-free coastal areas, were clearly asynchronous (Mackintosh et al., 2014). This may be due to individual climatic and relative sea-level histories in the different regions, but also to glaciological and morphological peculiarities. For instance, the more rapid post-LGM ice retreat at Vestfold Hills compared to other oases may be due to the over-deepened Svenner Channel on the adjacent shelf (O´Brien et al., 2015), which may have supported the grounding line retreat and subglacial erosion. Further support may have come from the fast-flowing Sørsdal Glacier to the south of Vestfold Hills, since dynamic outlet glaciers are believed to be more sensitive to climate and sea-level changes than areas with slow ice-sheet flow (White et al., 2011).

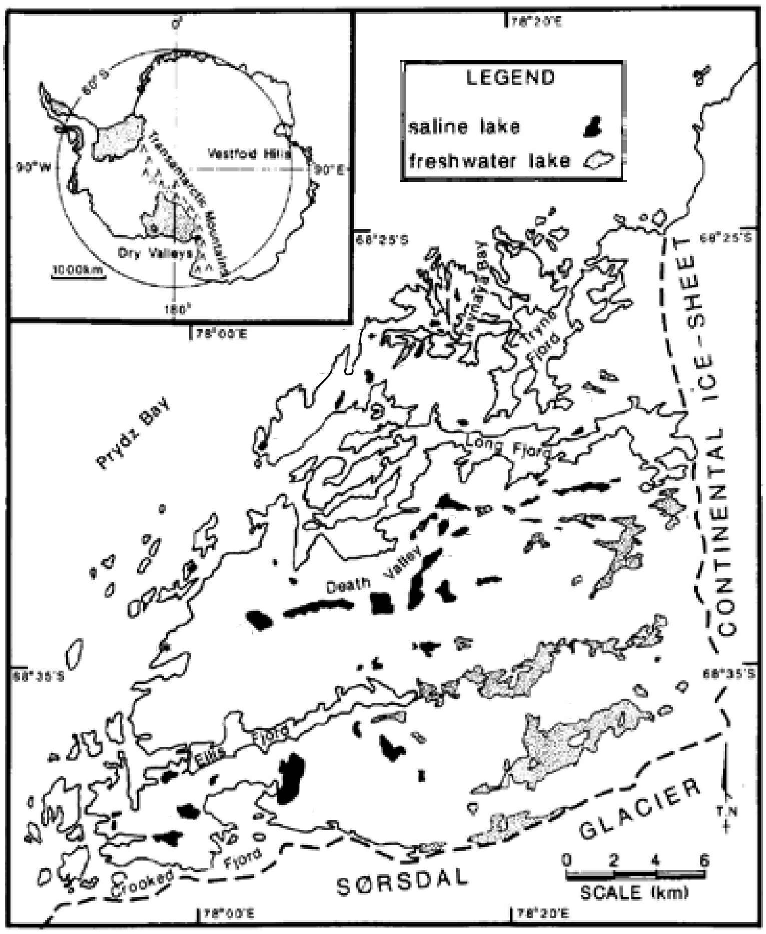

Fig. 5.2: Map of the Vestfold Hills (after Bird et al., 1991), with lakes (black and dotted) and marine basins (white), the wintering station Davis (green square), and summer huts (green triangles), inluding Watts hut (encircled) that forms the basis for the field camp on PS140. Potential coring sites on the lakes and on Ellis Fjord are indicated with blue and red circles, respectively.

Work on land and expected results

The field work in Vestfold Hills shall be conducted by five persons (see Appendix A.2) over a period of about three weeks. It shall focus on the southern part of the oasis, based on a field camp to be set up at the Watts hut of the AAD (Fig. 5.2). Transport into and out of the oasis will be by the helicopters stationed onboard *Polarstern*. The helicopters may also be used for a short-term shift to Abraxas Lake in northern Vestfold. Local transport within the oasis will otherwise be carried out by foot, on water bodies supported by skidoo and sled (in case of safe ice cover) or rubber boat and floating platform (in case of open waters).

