Importance of Sea-Level Controlled Depositional Architecture to the Understanding of Permafrost and Gas Hydrates on High Latitude Shelves*

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Abstract

Modern arctic continental shelves are characterized by the development of permafrost to sub-bottom depths of several hundreds of meters. Thermal modeling suggests that this thickness must have developed over several glacial-interglacial cycles. Shelves exposed at low sea level stands were subject to sub-zero average annual temperatures that allowed freezing temperatures to penetrate below the surface. During transgression and highstand conditions, bottom waters may have been slightly above the freezing point so that some melting of the permafrost would have ensued. Similarly, the depth of the gas hydrate stability zone, which is close to the seabed under present day conditions, would have been subject to large fluctuations through time, potentially leading to periods of de-gassing modulated by sea level fluctuations. Better understanding of the links between sea level and the distribution of permafrost and/or gas hydrate stability requires that the depositional history related to sea level fluctuations be better understood. A conceptual model for the construction of shelf depositional architecture, permafrost and gas hydrates is developed. The sawtooth character of Pleistocene glacial and sea level cycles involves progressive sea level fall punctuated by extended lowstand conditions and followed by rapid sea level rise. This would lead to a progradational stacking pattern with one or two mid-shelf lowstands per cycle. During these lowstands, permafrost would aggrade on the topset portion of the clinoform and degrade on the foreset portion. Thermal conditions at the topset/foreset hinge line would be most variable, potentially leading to destabilization of gases bound in hydrate form. In this model, gas release structures are inherently associated with lowstand hinge points, representing nearshore conditions.

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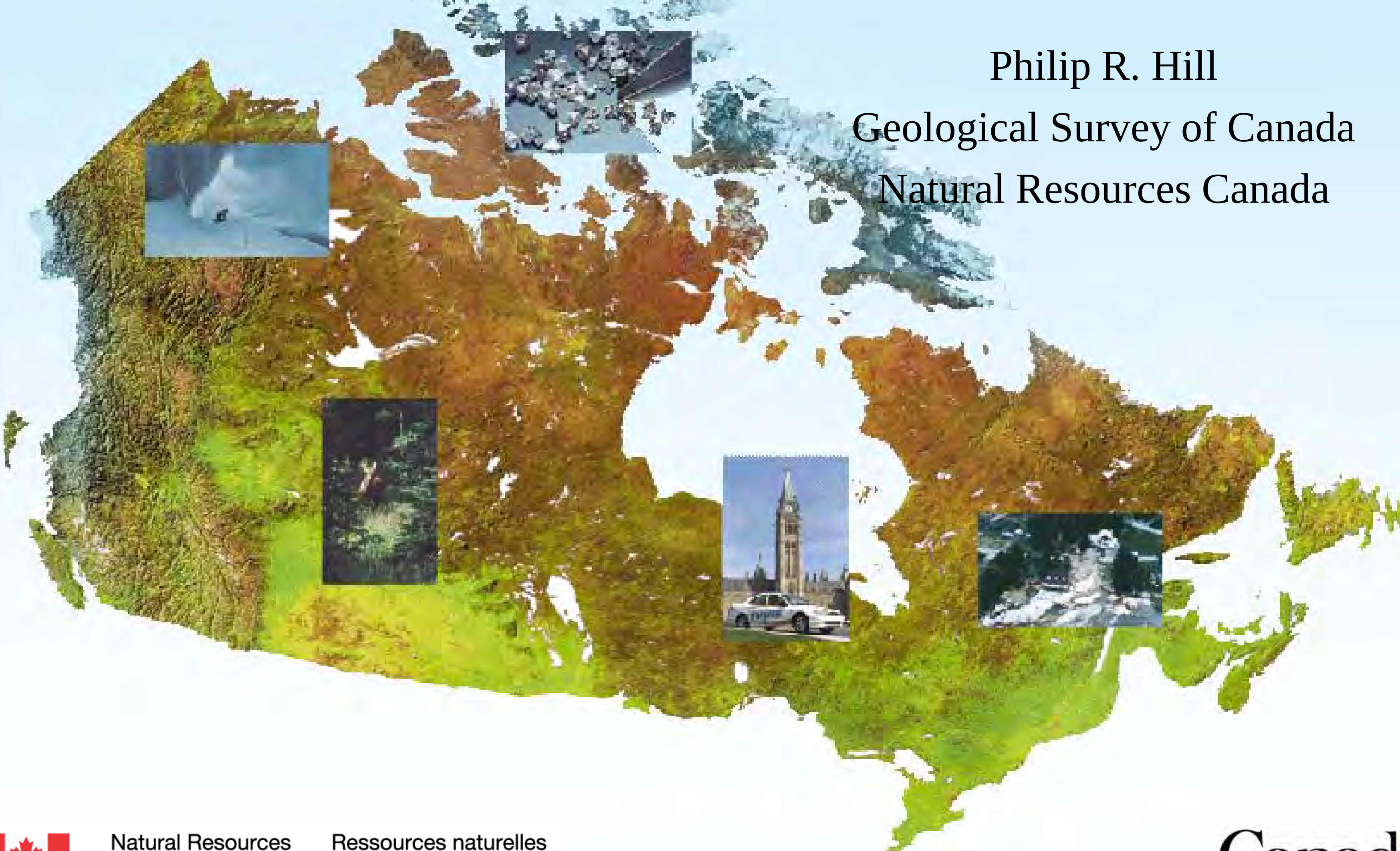

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Characteristics of (some) Polar Shelves

- Subsea Permafrost
- Negative temperatures extending hundreds of metres
- Shallow Gas Hydrate Stability Zone

Objective

- Highlight the need for a research effort on the depositional architecture of glacially influenced continental margins to better understand subsea permafrost and gas hydrates.

Plan

- Introduction to subsea permafrost and gas hydrates below modern arctic continental shelves.
- Relationships between thermal regime, sea level and stratal architecture.
- A modeling approach to understanding stratal architecture
- Controls on depositional architecture on glacially-influenced high latitude shelves

