Discovering the undiscovered:
The role and value of industry-academia collaboration

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2017 Bryan Lovell Meeting: Mining for the Future

Collaboration between academia and industry...

Undergraduate summer placement schemes

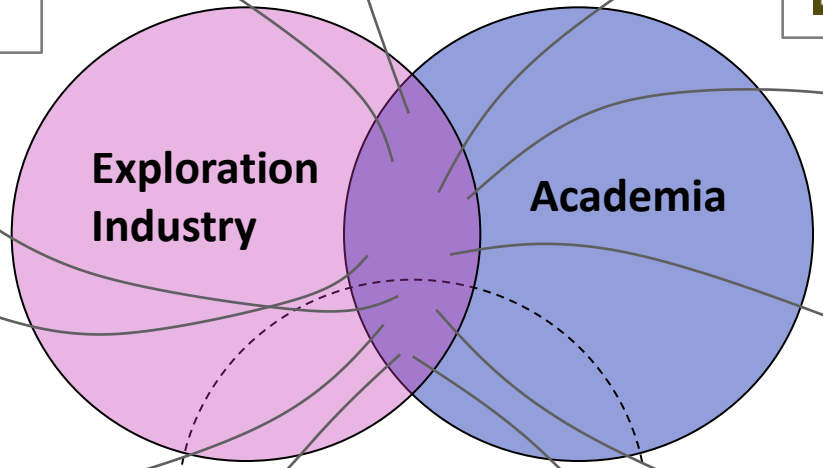
Academic entrepreneurship (e.g. spin-off companies)

Research partnerships (e.g. collabrotive R&D, research consortia, joint projects)

NERC SCIENCE OF THE ENVIRONMENT SoS MinErals

Interdisaplinary academia-industry colloboration

Internships , secondments, fellowships



Commercialisation of intellectual property

Scientific publications (e.g increasing open access)

Specialist Interest Groups

VMSG

TSG Tectonic Studies Group

Geological surveys, government agencies, learned societies

Conferences and workshops

Shared facilities and/or equipment

Funding and co-supervision of postgraduate research projects

Research services (e.g. consulting, geochemical and isotopic analyses, testwork, QA-QC)

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VIEWS

Industry-Academic Research Projects: The Good, The Bad, and The Ugly

RICHARD LILLY, Research Fellow, Department of Earth Sciences, University of Adelaide, SA 5005, Australia

RICHARD LILLY

Introduction

Industry-academic research projects should be a win-win collaboration; the company gets access to a knowledgeable specialist team that is able to dedicate valuable time and resources to a range of questions, and those in academia may receive funding to help generate new data and advance their research projects. As a bonus, students who are involved receive useful hands-on industry experience. What could go wrong? Why are there not more collaborative projects happening all the time? What can we do to make these projects work?

Over the last 15+ years I have been fortunate to have been involved in over 30 collaborative economic geology and exploration focused research spectrum of economic geology from exploration to production.

Getting Past Stereotypes

Being an industry-funded research-fellow/liaison is certainly not an easy job; after years working in exploration I didn't grasp how many hours those involved in research actually work. There is no clock-on and clock-off; it's certainly a lifestyle rather than just a job. I also quickly found out that researchers have completely different KPIs (Key Performance Indicators) and that the success of a research project is not measured in meters drilled, tonnes hoisted, or targets found (although it would be nice if that was the end result

from the academic side of the fence referring to their industry partners' "short-term goals" and suggesting that the recipients of their research products "don't care about the results" and "probably won't read it anyway." It is rare to visit an exploration office or mine geology office that doesn't have shelves of often unappreciated (dusty) technical reports and theses—a reminder that researchers have to be diligent in their method of transferring information. The high turnover of industry geologists during boom years is also a hindrance. It is not uncommon for the company geologist who initiated the research project to

Lilly, R. (2017), SEG Newsletter

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If we can get past this...

- We can deliver innovative solutions to complex challenges in mineral exploration
  - Academia can provide industry with cutting edge analytical techniques and expertise that may not be available “in-house”, nor within commercial labs
- Academia can develop practical applications for research & inform future research

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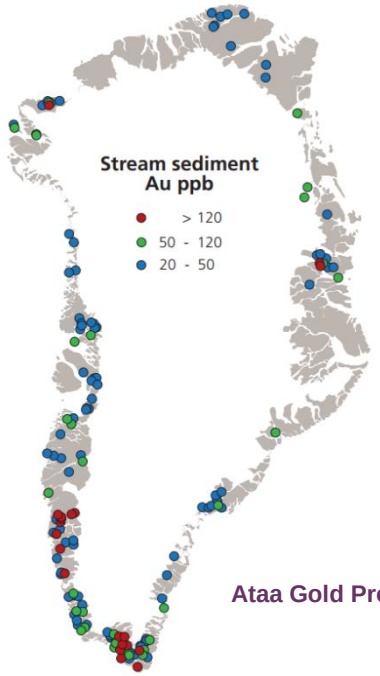
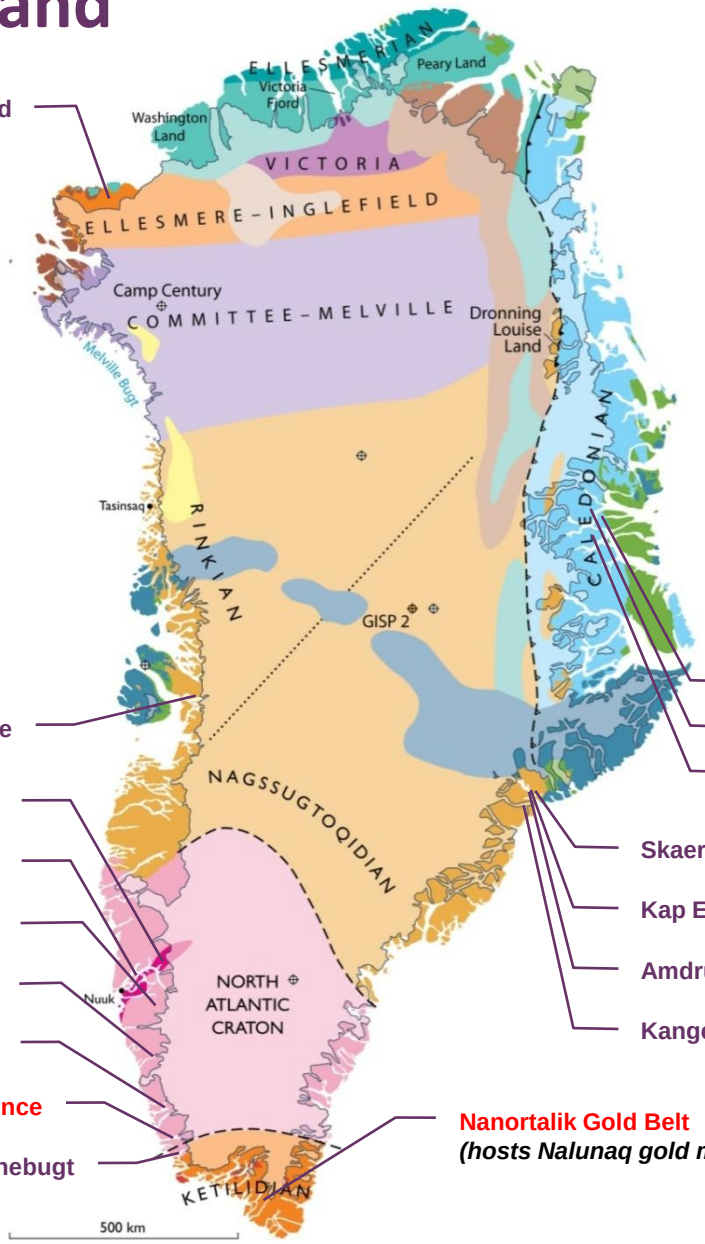
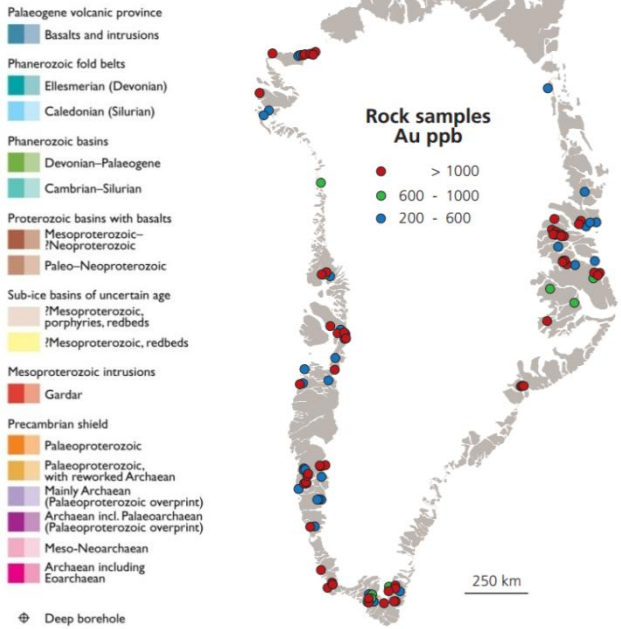
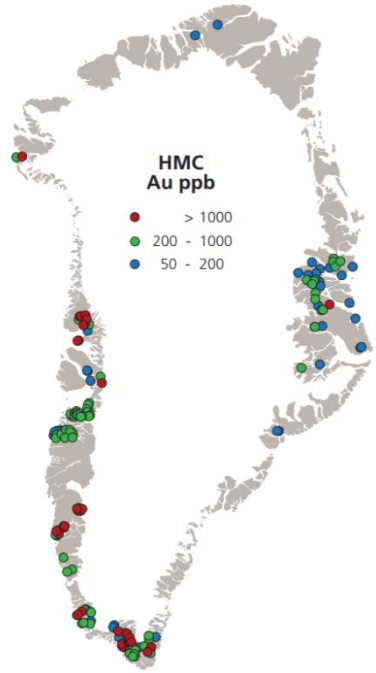
Gold in Greenland









Inglefield Land

Ataa Gold Province

Isua

Godthåbsfjord Gold Province

Tasiusarsuaq Gold Province; Sermilik

Bjørnesund

Paamiut Gold Province

Tartoq Gold Province

Kobberminebugt

Ymer Ø (Noa Dal)

Andrée Land

Lyell Land

Skaergaard Intrusion

Kap Edward Holm Intrusion

Amdrup Fjord

Kangerlussuaq

Nanortalik Gold Belt
(hosts Nalunaq gold mine)

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Figures adapted from: Dawes (2008), Kolb (2015)

GEUS-MMR "Mineral Resource Assessment Workshop on the Orogenic gold potential in Greenland"

NAALAKKERSUISUT
GOVERNMENT OF GREENLAND

GEUS

Held annually. Previous workshops on: **Cu, Zn, REE, Ni, W, V, Ti, Ni, U, Au and graphite**

"3-part undiscovered mineral resource estimation methodology" developed by the **USGS Global Mineral Resource Estimation Program**

International **Expert Panel** comprised of academics and industry geologists with specific knowledge on aspects of Greenlandic geology and/or expertise in the deposit type, e.g. Prof. Rich Goldfarb (USGS), Prof. Jochen Kolb (GEUS) and Prof. Pasi Eilu (GTK)

