The Greenland Analogue Project

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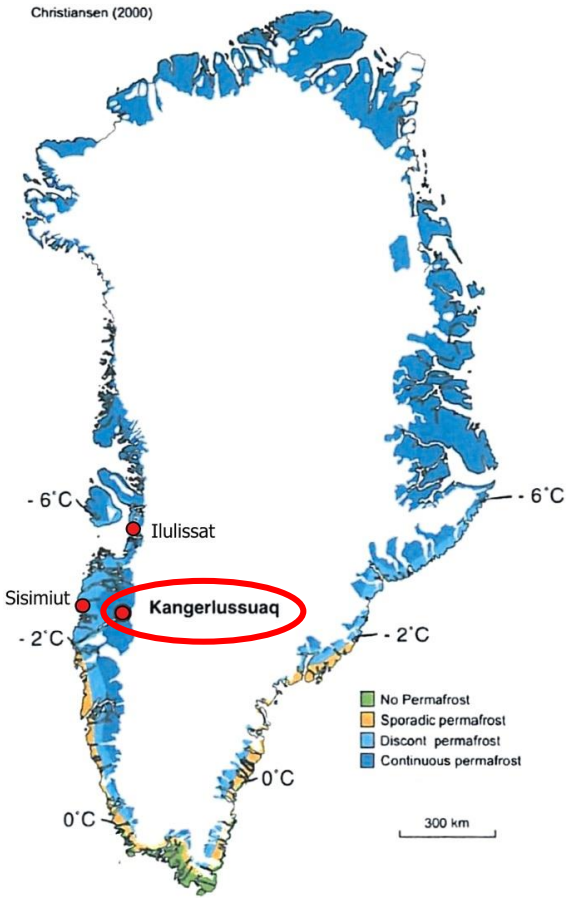
Lillemor Claesson Liljedahl, SKB
Anne Kontula, Posiva Oy
Timo Ruskeeniemi, GTK

NAWG-15, Prague 24.5.2017

The Greenland Analogue Project

- Co-ordinating and funding organizations
  - SKB (Sweden), Posiva (Finland) and NWMO (Canada)
  - 4.1 M€ (6 MUSD) for 2008-2014
- Research partners
  - Geological Surveys GTK and GEUS
  - Universities: UK/Aberystwyth, Bristol, Edinburgh, Swansea; USA/ Montana, Wyoming, Colorado, Indiana, Princeton, Washington; Canada/Waterloo, Toronto; Sweden/Stockholm, Uppsala
  - Geosigma AB, Lawrence Berkeley National Laboratory etc.

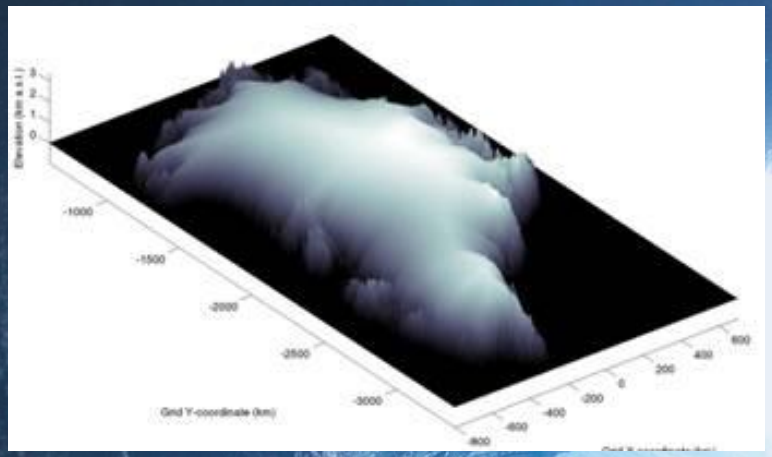


POSIVA

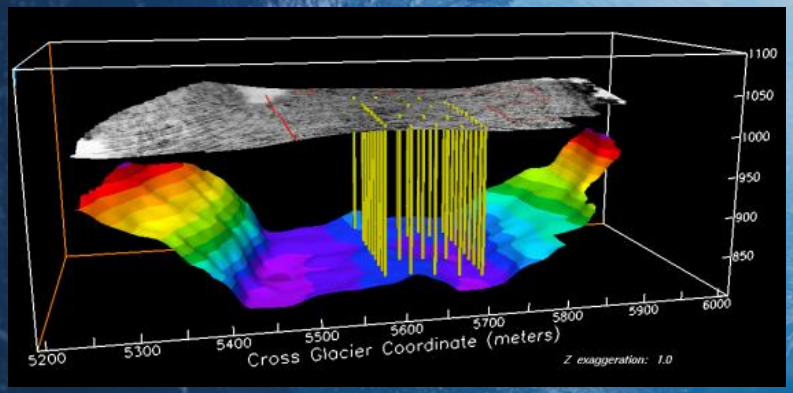
nwmo NUCLEAR WASTE MANAGEMENT ORGANIZATION SOCIÉTÉ DE GESTIO DES DÉCHETS NUCLÉAIRES

SKB Svensk Kärnbränslehantering AB

GTK gtk.fi



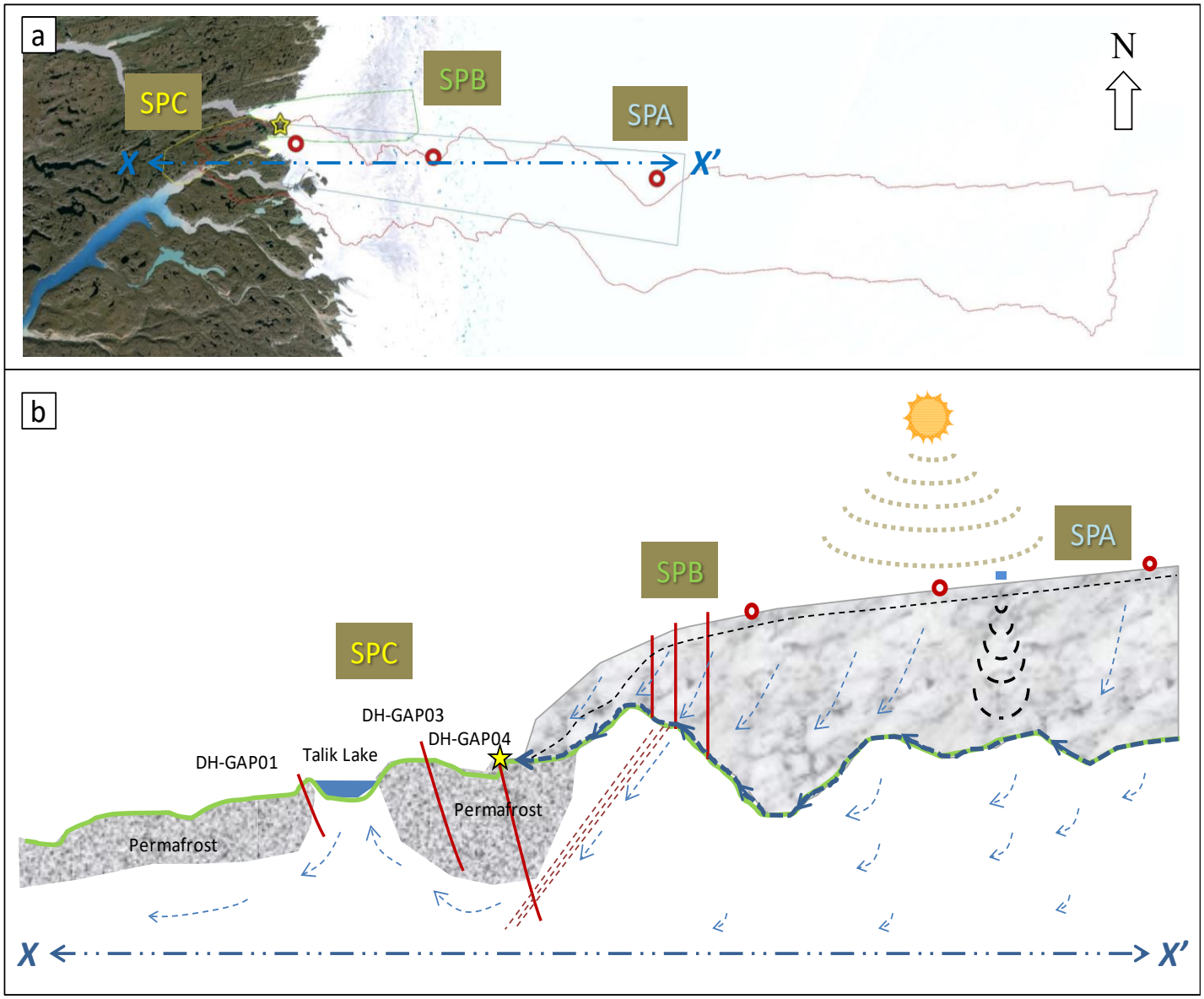
SPA (Alun Hubbard)
Indirect studies of the basal hydrological system and groundwater formation.
AWS, GPS, radar, seismics, remote sensing.



SPB (Joel Harper)
Direct studies of the basal hydrology & groundwater formation. Hot water ice drilling.

SPC (Timo Ruskeeniemi)
Groundawter chemistry, groundwater flow and permafrost. Bedrock drilling.

The Greenland Analogue Project



The results and research undertaken as part of the GAP has advanced the scientific understanding of hydrological processes associated with a retreating ice sheet GrIS.

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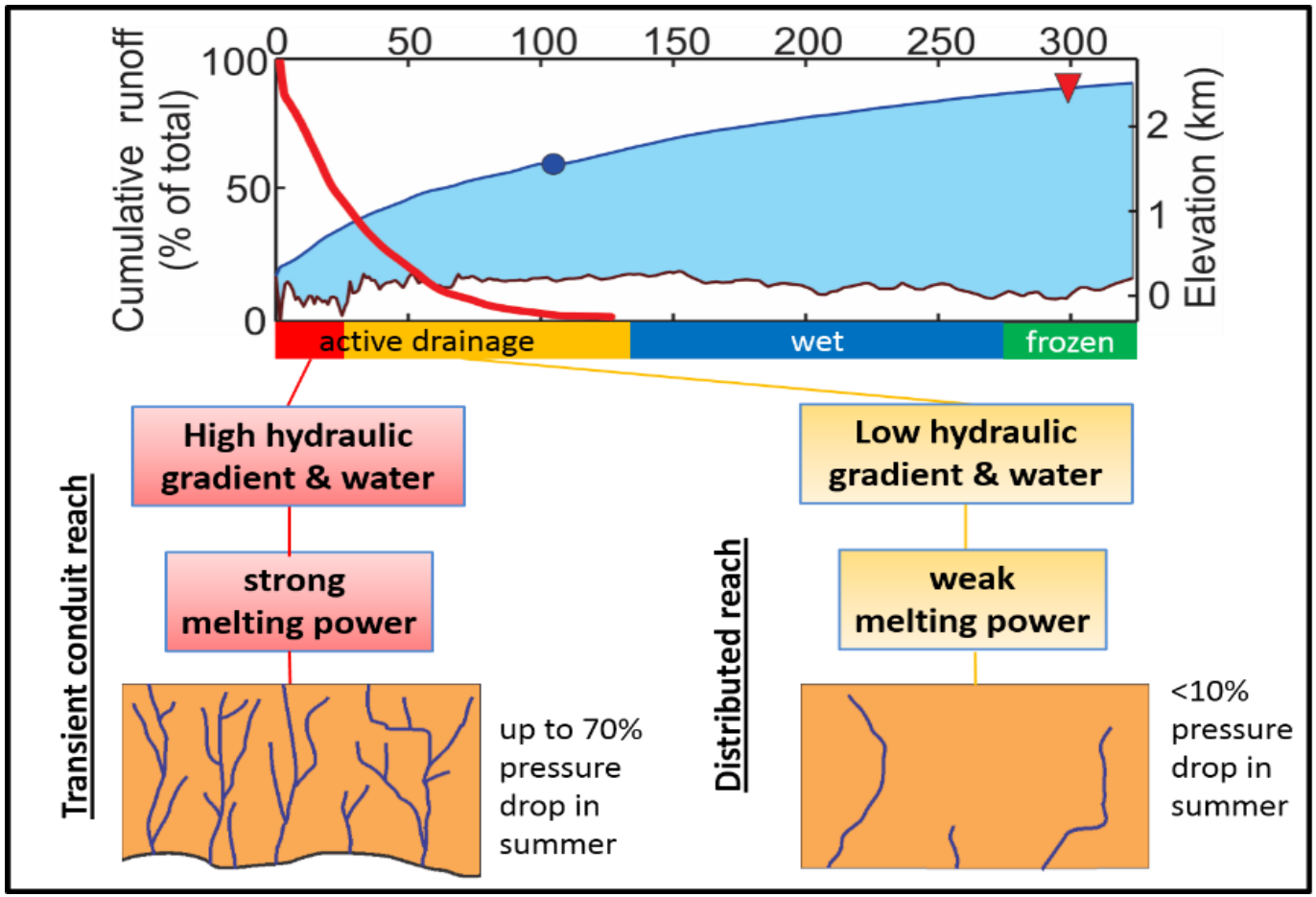
- Hydrologic conditions at the ice sheet bed were found to vary across. Between the ice divide and the margin, there is evidence for three different basal zones as defined by the amount and configuration of meltwater: ***the frozen zone, the wet bed zone, and the surface-drainage zone.***



- These zones result from surface, bed, and internal ice flow processes, and are likely representative of Northern Hemisphere ice sheets in a similar stage of development to the current GrIS.