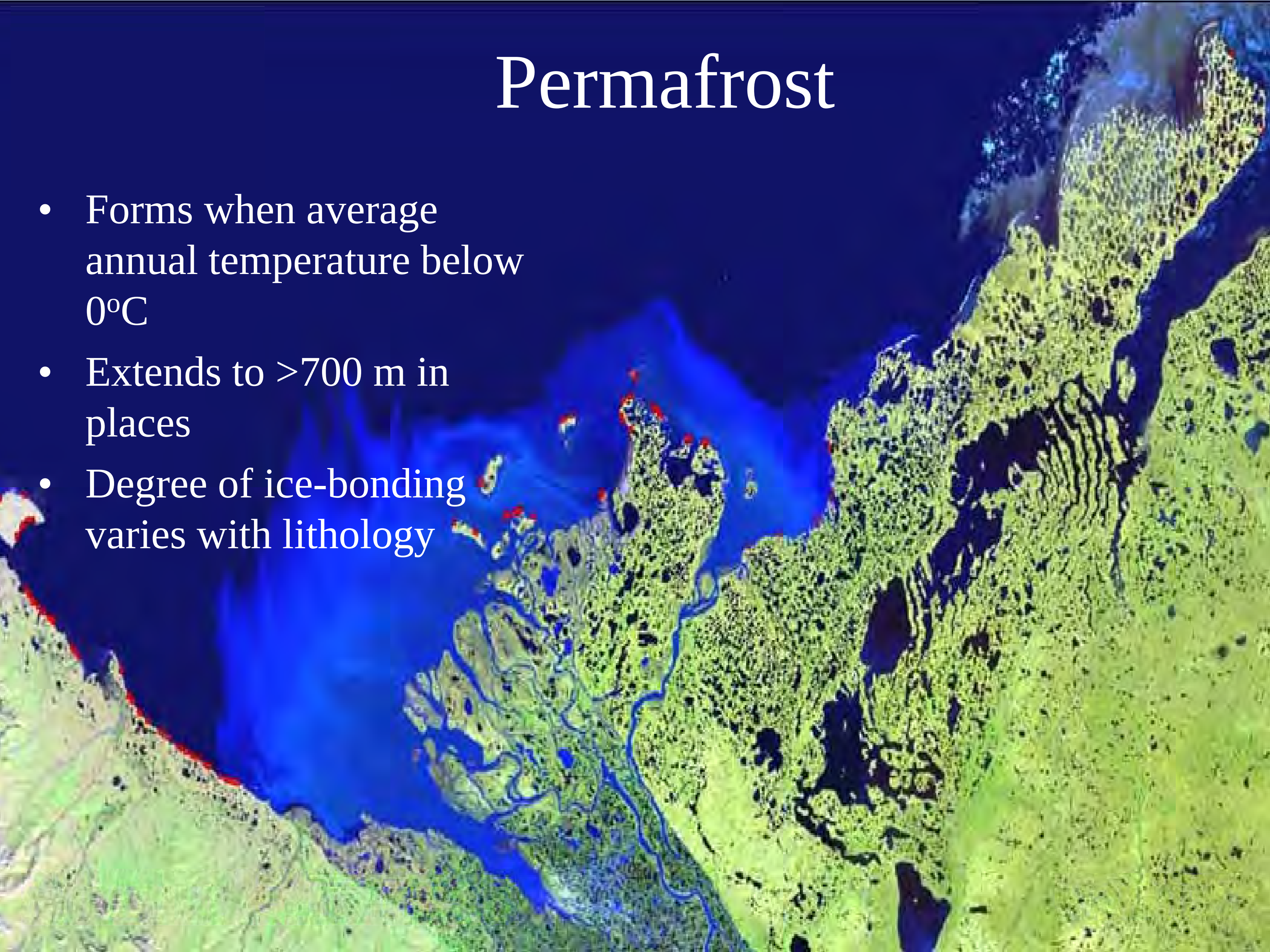
Permafrost and Gas Hydrates

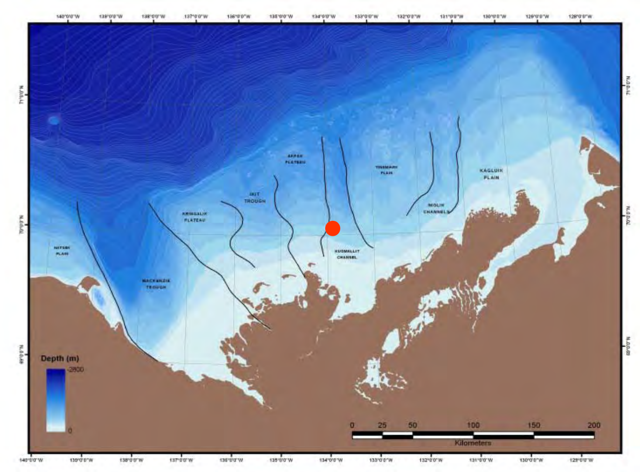
- Subsea permafrost, decomposition of gas hydrates and the migration of free methane gas are important geohazards hazards.

- Gas hydrates are a potential resource.

Permafrost

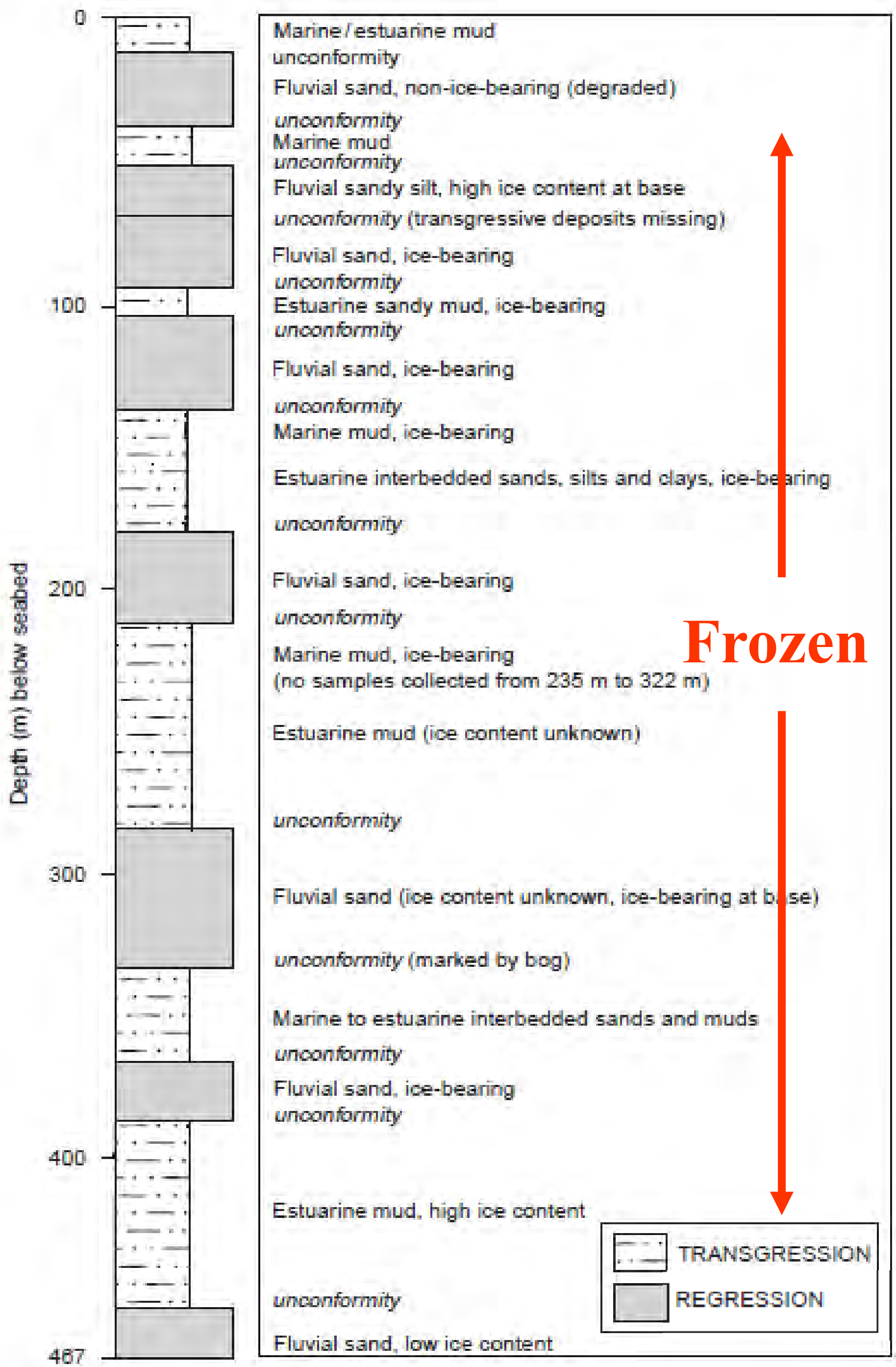
- Forms when average annual temperature below 0^{o}C
- Extends to >700 m in places
- Degree of ice-bonding varies with lithology





Base map courtesy S. Blasco

Subsea permafrost has been observed in offshore wells and boreholes to >600 m depth



