Remote sensing and in-situ studies of West Antarctic paleo-ice sheet beds: Implications for West Antarctic Ice Sheet dynamics during the late Quaternary

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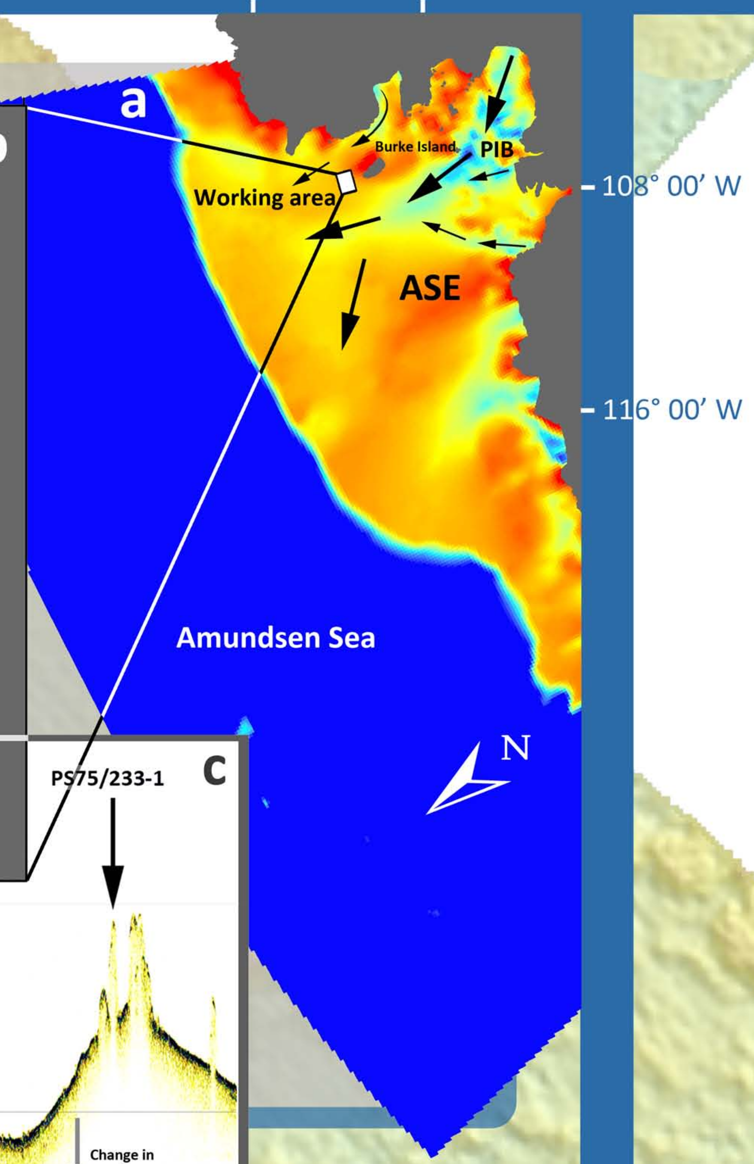
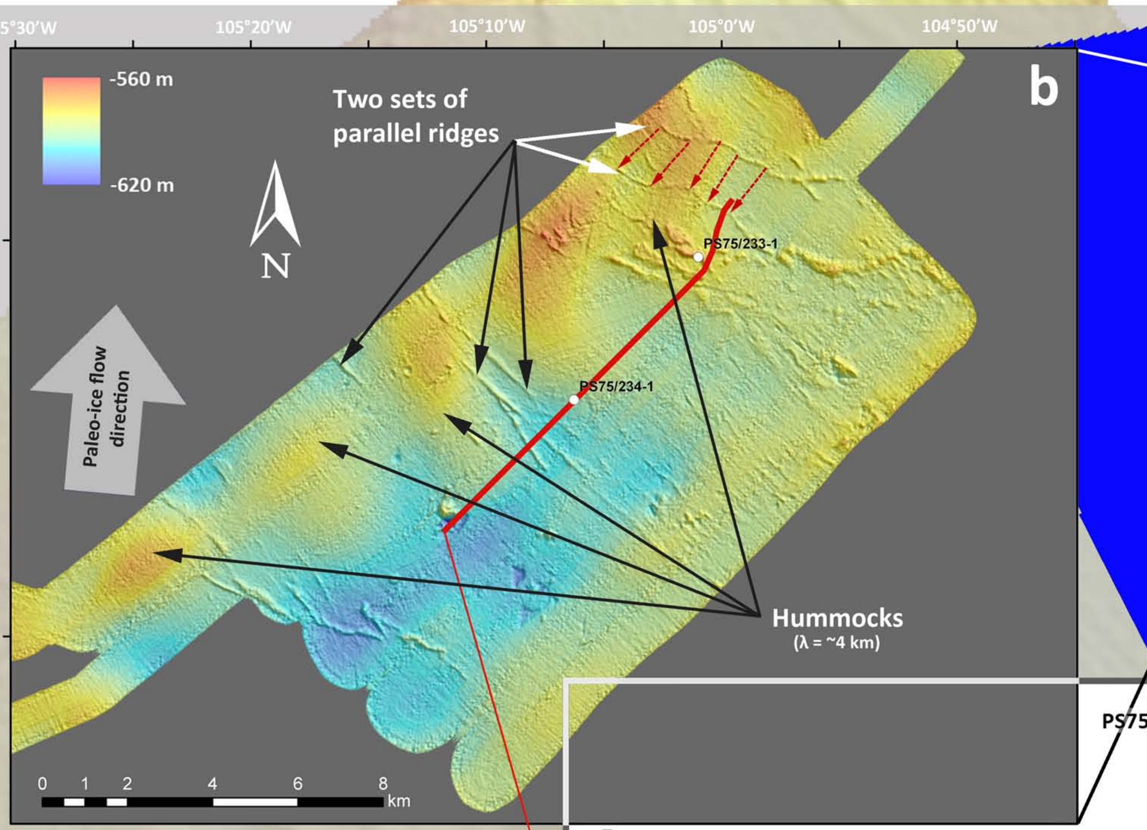
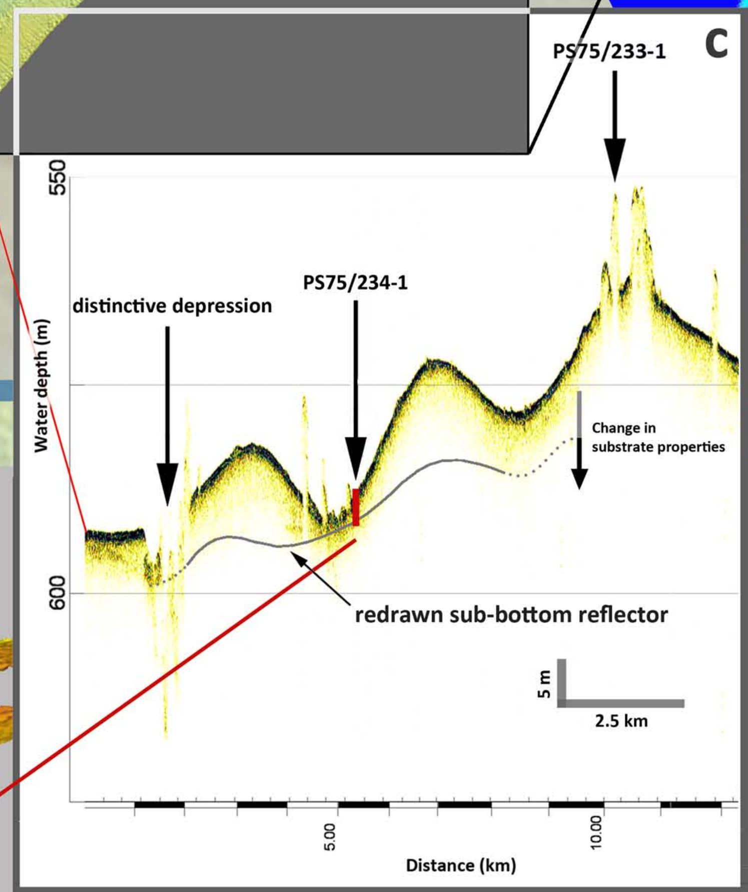
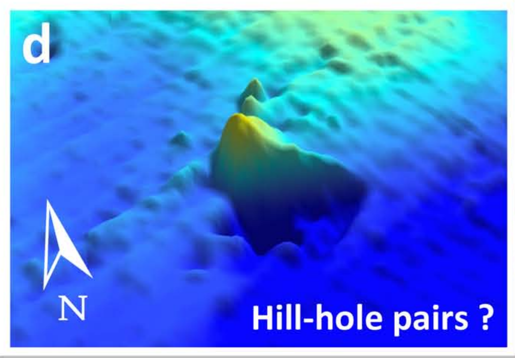
❶ Abstract