GAP has resulted in extensive and new process understanding and we can from the first time through observations describe the following:

- How pressure is varying through time and space underneath an ice sheet
- Groundwater formation underneath and in the vicinity of an ice sheet

➢ Important for the Groundwater models in Safety Assessments for RWD

- To what depth the meltwater is possible to penetrate into the bedrock in vicinity of an ice sheet
- What is the geochemical composition of the ground/meltwater in the bedrock underneath an ice sheet
- The effect of an ice sheet in a periglacial environment on the groundwater flow

➢ Important for the Bentonite stability in Safety Assessments for RWD

GAP is officially closed and the results are presented in the two final reports:

The Greenland Analogue Project: Data and Processes,
The Greenland Analogue Project: Final report


R-14-13

The Greenland Analogue Project:
Data and Processes

Harper J[1], Hubbard A[2], Ruskeeniemi T[3], Claesson Liljedahl L[4], Kontula A[5], Hobbs M[6], Brown J[7], Dirkson A[1], Dow C[7], Doyle S[8], Drake H[9], Engström J[3], Fitzpatrick A[2], Follin S[3], Frape S[10], Graly J[11], Hansson K[12], Harrington J[13], Henkemans E[10], Hirschorn S[8], Humphrey N[11], Jansson P[13], Johnson J[1], Jones G[7], Kinnbom P[14], Kennell L[4], Klint K E[15], Liimatainen J[5], Lindbäck K[13], Meierbachtol T[1], Pere T[5], Pettersson R[13], Tullborg E-L[16], van As D[13]

1 University of Montana
2 Aberystwyth University
3 Geological Survey of Finland
4 Svensk Kärnbränslehantering AB
5 Posiva Oy
6 Nuclear Waste Management Organization
7 Swansea University
8 Linnæus University
9 Golder associates
10 University of Waterloo
11 University of Wyoming
12 Geosigma AB
13 University of Stockholm
14 PKM Innovation AB
15 Geological Survey of Denmark and Greenland
16 Terralogica

August 2016

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel and Waste Management Co
Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00


Technical Report
TR-14-13

The Greenland Analogue Project:
Final report

Claesson Liljedahl L[1], Kontula A[2], Harper J[3], Näslund J-O[1], Selroos J-O[1], Pitkänen P[2], Puigdomenech I[1], Hobbs M[4], Follin S[5], Hirschorn S[4], Jansson P[6], Kennell L[4], Marcos N[7], Ruskeeniemi T[8], Tullborg E-L[9], Vidstrand P[1]

1 Svensk Kärnbränslehantering AB
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August 2016

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Final reports available at:

- www.skb.se
- www.posiva.fi
- www.nwmo.ca

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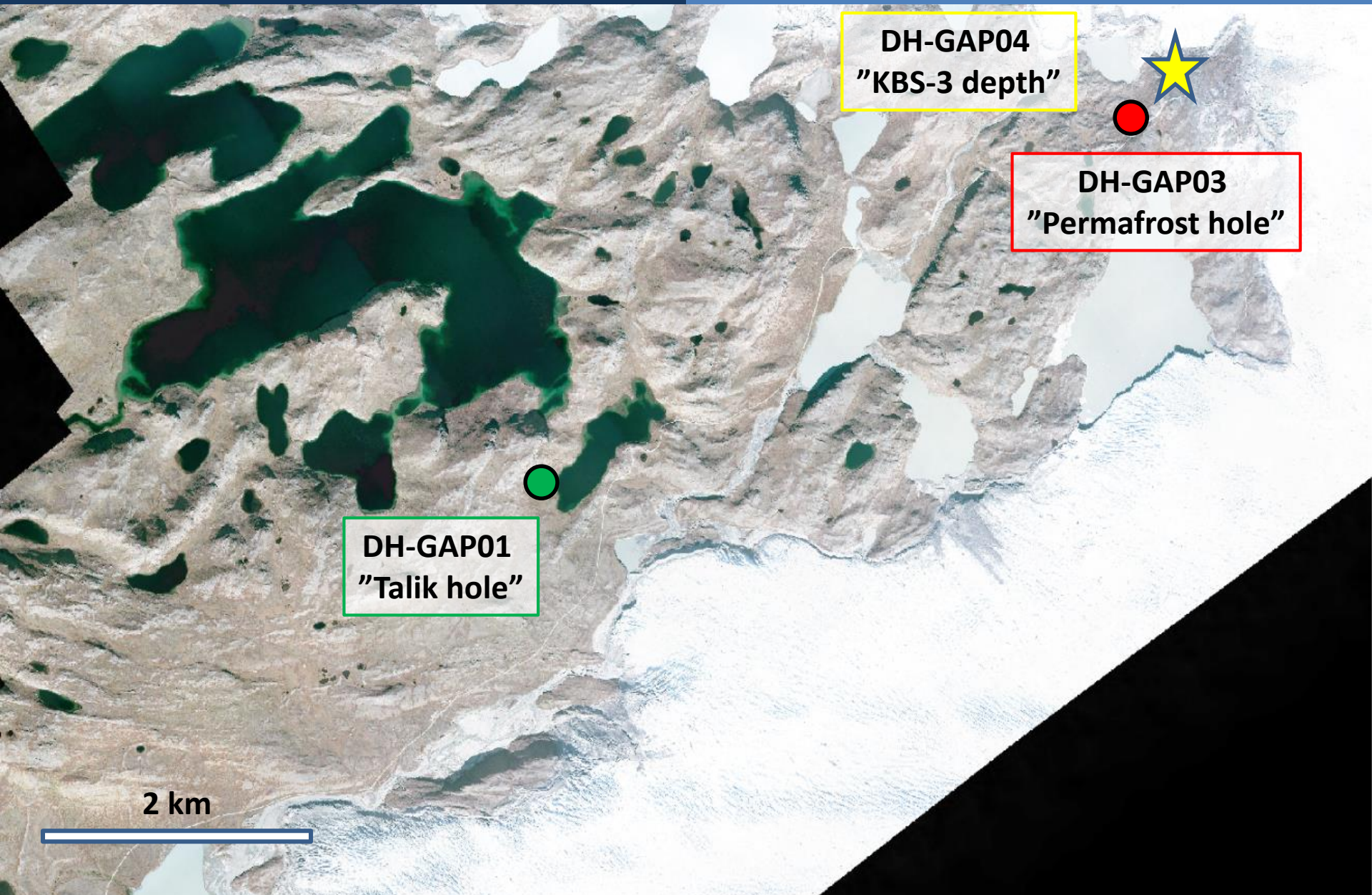
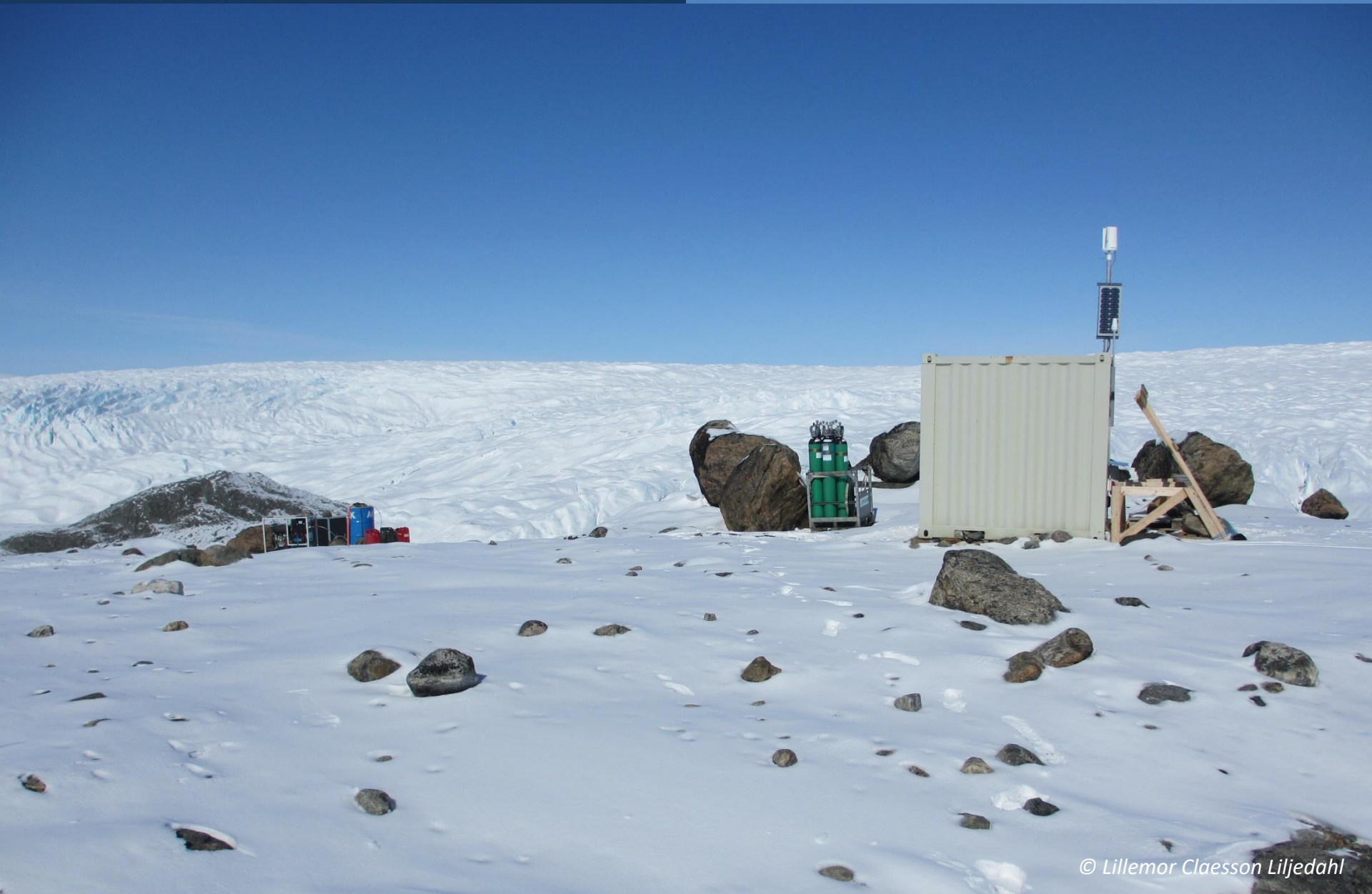
Borehole DH-GAP04