Canadian Beaufort Shelf at 32 m

S. Blasco, (in Ostercamp, 2001)

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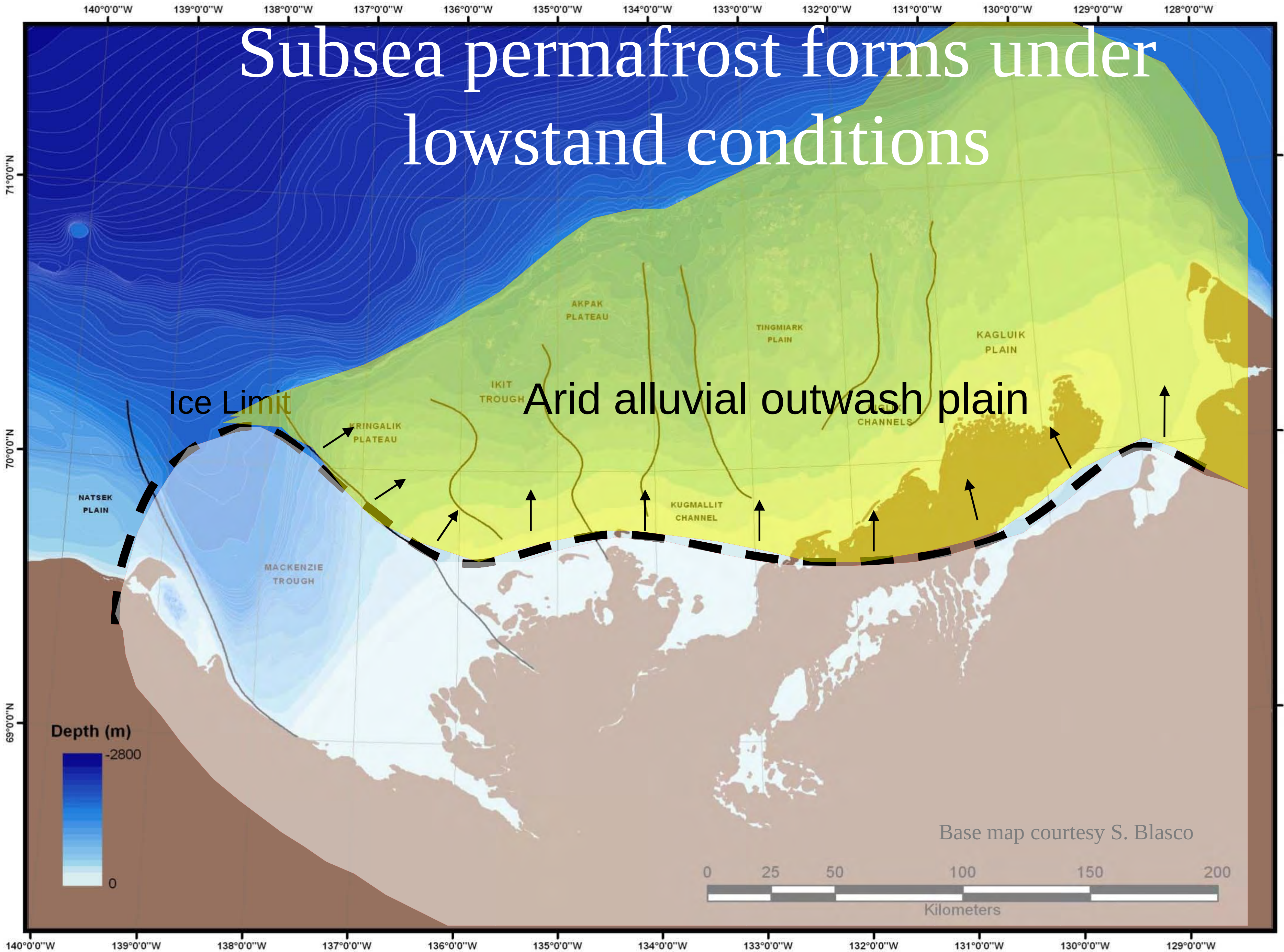
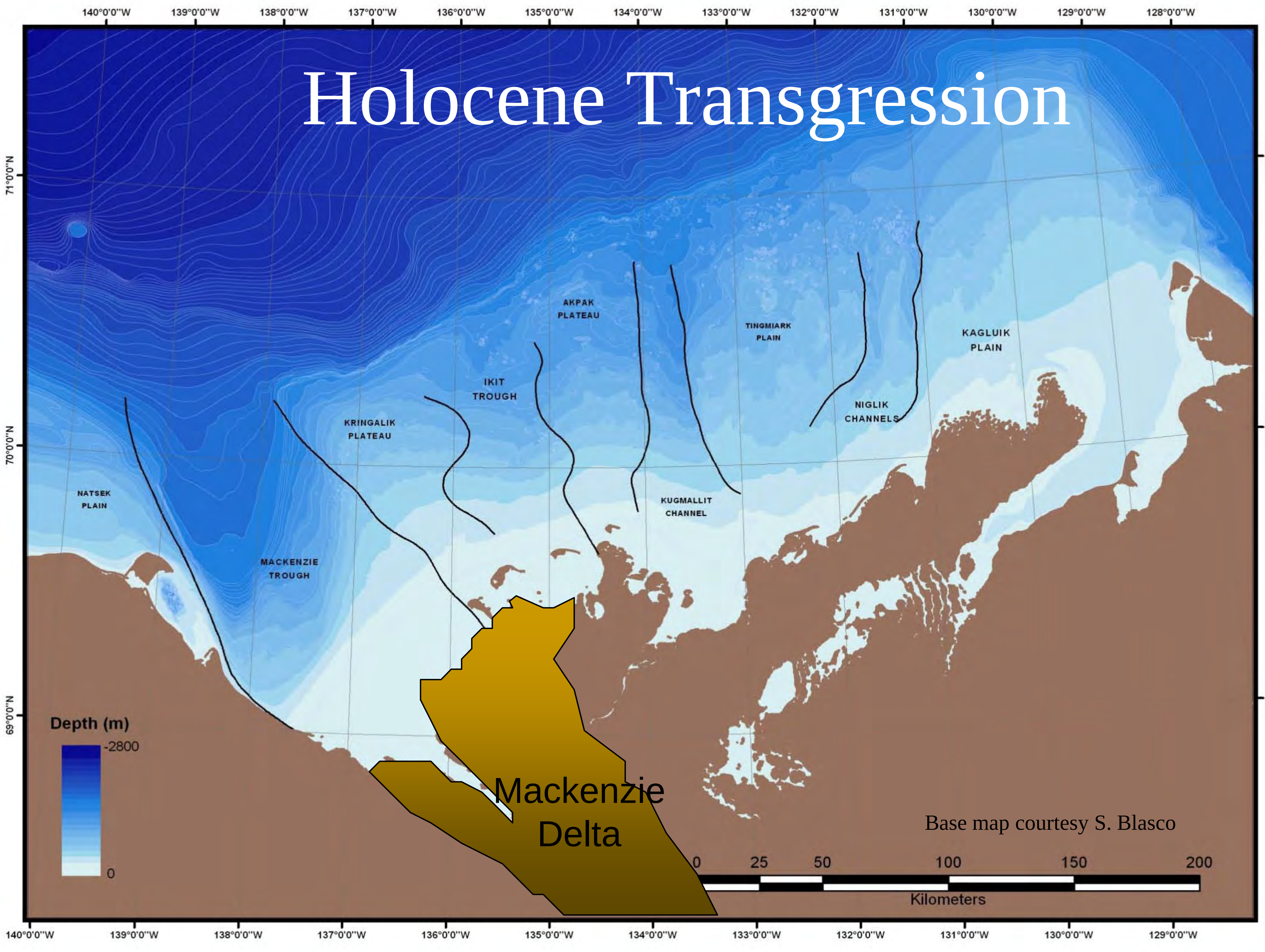
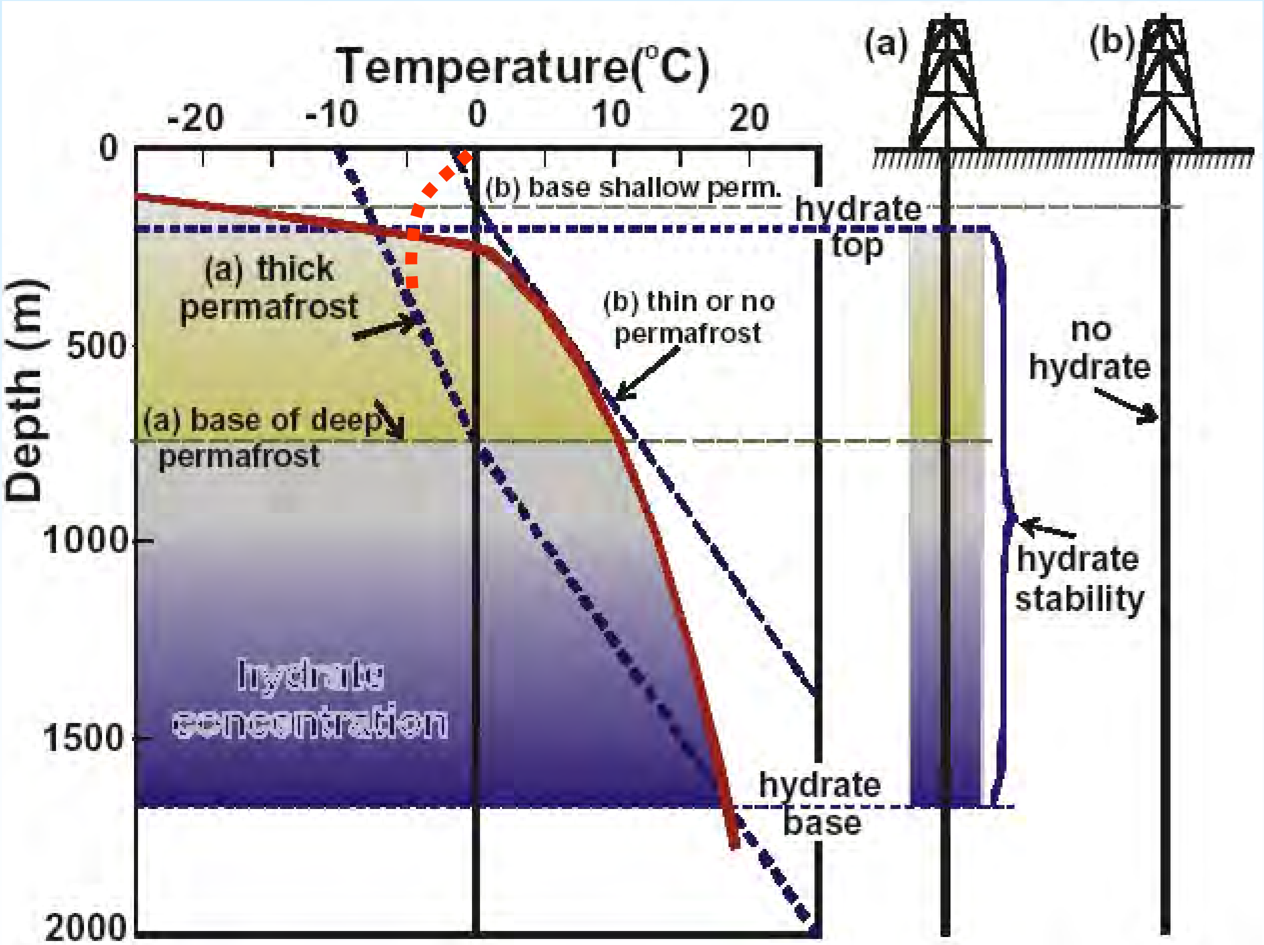
Subsea permafrost forms under lowstand conditions



Holocene Transgression



Methane Hydrates
stable from approx. 150m bsb on Beaufort Shelf



Source: NRCan (Hyndman and Dallimore)

