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

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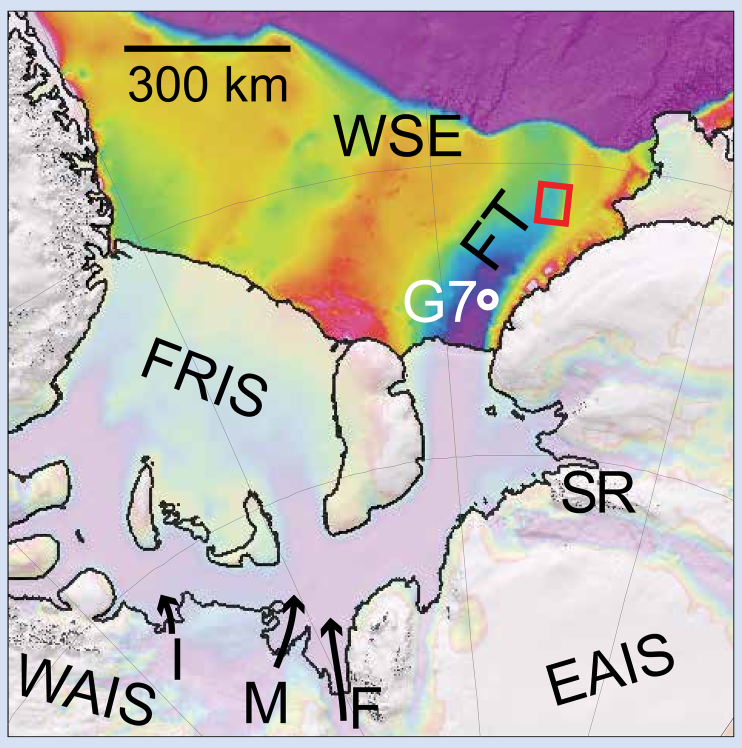


Fig. 1: *Location of study area (red box); EAIS = East Antarctic Ice Sheet, WAIS = West Antarctic Ice Sheet, FRIS = Filchner Ronne Shelf Ice, FT = Filchner Trough, WSE = Weddell Sea Embayment, EM = Ellsworth Mountains, SR = Shackleton Range, I = Institute Ice Stream, M = Möller Ice Stream, F = Foundation Ice Stream.*

Introduction:

The past ice sheet conditions in the southern Weddell Sea Embayment (WSE, **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 650 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. Here, we present new marine geophysical and geological data that suggests the presence of a dynamic ice system in Filchner Trough.

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 (JR97, 2005, *RRS JC Ross* and ANT-VIII/5, 1989/90, *RV Polarstern*). 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, contained foraminifera that were used to obtain accelerator mass spectrometry (AMS) ^{14}C radiocarbon dates.

Fig. 2: *Bathymetry in outer Filchner Trough showing a depression (blue to yellow) with GZW 1a on its eastern side (yellow) and GZW 1b (orange/red) to the south, note NNE 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 coring sites.*

