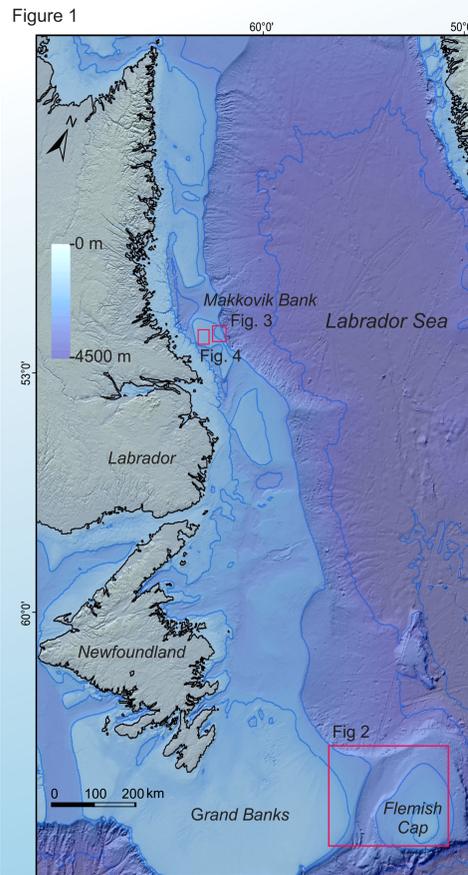


THE CONCEPT SUMMARY

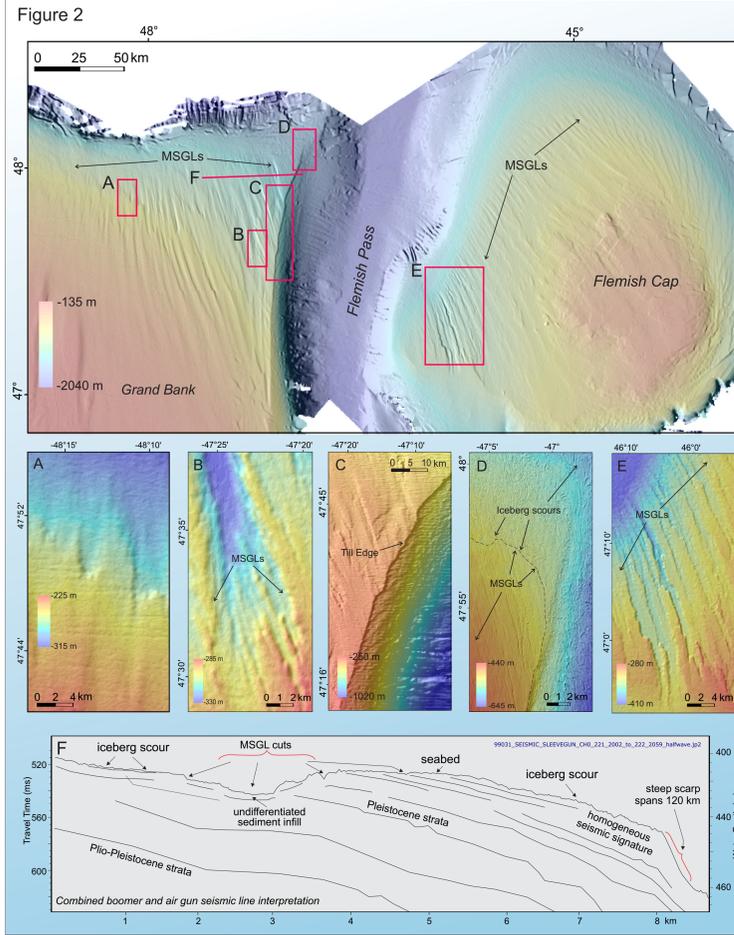
A new concept in the marine glacial regime has emerged from recent regional surficial geological mapping. Higher-resolution bathymetric images reveal north-south-oriented erosive lineations and shelf edge moraine, both of which are strong evidence of the presence of an ice shelf along the Newfoundland and Labrador continental margin. These large and numerous lineations occur on Makkovik Bank and on the outermost shelf, covering a 300 km wide area across outer Grand Bank and Flemish Cap, far beyond ice limits published by Dalton et al. (2020). Their large size, consistency of orientation, and relationship with glacial features of numerous former ice streams, further indicate their glacial origin. The ice shelf was nourished by glacial ice pathways across the shelves and from Hudson Strait. Buffering from destruction by climatological/oceanic processes on its seaward margin is apparent, but the ice shelf extent across the Labrador Sea, its dynamics and the buffering mechanisms remain speculative. Geological evidence of continental margin-scale paleo ice shelves, resembling present-day analogues in Antarctica, have only recently gained interest in Arctic settings (Jackobbsen et al. 2016; Reidel et al. 2020; Couette, P. et al. and Batchelor et al. 2024), and possibly the Norwegian Sea (Dowdeswell and Ottesen 2024).