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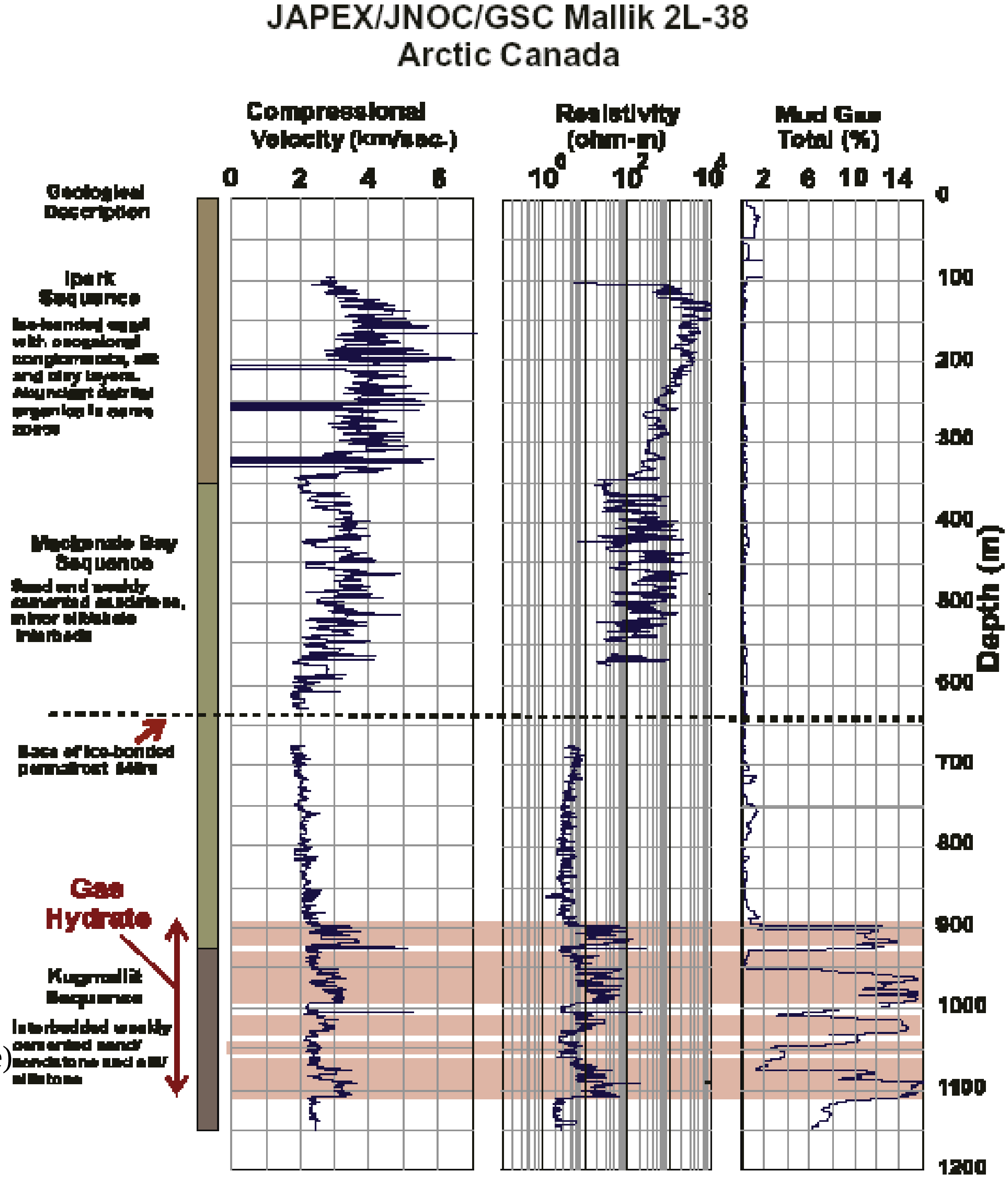
The most concentrated gas hydrate deposits sampled in the Mackenzie Delta occur well below the base of ice-bonded permafrost



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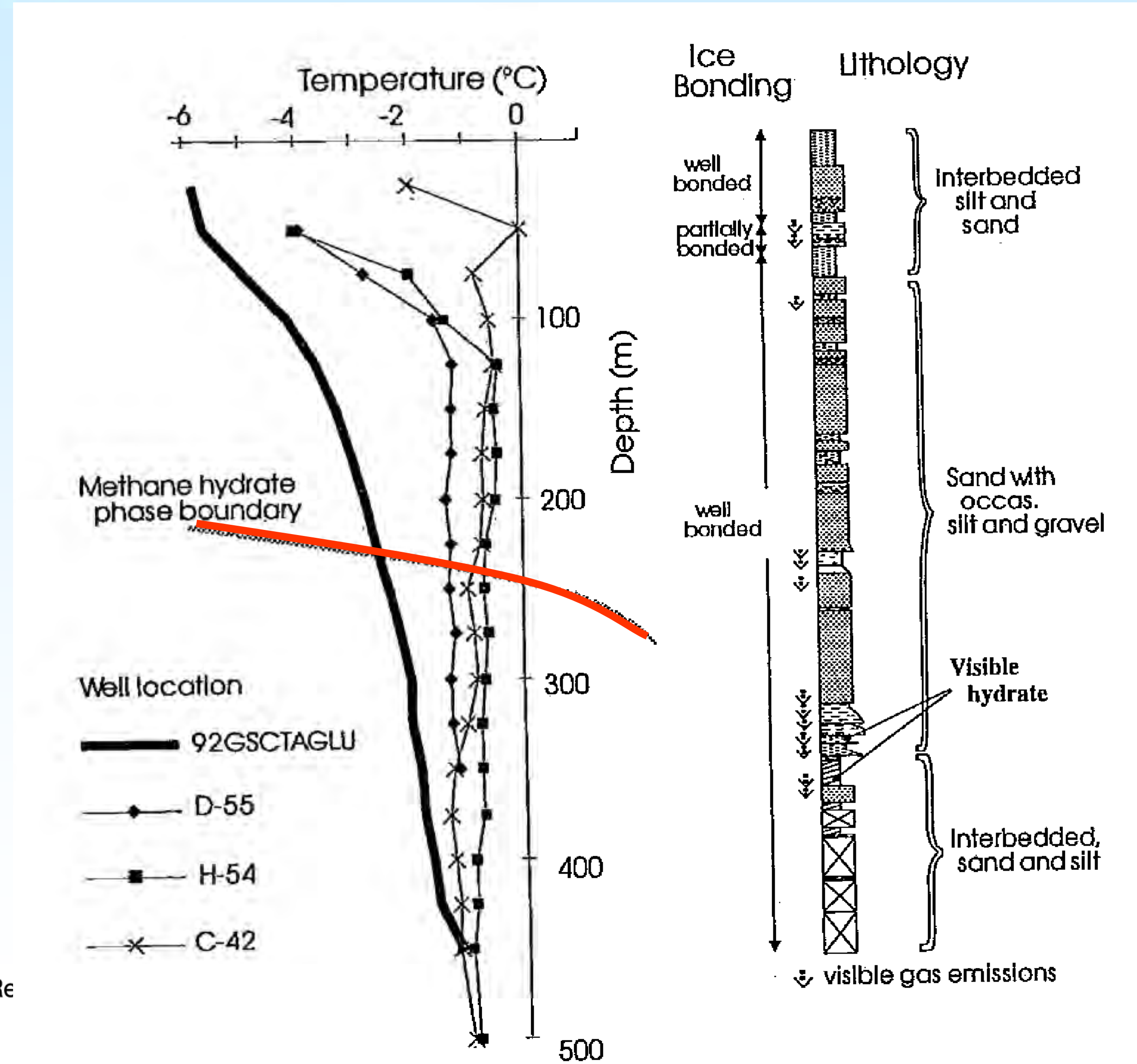
Intrapermafrost **gas hydrates** have been observed in boreholes on land but not offshore



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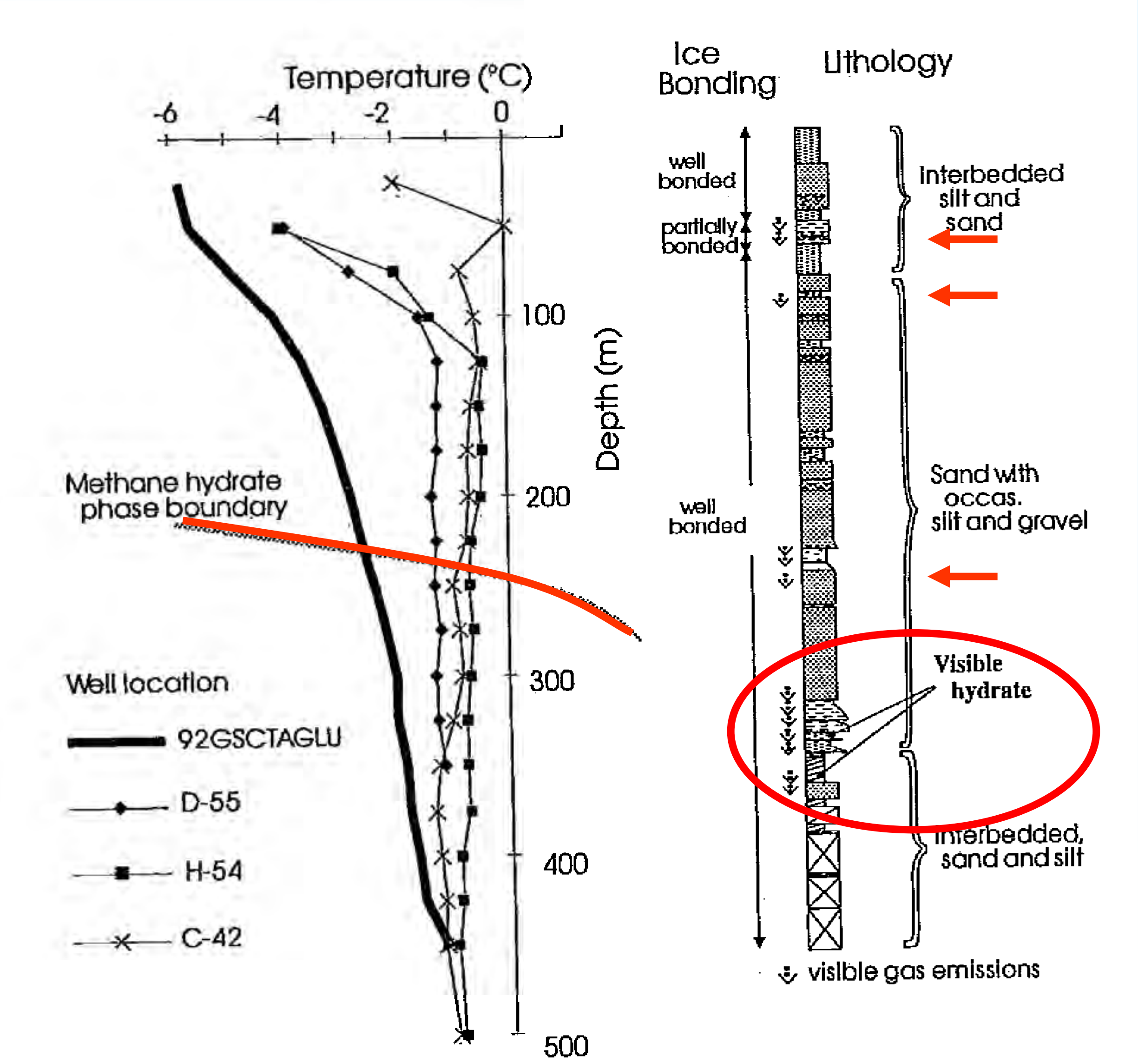

