Groundwater Resources Evolution in Degrading Permafrost Environments: A Small Catchment-Scale Study in Northern Quebec, Canada

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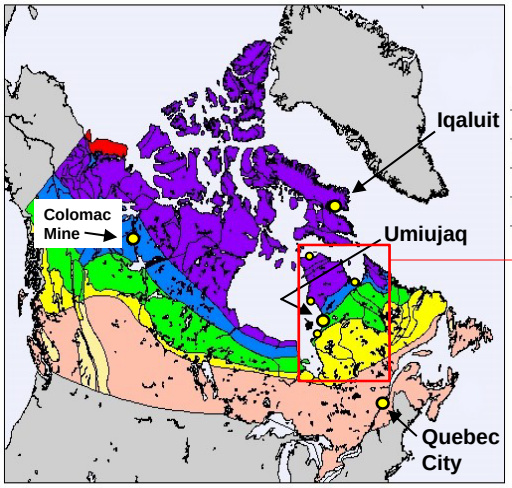
NATURWISSENSCHAFTLICHE FAKULTÄT

Research Sites in Canadian Permafrost

Permafrost map of Canada



Heginbottom et al. 1995

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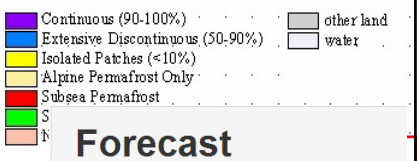
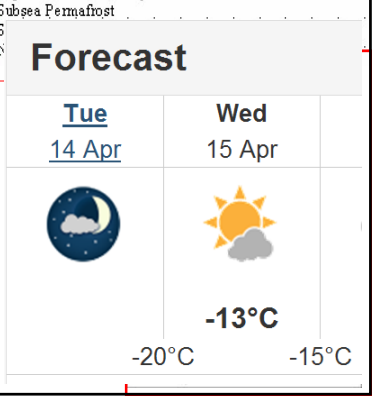
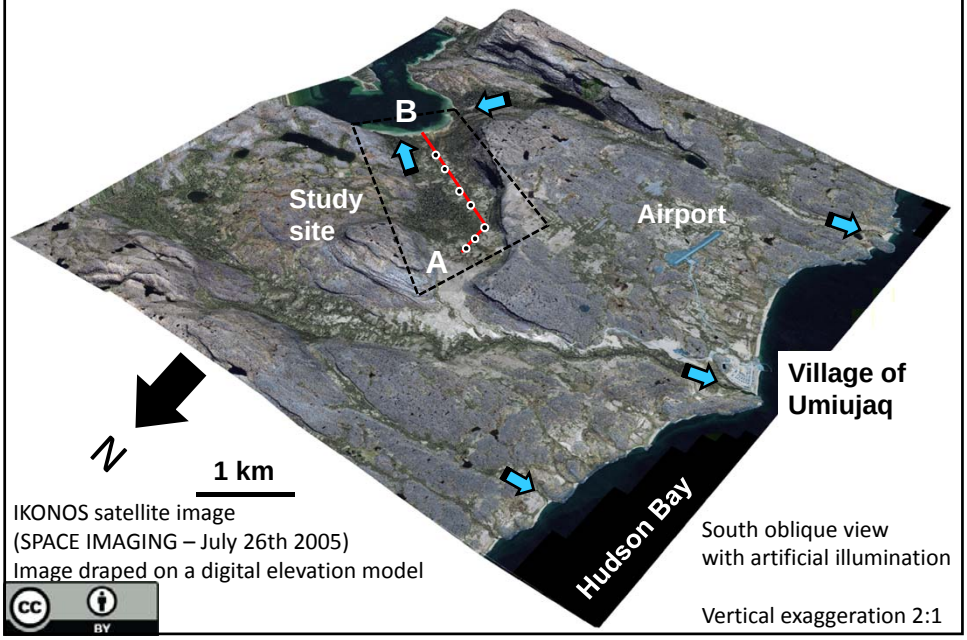




Immatsiak Network Location

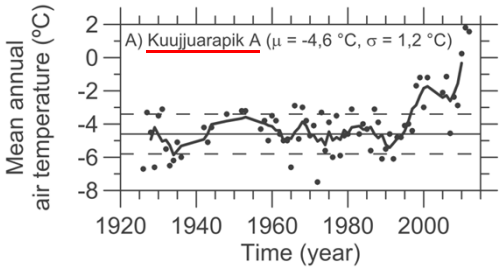


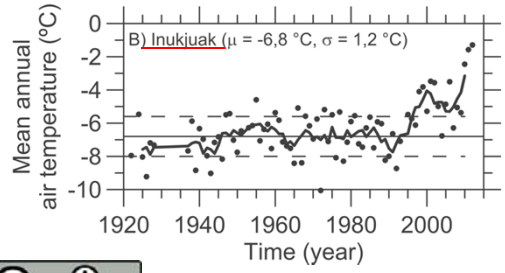
IKONOS satellite image
(SPACE IMAGING – July 26th 2005)
Image draped on a digital elevation model

