Gas Hydrates in Canadian Sverdrup Basin, Canadian Arctic Archipelago: A Potential New Focus for Canadian Resource Characterization*

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Abstract

Arctic Archipelago gas hydrates (GHs) are a potentially immense, poorly constrained petroleum resource, which is typically co-located with conventional petroleum. Fifteen or more GH accumulations may have GH/free gas contacts. Both characteristics enhance their commercial potential. Sverdrup Basin is a major extensional basin containing ~13 km of strata. The succession is deformed by several events including, diapiric salt structures and Eocene orogeny. The gas hydrate stability zone (GHSZ) is inferred developed discontinuously among the islands and inter-island seaways. Both significant permafrost and low annual surface temperatures or deep water with low sea bottom temperatures characterize the islands and the inter-island seaways, respectively. The result is that GHs are stable except near coastlines. GHs are inferred to occur in 57 of 150 wells. The average thickness of these occurrences is 65 m. This indicates the GH volume that might be expected, based on a small sample, from widely spaced wells in a huge region. Much of the resource is inferred to occur within Sverdrup Basin proper where fourteen wells show evidence that the GHSZ base lies above the gas/water contact, indicating possible GH/free gas contacts, although most GH accumulations are in contact with water above the GHSZ base. Another GH/free gas contact is inferred at a seismic prospect on Ellef Ringnes Island, and a bottom-simulating reflector (BSR) occurs on an Alpha Ridge seismic survey in the Arctic Ocean. These observations and modeling results suggest that Arctic GHs formed both by the transformation of previously trapped conventional theromogenic natural gas accumulations and due to sub-seafloor microbial methane migrating into the GHSZ. Well data suggests that up to ~52% of the available GHSZ might contain GH. Considering the uncertainties in reservoir parameters and the lateral persistence of GH between wells the resulting Arctic Archipelago GH contingent resource is estimated at 0.19-6.2 X 1014 m3 methane, of which the Sverdrup Basin holds the greatest part. Twenty-three inferred GH accumulations are found co-located with conventional Sverdrup Basin petroleum discoveries and shows which also enhances their commercial potential. Following the co-location of conventional and GH resources it might be possible to use GH occurrence as a prospecting tool for identifying conventional resources.

References

Hancock, S., Okazawa, T., and K. Osadetz, 2005, A Preliminary investigation of the economics of onshore gas hydrate production: Status of Unconventional Gas in Canada and the U.S., 7th Annual Conference on Unconventional Gas, 8 November 2005, Calgary, Alberta, Canada.

Majorowicz, J. A. and K.G. Osadetz, 2001, Basic geological and geophysical controls bearing on gas hydrate distribution and volume in Canada: AAPG Bulletin, v. 85/7, p. 1211-1230.

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A Potential New Focus for Canadian Resource Characterization

