Baffin Fan and its inverted rift system of Arctic eastern Canada; is this another Beaufort-Mackenzie Basin?

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Summary
Baffin Fan is a twelve km thick sedimentary wedge of Eocene to Pleistocene age in northwestern Baffin Bay; size and resource potential comparable to Beaufort-Mackenzie Basin (Figure 1). Notable is syntectonic sedimentation with possible volcanism and rifting in the Cretaceous-Danian. Sequences associated with inversion in the later Paleocene and Eocene display out-of-graben thrust anticlines formed over horst blocks in Lady Ann and Lancaster Sound basins. The Oligocene to mid-Miocene is associated with fluvial-deltaic systems; replaced since then by glacial-interglacial sequences including submarine canyons and deep-water fans. Exploration targets are located in Lancaster Sound, and a Baffin Bay fairway that runs 220 km northwestward to east of Coburg Island. Sixty-five percent of prospects are located under Neogene cover. Fourteen are each greater than 70 km^2, and five are between 334 and 592 km^2. Based on drilling success rates elsewhere and the existence of a petroleum system, 12 of the 40 mapped structures may contain hydrocarbons in significant quantity.

Introduction
Emerging areas for offshore exploration in Arctic eastern Canada are located on the continental margins of Labrador Sea and Baffin Bay, and in the fault-controlled grabens that underlie some of the larger bays and the entrances to several major inter-island channels. The northern limit of prospective basins on the southern Baffin shelf is defined by an arch and Paleogene flood basalt province, located in Davis Strait and extending northward from southeastern Baffin Island to central West Greenland. Northwest of this arch is the continental margin sediment prism of the Baffin shelf and slope, and a major sediment depocentre that lies in the mouth of Lancaster Sound. Fault-bounded basins also run westward from Baffin Bay through Lancaster and Jones sounds, and northwards into Smith Sound. The USGS provide a mean undiscovered resource estimate of 51.8 tcf gas and 7.3 bbl oil for the West Greenland-Arctic East Canada region north of the Arctic Circle (Schenk *et al.* 2008). Uncertainties are enormous but justified by the complete absence of exploratory drilling in the Canadian half of Baffin Bay, and very little published literature on geophysical data acquired by the resource sector in the 1970s and 1980s.

The present paper provides a geological overview of the Cretaceous to Cenozoic and Quaternary sedimentary basins of the western Baffin Bay, Lancaster Sound and Smith Sound region, and an introduction to hydrocarbon potential.

Method

Industry and government seismic surveys, studied together with published bottom sampling results, reports from an ODP site on the lower Baffin slope (Srivastava et al.,1987), from the West Greenland margin and from various onshore geological analogs, provide a starting point for understanding the gross architecture of these offshore basins.

Examples

Acoustic basement, where it underlies seismically recognizable Mesoproterozoic and younger strata, is identified as undivided Archean and Paleoproterozoic granitoid gneiss and high grade supracrustal rocks, not unlike rocks widely exposed on Baffin, eastern Devon and southeastern Ellesmere islands. Mesoproterozoic strata (1.27 to ~1.0 Ga) are prominently represented at the sea floor in offshore Thule Basin (between Greenland and Ellesmere Island, Harrison et al., 2006), and on eastern Coburg High (around Coburg Island). Long lived slide surfaces in these rocks include steeply-dipping planar normal faults in Thule Basin and seismically-defined bedding parallel detachment planes in the Coburg High area. Slide surfaces dip at 20 to 26 degrees southward from Coburg High and merge with a proposed detachment that appears to coincide with refraction Moho at a depth of 20 to 21 km under Lady Ann Basin east of Devon Island, under Lancaster Sound Basin, and under various detached and rotated horst blocks. The intersection of northerly striking faults of strike slip character in the granitoid-gneiss complex with the northerly limit of detachment-related extensional slip in the Mesoproterozoic suggests that transform motion associated with the opening of Baffin Bay (conventionally attributed to the Wegener Fault) may terminate at the northwestern corner of Thule Basin on southeastern Ellesmere Island.

Platformal lower Paleozoic strata under Lancaster Sound Basin are identified by their fast interval velocity and maximum thickness (~1000 m), similar to that now preserved on Borden Peninsula and on eastern Devon Island. An unconformity bound sequence above erosionally truncated Silurian in Lancaster Sound Basin and Lady Ann Basin may include sandstone, shale, coal and volcaniclastic Lower Cretaceous sediments. These strata occur, either undeformed in western Lancaster Sound Basin, or in simple synclines and thrust anticlines within grabens to the east and north. Especially significant are inversion thrust anticlines, tectonically emplaced over Cretaceous horst blocks during the Thanetian and Eocene.