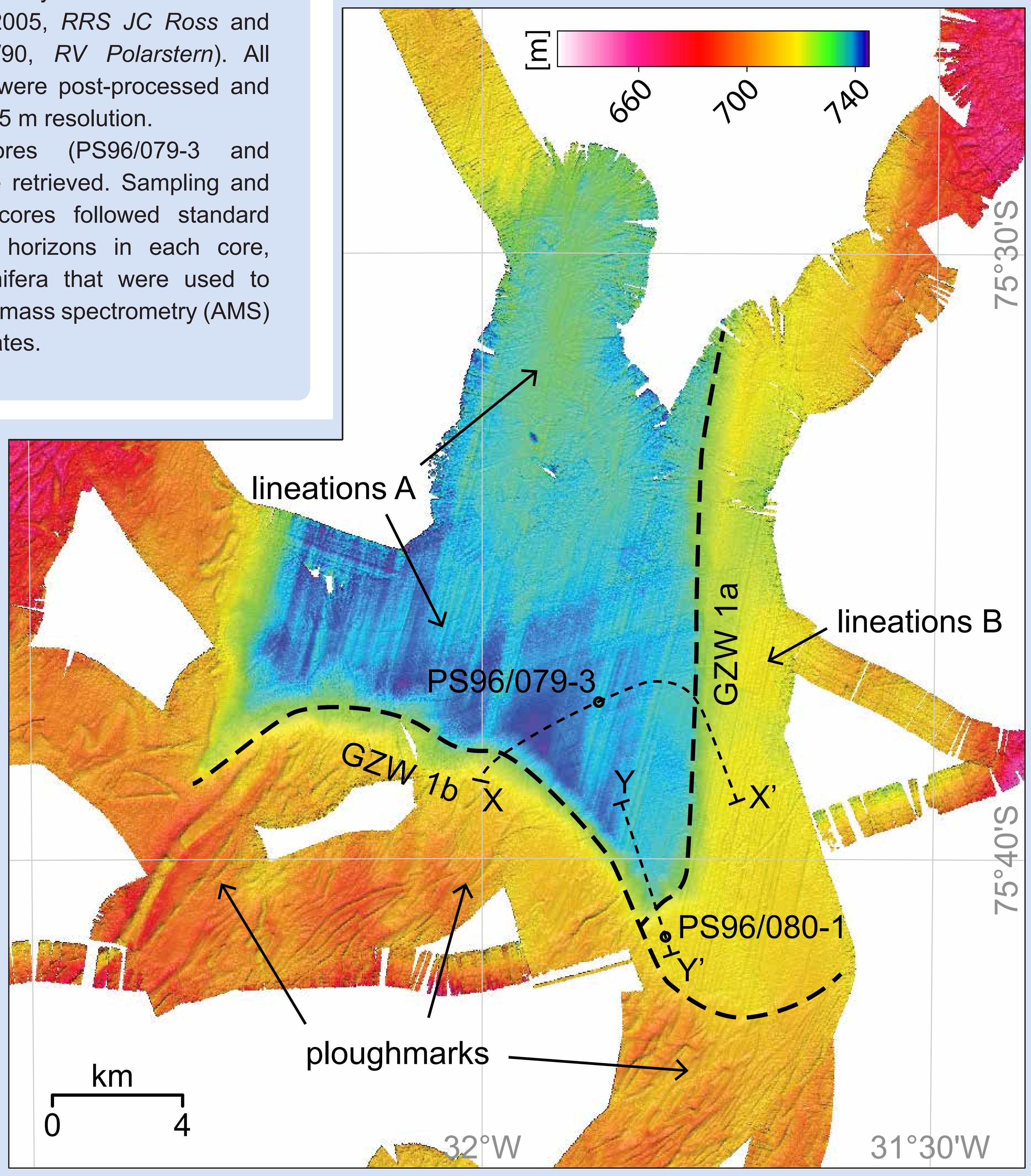
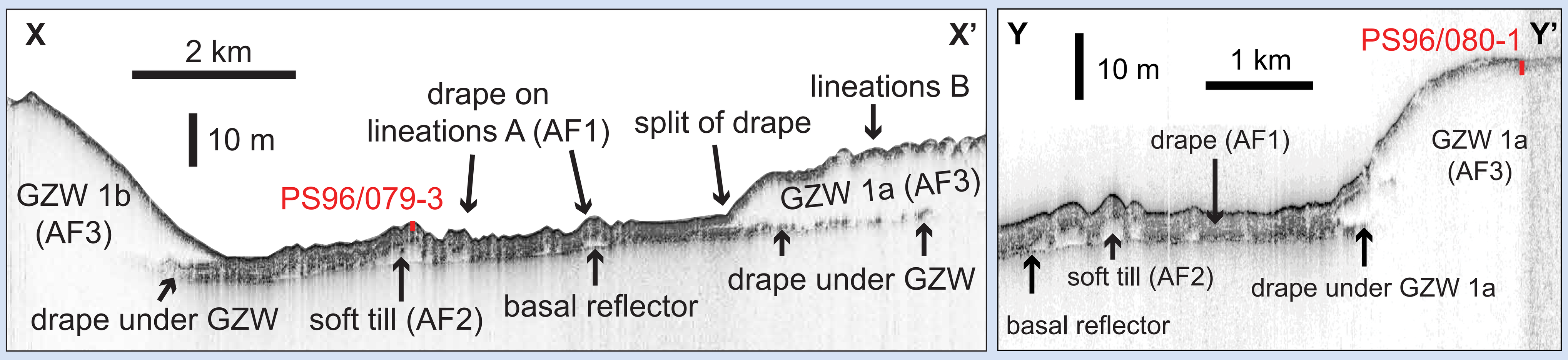


Fig. 3: *Sub-bottom profiles across lineations A, GZW 1a with lineations B, GZW 1b, and core locations (for location see Fig. 2); stratified acoustic facies (AF1) and transparent acoustic facies (AF2 and AF3) are indicated. Note the splitting of AF1 at GZW 1a and the continuation of AF1 underneath GZW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

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 palaeo-ice stream stabilized at this position at least two times (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 form lineations A (AF2) indicates that they were created prior to lineation B, on which no drape is visible, and also prior to the formation GZWs 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 glacimarine 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 extent seaward of 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 diamicton, 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 diamicton that we interpret as soft basal till. The AMS dates obtained from reworked foraminifera suggest that formation of GZW 1a took place after 11.8 cal. kyrs B.P..

Core G7, located further inland (see Fig. 1), revealed a minimum age for ice retreat at 8.7 cal. kyrs 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. kyrs B.P. and forms lineations A.

