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A Plan for Interdisciplinary Process-Studies and Geoscientific Observations beneath the Eckstroem Ice Shelf (Sub-EIS-Obs)

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Abstract: Antarctic ice sheet mass variability is related to ocean melting and freezing processes in the under-ice cavities. Basal melting is fueled by ocean heat transported from the open ocean underneath ice shelves or by high-saline waters formed in polynyas off ice shelf fronts. Processes in the sub-ice cavity lead to the formation of ice platelets, icicles, anchor ice and marine ice at the bottom of an ice shelf and/or at the fast ice in front. Brines are associated with ice growth and mineral precipitations like ikaite may occur – a possible precursor for carbonates that we detected in sedimentary archives. Anchor ice and tidal currents in narrow cavities create sediment redistribution and impurities in marine ice.
Here, we propose a project for multi-year hydrographic and biogeochemical observations underneath the Eckstroem Ice Shelf, video characterization underneath and at the seafloor, sediment trap deployment, seafloor mapping and sampling for (bio)geological studies by shallow coring. This project comprises a site study for potential drilling in that area to study the history of polar amplification and climate changes in Antarctica, the build up of the East Antarctic Ice Sheet during past warmer climates and its Cenozoic and future variability.

INTRODUCTION

The Eckstroem Ice Shelf (EIS) is one out of numerous characteristic small to medium scale ice shelves around East Antarctica. It is bordered by ice rises and ridges, has only a small catchment area and a slow flowing central ice stream. Nevertheless, this region is of critical importance to water-mass preconditioning in the Weddell Sea, and like other ice shelves in that area, particularly susceptible to future environmental changes. Its annual accessibility by ships and the good infrastructure provided by the German research station Neumayer III and DROMLAN (Dronning Maud Land Air Network) should be considered for a renewed focus for research in this area, since the region seems to have already traversed from a "cold" to a "warm" water regime. The results of the project, which will be related to research at the colder Filchner Ice Shelf (FIS) and to planned studies at the thicker fast ice in the Southern McMurdo Sound (SMS), are of general interest, e.g., for
(1) the mechanisms controlling the flow of warm water onto the continental shelf and into cold ice shelf cavities;
(2) brine, ice-platelet (Hoppmann et al. 2015), icicles (up to 20 m thick in the SMS) and anchor ice formation with related precipitates like carbonates (Monien et al. 2012) and biogeochemical sedimentation processes (Dayton et al. 1969) under present and past glacial conditions;
(3) grounding-line migration during the Holocene deglaciation and
(4) past East Antarctic Ice Sheet dynamic and climate history and, thus, the variability of ice sheet mass balance and global sea level.

Under the lead of AWI and BGR the project will bring together a large number of disciplines such as (1) Marine Geology, (2) Geophysics, (3) Glaciology, (4) Physical Oceanography, (5) Marine BioGeoScience, and (6) the HGF-MPG Group for Deep Sea Ecology and Technology. It will foster national collaboration between AWI the BGR and the German Research Center for Artificial Intelligence (DFKI) and international with the British Antarctic Survey (BAS), the universities of Bergen (UoB) and Tromsø (UiT), as well as institutions from the USA and New Zealand. In addition, several German universities (e.g., Bremen, Cologne, Göttingen, Tübingen and Leipzig) have indicated interest in collaborating and will add significant value to the project. This project will bring a major new and innovative scientific incentive and challenge for the Neumayer III Station with a seasonal, multiyear or permanently open ice hole observatory for multipurpose studies that could potentially be connected.

SCIENTIFIC GOALS

New striking encounters and discoveries below permanent ice coverage are our motivation to get access to this largely unknown space on earth. Life at the underside of the Ross Ice Shelf (RIS) (Daly et al. 2013) and a school of fish hidden under 740 m of ice and 850 km away from the coast and without daylight are a sensational discovery in the WISSARD project that drilled the ice shelf at the grounding zone of the RIS (WISSARD 2015). Similar sightings were done below the Amery Ice Shelf (Post et al. 2014) and below the Langhovde Glacier in East Antarctica (Sugiyama et al. 2014). How life and biogeochemical processes function under these harsh conditions is still unknown and show the need for more process-related studies. We aim to find geological archives below the Eckstroem Ice Shelf to get more information about these processes, their characteristics and temporal and spatial variability.

