Past collapses of the West Antarctic Ice Sheet:

Urgent need for IODP drilling in the Amundsen Sea Embayment

IODP proposal 839-Full:

Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment

by

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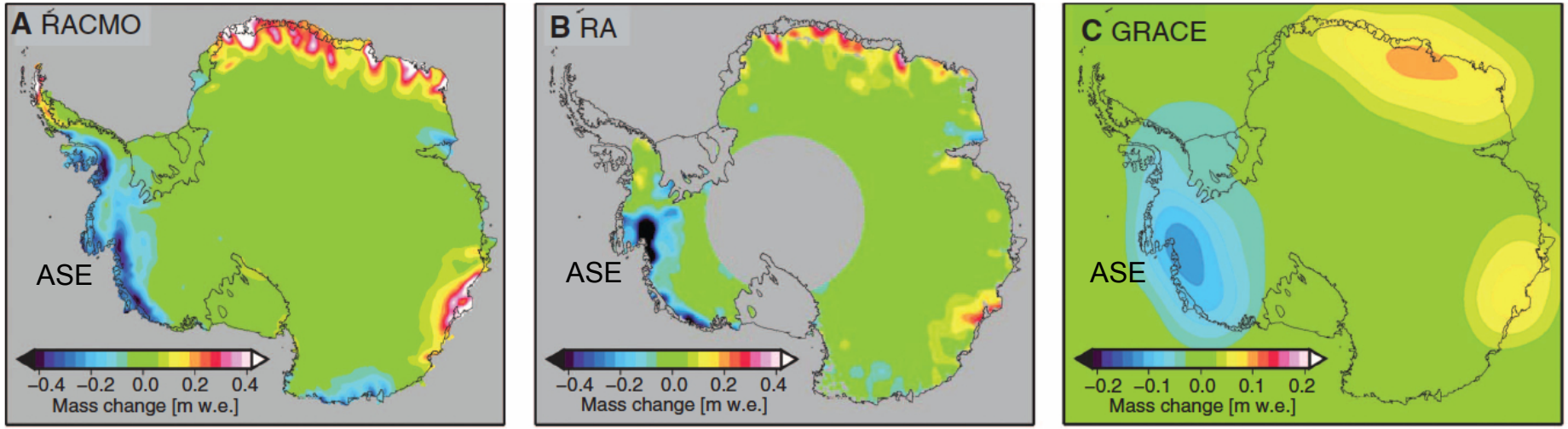
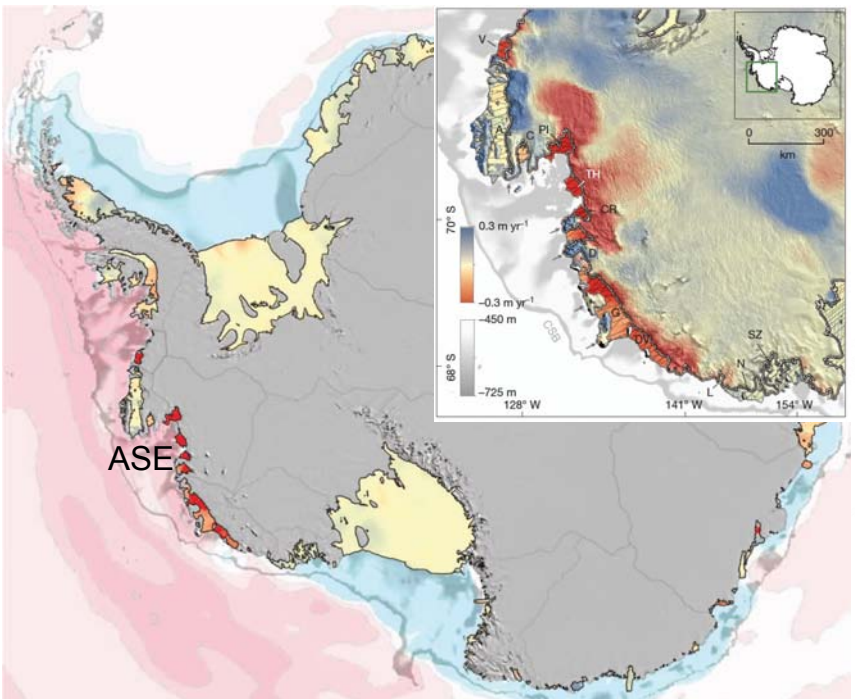
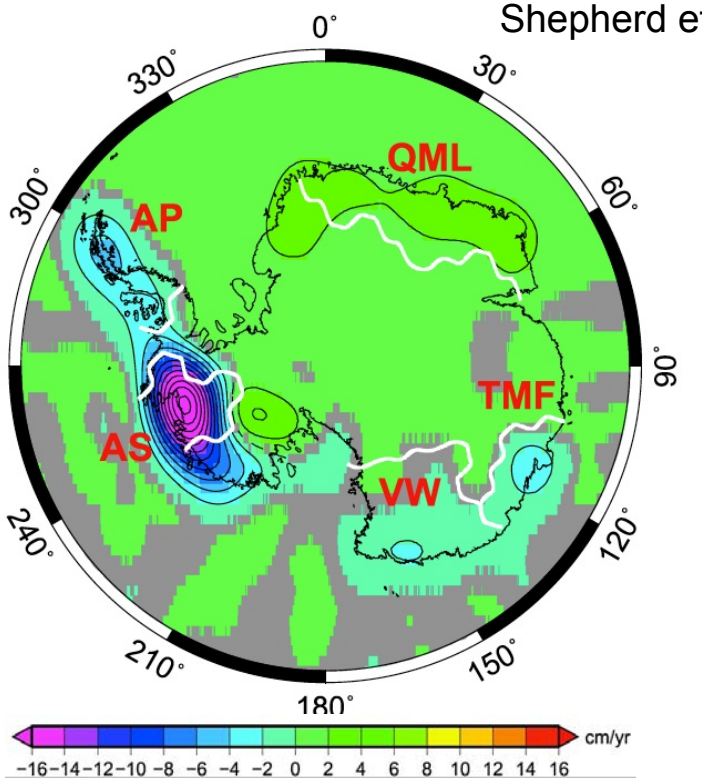
Why focussing on the Amundsen Sea Embayment (ASE)?