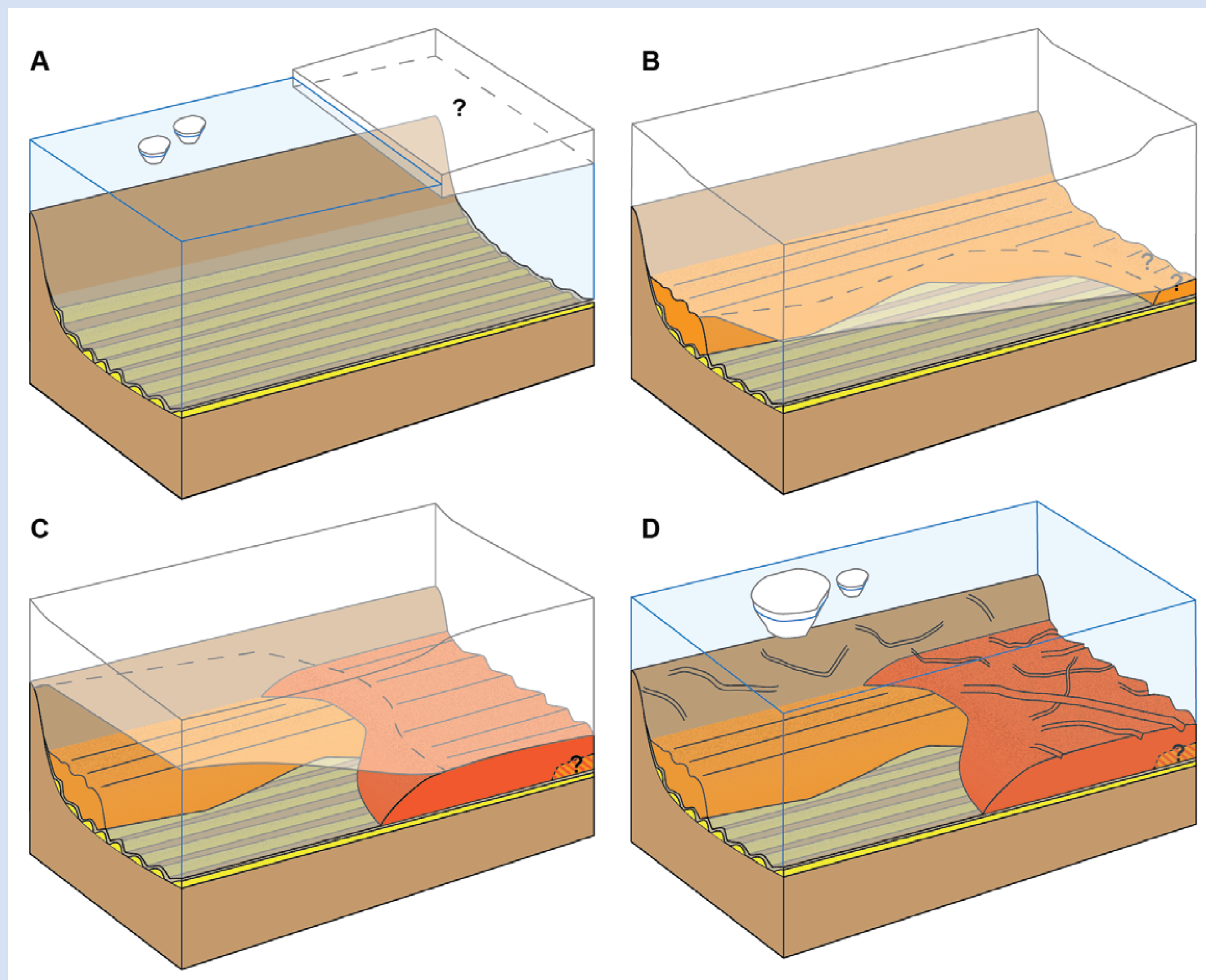
Phase 2 (Fig. 5A): The study area remains free of grounded ice, glacimarine sediments are deposited on top of lineations A, from ≥ 27.5 to ≥ 11.8 cal kyrs B.P., including the LGM.

Phase 3 (Fig. 5B): The groundingline advances and stabilizes to form GZW 1a, sometime between ≤ 11.8 and ≥ 8.7 cal kyrs B.P..

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

Phase 5 (Fig. 5D): The groundingline retreated inland and icebergs plough the seafloor where their draft is sufficient, sometime after ≤ 11.8 and definitely after 8.7 cal kyrs B.P..