Groundwater chemistry, hydrology & permafrost

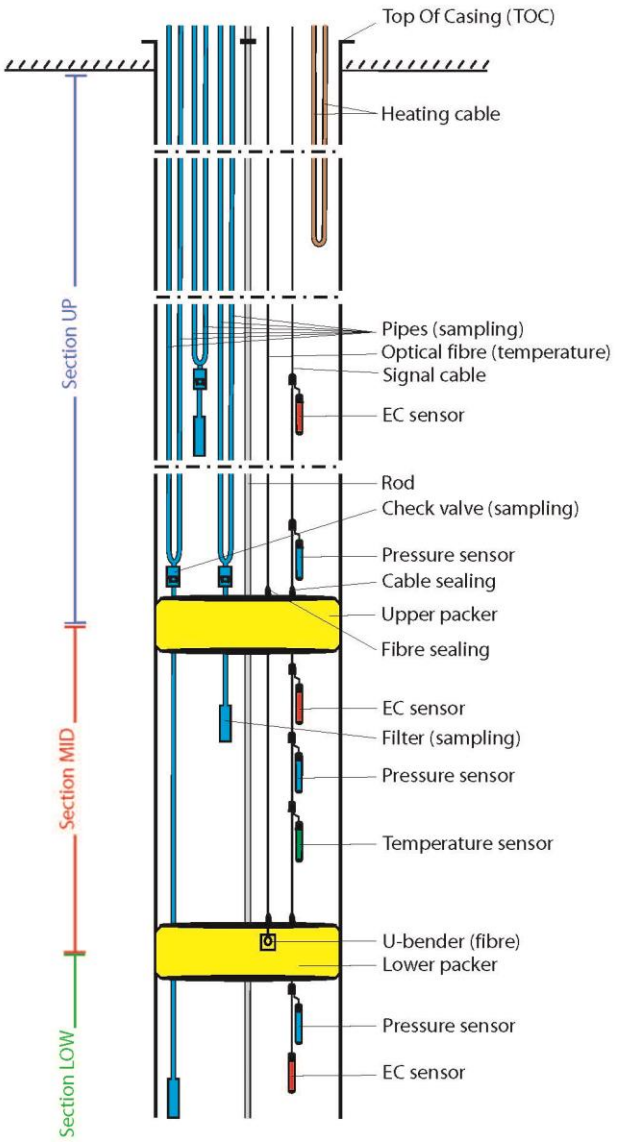


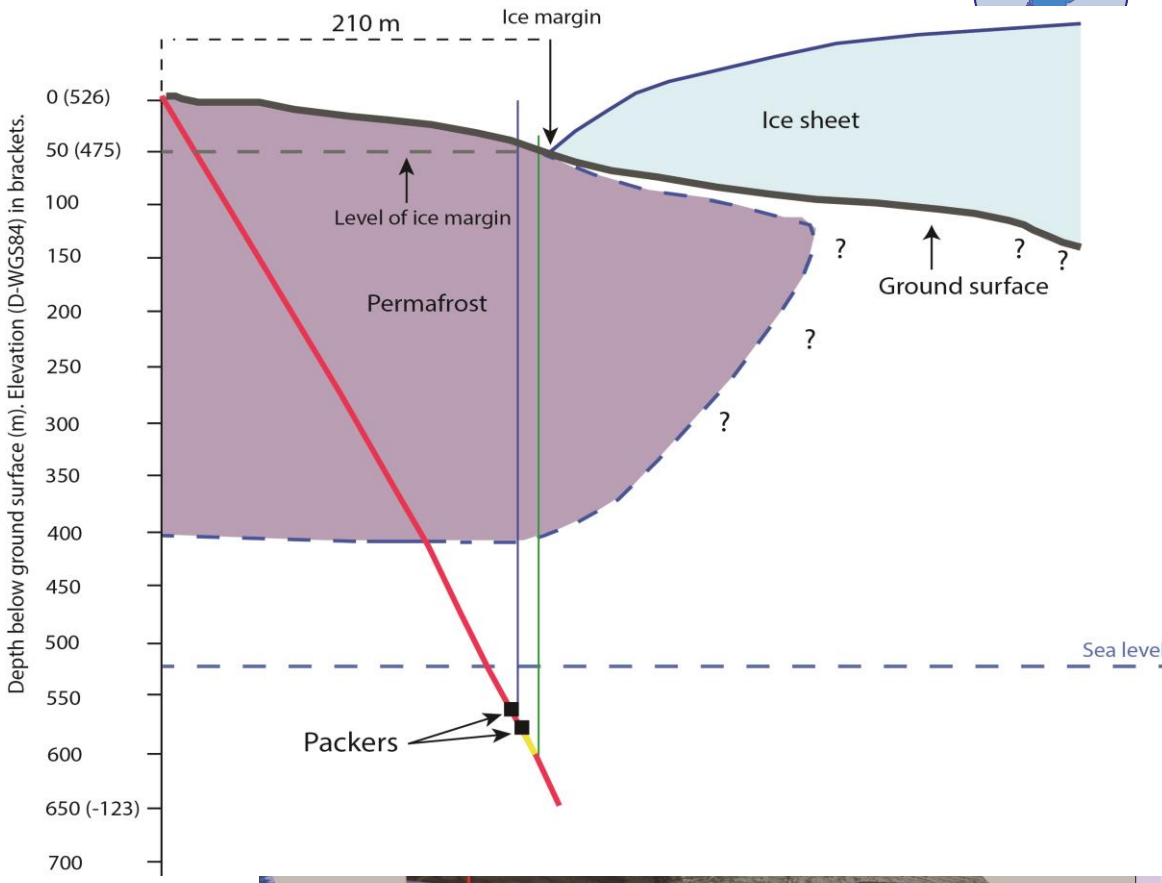
DH-GAP04
647 m , 70 °
~400 m permafrost

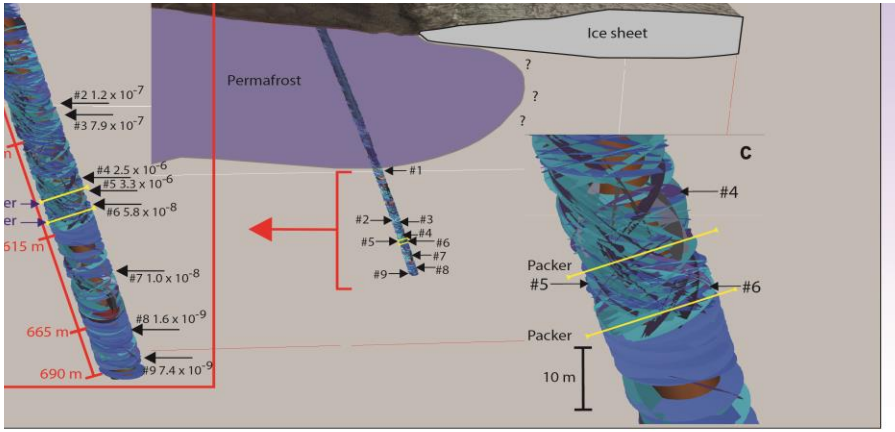
Hot water drilling
Posiva Flow Log
Instrument setup



The Greenland Analogue Project







Ongoing and future plans

- SKB continues monitoring of DH-GAP04 (at least until 2020).
- AWS-network on the ice sheet (KAN_U, KAN_M, KAN_L + KAN_B) through GEUS/Dirk van As (at least until 2020).
- Ice drilling project 'ICE' to study 'recharge' completed 2017. Funded by SKB, Posiva, Nagra and NWMO. Carried out by Univ. Montana and Univ. Wyoming.
- Unique data sets – ongoing publication in scientific journals.
- Validation of the permafrost model used by SKB and Posiva in safety assessments + coupling of the permafrost model and the ElmerICE ice sheet model.
- Paleo climatologic inverse modelling of borehole temperatures from DH-GAP04 (Jan Sundberg, Volker Rath).
- NSF-application "PIRE" to further study the dynamic coupling of the ice sheet/groundwater system (field studies, ice modelling, groundwater modelling) to better understand the subglacial drainage system (Joel Harper & Neil Humphrey). SKB, Posiva and Nagra participates in the project if funded.
- → Some day…..donate the GAP infrastructure to the research community.


Comments?
Questions?
Greenland Analogue Project
GAP
NWMO Posiva SKB
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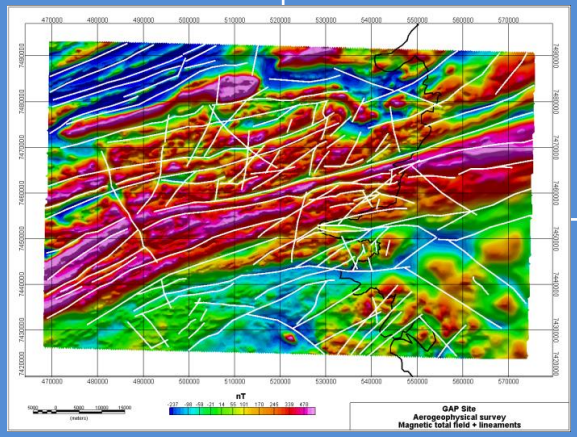
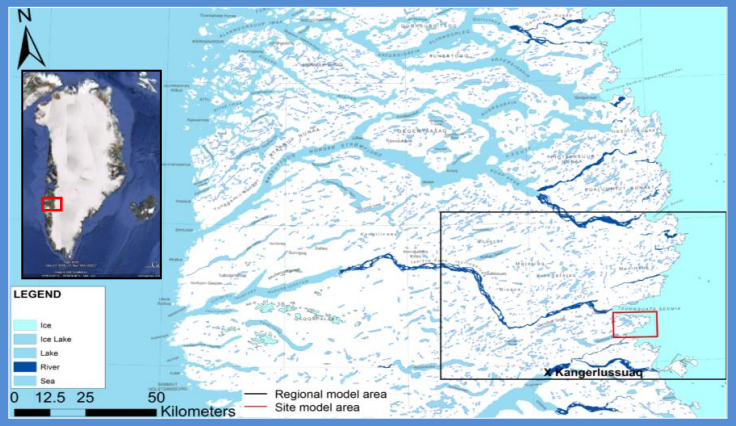
For the safety of future generations...
Mind the GAP
Good research makes good solutions

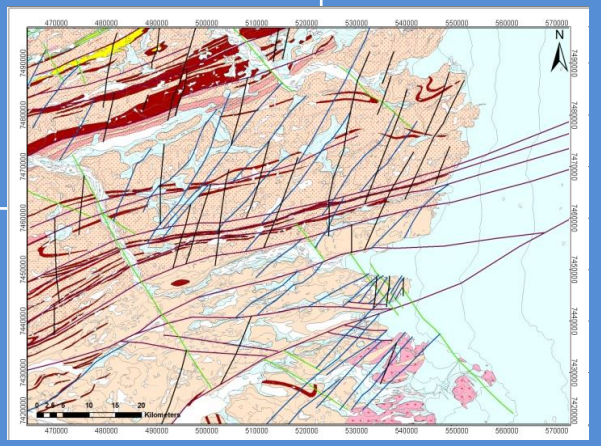
Constructing GAP Lineament model

Geophysical interpretation of Aeromagnetic data

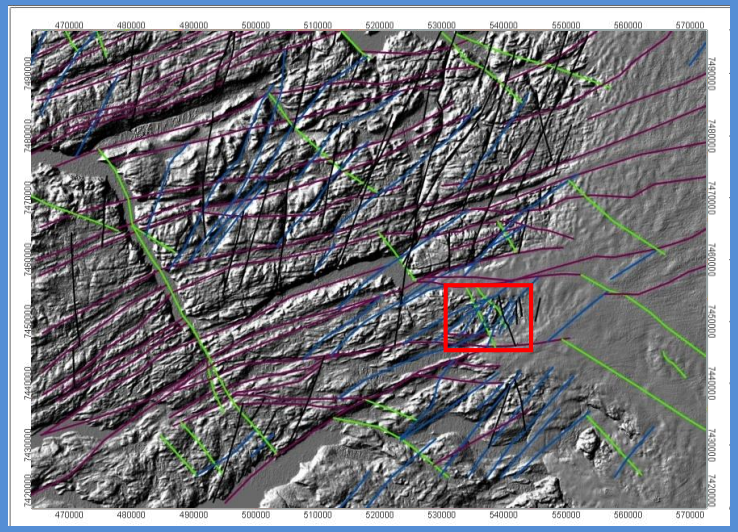




Interpretation of the Geological map and the Topographical Elevation data



GAP Lineament model



Klint, K.E.S.; Engström, J.; Parmenter, A.; Ruskeeneimi, T.; Liljedahl L.C.; Lehtinen, A. *Lineament mapping and geological history of the Kangerlussuaq region, southern West Greenland. Geol. Sur. Denmark Greenland Bull.* ***2013****, 28, 57–60.*