Relatively close to the Neumayer III Station, below the Eckstroem Ice Shelf from the calving line to about 40 km to the south, geological deposits that might contain signatures of the breakup of Gondwana and East Antarctica's Cenozoic ice sheet and climate evolution were detected by University of Bergen (Kristoffersen et al. 2014) and AWI (Eisen et al. 2015) vibroseismic profiles. They interpreted the seismic units as syn-rift Explora Wedge deposits with a volcanic origin as

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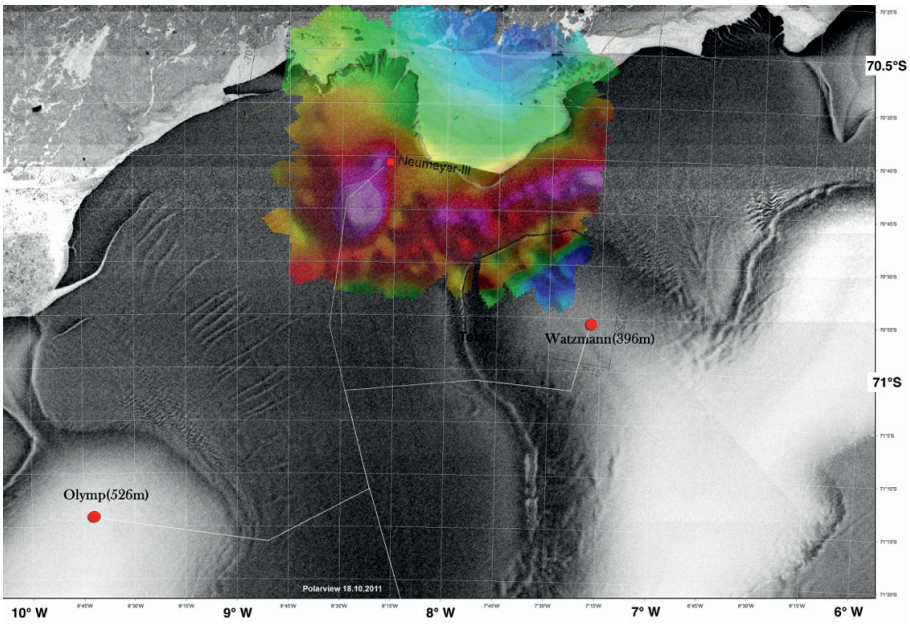

Fig. 1: Magnetic anomalies SW of Neumayer III could possibly indicate a "pseudo volcano" (Eckstaller pers. comm.). Deeper drilling could verify the volcanic origin of the Explora Wedge.

Abb. 1: Die magnetische Anomalie SW' der Neumayer III Station könnte auf einen „pseudo-Vulkan" hinweisen (Eckstaller pers. Mitteil.). Durch eine Bohrung könnte u.a. der vulkanische Charakter des Explora Wedge nachgewiesen werden.

shown in a new map of magnetic anomalies (Fig. 1, Eckstaller pers. comm.). On top of this Explora Wedge up to about 1000 m thick sedimentary sequences were detected that could have an age from upper Cretaceous to Pleistocene and perhaps may have been drilled partly by ODP Leg 113 or dredged in the Wegener Canyon area of the eastern Weddell Sea (FÜTTERER et al. 1990).

We aim to gain access to this realm for a detailed site study of bio/geo-processes and, especially, under-ice current measurements for sea riser and drill string modelling, planning, and budgeting. For a meaningful deep drilling pre-site survey, we plan to extend the vibroseis-coverage during coming field seasons and link the results to available marine seismic data. Hot-water drill holes through the ice shelf are needed for seafloor characterization, mapping and sampling and for under-ice sediment trap deployments (Fig. 2). Multi-year oceanographic sub-ice data collection could be designed and realized as well. Finally a plan for deeper geoscientific drill holes will be set up with the aim to drill within the successful international ANDRILL project.

