GEUS

European Geosciences Union
GIFT – Geosciences Information For Teachers

The Geological History and Mineral Deposits in Greenland - a Status on Current Projects

Majken D. Poulsen
Geologist madp@geus.dk
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Knowledge for life

GEUS

Water• Energy• Minerals • Nature and Climate • Data banks

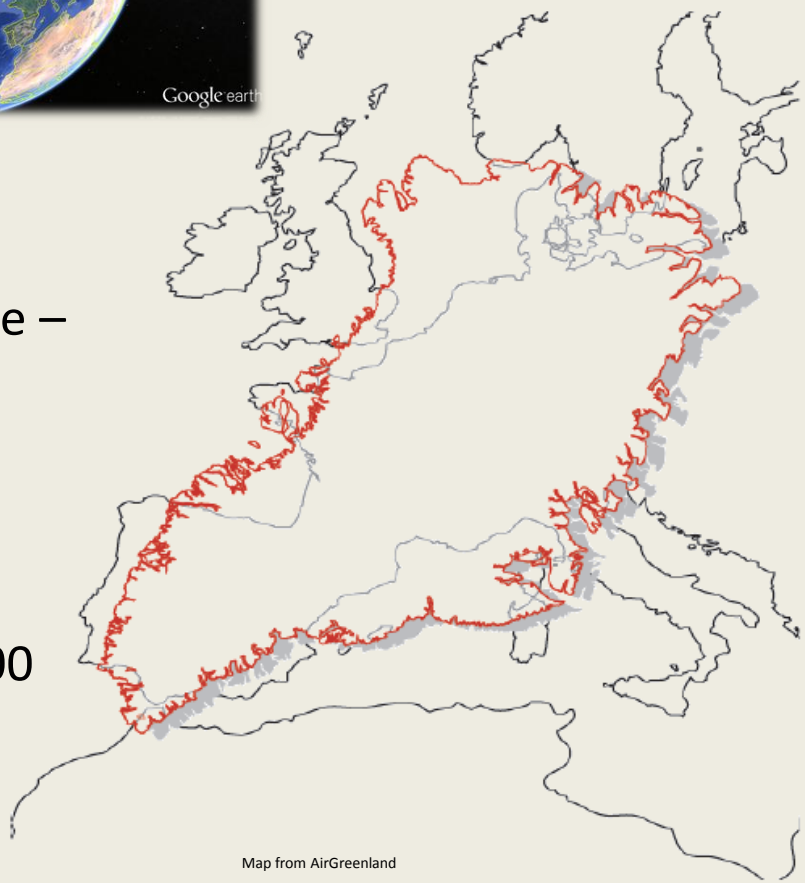
Geological Survey of Denmark and Greenland (GEUS)

- Danish research and advisory institution under the Danish Ministry of climate, Energy and Building
- Main building located in Copenhagen and has smaller offices in Aarhus (Jutland) and Nuuk (Greenland)
- A total of about c. 350 full time specialists, technicians and administrative staff. Approximately 200 hold PhD or MSc degrees
- Cover most geoscientific disciplines and activities – five programme areas: Mineral resources, Energy resources, Water resources , Nature and climate and Data banks
- International collaborative partners; collaborative partner to the Government of Greenland
- GEUS has geological experience with Greenland for more than 150 years

Greenland facts

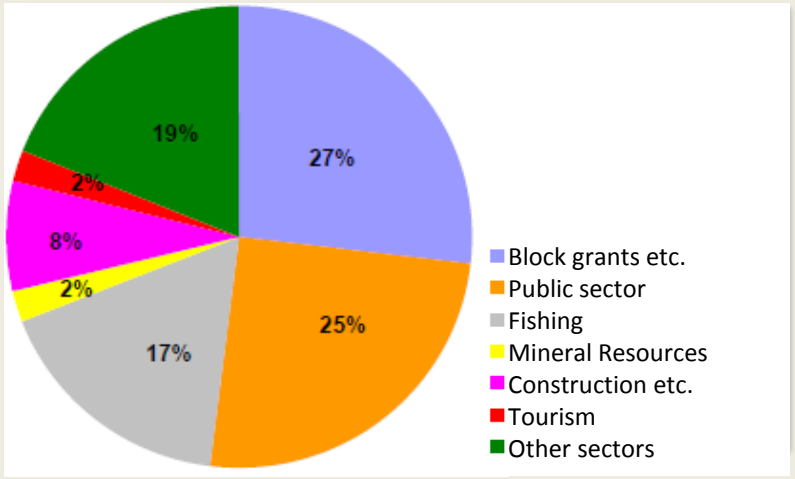
Greenland facts:

- North / South coordinates 59˚46'N / 83˚39'N
- 2,670 km N-S; 1,050 km E-W
- Coastline 44,087 km
- Total area 2,166,086 km^2
  - 12th largest nation
  - Ice-sheet up to 3.4 km thick in the middle – worlds largest fresh water reserve
- Ice-free area 410,449 km^2 (still growing…)
  - 60th largest nation; larger than Finland, Germany, Poland or Norway; Sweden is 450,000 km^2; France is 551,500 km^2
  - Australia is 7,692,024 km^2; 6th largest nation
  - Republic of Austria is 83,879 km^2



Map from AirGreenland

Greenland facts:



- Around 57,000 inhabitants
- About 76 towns and settlements
- The worlds largest island
- Fishery and block-grant is the main income
- Greenland is part of the Danish Kingdom
- Main language is Greenlandic and Danish
- Greenland was governed as a Danish colony since 1721, but in 1979 Greenland got Home Rule, and self-government in 2009
- In 2009 the Government of Greenland home took the right to possess and exploit mineral resources in the underground of Greenland
- In the Mining Act the Government of Greenland state GEUS may conduct research of special relevance to mineral resource exploration in Greenland, to the extent and as long as the research is conducted to meet the government's obligation to make such research available to the Government.

NAALAKKERSUISUT
GOVERNMENT OF GREENLAND

A few photos

A proven record of discoveries and mines....

Major discoveries and mines in Greenland:

1845: Collecting of graphite at Langø (NWG)

1852: Mining of copper at Josva mine (SG)

1852: Mining in Frederik VII mine (SG)

1854: Mining of lead in Ivittuut mine (SG)

1856: Mining of cryolite in Ivittuut mine (SG)

1903: Discovery of zirconium in Kringlerne (SG)

1903: Discovery of graphite at Akuliaruseq (WG)

1905: Reopening of the Josva copper mine (SG)

1915: Mining of graphite at Amitsoq (SG)

1924: Mining of coal at Qullissat (WG)

1933: Test mining of pyrite in Clavering Island (EG)

1936: Quarrying of marble in Maarmorilik (WG)

1951: Discovery of iron at Grønnedal-Ika (SG)

1954: Discovery of molybdenum in Malmbjerg (EG)

1955: Discovery of uranium in Kvanefjeld (SG)

1956: Mining of lead/zinc near Mestersvig (EG)

1964: Discovery of chromium in Fiskenæsset (WG)

1965: Discovery of the iron deposit at Isua (WG)

1965: Discovery of nickel and PGE at Maniitsoq (WG)

1966: Discovery of rubies at Fiskenæsset (WG)

1968: Discovery of REE at Qaqqarsuk (WG)

1972: Discovery of gold in Taartoq (SG)

1973: Mining of lead/zinc at Black Angel Mine (WG)

1973: Discovery of placer diamonds in Sarfartoq (WG)

1977: Discovery of niobium in Sarfartoq (WG)

1979: Test mining of uranium in Kvanefjeld (SG)

1979: Discovery of tungsten/antimony at Ymer Island (EG)

Ivittuut Cryolite Mine; shipping of cryolite 1889

1980: Discovery of tantanlum at Motzfeldt Lake (SG)

1982: Discovery of tungsten and gold in Nuuk Fjord (WG)

1984: Discovery of zinc and barite at Navarana Fjord (NG)

1985: Discovery of gold in Disko Bay area (WG)

1986: Discovery of gold and PGE's in Skaergaard (EG)

1992: Discovery of primary gold at Nalunaq (SG)

1993: Discovery of zinc at Citronen Fjord (NG)

1995: Find of in-situ diamonds near Maniitsoq (WG)

1995: Small-scale mining of olivine at Evighedsfjord (WG)

1996: Discovery of gold at Kangerluluk (SEG)

2003: Mining of gold mine at Nalunaq (SG)

2005: Mining of olivine at Seqi (WG)

2005: Discovery of the iron deposit at Isortoq (SG)

2008: Mining licence granted for Malmbjerg Mo-deposit (EG)

2010: Mining licence granted for Black Angel Mine (WG)

2011: Discovery of the iron deposit at Havik (NG)

2013: Mining licence granted for Isua iron deposit (WG)