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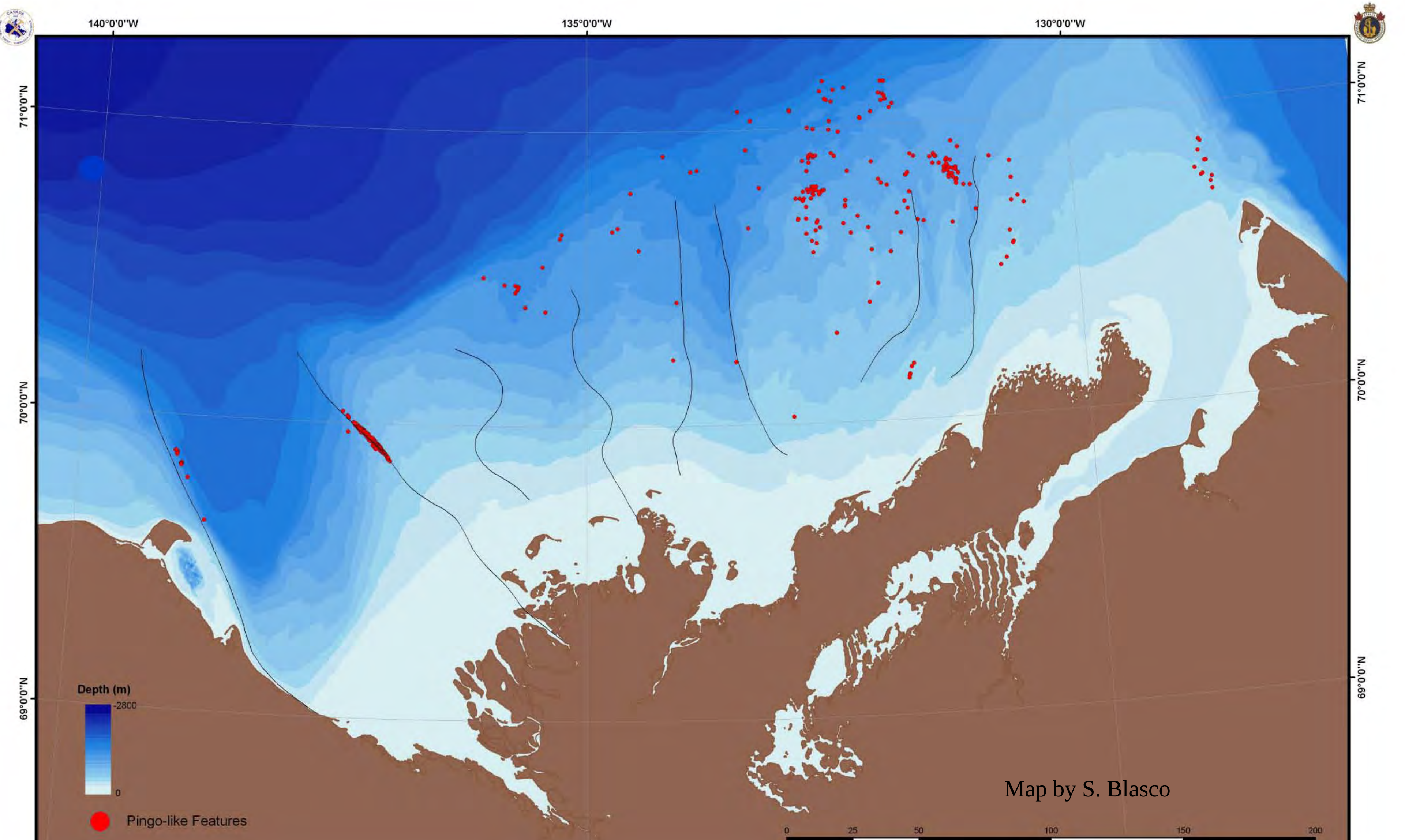
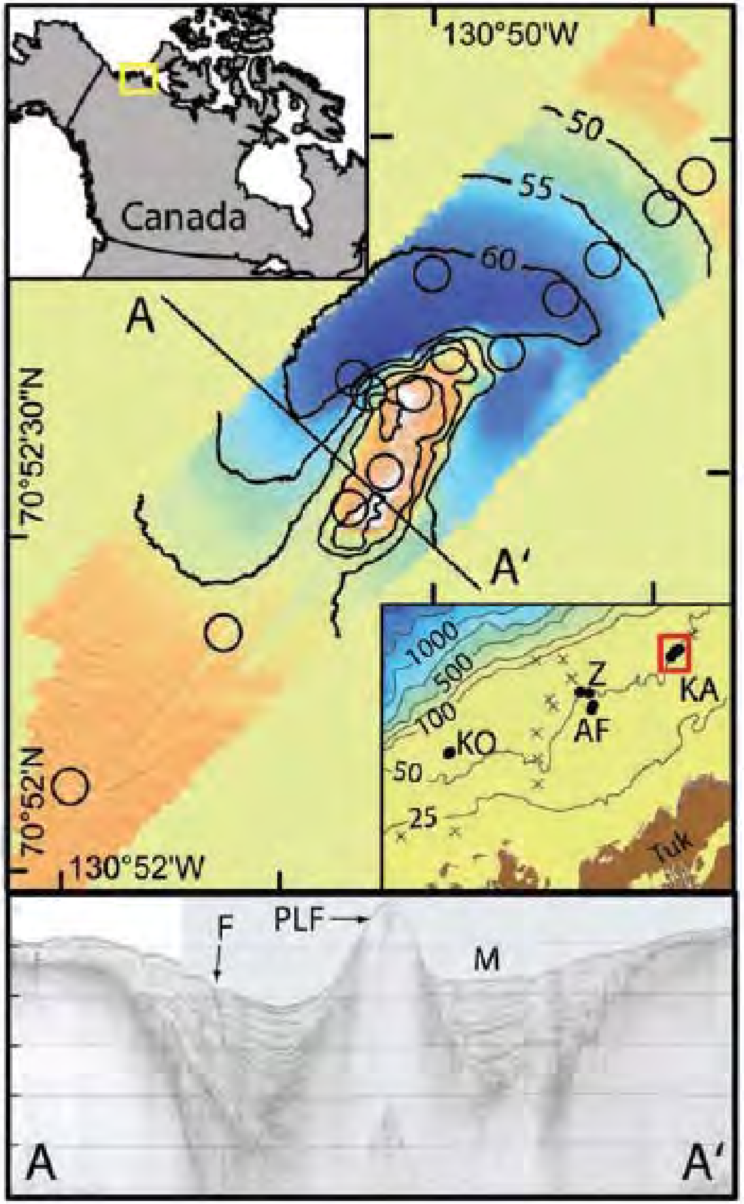
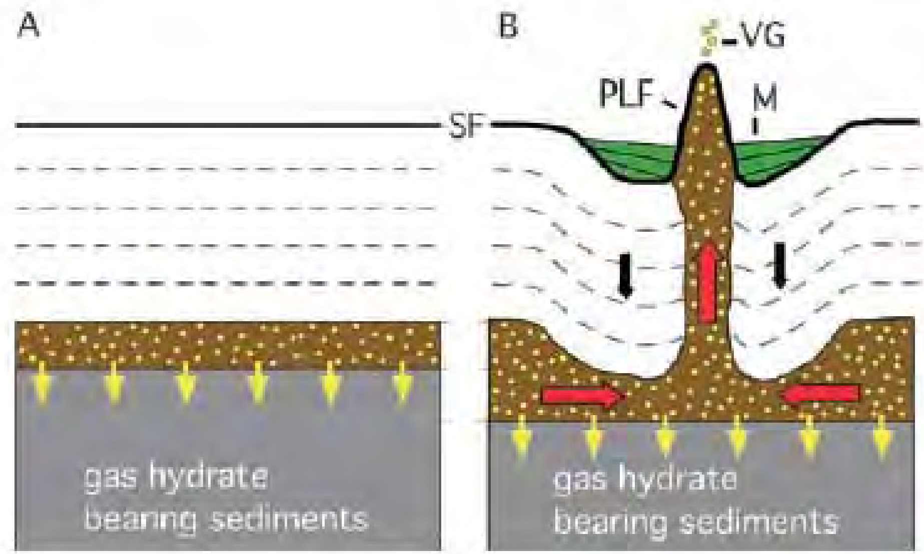
PLFs on shelf may be evidence for hydrate decomposition and gas migration to surface