Historic exploration (company reports, presentations)

Academic literature

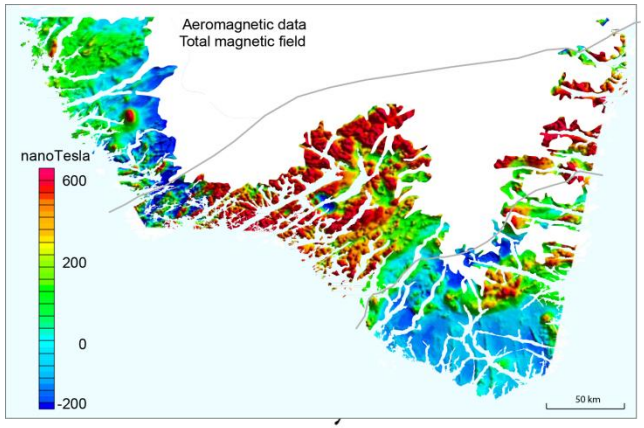
Geological Maps

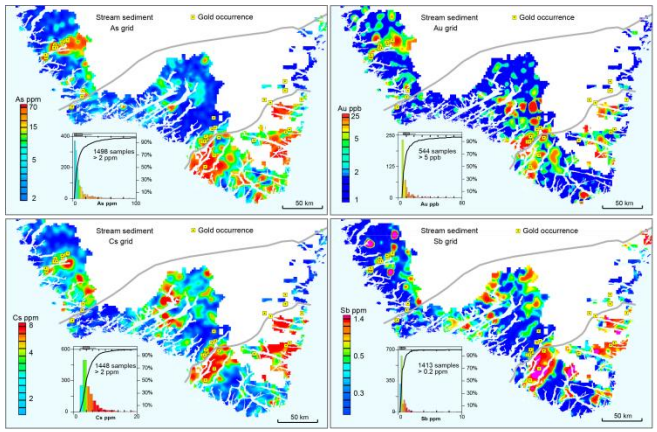
Global grade-tonnage models

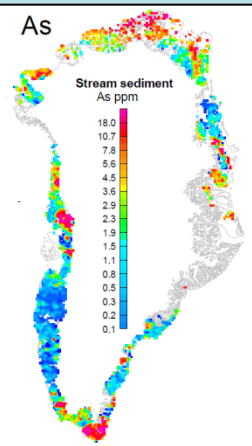
Geochemistry

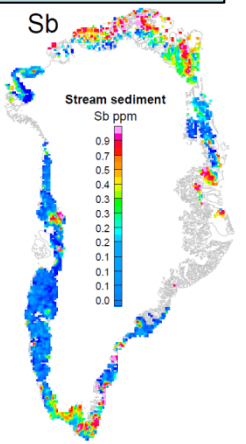
Geophysics

Geochronology







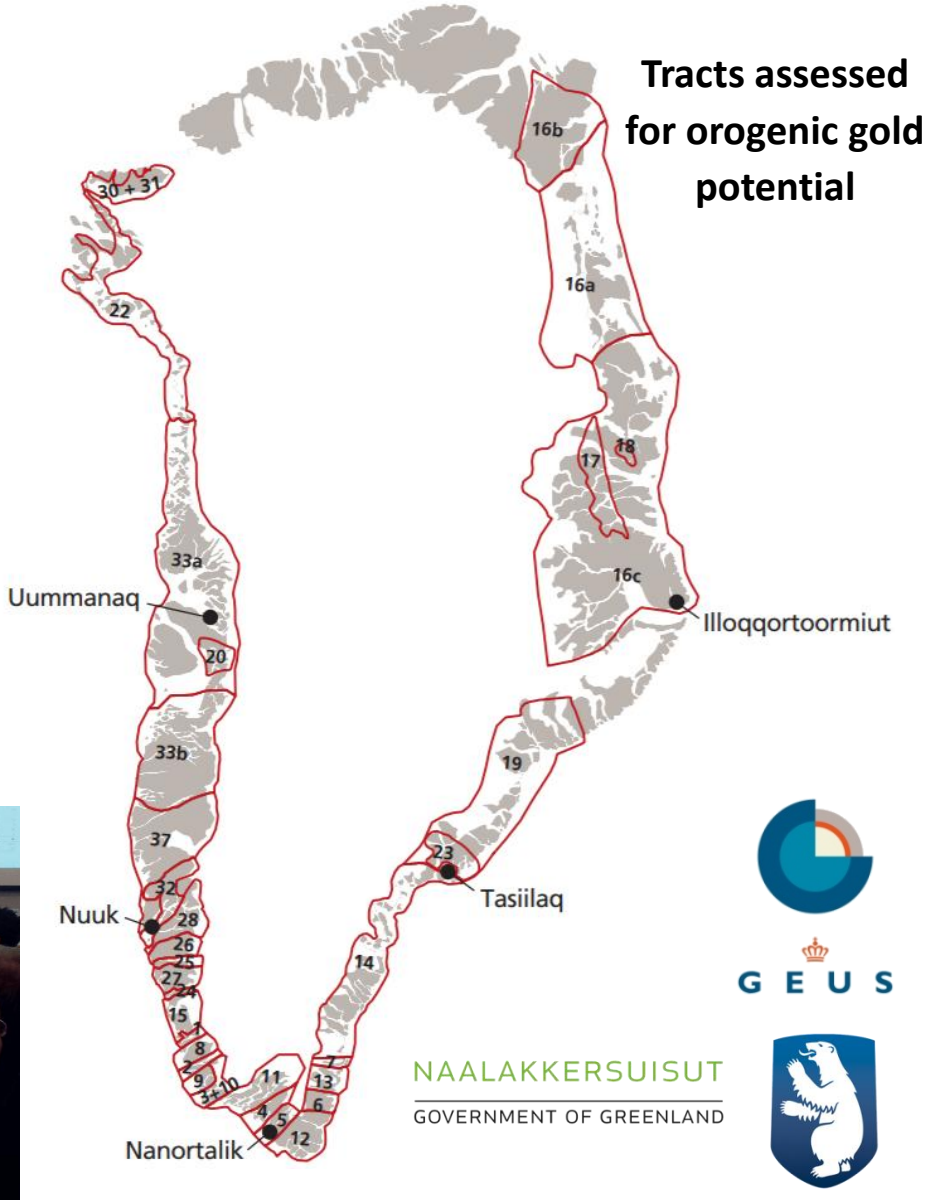


GEUS-MMR "Mineral Resource Assessment Workshop on the Orogenic gold potential in Greenland"

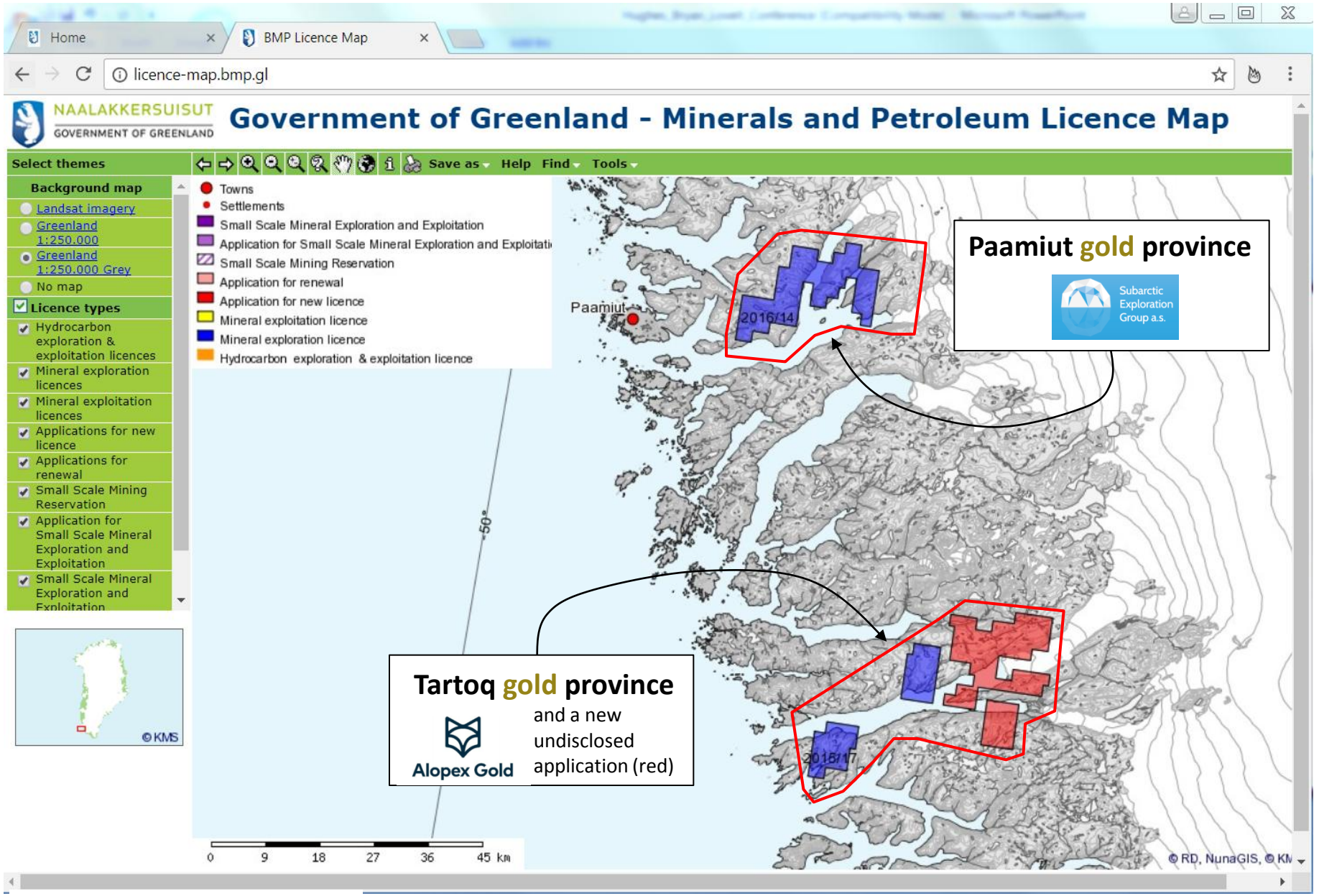
Figures from: Kolb (2015)