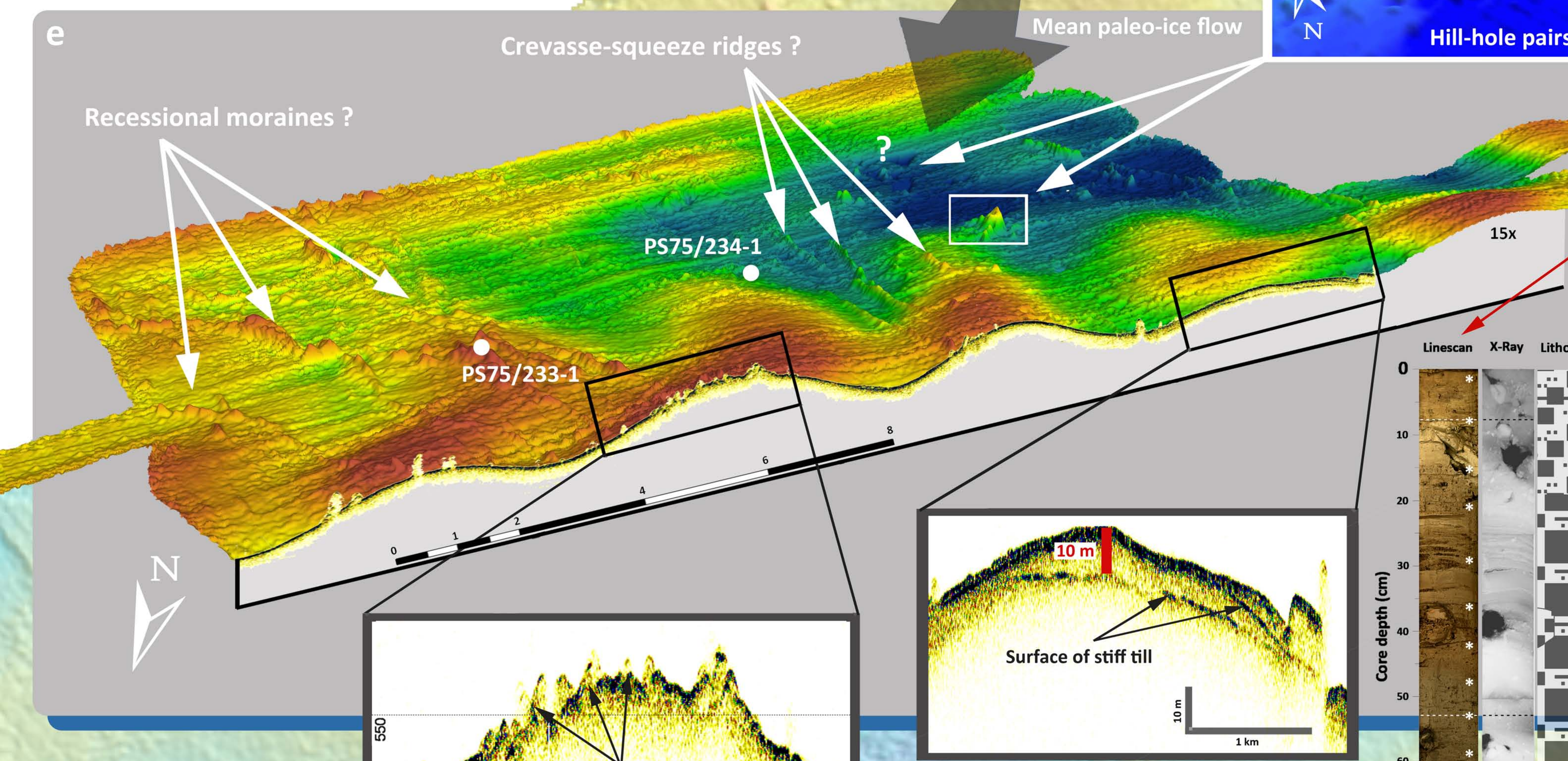
One of the largest uncertainties highlighted in the last IPCC report is future sea-level rise in response to polar ice-sheet melting. The behavior of the West Antarctic Ice Sheet (WAIS) is of particular interest because the WAIS is mainly marine based and therefore considered to be inherently unstable. A complete collapse of the WAIS would raise global sea level by ~3.4-5 meters. The risk of a future collapse of the WAIS could be estimated more precisely, if our understanding of the causes for accelerated ice flow and ice-sheet thinning (as it is observed in the Amundsen Sea sector of the WAIS today) could be improved. These deglaciation processes are likely to depend heavily on conditions at the ice-sheet bed. The inaccessibility of modern ice sheet beds, however, hampers *in situ* studies significantly. As a consequence, subglacial processes can only be insufficiently integrated into current ice sheet and climate models. An alternative method to investigate subglacial processes is remote sensing of the paleo-bed of the WAIS, which is exposed on the West Antarctic shelf. Its study gives important clues about mechanisms and modes of ice-sheet retreat following the last glacial maximum (LGM). Here, we investigate multibeam swath bathymetry data, PARASOUND subbottom profiles and sediment cores collected during RV Polarstern cruise ANT-XXVI/3 (01/2010-04/2010) from the West Antarctic continental shelf. Here we present initial results from Pine Island Bay (Amundsen Sea) that include multibeam swath-bathymetry images, PARASOUND subbottom profiles and lithological data of sedimentary sequences collected from a previously unsurveyed area north of Burke Island. The seabed there is characterized by unique pro-/subglacial landforms, which have not been reported from the West Antarctic shelf before. We present a preliminary interpretation of our data set and discuss possible implications for post-LGM ice-sheet retreat in the Amundsen Sea sector of the WAIS.

