West Greenland ice stream instability during the LGM/Holocene transition

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UNIVERSITY OF ABERDEEN

- ***LGM/Deglacial history of the GrIS***

- ***Marine-terminating Ice streams***
  - *Pathways*
  - *Deglacial history*
  - *Forcing mechanisms*
  - *Challenges*

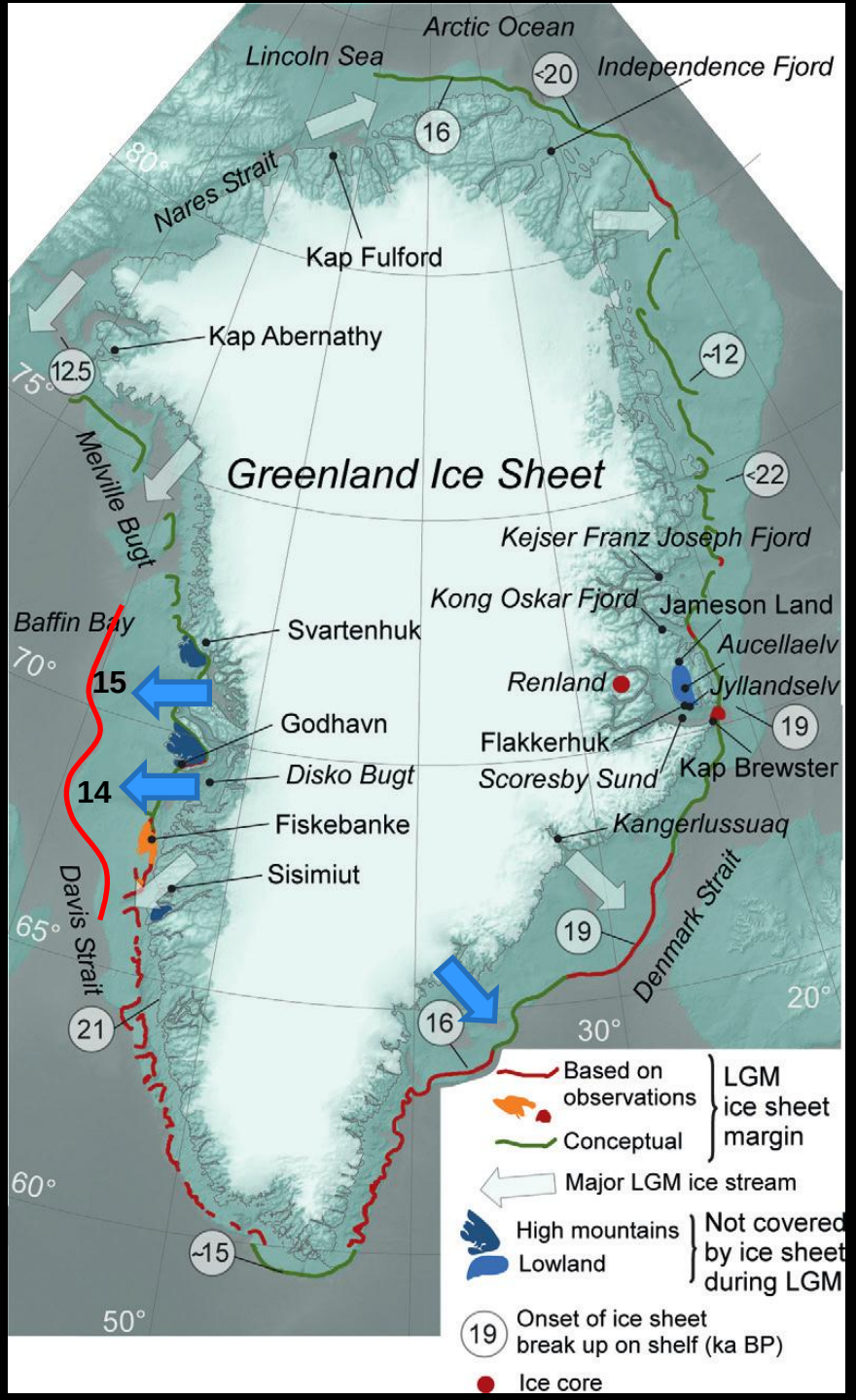
- ***LGM/Deglacial history***

- GrIS at the shelf edge with ice streams in large cross shelf troughs separated by inter-stream areas on shallower shelf

- Two stage deglacial history

- Stage 1: Deglacial from shelf edge at ~19-16ka BP but many sectors of the shelf have no data.

Funder et al., 2011; Simpson et al., 2009



- ***LGM/Deglacial history***

- Stage 2: 14.4 – 9.5 Ka BP for onset of melting of land-based ice

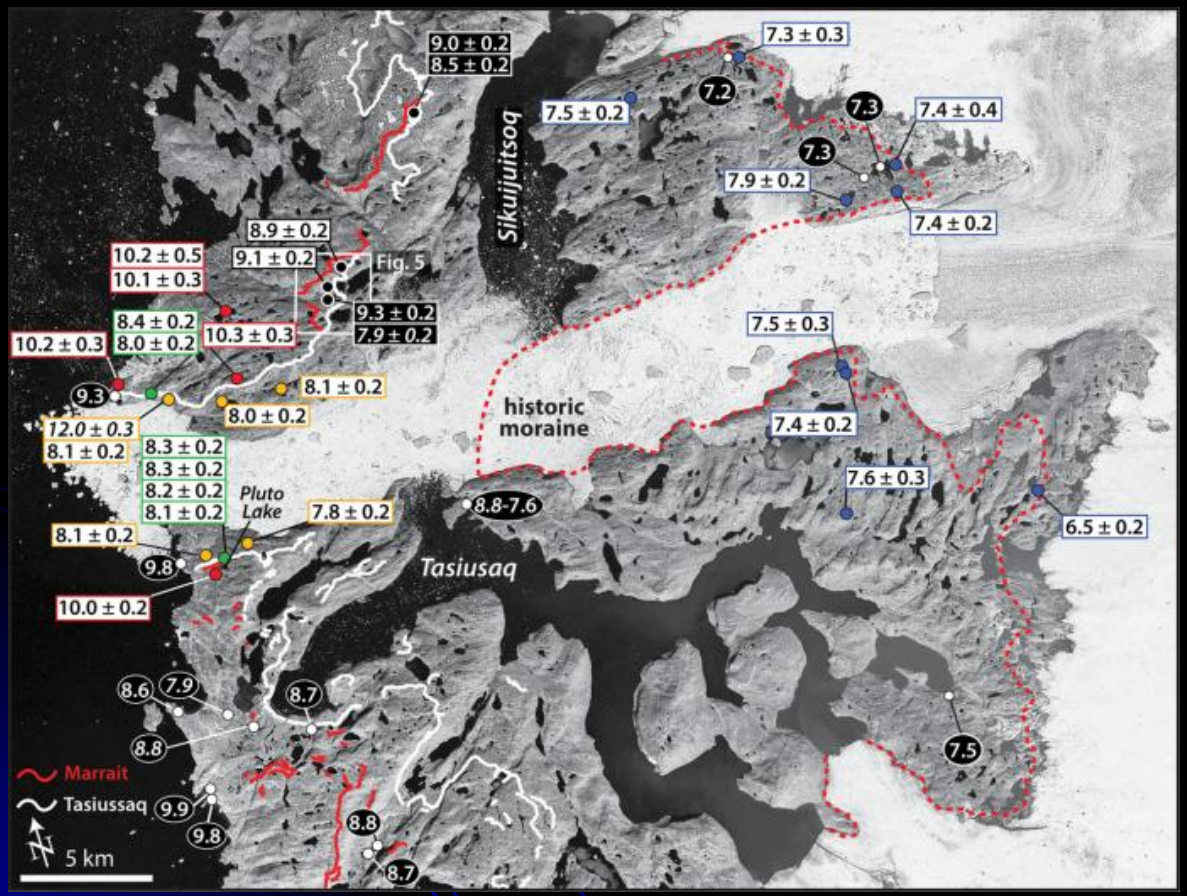
- prominent moraine stages mark temporary standstills and minor re-advances (e.g Fjord stage moraines)

