Subglacial conditions and ice flow across the Weddell Sea sector of Antarctica: synthesis from 2010/11 aerogeophysical survey

Robert G. Bingham[1], Neil Ross[2], Hugh F.J. Corr[3], Fausto Ferraccioli[3], Tom A. Jordan[3], Anne M. Le Brocq[4], David M. Rippin[5], Kathryn C. Rose[6], Andrew P. Wright[4], David W. Ashmore[7] and Martin J. Siegert[8]

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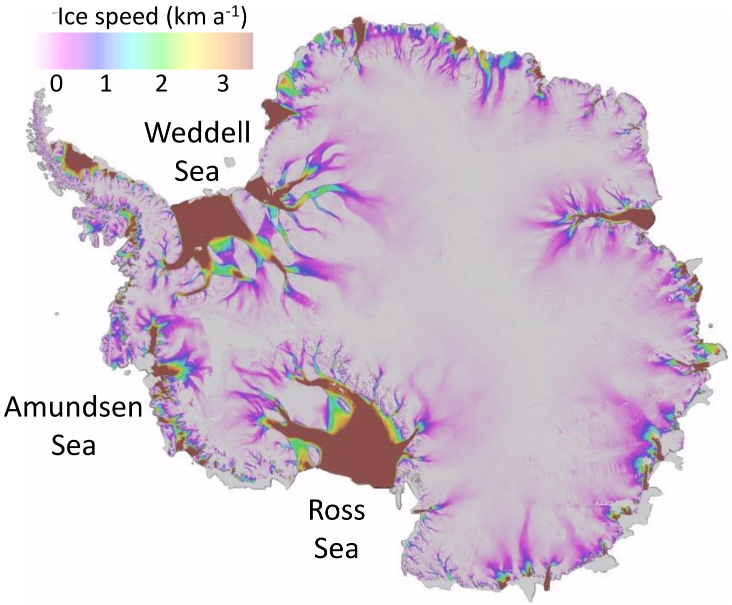
[2] School of Geography Politics and Sociology, Newcastle University
[3] British Antarctic Survey, Natural Environment Research Council, Cambridge
[4] Geography, College of Life and Environmental Sciences, University of Exeter
[5] Environment Department, University of York
[6] Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol
[7] School of Geosciences, University of Aberdeen
[8] Grantham Institute, Imperial College London

Photo: David Leatherdale

With thanks to the Operations and Logistics staff of British Antarctic Survey, Carl Robinson (Airborne Survey Engineer), Ian Potten, Doug Cochrane (Pilots), Mark Oostlander (Air Mechanic) & all the additional contributors to the various science outputs from this work

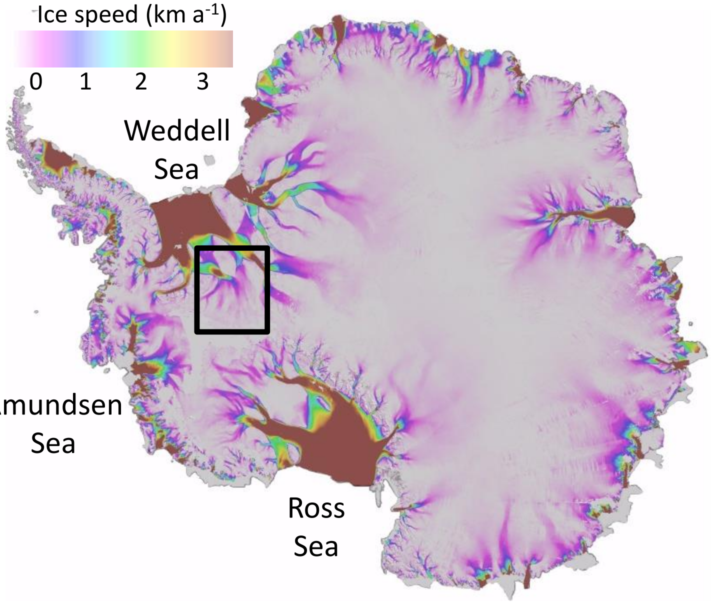


Introduction

- Extensive aerogeophysical surveys across the Ross sector (1990s onwards) and Amundsen sector (mid-2000s onwards) have enhanced understanding of ice flow and subglacial properties.

- Broadly speaking, we know that Ross (Siple) ice streams overlie relatively flat, sediment-rich landscape, and can migrate spatially… while Amundsen ice streams (e.g. PIG, Thwaites) are spatially confined and generally steered by features of geological origin (rifts?)

- **How does ice behaviour in the Weddell Sea sector compare with that in the Ross and Amundsen sectors?**



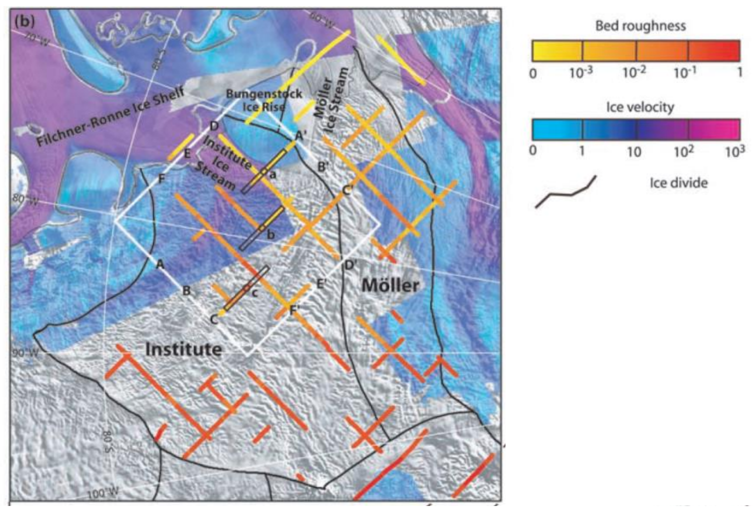
Introduction

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L21504, doi:10.1029/2007GL031483, 2007

Click Here for Full Article

Radar-derived bed roughness characterization of Institute and Möller ice streams, West Antarctica, and comparison with Siple Coast ice streams

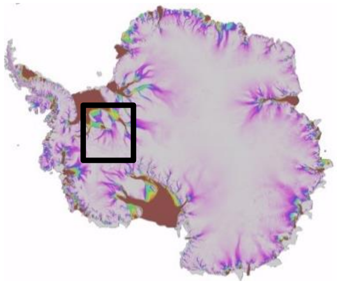
Robert G. Bingham[1,2] and Martin J. Siegert[3]

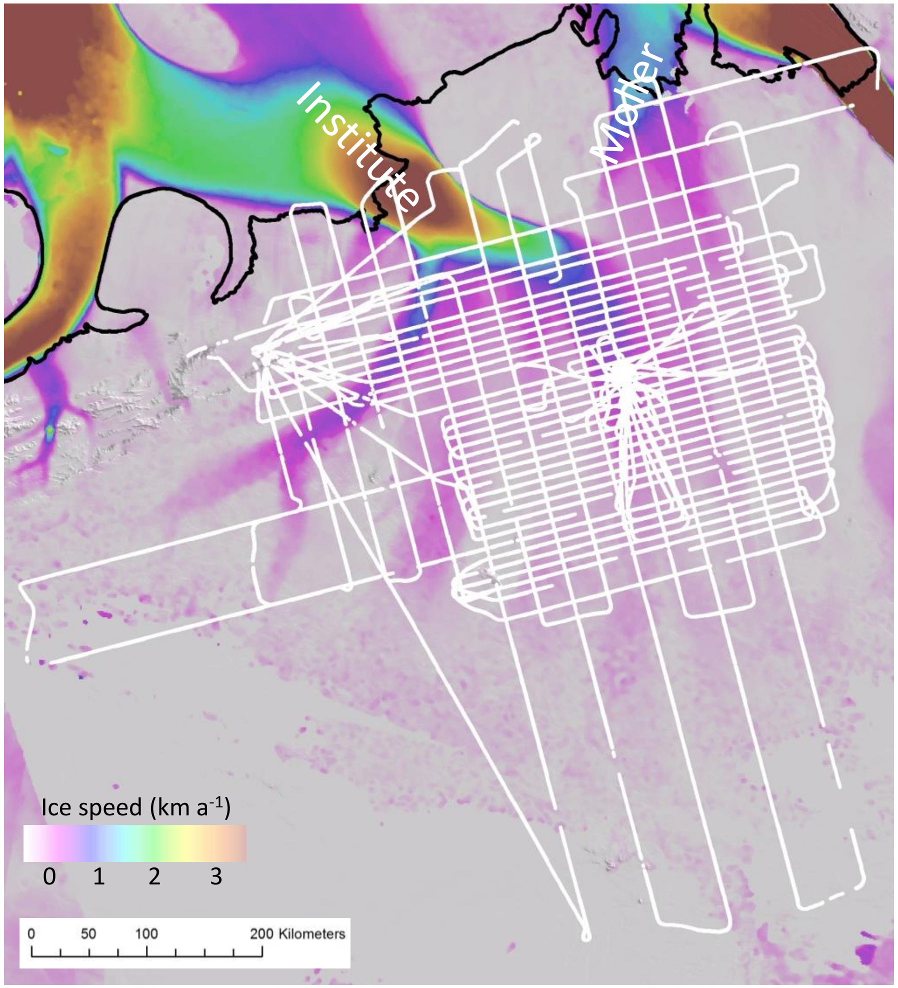


Hypothesis: "Institute and Möller Ice Streams are underlain by weak marine sediments, which were deposited when the WAIS was less extensive than today, and which can affect ice flow variability in a manner similar to that observed across the Siple Coast."