Sub-EIS-Obs would be AWI's third attempt to deploy instruments underneath the Eckstroem Ice Shelf. During the 1993 field season a hot-water drill was used to drill successfully three boreholes adjacent to the geophysical observatory of Neumayer III Station (NIXDORF et al. 1994). One borehole was used to install an ultrasonic echosounder below the ice-shelf bottom. A second hole was used to install a temperature string with eleven thermistors through the ice shelf. Through the third hole a pressure gauge was lowered to the sea bottom for recording tides and a one-conductor cable with two temperature sensors was lowered to the ocean bottom. The data were transmitted via ARGOS to Bremerhaven.

During the field season 2005 at the PALAOA site (Perennial Acoustic Observatory in the Arctic Ocean) near to Neumayer III Station, close to the calving front, the Eckstroem Ice Shelf (EIS) has been penetrated and multi-year measurements of various parameters have been performed.

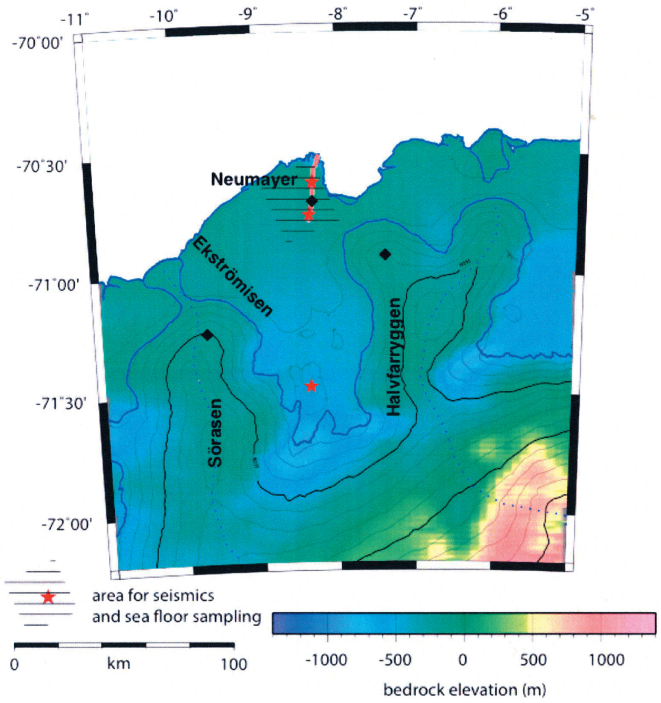

Fig. 2: Topographic map of the Eckstroem Ice Shelf (after EISEN et al. 2015) with planned hot water drill sites (red stars) and sea-floor sampling. Multiple profiles within the hatched area will complement the known profile (red line).

Abb. 2: Topographische Karte des Eckström Eisschelfs (nach EISEN et al. 2015) mit geplanten Heißwasserbohrungen (rote Sterne) und Beprobung des Meeresbodens. Das schraffierte Gebiet soll mit mehreren Vibroseismik Profilen das vorhandene Profil (rote Linie) ergänzen.

Now for the first time we would like to monitor the multi-year thermal characteristics of the hydrographical conditions beneath the EIS – for up to five years depending on battery reliability – in multiple holes, and together with other partners investigate the biogeochemical and geological processes at the ice-ocean and ice-sediment boundaries.