Major objective is to recover sediment cores from Ellis Fjord and adjacent lakes (Fig. 5.2). The sediment cores as yet existing from water bodies of Vestfold Hills are widely distributed, but have limited lengths of maximal 3.4 m and in most cases do not reach the basis of the aquatic sediments (e.g., Bird et al., 1991, McMinn et al., 2001). We are going to use a percussion piston corer produced by UWITEC (Austria), which can recover 2 or 3 m long core segments that succeed each other with an overlapping part to much longer composite records. This technique has successfully been employed by us in water depths down to more than 100 m. It has for instance recovered more than 10 m long cores at three sites in the Antarctic Windmill Islands and Rauer Group, which penetrated preglacial aquatic sediments below a glacial till and postglacial deposits (e.g., Kulbe et al., 2001; Cremer et al., 2003; Berg et al., 2016).

The multi-disciplinary investigation of the sediment cores has different objectives in order to answer the research questions outlined and explained above. For instance, the sediment core data shall shed new light on the glacial history of the oasis. If one or more of the cores penetrate into pre-glacial sediments, this would be the first evidence for ice-free areas prior to the LGM in the southern Vestfold Hills, allowing for investigations of the deposition times and of the environmental conditions that have existed (Q3). The oldest ages of the postglacial sediments in the core transect probably will confirm at least partial ice coverage during the LGM (Q1) but also provide unprecedented information on the time of deglaciation and the speed of ice retreat (Q2). Whether the ice had retreated beyond the modern ice margin, and whether ice re-advances took place (Q2), shall be derived from facies changes (glacial, ice-proximal, ice-distal) in the sedimentary records. Besides, marine-limnic and limnic-marine transitions in the records, and the water depths at the sills separating the basins and subbasins, will provide new information on the relative sea-level history of the oasis (Q5), which is rather well known for changes above modern during the Holocene, but not at all for the changes below the modern level during the Late Glacial (e.g., Hodgson et al., 2016). Finally, the sediment cores shall be investigated for sedimentological, chemical and biogenic indications for climatic changes, both in temperature and precipitation, and their dependence on ice-sheet or ocean proximity (Q4).

The recovery of long sediment cores from lakes and Ellis Fjord shall be accompanied by hydrological analyses (collaboration with K. Saunders, ANSTO, Australia) and some field work on adjacent land areas. The latter mainly aims on closing gaps in already existing data sets, thereby contributing to the understanding of the glacial and sea-level histories of the oasis (Q1, Q2, Q3 and Q5). Special attention shall be given to the mapping of geomorphological features (raised beaches, moraines, striations, etc.) and their sampling for radiocarbon, luminescence and exposure dating. If available, also snow petrel stomach oil deposits (so-called “Mumiyo”) shall be samples, whose radiocarbon ages and chemical compositions can provide complementary information on the glacial history of the oasis, but also on the diet and thereby environmental history of nearby shelf areas (e.g., Berg et al., 2023).

Besides, sediment-laden ice shall for the first time be sampled at the edges of the ice sheet and the Sørsdal Glacier (Fig. 5.2). The sediment in these samples shall be analysed for cosmogenic nuclides, organic remains and detrital neodymium and lead isotopes. The ^{10}Be concentrations may provide information whether the sediment originates from erosion of bedrock in the source area (low ^{10}Be) or from preglacial sediments (high ^{10}Be), which became formed in the currently ice-covered regions during times of ice retreats beyond the modern ice edge. A formerly larger ice-free area could also be documented by organic remains (calcareous fossils or dispersed organic carbon) in the sediments, which can potentially be dated by radiocarbon analyses. The neodymium and lead isotope analyses on these samples (realized by M. Gutjahr, Geomar Kiel, Germany) shall shed new light on the transport of radiogenic isotopes into the Southern Ocean, which may reflect provenances and weathering and thus support the interpretation of respective analyses on marine sediment cores to be recovered on PS140. It will further provide information towards continental crustal age and geological boundary conditions in the study areas.

The findings from Vestfold Hills shall eventually be put into a wider East Antarctic context, based on published data and new findings from the EASI expeditions PS128, PS140 and PS141. This on the one hand concerns the history of the adjacent ocean, in particular the sea-ice coverage and oceanic circulation and their potential impacts on the glacial history of the oasis (Q6). On the other hand, comparisons of the history but also glaciological and morphological characteristics of Vestfold Hills with respective information from other oases further east and west shell shed new light on the impact of regional peculiarities on the stability of the EAIS on land (Q7). Geochemical insights obtained from sampling of sediment-containing continental ice will equally be placed in a regional geological context and sampling of ice will be carried out in opportunistic manner wherever adequate outcrops can be reached via helicopter in the Antarctic coastal study area of PS140.

