ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

EXPEDITION PROGRAMME PS104

Polarstern

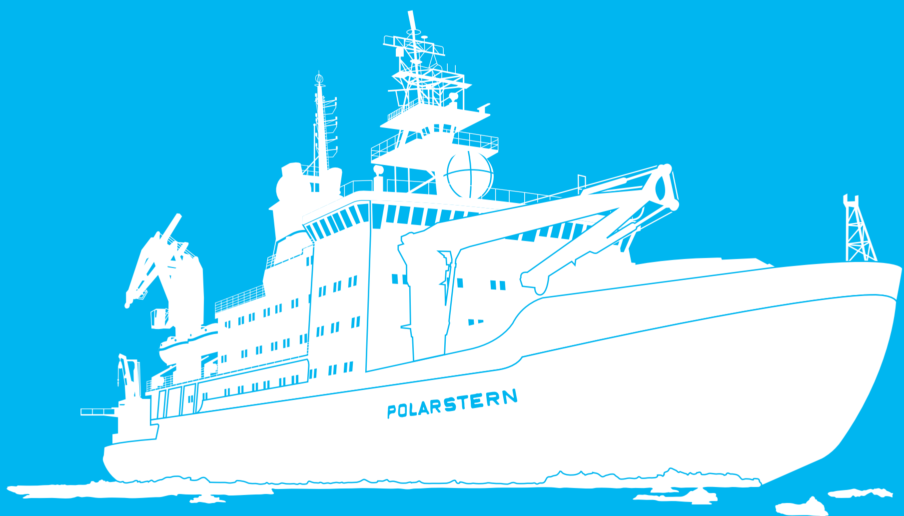
PS104

Punta Arenas – Punta Arenas

6 February 2017 - 19 March 2017

Coordinator: Rainer Knust

Chief Scientist: Karsten Gohl



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Contents

1. ÜBERBLICK UND FAHRTVERLAUF

Karsten Gohl
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Der westantarktische Eisschild (WAIS) hat in seiner Geschichte vermutlich eine sehr dynamische Aktivität erfahren, da ein Großteil seiner Basis unter dem Meeresspiegel aufliegt und daher empfindlich auf klimatische Änderungen reagiert. Ein vollständiges Abschmelzen des WAIS hätte einen globalen Meeresspiegelanstieg von 3-5 m zur Folge. Die Quantifizierung des Abschmelzens des WAIS in Warmzeiten der geologischen Vergangenheit in Kombination mit der Rekonstruktion der klimatischen Begleitumstände würde notwendige Parameter für Eisschildmodelle liefern, die sein zukünftiges Verhalten und seinen Beitrag zu Meeresspiegeländerungen prognostizieren sollen. Große Unsicherheiten bestehen bezüglich der räumlichen und zeitlichen Variabilitäten sowie der Geschwindigkeiten der vergangenen Vorschübe und Rückzüge des WAIS über die vorgelagerten kontinentalen Schelfe. Insbesondere die Region des Amundsenmeersektors zeigt seit einigen Jahrzehnten einen beobachteten ungewöhnlich rapiden Eisschildrückzug, der als Vorläufer für das Schicksal des gesamten WAIS vermutet wird.

Das Hauptforschungsprogramm der *Polarstern*-Expedition PS104 ist darauf ausgerichtet, unter Nutzung des Flachbohrgeräts *MeBo* eine Serie von bis zu 70 m langen Sedimentkernen von den ältesten zu den jüngsten Sediment-Sequenzen auf dem Schelf des Amundsenmeeres zu erbohren, um Sedimentmaterial für Analysen zur Rekonstruktion der Entwicklungsgeschichte und vergangene Dynamik des WAIS im Bereich des Amundsenmeeres zu erhalten. Die Bohrlokationen befinden sich primär entlang des zentralen glazialen Troges der Pine-Island-Bucht und vor dem Pine-Island-Gletscher. Weitere Bohrungen sind für Bereiche von glazialen Aufsetzzonen auf dem mittleren Schelf geplant, um die Prozesse der Eisflüsse im letzten glazialen Zyklus zu untersuchen. Über existierende Seismik sind ideale Bohrziele bereits weitgehend erfasst, aber weitere seismische Untersuchungen werden durchgeführt, um eine bessere flächenhafte Abbildung der erbohrten Sedimentsequenzen zu erhalten. Zusätzlich zum *MeBo*-Bohrprojekt sollen konventionelle Sedimentkerne gewonnen, geothermische Wärmeflussmessungen im Meeresboden betrieben sowie bathymetrische und sedimentechographische Kartierungen durchgeführt werden. Auf dem Festland und den Inseln im Bereich der Pine-Island-Bucht ist geplant, sowohl Gesteinsproben für thermochronologische Untersuchungen zur Hebungsgeschichte und Tektonik der Küstenregion zu sammeln, als auch GPS-Messungen zur Berechnung der glazial-isostatischen Bewegung der Region durchzuführen. Beide Landprojekte werden mit Hilfe der Helikopter unterstützt.

Der Fahrtabschnitt beginnt in Punta Arenas am 6. Februar 2017, führt zunächst zum südchilenischen Kontinentalrand, an dem bis zu drei Sedimentkerne mit dem Kolbenlot gewonnen werden sollen und setzt sich anschließend auf direktem Weg ins Hauptarbeitsgebiet des südlichen Amundsenmeeres und in der Pine-Island-Bucht fort. Nach Ende des geowissenschaftlichen Arbeitsprogramms kehrt das Schiff am 19. März 2017 nach Punta Arenas zurück.