The high-gain of this project is illustrated by the combination of glaciological, oceanographic and geoscientific sub-ice measurements, which will allow to relate changes in basal ice mass variability (melting and freezing) to ice thickness data (NECKEL et al. 2012) and ice stream dynamics to sub-ice ocean variability in a region affected entirely by the East Antarctic Ice Sheet. For the hot-water ice drilling we plan to use the ANDRILL hot-water drilling system that drilled four holes during one season of pre-site survey through the RIS. This system will be able to keep the ice hole open for an extended period. AWI and BGR will provide support for this pre-site survey. The planning and deployment of AUV (WYNN et al. 2014) or ROV submersible operations through the ice hole that could be used for imaging, mapping, oceanographic measurements, and optimistically sampling and rope manipulation for multi-year moorings will be done in close cooperation and with personal support by the DFKI (German Research Center for Artificial Intelligence). The EIS could be one of several test sites for this AUV development that is planned to be used sub-ice on Jupiter moon Europa decades later. This technology can potentially provide AWI with prominent primary access to Antarctica's sub-glacial lake environments, if aspired. The retrieval of shallow sediment cores from at least three sites under the EIS, the collection of new vibroseismic data and reinvestigation of old data with new techniques and finally new long drill cores are expected to result in a comprehensive description of the EAIS sheet's past evolution and variability with possible implications for its future development in a warmer climate.

Obviously, there are risks for the project including the following issues: (1) getting enough polar-experienced manpower and technical/logistic support during the field campaigns; (2) the hot-water drilling, sub-ice sampling and AUV technology itself, and (3) any instrument failure after deployment. However, these risks can be mitigated by careful planning, provided that appropriate funding will be made available. The ANDRILL hot water drilling system has been successfully used in more than three field seasons, but one expert and technical staff (four to five people) are needed for operation. In close cooperation with other ice coring projects at AWI, an AWI constructed and operational hot-water drilling system should be available in addition to the ANDRILL system for later field campaigns. A second field party (as well of about four persons) needs to cover an area of about 40 to 40 km with a dense grid of vibroseismic profiles to get more detailed information about dip and thickness of the geological sequences.

The various objectives of the Sub-EIS-Obs project can only be met by a multidisciplinary team as the scientific methods and parameters to be determined are cross-disciplinary. The understanding of ice-ocean interaction requires expertise from both oceanography and glaciology. Under-ice life and biogeochemical processes require expertise from biologists, geochemists as well as mineralogists, e.g., for saline brine carbonate precipitates. Measurements, sampling and under-ice observations require support from the underwater technology and in addition scientific polar diving groups for multiyear fast ice investigations in front of the ice shelf. The long-term goals will be investigated by geologists, geophysicists, and paleoclimate and ice-sheet modellers. Due to the collaboration with foreign partners, the team could consist of world leading experts in the field of glacialmarine geology, Antarctic tectonic and geophysical structures at the Dronning Maud Land margin, ocean-ice shelf/sheet interaction and ice sheet evolution.

Nationally, the project benefits from collaborations with the working group of Geodynamics of the Polar Regions at Bremen University, the Geoscience Department at the University of Tübingen, the Institute of Geophysics and Geology at University of Leipzig, Department of Geochemistry and Department of Sedimentology/Environmental Geology at the University of Göttingen and the Commission for Glaciology of the Bavarian Academy of Science and Humanities. AUV instrumentation will be developed together with the German Research Center for Artificial Intelligence (DFKI) in Bremen.

Internationally, the project will have close collaboration with the British Antarctic Survey (BAS) regarding ice shelf hot-water drilling, sub-ice mooring deployment, and sediment core retrieval. In addition, it will benefit from the BAS effort to deploy similar instruments on the FIS. University of Bergen (UoB) will assist in mooring design and provides additional deployment of instruments underneath and in front of FIS. They are co-designing the vibroseis study and have experts for the continental margin geology in this area. We have cooperation for the hot water and drilling system and for long time glacial influenced sedimentation processes with experts from Victoria University, Wellington NZ, the GNS and Antarctica NZ. Cooperation with US scientists are established for the ANDRILL, WISSARD and SCINI (ROV) projects.

Understanding the sub-ice and brine formation processes in Antarctica is of overarching importance to understand global circulation, climate processes and sea level variability. Therefore, this proposal has direct relevance and large benefit to society and should be a prioritized topic for the European Polar Board.

Therefore, we encourage interested scientists who would like to take part and collaborate within this project to contact us soon.

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