2014: Mining licence granted for rubies at Fiskenæsset (WG)

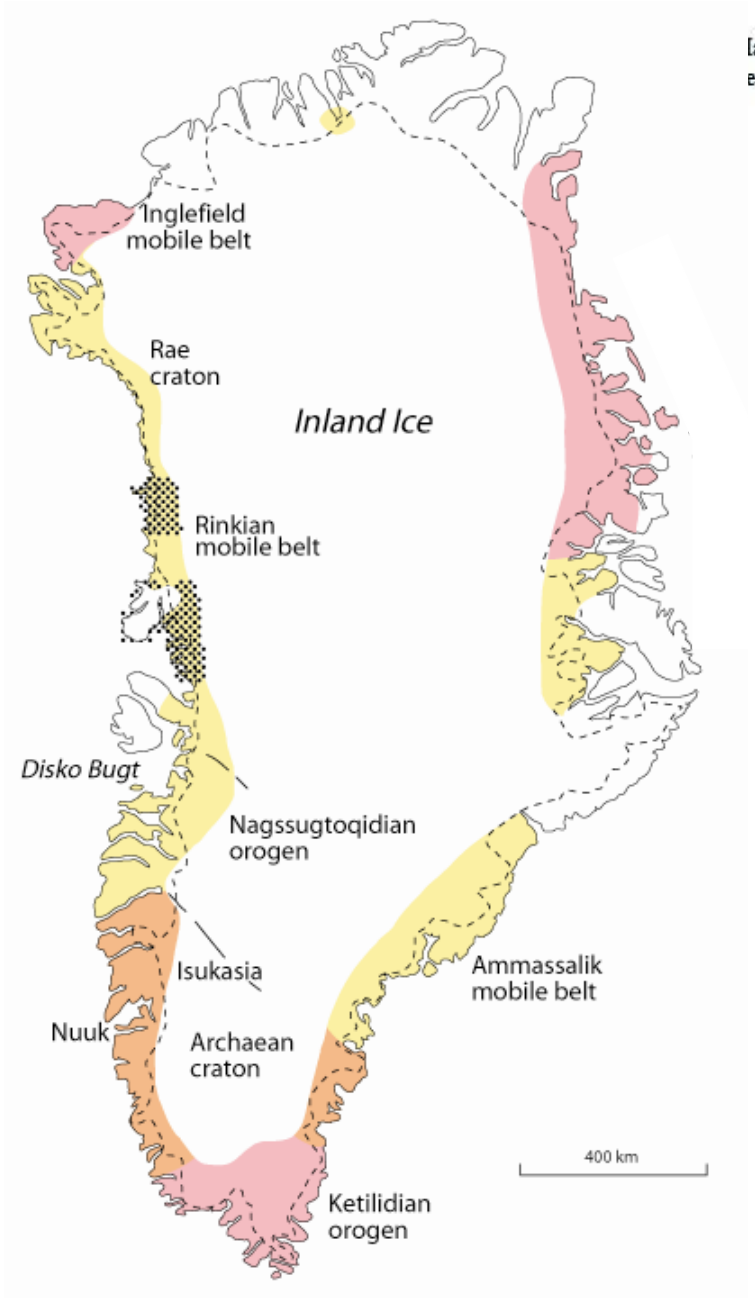
2014: Mining licence application for REEs at Kringlerne (SG)

Geology of Greenland

Geology of Greenland

- The Earth is 4.6 billion years
- Oldest rocks in Greenland ~3.8 billion years
- 70% older than 1.6 billion years
- Greenland is divided into different geological units that have evolved through time.
  - Precambrian shield area - craton (3.1-2.6 billion years; orange)
  - Old mountain chains - orogenic terran (1.85 billion years; yellow)
  - Juvenile terrane; new crust (2.0 - 1.75 billion years; pink)

- 30% younger than 1.6 billion years to present… (white)
  - Sedimentary basins
  - Volcanic provinces