5.2. Geodetic-geophysical measurements at land sites

Objectives

Using geodetic-geophysical *in-situ* data we will contribute to answering the scientific question:

What is the impact of the glacial history on the present-day deformation pattern of the solid Earth?

The glacial history of the Antarctic Ice Sheet – from the LGM up to present day – directly affects the deformation of the Earth. The response of the Earth is, on the other hand, governed by its rheological properties (especially effective elastic thickness of the lithosphere, viscosity of the upper and lower mantle). Both quantities – ice-load history and Earth's rheology – lead to the modelling of GIA (e.g., Whitehouse et al., 2019). For the first, the geological reconstructions of the climatic and glacial history shall be used to improve the ice-load history model. This will be based on published data, complemented by new findings gained by the land works and the marine geological investigations during PS140 and PS141.´

Work on land and expected results

The entire GIA modelling, on the contrary, will be constrained by geodetic GNSS (global navigation satellite systems) observations on the deformation pattern of the Earth's crust (Fig. 5.1, Tab. 5.1). For this, we collaborate with the University of Tasmania (group of Matt King), who already runs a number of GNSS sites along the East Antarctic coast (King et al., 2022). Additionally, new GNSS sites will be deployed. Especially at Gaußberg a new campaign GNSS site will be set up to gain measurements in preparation of the Gaußberg field campaign during the subsequent cruise PS141. Geophysical measurements, especially magnetotelluric observations (MT; Ramirez et al., 2022), will be collocated with GNSS (cooperation with the group of Kate Selway). In combination with further data (esp. from seismology, group of Tobias Stål and Anya Reading) these data will allow to improve our knowledge on the rheological properties of the Earth's interior. The MT equipment shall be retrieved during the subsequent cruise PS141.

The land locations will be reached during day visits where the helicopter will stay on site in order to accomplish the maintenance of existing GNSS sites (and of one seismometer) and the installation of new GNSS and MT sites, respectively. If time and manpower allow, the geodetic-geophysical measurements will be complemented by the sampling of rocks for exposure dating and sediment-laden ice for analyses of cosmogenic nuclides, organic remains and detrital neodymium and lead isotopes, as described in section 5.1.

Conversely, the geological field work at Vestfold Hills will be supported by geodetic measurements to gain a georeferencing of sampling sites as well as to measure the height of lake and sea levels.

Tab. 5.1: Land sites to be visited with planned maintenance of existing and deployments of new geodetic-geophysical observation sites (*cf.* Fig. 5.1)

SITE ID	Location	Longitude East	Latitude South	Method / Remarks
RANU	Ravich Nunatak (West Ice Shelf)	84.0689	67.1670	MT
CAD1	Carey Nunatak (West Ice Shelf)	85.8365	67.1306	GNSS (maint.), MT, Seismo (maint.)
GAUS	Gaußberg	89.1750	66.8043	GNSS (new campaign site), MT
CAD3	Gillies Is.	96.3661	66.5195	GNSS (maint.), MT

Explanation: MT = magnetotelluric measurements (new deployment), GNSS = global navigation satellite systems, Seismo = seismometer, maint. = maintenanceS

Sample and data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

The geological samples taken will be stored at the University of Cologne for the project duration. They will eventually be archived in the core repository of the University Bremen (sediment cores) and the National Polar Sample Archive (NAPA) in Berlin-Spandau (rock samples). Alliquots will be provided for collaboration on request.

Sediment-containing continental ice will be stored at the central core facility of GEOMAR Helmholtz Centre for Ocean Research Kiel and made available upon request.

In all publications based on this expedition, the **Grant No. AWI_PS140_04** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel *Polarstern* Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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6. IMPACT OF IRON/MANGANESE/B_{12} (CO-)LIMITATION AND LIGHT AVAILABILITY ON PRIMARY PRODUCTION AND COMMUNITY COMPOSITION OF EAST ANTARCTIC PHYTOPLANKTON