- modelled minimum Holocene extent of the ice sheet

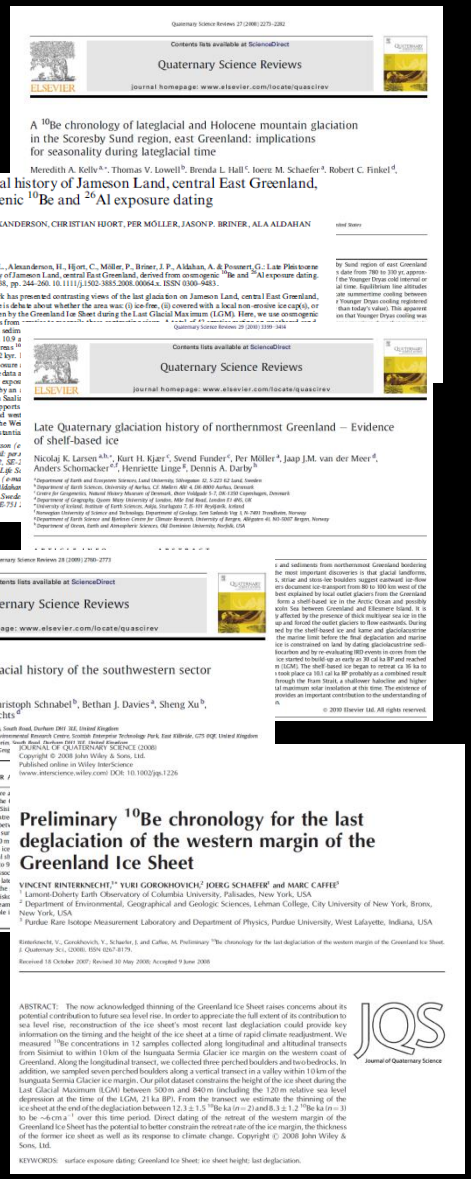
Funder et al., 2011; Simpson et al., 2009

- **LGM/Deglacial history**

  - The last decade has seen new high resolution records emerging from a number of areas



Young et al. 2013



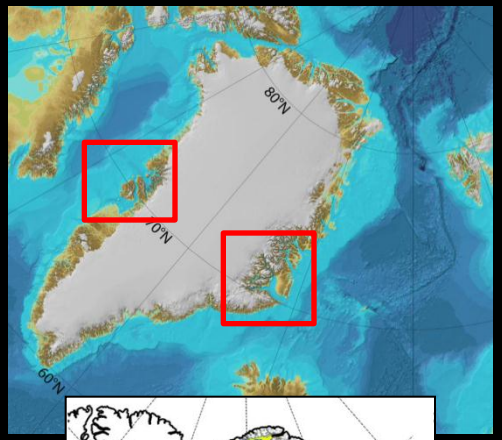
- **Marine-terminating Ice streams: *Pathways***

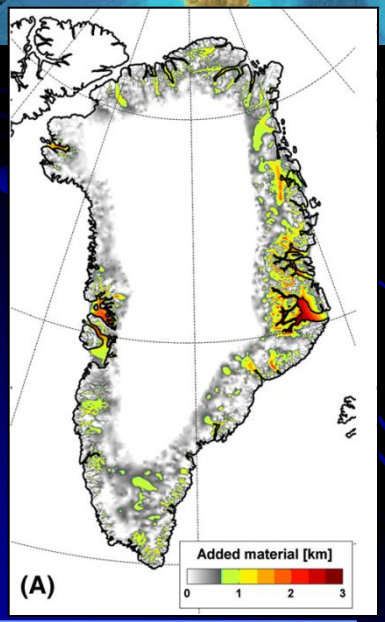
  - Numerous troughs on the shelf probably harboured ice streams
  - These flux gates controlled ice sheet discharge to Baffin Bay/North Atlantic and interacted with the ocean.
  - LGM dynamics poorly constrained.
  - Deglacial behaviour only partially understood with sea-level rise, insolation, increasing air/ocean temps and topography all possible forcing mechanisms.

GEBCO data;
image Martin Margold

- **Ice streams: *Pathways***

- ***Controls on trough evolution***: inheritance of pre-Quaternary fluvial systems; geology; uplift; selective linear erosion
- Onset zones controlled by fjord configuration and flow convergence





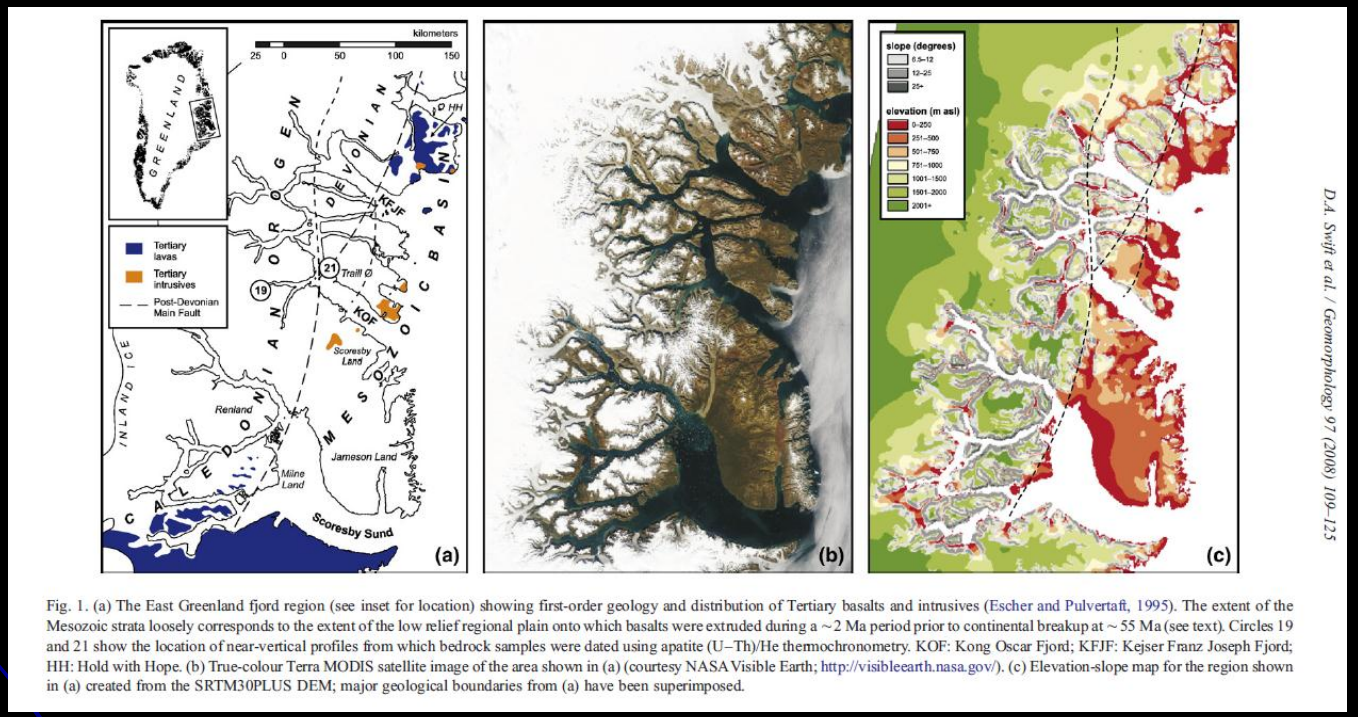


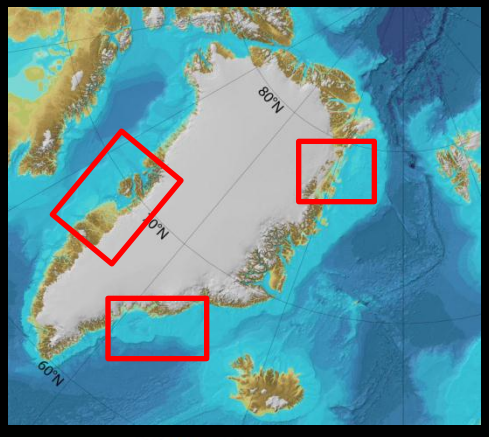
Fig. 1. (a) The East Greenland fjord region (see inset for location) showing first-order geology and distribution of Tertiary basalts and intrusives (Escher and Pulvertaft, 1995). The extent of the Mesozoic strata loosely corresponds to the extent of the low relief regional plain onto which basalts were extruded during a ~2 Ma period prior to continental breakup at ~55 Ma (see text). Circles 19 and 21 show the location of near-vertical profiles from which bedrock samples were dated using apatite (U–Th)/He thermochronometry. KOF: Kong Oscar Fjord; KFJF: Kejser Franz Joseph Fjord; HH: Hold with Hope. (b) True-colour Terra MODIS satellite image of the area shown in (a) (courtesy NASA Visible Earth; http://visibleearth.nasa.gov/). (c) Elevation-slope map for the region shown in (a) created from the SRTM30PLUS DEM; major geological boundaries from (a) have been superimposed.

