Evidence of a dynamic ice sheet system in Filchner Trough until the early Holocene

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Introduction:
The past ice sheet conditions in the southern Weddell Sea Embayment (Fig. 1) are only poorly known (Hillenbrand et al., 2014). Studies from this area have led to two contradicting scenarios of maximum ice extent during the Last Glacial Maximum (LGM) varying about 500 km in Filchner Trough. This leaves large uncertainties for: 1) the regions contribution to post-LGM meltwater pulses and sea-level rise; 2) the mechanisms and potential to create Antarctic Bottom Water (AABW) during glacials that today needs the presence of the Filchner-Ronne Ice Shelf; 3) past ice sheet dynamics in the study area. Here, we present new marine geophysical and geological data that suggests the presence of a dynamic ice system in Filchner Trough.

Fig. 1: Location of study area (red box); EAS = East Antarctic Ice Sheet, WAI = West Antarctic Ice Sheet, FRIS = Fram Strait Ice Shelf, FT = Fosheim Trough, WSE = Weddell Sea Embayment, EM = Ellsworth Mountains, SR = Shackleton Range, I = Institute Ice Stream, M = Miller Ice Stream, F = Foundation Ice Stream.

Methods:
Most of the geophysical data, multibeam bathymetry data (ATLAS Hydrosweep DS3) and acoustic sub-bottom profiles (ATLAS Parasound P-70), were acquired during RV Polarstern expedition PS96 (2015/16). Supplementary bathymetric data were included (JRS1, 2005, RRS JC Ross and ANT-IWS, 1989/90, RV PolaRatem). All bathymetric data were post-processed and jointly gridded at 25 m resolution.

Two gravity cores (PS96/079-3 and PS96/080-1) were retrieved. Sampling and analysis of the cores followed standard procedures. Two horizons in each core, each containing foraminifera that were used to obtain accelerator mass spectrometry (AMS) 14C radiocarbon dates.

Fig. 2: Bathymetry in outer Filchner Trough showing a depression (blue to yellow) with GZW 1a on its east side (yellow) and GZW 1b (orange) to the south. Note NWE striking mega-scale lineations within the depression (Lineations A and on GZW 1a (Lineations B) and iceberg ploughmarks on top of GZW 1b and the trough flanks. White circles mark core sites.

Fig. 3: Sub-bottom profiles across lineations A, GZW 1a and core locations (for location see Fig. 2); stratified acoustic facies (AF1) and transparent acoustic facies (AF2 and AF3) are indicated. Note the splitting of AF1 at GZW 1a and the continuation of AF1 underneath GZW 1a and GZW 1b.

Fig. 4: Lithofacies, shear strength, bedulk density (MBD), magnetic susceptibility, water content, grain-size composition of the sediment matrix and AMS 14C dates for core PS96/079-3 A and PS96/080-1 B Lithofacies: ML: laminated mud, MSD: laminated and stratified mud alternating with gravelly sandy mud and gravely muddy sand; MF: folded mud; MS: consolidated sandy mud with gravel- to pebble-sized intraclasts; SGMD: massive gravelly muddy sand with inclined (proximal) base; DMB: massive muddy diamicton with some diatoms; Dnt: massive, purely terrigenous muddy diamiction.

Results (Morphology):
Our key finding is a previously unknown stacked grounding zone wedge (GZW) located on the outer shelf (Fig. 2 and 3). This GZW shows that the Filchner paleo-ice stream stabilized at this position at least twice (GZW 1a and 1b). Mega scale glacial lineations A and B located offshore GZW 1b show a paleo-ice stream was active in Filchner Trough.

A layer of drape (AF1) on top of the unit that formed lineations A (AF2) indicates that they were created prior to lineation B. On no drape is visible, and also prior to the formation GZW 1a and 1b (AF3) that were deposited on top of the drape (Fig. 3). GZW 1b and trough flanks shallower than 710 m are reworked by iceberg ploughmarks.

Results (Lithology):
Core PS96/079-3 was retrieved from the draping layer on top of lineations A (Fig. 2). Its lithology suggests deposition of normally consolidated glaciomarine sediments (Fig. 4A). The two obtained AMS dates indicate that this setting prevailed at least for 27.5 cal kyr. Hence, lineations A were formed before that time and grounded ice did not extend beyond this position since then, including the LGM.

Core PS96/080-1 was retrieved from lineations B on top of GZW 1a (Fig. 2). The upper 25 cm of the core consist of a massive muddy diamict, bearing some diatoms at 11 cm, that indicate deposition in a (seasonally) open marine setting (Fig. 4B). Below, the core consists of a 172 cm thick purely terrigenous, homogenous muddy diamict that we interpret as soft as basal till. The AMS dates obtained from reworked foraminifera suggest that formation of GZW 1a took place after 11.8 cal kyr B.P. Core G7, located further inland (see Fig. 1), revealed a minimum age for ice retreat at 8.7 cal kyr B.P. (Hillenbrand et al., 2014).

Reconstruction:
Our results allow us to create a reconstruct different phases of ice stream settings in Filchner Trough.

Phase 1: Ice Stream is active in and possibly seaward of study area, ≥ 27.5 cal. kyr B.P. and forms lineations A.

Phase 2 (Fig. 5A): The study area remains free of grounded ice, glaciomarine sediments are deformed and recrystallized from A to ≥ 27.5 to ≥ 11.8 cal kyr B.P., including the LGM.

Phase 3 (Fig. 5B): The groundinglines advance and stabilizes to form GZW 1a, sometime between 11.8 and ≥ 8.7 cal kyr B.P.

Phase 4 (Fig. 5C): The groundinglines retreats, readvances an stabilizes to form GZW 1b, sometime between ≥ 11.8 and ≥ 8.7 cal kyr B.P.

Phase 5 (Fig. 5D): The groundinglines retreat inland and icebergs plough the seafloor where their draft is sufficient, sometime after ≤ 11.8 cal kyr B.P.

Implications:
1. The WSE sector of Antarctica did not contribute significantly to post-LGM meltwater pulses, but possibly to Holocene sea-level rise.
2. During the LGM an Ice shelf was present on the continental shelf that enabled formation of AABW.
3. Our data indicate the presence of a highly dynamic ice sheet system in Filchner Trough with large grounding line fluctuations at least until the early Holocene.

Discussion on ice dynamics:
A possible mechanism to explain the observed grounding line fluctuations are major reorganizations of ice-stream flow in the WSE hinterland resembling those reported until the Mid-Holocene (Nagler et al., 2005). Importantly, models suggest that only ice-flow reorganization re-directing the ice streams draining the WAIS into the Ronne Ice Shelf today (M. F. Fig. 5) into Filchner Trough, would have enabled grounding-line advance to the outermost part of Filchner Trough (Whillans et al., 2017). Ice flow switching and different histories of precipitation possibly also explain the restricted LGM expansion and late (i.e. early Holocene) readvance. Pre-LGM advance and retreat of the EAWS could have blocked and delayed WAIS drainage through Filchner Trough until the early Holocene, which needs to be taken into account in ice-sheet models.