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Objectives

The production of oceanic phytoplankton that forms the base of the marine food web depends on the availability of sunlight and nutrients, typically nitrogen and phosphorus (and silicate for diatoms). The Southern Ocean, however, is an important high nutrient low chlorophyll (HNLC) area (Bruland et al., 2014; Moore et al., 2013), where iron (Fe) affects the amount of atmospheric CO_2 sequestered in deep ocean waters and ocean sediments via the biological pump (De La Rocha and Passow, 2014), with far reaching implications for global climate and the local ecosystem (Arrigo et al., 2008; Boyd and Ellwood, 2010; Tagliabue et al., 2017). Yet, it is becoming increasingly clear that the situation is more complex, and controlled by factors beyond just the scarcity of Fe. New insights highlight the importance of other trace-metals (Morel et al., 2014), co-limitation by two or more nutrients (Arrigo, 2005; Middag et al., 2013; Saito and Goepfert, 2008; Saito et al., 2008) and variability in nutrient requirements between species and environmental conditions (Arrigo and van Dijken, 2003; Klunder et al., 2014; Moore et al., 2013). Specifically, manganese (Mn) and the cobalt containing cobalamine have also been found to be able to (co-)limit primary productivity (Balaguer et al., 2022; Bertrand et al., 2007; Browning et al., 2021; Wu et al., 2019) and to drive carbon export fluxes (Balaguer et al. 2023) in the Southern Ocean.

Notably for Fe, its solubility and probably also its availability depends strongly on the Fe-binding dissolved organic ligands (Ardiningsih et al., 2021; Gledhill and Buck, 2012). Microbial community composition as well as microbial interactions impact the production and cycling of metals and metal-binding ligands (Fourquez et al., 2023; Fourquez et al., 2022). Antarctic waters undergo rapid changes in physiochemical variables due to global climate change, including warming, changing light conditions and altered trace metal input (Jabre et al., 2021; Joy-Warren et al., 2022; McCain et al., 2021). This will reflect in a changing phytoplankton community as not all phytoplankton species are equally sensitive to change or able to withstand changing conditions and additionally, the metal requirements and availability change depending on the environmental conditions.

Specifically, we will:

- Identify Fe-Mn-B_{12} co-limitation of natural phytoplankton assemblages across the cruise transect

- Assess how different light and trace metal availabilities affect phytoplankton species composition and carbon fixation
- Determine the photophysiological state of phytoplankton communities and estimate the production of reactive oxygen species in response to Fe-Mn-B_{12} and light amendments
- Quantify vitamin B_{12} concentrations along a depth gradient at up to 5 stations
- Assess compositional changes of phytoplankton-associated bacterial communities under Fe-Mn-B_{12} co-limitation

Work at sea

Following GEOTRACES protocols (www.geotraces.org) and using the Titan trace metal clean seawater sampling system (De Baar et al., 2008) water will be collected for analysis of vitamin B_{12} profiles and to perform phytoplankton nutrient enrichment experiments:

To map concentrations of vitamin B_{12}, samples will be taken from surface seawater (20 m) at < 20 stations and additionally from 6 different depths at 5 of those stations. The collected water will be filtered onto 18C vitamin columns using a peristaltic pump.

To test the influence of changed trace metal and light availabilities on phytoplankton species composition up to 4 Fe-Mn-B_{12} addition experiments with natural phytoplankton assemblages will be performed under ambient and elevated light conditions. The natural phytoplankton communities will be sampled from 20 m depth. The treatments consist of 0.5 nM inorganic Fe, and combinations of Fe with either 1 nM Mn or 100 pM B_{12} to investigate potential co-limitation. The duration of the experiments is set between 7-10 days, depending on the community growth rates. All incubations will be grown in a temperature-controlled growth chamber under *in situ* temperature and respective light intensities. Primary production will be estimated via intracellular ^{13}C uptake. The physiological state of the cells as well as the production of reactive oxygen species will be determined via fast repetition rate fluorometry (FRRf, Chelsea) and fluorometry (Trilogy, Turner design), respectively onboard. At the beginning and end of the experiments, samples for phytoplankton and bacterial taxonomic composition, cell density and chemical parameters will be taken. Moreover, samples for pigments and particulate organic carbon will be collected. A 600 L tank will be filled at an HNLC region to provide natural Antarctic seawater for laboratory work back on land.

In addition to the longer incubations described above, numerous (up to 20-25) shorter (72 h, continuous light, ambient temperature) small volume bioassays will be conducted in order to reveal Fe, Mn and or B_{12} limitation in surface samples of stations of interest, by the addition of 0.5 nM inorganic Fe, and combinations of Fe with 1 nM Mn and 1 nM Mn + 100 pM B_{12} (triplicate samples). These experiments will use changes in photophysiology (fast repetition rate fluorometry, FRRf, Chelsea) and chlorophyll a (measured by fluorometry after extraction from filters) after 72 h as proxies to identify responses to the nutrient additions in comparison to the controls. Furthermore, growth is derived from changes in nitrate concentrations over 72 h. The outcome of these experiments can be compared with the environmental (nutrient and trace metal concentrations) and biological (phytoplankton biomass and taxonomic composition assessed from HPLC derived pigments) context of the sample. By doing so Fe, Mn and or B_{12} limitation will be mapped along the transect of PS140.