NERC/AFI NE/G013071/1 (2010-2014)
has been addressing this hypothesis

Objectives and Survey



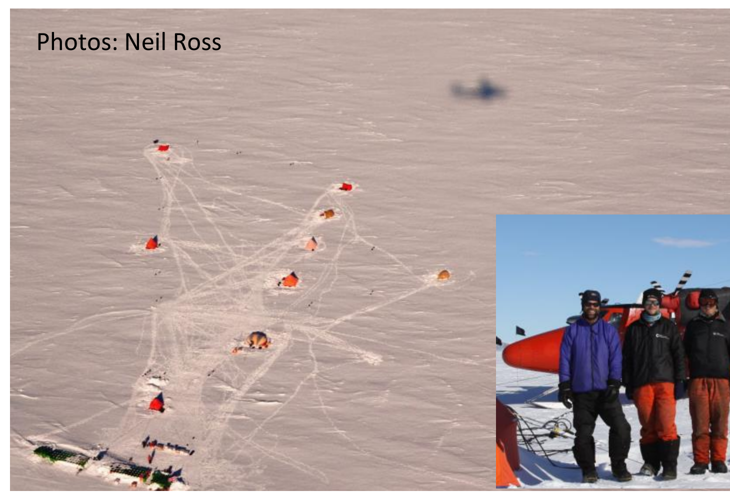


2010/11 aerogeophysical survey:

150 MHz radar: Subglacial topography, Water, englacial layers
Aeromagnetics: Rock type, structural boundaries
Gravimeter: Geological structures, crustal thickness
Scanning laser: Surface elevation

- 2 field camps
  - Patriot Hills
  - Institute E2 (site of "dynamic lake" from B. Smith et al. (2009; *J. Glac.*))
- 25,000 line km
  - Along track soundings every ~10 m
  - Longitudinal line spacing: 7.5 km
  - Transverse line spacing (tie lines): 25 km

Photos: Neil Ross



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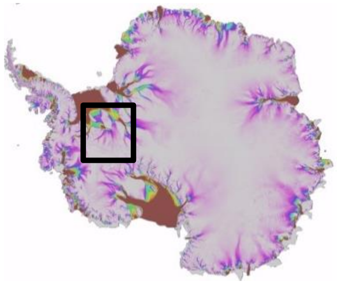
Outputs

- 12 papers published or in review, addressing:
    1. The setting: subglacial topography, roughness, geology
    2. Ice flow history recorded by surface & subsurface features, englacial layering
    3. Current dynamism: subglacial hydrology
    4. The future? Modelling of the region's sensitivity

Photo: Neil Ross

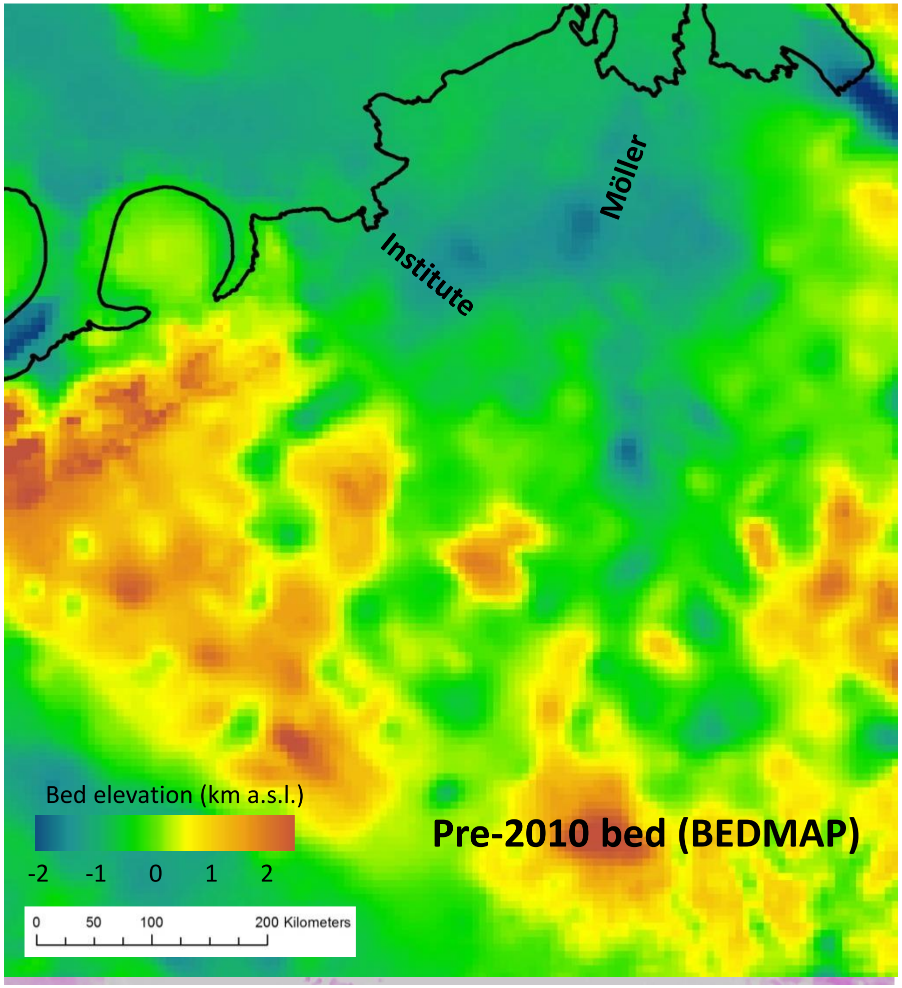
1. Setting: topography, roughness, geology



nature geoscience
LETTERS
PUBLISHED ONLINE: 9 MAY 2012 | DOI: 10.1038/NGEO1468

Steep reverse bed slope at the grounding line of the Weddell Sea sector in West Antarctica

Neil Ross[1]*, Robert G. Bingham[2], Hugh F. J. Corr[3], Fausto Ferraccioli[3], Tom A. Jordan[3], Anne Le Brocq[4], David M. Rippin[5], Duncan Young[6], Donald D. Blankenship[6] and Martin J. Siegert[1]*



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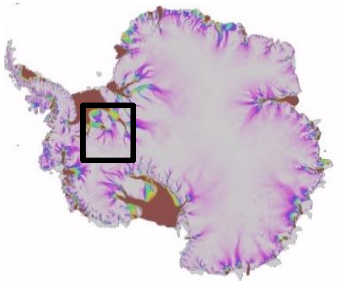

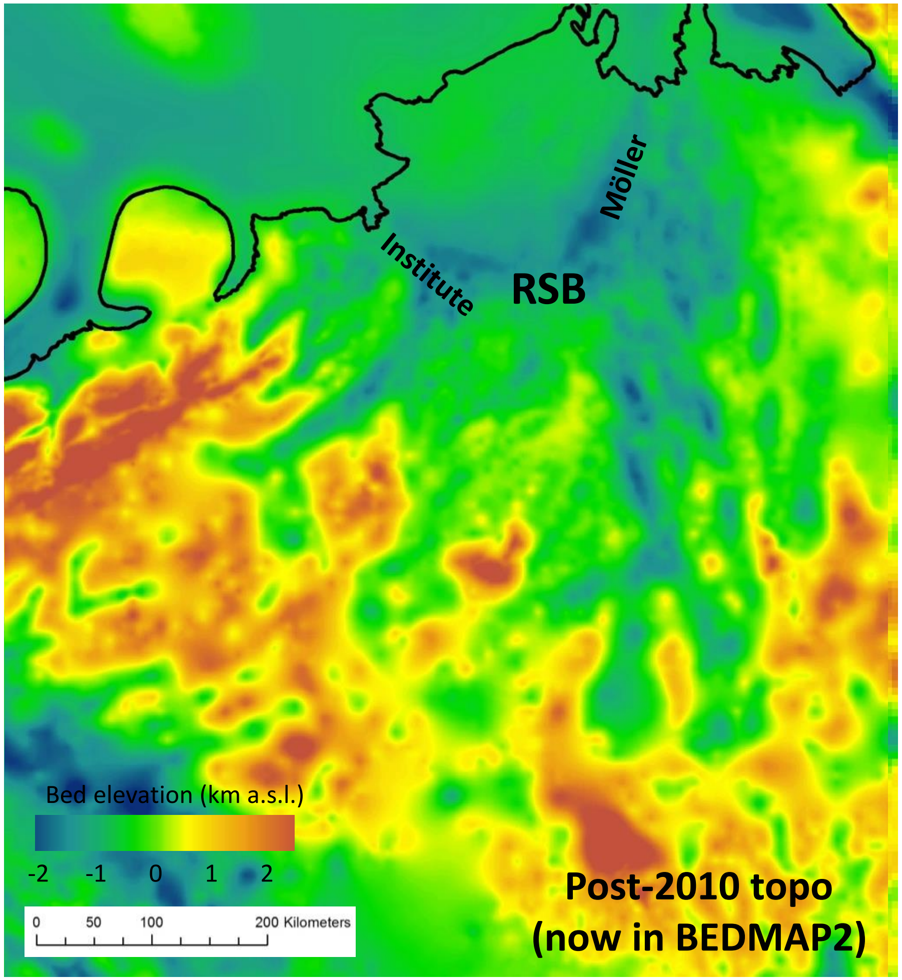

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- New coverage clearly images deep subglacial basin (Robin Subglacial Basin; RSB) extending 200 km inland of grounding line.