Shepherd et al. (Science, 2012)



Ice-shelf thickness (ΔT/Δt) and ice height (Δh/Δt) change rates (modified from Pritchard et al., Nature, 2012)



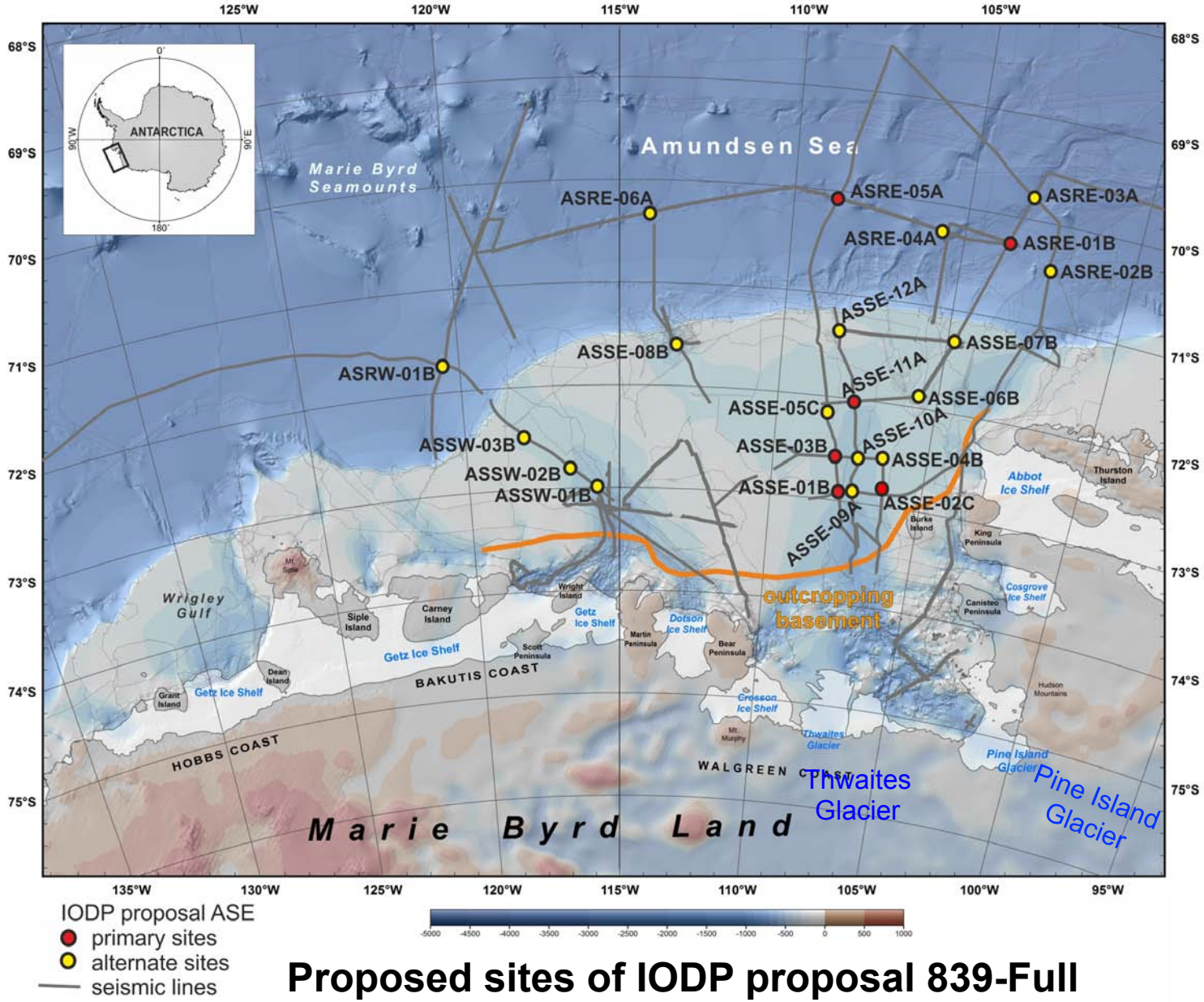
Velicogna et al. (GRL, 2014)

Present ice mass loss of ASE:

83-102 Gt/yr, accelerating!

1.5 m sealevel equivalent in ASE catchment area

3.3-4.3 m if all WAIS collapses

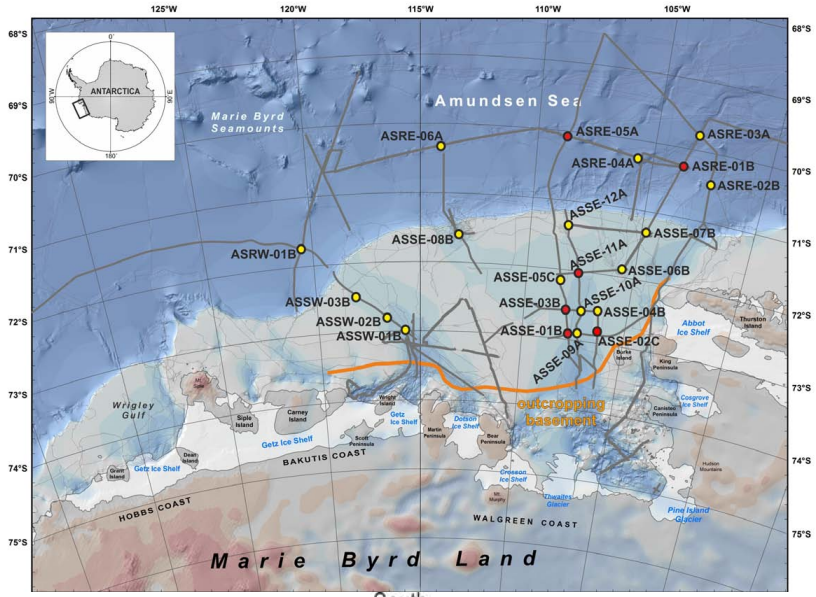


Proposed sites of IODP proposal 839-Full

Adressing 5 main hypotheses on West Antarctic Ice Sheet (WAIS) dynamics and related paleoenvironmental and paleoclimatic conditions

IODP proposal 839

Amundsen Sea Embayment (ASE)



seismo-stratigraphic transect of shelf sediments

from Gohl et al. (2013)