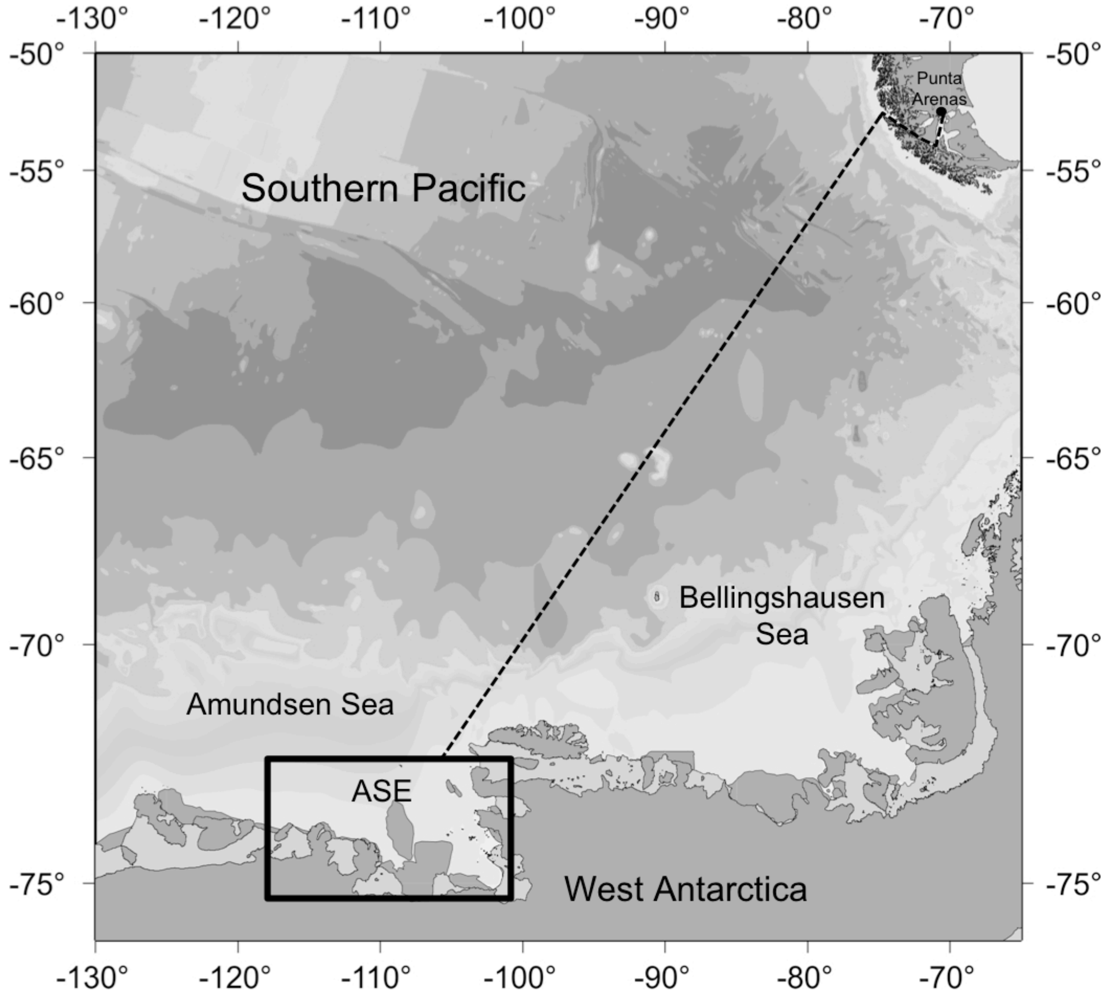

Fig. 1: Geplante Fahrtroute der Polarstern Expediton PS104 von Punta Arenas in das Amundsenmeer und zurück nach Punta Arenas. Das Hauptarbeitsgebiet in der Amundsenmeerregion ist im schwarzen Rechteck eingezeichnet, der Fahrtverlauf zum Shelf ist jedoch abhängig von den vorherrschenden Eisverhältnissen.

Fig. 1: Planned track of Polarstern during expedition PS104 from Punta Arenas to the Amundsen Sea and back to Punta Arenas. The black-framed box indicates the main working area in the Amundsen Sea Embayment (ASE) where ice conditions dictate accessibility onto the shelf.

SUMMARY AND ITINERARY

The West Antarctic Ice Sheet (WAIS) is likely to have been subject of a very dynamic activity during its history as most of its base is grounded below present sea level and, thus, is sensitive to climatic changes. Its collapse would result in a global sea-level rise of 3-5 m. The reconstruction and quantification of WAIS collapses in warm periods of the geological past will provide constraints required for ice sheet models predicting its future behaviour and resulting sea-level rise. Large uncertainties exist regarding the chronology, extent, rates and spatial and temporal variability of past advances and retreats of the WAIS across the continental shelves. The Amundsen Sea sector in particular has shown unusual rapid retreat and thinning of the ice sheet for the last decades, which has been suggested to be a precursor to the fate of the entire WAIS.

The main research programme of the *Polarstern* expedition PS104 is aimed to use the *MeBo* seabed drilling system to drill a series of up to 70 m long sediment cores from the oldest to the youngest sedimentary sequences of the Amundsen Sea Embayment shelf. These cores will provide material for analyses to help reconstructing the development and past dynamics of the WAIS in the Amundsen Sea sector. The drill locations lie primarily along the central glacial troughs of Pine Island Bay and in front of the Pine Island Glacier. Further cores will be recovered from grounding zone wedges in order to understand the processes that controlled ice retreat following the last glacial maximum. Ideal drill locations have already been identified through existing seismic profiles, but further seismic surveying will be necessary for improved regional imaging of the drilled sedimentary sequences. In addition to the *MeBo* drilling programme, we plan to conduct conventional sediment coring, geothermal heat flow measurements at the seafloor, bathymetric mapping and sub-bottom profiling. Two groups will collect rock samples on the main land and islands of Pine Island Bay for thermochronological analyses to study crustal uplift processes, and conduct GPS measurements for the calculation of regional glacial-isostatic motion. Both land-based projects will be supported by helicopters.

The expedition will begin on 6 February 2017 in Punta Arenas, will first go to the southern Chilean continental margin to collect up to three sediment cores, and will then continue directly to the main work area of the Amundsen Sea Embayment and Pine Island Bay. After the completion of the geoscientific programme, the ship will return to Punta Arenas on 19 March 2017.

2. ICE SHEET DYNAMICS OF THE AMUNDSEN SEA EMBAYMENT WITH *MEBO* SHALLOW DRILLING

K. Gohl, G. Uenzelmann-Neben, J. Klages, L. Lembke-Jene, O. Esper, T. Ronge, N. Lensch, M. Arevalo, A. Schüürman, R. Dziadek (AWI), T. Freudenthal, T. Bickert, H. Pälike, T. Frederichs, M. Bergenthal, T. Börner, R. Düßmann, K. Kausche, T. Klein, K. Noorlander, M. Reuter, S. Fröhlich (MARUM), R. Larter, C.-D. Hillenbrand, J. Smith (BAS), T. van de Flierdt, P. Simões Pereira (Imperial), S. Bohaty (NOCS), W. Ehrmann (U Leipzig)

Not on board: G. Kuhn (AWI), M. Schulz (MARUM), A. Graham (U Exeter)

Objectives

The behaviour of the West Antarctic Ice Sheet (WAIS) in relation to climatic changes and its contribution to global sea-level change are poorly understood. The WAIS is suspected to be highly sensitive to changes in global sea level and regional oceanographic conditions as well as atmospheric conditions. Its collapse would result in a global sea-level rise of 3.3-4.3 m (e.g. Fretwell et al., 2013). Satellite observations in the last decades have shown that the Pine Island, Thwaites, Smith, Kohler, Haynes and Pope glacier systems of the Amundsen Sea Embayment (ASE) (Fig. 2) have thinned at an alarming rate, while flow speed of some of them has dramatically increased (e.g. Joughin et al., 2011, 2012). It is unclear, however, if the current fast retreat represents a phase of ongoing ice retreat since the Last Glacial Maximum (LGM) (e.g. Hillenbrand et al., 2013), or if it is triggered by recent climatic or oceanographic changes. Significant sub-ice shelf melting by relatively warm Circumpolar

Deep Water (CDW) that spreads across the shelf through deep palaeo-ice stream troughs towards the grounding zone of the WAIS has been suggested as a possible cause (e.g. Joughin et al., 2012; Favier et al., 2014). Has the WAIS undergone similar thinning and retreat in warm climates of the past? What are the factors driving these retreats?

The main scientific questions and objectives addressed by this shallow drilling project include:

1) What is the contribution of the West Antarctic Ice-Sheet to past sea level changes in terms of rate and magnitude? Have sectors of the marine-based WAIS experienced "runaway collapses" as a result of climate warming and/or changes in ocean circulation?

Marine sediment cores from the West Antarctic continental shelf have the potential to provide datable records of the glacial history of the WAIS, including phases characterised by major reductions in ice-sheet size. Changes in the geochemical provenance of ice-rafted debris (IRD) deposited on the ASE shelf will allow to recognize not only complete WAIS collapses associated with the opening of Trans-Antarctic seaways, but also partial collapses of individual WAIS drainage basins along the Pacific margin. In addition, reconstructions of palaeo-seawater temperatures from micro-palaeontological (e.g. microfossil assemblages) and chemical proxies (biomarker, stable isotopes) will help to evaluate whether oceanic melting was the main driver of past WAIS collapses as modelling suggests.

2) How did the WAIS respond the last time when Earth's atmosphere contained more than 400 ppm CO_2?