- RSB floor is flat and smooth, and much of it is reverse sloping – leaving it vulnerable to marine ice-sheet instability.

* c.f. suggestion of Hellmer et al. (2012; *Nature*) of potential instability of Filchner-Ronne Ice Shelf

- Upstream of the basin:
    - Plateau dissected by well-defined "troughs"

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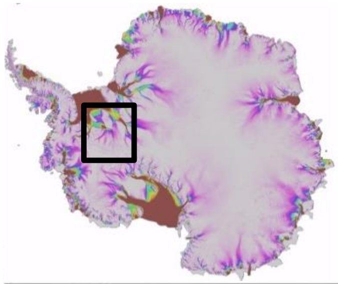
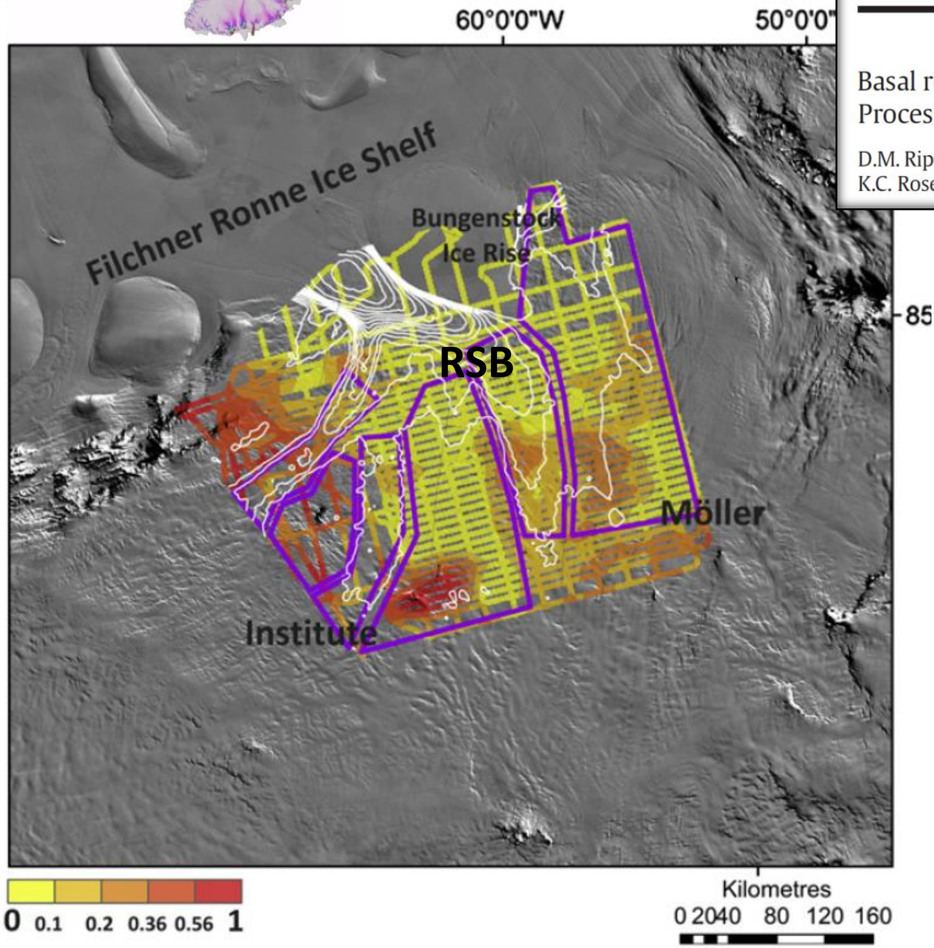
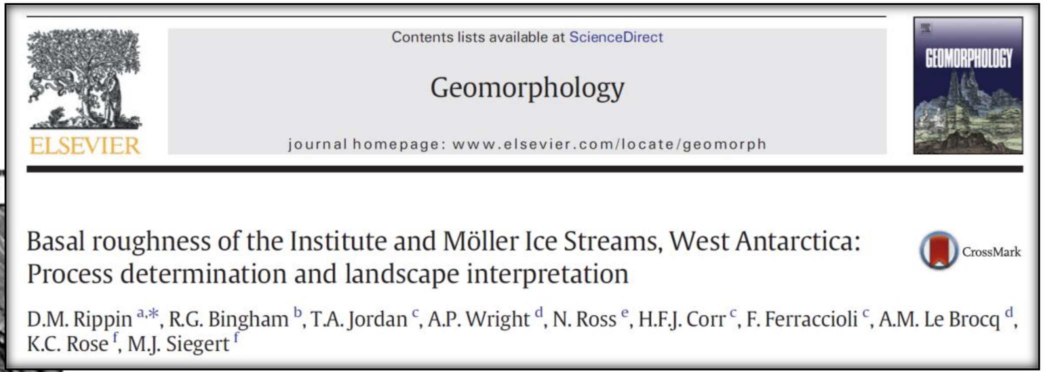
1. Setting: topography, **roughness**, geology







Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

ELSEVIER

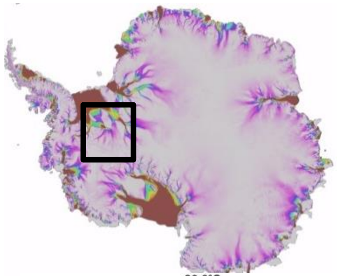
Basal roughness of the Institute and Möller Ice Streams, West Antarctica: Process determination and landscape interpretation

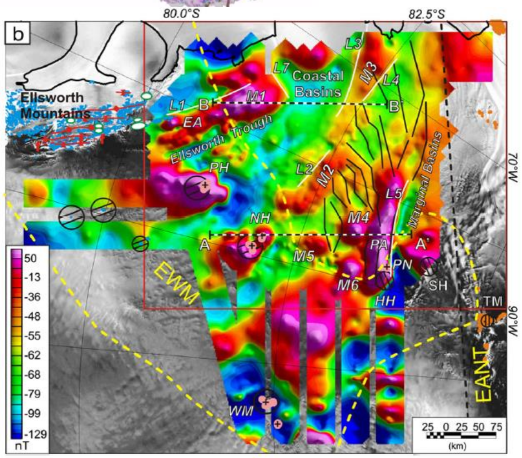
D.M. Rippin [a,*], R.G. Bingham [b], T.A. Jordan [c], A.P. Wright [d], N. Ross [e], H.F.J. Corr [c], F. Ferraccioli [c], A.M. Le Brocq [d], K.C. Rose [f], M.J. Siegert [f]

- New analysis of bed roughness shows:
  - Smooth bed across Robin Subglacial Basin
  - Mixed roughness upstream
    - Very rough mountainous landscape to north (Ellsworth Subglacial Highlands)
    - Further south, smooth topography across even much of upstream catchment, i.e. not in RSB

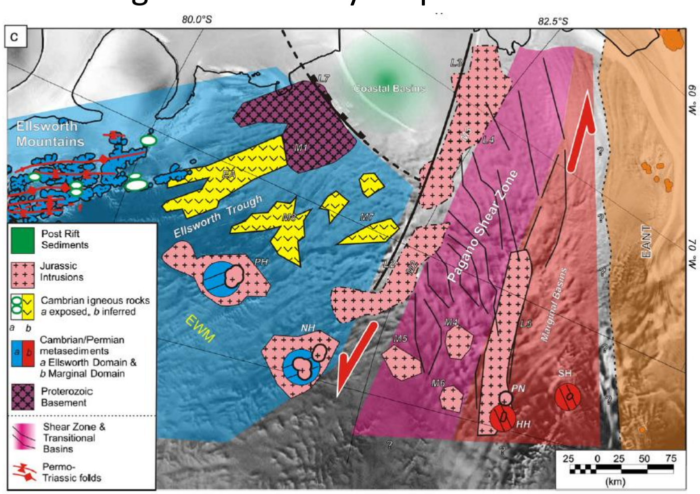
    (hence little restriction to ice-stream migration?)