Preliminary (expected) results

The expected data set will characterize vitamin B12 distribution in open water as well as coastal areas of East Antarctica and provide concentrations in surface and deep waters. Further, incubation experiments in which natural phytoplankton communites are enriched with trace metals (Fe and Mn) and vitamin B12 will reveal (co-) limitation of these nutrients in different regions of Prydz Bay. The exposure of these incubations to ambient and elevated light intensities will additionally elucidate physiological responses in relation to these two environmental drivers (trace metal and light availability) that are suspected to change in the future.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

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Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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7. RESPONSE OF ANTARCTIC PHYTOPLANKTON TO EPIBIOTIC MICROBIAL COLONIZATION

Marrit Jacob[1,2], Jasmin Stimpfle[2], Rob Middag[3,4], Florine Kooij[3], Robin van Dijk[4]
not on board: Tilmann Harder[1], Jan Tebben[2]

[1]DE.UNI-BREMEN
[2]DE.AWI
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Grant-No. AWI_PS140_01

Objectives

Diatoms are essential players in the global carbon cycle and the oceans' food webs (Field et al., 1998). Their productivity is substantially influenced by their microbiome, a community of bacterial epibionts colonizing the microenvironment ("phycosphere") immediately surrounding the host (Amin et al., 2012; Jackrel et al., 2021; Seymour et al., 2017). The taxonomic composition of microbiomes benefitting host growth varies between host taxa and is rather stable across time and different environments (Behringer et al., 2018; Mönnich et al., 2020). Phytoplankton hosts must therefore recognize and select their preferred epibionts from the surrounding water through processes yet uncovered. Southern Ocean phytoplankton assemblages are mainly dominated by the diatom genus *Fragilariopsis* (Pinkernell & Beszteri, 2014). The dynamics of microbiome assembly in the phycosphere of this important diatom and the effect of the microbiome on host productivity and fitness are largely unknown.

Pre-experiments revealed an algicidal effect of a *Croceibacter atlanticus* (*Flavobacteriales*) isolate obtained in the Weddell Sea to a co-occuring *F. kerguelensis* strain. After one week of co-culture, the diatom chlorophyll fluorescence was significantly reduced in the presence of C. atlanticus (Jacob et al., unpublished). These findings are in accordance with recent observations by (Bartolek et al., 2022; Van Tol et al., 2017), yet their studies used algae and bacteria from geographically unrelated environments. Long-term culturing revealed a delayed but similarly detrimental effect when *C. atlanticus* was inoculated to *F. kerguelensis* in conjunction with 36 other bacterial strains, as well as in the presence of an intact microbiome of a xenic *F. kerguelensis* culture. The difference in timing in the onset of the algicidal effect of *C. atlanticus* on *Fragilariopsis* suggests a potential protective or buffering effect of co-occuring bacteria and the established *F. kerguelensis* microbiome.

This project will

- examine the effects of natural Southern Ocean bacterial assemblages on *F. kerguelensis* growth (fitness/productivity effects of bacterial epibionts)
- examine the effects of natural Southern Ocean bacterial assemblages on the *F. kerguelensis* transcriptome at different timepoints (host recognition, signalling, and response to bacterial epibionts)
- assess the role of microbiome composition in mediating the vulnerability to the algicidal bacterium *C. atlanticus* (protective effect of different consolidated microbiomes)

Work at sea

Using the Titan trace metal clean seawater sampling system (De Baar et al., 2008), water from 20 m depth will be collected at four stations across a transect ranging from the Subantarctic Front to the Antarctic shelf to harvest natural bacterial communities. The seawater will be sequentially filtered over 200 µm and 3 µm and the filtrate will be concentrated over a 0.2 µm filter to harvest and concentrate bacterioplankton. Samples for phytoplankton and bacterial community composition as well as for macronutrients and iron will additionally be taken at each of the four stations to characterize the abiotic and biotic source conditions.