South oblique view
with artificial illumination

Vertical exaggeration 2:1

Recent climate variability and impacts





Motivation and Objectives

- Provincial Groundwater Monitoring Network
- Assess the impacts of climate change on groundwater resources (Quebec Climate Change Plan)
- Immatsiak network (meaning "source of fresh water" in Inuktitut), Umiujaq
- Study the groundwater dynamics in permafrost environments
- Hypothesis 1: Improved groundwater availability
- Hypothesis 2: Groundwater flow increases permafrost degradation

http://www.mddep.gouv.qc.ca/eau/piezo/index.htm

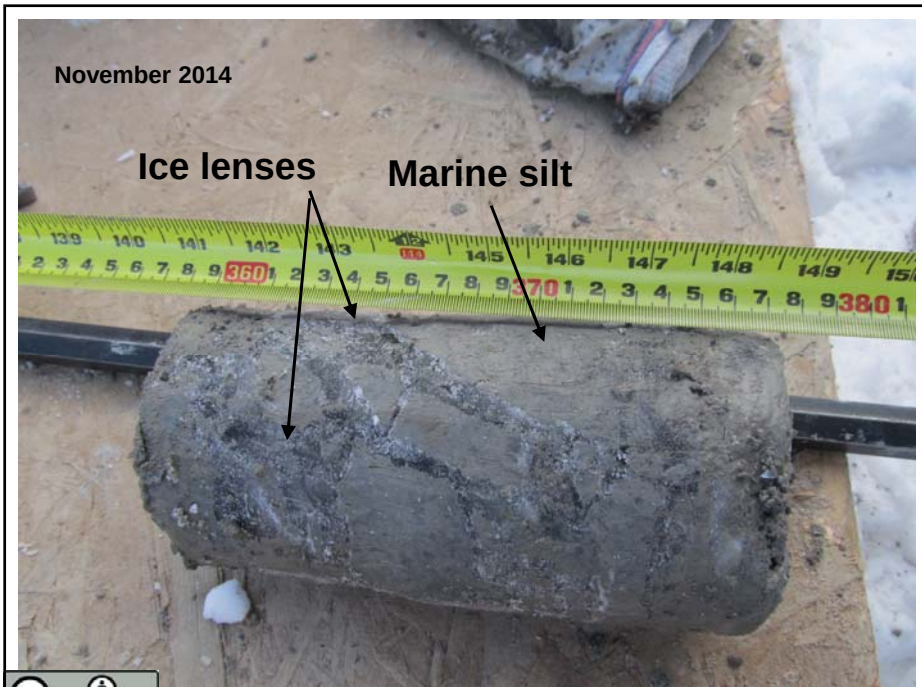
5

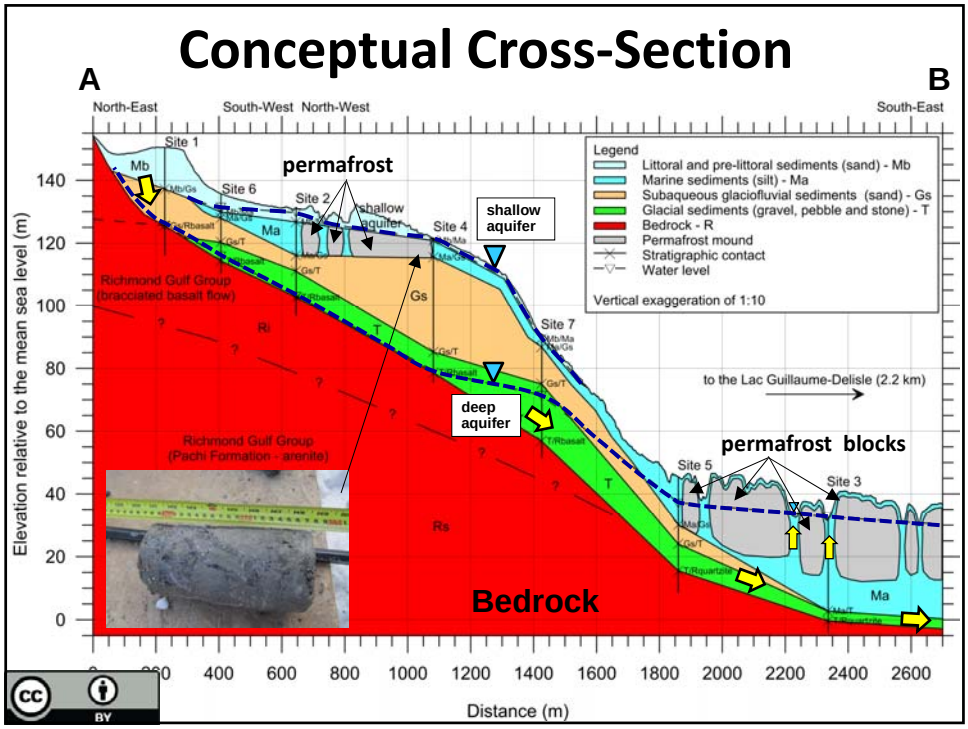

CEN Residence
Hudson Road
ARRÊT
STOP

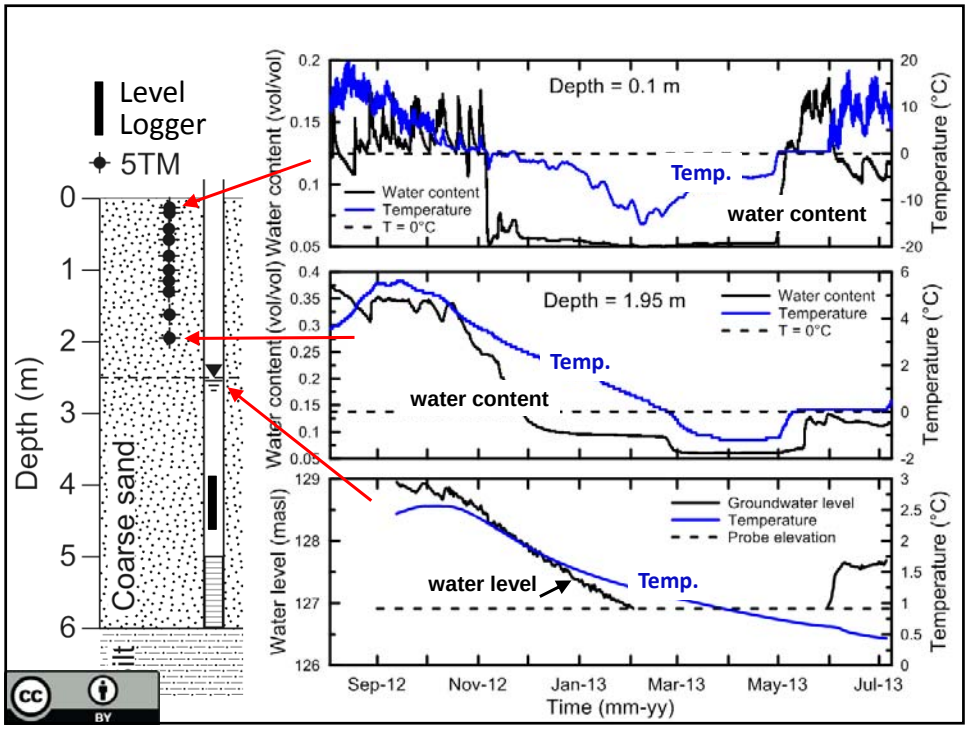

Drilling campaign June 2012
Sampling campaign July 2013

July 2013

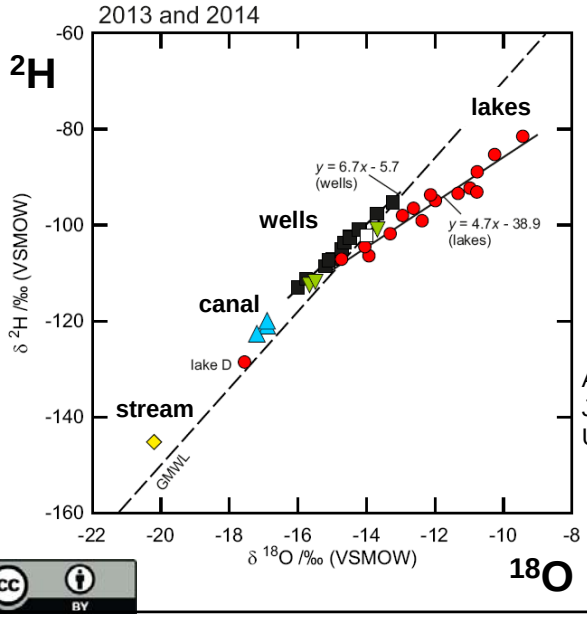

November 2014


November 2014