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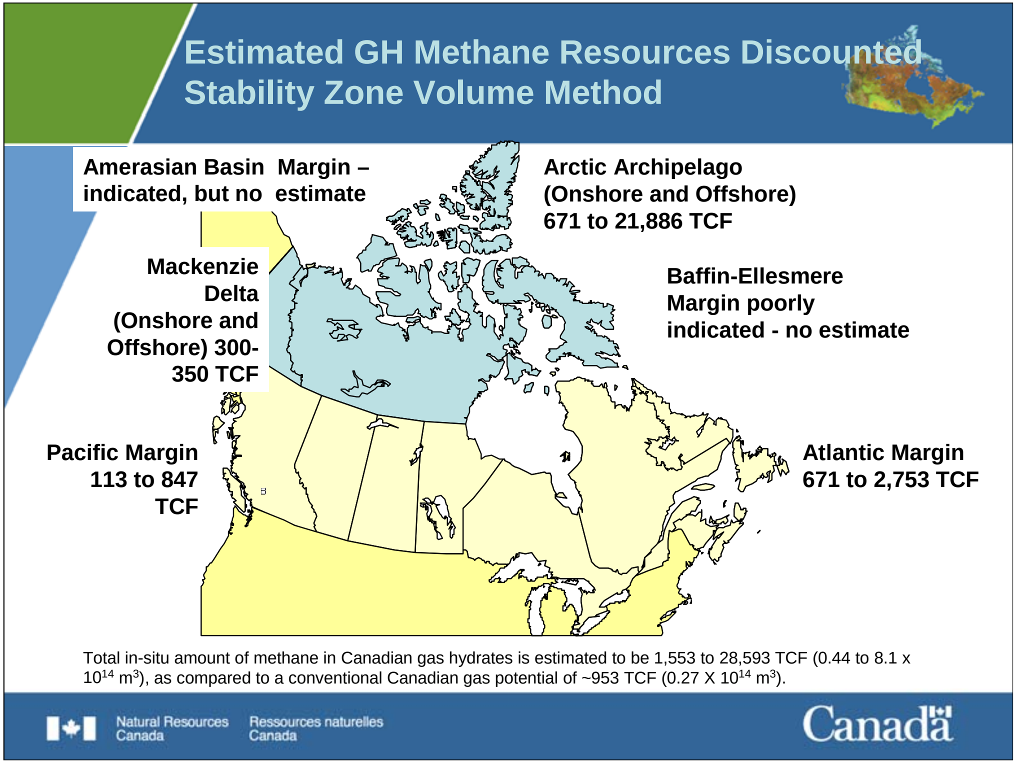
Presenter's notes:

Focus of talk is on the present thermal regime of Sverdrup Basin. This work is part of a multi-year, multi-disciplinary study of petroleum systems of the Sverdrup Basin that is continuing under the new GEM-Energy Program.

Sverdrup Basin GH occurrences

- **Possibly the largest, but also the most poorly constrained, Canadian GH resource.**
- **Complicated occurrences and history: onshore on islands and offshore in inter-island channels.**
- **Some continuing controversy about Pleistocene glacial history: Innuitian Ice Sheet model (consistent with recent geodynamics) versus Franklinian Ice Complex (climate-driven hypothesis due to proximity of Arctic Ocean).**
- **GHs occur in lithified successions with potentially better seismic images than in the Mackenzie Delta and Beaufort Sea.**
- **Large co-located conventional resources.**
- **Significantly colder mean annual surface temperature (current mean annual ground surface temperatures -20°C in Sverdrup Basin, but -6°C at Mallik), which improves opportunities for GH pellet marine transportation to market.**
- **A different political jurisdiction (Nunavut Territory).**



Presenter's Notes:

Canada is an Arctic and marine nation, and gas hydrates are confirmed or inferred to occur widely in its continental margins and permafrost regions. The total in-situ amount of methane in Canadian gas hydrates is estimated to be 1,553 to 28,593 TCF (0.44 to 8.1 x 10^{14} m^3), as compared to a conventional Canadian gas potential of ~953 TCF (0.27 X 10^{14} m^3). The geographic distribution of Canadian gas hydrates is:

Region ; Imperial Measure Metric Measure

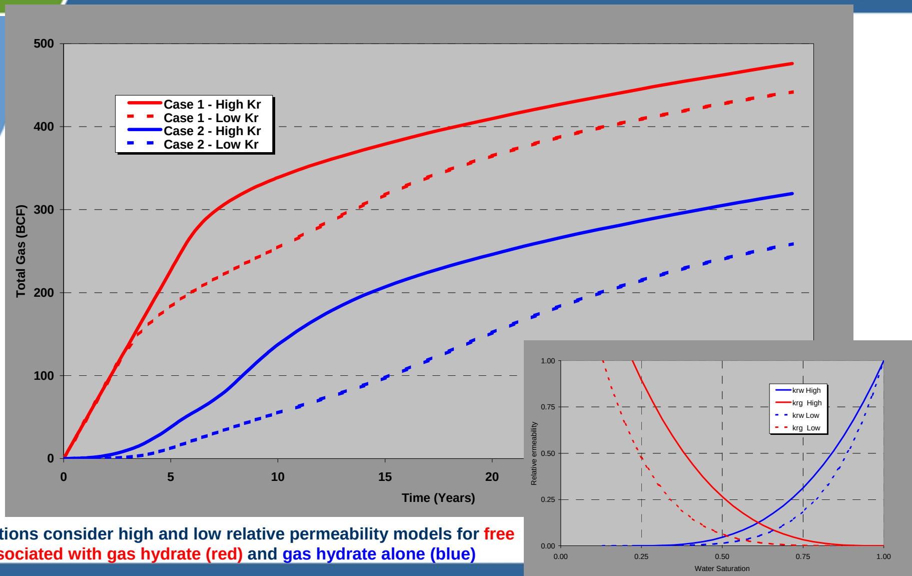
Mackenzie Delta–Beaufort Sea ; 300 to 350 TCF ; 8.82 to 10.23x10^{12} m^3. Arctic Archipelago ; 671 to 21,886 TCF; 0.19 to 6.2 x 10^{13} m^3. Atlantic Margin ; 671 to 2,753 TCF ; 1.9 to 7.8 x 10^{13} m^3. Pacific Margin ; 113 to 847 TCF; 0.32 to 2.4 x 10^{13} m^3.

Gas hydrate accumulations are also identified in Alaska and the offshore U.S.A. This suggests that gas hydrates represent a potential future assurance of North American natural gas supply, if the gas can be recovered economically. See Majorowicz and Osadetz (2001).

From Previous Mallik Studies and Models

- Geological occurrence and characteristics suggest that GHs formed as environmental conditions changed in conventional natural gas accumulations.
- Models confirm that the observed “gap” between the base of permafrost and gas hydrate is also consistent with this model of GH formation.
- The coincidence of the base of GHSZ with GH occurrence is unexplained or fortuitous.
- If formed by conversion of conventional accumulations, the gas “drying” effect remains similarly unexplained.

Rate, UER and Performance of GH Reservoirs: Shown with and without associated free gas



Simulations consider high and low relative permeability models for free gas associated with gas hydrate (red) and gas hydrate alone (blue)

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(Hancock, Okazawa and Osadetz, 2005)

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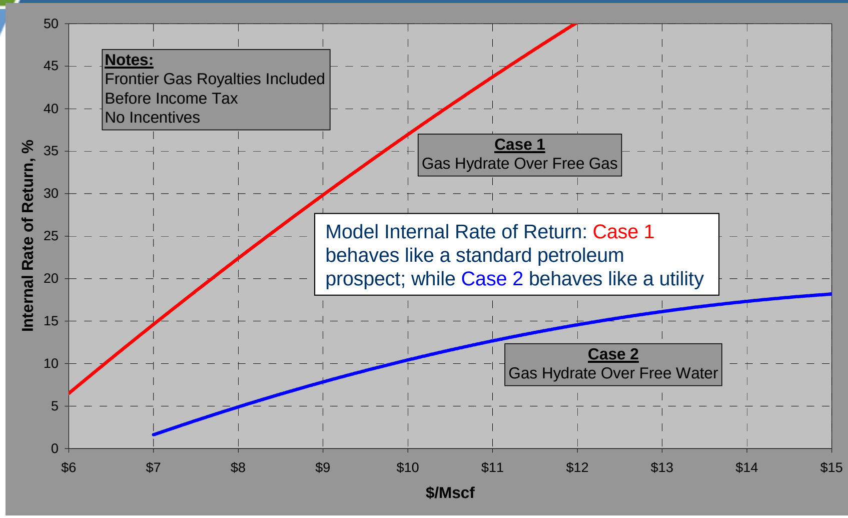
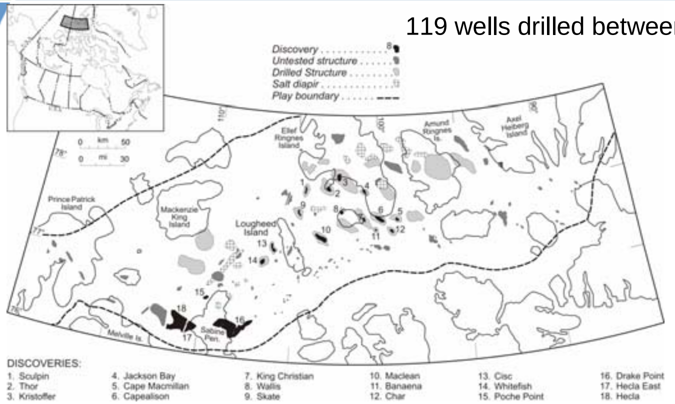
Rate, UER and Performance of GH Reservoirs: Shown with and without associated free gas