Tract name	Tract Area (km²)	Consensus bid on the number of undiscovered orogenic gold deposits at different confidence levels					Summary statistics		
		N90	N50	N10	N05	N01	Number of unknown deposits	Deposit density	Mean estimate of undiscovered orogenic gold (metric tons)
1	702	1	2	4	7	10	3	3.6	44
2	866	2	5	7	11	13	5	5.7	87
3+10	1,543	0	1	2	4	6	1	0.8	22
4	1,961	0	0	2	3	5	1	0.4	14
5	2,078	4	6	10	16	23	6	3.5	110
6	787	0	2	3	4	5	2	2.3	32
7	205	0	0	0	1	3	0	0.7	3
8+9+15+26+27	12,277	0	0	2	5	7	1	0.1	15
11	4,367	0	0	1	2	3	0	0.1	7
12	4,402	1	2	4	6	8	2	0.5	41
13	635	0	0	0	1	3	0	0.2	2
14	7,967	0	0	2	4	6	1	0.1	15
16a	19,297	0	2	10	20	50	6	0.3	96
16b	14,985	1	2	3	5	10	2	0.2	40
16c	65,921	1	3	8	16	36	5	0.1	91
17+18	7,715	2	4	8	12	20	5	0.7	92
19	8,728	0	1	2	4	6	1	0.1	23
20	2,344	2	4	5	8	10	4	1.6	67
22	5,733	0	1	2	5	7	1	0.2	24
23	3,238	0	0	2	4	6	1	0.3	13
24	543	0	0	2	3	5	1	1.4	13
25	751	0	0	2	2	4	1	0.9	12
28	5,191	0	0	2	3	6	1	0.1	14
30+31	5,206	0	1	3	6	9	2	0.3	29
32	5,211	4	7	11	20	33	8	1.6	150
33a	29,440	0	2	6	11	15	3	0.1	55
33b	25,338	0	0	2	3	5	1	0.1	12
37	16,892	0	1	3	5	7	2	0.1	28

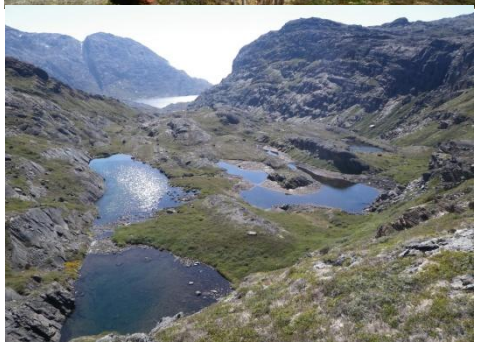
N90, N50, N10, N05, N01 = Confidence levels; a measure of how reliable a statistical result is, expressed as a percentage that indicates the probability of the result being correct. A confidence level of 10% (N10) means that there is a probability of 10% that the result is reliable. Deposit density = The total number of deposits per 1000 km².



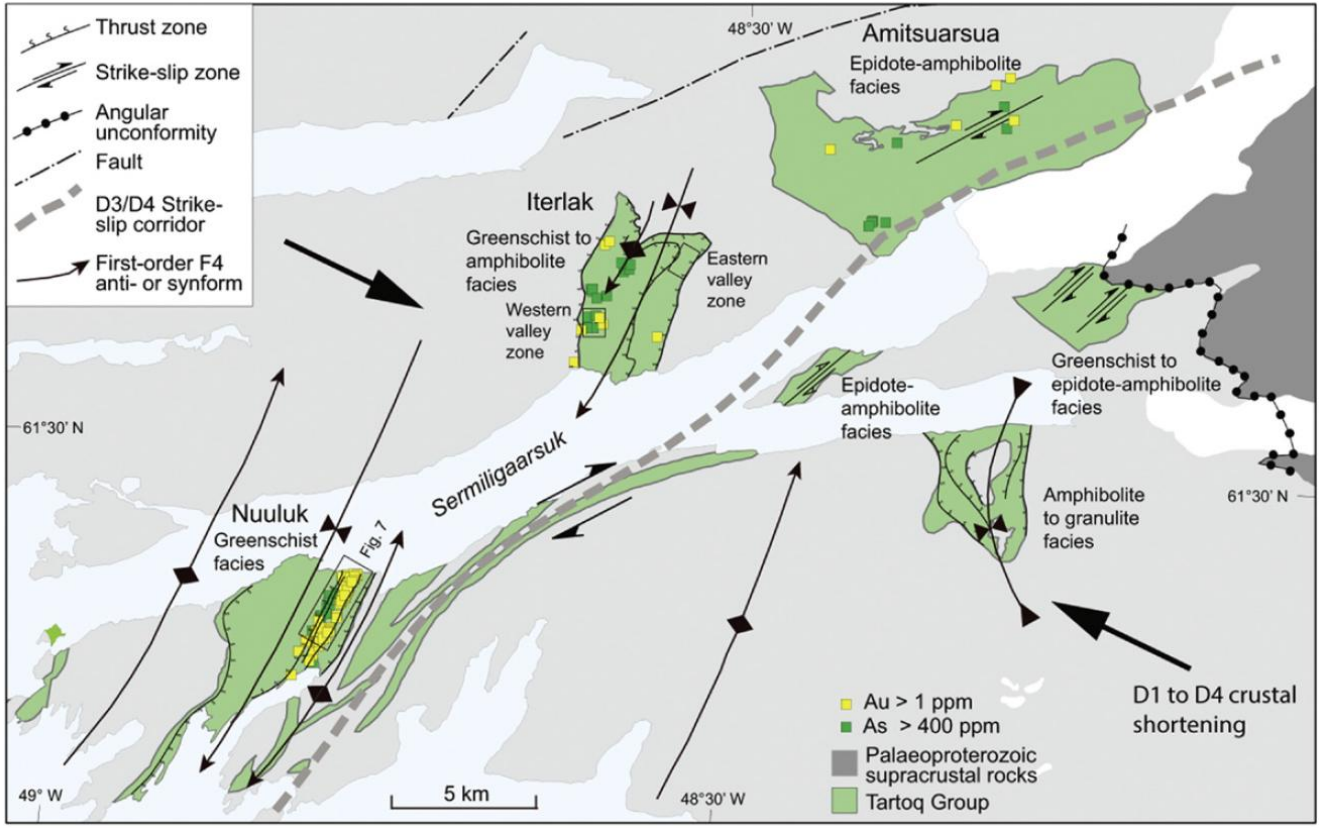
Uptake of mineral exploration licences following the gold workshop



(website accessed: 19th November 2017)

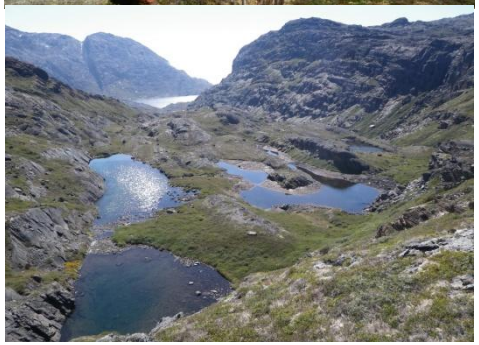


The Tartoq gold province



Mineral Exploration Licence acquired by **Nanoq Resources Ltd** following the Mineral Resource Assessment Gold Workshop, and later sold to **Alopex Gold Inc.** (TSX.V: AEX) in 2016

Recent exploration highlights: massive sulphide lenses (**up to 0.4 m @ 11.7 g/t gold**), quartz-ankerite veins (**up to 0.5 m @ 106 g/t gold**)



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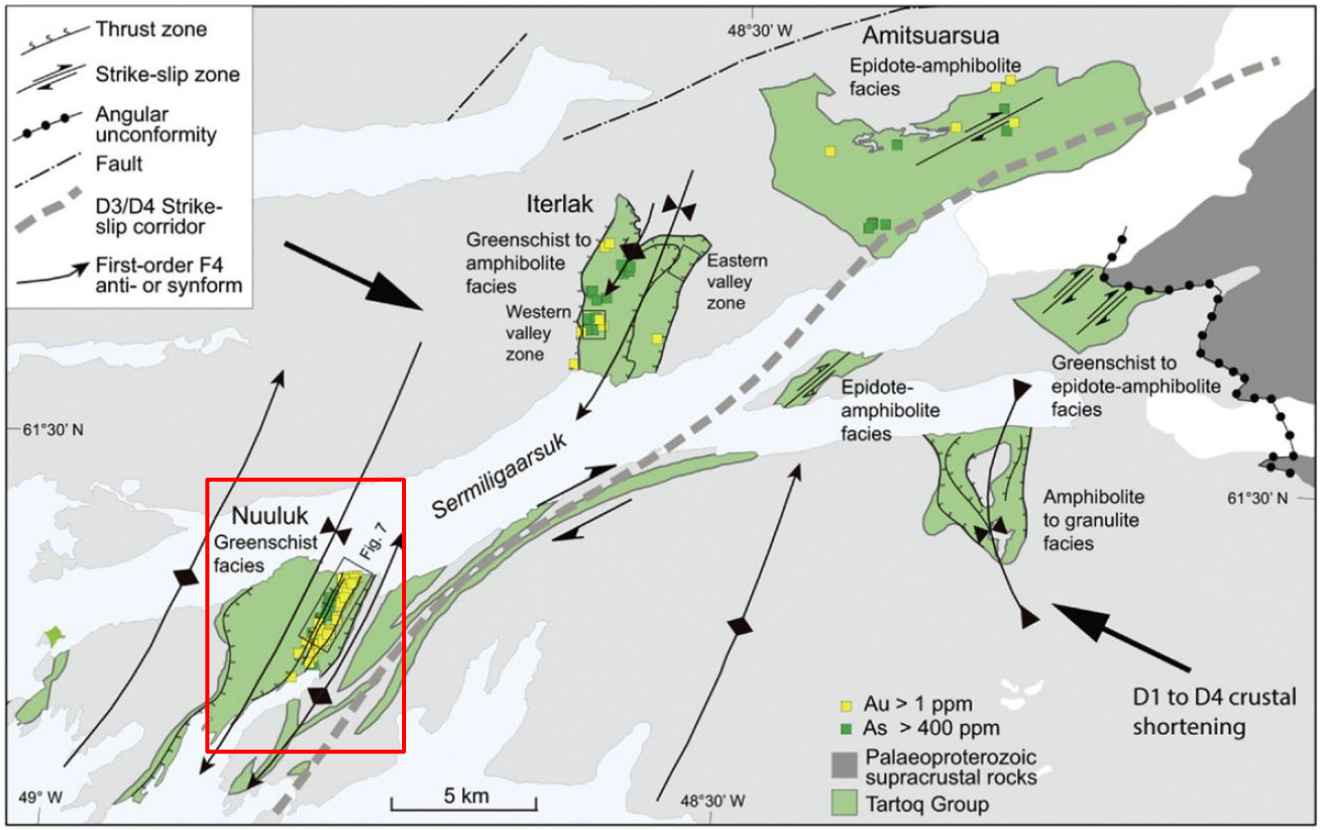