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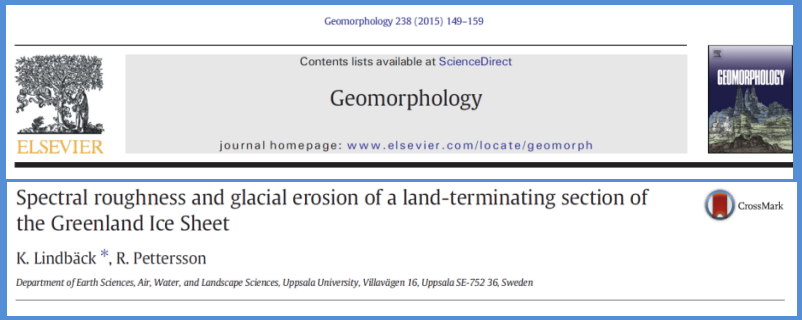
Lindbäck K, Pettersson R, 2015.
Spectral roughness and glacial erosion of a land-terminating section of the Greenland Ice Sheet. Geomorphology, Volume 238, Pages 149–159.



Geomorphology 238 (2015) 149–159

Contents lists available at ScienceDirect

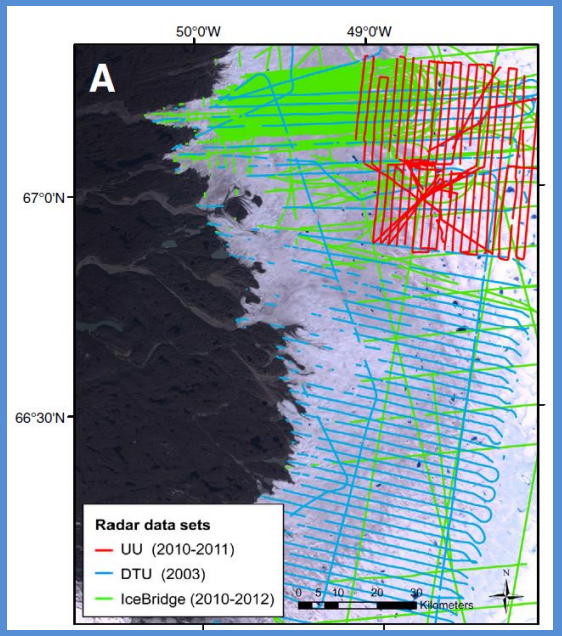
Geomorphology

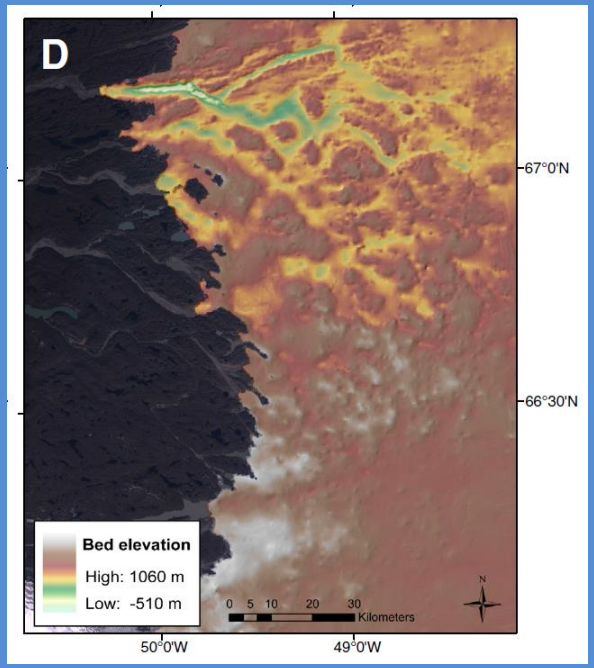
journal homepage: www.elsevier.com/locate/geomorph

Spectral roughness and glacial erosion of a land-terminating section of the Greenland Ice Sheet

K. Lindbäck *, R. Pettersson

Department of Earth Sciences, Air, Water, and Landscape Sciences, Uppsala University, Villavägen 16, Uppsala SE-752 36, Sweden





Fieldwork 2009.
Photo Sam Doyle.

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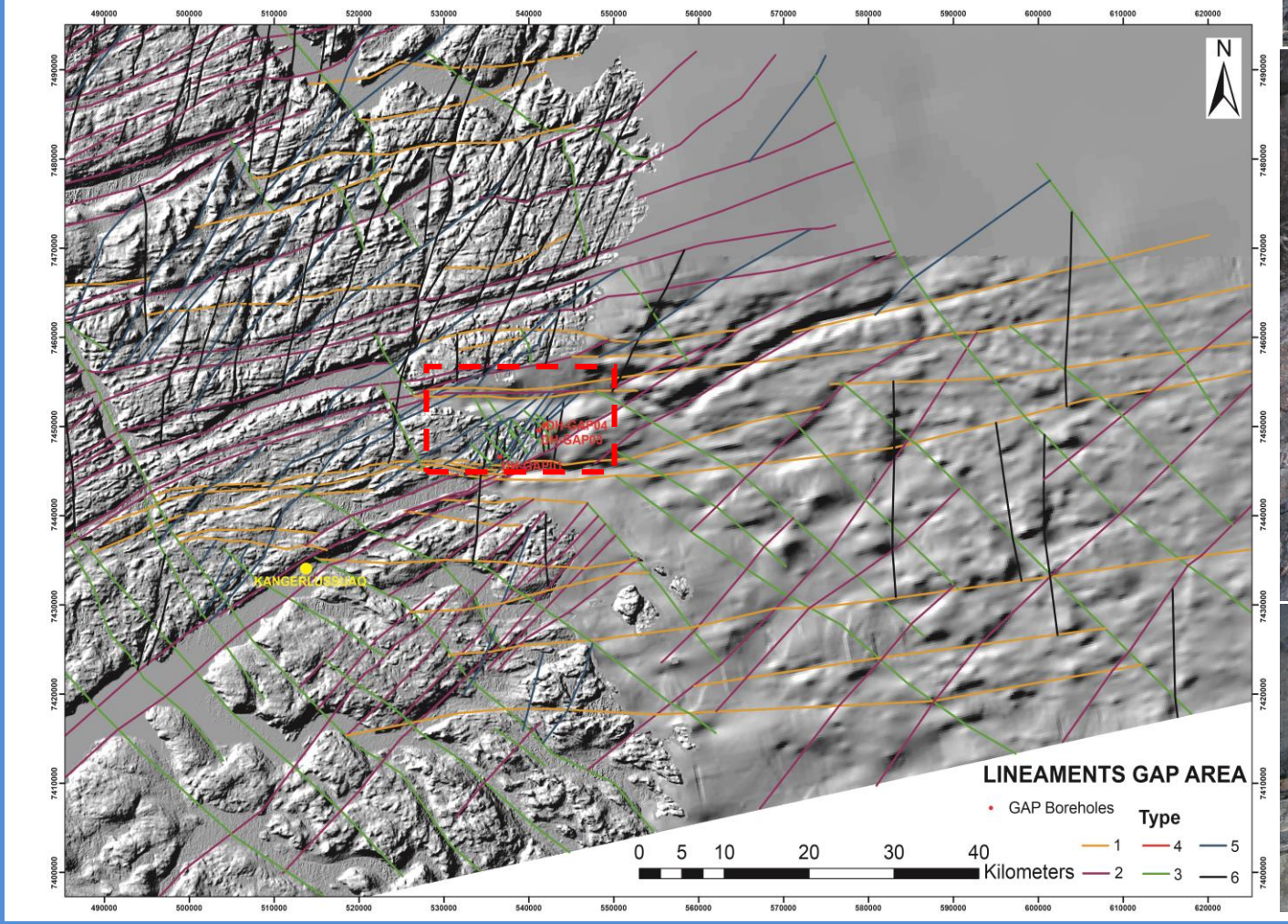
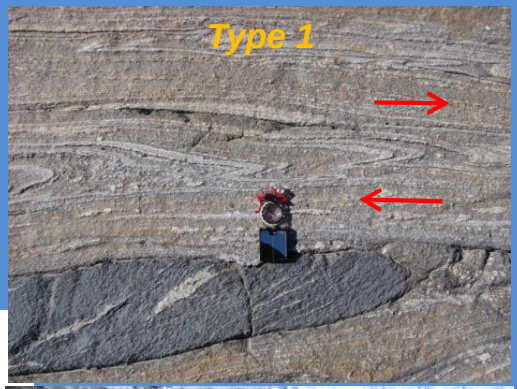
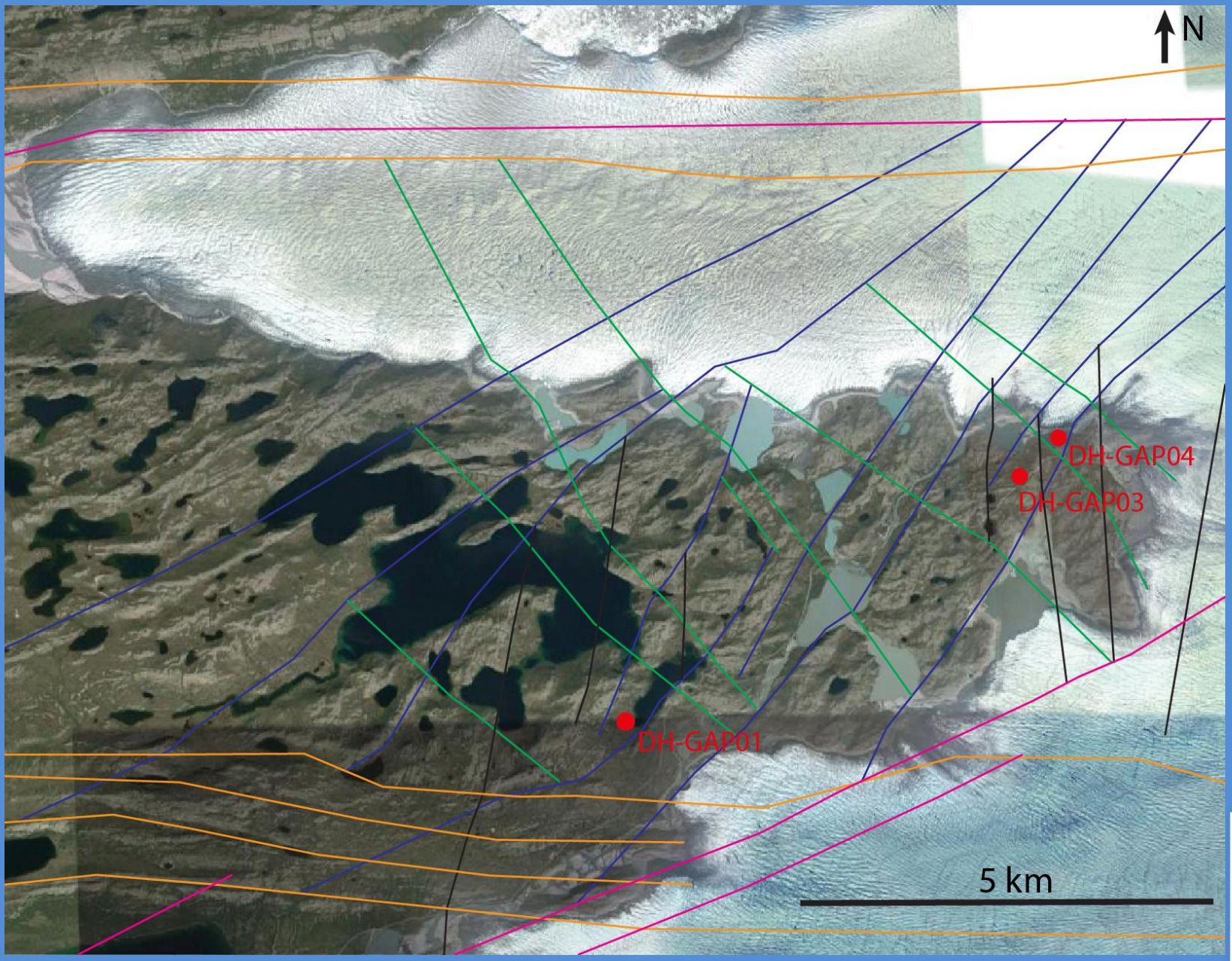
Updated Lineament map from new produced DEM, extending further in under the ice sheet.