The middle Pliocene represents the last time when Earth's atmospheric temperature was as high as it is predicted for the year 2100 (~3-4°C warmer than present). However, this warmth was achieved when the atmospheric pCO_2 concentration was just ca. 365-415 ppm and other climatic boundary conditions (e.g. plate-tectonic configuration) were the same. The ANDRILL AND-1B core provides a record of the variability of the East and West Antarctic ice sheets in the western Ross Sea during the Neogene. It has provided some critical insights into the dynamic behaviour of the WAIS and suggested WAIS collapses during past warmer-than-present interglacials, especially during the Pliocene. This conclusion, however, needs confirmation with an additional, less ambiguous WAIS-proximal record, and such a record can be acquired in the ASE.

3) How does the ice-sheet dynamics correlate with records of deep-ocean oxygen isotopes, atmospheric and oceanic temperatures and eustatic sea level?

Throughout most of the Cenozoic era, there are obvious but still unexplained discrepancies between Earth's temperature and global ice volume reconstructed from proxies in deep-sea sediments (such as stable oxygen isotope and Mg/Ca-derived temperature records from benthic foraminifera) or climate models, global sea-level estimates, and proximal evidence from Antarctica. The drill cores from the ASE are expected to characterise the climatic conditions during glacial and interglacial periods of the last 5 Ma, and to determine, whether major deglaciation had affected Antarctica during that time. Moreover, the study of the drill cores from the ASE will decipher, if the WAIS responded directly to the orbitally-paced climatic cycles of the Pliocene and Quaternary, or if it varied at periods determined by its internal dynamics.

4) How does the Antarctic Circumpolar Current (ACC) and Circumpolar Deep Water (CDW) incursions onto the continental shelf control the stability of marine ice-sheet margins?

Incursions of relatively warm CDW onto the West Antarctic continental shelf have been implicated in regulating WAIS behaviour on orbital and shorter timescales. Therefore, palaeo-records of CDW-pumping onto the West Antarctic shelf are urgently needed to understand the relationship between ice sheet variability and ocean circulation. Producing proxy records of past CDW incursions from marine sediment cores is still a challenge. With recent observations of present deep water incursions into the deep palaeo-ice stream troughs of the ASE shelf, shallow drilling in this area is expected to recover the sample material required for testing and improving proxies for CDW upwelling onto the shelf and its effect on WAIS dynamics.

5) How did processes operating at the base of the ice sheet enable streaming flow at the Last Glacial Maximum, and how did they affect the post-LGM retreat?

Does the sediment infill of deep subglacial meltwater channels and basins characterising the inner ASE shelf consist of sorted and graded coarse material indicating that the channels were active meltwater conduits during the last glaciation? How are grounding zone wedges constructed, how quickly did they form, and what are the implications for their potential to stabilise retreating grounding lines? What are the implications for subglacial processes operating at the ice sheet base during the LGM?

6) When did the WAIS first expand onto the ASE continental shelf and was ice sheet expansion related to uplift in neighbouring Marie Byrd Land? Does the denudation history of Marie Byrd Land recorded in ASE sediments indicate changes in the dynamic behaviour of the WAIS through time?

The beginning of major ice sheet build-up in West Antarctica is still unknown because of sparse drill sites with datable material. Ice sheet models have reconstructed an early ice-sheet nucleus on the top of elevated Marie Byrd Land, the Ellsworth Mts and parts of the southern Antarctic Peninsula mountain chain. The exhumation and erosion history of Marie Byrd Land, and particularly that of the Marie Byrd Land Dome, is particularly relevant for the interrelations between ice sheet and lithosphere dynamics. As subglacial erosion is a very effective mechanism, the onset of glaciation and changes in the style of glaciation will directly change erosion rates, and, due to isostatic adjustment, also exhumation rates. This objective will be addressed in collaboration with the fission-track analysis and provenance research programme at the University of Bremen.

7) What were the environmental and climatic conditions of West Antarctica in the Cretaceous to Eocene greenhouse period?

Although the atmospheric pCO_2 concentration in the Cretaceous exceeded twice the present level, fossil dinocyst data give evidence for the presence of sea-ice, suggesting that glaciers and ice caps existed in areas of high elevation in Antarctica. The current horizon-stratigraphic model for the ASE (Gohl et al., 2013) indicates that Cretaceous sediments crop out at the seafloor of the inner shelf, which makes this a unique opportunity for collecting such rare samples from the Pacific margin of central West Antarctica.

Work at sea

The primary aim of this expedition is to drill cores in the eastern ASE using the seabed-drilling device *MeBo* of MARUM (Freudenthal and Wefer, 2013) along transects from the oldest sequences in the south to the younger sequences in the north. The existing seismic sections (Gohl et al., 2013) indicate that the dipping strata on the inner to middle shelf are cut by a glacial unconformity which is locally overlain by only a few meters or tenths of meters of post-glacial and LGM sediments. The *MeBo* maximum drill depth of 70-80 m would penetrate into the dipping strata.

A shallow ice-proximal sedimentary basin, which is located near the Pine Island Glacier front (Fig. 2), will be a prime target for drilling. The near-horizontal seismic reflection horizons may represent a sequence of continuously deposited terrigenous debris, meltwater deposits and semi-pelagic sediments preserved from later glacial erosion and/or a series of unconformities caused by erosion resulting from grounding line oscillations.

Grounding zone wedges (GZWs) are widely thought to be important in stabilising grounding line positions during ice-sheet retreat, but hypotheses about the processes and duration of their formation and their composition are mainly based on conceptual models. Drill cores will be drilled to establish the nature of the sediments within GZWs, their formation processes, and their rates of growth.

We also intend to drill into crystalline bedrock (about 1 m) outcropping on the inner shelf. Such offshore sites will provide important information on the petrology and geochemistry of the bedrock. Samples from sills crossing the main glacial troughs would be of particular importance as they form obstacles for glacial erosion, pinning points for the grounding line during phases of grounding-line retreat, and barriers that regulate the inflow of warm CDW to the retreating ice margin.

Although most potential drill sites have already been identified from the existing seismic lines, bathymetry and available sediment cores, it may be necessary to search for alternative or additional sites in case of unfavourable sea-ice or difficult drill site conditions. Therefore, some additional multibeam bathymetry, sub-bottom profiler and seismic surveys as well as gravity/piston/multi/box cores may have to be collected during the expedition (see chapters below).

Preliminary (expected) results

The sediment cores will be logged onboard for wet bulk density, P-wave velocity, and magnetic susceptibility for a preliminary lithological characterisation, inter-core correlation and correlation with seismic profiles. After core splitting, the sediments will be lithologically described, their facies will be analysed and samples for x-radiographs and multiproxy studies (biostratigraphic, geochemical, isotopic, grain size and mineralogical analyses) will be taken. The results will provide a spatial image of the evolution of the WAIS in the ASE. There is a unique potential to analyse these sediments for reconstructing the palaeo-environmental conditions during their deposition and their role in influencing former ice flow by providing a soft subglacial substrate that may have facilitated streaming of ice.

Data management

All data will be uploaded to the PANGAEA database. Unrestricted access to the data will be granted after about three years, pending analysis and publication.