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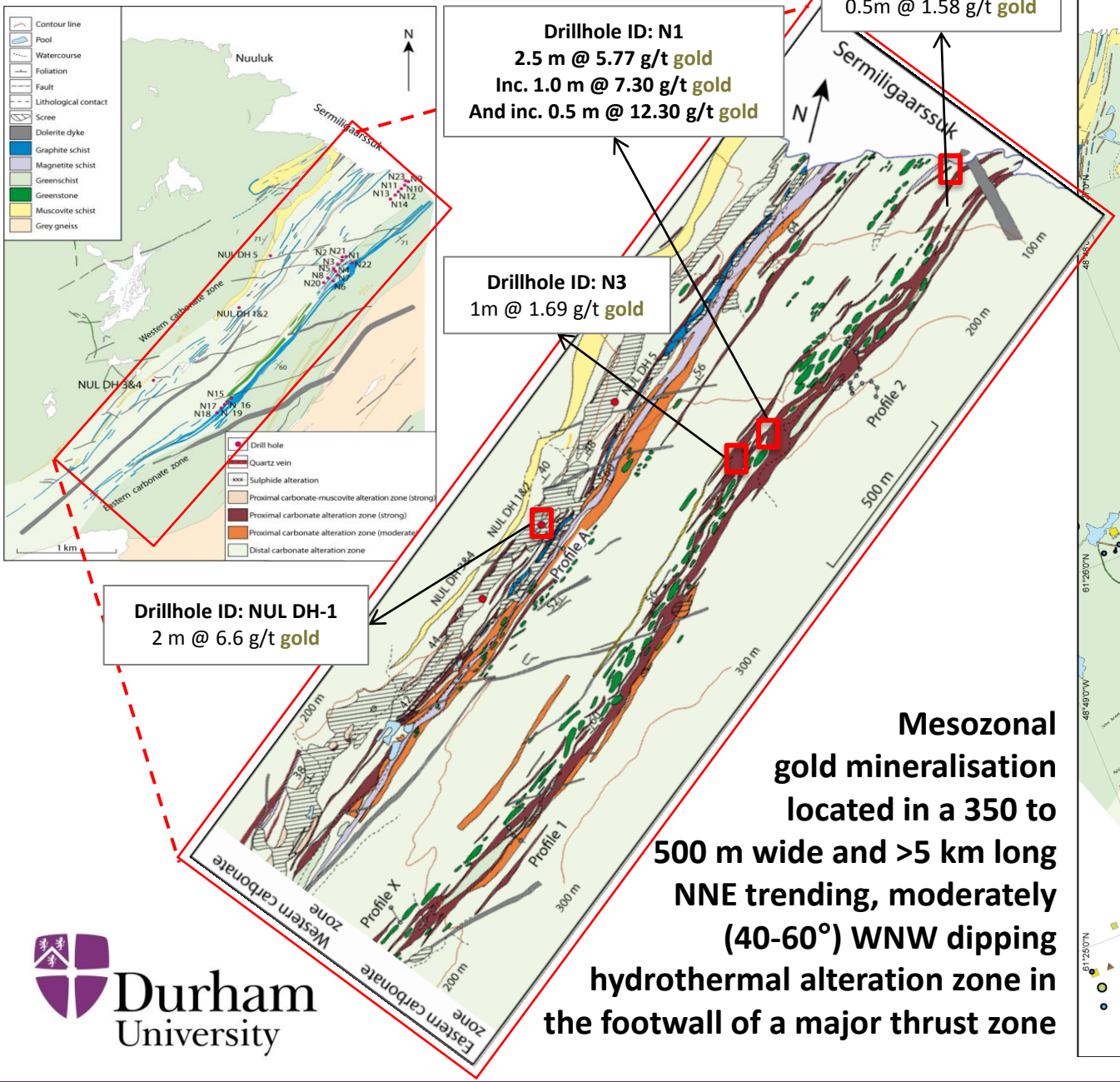
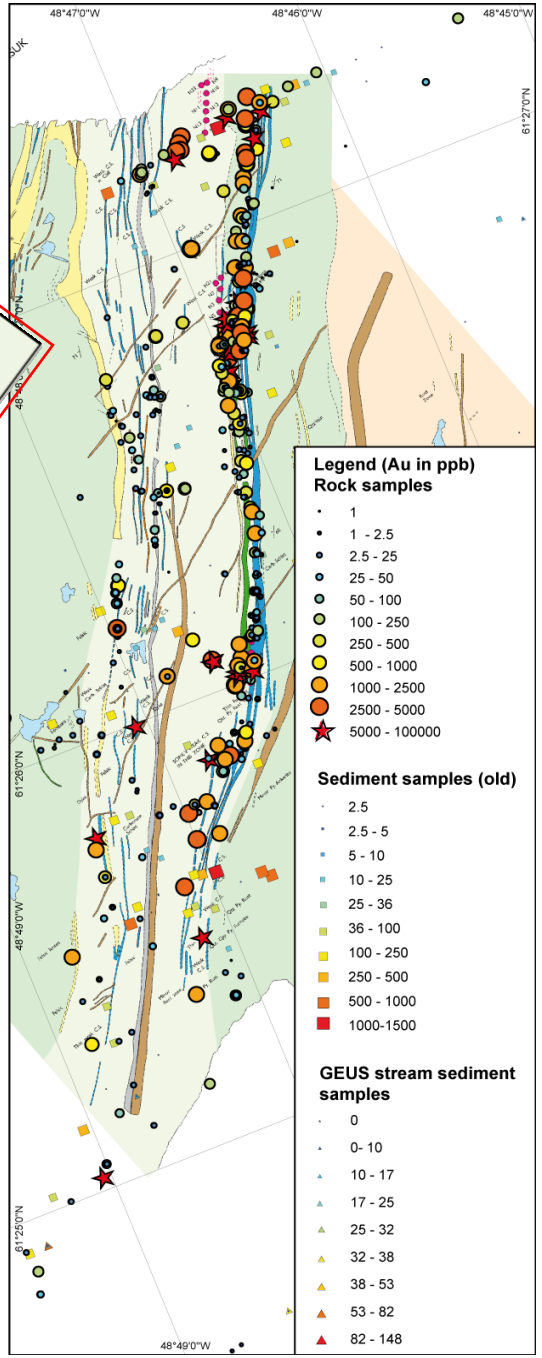
The Tartoq gold province - Nuuluk





Mesozonal gold mineralisation located in a 350 to 500 m wide and >5 km long NNE trending, moderately (40-60°) WNW dipping hydrothermal alteration zone in the footwall of a major thrust zone

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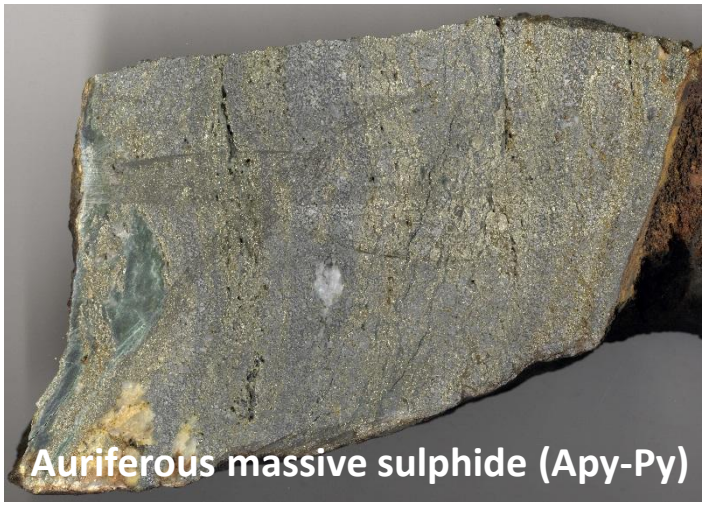
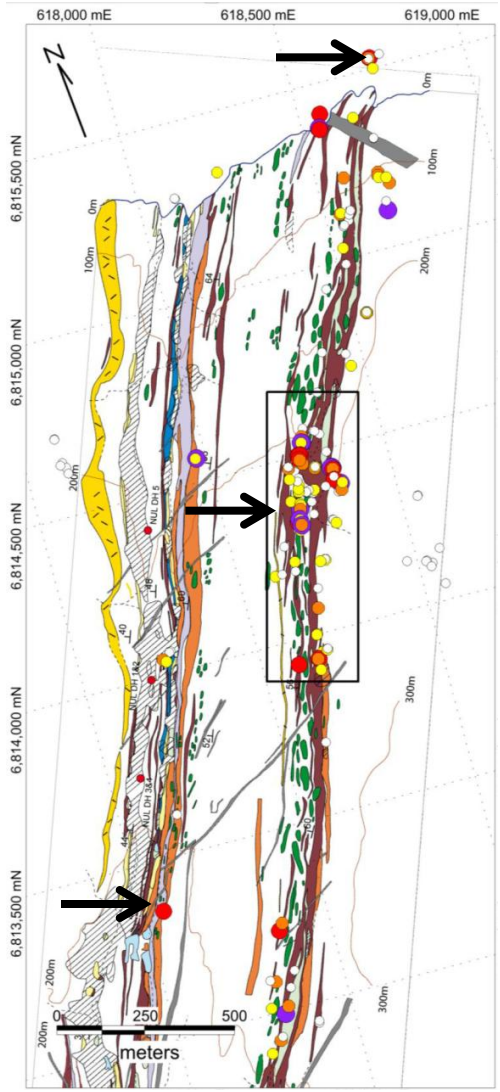
Dating of the orogenic gold mineralisation at Nuuluk by Ar-Ar (fuchsite) and Re-Os (arsenopyrite)

Objectives: time-resolved gangue and sulphide precipitation in a well-constrained structural and tectonic framework



Photographs: Dr Nic Saintalin



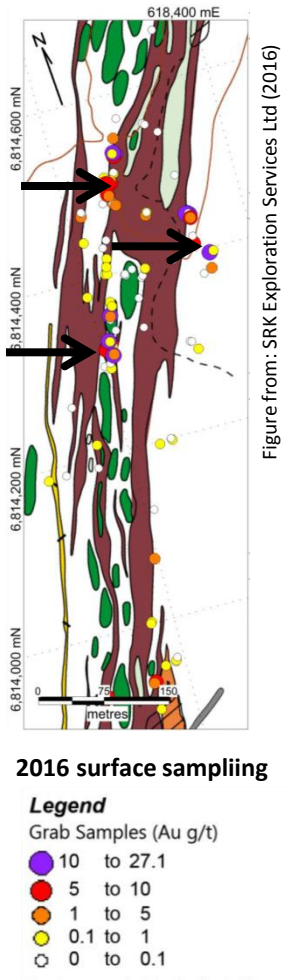


Figure from: SRK Exploration Services Ltd (2016)

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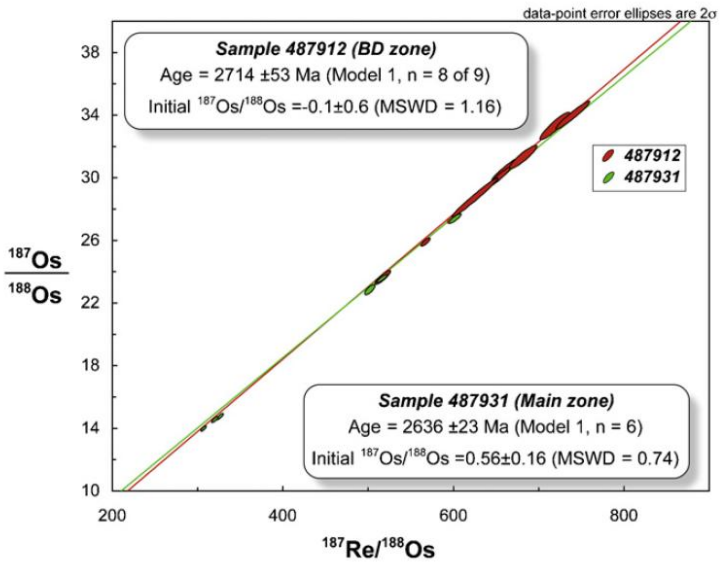
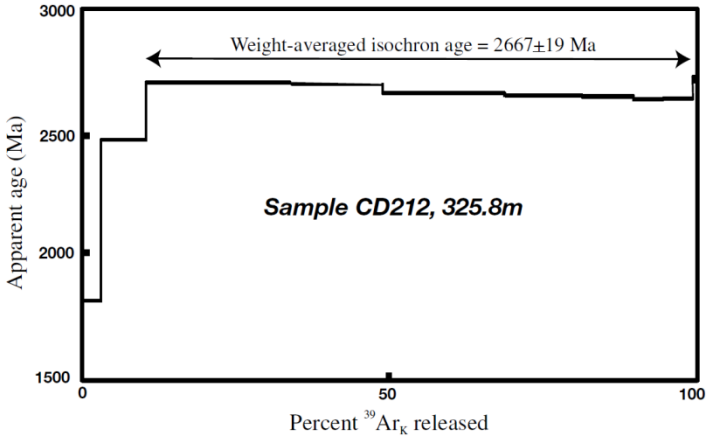
Dating of the orogenic gold mineralisation at Nuuluk by Ar-Ar (fuchsite) and Re-Os (arsenopyrite)