1. Setting: topography, roughness, geology





Aeromagnetic anomaly map



Interpreted regional geology


Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Inland extent of the Weddell Sea Rift imaged by new aerogeophysical data

Tom A. Jordan [a,*], Fausto Ferraccioli [a], Neil Ross [b], Hugh F.J. Corr [a], Philip T. Leat [a], Rob G. Bingham [c], David M. Rippin [d], Anne le Brocq [e], Martin J. Siegert [f]

- Geologically, this is the region where West Antarctica meets East Antarctica
- Newly discovered strike-slip faulting and considerable shear *aligned with* direction of overlying Möller Ice Stream
- Hypothesised inland extension of Jurassic-origin Weddell Sea Rift

Outputs

- **12 papers published or in review, addressing:**

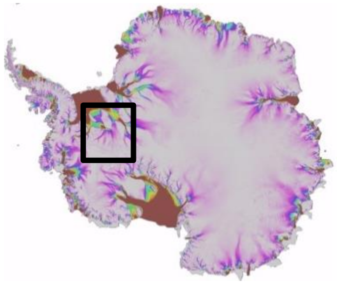
Summary of setting: The basin has characteristics similar both to the Ross Sector (smooth bed, possibility for ice-stream migration) and Amundsen sector (some degree of subglacial geological control)

2. **Ice flow history recorded by surface & subsurface features, englacial layering**

3. **Current dynamism: subglacial hydrology**

4. **The future? Modelling of the region's sensitivity**

Photo: Neil Ross



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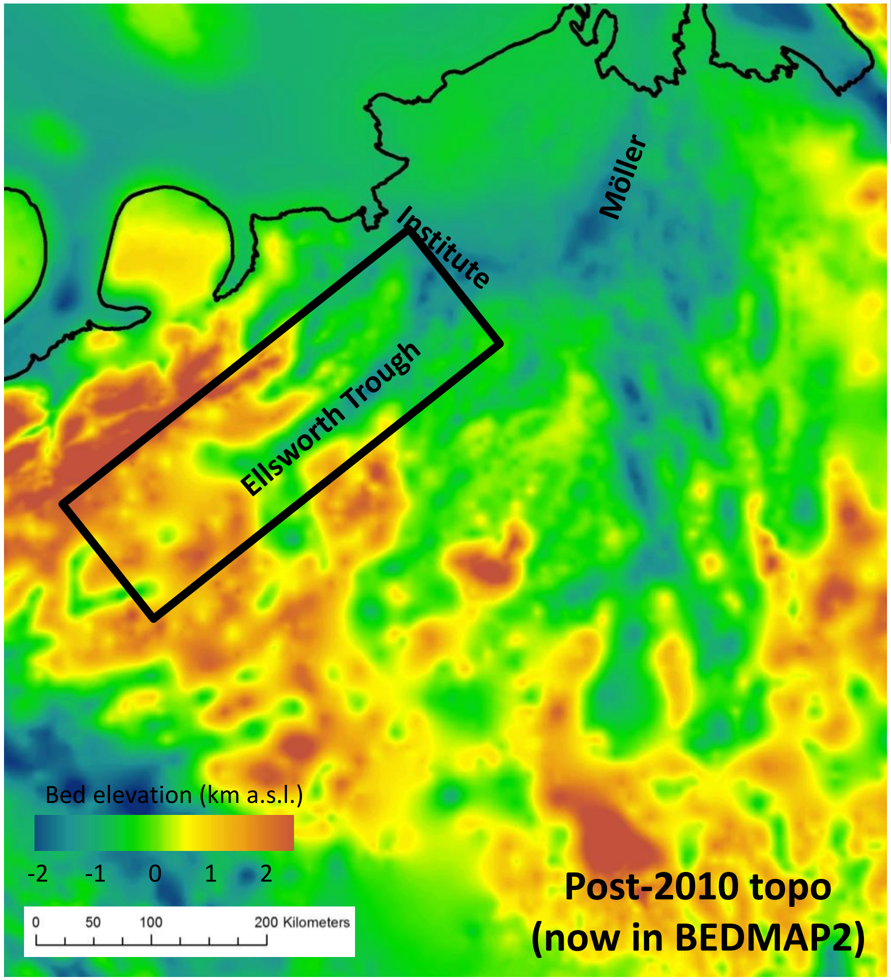
surface features & subglacial geomorphology, englacial layering



Geological Society of America Bulletin

The Ellsworth Subglacial Highlands: Inception and retreat of the West Antarctic Ice Sheet

Neil Ross, Tom A. Jordan, Robert G. Bingham, Hugh F.J. Corr, Fausto Ferraccioli, Anne Le Brocq, David M. Rippin, Andrew P. Wright and Martin J. Siegert

Geological Society of America Bulletin 2014;126, no. 1-2;3-15
doi: 10.1130/B30794.1

- Compares new knowledge of the bed with features visible on the ice surface with MODIS

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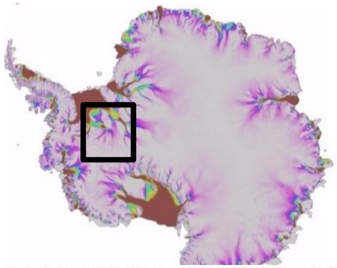

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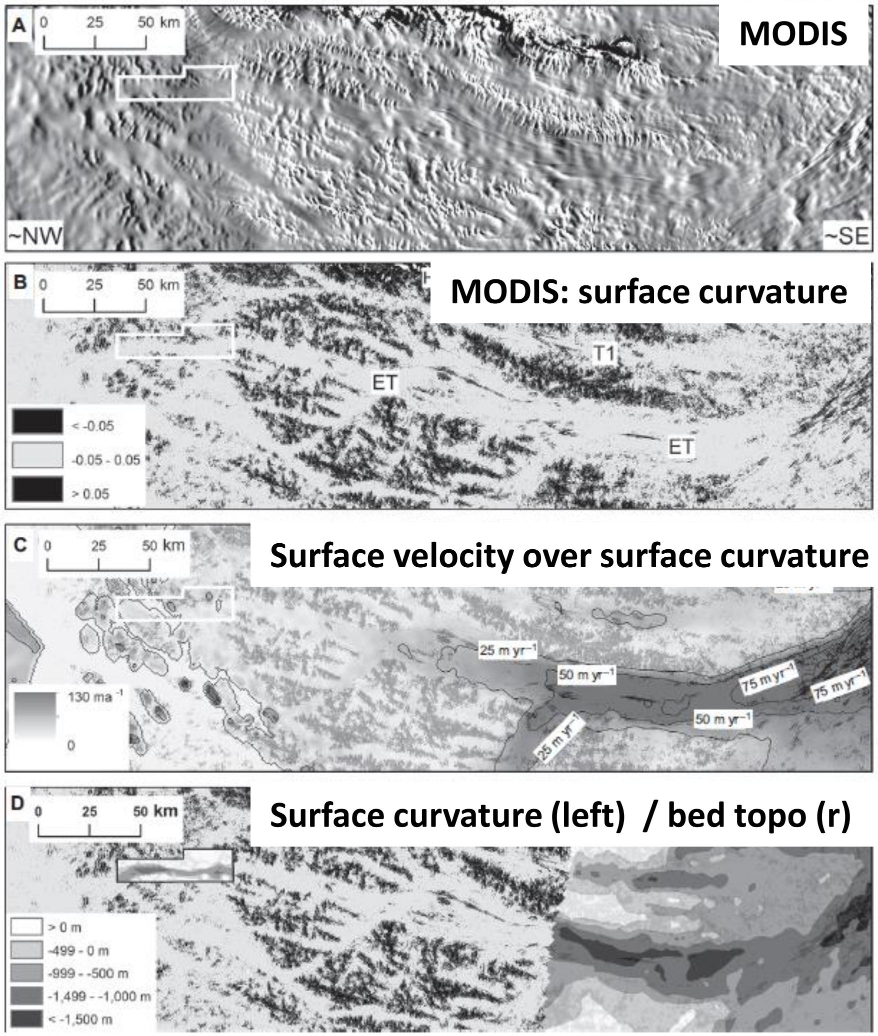

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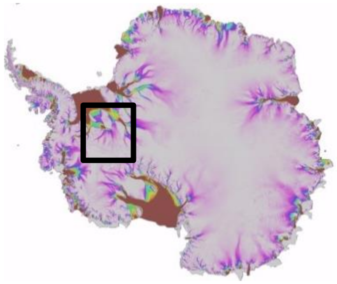
doi: 10.1130/B30794.1

- Compares new knowledge of the bed with features visible on the ice surface with MODIS
- Shows that subglacial geomorphology can be interpreted from surface imagery
- Ellsworth Subglacial Highlands (upstream IIS) characterised by well-preserved landforms diagnostic of marine-proximal alpine glaciation
- **Region represents major seeding centre of palaeo-WAIS, and probable future pinning points where future WAIS retreat might be arrested.**