Simulations consider high and low relative permeability models for free gas associated with gas hydrate (red) and gas hydrate alone (blue)

Sverdrup Basin: Conventional Petroleum System

119 wells drilled between 1969 and 1986



Use GHs both as indications for conventional petroleum as well as a resource augmentation

- **294.1 X 10^6 m^3 OOIP and 500.3 X 10^9 m^3 OGIP 19 discovered fields (8 oil pools and 25 gas pools)**
- **540 to 882 X 10^6 m^3 OOIP and 1242 to 1423 X 10^9 m^3 OGIP total resource**
- **expected in ~93 fields, containing ~25 crude oil pools and ~117 natural gas pools.**
- **Observed co-location of conventional and GH resources**

Sverdrup Basin GH occurrences

- **The GHSZ is discontinuous, extending up to 2 km underneath the Islands and 1 km below sea level in deep inter-island channels.**

- **GHSZ occurs in many formations including both sandstones and, in the majority of cases, shales and siltstones. All hosting formations are well indurated and lithified – *different from the Mackenzie Beaufort region*.**

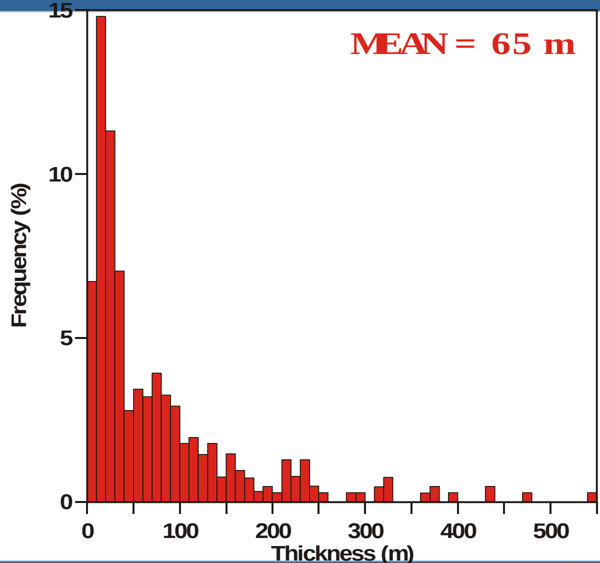
- **Methane hydrates are commonly inferred, well logs suggest that hydrates occur within at least 57 and possible 93 of 150 wells.**

- **GHs occur commonly 300 to 700 m above the base of the GHSZ.**

- ***Yet, gas hydrate/free gas contacts are inferred in 14 wells.***

- **23 inferred hydrate occurrences overlie conventional pools and other occurrences are on 'dry' structures, some exhibiting oil staining, where the top seal is inferred to have failed – a clear association with the conventional petroleum system – *similar to the Mackenzie Beaufort region*.**