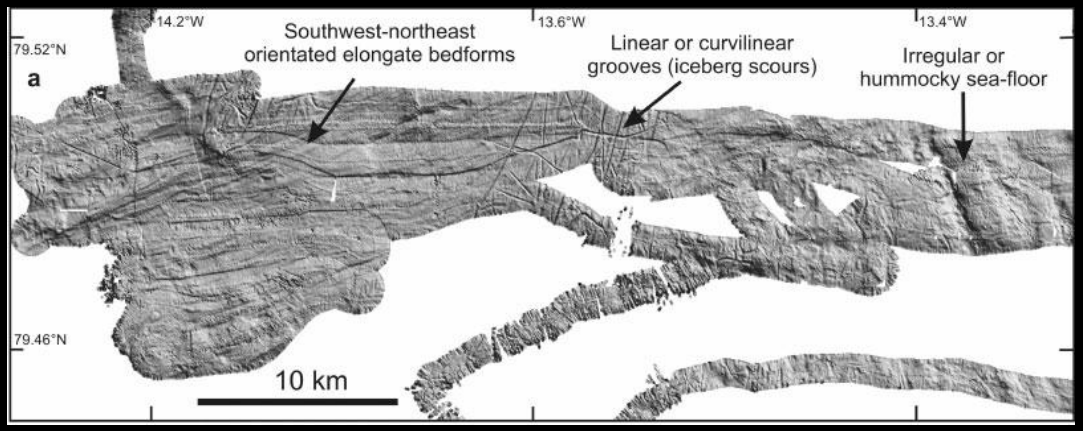
D.A. Swift et al. / Geomorphology 97 (2008) 109–125

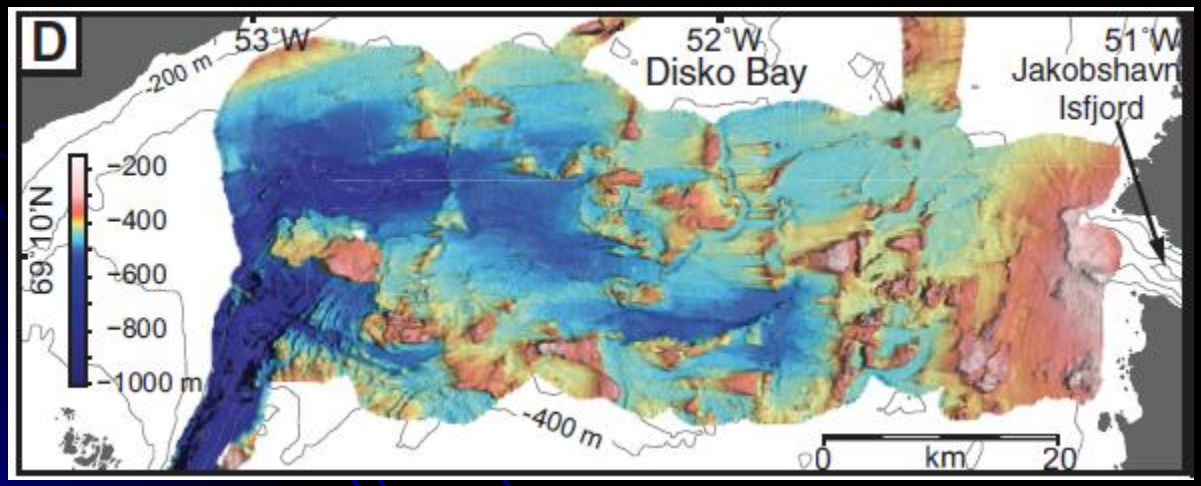
Swift et al., 2008; Medvedev et a. 2013

- **Ice streams - *Pathways***

- Despite a lack of coverage several large trough systems are now known to have ice stream imprints from the last glacial cycle