Interpretation of sub-ice bedrock

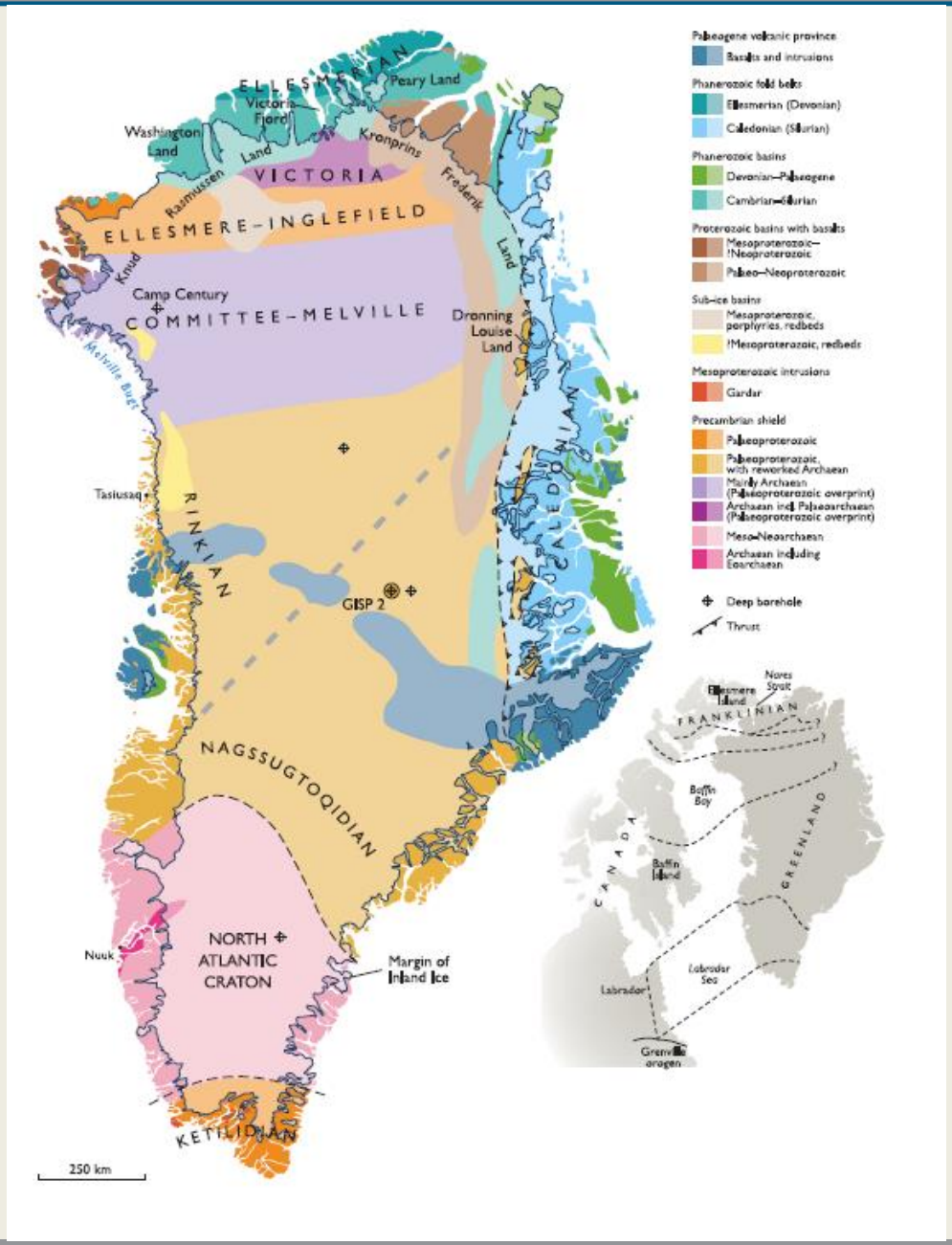