INTERPRETED THICKNESS OF GAS HYDRATES IN THE ARCTIC ARCHIPELAGO



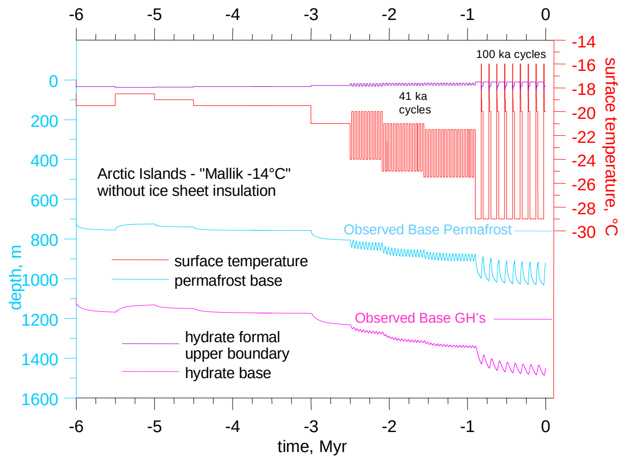
Sverdrup Basin Model without Ice Sheet Insulation or Pressure Effects

- Last 6 m.y. Sverdrup Basin Island setting with surface temperature forcing without ice insulation or pressure effects.

- Current mean ground surface temperatures -20°C in Sverdrup Basin, but -6°C at Mallik.

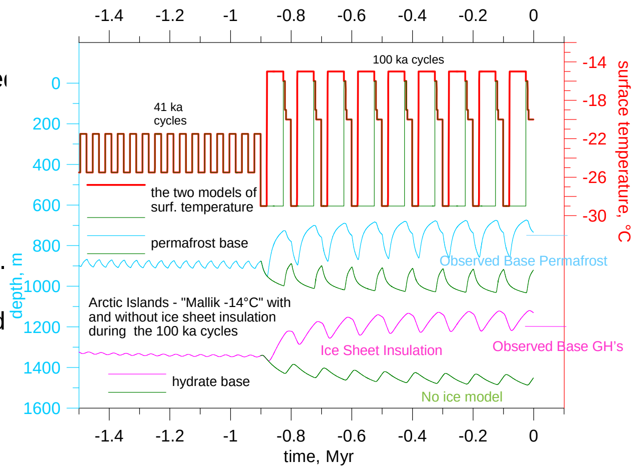
- Without ice sheet insulation or pressure effects the Sverdrup GHSZ is predicted deeper than observed.

- Note that GH are stable almost at the surface.



Sverdrup Basin Model with and without Ice Sheet Insulation, no pressure effect

- •Last 1.5 m.y. using surface forcing and ice sheet insulation compared to the previous model.
- •The effects of ice sheet thermal insulation are shown without the pressure effect of the ice.
- •Base of gas hydrate and permafrost layers are much shallower due to insulating effects of ice, but still not a match.



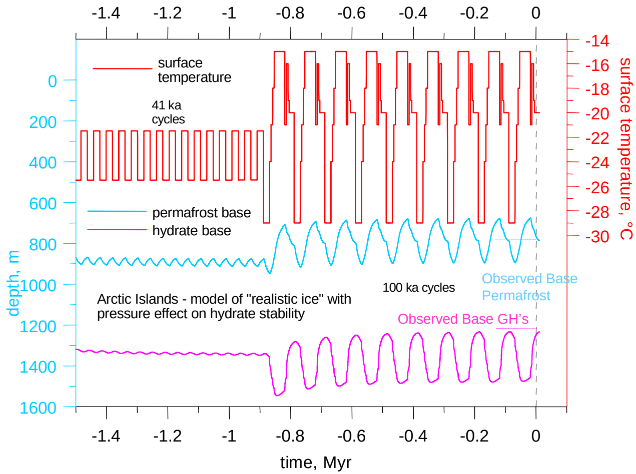
Sverdrup Basin "Realistic Ice" Model: Thermal Insulation and Pressure Loading

- Models of the last 1.5 m.y., using surface forcing to produce reasonable freeze and thaw cycles.

- Both insulation and the pressure effects of the ice sheets are considered.