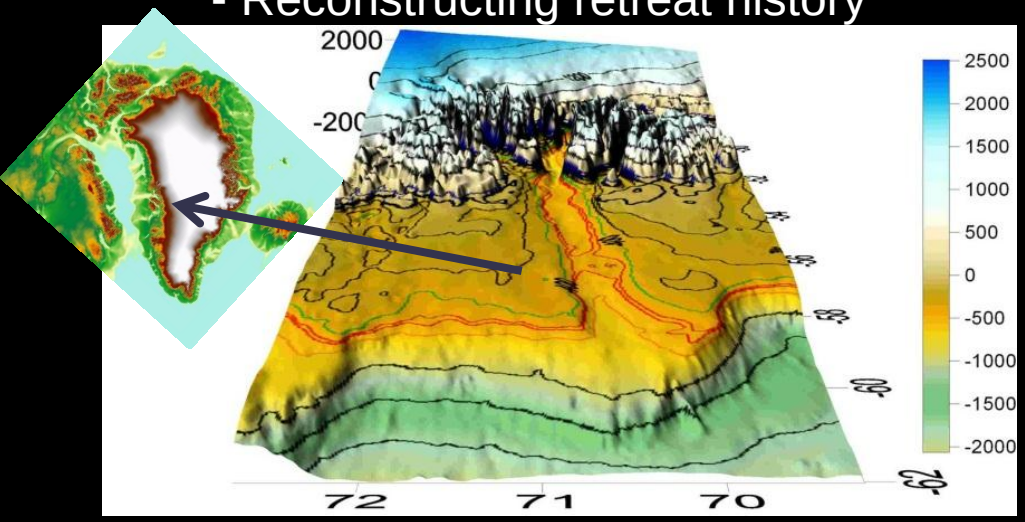


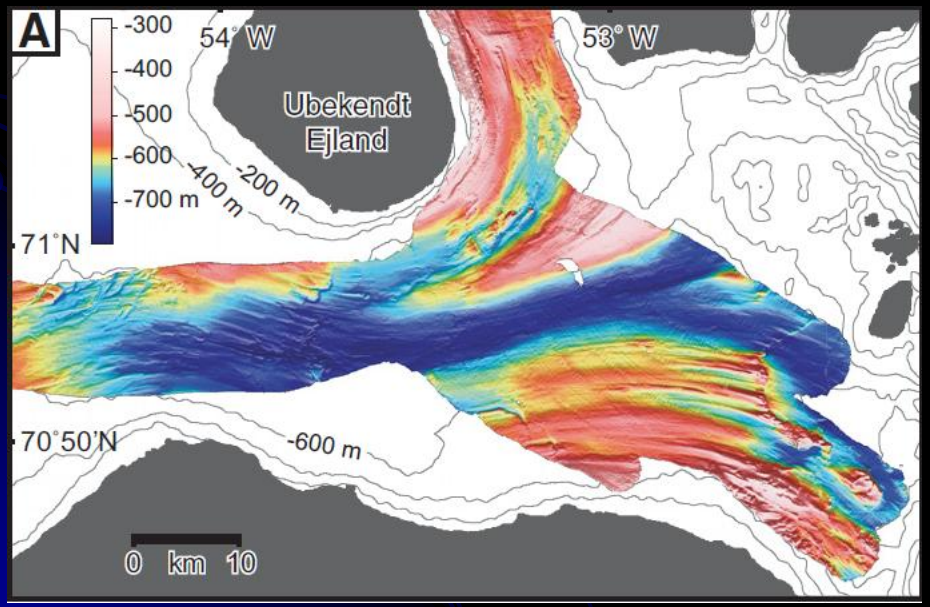


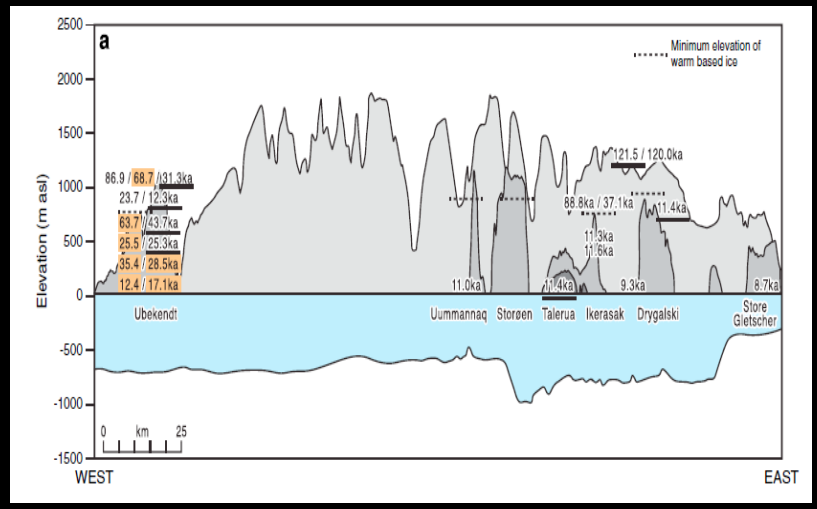
Ó Cofaigh et al., 2013; Roberts and Long, 2005; Winklemann et al., 2010; Evans et al., 2010; Dowdeswell et al. 2010

- ***Ice streams - Deglacial behaviour***

  - E.g.1: The Uummannaq ice stream (UISS)
  - Reconstructing retreat history





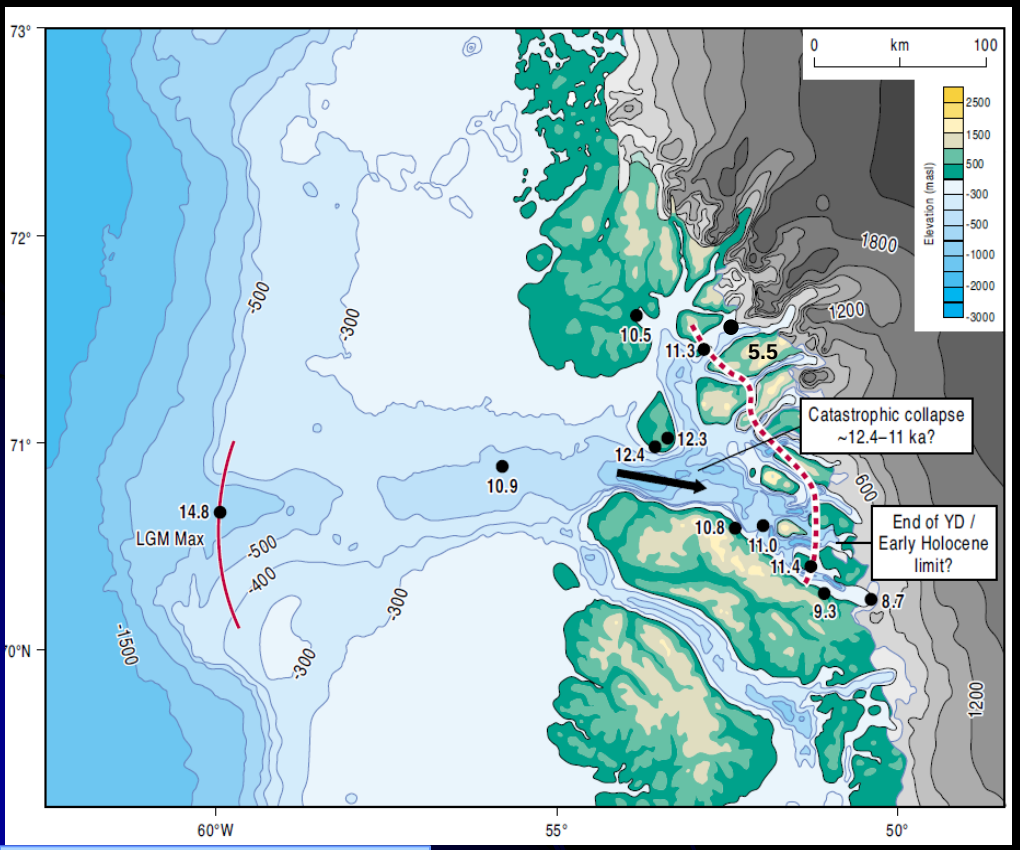


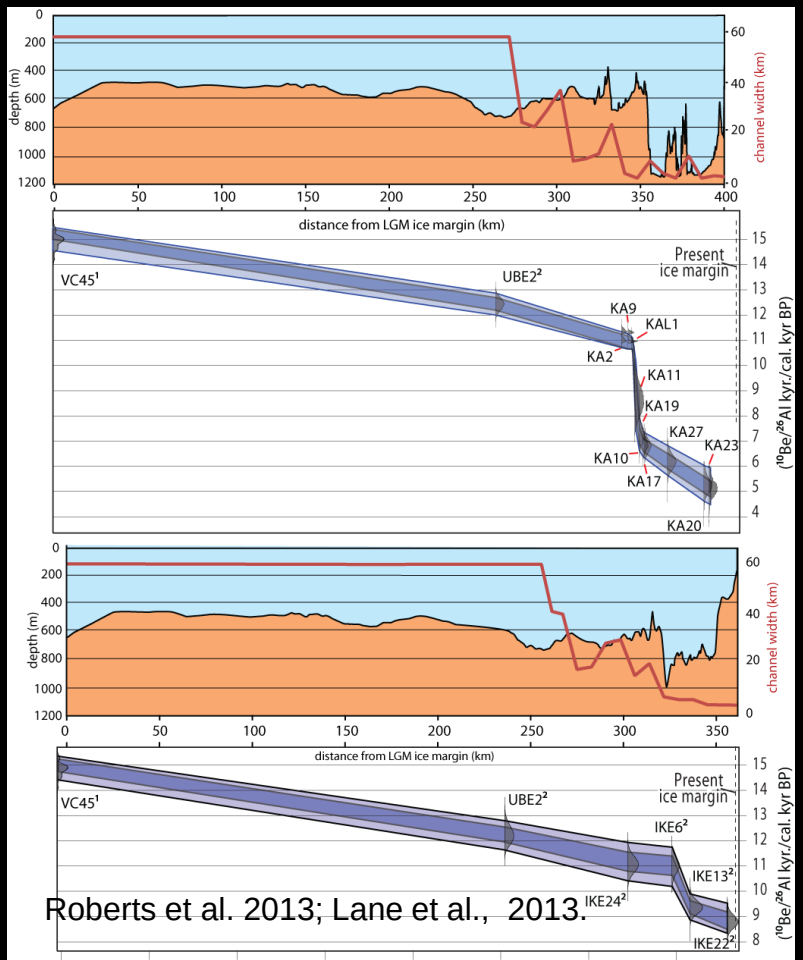
Roberts et al. 2013; O Cofaigh et al., 2013.