Syn-rift Upper Cretaceous to Danian strata are correlated with exposures in West Greenland, Bylot Island and the Canadian Arctic Islands. The existence of Cretaceous oil source rocks at depth is indicated by the organic geochemical signature of hydrocarbons collected and analyzed from Scott Inlet seep (MacLean *et al.* 1981; Fowler, pers. comm.., 2008).

Seismic Selandian strata, deposited during an early phase of sea floor spreading in Baffin Bay, are correlated with the lower Eureka Sound Group of central Ellesmere Island. These reach 3000 m in some grabens documented within and north of Lancaster Sound Basin. The next three seismic depositional sequences that span the Thanetian to Eocene interval were deposited during predominantly northward motions of Greenland, and the related second phase of sea floor spreading in Baffin Bay. Age range and facies are based on features present in the upper Eureka Sound Group of Ellesmere Island and include fluvial-deltaic sandstones, coal, and conglomerate. These sequences, in outcrop and on seismic profiles, were deposited during phases of compressive

deformation and during growth of anticlines and inversion structures observed on horst block highs.

Baffin Fan is an Eocene to upper Pleistocene sediment wedge up to 12 km thick in a depocentre located east of the mouth of Lancaster Sound (Figure 1). The fan occupies an area comparable to that of the entire Beaufort-Mackenzie Basin. Peak sediment accumulation rates are associated with an Oligocene to upper Miocene seismic sequence that ranges to 5700 m thick below the mid-Miocene shelf edge. Although the wedge top currently lies in water depths ranging to 900 m, Miocene and older shelf-deltaic facies are preserved under a Plio-Pleistocene submarine canyon complex and under correlative Plio-Pleistocene submarine fan deposits east and southeast of Lancaster Sound.

The petroleum geology of Baffin Fan and its inverted rift system, although entirely based on indirect evidence, compares favourably to that of the much better known Beaufort-Mackenzie Basin of northwestern Arctic Canada. Although the rift and drift phases are younger for Baffin Fan, there is strong indication of several phases of pre-migration structure development. With some certainty, it can be predicted that gas prone source rocks and suitable reservoirs are thick and widespread in various Cretaceous through Eocene formations. Cenomanian-Turonian oil source rocks are likely preserved in the major half grabens and it is probable that Eocene oil source rocks are present throughout deeper buried parts of Baffin Fan.

From a depth to basement map, forty (40) structural targets, all untested by drilling, are identified in western Baffin Fan and in its rift system. Additional targets will arise from systematic mapping of various sequences that span the Lower Cretaceous to end-Eocene package. The known structures are located in eastern Lancaster Sound, and in western Baffin Bay in a belt of prospects that runs northwestward more than 220 km from east of Bylot Island to east of Coburg Island. Sixty-five percent (i.e. 28 of the 40) are located under Neogene cover of Baffin Fan. There are 14 structures that each enclose an area in excess of 70 km^2; five of these range between 334 and 592 km^2. Based on success rates from drilling in the Beaufort-Mackenzie Basin it can be expected than approximately 29%, or 12 of the 40 mapped structures, might contain hydrocarbons in significant quantity.

Conclusions

Baffin Fan is a twelve km thick sedimentary wedge of Eocene to Pleistocene age in northwestern Baffin Bay. Considered together with the underlying inverted Cretaceous-Paleocene rift system, size and resource potential of the region may be comparable to Beaufort-Mackenzie Basin.

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References

Harrison, J.C., Brent, T.A. and Oakey, G.N., 2006. Bedrock geology of the Nares Strait region of Arctic Canada and Greenland, with explanatory text and GIS content. Geological Survey of Canada Open File 5278.

MacLean, B., Falconer, R.K.H. and Levey, E.M., 1981. Geological, geophysical and chemical evidence for natural seepage of petroleum off the coast of Baffin Island. Bulletin of Canadian Petroleum Geology, 29, 97-95.

Schenk, C.J., Bird, K.J., Brown, P.J., Charpentier, R.R., Gautier, D.L., Houseknecht, D.W., Klett, T.R., Pawlewicz, M.J., Shah, A., and Tennyson, M.E., 2008. Assessment of undiscovered oil and gas resources of the West Greenland–East Canada Province. U.S. Geological Survey Fact Sheet 2008–3014, 2008-3014.