- **^{187}Re-^{187}Os geochronology at Durham University (Dr Nic Saintilan and Prof. Dave Selby)**
- **^{40}Ar/^{39}Ar geochronology – sample irradiation in Orogen (USA) and analysis at the University of Geneva (Dr Nic Saintilan and Dr Richard Spikings)**

- At Nuuluk arsenopyrite (Apy) is the earliest sulphide phase, which is intensely brecciated before being incompletely replaced by pyrite (Py). Locally both Apy & Py are brecciated and cross cut by quartz +/- minor chalcopyrite
- Apy and Py are associated and coeval with fuchsite (resulting from potassic alteration with Cr being stripped from the ultramafic host rocks)
- Apy is a robust mineral for ^{187}Re-^{187}Os geochronology (e.g. Davies *et al.*, 2010: Morelli *et al.*, 2010; Scherstén *et al.*, 2012; Saintilan *et al.*, 2017) with closure temperatures for Re-Os estimated as >400°C
- Fuchsite is a robust mineral for ^{40}Ar/^{39}Ar with closure temperatures >350°C (e.g. Brown *et al.*, 2002)



Example Apy Re-Os isochron for Archean gold mineralization at Storø, West Greenland (Scherstén *et al.*, 2012)



Example argon release spectrum for fuchsite from the Sunrise shear zone in Western Australia (Brown *et al.*, 2002)

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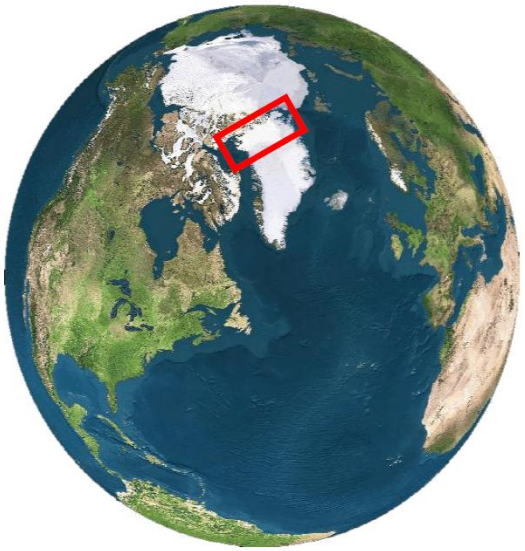
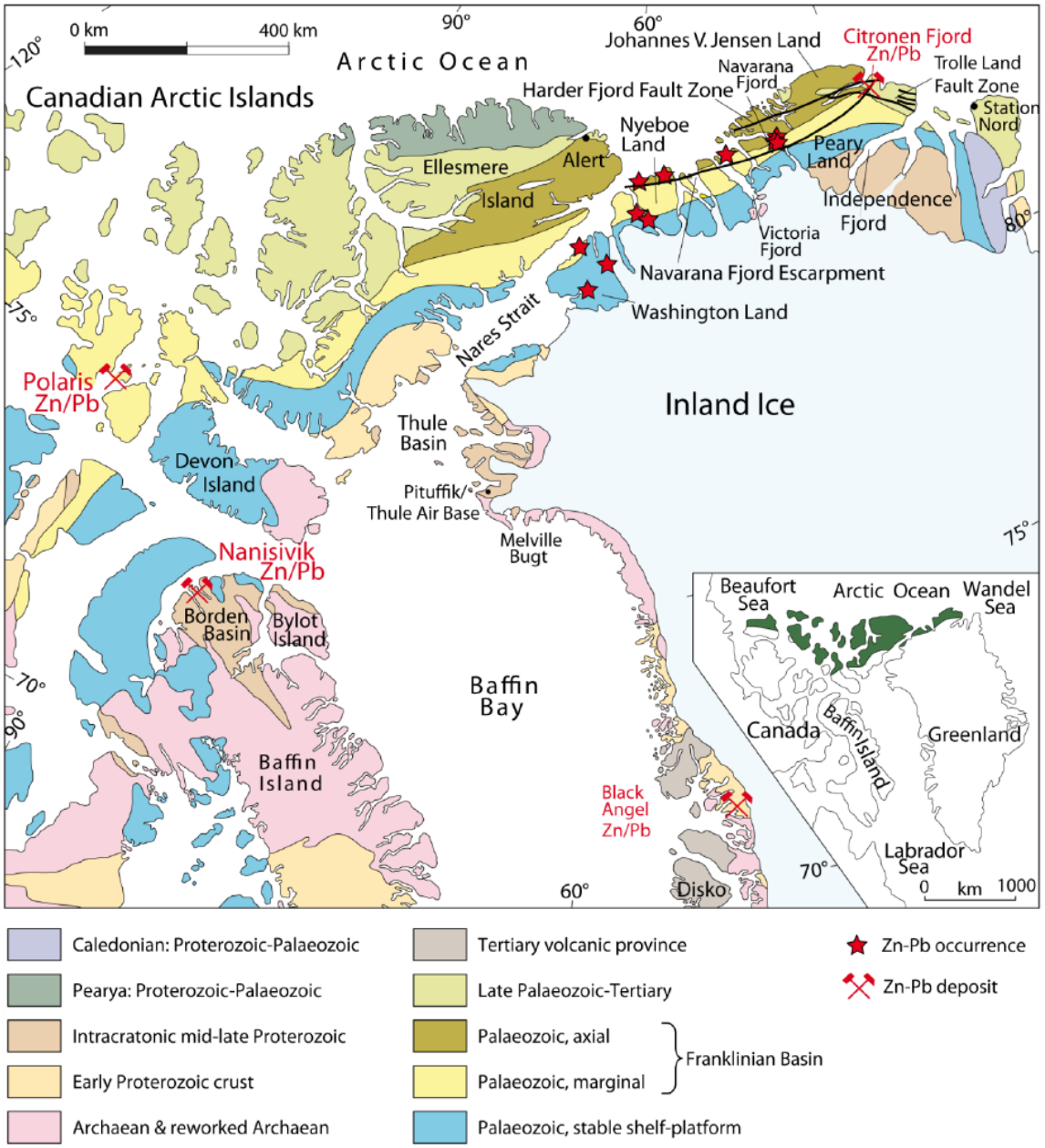
Geology doesn't stop at borders...





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The North Atlantic Craton Conference, and a “craton-specific” approach to mineral exploration...

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The North Atlantic Craton Conference (University of St Andrews, March 2014)

- 71 delegates, 13 countries represented
- Keynotes includes:
  - **Prof. Richard Goldfarb** (USGS)
  - **Prof. Sarah-Jane Barnes** (Uni. Québec)
  - **Prof. Jochen Kolb** (then GEUS)
  - **Dr Graham Begg** (Minerals Targeting International)
  - **Prof. Chris Hawkesworth** (then Uni. St Andrews)
- Post conference fieldtrip to the NW Scottish Highlands
- Resulted in a thematic issue of Mineralogical Magazine

Sponsors and organisers:

University of St Andrews

midland valley
the structural geology experts

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SOCIETY OF ECONOMIC GEOLOGISTS FOUNDED 1920

SEG
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NORTHERNSHIELD RESOURCES

The North Atlantic Craton + Conference (Edinburgh, March 2016)

- 64 delegates, 11 countries represented
- Keynotes includes:
  - **Prof. Nick Arndt** (Uni. Grenoble)
  - **Dr Simon Jowitt** (Monash Uni)
  - **Dr Bo Moller-Stensgaard** (then GEUS)
  - **Prof. Raimo Lahtinen** (GTK)
  - **Prof. Andrew Kerr** (Memorial Uni. Newfoundland)
- Post conference fieldtrip to the Outer Hebrides (Isle of Lewis & Harris)

Sponsors and organisers:

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Natural Resources Canada
Mineralogical Society
srk exploration

Geological correlation between gold belts in Greenland and Scandinavia

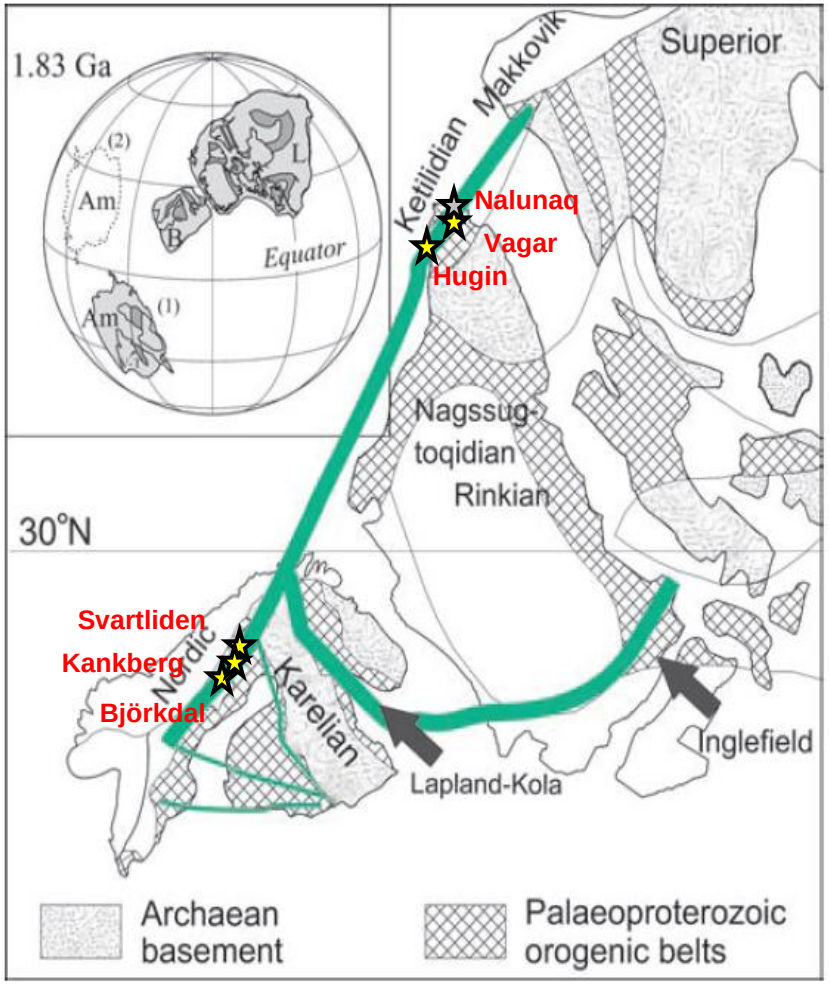
The 1.8 Ga **Ketilidian orogeny** which hosts the Nanortalik Gold Belt has geological correlations with the **Makkovik Province** (Canada) and **Svecofennian Orogeny** (Scandinavia) as supported by paleogeographical reconstructions for the Paleoproterozoic.