- ***Ice streams - Deglacial behaviour***

  - **E.g. 1: UISS**

1. ***Retreat from continental shelf: 14.8 – 12.4 ka BP***
2. ***Unzipping of onset zone: 12.4 – 11.0 ka BP (YD extent?)***
3. ***South feeder zone stabilises at fjord mouths 11.4 - 9ka BP; retreats inland of present margin by 8.7 ka BP***
4. ***North feeder zone stabilises at fjord mouths 11.3 - 5.5 ka BP***



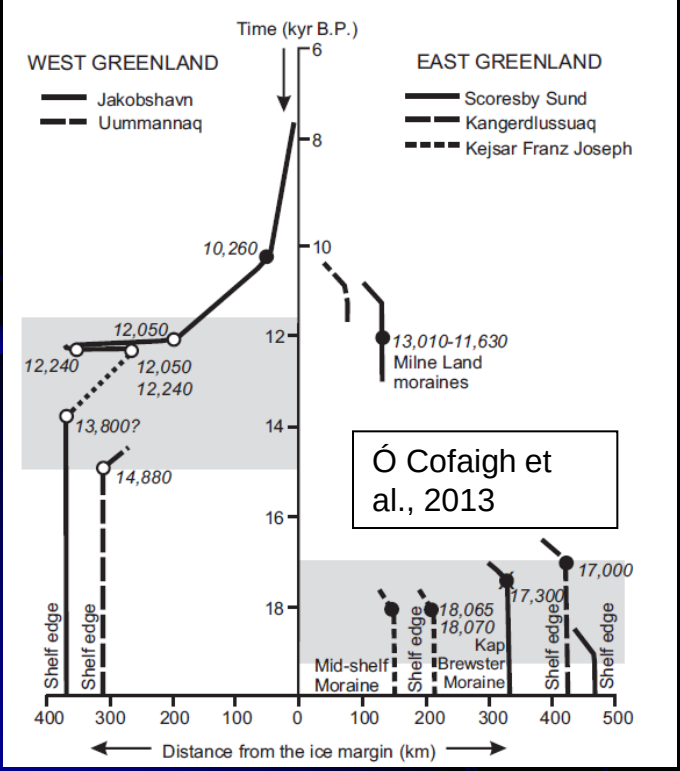


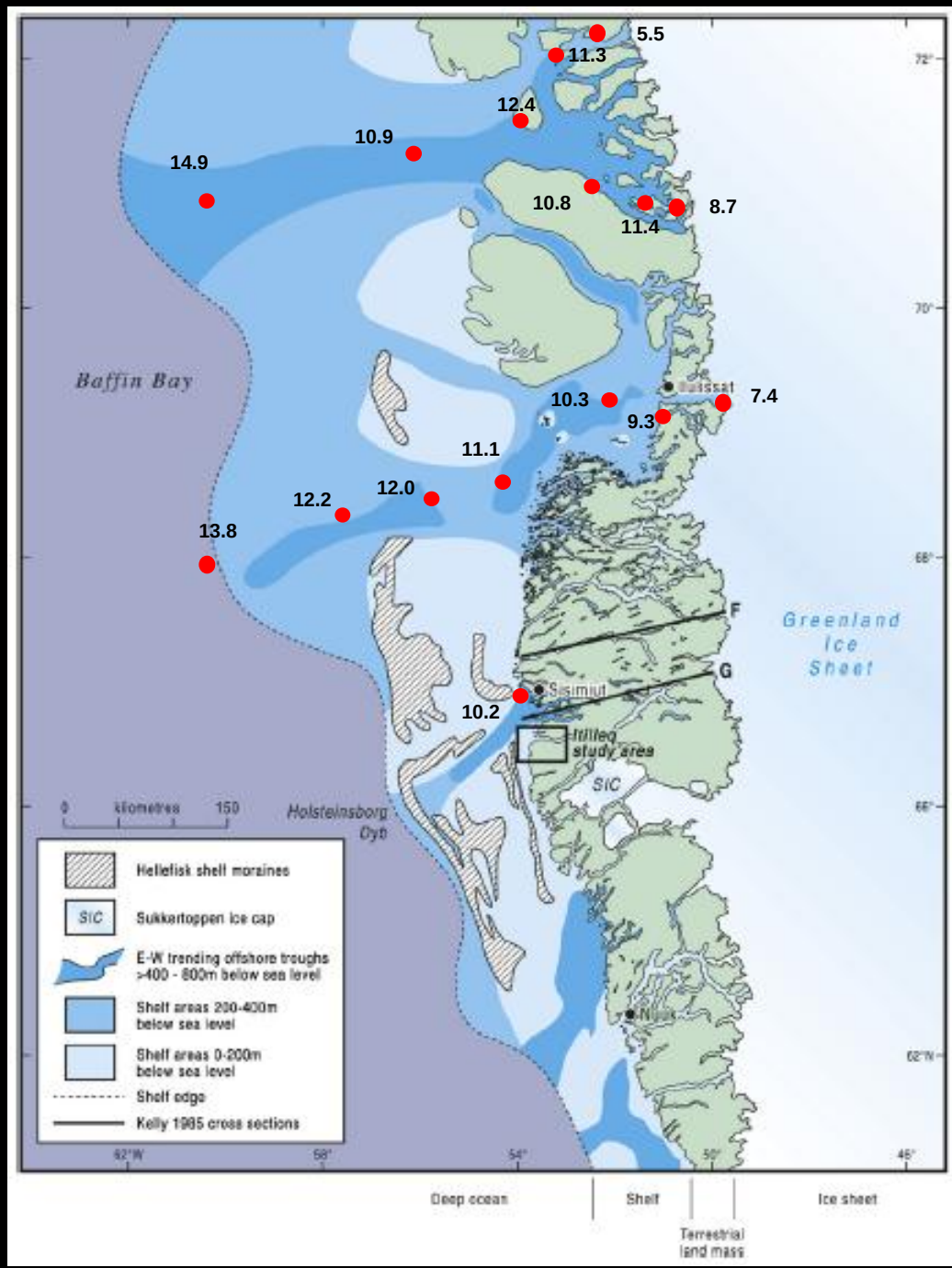
Roberts et al. 2013; Lane et al., 2013.

- ***Ice streams - Deglacial behaviour***

- E.g. 2: Jakobshavn Isbrae (JI)

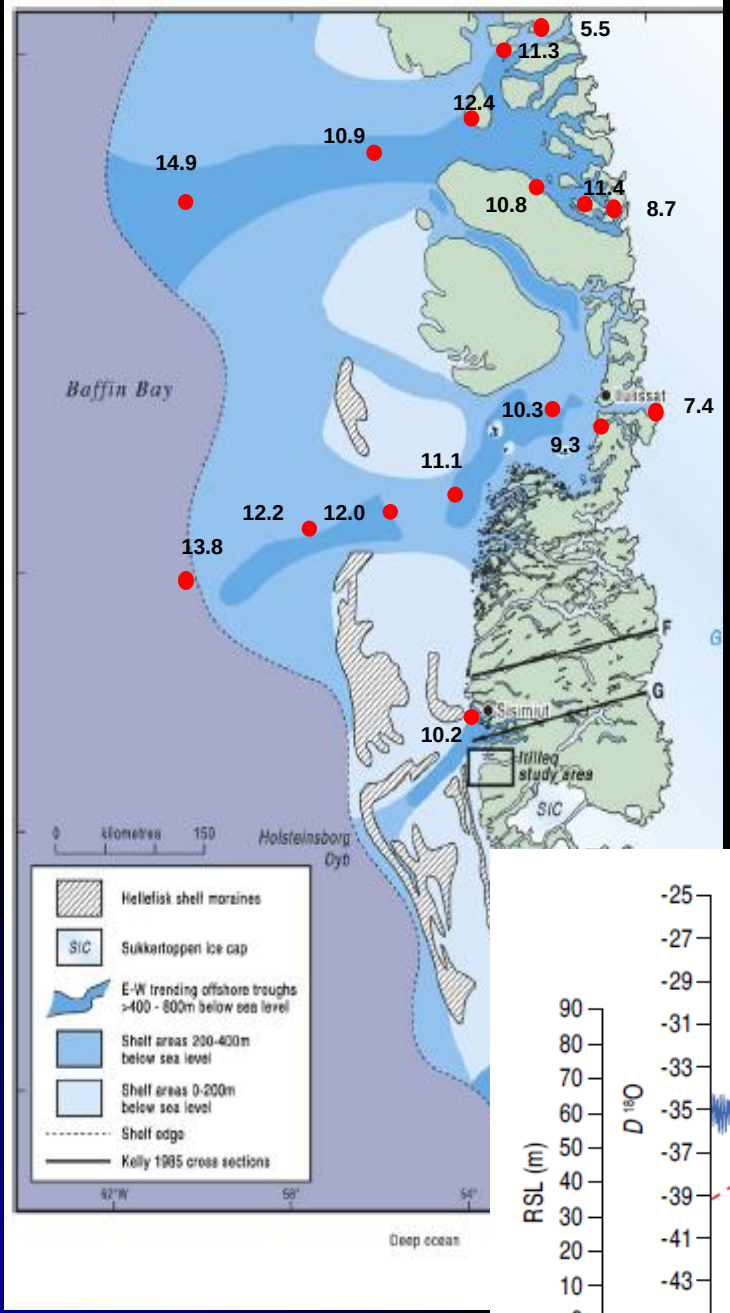
- **13.8 – 12.0**: ice still on the mid-shelf. YD re-advance?
- **11.1- 10.3**: retreat mid to inner shelf
- **10.2 – 8.2**: Stabilises outer Isfjord
- **7.4 - 6.5**: back at present margin