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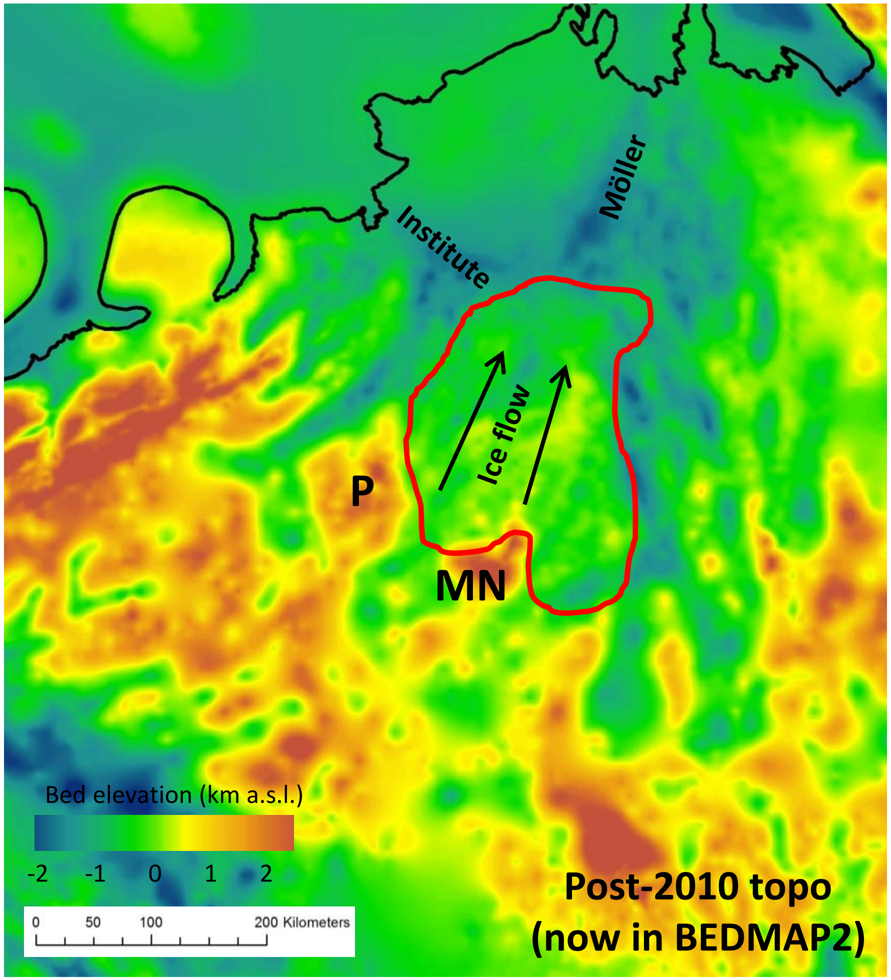
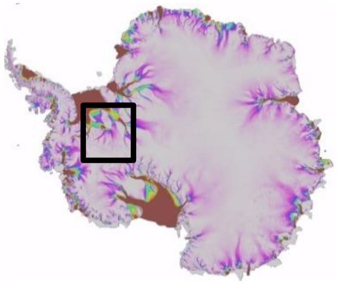


Earth Surface Dynamics
Discussions
Open Access

Ancient pre-glacial erosion surfaces preserved beneath the West Antarctic Ice Sheet

K. C. Rose[1], N. Ross[2], R. G. Bingham[3], H. F. J. Corr[4], F. Ferraccioli[4], T. A. Jordan[4], A. M. Le Brocq[5], D. M. Rippin[6], and M. J. Siegert[7]

- Identifies 150-km wide planation surfaces, interpreted as marine-erosion cut platforms.
- Preserved in lee of Pirrit and Martin-Nash Hills
- (These smooth surfaces account for larger interpreted marine basin pre-2010 survey)
- Formation of such surface requires relatively sea-ice free conditions, the most recent likely period being mid-Miocene (17-15 Ma)



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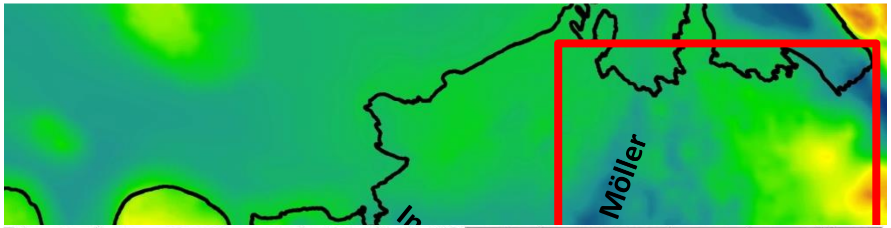
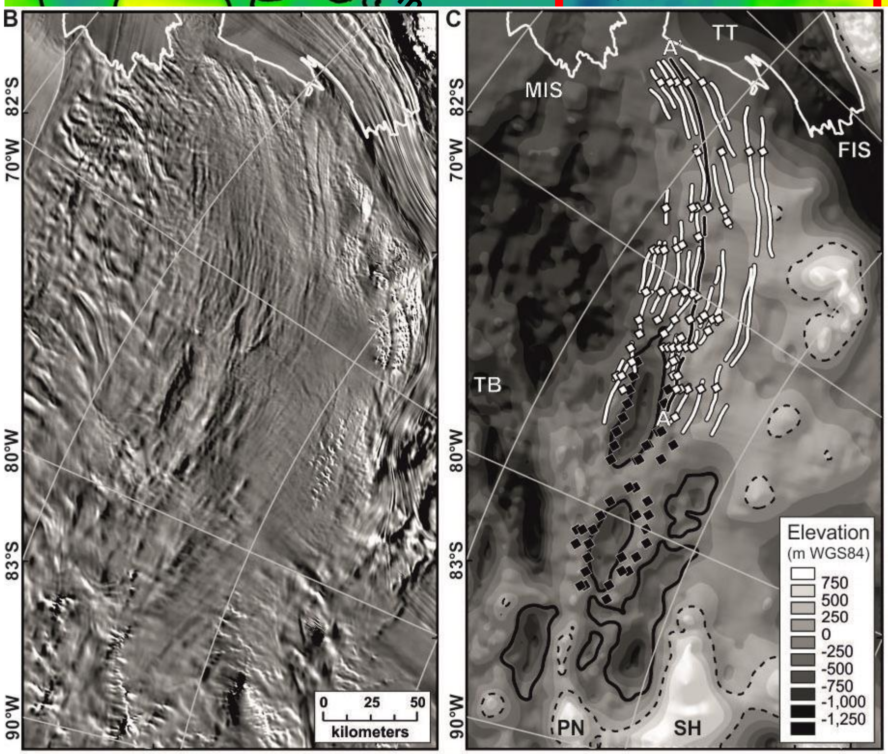




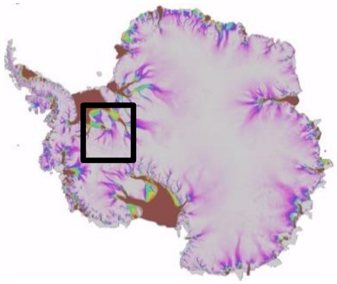
In press

GEOLOGY

A temperate former West Antarctic ice sheet suggested by an extensive zone of subglacial meltwater channels

Kathryn C. Rose[1*], Neil Ross[2], Robert G. Bingham[3], Hugh F.J. Corr[4], Fausto Ferraccioli[4], Tom A. Jordan[4], Anne M. Le Brocq[5], David M. Rippin[6], and Martin J. Siegert[7*]

- Maps a series of sub-parallel subglacial channels between Möller and Foundation Ice Streams
- Channels have size and geomorphology most consistent with supraglacial sources, similar to Greenland today.
- Likely formation under thinner ice with surface melting…
- Evidence that temperate ice sheet has occupied this area, most recent possibility being Pliocene (5.3 – 2.6 Ma).



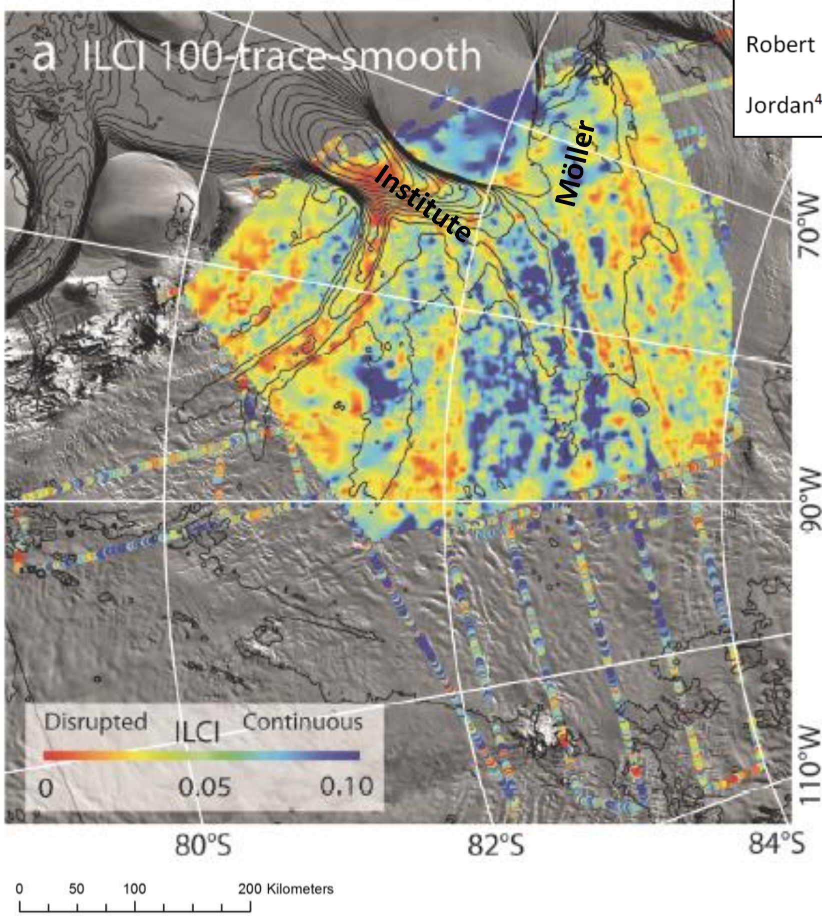
2. Ice flow history:

surface features & subglacial geomorphology, **englacial layering**

In review

Ice-flow structure and ice-dynamic changes in the Weddell Sea sector of West Antarctica from radar-imaged internal layering

Robert G. Bingham[1*], David M. Rippin[2], Nanna B. Karlsson[3], Hugh F.J. Corr[4], Fausto Ferraccioli[4], Tom A. Jordan[4], Anne M. Le Brocq[5], Kathryn C. Rose[6], Neil Ross[7] and Martin J. Siegert[8]



- Lack of correspondence between patterns of englacial layering and current ice flow configuration in upstream and southern sectors away from Ellsworth Subglacial Highlands.
- Likely that ice-flow configuration change *has* occurred, fundamentally influenced by ice thinning since LGM & concomitant effects on subglacial hydrological routing.
- Supported by Siegert et al. (2013) who present evidence for recent (last 4000 years) switch-off of flow over Bungenstock Ice Rise.