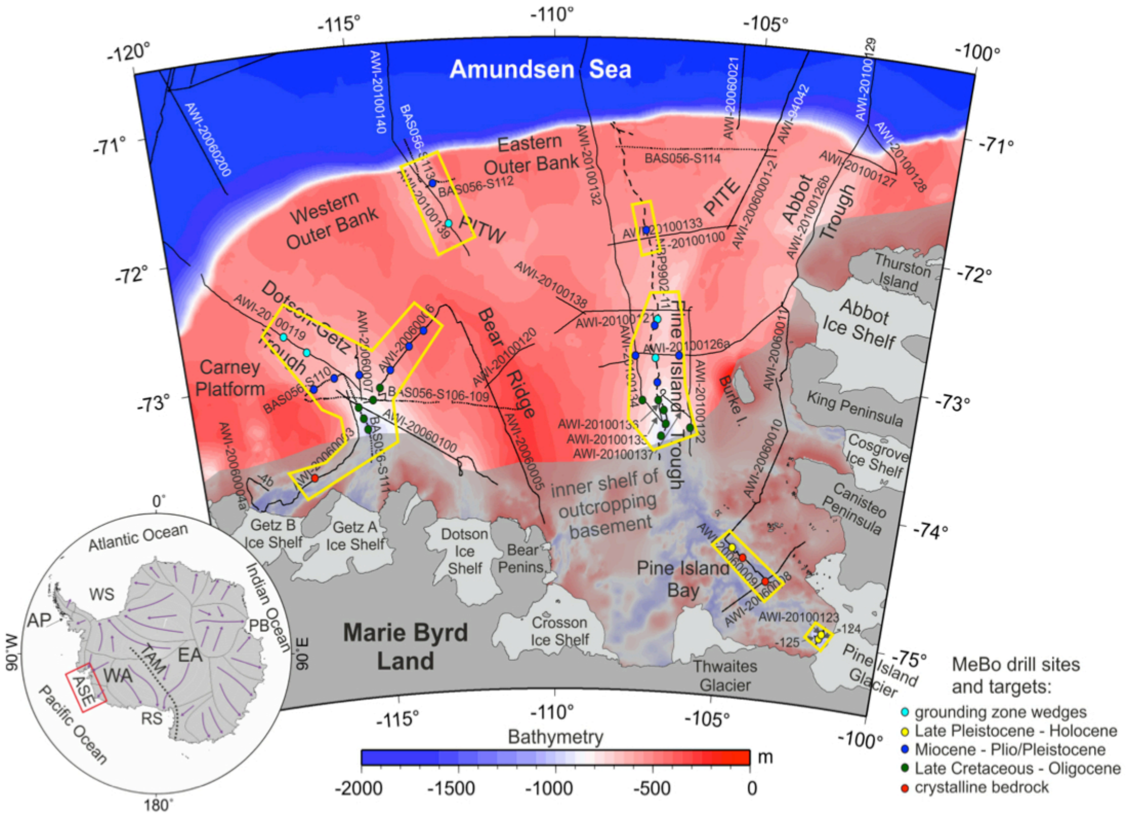

Fig. 2: Bathymetric map of the Amundsen Sea Embayment shelf (Nitsche et al., 2007, 2013) (marked work area in Fig. 1) with possible drill locations (dots) in areas of highest interest (yellow boxes). Black lines mark existing seismic profiles. The exact drilling, coring and geophysical profile locations will depend on sea-ice distribution.

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3. NEAR AND FAR FIELD EFFECTS OF ANTARCTICA'S QUATERNARY ICE SHEET DYNAMICS FROM SEDIMENT CORING

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not on board: G. Kuhn, F. Lamy (AWI)

Objectives

Antarctica's ice sheet and sea-ice dynamics during the Quaternary glacial-interglacial climate cycles had a large effect on the frontal system in the Southern Ocean and on related sedimentary records from the sea floor. Observations during the last few decades have shown that glaciers draining the West Antarctic Ice Sheet (WAIS) into the Amundsen Sea Embayment (ASE) (Fig. 2.1) have drastically thinned; flow speed of some of them has dramatically increased and numerical models simulated that ocean forcing has the potential to drive a future WAIS collapse (e.g. Favier et al., 2014; Joughin et al., 2012; Rignot et al., 2014). It is unclear, however, if the current fast retreat represents a phase of ongoing ice retreat since the Last Glacial Maximum (LGM) (e.g. Hillenbrand et al., 2013; Larter et al., 2014), or if it is triggered by recent climatic or oceanographic changes. Significant sub-ice shelf melting by relatively warm Circumpolar Deep Water (CDW) that spreads across the shelf through deep palaeo-ice stream troughs towards the grounding zone of the WAIS has been suggested as a possible cause for the current mass loss (e.g. Joughin et al., 2012). With our conventional sediment coring tools that will be used in addition to the *MeBo* drilling system we will investigate the post LGM deposits on the ASE shelf. We will utilize the recovered sediment samples to help answering our main geoscientific questions addressed by *MeBo* drilling: Has the WAIS undergone similar fast thinning and retreat during warmer early Holocene climate already? What were the factors driving the post-LGM retreat? Was the retreat continuous or characterized by phases of fast retreat that alternated with phases of stabilization or even re-advances? What impact had ocean forcing when compared to atmospheric or sea level forcing? What were the processes at the ice/subglacial substrate interface and how did the ice flow and subglacial hydrological system shape the sea floor?

The main objectives and questions addressed by conventional sediment coring on cruise PS104 are:

1) Reconstructions of Late Quaternary glacial and interglacial conditions in the ASE and of subglacial to glaciomarine sedimentary processes on the shelf, and characterization of the distribution and formation of glacial-geomorphological bedforms on the ASE shelf.

New marine geological and marine geophysical data will be collected to (i) determine the maximum LGM extent of the WAIS between the easternmost Ross Sea and the Antarctic Peninsula, (ii) map the seafloor characteristics of palaeo-ice streams and inter ice stream ridges, (iii) reveal the post-LGM retreat history of the WAIS, thereby focussing on grounding-zone wedges (GZWs), and (iv) reconstruct the timing and forcing of a possible WAIS collapse in the past.

The following science questions address objectives by conventional coring that are identical with objectives for *MeBo* drilling as defined in chapter 2:

2) How does the ice-sheet dynamics correlate with records of deep-ocean oxygen isotopes, atmospheric and oceanic temperatures and eustatic sea level?

3) How does the Antarctic Circumpolar Current (ACC) and Circumpolar Deep Water (CDW) incursions onto the continental shelf control the stability of marine ice-sheet margins?

4) How did processes operating at the base of the ice sheet enable streaming flow at the Last Glacial Maximum, and how did they affect the post-LGM retreat?

Work at sea

We will select coring sites on the basis of Hydrosweep and PARASOUND mapping (see chapter 4). We will use a box corer (GKG) and a multiple corer (MUC) for sampling undisturbed seafloor surface sediments. Sediment cores will be taken with piston (KOL) and gravity (SL) corers, and a large volume kasten corer (KAL).

We have six main, supplementary and contingency targets for cruise PS104 (Fig. 3):

1. Mapping and coring of the formerly ice shelf covered seabed in front of Pine Island Glacier
2. Coring of deep hollows (palaeo-subglacial caverns or lakes?) and shallow sediment pockets (with the potential of bearing calcareous microfossils) on the inner shelf.
3. Complete mapping, profiling and core coverage of GZWs 1-4 in Pine Island Trough East (PITE)
4. Complete mapping and coring of the Abbot-Cosgrove palaeo-ice stream system (incl. GZWs), the transition between the Burke Island inter-ice stream ridge (Klages et al., 2013) and PITE, and past ice-stream margins.
5. Mapping of the connection between PITE- and Pine Island Trough West
6. Complete mapping, profiling and core coverage of GZWs in the Dotson Getz Trough.

If the ASE should be inaccessible due to heavy sea-ice conditions, Wrigley Gulf (western Amundsen Sea) or Belgica Trough (southern Bellingshausen Sea) will be alternative study areas.