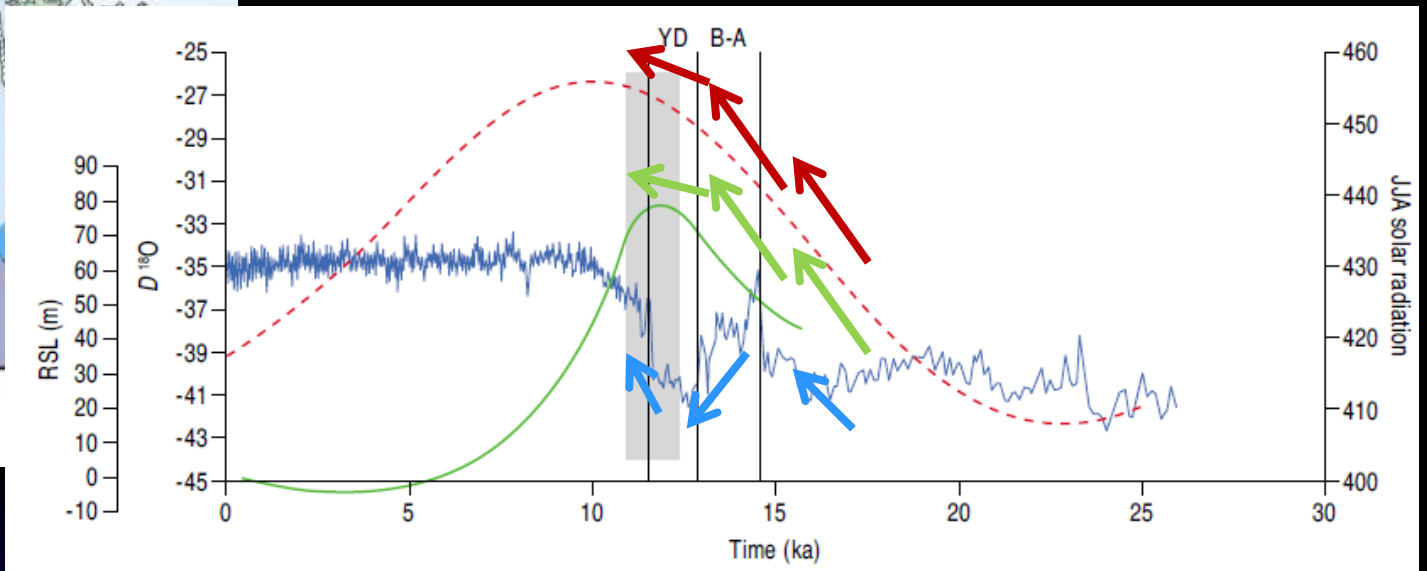




Ice streams -Forcing Mechanisms

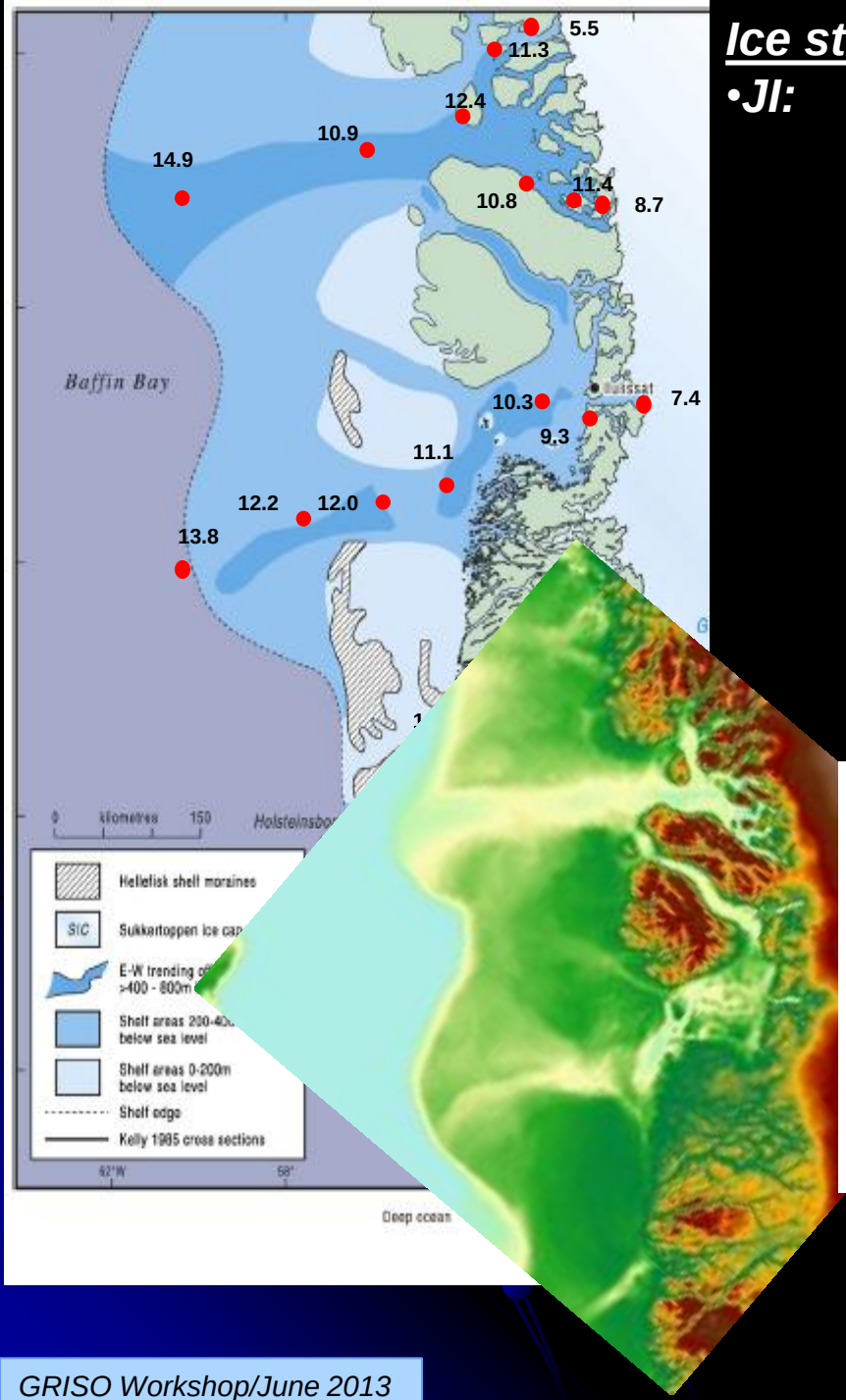
- Deglacial histories of UIIS and JI are asynchronous
- ***UISS:*** -16.0 and 14.5: Early deglaciation from the shelf edge – ↑ insolation, air temp + eustatic sea-level rise.
  -14.5 -12.4: – air temp falls but insolation + SL rise + bathymetry drive continued retreat
  - 12.0 and 11.0: Deglacial to inner fjords coincides with peak sea-level rise + post YD ↑ in air temp and insolation
  - 11.0 – 5.5: inner fjord topography critical in moderating ice margin position as Holocene air temps peaked.