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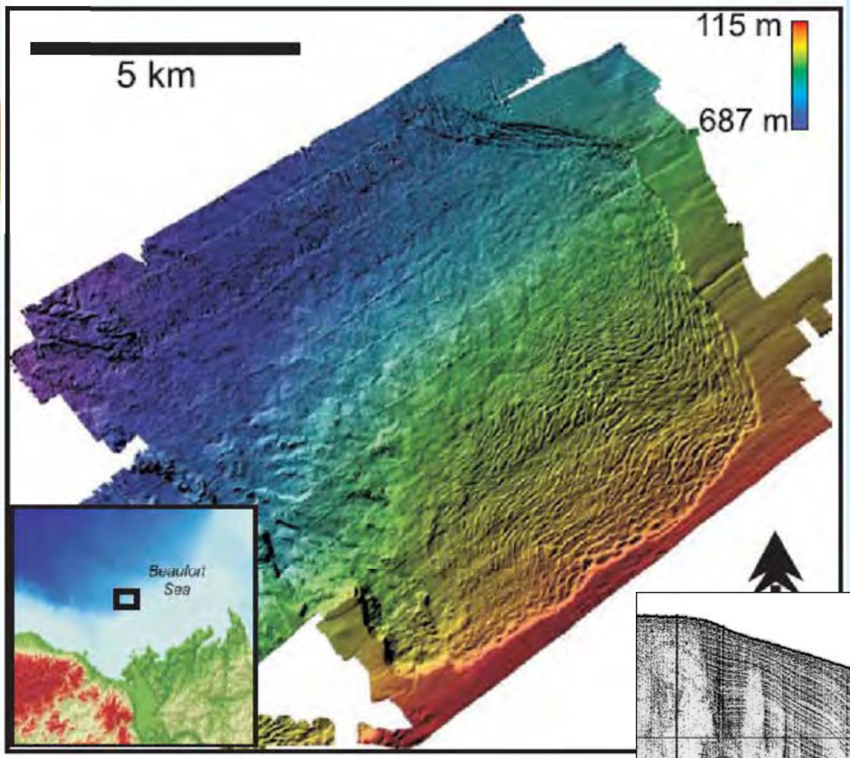
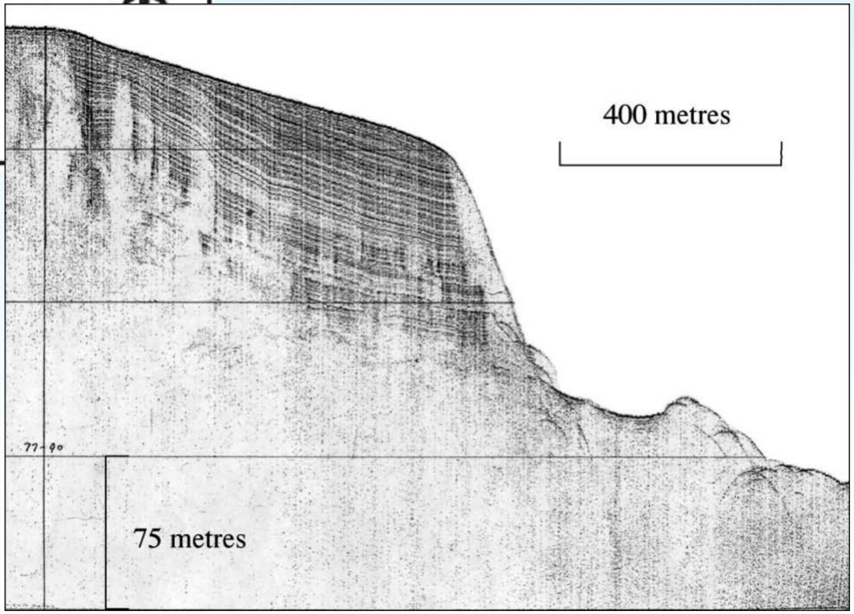
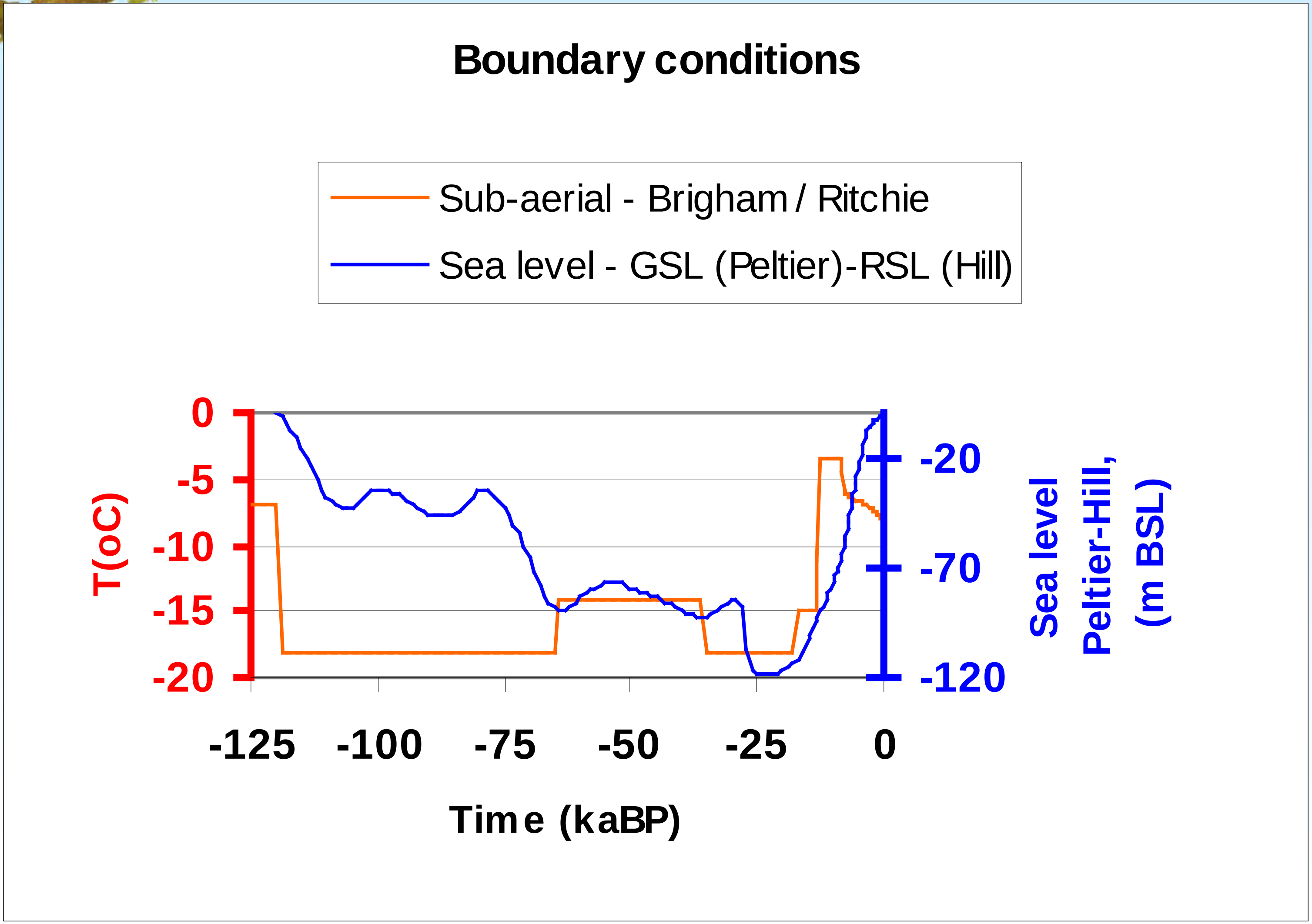


Mosher (2009) after Bennett et al. 2004)



O'Connor (1981)

Modeling permafrost (and hydrates)