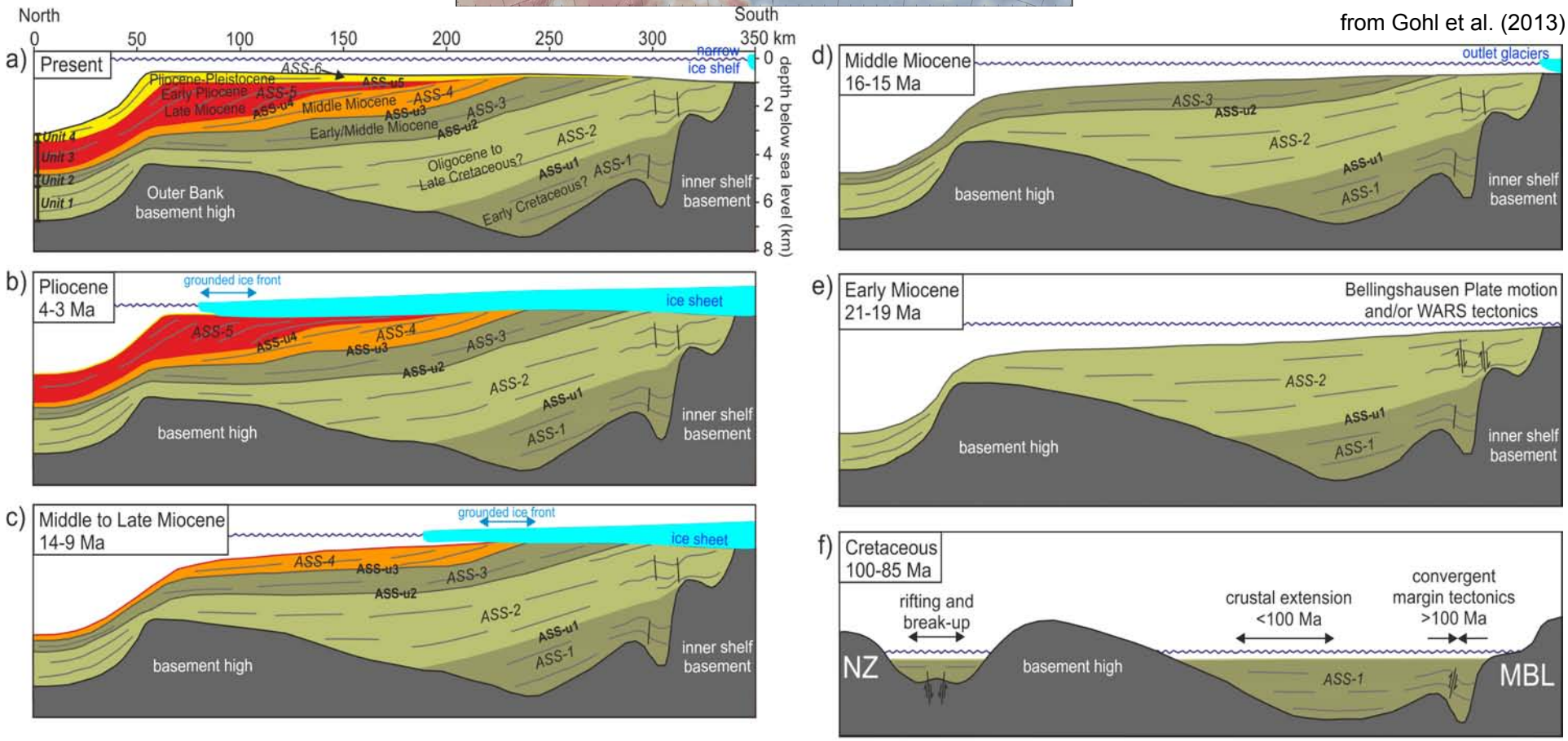
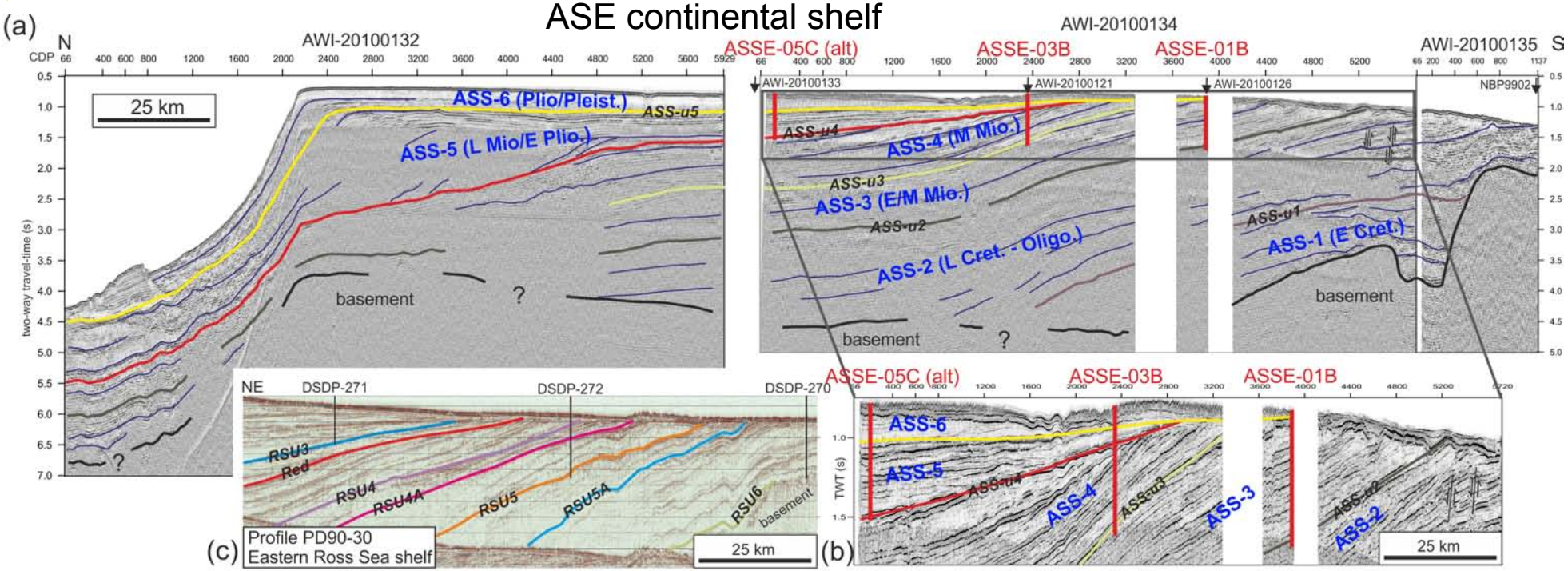
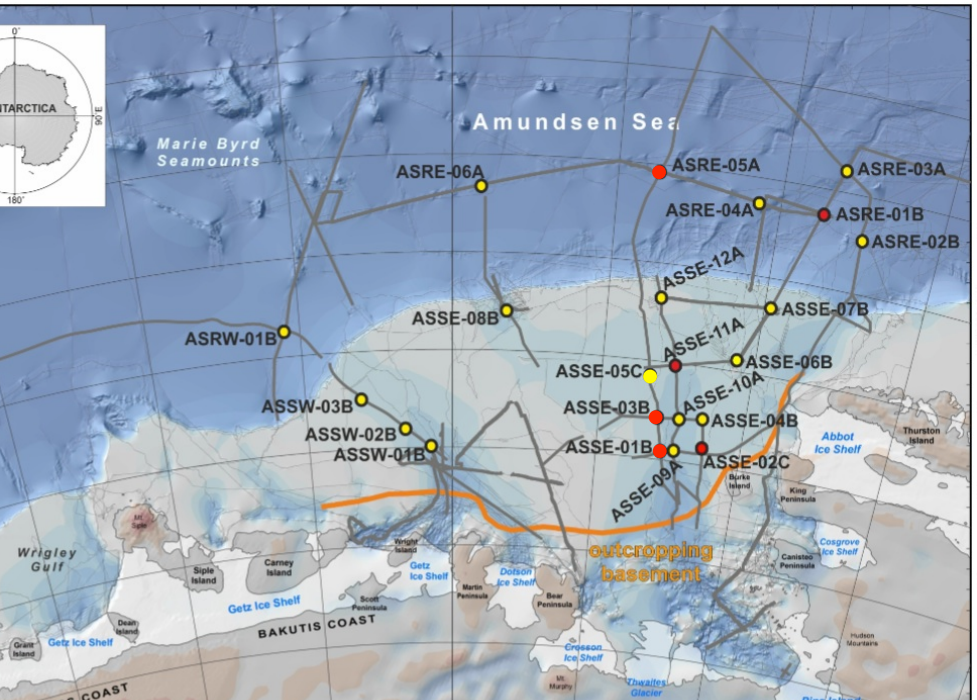