Axenic (bacteria-free) *F. kerguelensis*, which are brought on board from the lab, will be inoculated with bacterial communities obtained at four stations in triplicates. Samples of diatom RNA will be taken from these co-cultures in fixed time intervals (ranging from 30 minutes to several days) after inoculation to track the transcriptomic response of the diatom to bacterioplankton. The co-cultures will be incubated for approximately 14 days, depending on growth rate, in a temperature-controlled growth chamber under fixed temperature and light intensity. Growth of the diatom will be tracked by in vivo chlorophyll fluorescence over time.

After establishment of stable diatom microbiomes (approx. 14 days), samples for diatom abundance, bacterial community composition and for RNA will be taken, before the co-cultures are diluted to matching abundances and exposed to the algicidal bacterium *Croceibacter atlanticus*. Again, the transcriptomic response and diatom growth as well as shifts in bacterial community composition will be tracked over time.

Preliminary (expected) results

F. kerguelensis growth will be tracked and correlated with the relative abundances of different bacterial taxa in the source communities to characterize the influence of different bacterial communities on diatom growth. The host transcriptome will be analysed to assess the accompanying processes of recognition, signal transduction, and host response. After establishment of newly consolidated microbiomes in the co-cultures, exposure to different concentrations of *C. atlanticus* will be used to assess the role of the newly established microbiomes in facilitating the host's resilience towards algicidal bacteria. The project seeks to improve the understanding of diatom-bacteria community dynamics in a host species with great importance for Southern Ocean ecosystems, and to foster a mechanistic understanding of general processes in the assembly and consolidation of diatom microbiomes and their implications for diatom productivity under ongoing global change.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

In all publications, based on this cruise, the **Grant No. AWI_PS140_01** will be quoted and the following *Polarstern* article will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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Van Tol HM, Amin SA, Armbrust EV (2017) Ubiquitous marine bacterium inhibits diatom cell division. ISME J 11(1), 31–42. https://doi.org/10.1038/ismej.2016.112

8. ISOMETHANE: ONBOARD *IN SITU* ANALYSES OF METHANE CONCENTRATION AND ITS STABLE CARBON ISOTOPIC SIGNATURE ($\delta^{13}C$-CH_4) IN THE LOWER TROPOSPHERE ABOVE THE SOUTHERN OCEAN

Samuel Sellmaier[1]
not on board: Ellen Damm[1], Markus Rex[1]

[1]DE.AWI

Grant-No. AWI_PS140_11

Objectives

The objective is to record a time series of methane concentration and its stable carbon isotopic signature in the lower troposphere during the cruise. Methane is the second most important human-influenced greenhouse gas in terms of climate forcing. For methane, both bottom-up and top-down approaches are subject to large uncertainties, leading to a significant mismatch in modelling. The time series will contribute to quantify methane sources and sinks in the Southern Ocean needed for the improvement of model parameterizations.

Work at sea

The continuous ship-borne measurements of CH_4 concentration and $\delta^{13}C$-CH_4 will be carried out by Cavity Ring-Down Spectroscopy (CRDS) using a Picarro G2132-i isotope analyser (Picarro, Inc., Santa Clara, USA). CRDS is a highly sensitive gas analysis technique that measures the near-infrared absorption spectra of small gas-phase molecules within a high-reflectivity cavity using a laser diode. Air will be sucked from the starboard side of the Peildeck at about 21 m above sea-ice/water surface using a Teflon tube. A constant flow will be generated with a 3KQ Diaphragma pump (Boxer, Ottobeuren, Germany).

Preliminary (expected) results

Variations in CH_4 concentration and $\delta^{13}C$-CH_4 ratios over time will help to understand and validate source and sink capacities. The data evaluation focuses on using backwards airmass trajectories to monitor air masses and to distinguish locally induced signals from signals transported from remote areas. Combined with the time series recorded during MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate 2019-2020) the project aims to study differences in the source-sink balance along a global North-South transect.

Data management

The Picarro G2132 will be calibrated and maintained during the cruise to ensure high data quality. The recorded raw data will be processed with a spike detection code to distinguish the background signal from contamination by local pollution (like pollution from the ship stack). The atmospheric data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 2.1 Warming Climates.