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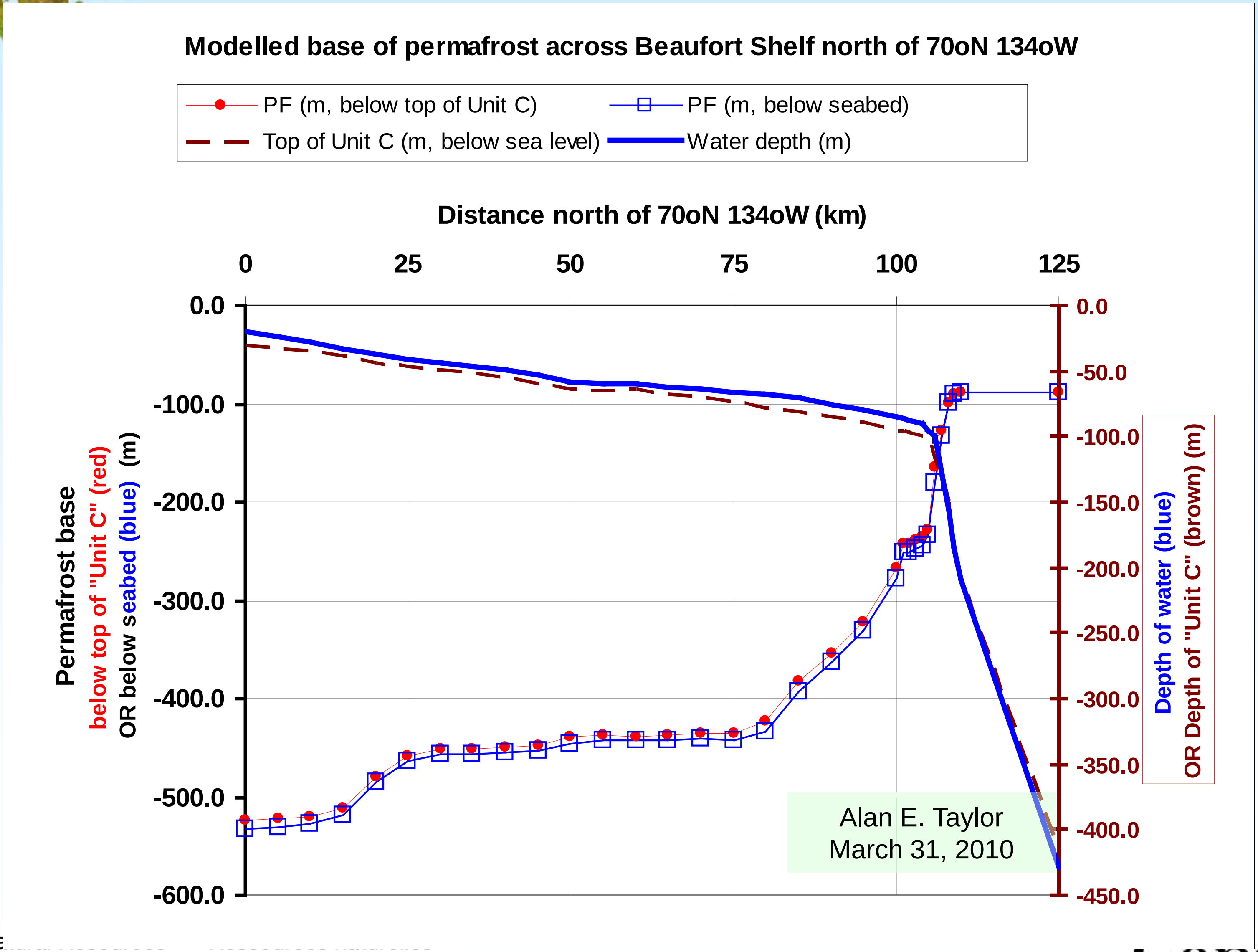
Simple model - function of sea level



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Uncalibrated

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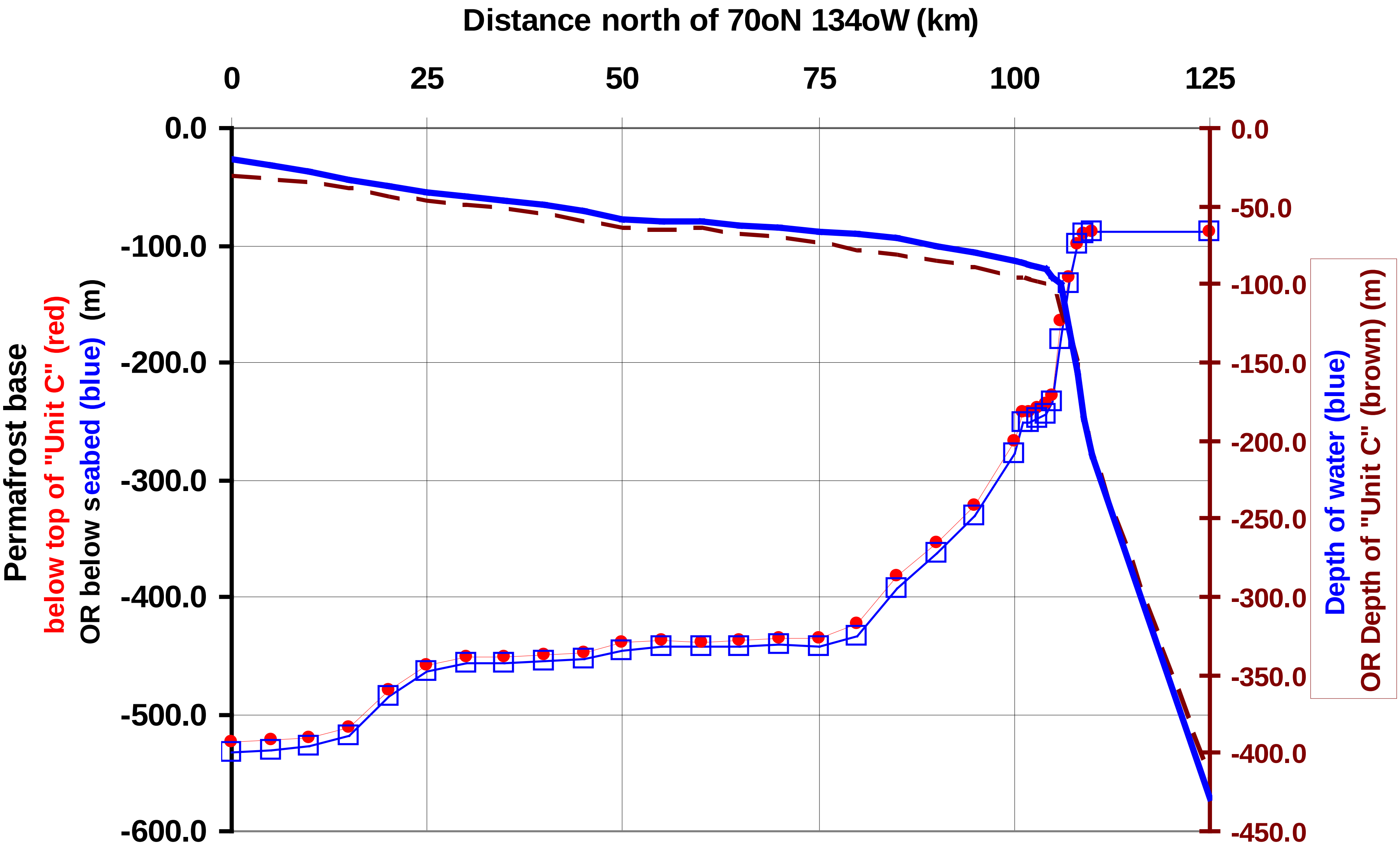
But shelf architecture evolves with time



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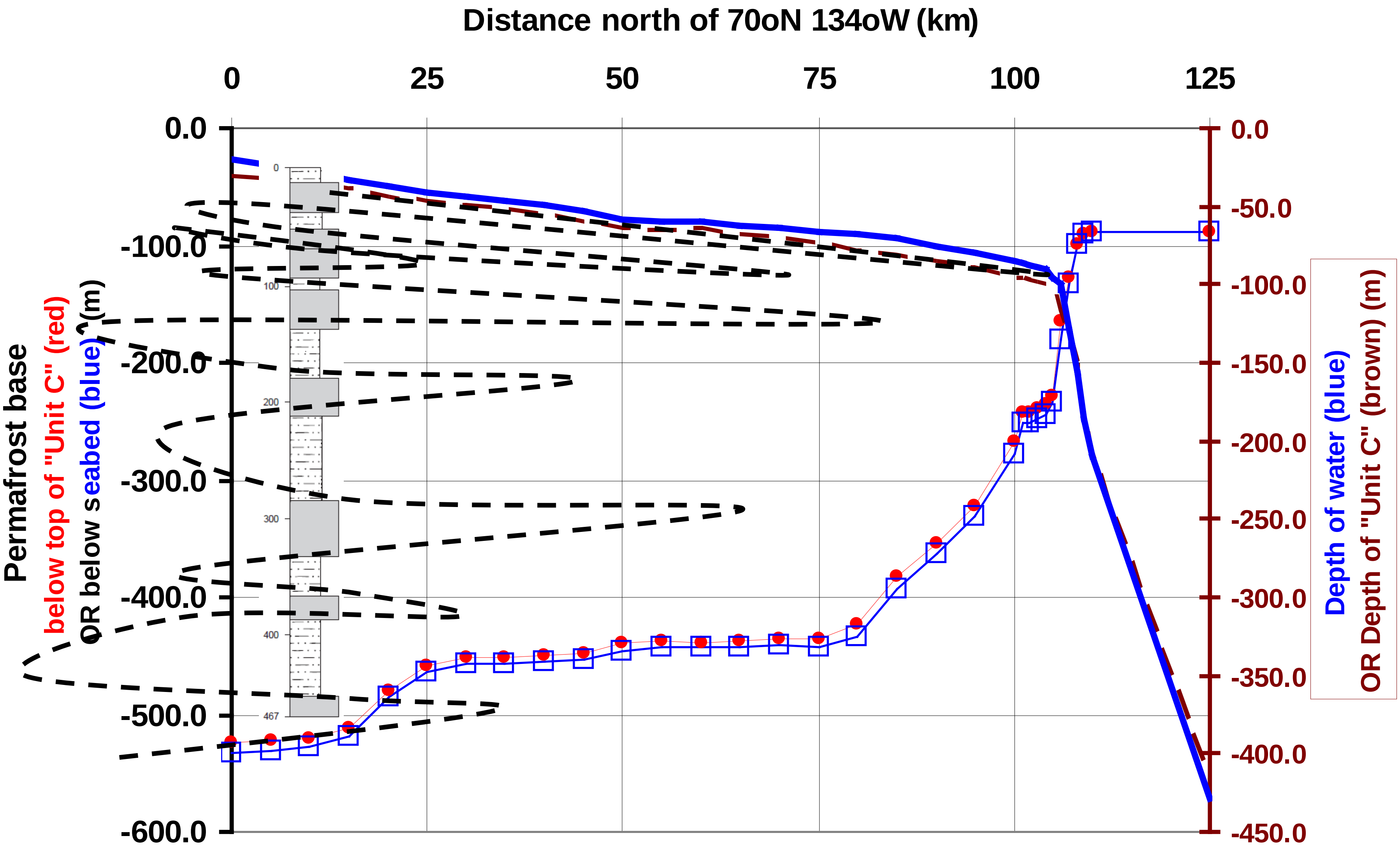