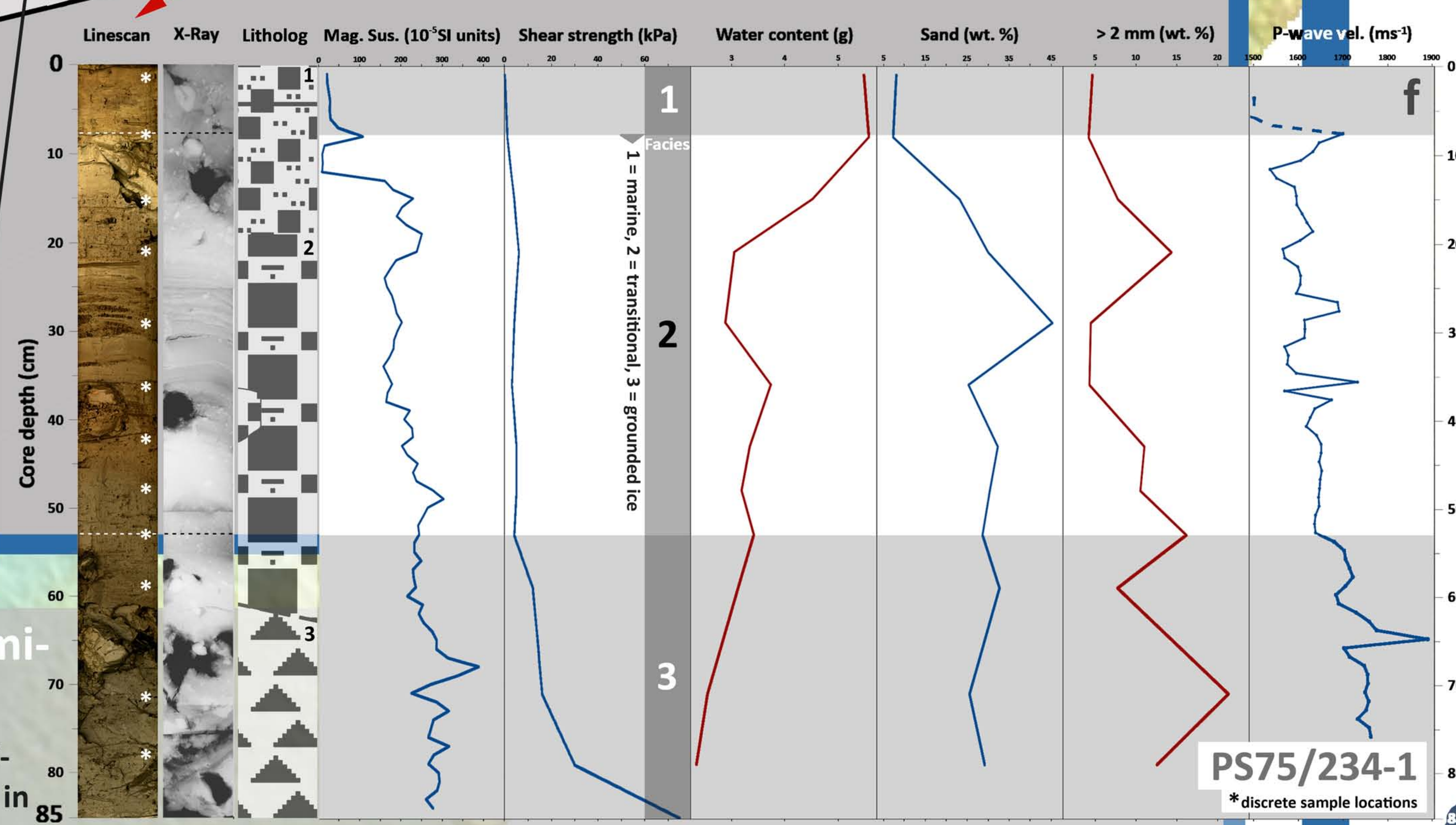


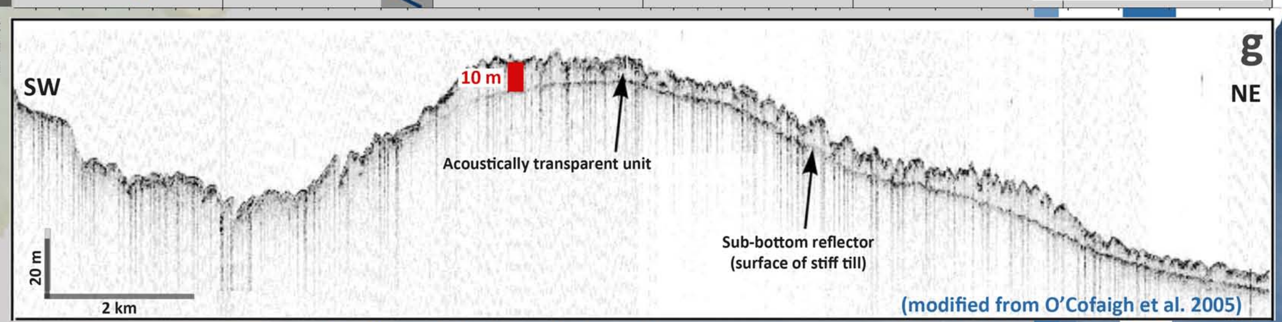












Similar sub-bottom information from Marguerite Trough, NW Antarctic Peninsula

❷ Regional setting & methods

East of 110° W, the Amundsen Sea Embayment's (ASE) bathymetry is characterized by four ~10-40-km-wide troughs. The most extensive one is the Pine Island Trough with a width of approximately 40 km and a longitudinal extension from ~75°S to 72°S. Three distinctive glaciers drain into the inner PIB, Pine Island-, Thwaites- and Smith Glaciers. The area around Burke Island is situated between the Pine Island paleo-ice stream trough and an over-deepened fjord in Ferrero Bay to the east. Here we investige an area north of Burke Island at ~ 105° 0' W, 72° 45' W (Fig. a). Multibeam echo-sounding data were collected on RV Polarstern Expedition ANT-XXVI/3 in early 2010. An Atlas Hydrosweep DS-2 system with 59 beams at 15.5 kHz was applied. Beam raypaths and seafloor depths were calculated in near real time using sound velocity profiles derived from CTD casts on the same cruise. Parametric sub-bottom echo sounder profiles were collected simultaneously to the multibeam swath bathymetry survey, using an Atlas PARASOUND system (secondary frequency of 3.5 kHz). PARASOUND profiles display the sub-surface at a very high resolution (up to ~ 1 m vertically), to as much as 10-30 m below sea floor. Sediment coring was also undertaken to obtain detailed information about the characteristics of the sea-floor sediments. The sedimentological analyses for both cores (PS75/233-1 [559.6 m] and PS75/234-1 [583.5 m]) focused on determining of the physical properties (P-wave velocities, magnetic susceptibility), shear strength measurements, determination of the water content and grain size analyses of the coarse fraction (63 µm - 2mm and > 2 mm-fractions). The P-wave velocity data derived from a GEOTEK multisensor core logger were measured on the whole cores while still aboard RV Polarstern. Magnetic susceptibility was additionally measured on split cores with a GEOTEK F-point sensor. Finally Linescan images and X-radiographs were obtained to further refine lithological units and downcore structural changes. Here we present data for core PS75/234-1 (Fig. f).