The Nanortalik gold belt hosts several known gold deposits:

- Nalunaq mine (375,650 oz produced; 15 g/t gold)
- Vagar prospect (up to 11 m @ 80.2 g/t gold)
- Jokum's Shear prospect (up to 3.1 m @ 9.3 g/t gold)

The Svecofennian Orogeny hosts the Lycksele – Storumen gold belt and the neighboring Skelefteå Mining District. Producing gold mines include:

- Svartliden mine (2.9 Mt @ 4.3 g/t gold)
- Björkdal mine (7.5 Mt @ 2.5 g/t gold)
- Kankberg mine (2.8 Mt @ 4.1 g/t gold)



Adapted from: Lahtinen *et al.* (2008)

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The Nanortalik Gold Belt

Located along the southern margin of the Palaeoproterozoic Julianehåb Igneous Complex - part of a juvenile continental arc formed during oblique northwards subduction (sinistral transpression), emplaced during the Ketilidian Orogeny, 1850-1725 Ma

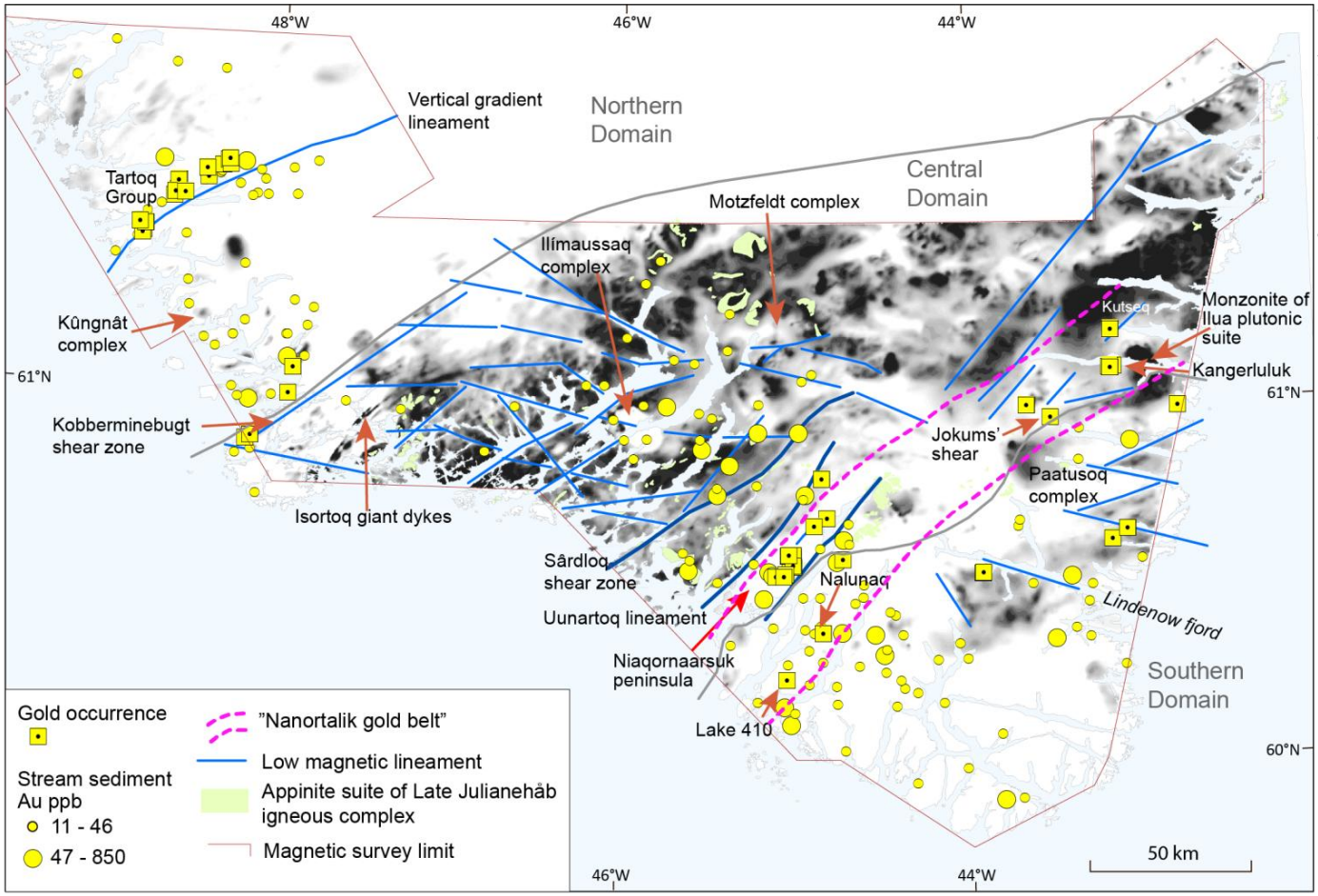

Figure from: Steenfelt *et al.* (2016)

Province scale gold play:

>175 km long highly underexplored gold belt

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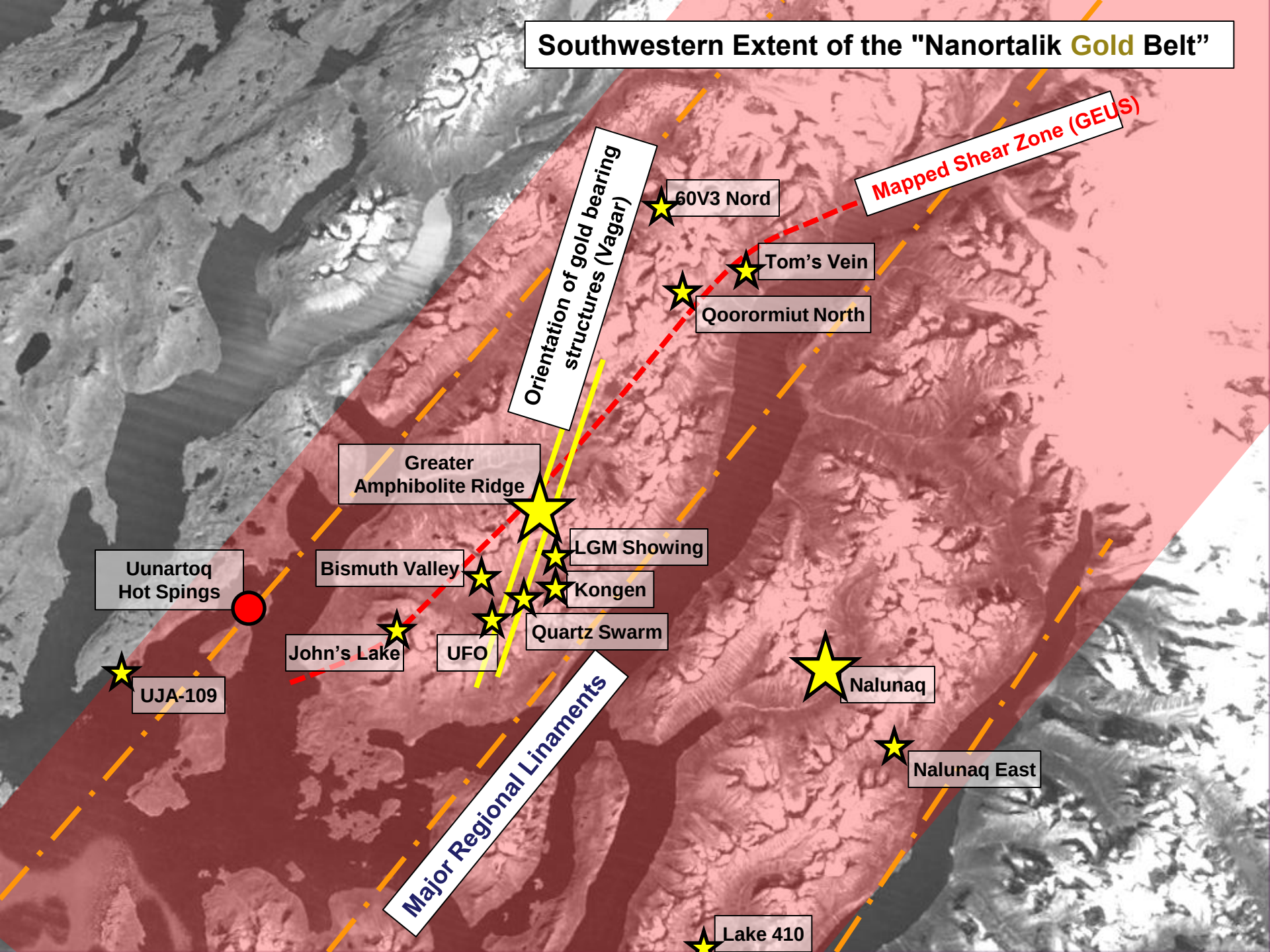
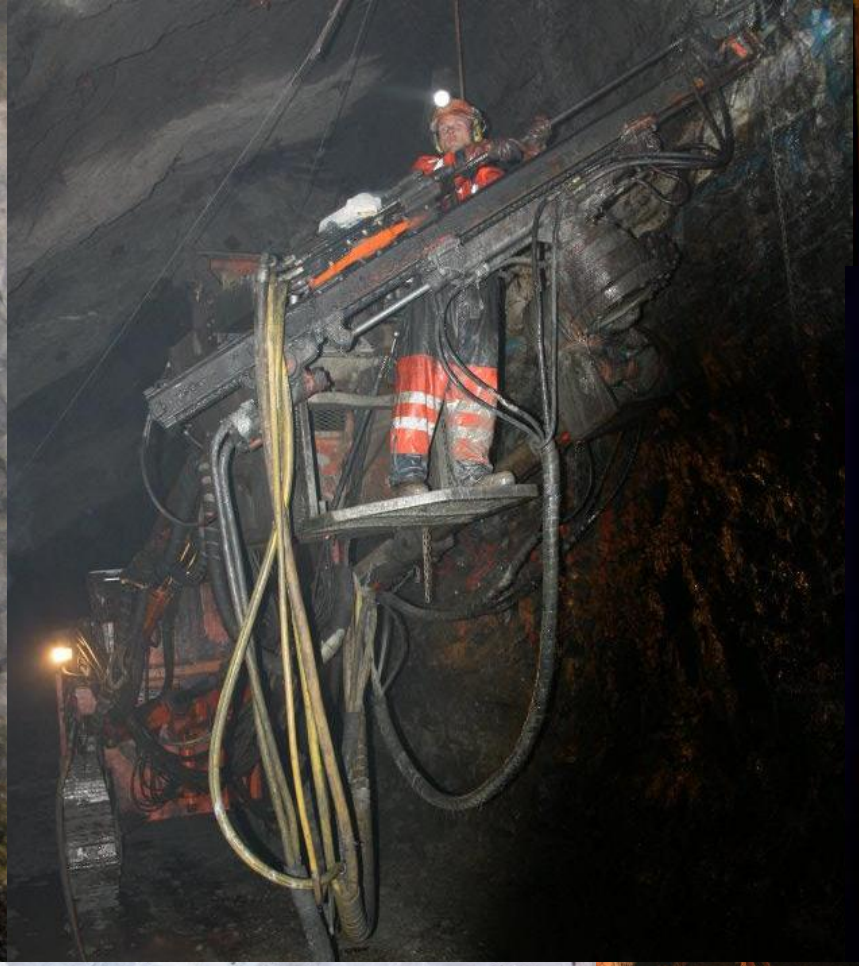
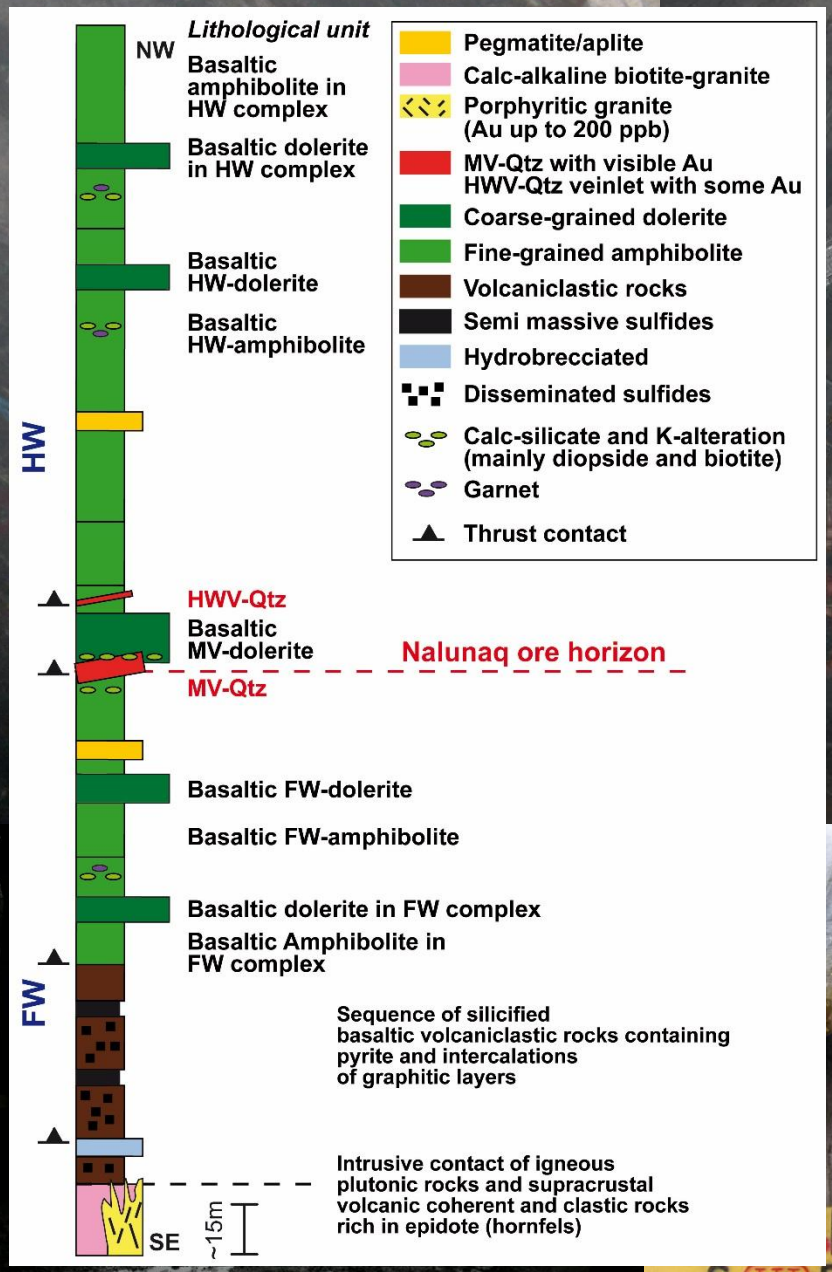