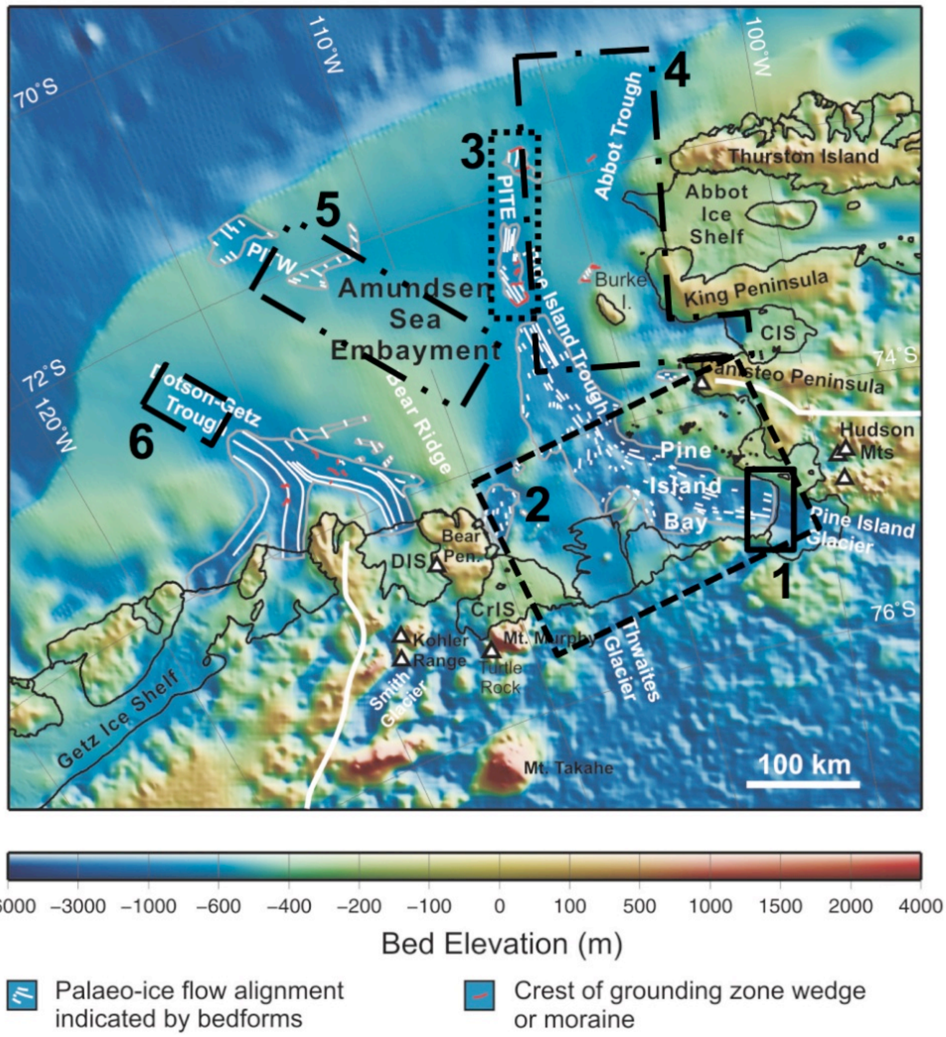

Fig. 3: Bathymetric map of the Amundsen Sea Embayment with main and contingency working areas 1-6, Grounding Zone Wedges (GZWs) and palaeo-ice flow directions (modified from Larter et al., 2014). The modern grounding line of the WAIS is indicated by the thin black continuous line. PITE: Pine Island Trough East, PITW: Pine Island Trough West, DIS: Dotson Ice Shelf, CrIS: Crosson Ice Shelf, CIS: Cosgrove Ice Shelf.

Expected preliminary results

The sediment cores will be logged onboard for wet bulk density, P-wave velocity, and magnetic susceptibility for a preliminary lithological characterisation, inter-core correlation and correlation with seismic profiles. After core splitting, the sediments will be lithologically described, their facies will be analysed and samples for X-radiographs and multiproxy studies (biostratigraphic, geochemical, isotopic, grain size and mineralogical analyses) will be taken. The results on the Amundsen Sea cores will provide a spatial image of the evolution of the WAIS in the ASE. There is a unique potential to analyse these sediments for reconstructing the palaeoenvironmental conditions during their deposition and their role in influencing former ice flow by providing a soft subglacial substrate that may have facilitated streaming of ice.

Data management

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4. BATHYMETRIC MAPPING AND SUB-BOTTOM PROFILING

C. Gebhardt, J.E. Arndt, T. Haupt, A. Braakmann-Folgmann, J. Klages, G. Uenzelmann-Neben, K. Gohl (AWI), R.D. Larter, C.D. Hillenbrand (BAS)

not on board: B. Dorschel, G. Kuhn (AWI), A. Graham (U Exeter)

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. Supplementing the bathymetric data, high-resolution sub-bottom profiler data of the top 10s of meters below the seabed provide information on the sediments at the seafloor and on the lateral extension of sediment successions. Furthermore, bathymetric data provide valuable information for coring site selection. Especially with sophisticated equipment such as *MeBo*, accurate knowledge of the seabed morphology in the deployment area supports successful operations. In combination with sub-bottom information, these data can be used to optimise the on-site sampling strategy. For example areas of outcropping older strata and areas of reduced or enhanced sediment accumulation can be identified. Furthermore, these data provide information on the adjacent and regional context of the sediment and rock samples.

Although frequently visited by research vessels, parts of the Amundsen Sea Embayment and Pine Island Bay still remain unmapped. 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. The planned survey in the Amundsen Sea Embayment and Pine Island Bay area will help unravel the glacial history that formed the glacio-morphological features on the seafloor. For example, a large area in front of the Pine Island Glacier that has been unreachable due to ice-shelf cover for a long time has recently become ice-free due to calving of a large iceberg; we aim at taking the opportunity to map this area close to the Pine Island Glacier grounding line.

Work at sea

Bathymetric data will be recorded with the hull-mounted multibeam echosounder Atlas Hydrosweep DS3, and sub-bottom data will be recorded with the hull-mounted sediment echosounder Atlas Parasound P70. The main task of the bathymetry group is to plan and run bathymetric surveys in the survey 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 area of the expedition. Simultaneously recorded sub-bottom data provide information on the sedimentary architecture of the surveyed area. High-resolution seabed and sub-bottom data recorded during the survey will be made available for site selection and cruise planning. In addition, sediment samples will be collected for ground-truthing the acoustic data and to analyse the physical properties of the sediments in the survey area. During the survey, the acoustic measurement will be carried out by four operators plus additional watch-keepers in a 24/7 watch mode.

Expected preliminary results

Expected results will consist of high-resolution seabed maps and sub-bottom information along the cruise track and from the target research sites. The bathymetric and sediment acoustic data will be analysed to provide geomorphological information of the Amundsen Sea Embayment shelf and Pine Island Bay. Expected outcomes aim towards a better understanding of the geological and, particularly, the sedimentary processes in the research area.

Data management

Hydroacoustic data (multibeam and sediment echosounder) collected during the expedition will be stored in the PANGAEA data repository at the AWI. Furthermore, the data will be provided to mapping projects and included in regional data compilations such as IBCSO (International Bathymetric Chart of the Southern Ocean) and GEBCO (General Bathymetric Chart of the Ocean).