Study Area-Eastern Canadian Margin

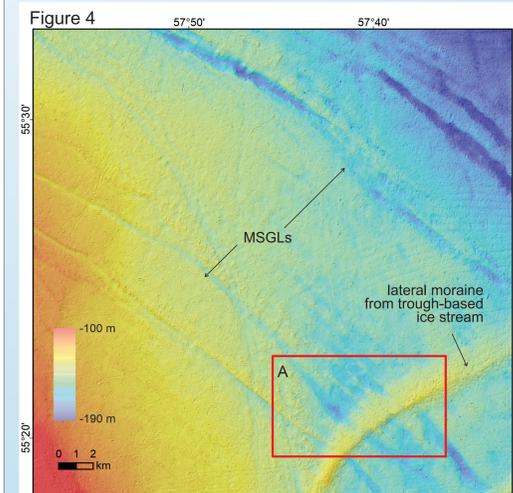
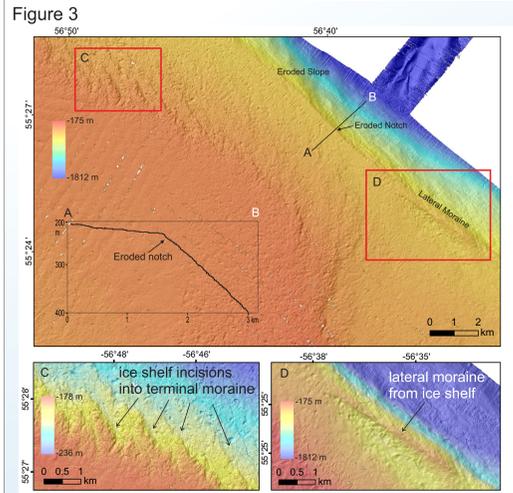


The Seabed Evidence

Grand Banks and Flemish Cap



Northern Labrador Shelf; Makkovik Bank



ICE SHEETS, ICE STREAMS AND ANOMALOUS GLACIAL FLOW DIRECTION FINDINGS

Large curvilinear mega scale glacial lineations (MSGL) are identified on Flemish Cap, northeast Grand Bank and on Makkovik Bank where a slope edge moraine is also identified, (Figs. 2, 3 and 4). MSGLs are glacial flow direction indicators from the continental ice sheet and ice shelf, eroding self-crossing troughs and deep water areas along the shelf break. The flow directions are parallel to the Labrador shelf-break or are in a southerly orientation on northeastern Grand Bank and Flemish Cap. On northeast Grand Bank seabed imagery shows a population of parallel to sub-parallel MSGLs occurring above 520 m wd. Large MSGLs can exceed 4 kms in width, with many over 2 kms wide and up to 54 kilometers long and 25 m deep or more. The lineations are developed in glaciogenic deposits, while others cut into older pre-glacial strata. Both sets of lineations were created by the ice shelf and have the same orientation trending northwest and southeast, (Fig. 2, 3 and 4). The northwest and southeast trending MSGLs on west and northern Flemish Cap are up to 54 kms long, 6 kms wide and over 28 m deep. They commonly have ragged edges in the west and shallow from north to south starting in 380 m and ending in 300 m water depth.

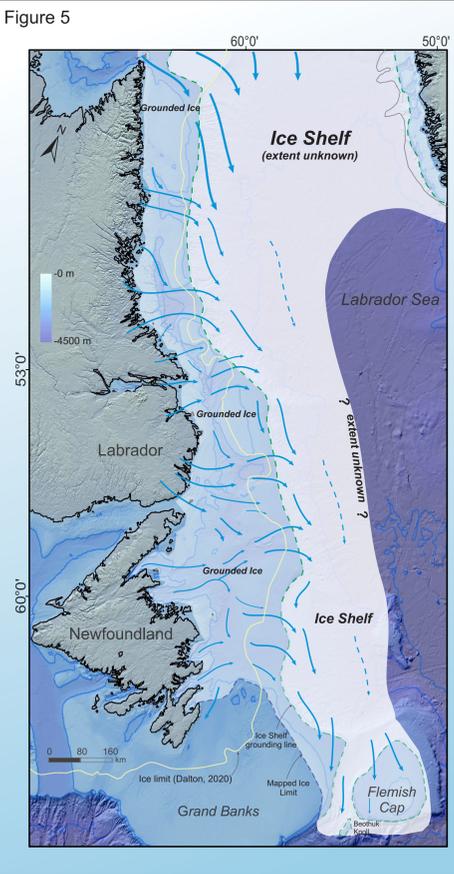
Broad MSGLs on Flemish Cap may be 7-8 km wide and as much as 100+ km long. MSGLs in all areas appear fresh, with no sign of infilling. The regional coherency of flow pattern, despite landmass barriers and the deep water of Flemish Pass, eliminates formation of these lineations from icebergs or ice island groundings. The up-hill flow on Grand Bank and their large size indicates a significant flow force. We propose that a contiguous ice shelf, nearly 600 m thick and 300 km broad (in the south), flowed southward (Fig. 5), fringing the continental shelf-based glaciers which were deflected southward by the thicker ice shelf. The ice shelf was fed from Baffin Bay, Hudson Strait and by numerous shelf-crossing troughs on Labrador and the northeast Newfoundland Shelf. The Poffluchkraft (Engelhardt, et al. 2017) and the Labrador current likely contributed to the southerly flow. Though a paleo-ice shelf has been proposed on theoretical grounds in the past (Denton & Huges 1983), our recognition of the MSGLs and their shelf-edge parallel flow are the first definitive seabed evidence. The implications of a massive North Atlantic ice shelf requires a re-thinking of numerous phenomena, not the least from glaciologic, paleo oceanographic and sedimentologic perspectives.