Southwestern Extent of the "Nanortalik Gold Belt"
Mapped Shear Zone (GEUS)
Orientation of gold bearing structures (Vagar)
60V3 Nord
Tom's Vein
Qoormiut North
Greater Amphibolite Ridge
LGM Showing
Kongen
Quartz Swarm
Bismuth Valley
Uunartoq Hot Spings
John's Lake
UFO
UJA-109
Major Regional Linaments
Nalunaq
Nalunaq East
Lake 410

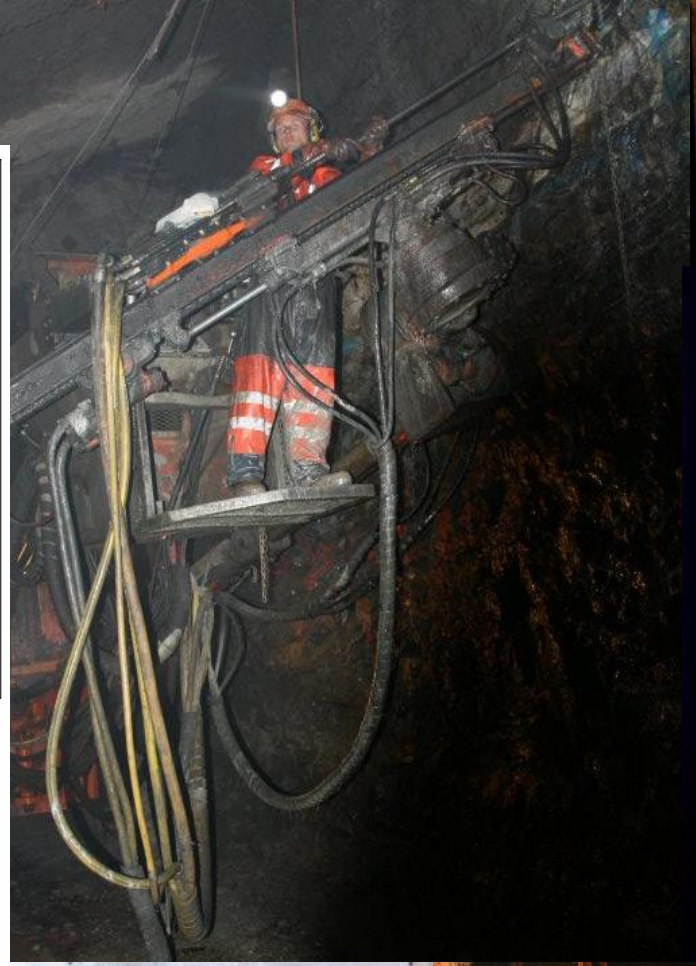

Nalunaq Gold Mine

Nalunaq Gold Mine

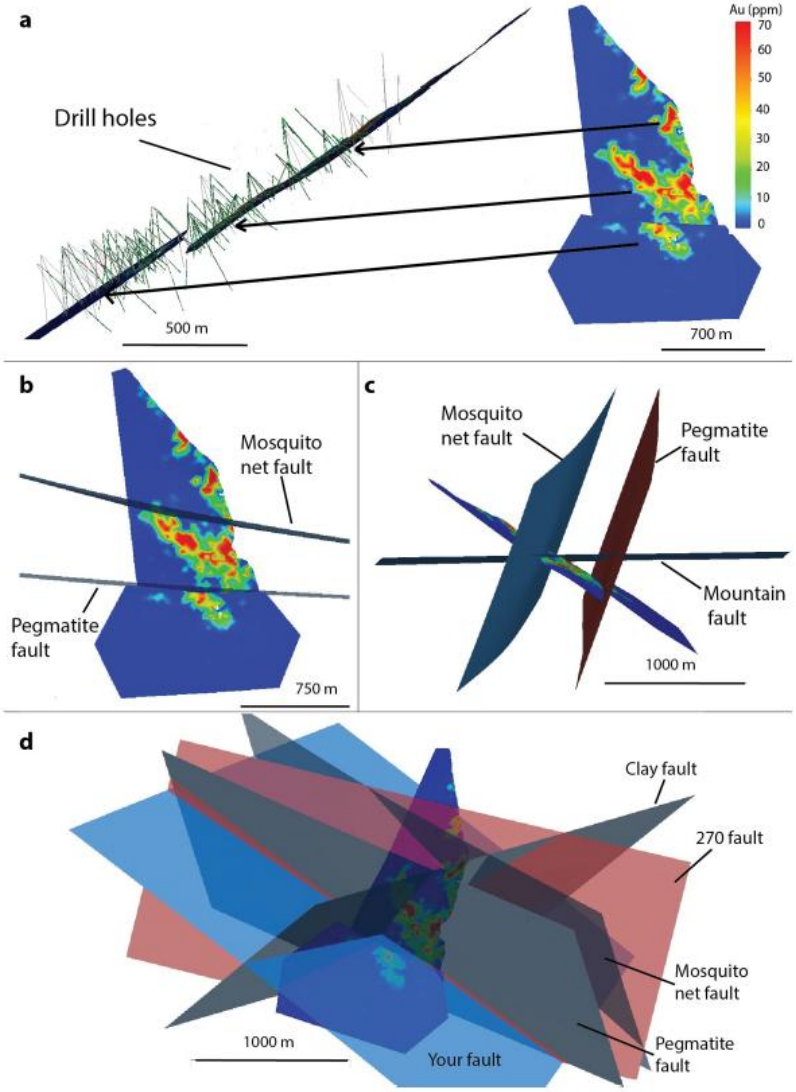


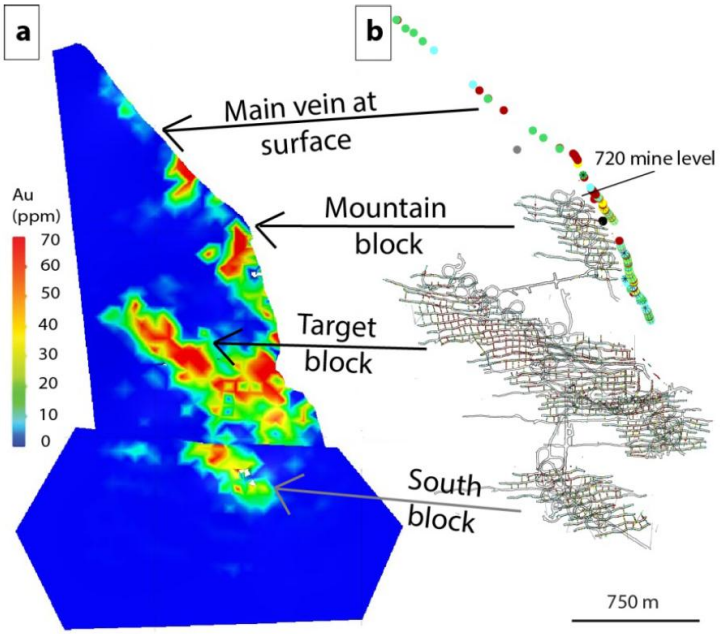
Nalunaq Gold Mine

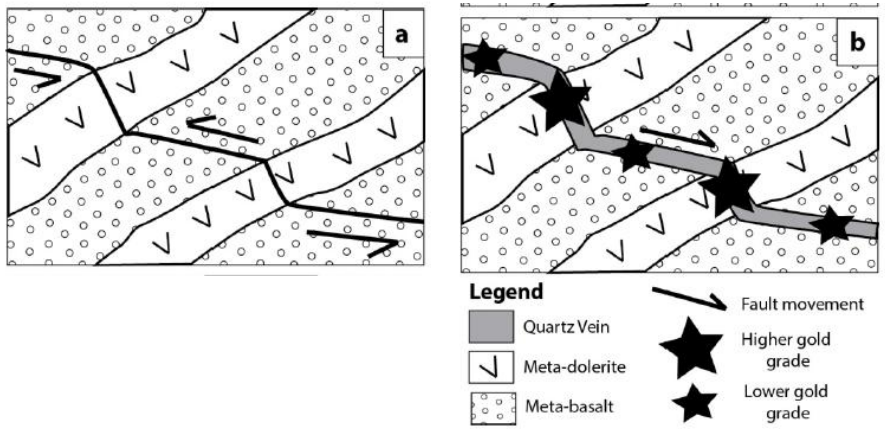




Recent structural, petrological and geochemical at Nalunaq gold mine



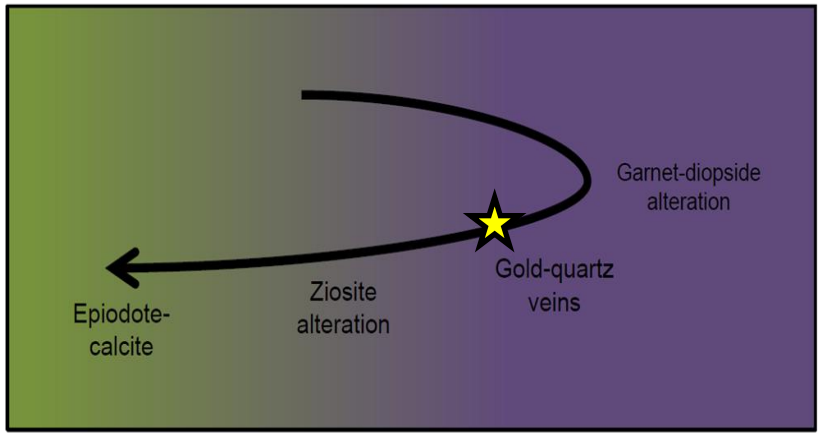


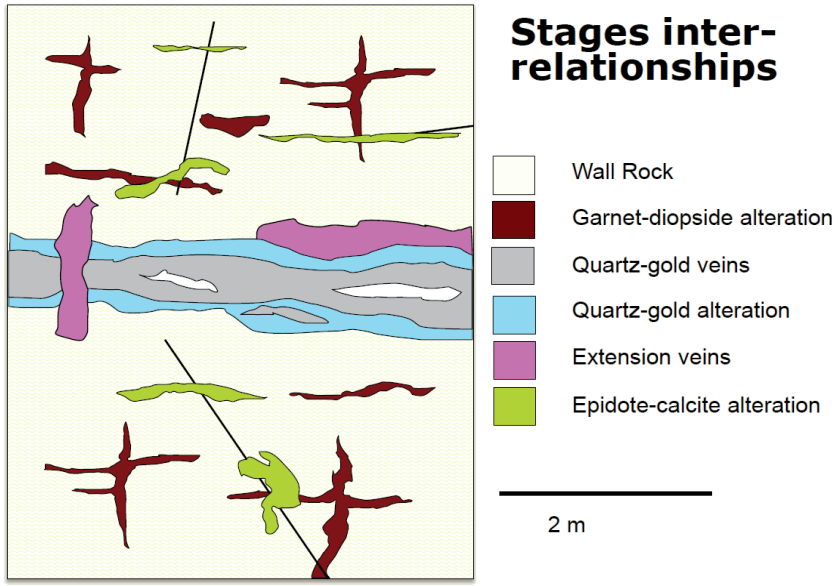


Figures: Bell et al., (2017)

Recent structural, petrological and geochemical at Nalunaq gold mine

Events at Nalunaq	Hydrothermal alteration	Age (Ma)	Metamorphic conditions	Regional geology*	
				Deform-ation stage *	Age data* (Ma)