5. SEISMIC IMAGING AND STRATIGRAPHY OF THE SHELF SEDIMENTS

G. Uenzelmann-Neben, K. Gohl, C. Gebhardt, K. Hochmuth, F. Riefstahl, R. Dziadek, D. Penshorn, T. Eggers, E. Burkhardt, M. Flau (AWI), R. Larter (BAS), V. Afanasyeva (VNII), A. Cammareri (Marybio)

not on board: A. Graham (U. Exeter)

Objectives

The Amundsen Sea Embayment forms the third-largest outflow area for the WAIS. The main ice streams in this embayment stem from the Pine Island, Thwaites and neighbouring glacier systems and have followed deeply eroded troughs on the inner to middle shelf. Most of the glacial-marine sediments have been transported onto the outer shelf of the Amundsen Sea Embayment and across the continental slope into the deep sea where they were redistributed by bottom currents. Seismic surveys of the sedimentary sequences and the underlying basement of the shelf, slope and rise along the continental margin of Marie Byrd Land, in the Amundsen Sea Embayment and in Pine Island Bay have allowed to decipher the main tectonic and sedimentary processes (e.g. Lowe and Anderson, 2002; Gohl et al., 2013; Uenzelmann-Neben and Gohl, 2014). However, stratigraphic ages have only been derived indirectly through 'jump' correlation with similar seismic characteristics observed from the Ross Sea shelf (Gohl et al., 2013).

The main aim of seismic surveys during this expedition is to link the *MeBo* drill sites with the existing seismic network on the shelf in order to establish a stratigraphic model that is age- and process-constrained using results from the drill records. Cross-lines across the drill sites will enable three-dimensional images of the subsurface to better place the drill records into a regional deposition pattern.

Work at sea

Seismic reflection profiling, using a 100 m, 150 m or 600 m long streamer and a small GI-Gun array, will be conducted across the *MeBo* drill sites on the Amundsen Sea Embayment shelf in order to acquire cross-lines or to tie new drill sites into the existing seismic network. Seismic profiling is also planned for crossing some sites of the IODP drilling proposal 839. Exact profile locations will be selected during the cruise, depending on final selection of drilling sites and on sea-ice distribution. Depending on local sea-ice conditions and on the *MeBo* drilling operation, contingency areas for seismic surveying would include other parts of the Amundsen Sea and Bellingshausen Sea shelves such as the Wrigley Gulf, Eltanin Bay or Belgica Trough.

The seismic survey will be accompanied by marine mammal mitigation efforts. These will be based on thermographically assisted, visual sightings efforts conducted throughout the expedition. Marine mammal observers (MMO) will monitor the ship's perimeter by naked eye and binoculars from the bridge, while an infrared (IR) scanner mounted in the crow's nest will provide a thermographic video stream. Sound levels of some seismic profiling will be monitored by means of an autonomous underwater sound recorder, hosted by a single deep-sea mooring to be deployed prior to and recovered after the seismic survey.

Expected preliminary results

First preliminary data processing will be performed on-board. The result of the final processed data will be integrated into the existing network of seismic profiles and the *MeBo* drill sites in order to establish an improved seismic stratigraphy of the shelf. It is expected that the analysed characteristics of seismic reflection sequences and horizons provide important constraints on the glacial sedimentation and erosion processes.

Data management

All seismic data will be uploaded to the SCAR Antarctic Seismic Data Library System (SDLS) 4 years after acquisition for restricted access and 8 years after acquisition for unrestricted access.

References

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6. GEOTHERMAL HEAT-FLOW OF THE AMUNDSEN SEA SHELF

R. Dziadek, K. Gohl, K. Hochmuth (AWI)
not on board: N. Kaul (U Bremen)

Objectives

Causes for the accelerated retreat of the Pine Island and Thwaites Glaciers are currently being debated. In addition to the influx of warm Circumpolar Deep Water into the deep troughs of the Pine Island Bay shelf towards the grounding lines of the glaciers, increased heat flow can be considered to have an additional effect on the sensitivity of this part of the West Antarctic Ice Sheet. Schroeder et al. (2014) make a three to four times enhanced geothermal heat flow underneath the Thwaites Glacier responsible for accelerated glacier movement. Recent volcanism has been identified in the area of the Hudson Mountains close to Pine Island Glacier. Successful heat flow measurements in the Amundsen Sea and Pine Island Bay during ANT-XXVI/3 (2010) revealed a pattern of low and medium high geothermal heat flow. Furthermore, transient effects of inflowing ocean water near the seafloor were observed. With a larger number of temperature gradient measurements, we expect a better understanding of the geothermal energy flux as well as the influence of warm bottom-water.

Work at sea

Geothermal heat flow measurements will be conducted at various locations on the shelf of the Amundsen Sea Embayment, in particular in the inner Pine Island Bay close to the volcanic Hudson Mountains, using a 6-m long temperature gradient probe of University of

Bremen. Exact measurement locations will be decided on-board based on bathymetric and sub-bottom profiler data.

Expected preliminary results

Temperature gradients and thermal conductivities will be calculated on-board after the measurements. It is expected that the derived heat-flow values provide a first trend of their distribution on the area. A project, supported by a DFG grant to fund R. Dziadek's doctoral research, is aimed to analyze the geothermal conditions in the Amundsen Sea Embayment in context with the tectonic-magmatic processes by using the direct heat-flow measurements as well as an indirect derivation of heat-flow through Curie depths calculated from the magnetic anomaly grid.

Data management

All data will be uploaded to the PANGAEA database. Unrestricted access to the data will be granted after about three years, pending analysis and publication.

References

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7. EXHUMATION AND DEGLACIATION OF THE AMUNDSEN SEA REGION

M. Zundel (U Bremen), Y. Najman (U Lancaster)
not on board: C. Spiegel, F. Lisker (U Bremen)

Objectives

The tectonic and morphologic history of the West Antarctic Rift System is still poorly understood, but is of particular interest, since it hosts the West Antarctic Ice Sheet. Influence of the tectonomorphic evolution of the underlying lithosphere on the glacial dynamics of the overlying ice sheet involve, amongst others (i) that a certain amount of emerged topography is a prerequisite for continental glaciation, (ii) that deeply incised rift valleys provide pathways for warm deep ocean water melting the glaciers from below, and (iii) that elevated heat flows associated with areas of active extension control the basal thermal regime of glaciers.

Also insufficiently constrained is the long-term (i.e., post-LGM) thinning and retreat history of the glaciers draining into the Amundsen Sea Embayment, currently in a state of rapid thinning and retreat. For understanding their future evolution it is of prime importance to understand how they responded to environmental changes during the past.

Thus, we pursue the following objectives:

Reconstructing Cenozoic rifting activity along Pine Island Bay: Thermochronology data from samples of the 2010 *Polarstern* expedition (ANT-XXVI/3) suggest early Oligocene rifting activity along western Pine Island Bay, probably kinematical linked to activity along the Bellingshausen Sea and beneath the Pine Island Glacier. So far, evidence for Cenzoic rifting is only based on three samples, so we hope to extend the data basis and refine and extend the reconstruction of Cenozoic activity of the West Antarctic Rift System.

Reconstructing the exhumation history of the Marie Byrd Land Dome: Also based on thermochronology data of samples from the 2010 expedition, first results suggest that erosion and thus presumably uplift of the Marie Byrd Land Dome only started at ~20 Ma, i.e., nearly 10 Ma later than previously assumed. Again, this suggestion is only based on few data points and requires corroboration from a larger data basis. The question of the Marie Byrd Land Dome uplift is of particular importance, since the dome is the only area of West Antarctica significantly elevated above sea level. If uplift of the dome only commenced during the early Miocene, as suggested by our initial data, then continental glaciation of West Antarctica already at the Eocene-Oligocene boundary, as assumed by most current models, is highly unlikely.

