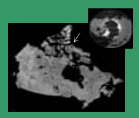
WHEN TREES WHERE GROWING IN THE ARCTIC: A TWO MILLION YEARS OLD GLACIAL-INTERGLACIAL TRANSITION ON BYLOT ISLAND.

STUDY SITE LOCATION, GEOLOGY AND GEOMORPHOLOGY

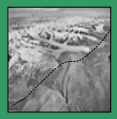
Bylot Island is located in the eastern Canadian Arctic, north of Baffin Island (73°N, 80°W), more than 2000 km north of the present-day tree line. The Island is separated from Baffin Island by a graben (of Early-Cretaceous age) occupied by the Eclipse Sound inlet. Two major physiographical units of the Canadian Arctic make up the landscape of the island: the Davis Highlands, represented by the Byam Martin Mountain range and the Arctic Lowlands, represented by the coastal plains on either side of the mountains. These mountains (average elevation 1400 meters a.s.l.) are oriented Northwest-Southeast and are made of metavolcanic and metasedimentary rocks dominated by gneiss, mainly of Precambrian age. The glacier-covered range extends across the island over its whole length. The Arctic Lowlands, which extend notably over the southern plain of the island, are made of shale and coarse grained sandstone of the Lancaster formation (Cretaceous to Tertiary age). They form plateaus and plains at elevations below 550 m a.s.l (Miall *et al.*, 1980).

The plateaus are dissected by U-shaped and V-shaped valleys and large gullies that were eroded by glaciers and rivers during the Tertiary and the Quaternary. They are covered by tundra vegetation. The contact between the two geological formations is along a fault line that is easily observable in the field and on aerial photographs. Several glaciers flow out of the valleys from the mountains onto the lowlands.


Location of Bylot Island

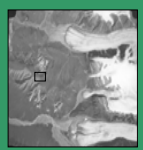

Study site location


Geological map


Contact line between the two geological formations

The study site is located at an elevation of about 500 m a.s.l. at the head of large gullies cut in the Cretaceous-Tertiary formations of the plateau, about 1 km from the contact line with the Precambrian rocks. The surface of the plateau is crossed by a network of ice-wedge polygons developed in glacial drift. According to exposures in erosional bluffs at gully heads, the thickness of the drift varies from 2 to 10 m. Organic-rich layers outcrop under the drift.

Present-day mean annual air temperature is about -15 °C and the mean annual ground temperature at a depth of 10 m in the permafrost is about -12 °C.


1:50 000 aerial photo of the study site


Plateau surface


Outcrop location at gully head

STRATIGRAPHY

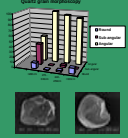
Reconstructed through the combination of seven small sections within a 1 km radius, the sequence overlying the Cretaceous-Tertiary bedrock is composed of three units.

1- Basal till

The lowermost unit is a diamicton comprising striated sub-angular to sub-rounded pebbles, cobbles and boulders in a poorly sorted very fine-grained matrix. The layer is barren of fossils. Precambrian gneisses make up the majority of the clasts, but the deposit also contains clasts of shale and sandstone originating from the underlying bedrock. Microscopical analysis and scanning electron microscope (SEM) imagery of quartz grains showed a dominance of angular grains with conchoïdal fractures that are typical of glacial abrasion and transport. The presence in the till of some rounded, pitted and iron-stained quartz grains, typical of the local Tertiary sandstone indicates a glacial erosion of the local bedrock. The till appears devoid of allochtonous lithology which suggest a glaciation of local origin so that glaciers where flowing from the mountain range, or highlands, to the lower plateaus, in a way similar to the present-day glacial flows.


Basal till exposure


Clasts from basal till



SEM imagery: Presence of rounded, pitted and iron-stained quartz grains that are typical of the local sandstone bedrock.

2- Organic-rich sediment sequence

The lodgment till is covered by a water-laid deposits that comprises abundant, well-preserved, organic remains. The mineral fraction of the water-laid sediments has a lithology similar to the underlying till. From the top of the till deposit up, there is a gradual transition from clast-rich material to fine-grained organic-rich sediments, thereby indicating a transition from lifeless glacial conditions to a thriving post-glacial ecosystem. The different facies of the unit comprise layers of organic-rich alluvial sediments incorporating logs as well as some thick peat layers. The thickness of the organic sequence varies from a few cm up to 2 m, from one studied section to the other.