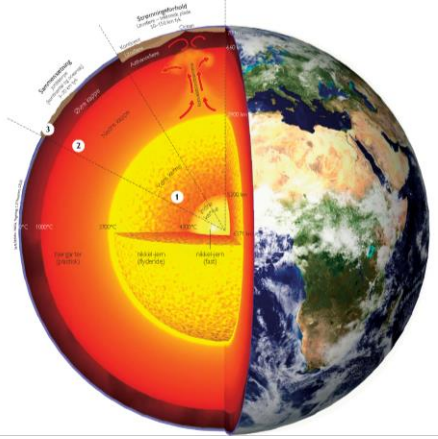
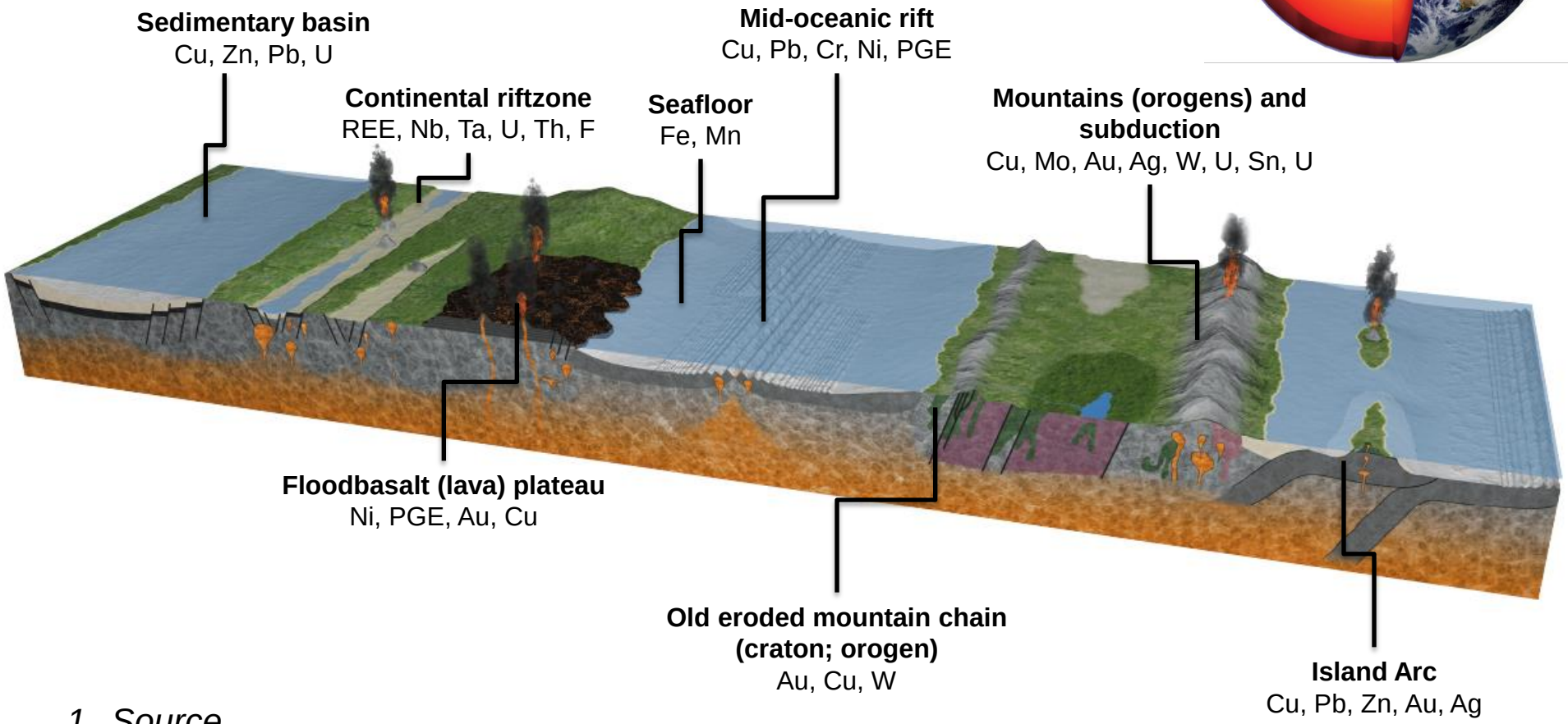