Reconstructing post-LGM glacial thinning and retreat: The third objective is to reconstruct the post-LGM glacial evolution around the Amundsen Sea Embayment. Exposure ages from ^{10}Be cosmogenic nuclide analysis again on samples from the 2010 expedition provided a first impression and showed that the currently observed thinning rates are at least one order of magnitude higher than the long-term rates. However, our data only allows integrating rates over several thousands years, thus obliterating glacial responses to short-term environmental change. Our aim for the upcoming expedition is thus a higher-resolution sampling strategy with special emphasis to (a) sampling different elevations across the coastal nunataks, allowing for reconstructing high-resolution vertical thinning rates, and (b) sampling different distances to the present glacial front of the Pine Island Glacier, allowing for reconstructing lateral retreat rates. This way, we also plan to reconcile the onshore glacial thinning history with the offshore glacial retreat history.

Work at sea

We plan to sample basement rocks drilled by the *MeBo* device (see above), since we expect that the thermal signature of the strongly extended bottom of the Amundsen Sea differs from that of basement rocks exposed onshore and will give further evidence on the tectonic evolution of West Antarctica. Furthermore, special interest is on coarse-clastic sediments (sand fraction and coarser) of different stratigraphic layers drilled by *MeBo*, because dating these allows reconstructing paleo-denudation rates of the source areas back through time. Coordinated with the Marine Geology Programme, we will also deploy box corers, preferably at sites of glacial outlets, since these deposits provide denudation rates integrated over the whole glacial catchment and thus ideally complement the spot-like data from coastal nunataks.

In addition, we will use the helicopters on board of *Polarstern* to sample onshore outcrops. Special emphasize will be on nunataks of the Kohler Range (sampling for exposure dating and for thermochronology) and on the numerous small islands of Pine Island Bay, situated at various distances from the present-day ice front of the Pine Island Glacier (sampling only for exposure dating). In case ice conditions demand working farther to the west, another target area for sampling for both, thermochronology and exposure dating would be the coastal nunataks along the Hobbs Coast.

Expected preliminary results

Measurements for topographic shielding required for correcting exposure ages will be performed directly in the field. Sample processing, thermochronologic analysis (apatite fission track and (U-Th-Sm)/He dating), as well as cosmogenic nuclide analysis (^{10}Be exposure dating) will be performed after the cruise.

Data management

After publication, all data will be uploaded to the PANGAEA database.

8. REPEATED GNSS MEASUREMENTS IN THE AMUNDSEN SEA REGION TO INVESTIGATE GLACIAL ISOSTATIC ADJUSTMENT AND ICE-SHELF DYNAMICS

M. Scheinert (TUD), D. Roberts (U Durham & TUD), T. Haupt (AWI)

Objectives

The Antarctic ice-mass loss is presently estimated to be in the range of 110 to 150 Gt/a, where the largest part is attributed to the West Antarctic Ice Sheet (WAIS). The equivalent global (eustatic) sea-level change amounts to approx. +0.4 mm/a. A collapse of the marine-based WAIS would raise the global sea level far beyond values predicted until 2100. The region of the Amundsen Sea is the most sensitive region of the WAIS, especially with the large outlet glaciers Pine Island, Thwaites and Smith Glacier. Therefore, in the last years, this region has gained superior attention as a key region for intensified multidisciplinary research. In order to come up with reliable estimates of the ice-mass balance the geodetic methods of satellite gravimetry and satellite altimetry are being utilized. The results of these methods have to be corrected for the effect of glacial isostatic adjustment (GIA). However, the GIA correction still forms a main source of uncertainty and, especially for satellite gravimetry, the largest error contribution. The GIA mass effect stays in the same order of magnitude as present ice-mass changes themselves (Groh et al., 2012, 2014). Models that are being used to predict the GIA effects still lack observational constraints as well as sufficient complexity in terms of ice-load history and rheology.

Geodetic GNSS measurements on bedrock are used to record the vertical deformation of the earth. The inferred height change (interpreted as vertical deformation) includes the sum of all effects affecting the location under investigation. Beside the GIA effect one has to pay attention to the elastic deformation due to present-day ice-mass changes. The latter can be determined by means of satellite altimetry and, hence, separated from the total deformation. Therefore, geodetic GNSS measurements deliver independent data to validate GIA models (e.g. IJ05-R2 by Ivins et al., 2013, or W12a by Whitehouse et al., 2012). Even more, they provide the only tool to directly measure the GIA effect.

Already in 2006 and 2010, the group of TU Dresden (TUD) realized GNSS measurements in the area of investigation. For three stations (PIG2, MANT and BEAR) vertical deformation rates from 14 to 22 mm/a were determined from those repeated GNSS observations (Groh et al., 2012). In 2010 it was not possible to realize measurements at the fourth site MURP, such that for this station a respective result cannot be given yet. Further GNSS measurements are needed to repeat the observations, to get first results for the site MURP, and to improve the reliability and accuracy of the inferred results. The long time basis of eight years and the technologically identical setup enable a comparable accuracy also for MURP. Even more, that station is situated in an area of an increased ice-mass loss dedicated to the discharge of Smith Glacier.

In the marginal areas of the Amundsen Sea Embayment and especially in Pine Island Bay, we estimate the regional sea level fall to be in the order of approx. 5 to 8 mm/a (Groh, 2014). It has to be emphasized that this sea level fall has to be dedicated to the mentioned considerable ice-mass changes having occurred in recent years and ongoing until present. Therefore, it is one further goal of this project to collect organic material, which may, once dated, serve as a proxy for minimum ages of recent deglaciation and, hence, of being situated above sea level.

Furthermore, GNSS measurements on ice shelves (preferably Crosson and Dotson) shall complement the programme. Coordinate time series from these kinematic measurements shall contribute to investigate tidal dynamics in the coastal areas, where satellite altimetry or classic tide gauge measurements are not feasible. In combination with geodetic remote sensing techniques (feature tracking, SAR interferometry), the flow regime of the outlet glaciers and their adjacent ice shelves can be determined. Additionally, GNSS measurements on ice shelves contribute to validate height change rates inferred from satellite altimetry.

Work at sea

All locations to be investigated are situated on land. Hence, they will be reached by helicopter. We will visit those GNSS sites already observed in 2006 and/or 2010 (PIG2, MANT, BEAR, MURP). At islands in Pine Island Bay, additional new GNSS sites shall be set up to extent the regional GNSS network and to facilitate geo-referencing of local data collections (organic material, recent sea-level curves). At ice shelves, GNSS observations should be realized at (or close to) locations already observed in 2006 and/or at new locations. Our activities will be closely coordinated with those of other groups operating on land (especially geology) in order to conduct the work in an economic way.

Expected preliminary results

The GNSS observations will be processed at the home institution (so-called post-processing using the Bernese GNSS Software). In the analyses latest standards have to be incorporated used in geodesy (e.g. consistent and precise realization of the reference frame). In terms of the vertical deformation rates we expect to obtain updated results for the sites PIG1, MANT and BEAR, and first results for the site MURP.

Data management

The geodetic GPS data will be stored within the frame of the SCAR GPS Database, which is maintained at TU Dresden. The long-term preservation of the data will be maintained also through the close cooperation within the SCAR Scientific Programme SERCE (Solid Earth Responses and Influences on Cryosphere Evolution). A common structure of the data holdings is ensured through the application of the same scientific software package utilized to analyse geodetic GNSS measurements at TU Dresden (i.e., the Bernese GPS Software). Further products and resulting models will be archived in the PANGEA database at AWI.