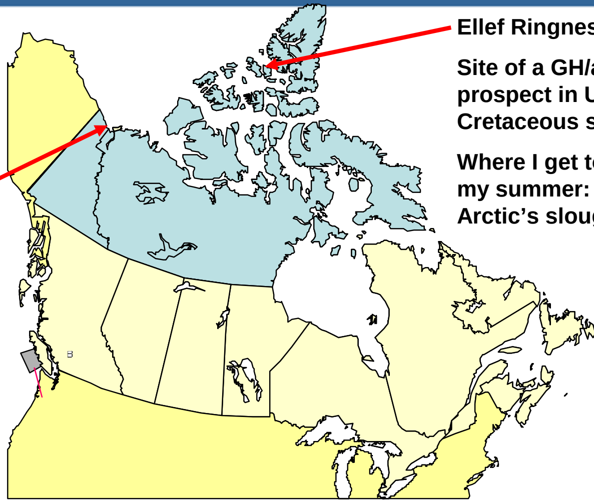
- Thermal insulation effects on the base of the GH layer are significant, but this acts contrary to the moderate pressure effects of ice sheet loading.

- Predicted GH and permafrost layer bases are in good agreement with observations.



Seismic Hassel Fm. GH/Free Gas Prospect: Ellef Ringnes Island

Mallik Site

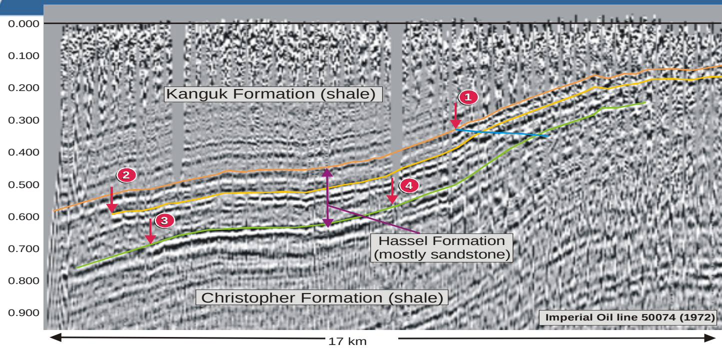


Ellef Ringnes Island

Site of a GH/associated Gas prospect in Upper Cretaceous sst.

Where I get to spend part of my summer: a.k.a. the Arctic's slough of despond.

Seismic Hassel Fm. GH/Free Gas Prospect: Ellef Ringnes Island

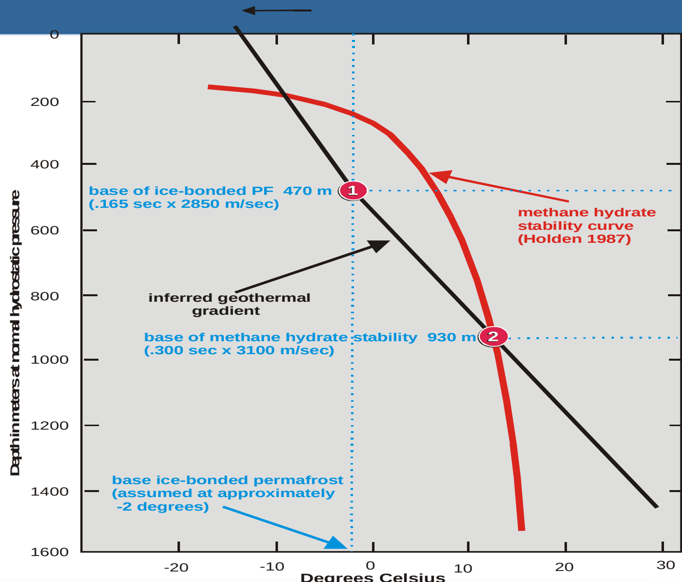


1 Level of the base of ice-bonded permafrost (blue) as interpreted at top of porous Hassel Formation (orange). Note: very fine-grained overlying Kanguk Formation shows no evidence of the lateral continuation of ice-bonded permafrost .

2 Level of the base of gas hydrate in an intra-Hassel Formation sandstone (yellow) interpreted at amplitude decrease caused by water replacing gas hydrate downdip.