Ice lenses
Marine silt


Conceptual Cross-Section
A
B
North-East
South-West
North-West
South-East
permafrost
shallow aquifer
deep aquifer
permafrost blocks
Bedrock
Richmond Gulf Group (bracciated basalt flow)
Richmond Gulf Group (Pachi Formation - arenite)
to the Lac Guillaume-Delisle (2.2 km)
Legend
Littoral and pre-littoral sediments (sand) - Mb
Marine sediments (silt) - Ma
Subaqueous glaciofluvial sediments (sand) - Gs
Glacial sediments (gravel, pebble and stone) - T
Bedrock - R
Permafrost mound
Stratigraphic contact
Water level
Vertical exaggeration of 1:10
Elevation relative to the mean sea level (m)
Distance (m)


Level Logger
5TM
Depth (m)
Coarse sand
Depth = 0.1 m
Depth = 1.95 m
Water content
Temperature
T = 0°C
Temp.
water content
Groundwater level
Probe elevation
water level
Water content (vol/vol)
Temperature (°C)
Water level (masl)
Time (mm-yy)
Sep-12
Nov-12
Jan-13
Mar-13
May-13
Jul-13

Umiujaq Isotope Data 2013-2014



Analysis by:
J. Barth and R. van Geldern
University of Erlangen, Germany

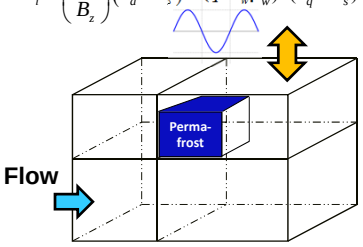
Numerical Simulation Approach:

HEATFLOW/SMOKER (Molson & Frind, 2015)

- **3D deformable Galerkin finite element**
- **Porous medium & discrete fractures**
- **Heat, mass transport & mean age**
- **Equilibrium geochemistry**
- **Liquid & ice phases, latent heat**

Surface boundary:

$$J_i = \left(\frac{\lambda_u}{B_z}\right)(T_a - T_s) + (q \cdot c_w \rho_w)\cdot(T_q - T_s)$$



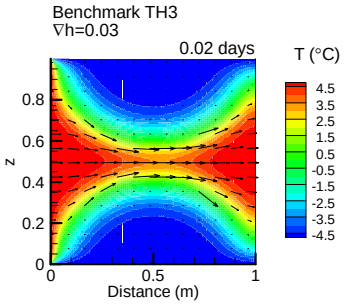
Groundwater Flow: (ψ)

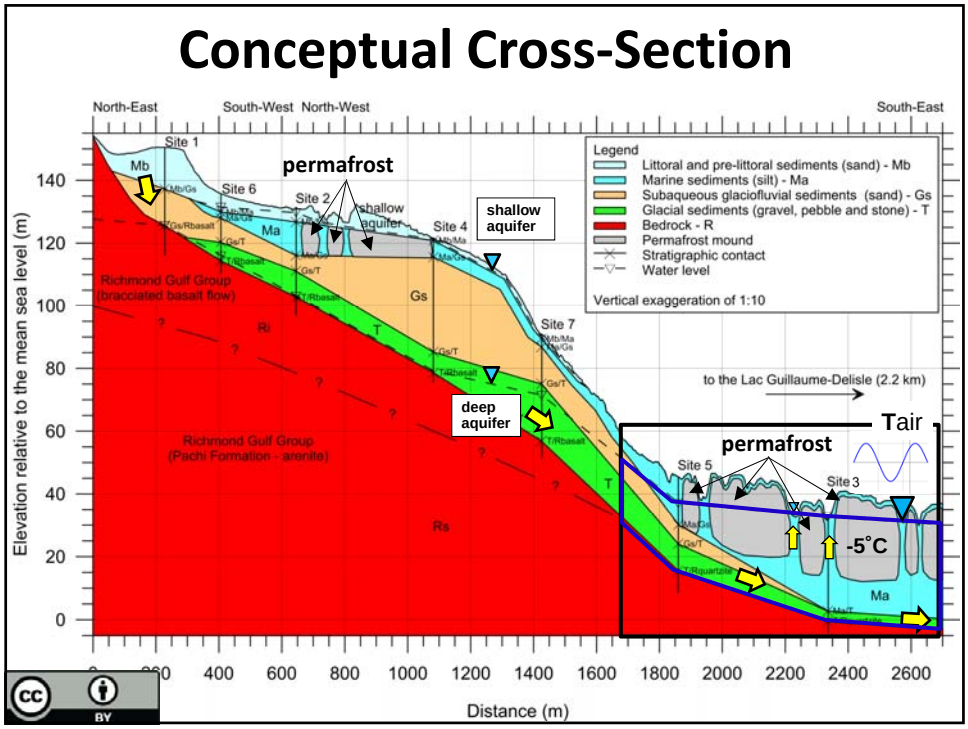
$$\frac{\partial}{\partial x_i}\left[K_{i,j}\cdot k_r(T)\left(\frac{\partial \psi}{\partial x_j} + \rho_r(T)\cdot \overline{n}_j\right)\right] - \sum_{k=1}^{N} Q_k(t)\cdot\delta(x_k, y_k, z_k) = S_s\frac{\partial \psi}{\partial t}$$