The type and character of the lineaments were verified with field work and were classified as different deformation zones.





Deformation zone model of site area



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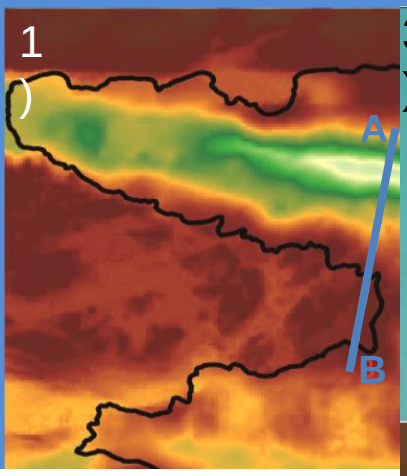

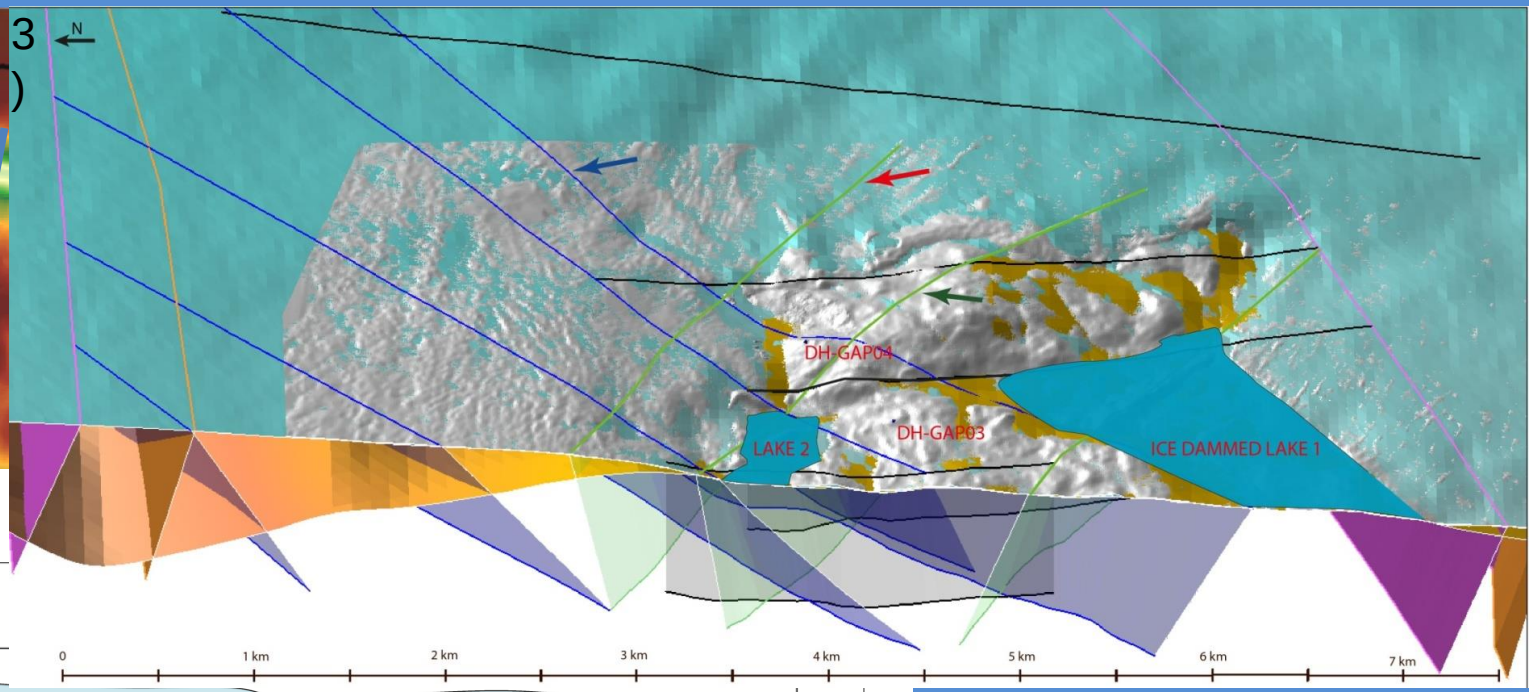

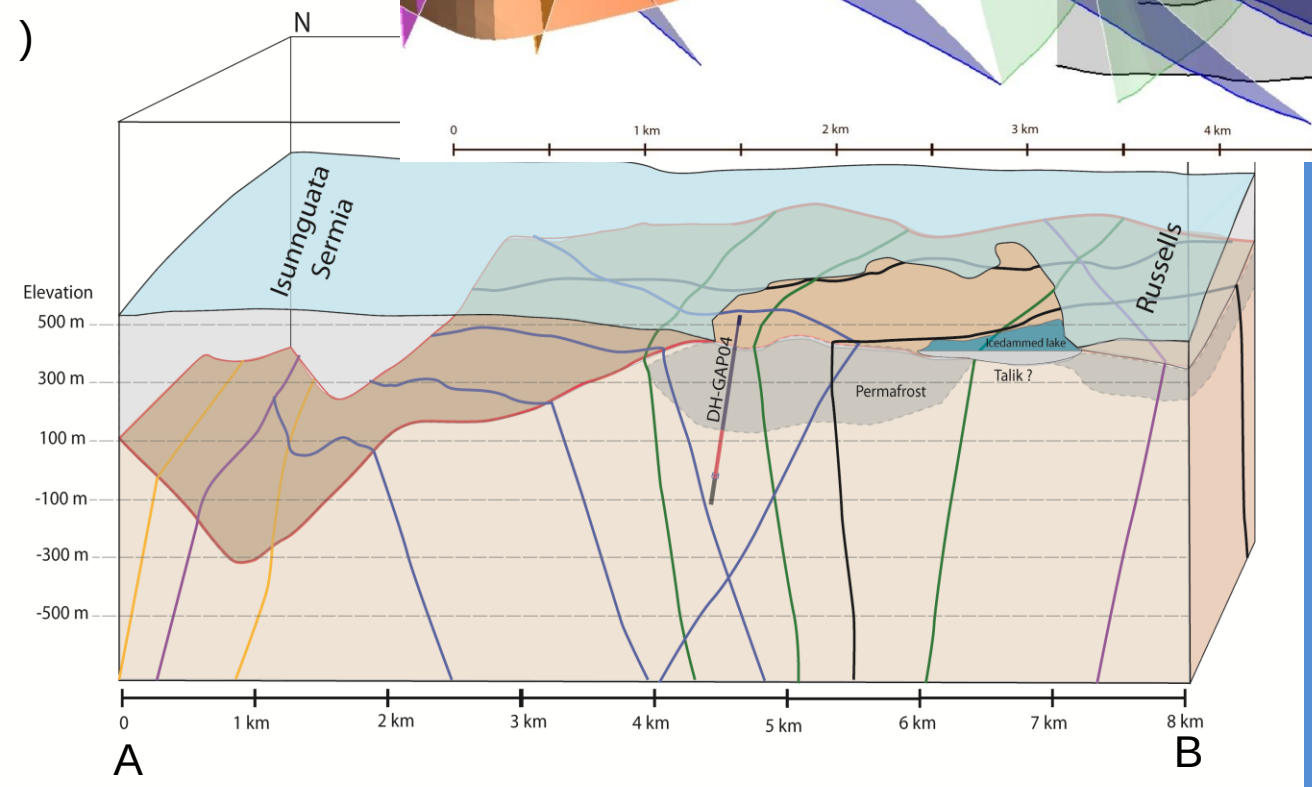

1) Ice bed elevation based on GPR

2) N-S intersection from Russells Glacier to Isunnguata Sermia

3) Surpac View of the aforementioned intersection in 3D

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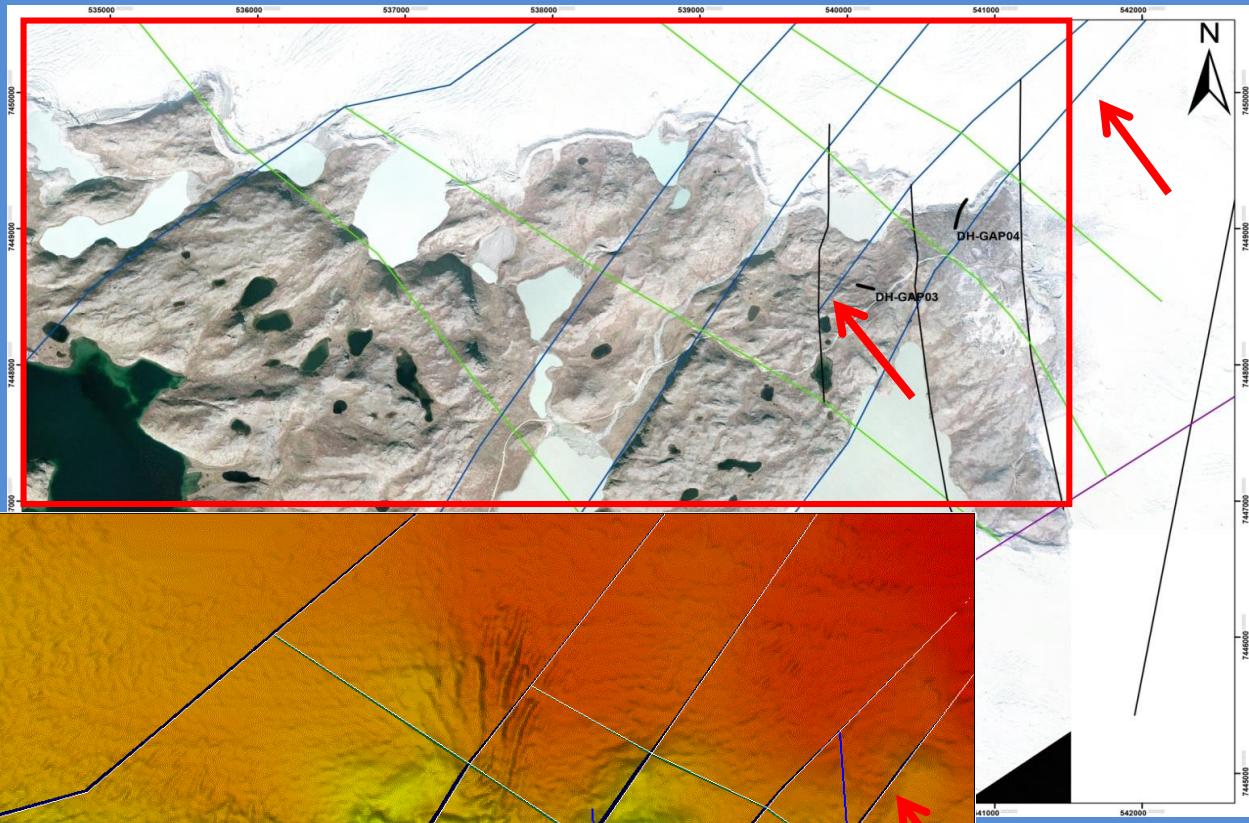
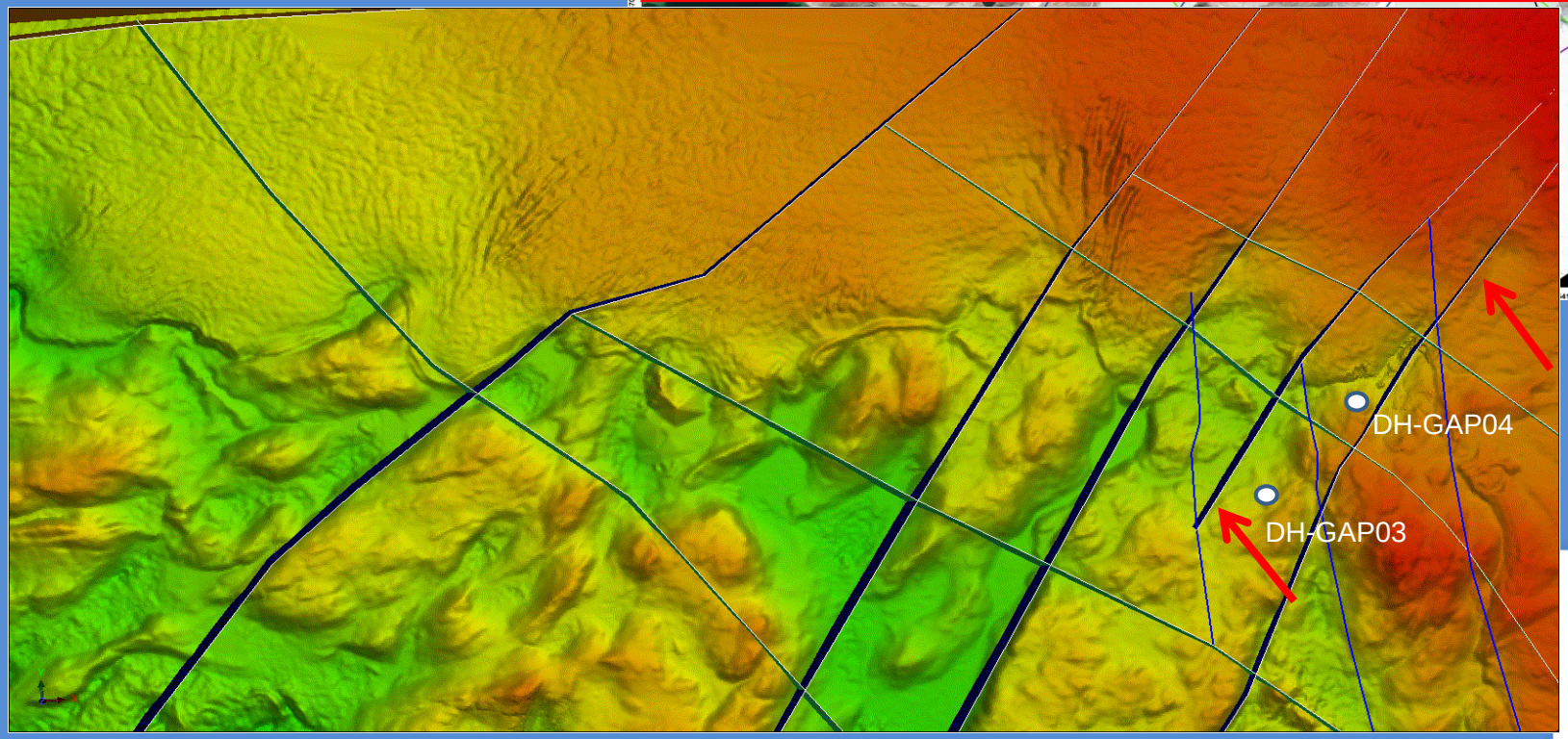
Deformation zones: DH-GAP04 area

Deformation zones
Orthomap view

Top view
SURPAC view





