Palaeo Ice Streams: a key to the form and flow of past ice sheets

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What are ice streams?
• Fast-flowing (100s to 1000s m/yr)
• Deforming sedimentary bed (cm to m thick)
• Curvilinear (5-50 km wide, up to 100s km long)
• Heavily crevassed
• Easily identified from satellite imagery

Byrd Glacier, Antarctica

East Greenland

Why are ice streams important?
• Present in almost all modern ice caps and ice sheets
• Responsible for over 80% of mass loss from Antarctic and Greenland ice sheets
• The major source of icebergs to the polar oceans

Modern Antarctic and Greenland ice streams

Ice streams within a Russian Arctic ice cap from satellite radar interferometry

Marine geological and geophysical data to identify past ice-stream form and flow
• swath bathymetry - streamlined submarine bedforms
• Shallow acoustic stratigraphy
• Core sedimentology and geotechnical properties
Evidence for Reconstruction of Past Ice Sheets

- Ice-stream location and dimensions
- Flow direction(s)
- Ice to continental shelf edge
- Insights into conditions at ice-stream beds
- Each important to modelling of former ice sheets

Submarine bedform evolution and insights into ice stream flow

300 km-long Marguerite Trough, Antarctica

(O’Cofaigh et al., 2002, GRL; Dowdeswell et al., 2004, Geology)

Inner Shelf – bedrock and meltwater channels

- Bedrock drumlins & ice-moulded bedrock

Middle Shelf – transition from bedrock to sedimentary bed

- Large-scale glacial lineations in sediment
- Lineations: 10-17 km long, 100-400 m wide
- Meltwater features absent

Outer Shelf – sedimentary bed

- Pine Island Bay shelf, West Antarctica
- Melting feature absent
- Continental shelf edge
Mega-scale lineations in Traenadjupet, Norwegian Shelf

Morphological detail within mega-scale glacial lineations

Bifurcation downflow (B)
Point source initiation
Sticky Spots? (S1, S2)

Streamlined and sediment-rich base of overturned iceberg about 200 m long

Reconstructing past ice-flow directions and former ice-sheet drainage basins

An example from the Bellingshausen Sea - the 'Lost Drainage Basin' of West Antarctica

Ice flow
10 km
Subglacial Bedforms
Eltanin Bay & Belgica Trough

Outer Belgica Trough: Subglacial Bedforms

Lineations formed in sediment

Mega-scale glacial lineations

Iceberg scours

Trough edge

Acoustically-transparent sediment unit

Sub-bottom reflector

The ‘Lost Drainage Basin’ of West Antarctica

Ice flow directions for a major ice-sheet outlet from the West Antarctic Ice Sheet
Drainage basin area of 300,000 km²

Precipitation map of Antarctica

Implications

Belgica Trough contained a major ice stream of the West Antarctic Ice Sheet at the LGM. Drainage basin area of ~300,000 km²

Ice stream about 90 km wide and up to 300 km long

Deposition of a trough-mouth fan on the continental margin

Grounded ice extended to the outermost shelf. Dynamic West Antarctic Ice Sheet at LGM
Antarctic Peninsula Margin

Gullies and channels
No submarine fan

(Dowdeswell et al., 2004, Marine Geology)

Antarctic Peninsula Continental Slope

1500 km-long continental margin of West Antarctica
the Amundsen and Bellingshausen seas

Norwegian Margin

Submarine fans common offshores of former ice streams
Low gradient slope

(Dowdeswell et al., Geology 2004)

Substrate beneath former ice streams

- Largely inaccessible beneath modern ice sheets
- Accessible on polar continental shelves using ships
- Shallow acoustic stratigraphy
- 3D form of deformable sediments
- Sediment cores - lithofacies
- Grain size and shape
- Geotechnical properties
Sub-Bottom Acoustic Profiler Records

Mega-scale glacial lineations

Till-sheet in outer shelf trough, Marguerite Bay, Antarctica

Sediments from upper acoustically transparent layer

Core Stratigraphy and shear strength, Marguerite Bay

Debris comminution in subglacial deforming layer

Deformation till thickness

Using submarine bedforms to reconstruct past ice sheet form and flow (the 2,500 km long Norwegian-Svalbard margin)
The 2,500 km long Norwegian-Svalbard margin

Palaeo ice streams defined from geological record
Test numerical model reconstructions of former ice sheets

Evidence for Reconstruction of Past Ice Sheets

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- Flow direction(s), drainage basin area
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Modelling of subglacial bedform evolution