Fig. 5: *Cartoon of environmental conditions during different phases of the last glacial cycle in the study area. A: Phase 2, B: Phase 3, C: Phase 4, D: Phase 5.*



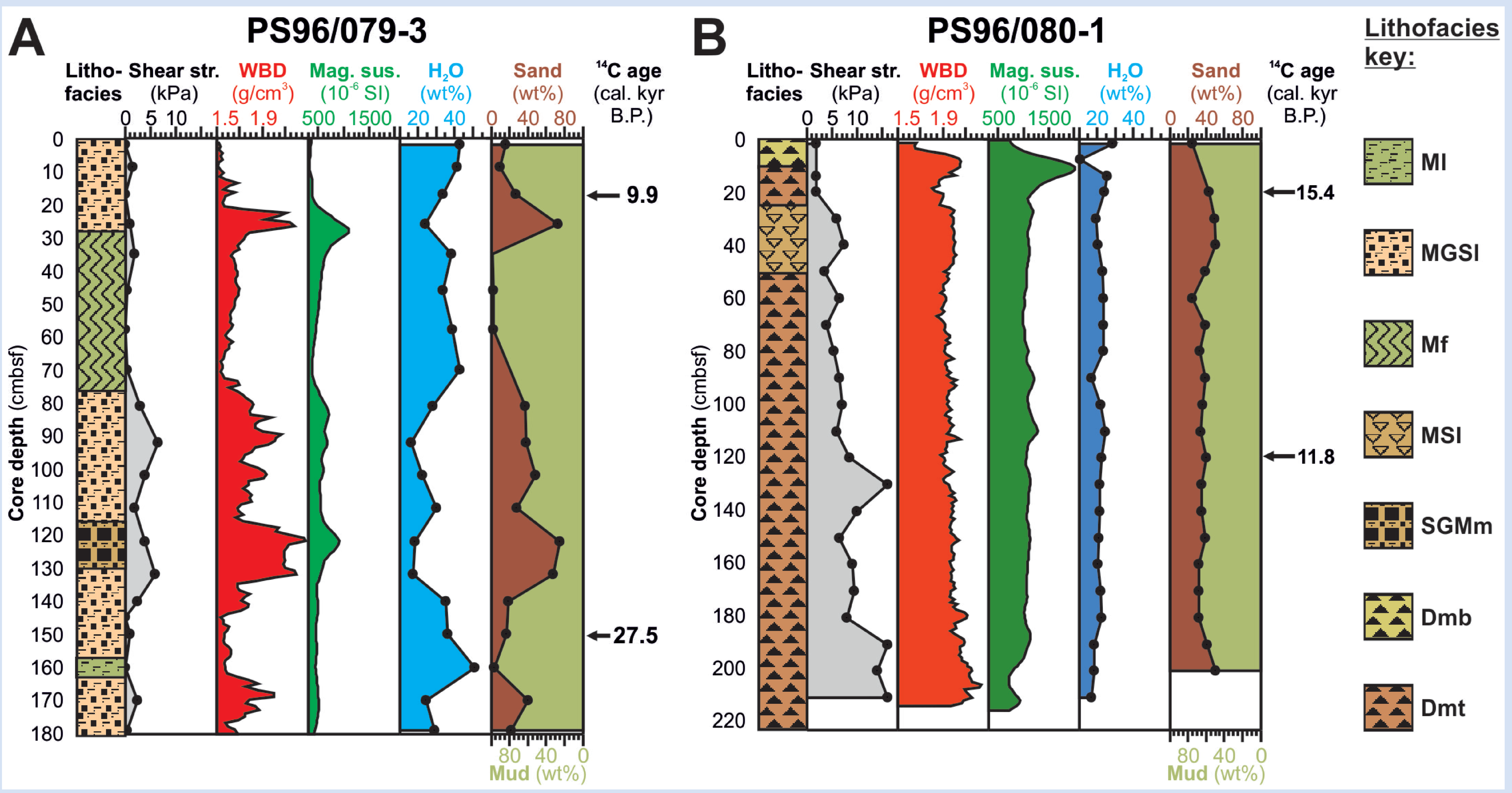


Fig. 4: *Lithofacies, shear strength, wet-bulk density (WBD), magnetic susceptibility, water content, grain-size composition of the sediment matrix and AMS ^{14}C dates for cores PS96/079–3 (A) and PS96/080–1 (B).Lithofacies: Ml: laminated mud, MGSl: laminated and stratified mud alternating with gravelly sandy mud and gravelly muddy sand, Mf: folded mud, MSl: consolidated sandy mud with gravel- to pebble-sized intraclasts, SGMm: massive gravelly muddy sand with inclined (erosional) base, Dmb: massive muddy diamicton with some diatoms, Dmt: massive, purely terrigenous muddy diamicton.*

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 (e.g., Winter et al., 2015). Importantly, models suggest that only ice-flow reorganization redirecting the ice streams draining the WAIS into the Ronne Ice Shelf today (I, M, F; **Fig. 1**) into Filchner Trough, would have enabled grounding-line advance to the outermost part of Filchner Trough (Whitehouse 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 EAIS 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.

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