Intrusion of granite Formation of late-stage faults	Zoisite and epidote-calcite alteration	1744.5 ± 4.6	Greenschist-Subgreenschist facies	D_4	1737
	Calcite-titanite alteration	1765.7 ± 8.5	Greenschist facies		
Normal reactivation of reverse shear zones	Gold-quartz veins and biotite-arsen-opyrite alteration Introduction of extension veins		Amphibolite-Greenschist facies	D_3	1786-1778
Reverse shearing of the deposit Isoclinal folding	Formation of plagioclase-quartz veins and CPGZ	1783.3 ± 8.7	Amphibolite-Upper Amphibolite facies	D_2	1792
Foliation development Formation of the sedimentary and volcaniclastic rocks				D_1	





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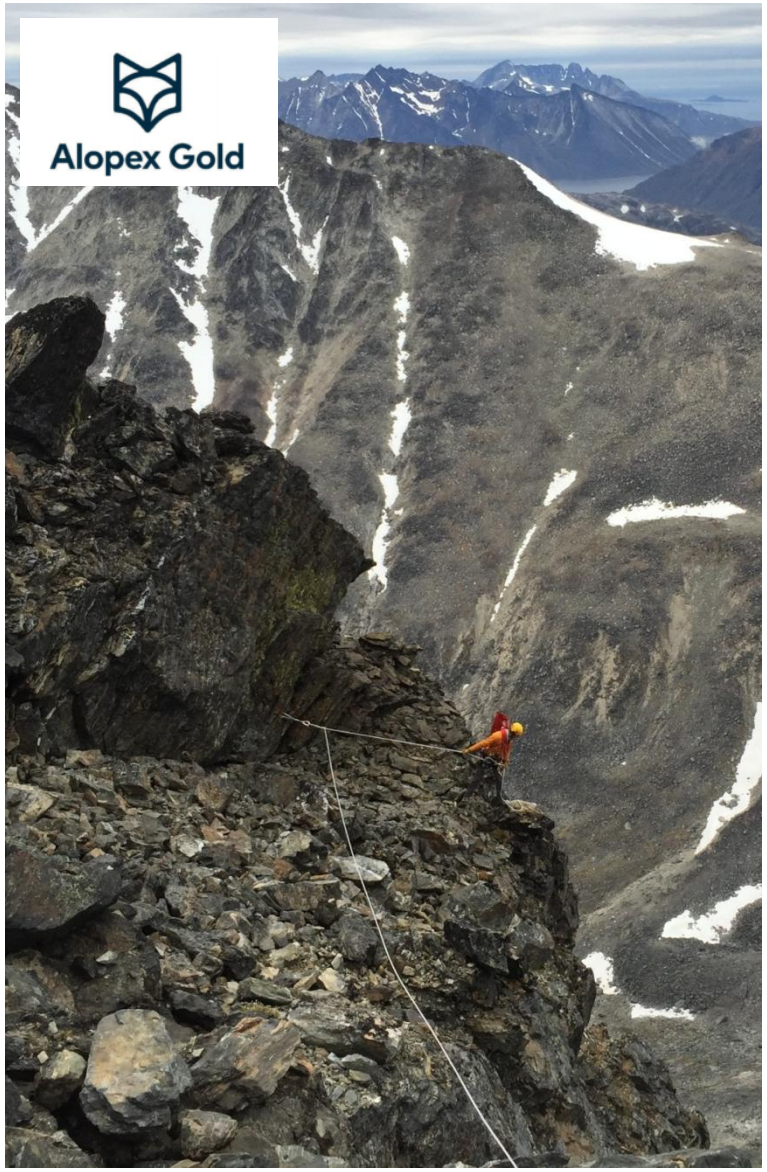
Figures: Bell et al., (2017)



Alopex Gold

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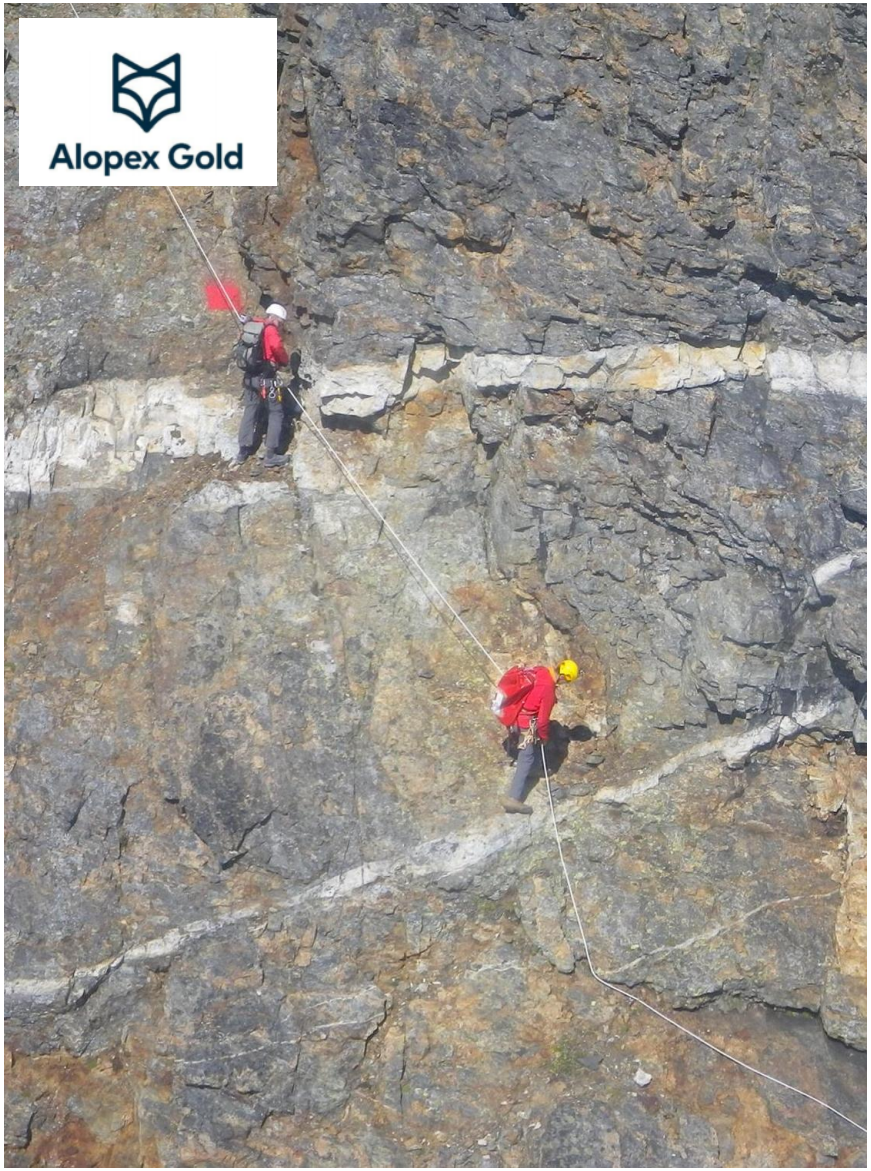

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Qujanaq

Apeqqutissaqarpisi?

Thank you

Any questions?

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