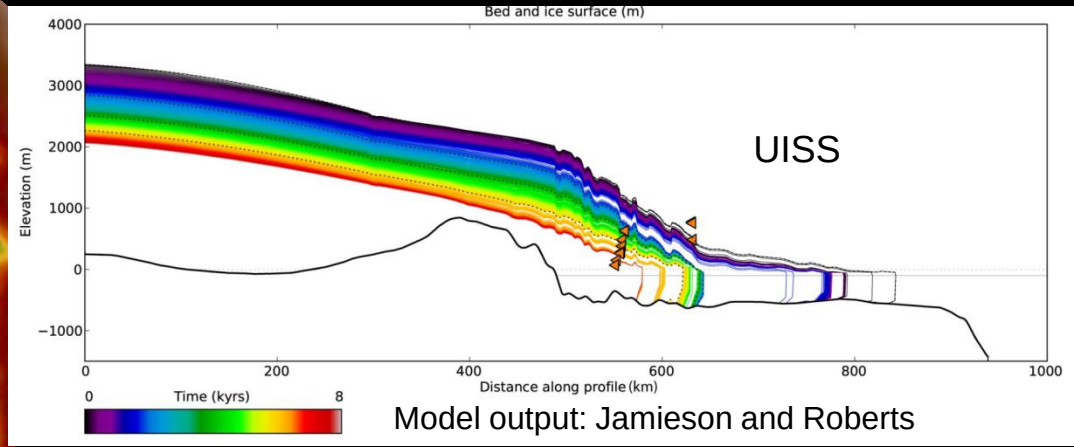




Ice streams - Forcing Mechanisms

- ***JI:*** ***Similar regional forcing mechanisms to UISS but later deglaciation from the shelf***
  - -13.8 -12.0: Ice remains on the mid shelf at start of YD. Trough constriction/pinning?
  - 12.0 and 11.0: Late deglacial to inner/mid shelf. Trough constriction/pinning?
  - 11.0 – 9.3: retreat across Disko Bugt well in to the Late Holocene. Pinning/Shallow embayment?
  - 9.3 – 7.4: Isfjord topy also moderates ice margin position as Holocene air temps peaked + SL↓.





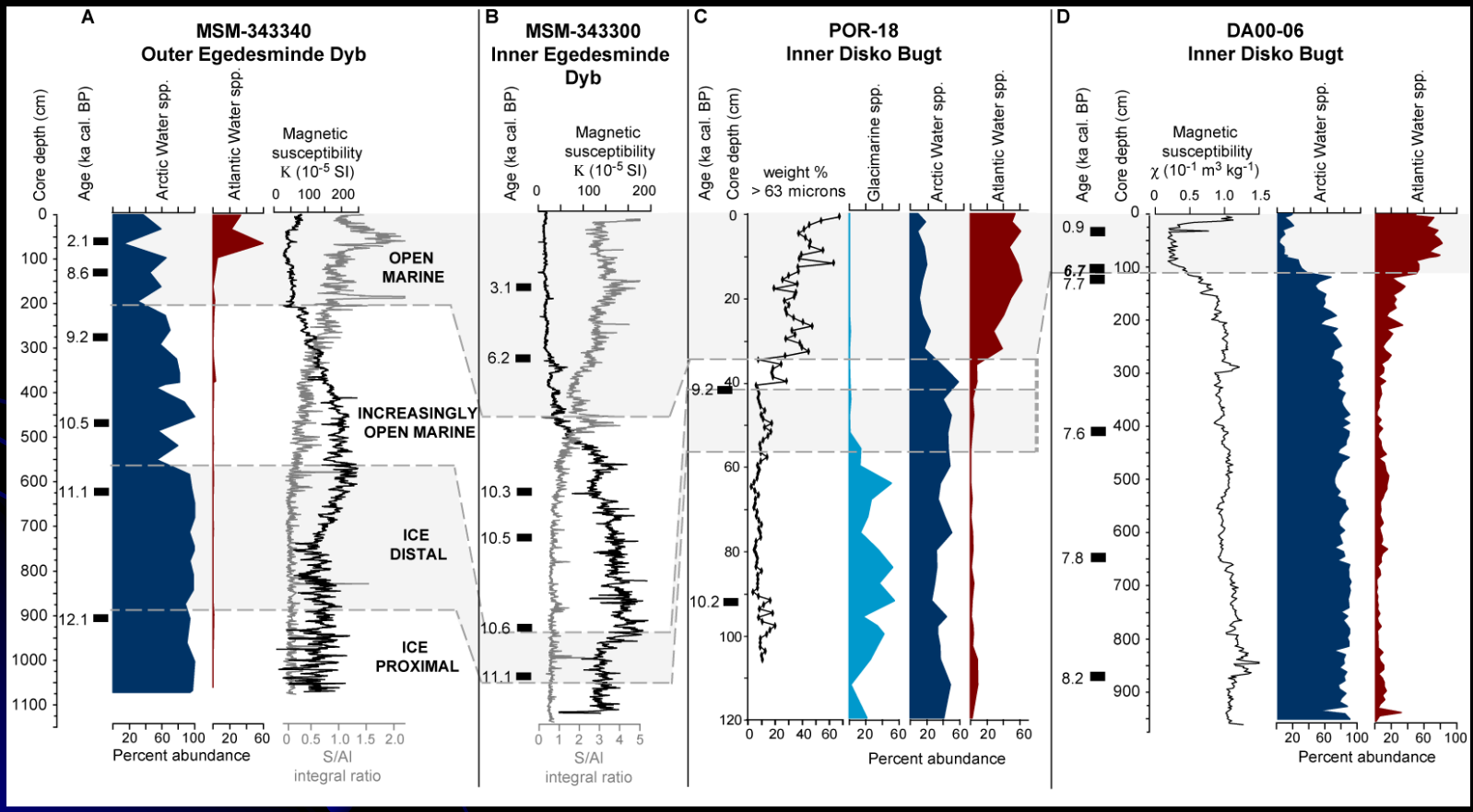
Model output: Jamieson and Roberts

- Undertsanding topographic control on marine margin stability is critical when considering forcing mechanisms

Ice streams - Forcing Mechanisms

- Ocean forcing?

- Disko Bugt/Jakobshavn Isbrae
  - AW did not penetrate in the inner shelf until ~ 9.2 ka BP
  - not involved in early deglaciation?
  - Meltwater masking?