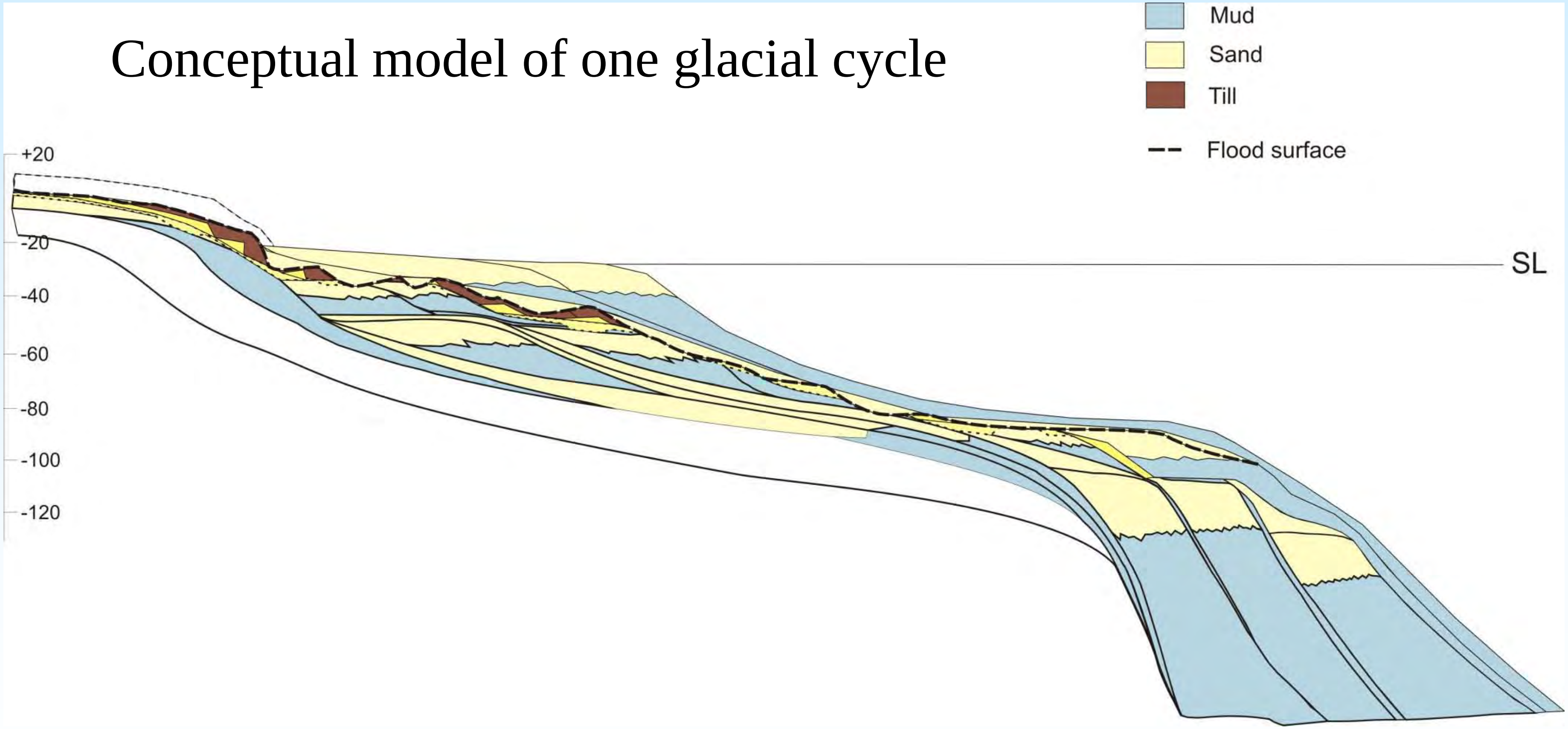
Hypothesis

- Gas hydrate decomposition is controlled by the complex interactions between sea level, stratal deposition and thermal history of the shelf.

(Present understanding of shelf stratigraphy does not consider the dynamic relationship between sea level, sediment supply and thermal history.)

Modeling depositional reality

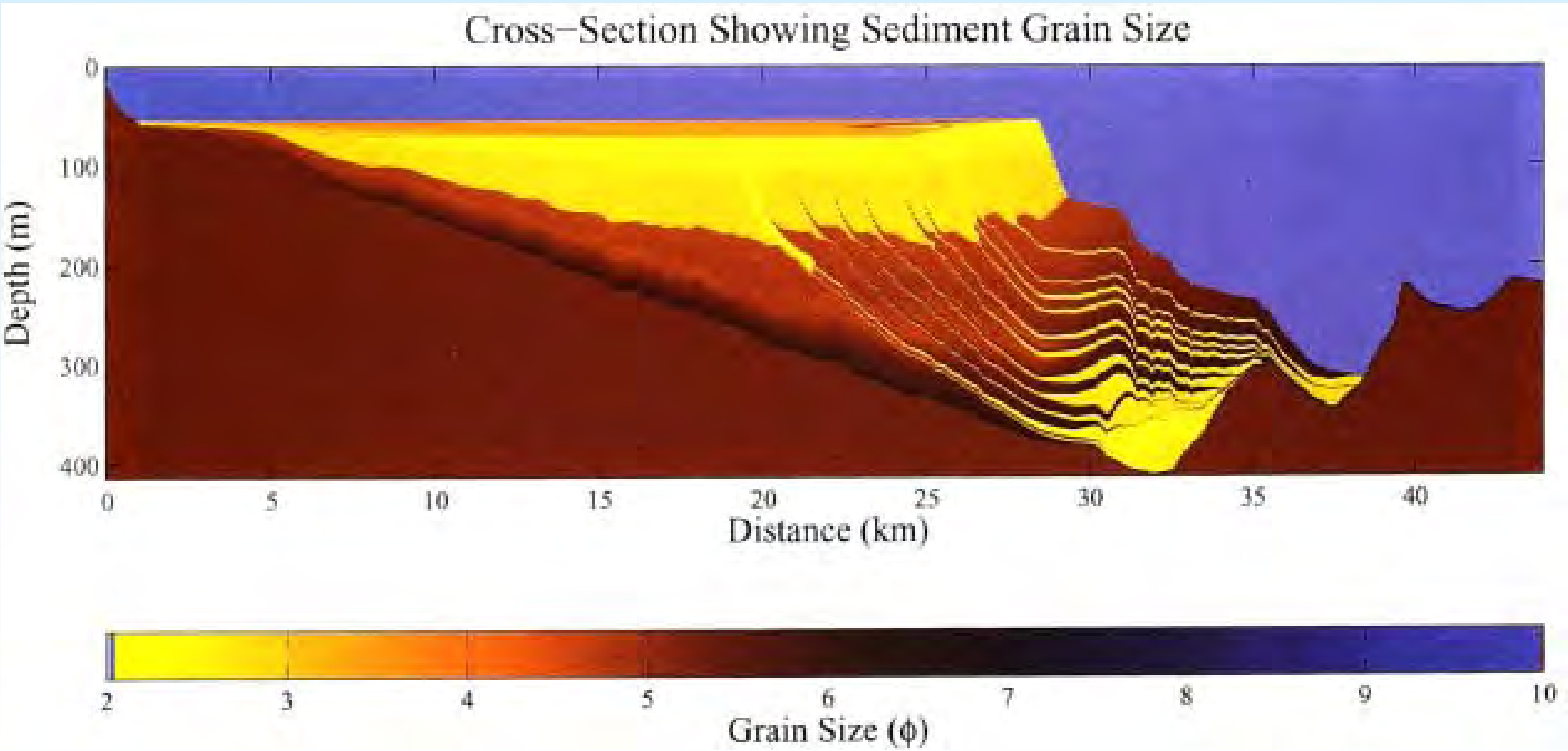
Conceptual model of one glacial cycle



Courtesy Kim Picard, NRCan

SEDFLUX model

(Syvitski & Hutton, 2001)



Controls on Depositional Architecture on Glacially-Influenced High Latitude Shelves (Input Parameters)

- Sediment supply
  - modulated by glaciations; single fluvial source vs braidplain, catastrophic outburst flows
- Sediment grain size supplied
  - proximity of ice front
- Sea level
  - high frequency, local effects of glacial loading
- Dispersal dynamics
  - reduced wave and tide influence

(after Swift et al. 1991)

Conclusions

- Subsea permafrost distribution and gas hydrate decomposition are controlled by complex interactions between sea level, stratal deposition and thermal history of the shelf.

- Present understanding of shelf stratigraphy does not consider the dynamic relationship between these parameters.

- Filling this knowledge gap would provide an improved framework for evaluating and mitigating geohazards related to permafrost and methane gas in the arctic offshore.