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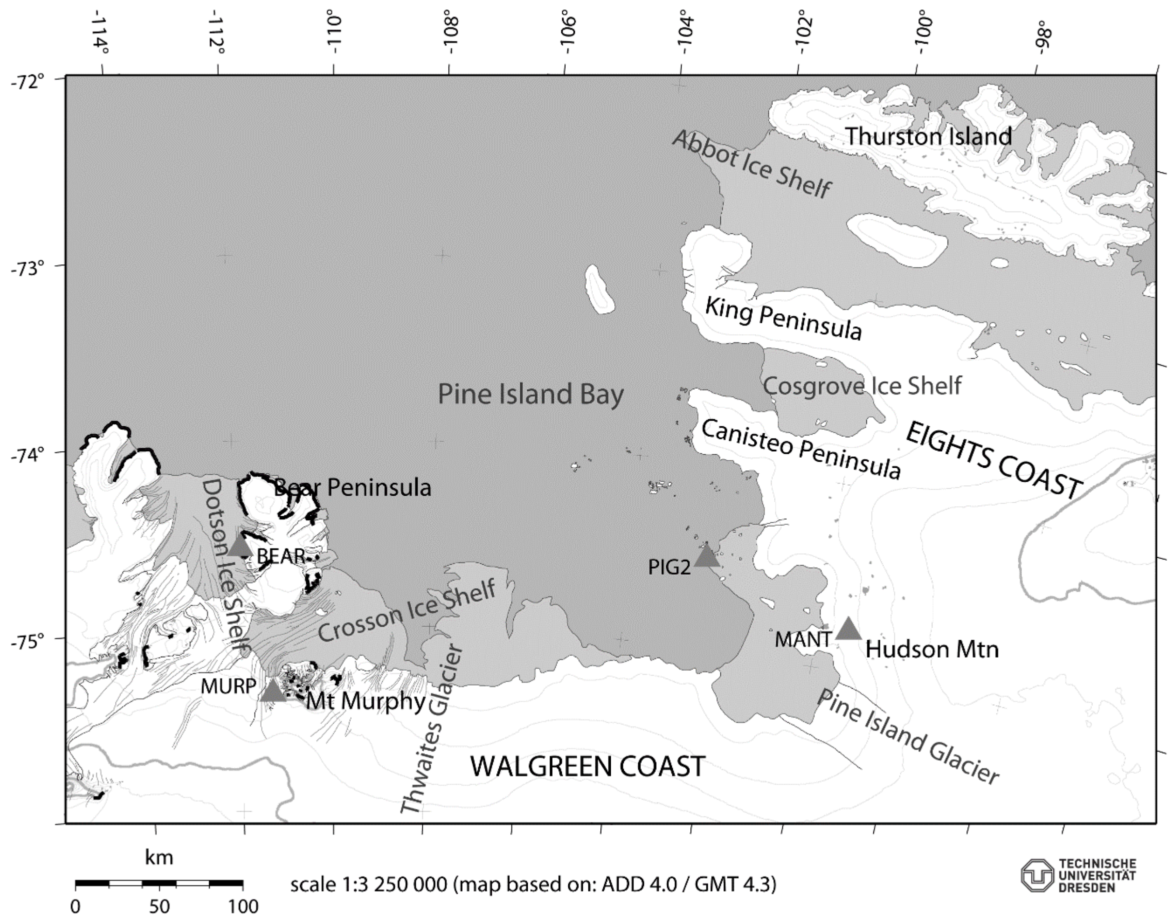

Fig. 8: Overview map of the area of investigation. Filled triangles denote the GNSS sites already observed in 2006 and partly re-observed in 2010. It is planned to set up further GNSS sites at (three to four) islands in the Pine Island Bay and at Crosson and Dotson Ice Shelves.

9. HELICOPTER-MAGNETIC SURVEYING TO DELINEATE BASEMENT TECTONICS

F. Riefstahl, R. Dziadek, T. Eggers, K. Gohl (AWI)

Objectives

Major boundaries between suspected crustal blocks and volcanic zones in Pine Island Bay have been proposed by various researchers without available data to prove their existence. The glacier troughs and Pine Island Bay itself are thought to have developed along such tectonic boundaries. Heli-magnetic surveys in the Pine Island Bay area will provide the necessary database to map these boundaries and to derive models that link tectonic lineaments to preferential sedimentary and ice stream transport paths.

Work at sea

Magnetic data will be collected using a helicopter-towed caesium-vapour aeromagnetic sensor system. Heli-magnetic surveys will be performed at selected locations along the shiptrack on the shelf of the Amundsen Sea Embayment to complement the magnetic survey grids of previous expeditions.

Expected preliminary results

First data processing will be conducted on-board after the measurements. The flight line data will be then integrated to the existing magnetic database of this area to complement the magnetic anomaly grid. It is expected that the refined grid will improve the analysis on the crustal type and characteristics of the crystalline basement in terms of its tectonic evolution.

Data management

All data will be uploaded AWI geophysical database and to the ADMAP database. Unrestricted access to the data will be granted after about three years, pending analysis and publication.

10. TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

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NN		DWD	Meteorologist
NN		DWD	Technician, meteorology
NN		HeliService	Pilot, helicopter
NN		HeliService	Pilot, helicopter
NN		HeliService	Technician, helicopter
NN		HeliService	Technician, helicopter

12. SCHIFFSBESATZUNG / SHIP'S CREW

No.	Name	Rank
01.	Schwarze, Stefan	Master
02.	Grundmann,	1.Offc.
03.	Farysch, Bernd	Ch. Eng.
04.	Langhinrichs, Moritz	EO Ladung
05.	Hering, Igor	2.Offc.
06.	Fallei, Holger	2.Offc.
07.	Scholl, Thomas	Doctor
08.	Christian, Boris	Comm.Offc.
09.	Grafe, Jens	2.Eng.
10.	Krinfeld, Oleksandr	2.Eng.
11.	Holst, Wolfgang	3. Eng.
12.	Redmer, Jens	Elec.Tech.
13.	Frank, Gerhard	Electron.
14.	Hüttebräucker, Olaf	Electron.
15.	Nasis, Ilias	Electron.
16.	Himmel,Frank	Electron
17.	Loidl, Reiner	Boatsw.
18.	Reise, Lutz	Carpenter
19.	Hagemann, Manfred	A.B.
20.	Winkler, Michael	A.B.
21.	Scheel, Sebastian	A.B.
22.	Bäcker, Andreas	A.B.
23.	Brück, Sebastian	A.B.
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25.	Leisner, Karl-Heinz Bert	A.B.
26.	Löscher, Steffen Andreas	A.B.
27.	Schröder, Horst	A.B.
28.	Preußner, Jörg	Storek.
29.	Teichert, Uwe	Mot-man
30.	Rhau, Lars-Peter	Mot-man
31.	Lamm, Gerd	Mot-man
32.	Schünemann, Mario	Mot-man
33.	Schwarz, Uwe	Mot-man
34.	Redmer, Klaus-Peter	Cook
35.	Silinski, Frank	Cooksmate
36.	Martens, Michael	Cooksmate
37.	Czyborra, Bärbel	1.Stwdess
38.	Wöckener, Martina	Stwdss/KS
39.	Dibenau, Torsten	2.Steward
40.	Silinski, Carmen	2.Stwdess
41.	Duka, Maribel	2.Steward
42.	Arendt, Rene	2.Steward
43.	Sun, Yong Shen	2.Steward
44.	Chen, Dan Sheng	Laundrym.