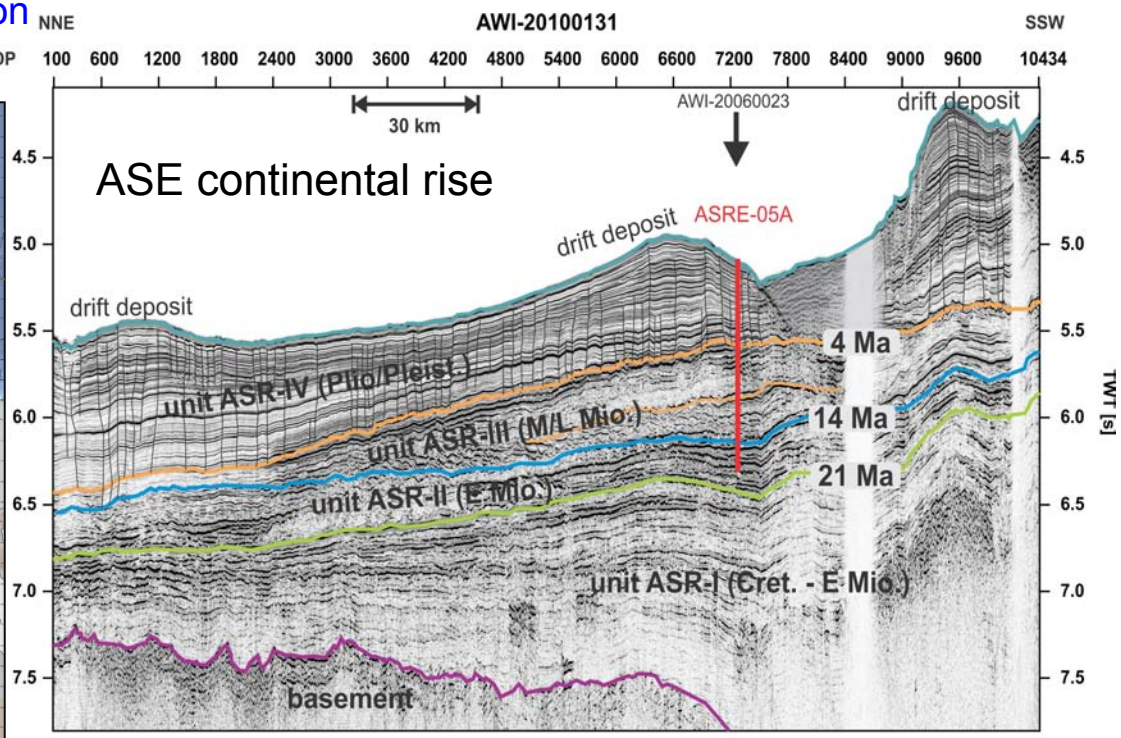
Fig. 5. (a) Seismic stratigraphic model of the eastern ASE shelf with sedimentary units ASS-1 to ASS-6 and major unconformities ASS-u1 to ASS-u5