The University of Edinburgh | Newcastle University | British Antarctic Survey, Natural Environment Research Council | University of Exeter | The University of York | University of Bristol | University of Aberdeen | Imperial College London | NERC Science of the Environment

Outputs

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Ice flow history: Subglacial geomorphology records periods of limited glaciation and ice-free conditions. Englacial layering consistent with recent changes to flow routing between Institute & Möller with ice thinning.

3. Current dynamism: subglacial hydrology

4. The future? Modelling of the region’s sensitivity

Photo: Neil Ross

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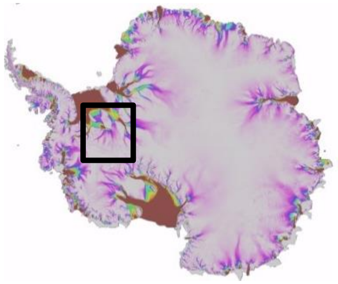
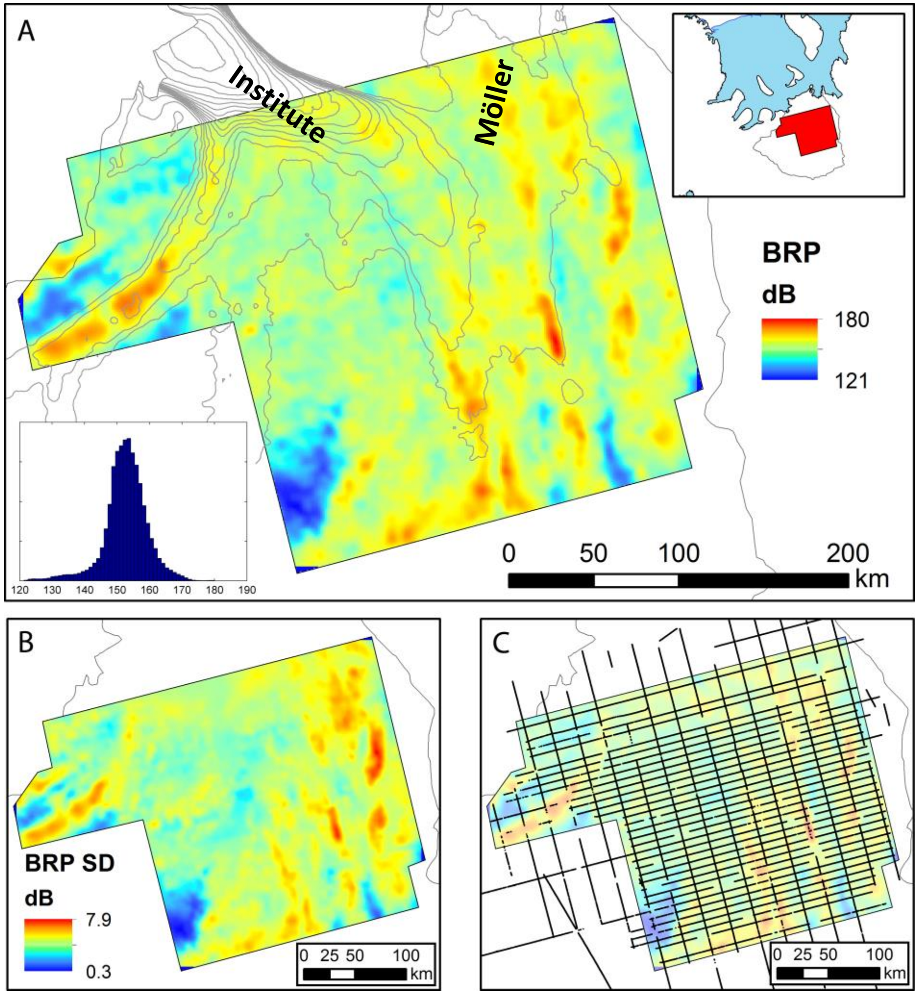


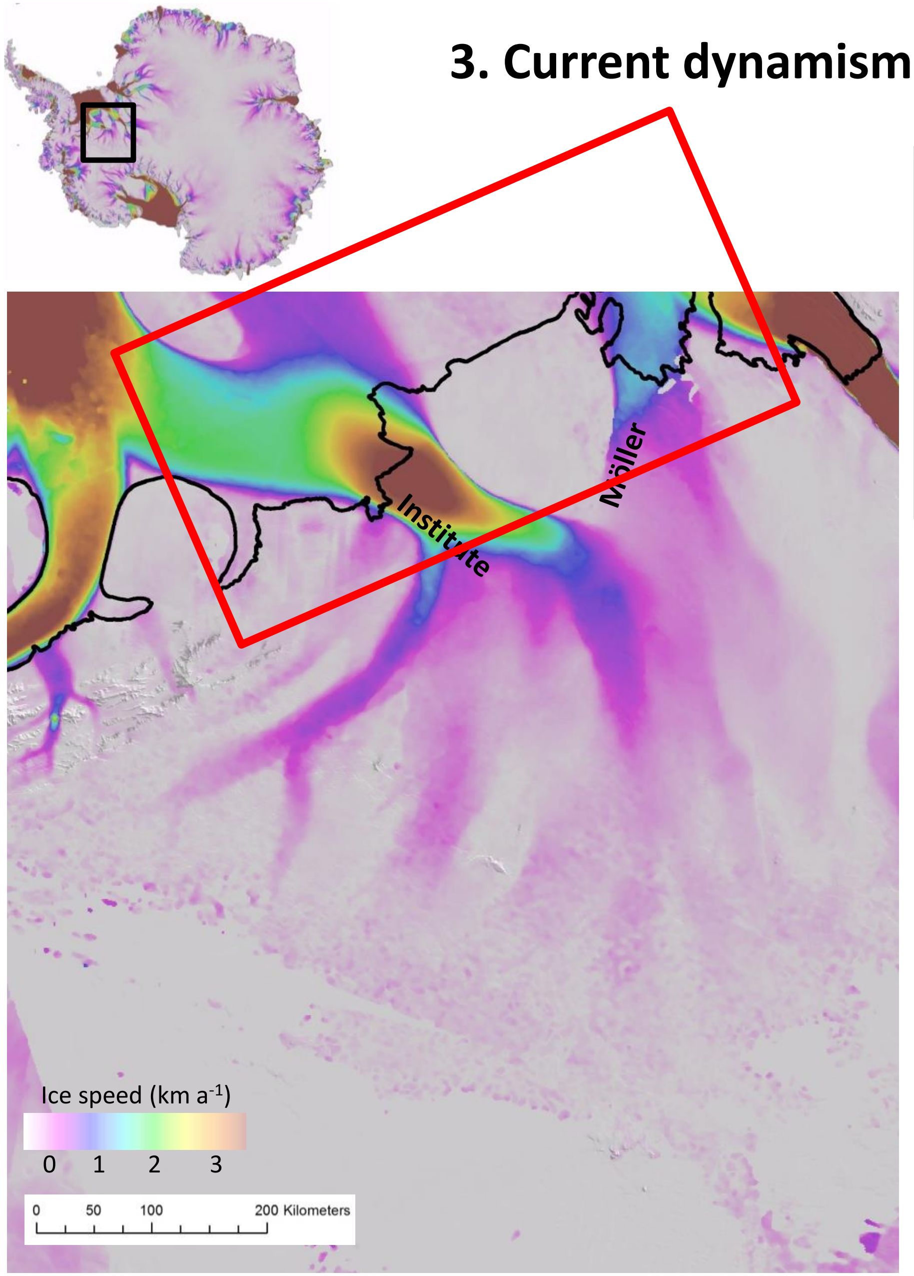
3. Current dynamism: subglacial hydrology

David Ashmore, Ph.D. work



- Basal reflectivity derived from radar data
- Bright (wet) bed in deep ice beneath major flow features
- Generally strong correspondence between bright beds and current ice-flow routing

3. Current dynamism: subglacial hydrology



nature geoscience

LETTERS

PUBLISHED ONLINE: 6 OCTOBER 2013 | DOI: 10.1038/NGEO1977

Evidence from ice shelves for channelized meltwater flow beneath the Antarctic Ice Sheet