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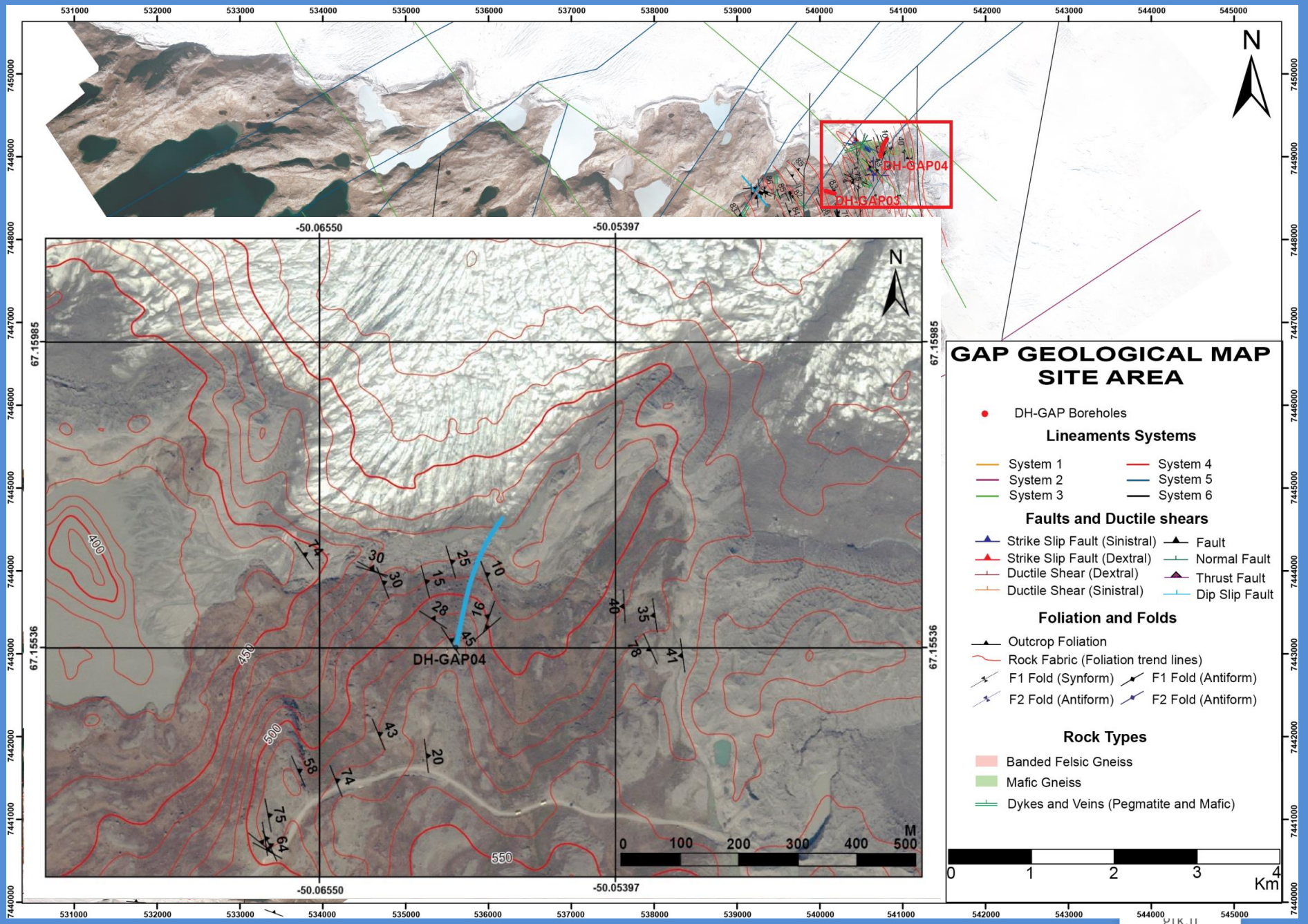
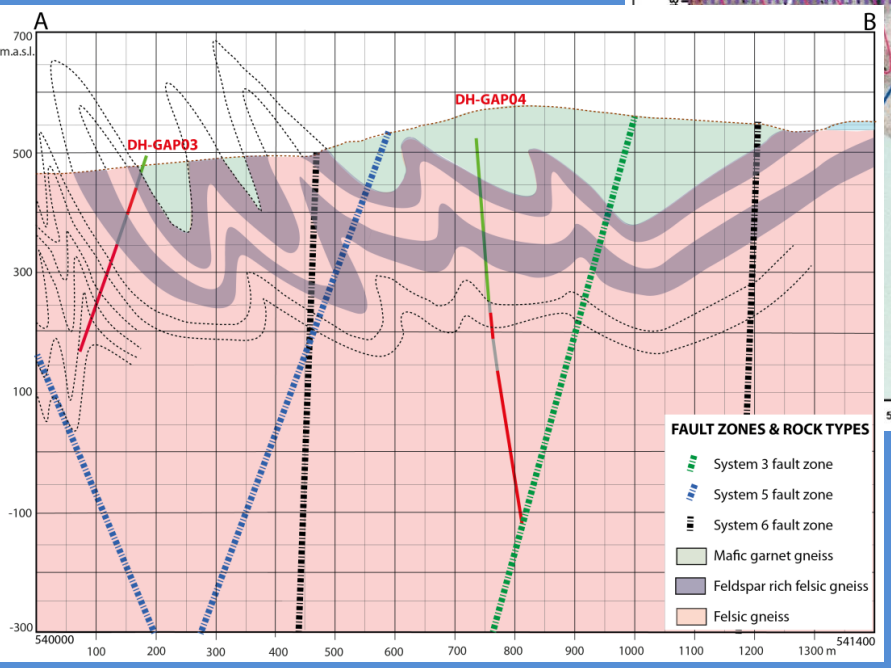

GAP GEOLOGICAL MAP
SITE AREA
DH-GAP Boreholes
Lineaments Systems
System 1
System 2
System 3
System 4
System 5
System 6
Faults and Ductile shears
Strike Slip Fault (Sinistral)
Strike Slip Fault (Dextral)
Ductile Shear (Dextral)
Ductile Shear (Sinistral)
Fault
Normal Fault
Thrust Fault
Dip Slip Fault
Foliation and Folds
Outcrop Foliation
Rock Fabric (Foliation trend lines)
F1 Fold (Synform)
F1 Fold (Antiform)
F2 Fold (Antiform)
F2 Fold (Antiform)
Rock Types
Banded Felsic Gneiss
Mafic Gneiss
Dykes and Veins (Pegmatite and Mafic)
DH-GAP04
DH-GAP03
N
-50.06550
-50.05397
67.15985
67.15536
0 100 200 300 400 500 M
0 1 2 3 4 Km