ASE continental shelf



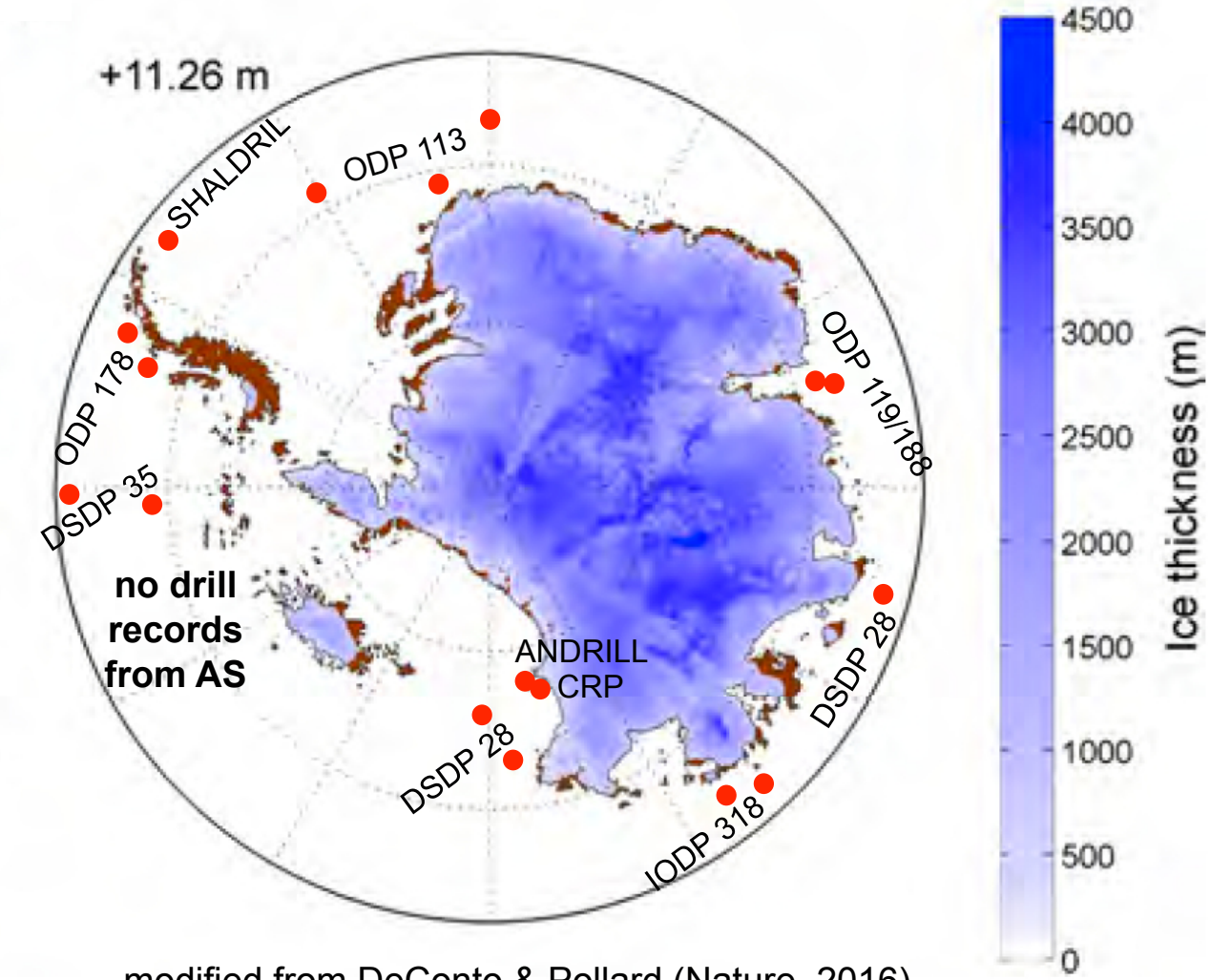
Ross Sea record for comparision





Hypothesis H1: ***The WAIS responded to atmospheric and/or oceanic warming by major retreat from the shelf or by even partial to full collapse.***

warm early-middle Pliocene:
~400 ppm CO_2; ~3°C higher; SL 10-30 m higher



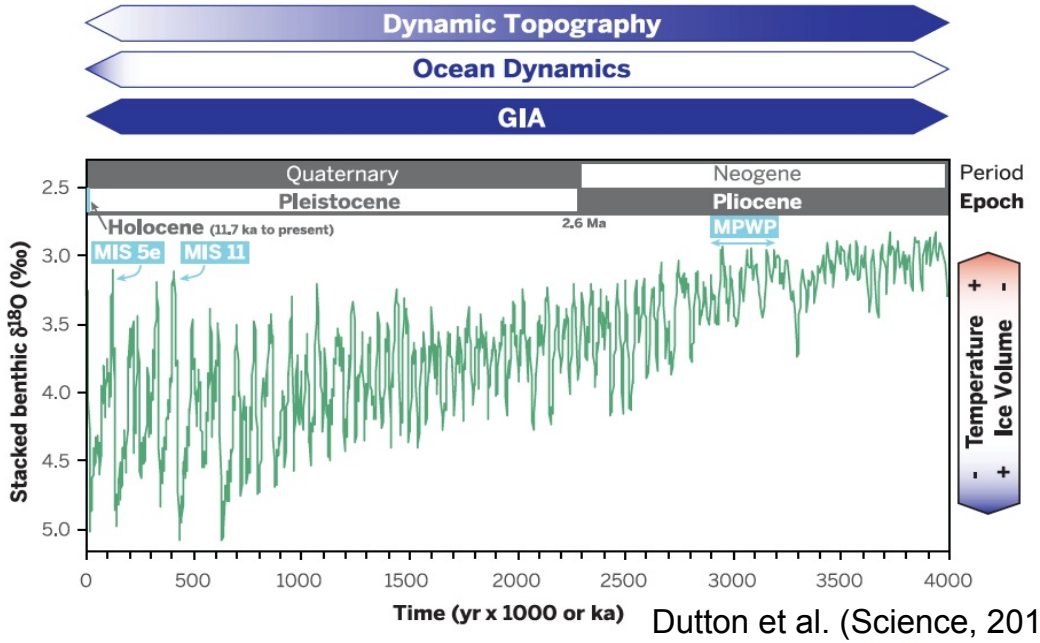
modified from DeConto & Pollard (Nature, 2016)

- Repeated phases of collapsed WAIS predicted by modelling
- ANDRILL records show evidence for repeated grounded ice, ice-shelf and open water conditions in Ross Sea embayment from Late Miocene to Pliocene
- Past retreat processes remain unclear
- Other proximal drill data do not exist to verify past partial or full collapses of WAIS

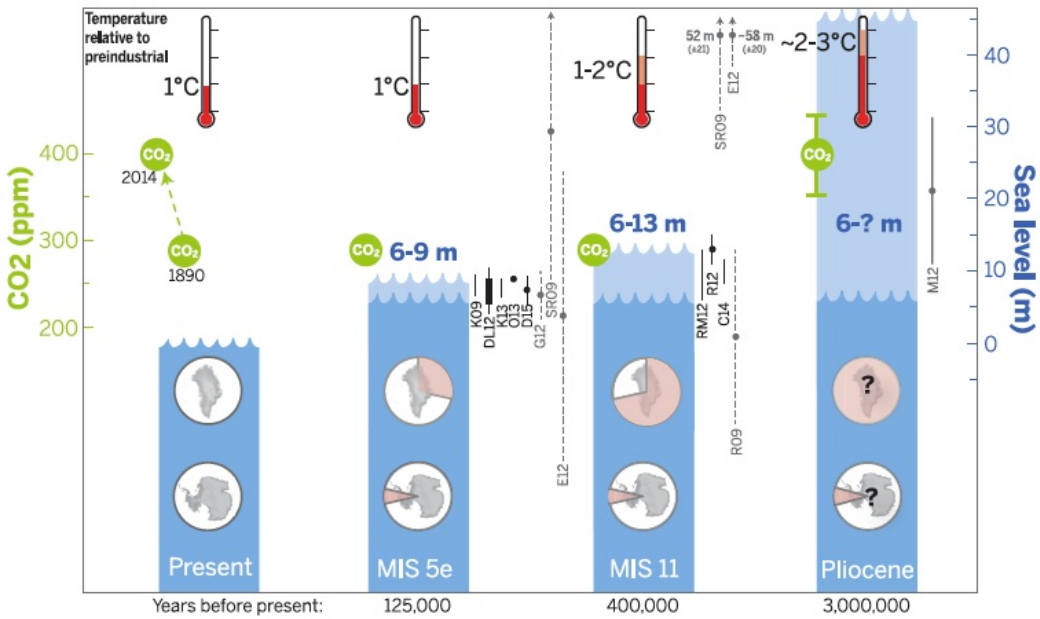
>> Improvement of large modelling/prediction uncertainty requires more representative (spacial & temporal) geological records