Anne M. Le Brocq[1]*, Neil Ross[2], Jennifer A. Griggs[3], Robert G. Bingham[4], Hugh F. J. Corr[5], Fausto Ferraccioli[5], Adrian Jenkins[5], Tom A. Jordan[5], Antony J. Payne[3], David M. Rippin[6] and Martin J. Siegert[3]

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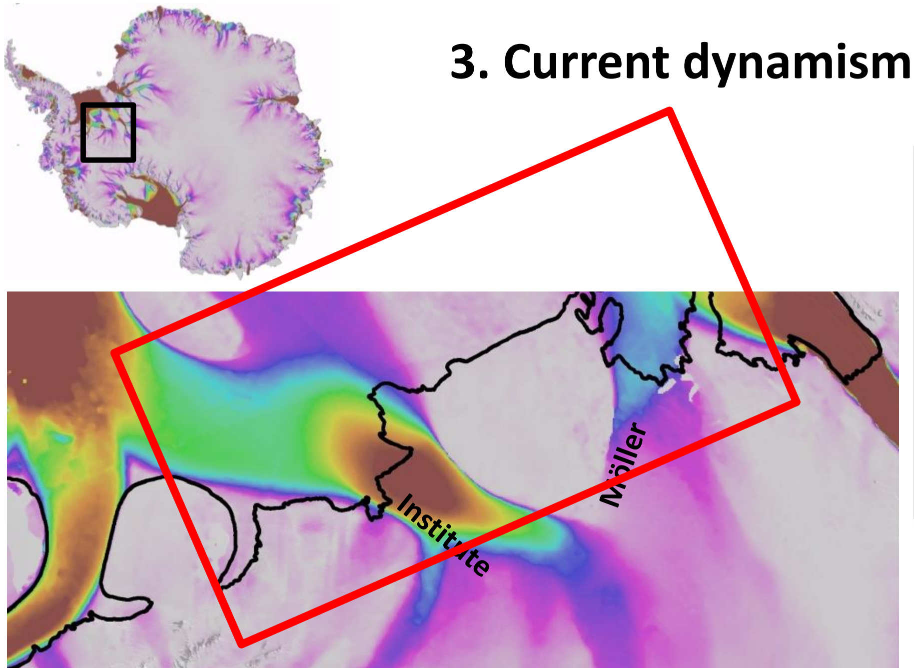

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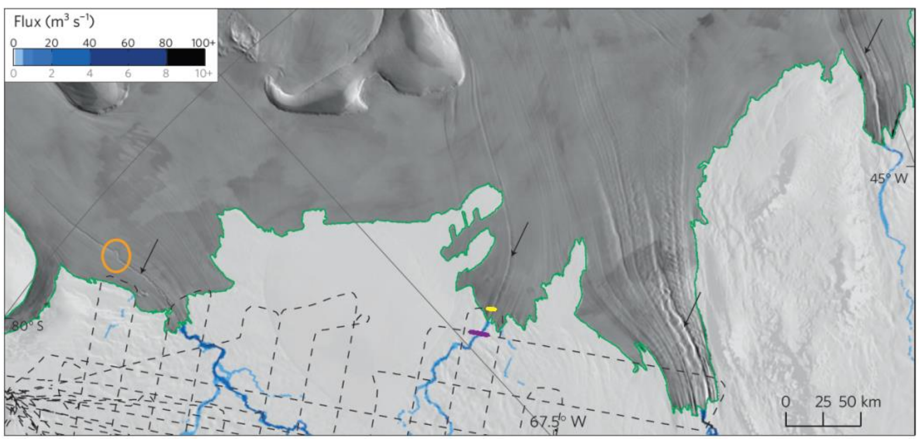
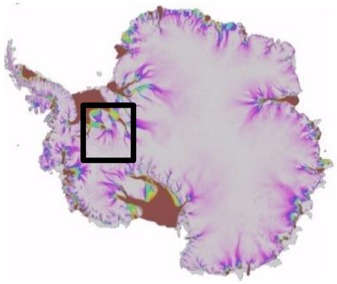


- Highlighted the occurrence of large channels depressed into the ice-shelf surface at the outlets of ice streams.
- Radar shows channels are surface expression of channels melted into underside of ice shelf at ice-stream outlets.
- Evidence that large channels incised into ice from some way beneath grounded ice (contrasting with usual assumption of distributed flow).

3. Current dynamism: subglacial hydrology

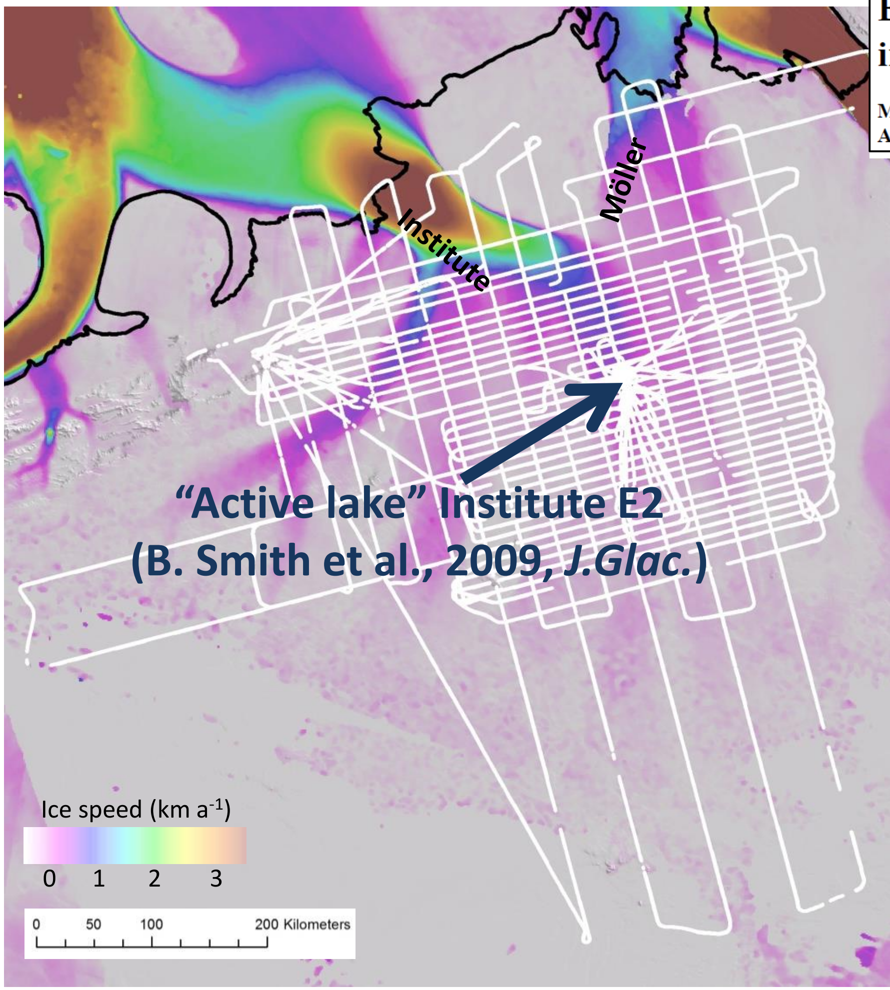


The Cryosphere

Open Access

Boundary conditions of an active West Antarctic subglacial lake: implications for storage of water beneath the ice sheet

M. J. Siegert[1], N. Ross[2], H. Corr[3], B. Smith[4], T. Jordan[3], R. G. Bingham[5], F. Ferraccioli[3], D. M. Rippin[6], and A. Le Brocq[7]



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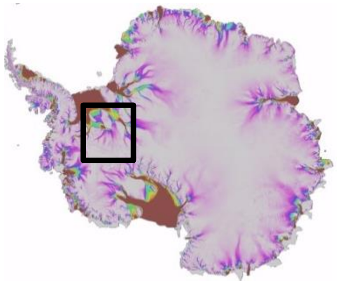

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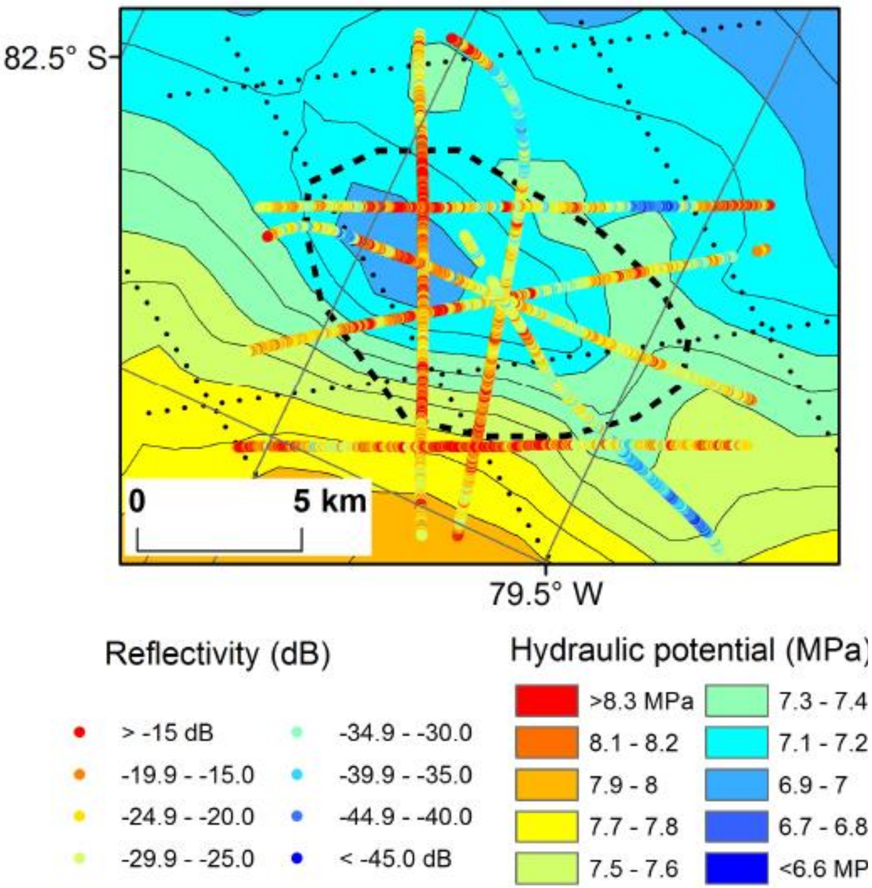