Organic-rich sediment sequence

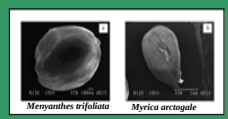

Wood pieces in water-laid sediments

Remains of tree trunks (*Picea mariana*, *Larix* sp., *Pinus spp*., *Betula* spp., etc), branches, leaves, cones, roots and rhizomes in soil, along with remains of herbaceous plants (*Andromeda polifolia, Decodon* sp., *Camaedaphne calyculata, Menyantes trifoliata*, etc.) and bryophytes (e.g. S*phagnum* sp. and mosses) indicate that these species lived on the site. Insects remains and diatoms were also collected from the organic horizon and the alluvial sediments. Some plant (e.g. *Aracites globosa*, *Myrica arctogale)* and insects *(e.g. Diachella matthewsi*) in the fossil assemblages belong to extinct species already recognized as of Late Pliocene age (between 2 and 3 million years ago). This organic-rich unit is the inheritance of a wet open forest-tundra environment bordered by rivers, ponds, marshes and peatlands.

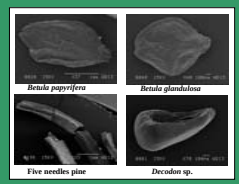
In one section, a layer of gelifracted gneiss boulders is embedded in peat, suggesting, in accordance with the fossil content, that periglacial conditions were prevailing, with geomorphological features such as block streams.



Exemple of some of the logs found at the site.



SEM photo from seeds of extinct species



SEM photo from seeds, pollens and needle

Cones found in the organic rich deposit

The organic remains and sediments likely reflect an environment of forest-tundra with rivers, lakes, ponds, bogs and fens. The temperature was probably 7 to 8 °C higher than today.

This picture from the region of Umiujaq, in Northern Quebec (55° 17' N, 77° 46' O), could be used as an analogy to this type of ecosystem.

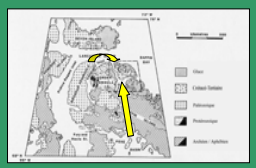
Piraux O., Allard M., Fortier D., Lavoie C., Laval University, Centre d'études nordiques.

3- Surficial drift

A sequence of glacio-fluvial and glacial deposits overlies the fossil organic unit through an erosion unconformity. The drift contains clasts of Paleozoic limestone that are allochtonous to Bylot Island. Broken fragments of marine shells were found in the drift. Earlier studies suggested that this "foreign" drift was probably deposited during an old Quaternary glaciation named "Baffin glaciation" (Klassen, 1993).

Gelifracted erratic at the surface of the plateau

Glacio-fluvial and glacial deposit



Possible source of the Paleozoic limestone erratics in the surficial drift

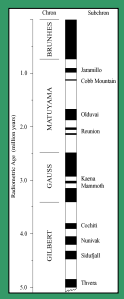
CHRONOLOGY AND CORRELATIONS

Magnetostratigraphy

Magnetostratigraphy is a technique used to date old sedimentary stratigraphic sequences beyond the range of dating methods such as ^{14}C, thermo-luminescence or Uranium series. Oriented samples are collected throughout a section. The Detrital Remanent Magnetization (DRM) of the samples is determined in order to know the polarity of Earth's magnetic field at the time of deposition. Indeed, when very fine-grained magnetic minerals (< 17 μm) fall through the water column, they orient themselves following the Earth's magnetic field. Upon burial that orientation is preserved, provided there is no subsequent perturbation of the sediments. A normal polarity corresponds to the present-day magnetic field. An inverse polarity indicates that the North Magnetic Pole was near the South Rotational Pole. The chronology of inversions is known from magnetic measurements on lavas dated by the K-Ar method in various part of the World (Cox et al., 1968).

A reverse to normal polarity transition was found in the organic-rich sedimentary unit. Considering the paleontological context (i.e. > 2 M.A.), the polarity change could tentatively be assigned to one of the two Réunion reverse subchrons (2.01 – 2.04 and 2.12 – 2.14 Ma), or to the Keana reverse subchron (2.92 – 3.01 Ma). The analysis also showed that the overlying glacio-fluvial sediments were deposited during a period of normal polarity, assigned to the Brunhes polarity chron (younger than 0.78 Ma)

Magnetostatigraphy sampling and location of the polarity transition in one of the organic rich unit.



Magnetic polarity time scale

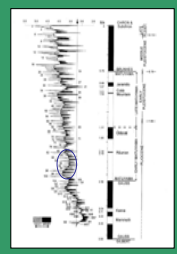
Possible correlations for the older till

The till at the base of the sequence was laid down during a local glaciation that has never been reported so far. This till may be one of the oldest occurrence of continental glacial deposit in the eastern Canadian Arctic. This glacial event could potentially be correlated with some tills reported in northwest Canada and east-central Alaska, dated between 2.9 and 2.6 Ma. Correlations can also be attemped with some of the first occurrences of ice-rafted debris in the North Atlantic marine sediments starting at about 2.6 Ma ago.