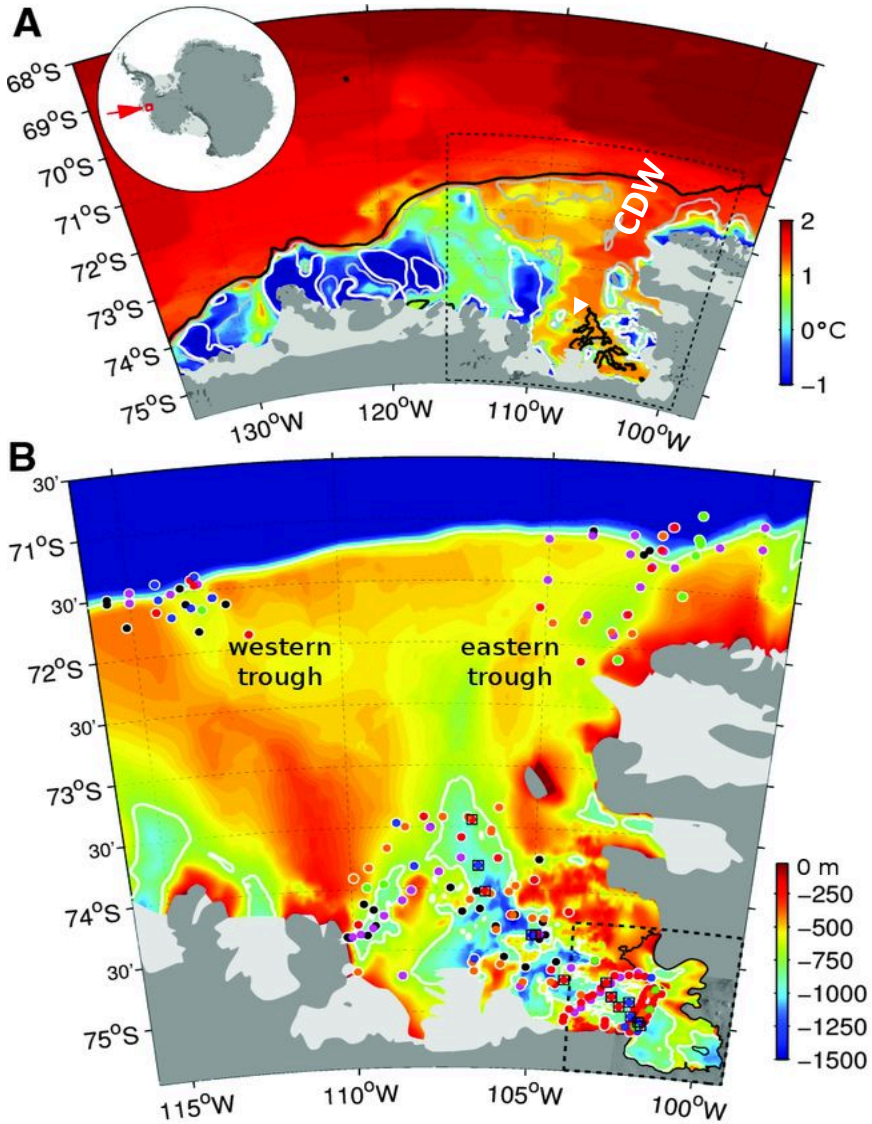
Hypothesis H2: *Ice-proximal records of ice sheet dynamics in the ASE correlate with global records of ice-volume changes and proxy records for atmospheric and ocean temperatures.*

- **Ice-proximal records** from ASE shelf and rise sites to be **linked to ice-distal** deep-sea and global paleoceano-graphic records.
- Deciphering of WAIS response to **orbitally-paced climatic cycles** of Pliocene and Quaternary, or to periods controlled by **internal dynamics**.
- Correlation of **episodic ice retreat phases** (e.g. as observed for post-LGM).
- Testing **discrepancies between global temperature and ice volume** reconstructed from proxies in deep-sea, climate models, sea-level estimates, and ice cores.



Dutton et al. (Science, 2015)

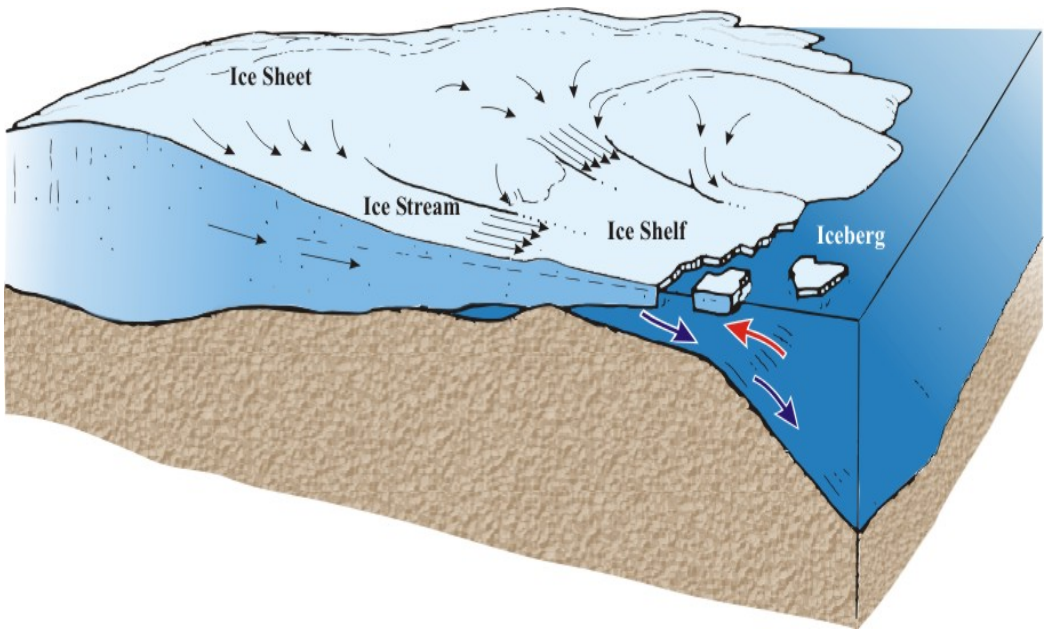




Dutrieux et al. (Science, 2014)

Hypothesis H3:

The stability of marine-based WAIS margins is and has been controlled by warm deep-water incursions onto the shelf.