❸ Visible features & preliminary interpretation

Figures b & c depict clearly the set of different morphological features present in the working area:

1. Two sets of parallel ridges:
   - parallel and undulated ridges in the north and south
   - parallel but linear ridges in the central part
2. Hummocky structures with an approximate wavelength of 4 kilometers along the whole northwestern side; the isolated shiptracks in the southwest and northeast suggest that these features continue NE- and SW-wards.
3. Distinctive depressions in the central southwestern part with remarkable elevations on their northeastern sides.
4. A clear undulating sub-bottom reflector is visible on several PARASOUND profiles (two shown here; Fig. c and e).

1. We refer to the parallel and undulating ridges as either recessional or lateral moraines; the parallel orientation through the whole area (S to N) possibly implies they formed during ice sheet recession, whereas the typical ridge-orientation, as recently described by Winkelmann et al. 2010, (NE Greenland) is missing or was not imaged by the sub-bottom profiler.
2. However, the parallel but linear ridges (Fig. b and e) in the central part probably suggest a formation by crevasse-squeezing in ice-crevasses initiated by deformed grounded ice on hummocks; Crevasse-fill ridges mainly form in areas of temporarily stagnating or slow flowing ice, which was most likely the case in our working area north of Burke Island.
3. The hummocks along the whole northwestern side of the working area probably represent the recent stage of a former area of stagnating ice on an elevated plateaux, which is distinctive around Burke Island (Fig. a). Eyles et al. 1999 suggested the formation of hummocks perpendicular to the mean ice flow by huge icebergs resting on underlying substrate.