•The age of the glacial deposits in Yukon and Alaska has been attributed to the Gauss reverse polarity and is therefore older than *2.58 Ma* (Duk-Rodkin et Barendregt, 2003)

•Core from ODP site 646, 647 (Baffin Bay) contain dropstones overlaid by pollen-rich sediments around 2.6 Ma
(de Vernal et Mudie, 1989)

•Cores from ODP site 552A (South of Iceland) contain a series of alternating glacial and non glacial periods starting after 2.7 Ma (from $\delta^{18}O$ et $\%CaCO_3$)
(Shackelton et al., 1984)



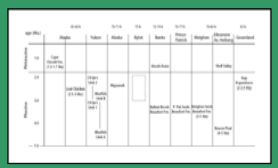
Late Pliocene glacial-interglacial transitions from $\delta^{18}O$ of marine sediments.

Paleontological correlations with other well known sites

The Bylot Island fossil assemblage shares similarities with other sites in the Arctic. Furthermore, the presence of extinct key species allow to better ascertain the age of this ancient environment.

Kap Kobenhavn, Greenland (2 - 2.5 Ma) (Bennike, 1990)
The basal part of this shallow marine sediment sequence bears evidence of glaciation (dropstones from Icebergs)
Presence of *Aracites* and *Myrica*
Absence of *Pinus* could mean the Bylot site is somewhat older.

Lost Chicken, Alaska (2.5 - 3 Ma) (Matthews, unpublished report)
Similar plant species composition
Presence of *Epipremnum cressum* could imply that Bylot is somewhat younger.



Possible correlations with other sites.

Location of other Late Pliocene and early Pleistocene deposits.

Conclusion

Paleontological correlations suggest that the organic-rich unit likely dates between 2.5 and 2.0 MA. The gradual sedimentary transition from the underlying till to the organic unit indicates a transition from glacial to interglacial conditions rather similar to what took place after the last deglaciation whereas the mineral fraction of riverbeds, lakebeds and other Holocene sediments at the base of bogs was reworked from Wisconsin glacial drift. One glacial-interglacial transition in the North Atlantic marine record corresponds in time with the first Reunion reverse subchron at 2.15 MA, thereby pointing to this probable date for the organic unit.

This terrestrial glacial-interglacial transition recorded in the Bylot terrestrial record is one of the oldest found so far in the eastern canadian archipelago . It took place during the Late Pliocene (a period which will eventually be redefined as Early Quaternary). Since both the subarctic climate conditions reflected by the fossil assemblage and the periglacial context reflected by the sedimentary facies indicate conditions favourable at least for discontinuous permafrost, it is likely that the organic debris were soon frozen after their burial and kept frozen in permafrost since then.

References:

Bennike, O. 1990. The Kap København Formation: Stratigraphy and palaeobotany of a Plio-Pleistocene sequence in Peary Land, North Greenland. MoG Geoscience vol. 23, 85 pp.
Cox, A., Doell R. R. and Dalrymple, G. B., 1968. Radiometric time-scale for geomagnetic reversals, Quart. J. Geol. Soc., v. 124, 53–66.
De Vernal, A. et Mudie P.J. 1989. Pliocene and Pleistocene palynostratigraphy at ODP sites 646 and 647, Eastern and Southern Labrador sea. Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 105 : 401-421.
Duk-Rodkin, A. et Barendregt R.W., 2003. Timing and extend of Plio-Pleistocene glaciations in Northwestern Canada and East-Central Alaska. Geological Society of America *Abstracts*, p. 114
Klassen, R.A. 1993. Quaternary geology and glacial history of Bylot Island, Northwest territories. Ottawa : Energy, Mines and Ressources Canada, 93p.
Miall, A.D., Balkwill, H.R., et Hopkins Jr., W.S. 1980. Cretaceous and Tertiary Sediments of Eclipse Trough, Bylot Island Area, Arctic Canada, and their Regional Setting. Geological Survey of Canada. Paper 79-23. 20 p.
Matthews, J.V., Late Cenozoic plant and insect macrofossils from Alaska and Arctic/Subarctic Canada : new data, intercontinental comparaisons and correlations. Personal data, unpublished report.
Piraux, O. 2004. Paleogeographical context of the fossil forest of Bylot Island, Canadian Arctic. M.Sc. Geography Thesis. Laval University, Quebec: 125 pages.
Shackleton *et al.*, 1984. Oxygene isotope calibration on the onset of ice-rafted and history of glaciation in the North Atlantique region. Nature, Vol. 307: 620-623.

Acknowledgements: NSERC, Parks Canada, FQRNT, PCSP, DIAND, Community of Pond Inlet