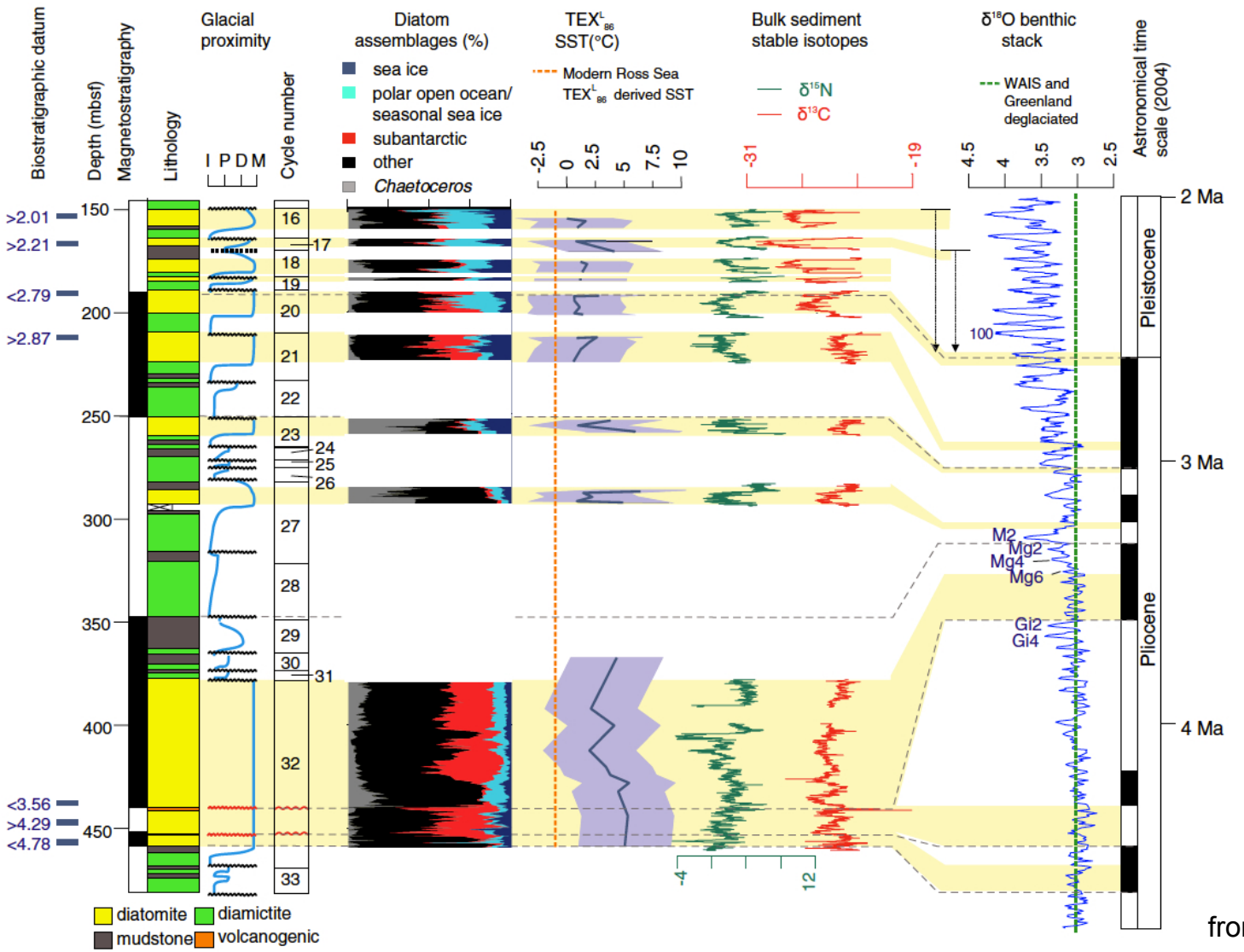


Today, Circumpolar Deep Water (CDW) upwells onto the Amundsen Sea Embayment (ASE) shelf and melts ice shelves of ice streams (e.g. Pine Island Glacier) from below.

Hypothesis H4: *Major WAIS advances onto the middle and outer shelf occurred since the middle Miocene*.

Pliocene/Pleistocene lithofacies log of AND-1B, Ross Sea shelf:

- Possible analogue for ASE?
- Or are step-wise ice-sheet expansions different in onset (age) and duration?



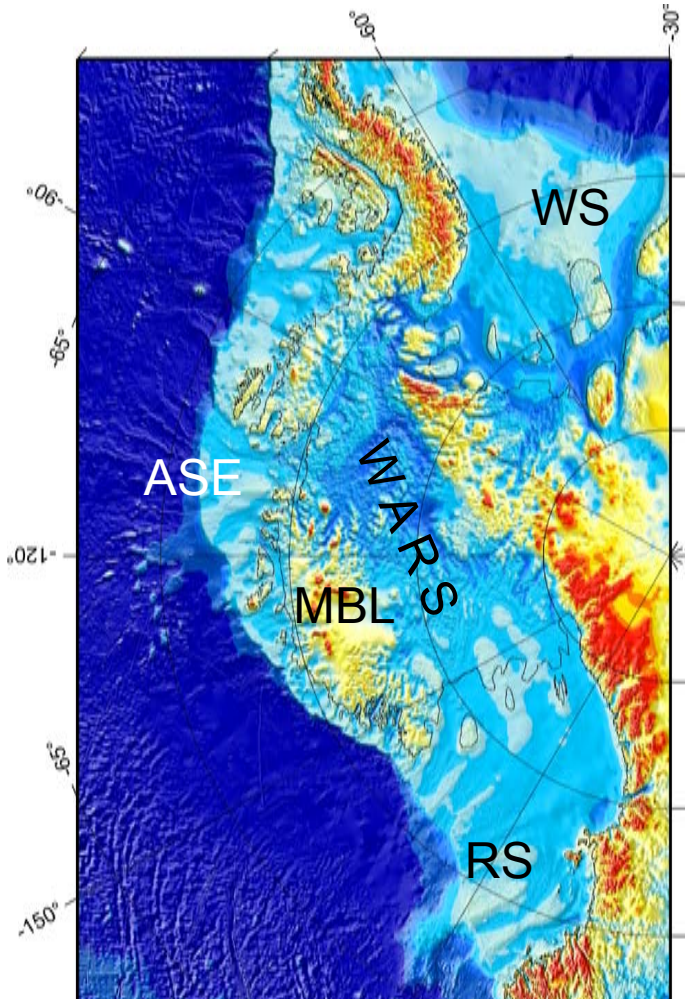
Deriving oceanographic changes and forcing mechanisms from TEX_{86} temperature proxy, even from ice-proximal records.