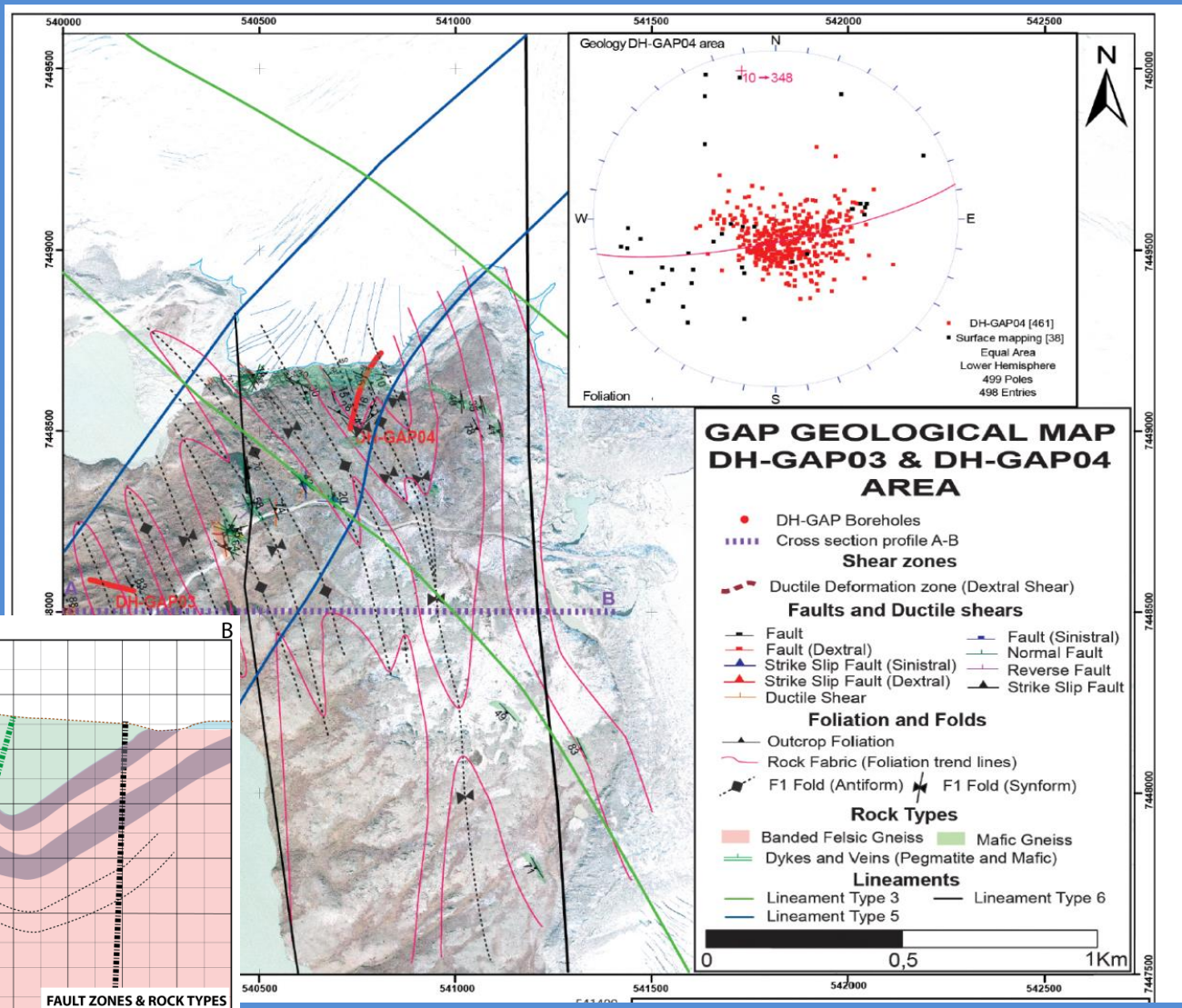
Geological map of DH-GAP03 & DH-GAP04 area

→

Cross-section E-W orientated section A-B in the map

↓





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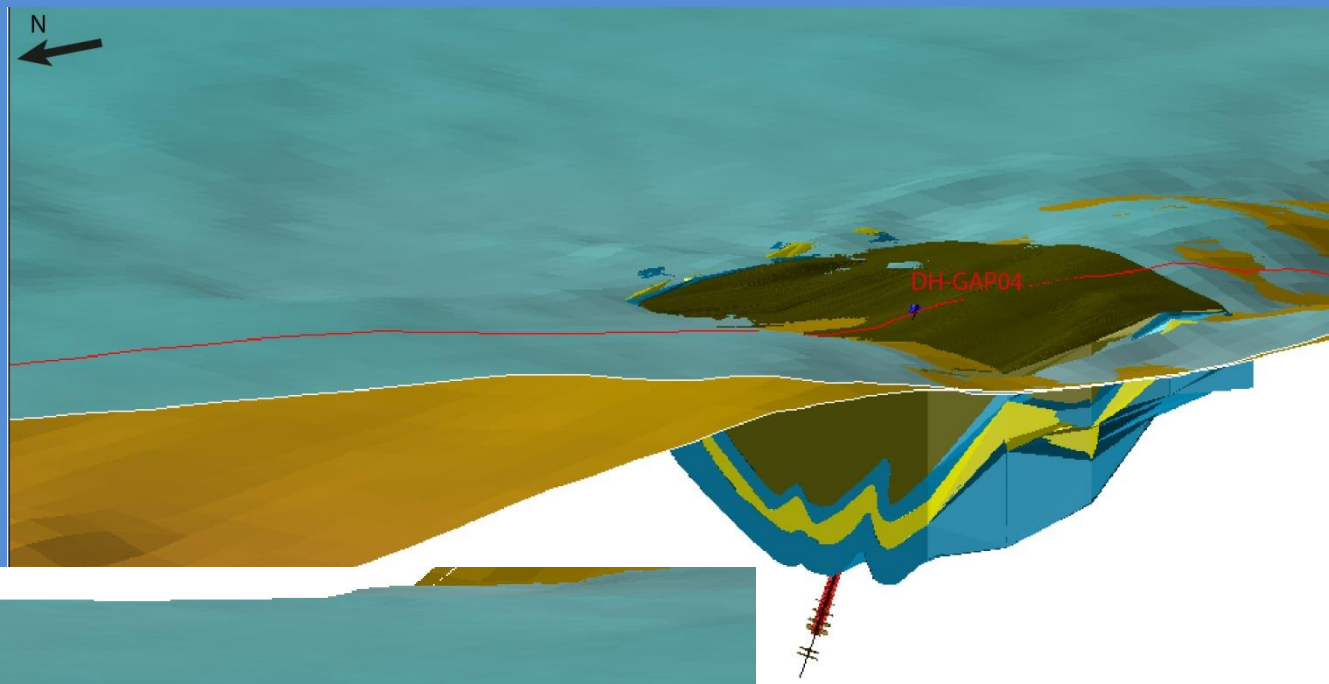
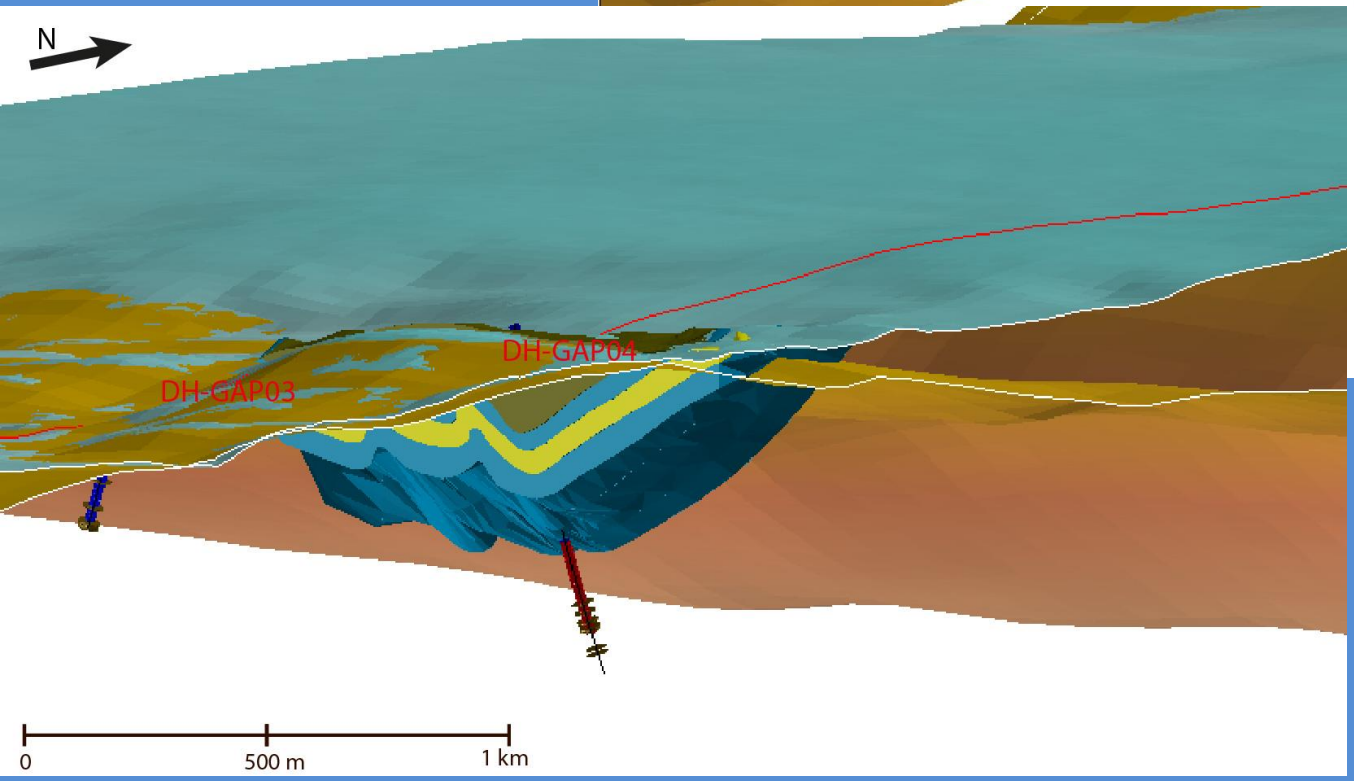
Surpac view
of the folded bedrock.
View from NW.

Surpac view
of the folded bedrock.
View from SE.





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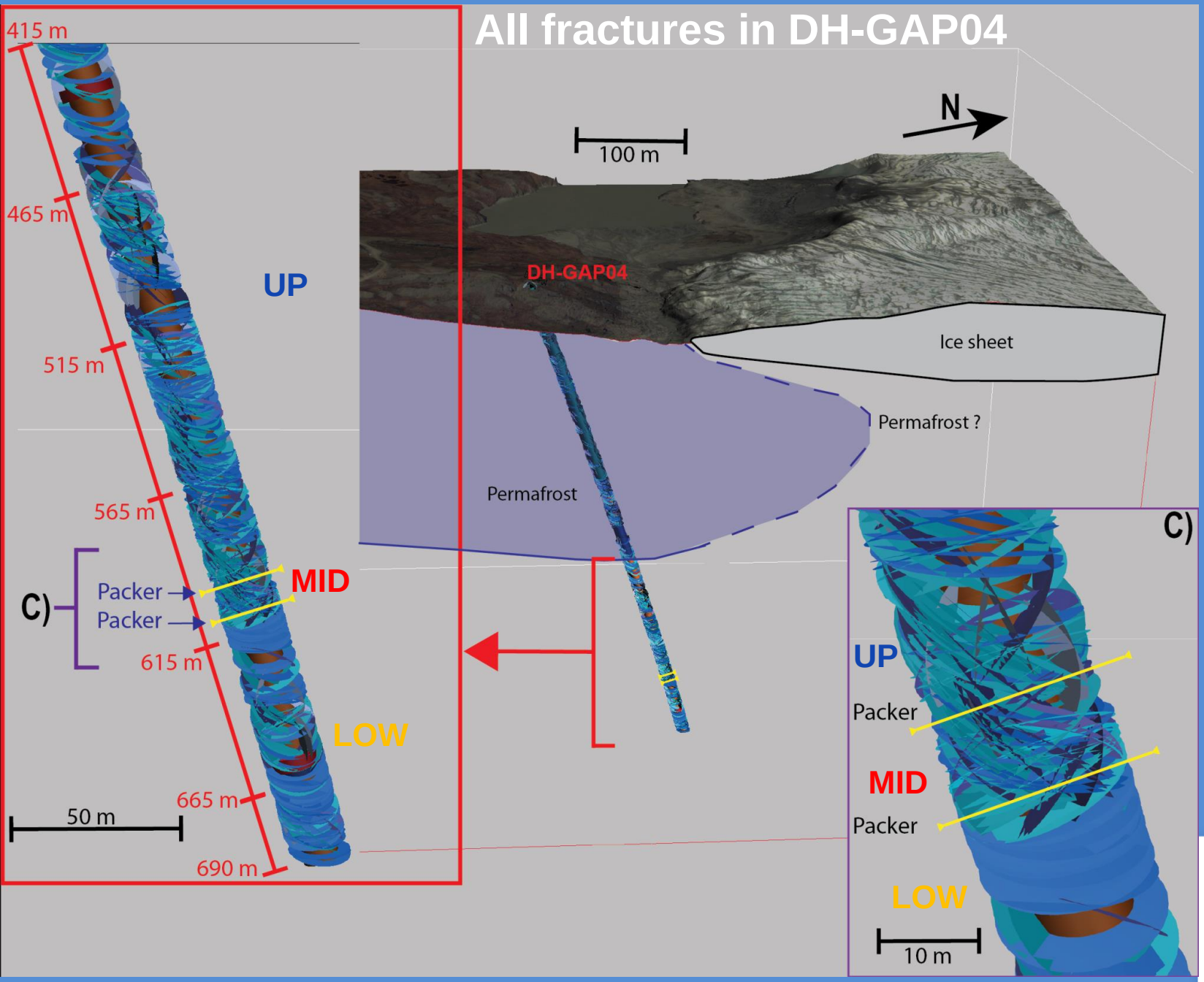
All fractures in DH-GAP04