3 Level of gas/water contact in sandstone near base of Hassel Formation. Interpreted at amplitude decrease and polarity reversal from water replacing free gas downdip. Note: very-fine grained Christopher Formation underlies Hassel Formation.

4 Level of base free gas/gas-hydrate within a lower Hassel Formation sandstone. Interpreted as polarity reversal of reflector caused by shale on gas sand (negative) changing to shale on gas hydrate sand (positive).



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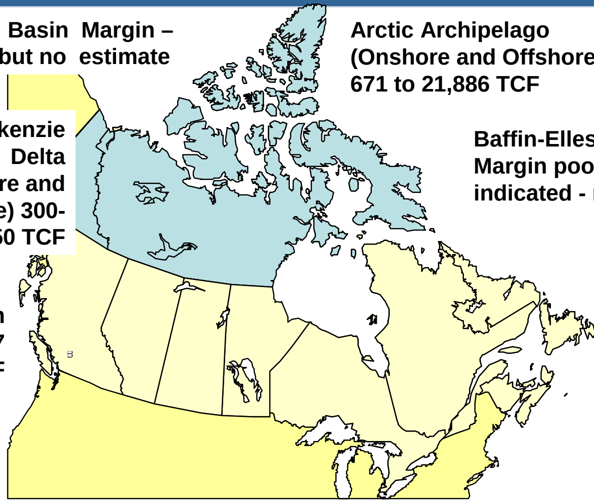
Estimated GH Methane Resources Discounted Stability Zone Volume Method



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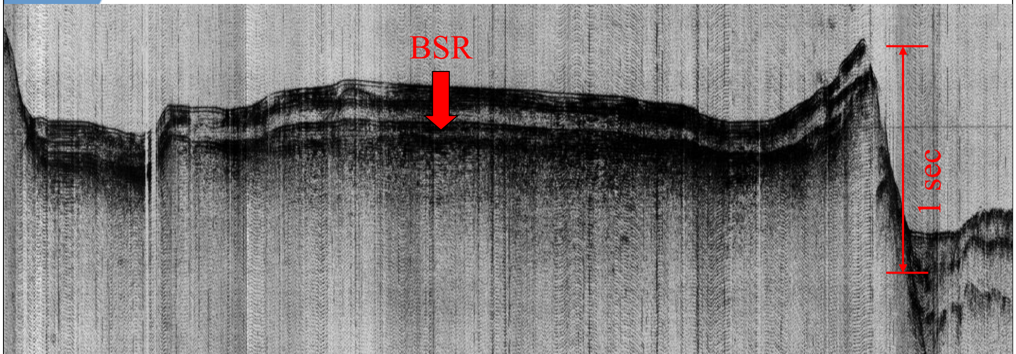
Indications for Gas Hydrate Resources in the Arctic Ocean Basin



Data from the Canadian Expedition to the Alpha Ridge
(Jackson, 1985)

Conclusions

- Very large and “rich” GH accumulations occur throughout Sverdrup Basin co-located with very large conventional petroleum resources.
- Models indicate that Sverdrup GHs formed in conventional accumulations in response to environmental changes that exhibit the effects of both thermal insulation and pressure from the overlying Innuitian ice sheet.
- A seismic prospect onshore Ellef Ringnes Island suggests the presence of a gas hydrate and associated free gas accumulation.
- GH indications may provide an aid to prospecting of conventional petroleum accumulations.
- Low (-20°C) annual mean surface temperatures favour GH pellet transportation for both conventional and unconventional natural gas production from Sverdrup Basin.

Presenter’s Notes:

The purpose of this study is to provide a simple initial model that attempts (1) to reconcile GH and IBP current state with independently determined ground surface temperature history (GSTH), (2) to characterize the nature of changes of IBP and GH layers with GSTH during the last 500,000 years, (3) to predict the impact of the high regional GST warming trend on the fate of the GH and IBP layers to the end of the current interglacial (11.5 kyrs in the future), (4) to begin an investigation of the past role and future fate of the GH carbon reservoir in relation to climate change.