from McKay et al. (PNAS, 2012)

Hypothesis H5: ***The first WAIS advance onto the inner ASE shelf occurred during the Oligocene or early Miocene and was related to the uplift of Marie Byrd Land.***

Thermochronological (fission track) records of samples from central and eastern Marie Byrd Land (MBL) sector:

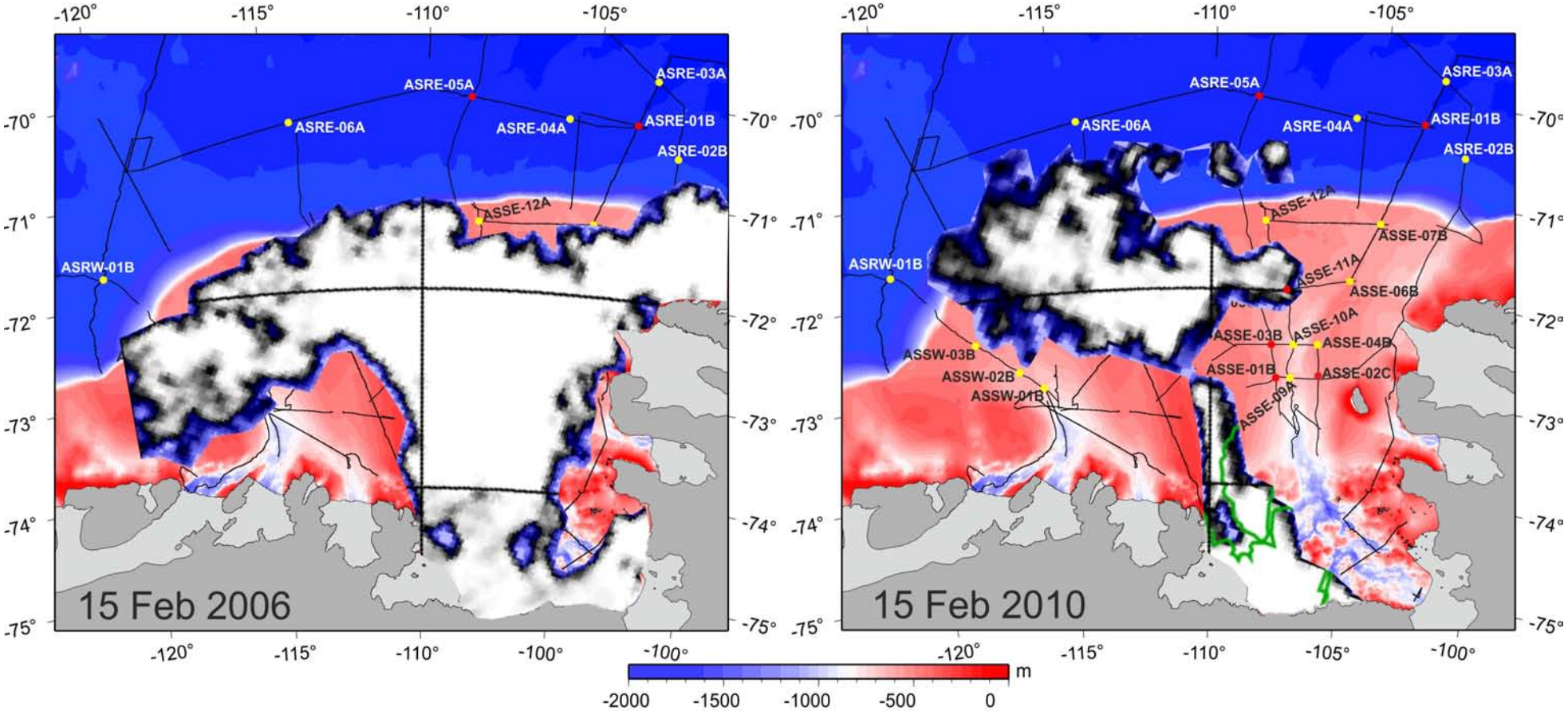
- MBL dome uplift started at about 20 Ma (10 myrs later than in earlier models)
- Correlation with early WAIS evolution/ expansion?



Present-day subglacial topography (BEDMAP-2, Fretwell et al., 2013).

Mitigating sea-ice risk

- Contingency plan with a total of 22 sites (6 primary, 16 alternate) to select from, including sites on continental rise with no sea-ice risk; H1-3 can always be addressed, H4-5 most likely
- Near real-time satellite imagery at high resolution (e.g. TerraSAR-X and Sentinel)
- Icebreaker support not necessarily required



Worst sea-ice cover since 2005 **Best sea-ice cover since 2005**

CONCLUSIONS

7 main reasons for drilling IODP proposal 839 in the Amundsen Sea Embayment:

① Amundsen Sea Embayment is currently experiencing **dramatic loss of Antarctic ice mass**, more than any other region in Antarctica (except for northern Antarctic Peninsula).

② Highest likelyhood of testing for **warm deep-water incursions** at past warm times, because of best understood present CDW melt processes.

③ ASE ice loss may have been **precursor to total/partial West Antarctic Ice Sheet collapse in all times of global warming**. Have warm deep water incursions been the primary driver of melting in the past?

④ **Highest societal relevance for sealevel prediction** (IODP Science Plan; ASE statements in latest IPCC report).

⑤ Glacial sedimentary record in ASE represents processes of **100% West Antarctic Ice Sheet**, unaffected by the dynamics of other ice sheets; it‘s at the ‘***heart of WAIS***‘.

⑥ Single leg covers range from **greenhouse-icehouse transition to Pleistocene**.

⑦ **Amundsen Sea has never been drilled**; thus records would contribute to vital studies of South Pacific stratigraphy, paleoceanography, and Antarctic paleotopography/bathymetry.