In all publications based on this expedition, the **Grant No. AWI_PS140_11** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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Damm E, Rudels B, Schauer U et al. (2015) Methane excess in Arctic surface water- triggered by sea ice formation and melting. Sci Rep 5:16179. https://doi.org/10.1038/srep16179

Damm E, Bauch D, Krumpen T et al. (2018) The Transpolar Drift conveys methane from the Siberian Shelf to the central Arctic Ocean. Sci Rep 8:4515. https://doi.org/10.1038/s41598-018-22801-z

Lampert A et al. (2020) Studying boundary layer methane isotopy and vertical mixing processes at a rewetted peatland site using an unmanned aircraft system, Atmos MeasTech 13:1937–1952. https://doi.org/10.5194/amt-13-1937-2020

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

Affiliation	Adress
AU.UNI-ADELAIDE	The University of Adelaide 5005 Adelaide SA Australia
AU.UNI-CANBERRA	University of Canberra 11 Kirinari St, 2617 Bruce ACT Australia
AU.ANSTO Sydney	Australia's Nuclear Science and Technology Organisation New Illawarra Rd, 2234 Lucas Heights NSW Australia
AU.CSIRO-ENVIRONMENT	Commonwealth Scientific and Industrial Research Organization Oceans and Atmosphere and Centre for Southern Hemisphere Oceans Research Hobart,Tasmania Australia
CN.SUN-YAT-SEN-ZHUHAI	Sun Yat-sen University Hailin Rd 519082 Zhuhai China
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
DE.DWD	Deutscher Wetterdienst Seewetteramt Bernhard Nocht Str. 76 20359 Hamburg Germany
DE.GEOMAR	GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel Wischhofstraße 1-3 24148 Kiel Germany
DE.MEDIA-UNI	Stuttgart Media University (Hochschule der Medien) Nobelstraße 10, 70569 Stuttgart Germany
DE.UNI-KIEL	University of Kiel Christian-Albrechts-Platz 4, 24118 Kiel Germany

Affiliation	Adress
DE.TUD	Technische Universität Dresden Helmholtzstr. 10 01069 Dresden Germany
DE.TUM	Technische Universität München Arcisstraße 21 80333 München Germany
DE.UNI-BREMEN	Universität Bremen Bibliothekstraße 1 28359 Bremen Germany
DE.UNI-Köln	Universität Köln Albertus-Magnus-Platz, 50923 Köln Germany
DE.UNI-HEIDELBERG	Universität Heidelberg Im Neuenheimer Feld 69120 Heidelberg Germany
NL.NIOZ	NIOZ Koninklijk Nederlands Instituut voor Onderzoek der Zee Landsdiep 4 1797 SZ ‘t Horntje, Texel Netherlands
NL.UNI-GRONINGEN	University of Groningen Broerstraat 5 9712 CP Groningen, Netherlands
NL.UNI-RADBOUD	Radboud University Nijmegen Houtlaan 4 6525 XZ Nijmegen, Netherlands

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Anagnostou	Eleni	DE.GEOMAR	Scientist	Oceanography
Andreas	Pascal Horst	DE.UNI-BREMEN	Student (Master)	Glaciology
Arevalo Gonzalez	Marcelo	Servicio de Apoyo a Expediciones Científicas y Exploración	Engineer	Geology
Asadi	Nazanin	DE.UNI-BREMEN	Student (Master)	Earth Sciences
Boren	Goran Ingemar	AU.UNI-ADELAIDE	Scientist	Geophysics
Bozkuyu	Tarik	DE.UNI-BREMEN	Student (Master)	Earth Sciences
Brehmer-Moltmann	Johanna Karen	DE.UNI-BREMEN	Student (Master)	Geophysics
Colias Blanco	Manuel	Northern HeliCopter GmbH	Technician	Helicopter Service
Creac'h	Layla	DE.UNI-HEIDELBERG	Scientist	Chemistry
Deprie	Patrick	DE.GEOMAR	Student (Bachelor)	Biology
Ederer	Katrin	DE.AWI	Engineer	Engineering
Ehnis	Manuel	DE.UNI-HEIDELBERG	Student (Master)	Earth Sciences
Esper	Oliver	DE.AWI	Scientist	Geology
Feller	Jacob Ryan	DE.UNI-Köln	Technician	Geology
Gischler	Michael	Northern HeliCopter GmbH	Pilot	Helicopter Service
Groß	Kathrin	DE.UNI-KIEL	Student (Master)	Earth Sciences
Gutjahr	Marcus	DE.GEOMAR	Scientist	Earth Sciences
Huang	Huang	CN.SUN-YAT-SEN-ZHUHAI	Scientist	Chemistry
Ivanova	Alina	DE.UNI-BREMEN	Student (Master)	Geology
Jacob	Marrit	DE.UNI-BREMEN	PhD Student	Biology
Jeromson	Matthew	AU.UNI-CANBERRA	Scientist	Geology
Kooij	Florine	NL.NIOZ	PhD Student	Oceanography
Leicher	Niklas	DE.UNI-Köln	Scientist	Geology
Lembke-Jene	Lester	DE.AWI	Scientist	Geology