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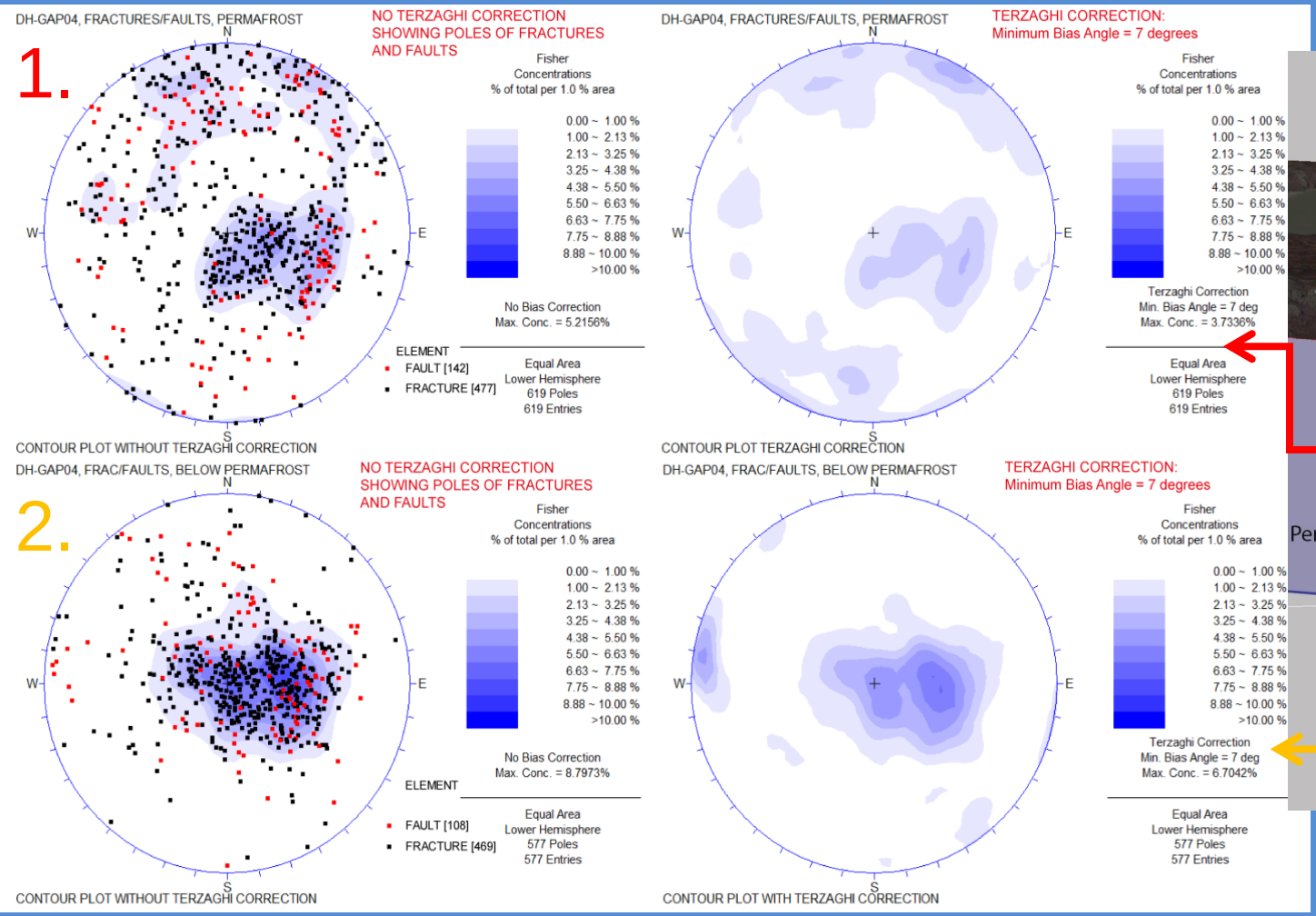
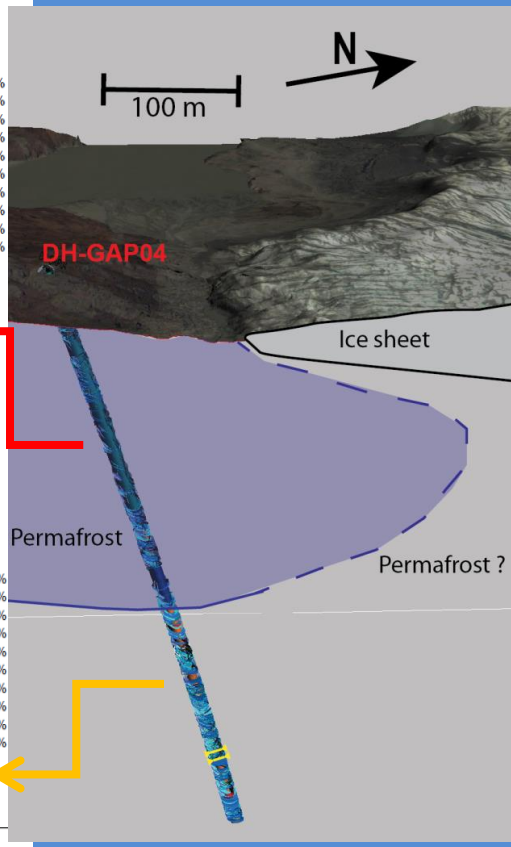
Fractures & Faults within Permafrost and below Permafrost





1. Within Permafrost
2. Below Permafrost

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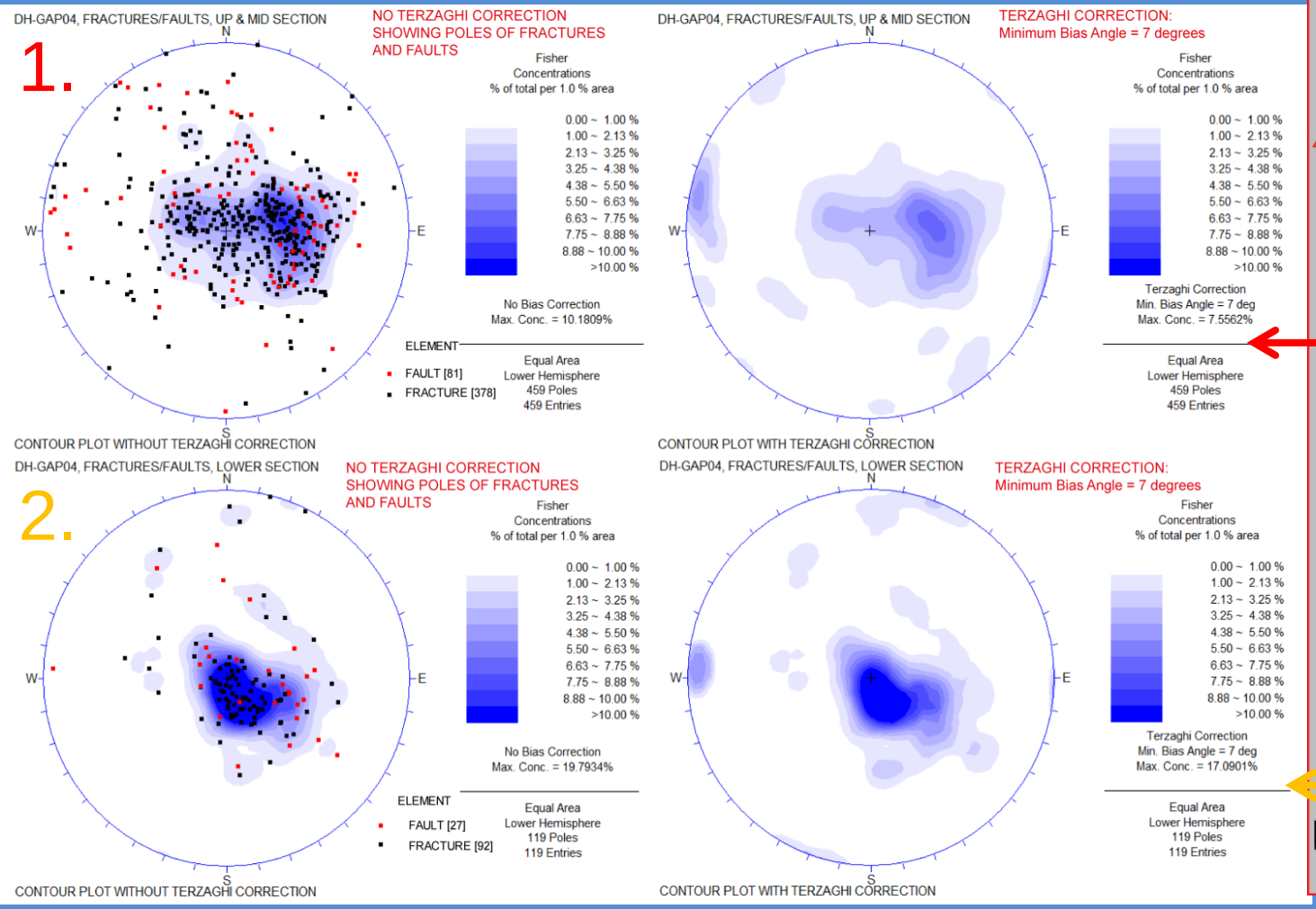
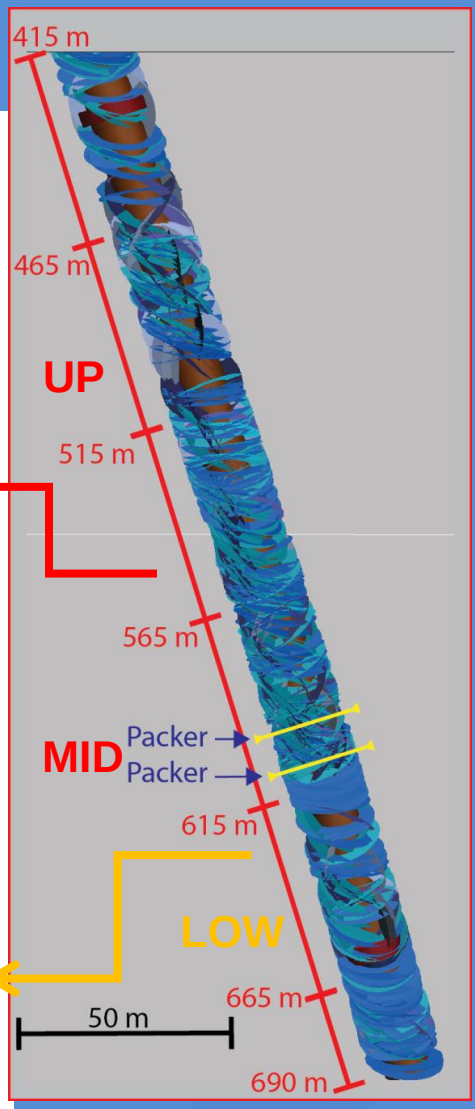
Fractures & Faults below Permafrost





1. Up & Mid section
2. Lower section

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