4. We suggest that the distinctive depressions with adjacent elevations (best visible in the 3D-image of the working area in Fig. e) represent Hill-hole pairs, which therefore would provide reliable information on the paleo-ice flow direction.
5. Several PARASOUND profiles of the area show a clear sub-bottom reflector (e.g. Fig. c and e) in depths below seafloor around 10-15 m. This corresponds well with other datasets (e.g. O'Cofaigh et al. 2005) and reflects the surface of stiff till. The sedimentological measurements for sediment core PS75/234-1 support this assumption clearly (Fig. c and f) with increasing P-wave velocities and shear strength values up to 74 kPa. This high value eventually suggests stagnant or slow flowing ice with the formation of a lodgement till (Facies 3, Fig. f). Distinctive sandy, gravelly layers in the transitional facies 2 may indicate an initiation of meltwater flow between the resting icebergs on the hummocky uplands. Finally, the marine influence becomes most prevalent in facies 1.

❹ Conclusions & future work

As we have shown, the area N of Burke Island consists of some unique pro- and subglacial morphological features, which have never been described on an Antarctic shelf before. Through the combination of high resolution swath bathymetry and sub-bottom profiler data, as well as detailed sedimentological information, we were already able to get an idea of the paleo-ice flow behaviour in matters of directions and rel. velocities. Most likely we found features, which suggest decelerated or even sometimes almost stagnant ice flow in this area, which could mean that the resting ice here was more durable then surrounding ice streams. To validate this, our future work will focus on searching for dateable material, defining the volume of the potential Hill-hole pair, etc., to deliver suitable basic data for potential ice-flow models of the area.

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