ICE SHELF STABILITY IN THE OPEN OCEAN

It has been long known in Antarctica that present day floating ice shelves extend far beyond their driving and feeding ice sheet and ice streams. Evidence for a paleo- ice shelf, also spanning the Arctic Ocean, has grown over the past decade, with seabed and buried MSGL recognition along much of the shelf break. Pan-Arctic ocean sea-ice and iceberg melange there provided a buttressing force, while the draining ice from the continent and shelves, along with ocean currents, drove a clockwise flow.

Continental glacier outlets to the North Atlantic feed the ice shelf sufficiently to overcome calving and basal melting, while ocean currents drove its flow. The flow evidence forces a glaciological re-thinking about the build-up, flow mechanism and stability of an ice shelf in a very different configuration than the modern Antarctic and Arctic Ocean examples. What forces maintain the oceanward edge from instabilities of massive calving, basal melting and resultant collapse? Even more puzzling is the proposed North Atlantic Ocean configuration, a similar buttressing force can have built without the land or seabed mounds that effectively pin the Arctic and Antarctic ice shelves.

Proposed Ice Shelf Reconstruction



WHEN WAS THIS ICE SHELF EXTANT?

Age dating when the ice shelf was extant is our primary challenge. Traditional methods of sediment dating are limited, largely due to absence of sediment cover or its destruction by iceberg scour during ice shelf break-up.

be at least as old as the penultimate glaciation, based on core-based age extrapolations of partially infilling sediments. It may be that both the last (35 000 to 20 000 years ago) and penultimate glaciation (more than 130 000 years ago) grew and supported such ice shelves.

Age evidence so far is equivocal, based mainly on cross-cutting relationships of moraines and iceberg scour of the seabed. For example, the largest iceberg scours on Grand Bank were as deep-draughted or even deeper than those from the previous glaciation (Fig.2D). The icebergs responsible either originated north of Hudson Strait or the calving of our thick ice shelf (or both). These icebergs cut upper slope stratified sediments from the last glaciation suggesting the large ice shelf was their source.

The last glacial period, at its marine margin, deposited numerous (H0 to H-6) carbonate-rich Heinrich layers across the North Atlantic, making it more dynamic than the penultimate glaciation which deposited only one (H-9). These Heinrich layers are attributed to rapid and short-lived calving events. The temporal stability of the ice shelf would have played a large role in generating these events and need not be exclusive to calving events, but also involve sub-ice shelf detrital meltout and perhaps limited ice shelf breakup events. In this scenario, the drivers of ice shelf stability would have been governed by meteorologic and oceanographic realms, rather more than internal glaciological drivers such as the Hudson Strait ice stream "binge and purge" model (MacAyeal 1993).

IMPLICATIONS OF AN ICE SHELF RECONSTRUCTION

Antarctic ice shelves play a role in slowing the flow of the voluminous Antarctic ice streams and are far more sensitive to sea-level rise. Large ice-island calving events of the ice shelves may be the forerunner of ice stream destabilization and sudden ice stream surging as the buttressing shelf is removed. Sea level rise from melting glaciers creates positive feedback, with its mechanisms and rates being key unknowns in climate and sea-level predictions.

With a new paleo-North Atlantic ice shelf concept, how might this past glacial history lead to better prediction of present marine-terminating glaciers?

THE DATASET

A low-resolution seabed bathymetric dataset, OLEX, populated by fishing vessels with ancillary data from government and academic institutions, now provides far-improved resolution of seabed features with shelf-wide coverage. This sea-scape rendering combined with legacy geophysical survey data was critical in recognition of a widespread system of glacial features.

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