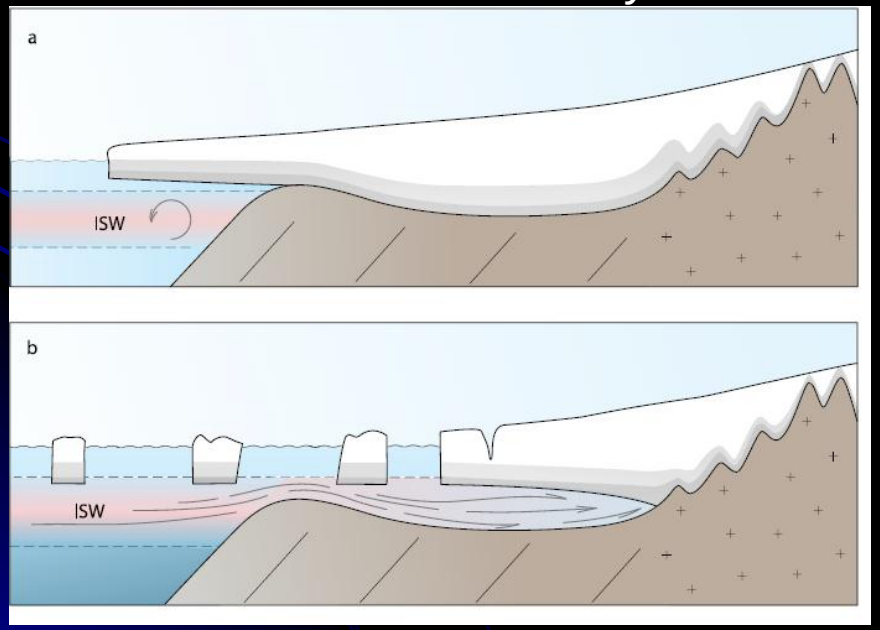


Lloyd et al., 2005; McCarthy 2010

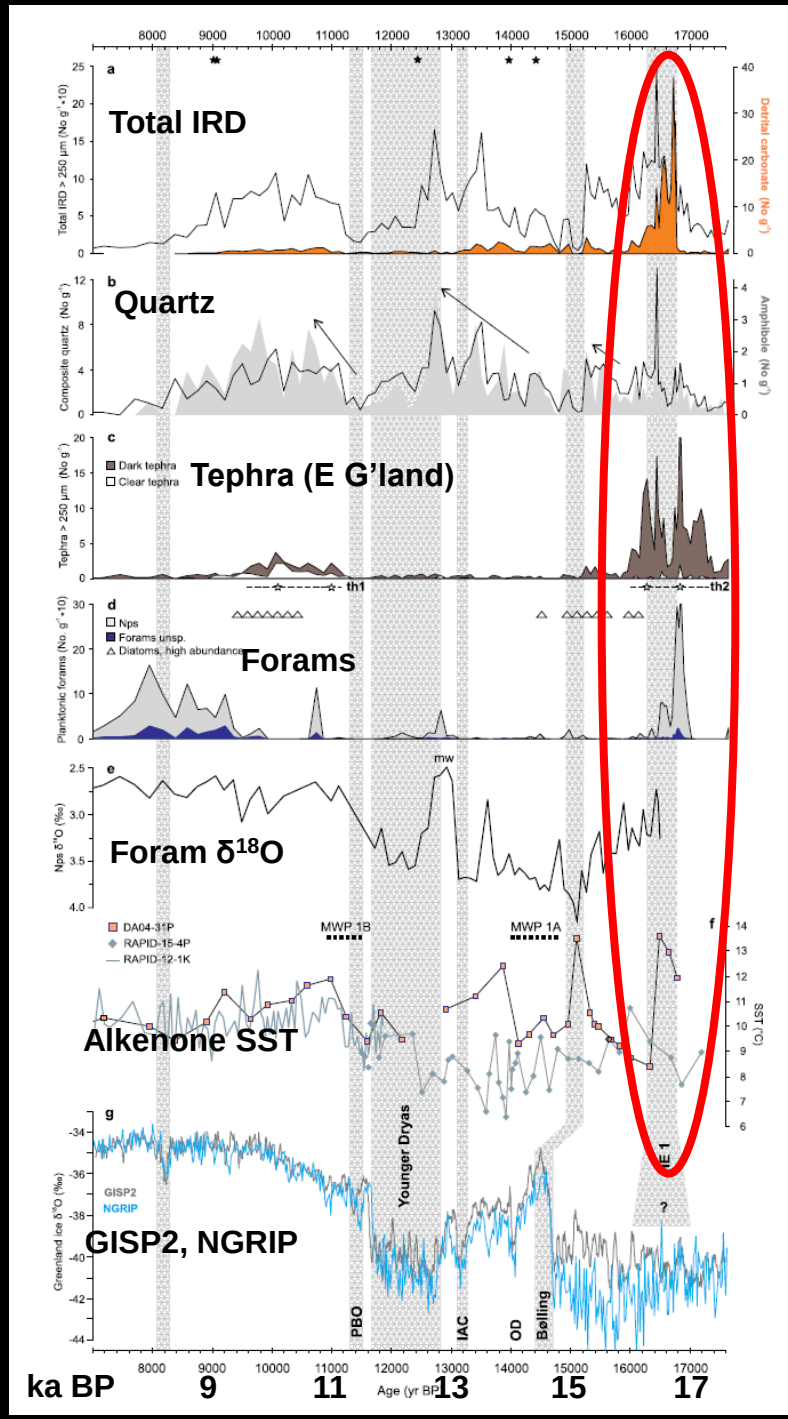
Forcing Mechanisms – Wider context

Early Ocean forcing?

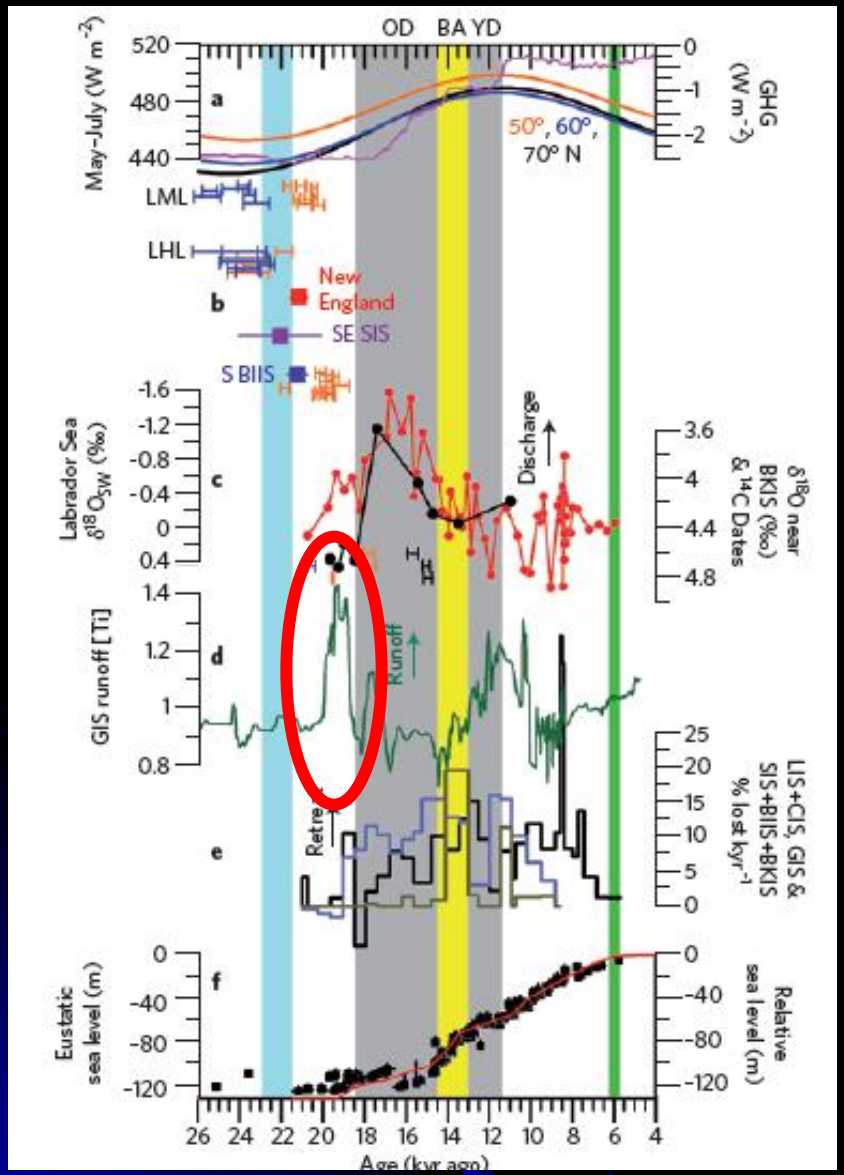
- Jennings et al. (2006) + Knutz et al. (2011) suggest early deglaciation of the GrIS was prompted by the incursion of ISW on to shelf.
- ^{18}O, IRD, alkenone and foram records show ↑ ISW during the early deglacial, Bølling and Allerød
- Ice retreat from the shelf started in the SE and migrated to SW Greenland- clockwise migration of EGC and IC.
- Knudsen et al. (2008) report AW influence as early as 12.3 ka BP in N Baffin Bay.



Knutz et al. (2011)



Forcing Mechanisms – Wider context



Early Boreal summer insolation

(Carlson and Winsor, 2012)

- Subsurface NA ocean temperatures were important for the onset of marine-based ice-sheet retreat, but southern GrIS runoff records show that ↑ boreal summer insolation was also critical in driving early deglaciation between ~20 - 18 ka BP onwards.

(Carlson and Winsor, 2012)

***Challenges*?**

- *Improved spatial data coverage on the shelf including ice stream troughs and inter-stream areas to test linear v non linear behaviour*
- *Constraining and quantifying local records of ocean temp in troughs*
- *Integrated proxy records from east to west to test phasing of retreat*
- *Improved data/model integration and sensitivity testing*
- *Reducing error ranges (geochronology)*
- ……..
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Thank you.....