Srivastava, S.P.. Arthur, M.A., Clement, B. and Shipboard Scientific Party, 1987. Part A: Initial report; Baffin Bay and Labrador Sea, Leg 105. Proceedings of the Ocean Drilling Program 105.

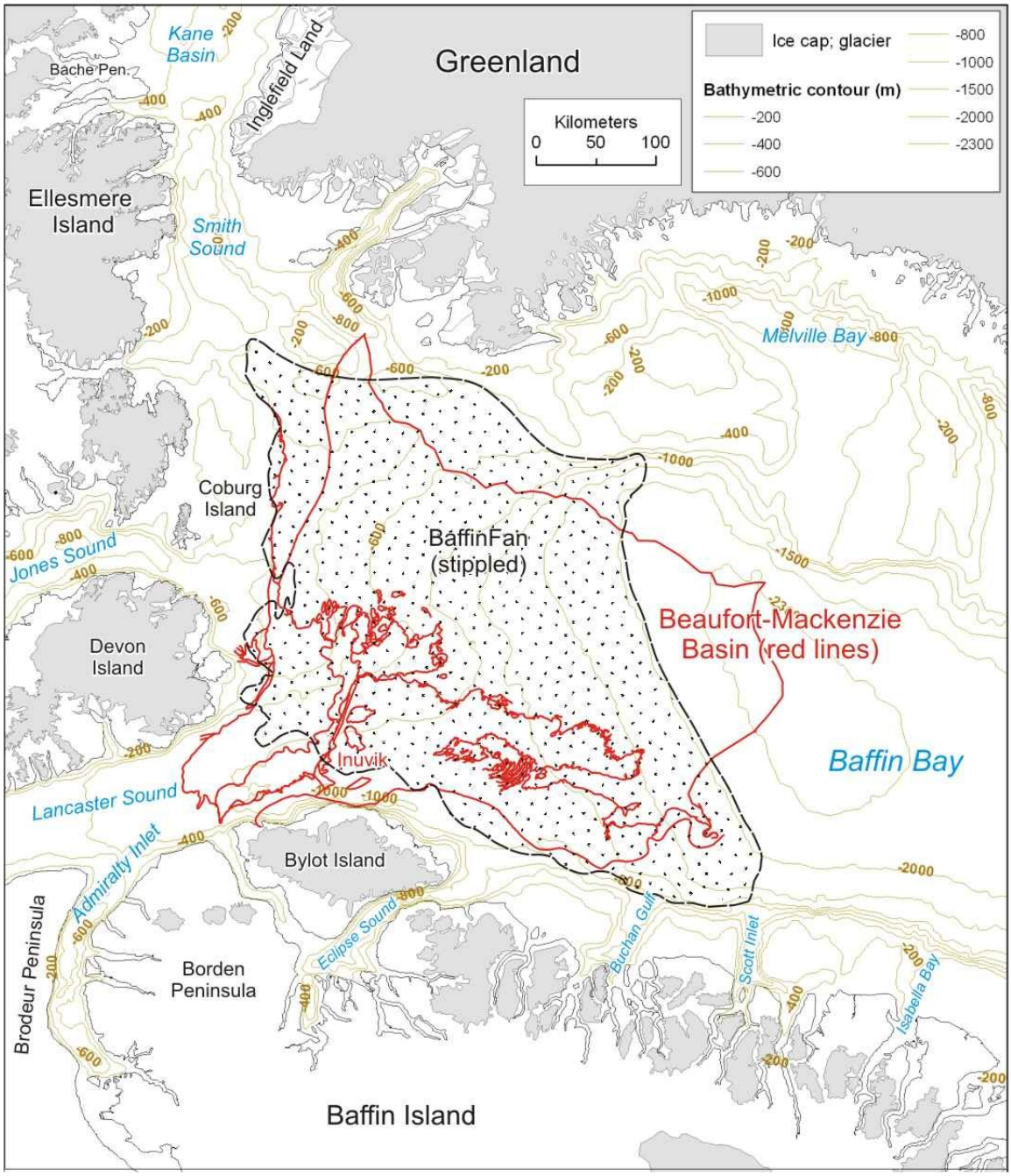

Figure 1: Size comparison of Baffin Fan (Eocene and younger) and Beaufort-Mackenzie Basin. Significant Cretaceous-Paleocene grabens are located under the fan and in Lancaster Sound, Jones Sound and Smith Sound, and in Melville Bay on the northwest Greenland shelf.