Heat Transport (T):

$$-\frac{\partial}{\partial x_i}\left(\theta S_w c_w \rho_w v_i T\right) + \frac{\partial}{\partial x_i}\left(\overline{\lambda}(T) + \theta S_w c_w \rho_w D\right)\frac{\partial T}{\partial x_j} + \Omega = \frac{\partial (C_o T)}{\partial t}$$

$$C_o = \theta S_w c_w \rho_w + \theta S_i c_i \rho_i + (1-\theta) c_s \rho_s + \theta \rho_i L\left(\frac{\partial S_w}{\partial T}\right)$$

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South-West
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South-East
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Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
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shallow aquifer
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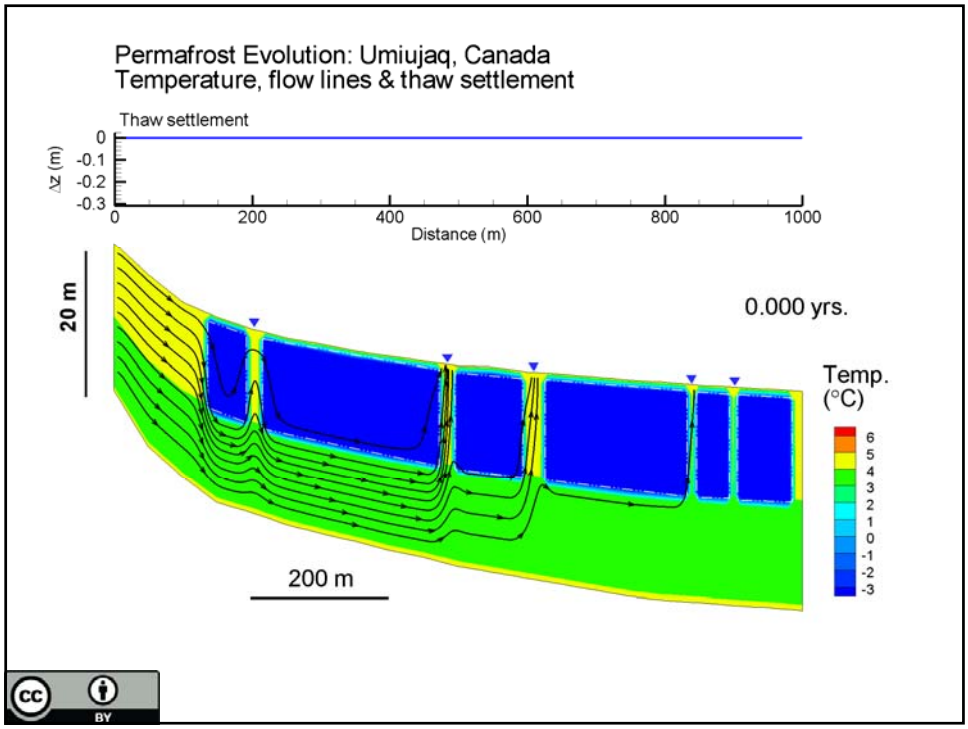
Permafrost Evolution: Umiujaq, Canada
Temperature, flow lines & thaw settlement
Thaw settlement
Δz (m)
Distance (m)
20 m
200 m
0.000 yrs.
Temp. (°C)

Summary

- On-going study 2013-2016
- Isotope data : evaporation, old permafrost meltwater (?)
- 3D geological and numerical model development
- Methodology to evaluate groundwater resource potential

Acknowledgements

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Centre d'études nordiques
Université Laval

interfrost