- Radar returns & reflectivity DO NOT show evidence for "obvious" (>10 m) lake where "active lake" was interpreted from ICESat…
- Suggests not all active lakes are lakes…
- Vertical motion may be related to periodic draping of water over hydropotential sinks as it is flushed through the system.
- **From last 3 examples: Institute and Möller ice streams underlain by dynamic hydrological system**

Outputs

- **12 papers published or in review, addressing:**

Summary of setting: The basin has characteristics similar both to the Ross Sector (smooth bed, possibility for ice-stream migration) and Amundsen sector (some degree of subglacial geological control)

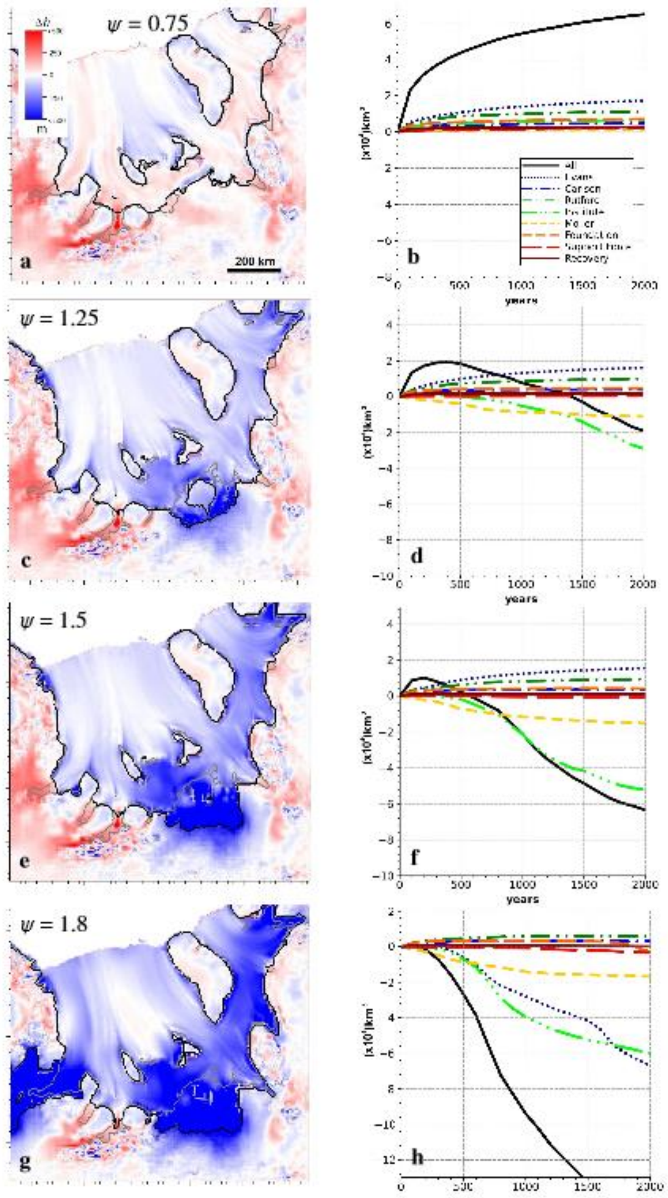
Ice flow history: Subglacial geomorphology records periods of limited glaciation and ice-free conditions. Englacial layering consistent with recent changes to flow routing between Institute & Möller with ice thinning.

Subglacial hydrology: Evidence from bed reflectivity, ice-shelf channels and “active-lake” site that the region is underlain by dynamic hydrological system – conducive to overlying dynamism in the ice.

4. **The future? Modelling of the region’s sensitivity**

Photo: Neil Ross

4. The future? Modelling regional sensitivity



The Cryosphere
Discussions
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Sensitivity of the Weddell Sea sector ice streams to sub-shelf melting and surface accumulation

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- Wright et al. (2013) use BISICLES to model ice thinning and grounding line retreat of Filchner-Ronne ice streams in response to surface and sub-shelf mass balance forcing.

- Shown left are results for varying a linear multiplier ω to the sub-shelf ablation/accumulation
- LHS thickness & g.l. change; RHS basin volume change

- **Results show that Institute and Möller Ice Streams, in particular, are highly sensitive to changes in basal melting near to grounding lines or ice rises in FRIS**

- (Little change to Rutford, Carlson, Foundation… Evans changes only after melt at grounding line is order-of-magnitude greater than likely present-day).

Conclusions

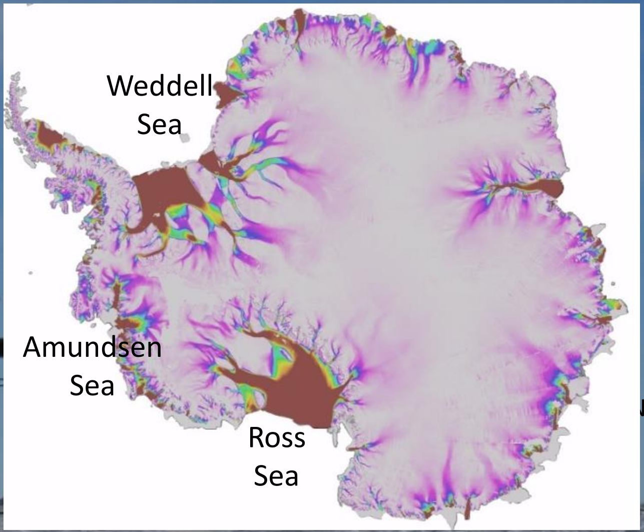
Summary of setting: The basin has characteristics similar both to the Ross Sector (smooth bed, possibility for ice-stream migration) and Amundsen sector (some degree of subglacial geological control)

Ice flow history: Subglacial geomorphology records periods of limited glaciation and ice-free conditions. Englacial layering consistent with recent changes to flow routing between Institute & Möller with ice thinning.

Subglacial hydrology: Evidence from bed reflectivity, ice-shelf channels and "active-lake" site that the region is underlain by dynamic hydrological system – conducive to overlying dynamism in the ice.

The future: Modelling suggests that should major melting take place beneath Filchner-Ronne Ice Shelf, then Institute and Möller Ice Streams have strong potential to thin and retreat rapidly.

Hypothesis: "Institute and Möller Ice Streams are underlain by weak marine sediments, which were deposited when the WAIS was less extensive than today, and which can affect ice flow variability in a manner similar to that observed across the Siple Coast."



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The future: Modelling suggests that should major melting take place beneath Filchner-Ronne Ice Shelf, then Institute and Möller Ice Streams may thin and retreat most rapidly.

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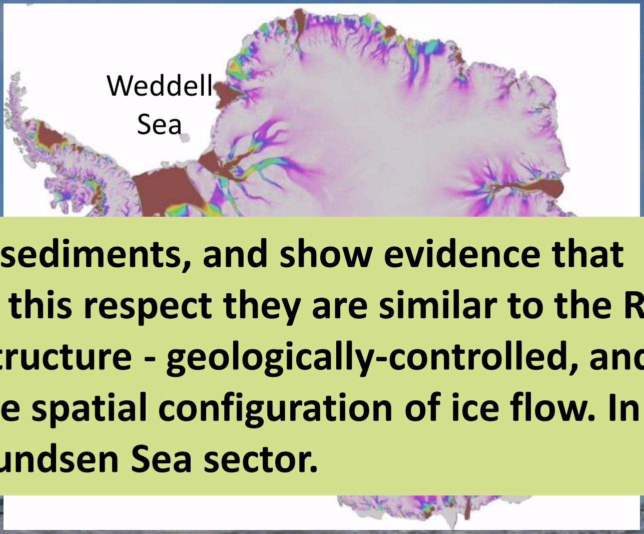

Institute and Möller ice streams are partly underlain by marine sediments, and show evidence that some of their tributaries have migrated during the Holocene. In this respect they are similar to the Ross (Siple Coast) ice streams. BUT there is considerable subglacial structure - geologically-controlled, and glacially exaggerated – that exerts some degree of control on the spatial configuration of ice flow. In this respect the ice streams are more akin to those draining the Amundsen Sea sector.

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