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Lemire	Annie Catherine Juliette	DE.TUM	Student (Master)	Geophysics
Lensch	Norbert	DE.AWI	Technician	Geology
Lenstra	Wytze	NL.UNI-RADBOUD	Scientist	Oceanography
Melles	Martin	DE.UNI-Köln	Scientist	Geology
Menzel	David Milan Joshua	DE.GEOMAR	Student (Master)	Oceanography
Middag	Rob	NL.NIOZ	Scientist	Chemistry
Oetjens	Annika	AU.UNI-TASMANIA	PhD Student	Oceanography
Otte	Frank	DE.DWD	Scientist	Meteorology
Otto	Denise	DE.UNI-BREMEN	Student (Master)	Geology
Reinisch	Ines	Ines Reinisch - Design & Film	Other	Öffentlichkeitsarbeit Science outreach
Rieke	Ole	AU.UNI-TASMANIA	PhD Student	Oceanography
Rode	Jörg	DRF Luftrettung gAG	Engineer	Engineering
Ruben	Manuel	DE.AWI	PhD Student	Earth Sciences
	Stefan	Northern HeliCopter GmbH	Pilot	Helicopter Service
Schneider	Fabian Wieland Patrick	DE.UNI-HEIDELBERG	Student (Master)	Physics
Schröter	Benjamin	DE.TUD	PhD Student	Earth Sciences
Schulze Tenberge	Yvonne	DE.AWI	Scientist	Geophysics
Schumacher	Valea	DE.AWI	Technician	Geology
Sellmaier	Samuel	DE.UNI-POTSDAM	Student (Master)	Earth Sciences
Sinnen	Vivian Marissa	DE.AWI	PhD Student	Geology
Stimpfle	Jasmin	DE.AWI	PhD Student	Biology
Stöckle	Sonja	DE.DWD	Other	Meteorology
Thielen	Bianca	DE.MEDIA-UNI	Student (Master)	Öffentlichkeitsarbeit Science outreach
van Dijk	Robin	NL.UNI-GRONINGEN	Student (Master)	Biology

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

No.	Name/ Last name	Vorname/ First name	Position/ rank
1	Lauber	Felix	Master
2	Kentges	Felix	C/M
3	Eckenfels	Hannes	2/M Cargo
4	Rusch	Torben	C/E
5	Weiß	Daniel	2/M
6	Peine	Lutz	2/M
7	Dr. Guba	Klaus	Doc
8	Müller	Andreas	E/E Com.
9	Ehrke	Tom	2/E
10	Krinfeld	Oleksandr	2/E
11	Farysch	Tim	2/E
12	Zivanov	Stefan	E/E SET
13	Frank	Gerhard	E/E Brücke
14	Schwedka	Thorsten	E/E Labor
15	Winter	Andreas	E/E Sys
16	Krüger	Lars	E/E Winde
17	Brück	Sebastian	Bosun
18	Keller	Eugen Jürgen	Carpenter
19	Möller	Falko	MPR
20	Buchholz	Joscha	MPR
21	Schade	Tom	MPR
22	Decker	Jens	MPR
23	Niebuhr	Tim	MPR
24	TBN		MPR
25	Mahlmann	Oliver Karl-Heinz	MPR
26	TBN		MPR
27	Probst	Lorenz	MPR
28	Clasen	Nils	MPR
29	Wieckhorst	André	MPR
30	Waterstradt	Felix	MPR
31	Plehn	Marco Markus	Fitter/E
32	TBN		Cook

No.	Name/ Last name	Vorname/ First name	Position/ rank
33	Fehrenbach	Martina	2./Cook
34	TBN	2./Cook	2./Cook
35	Witusch	Petra	C/Stew.
36	Ilk	Romy	Stew./Nurse
37	Probst	Sabine	2./Stew.
38	Golla	Gerald	2./Stew.
39	TBN		2./Stew.
40	Shi	Wubo	2./Stew.
41	Chen	Quanlun	2./Stew.
42	Deutschbein	Felix Maximilian	Trainee
43	Schröder	Paul	Trainee