Figure 1: Geological map of Greenland with interpretation of sub-ice bedrock in terms of major provinces. Smaller map shows Canadian- Greenland correlations in the Precambrian shield (from Dawes & Henriksen, 2008).

Different geological environments have different potential for metals…





Sedimentary basin
Cu, Zn, Pb, U

Continental riftzone
REE, Nb, Ta, U, Th, F

Seafloor
Fe, Mn

Mid-oceanic rift
Cu, Pb, Cr, Ni, PGE

Mountains (orogens) and subduction
Cu, Mo, Au, Ag, W, U, Sn, U

Floodbasalt (lava) plateau
Ni, PGE, Au, Cu

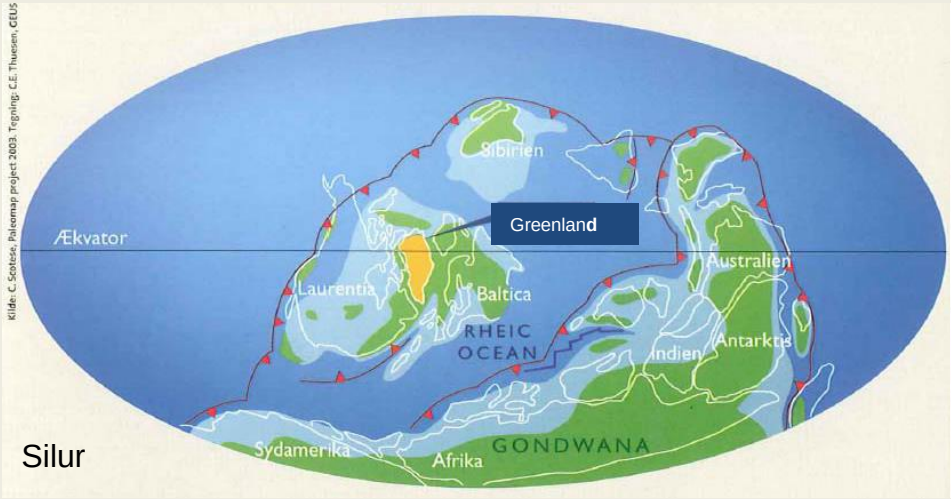
Old eroded mountain chain (craton; orogen)
Au, Cu, W

Island Arc
Cu, Pb, Zn, Au, Ag

1. *Source*
2. *Pathway*
3. *Transport*
4. *Trap*

The plate tectonic movement of Greenland

Greenland 425 Ma.

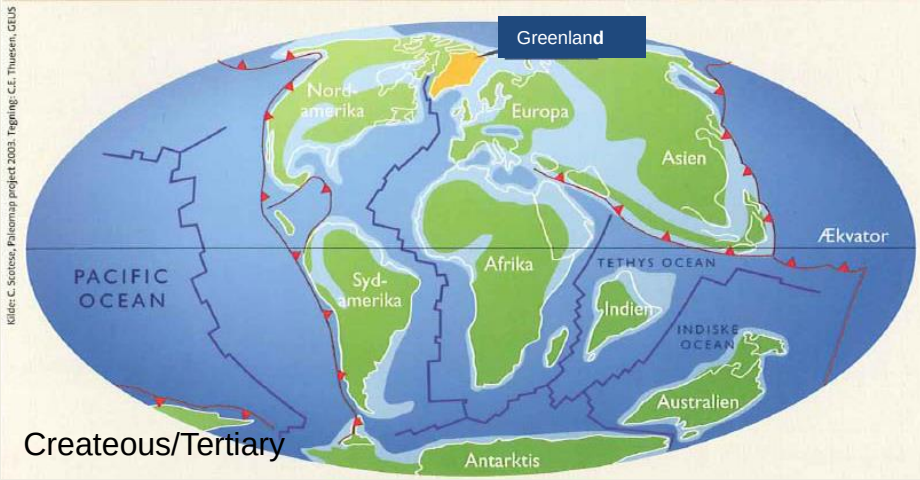


Silur

Greenland 390 Ma.

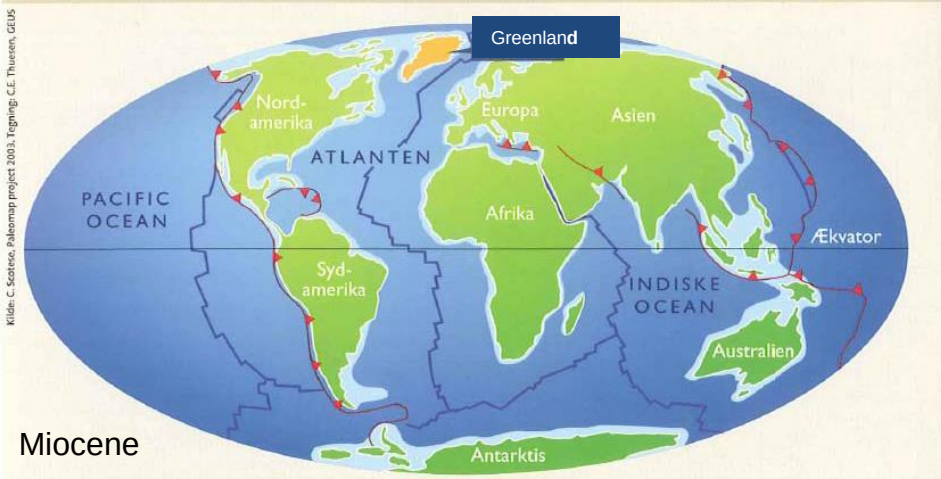
Permian

Greenland 65 Ma.



Createous/Tertiary

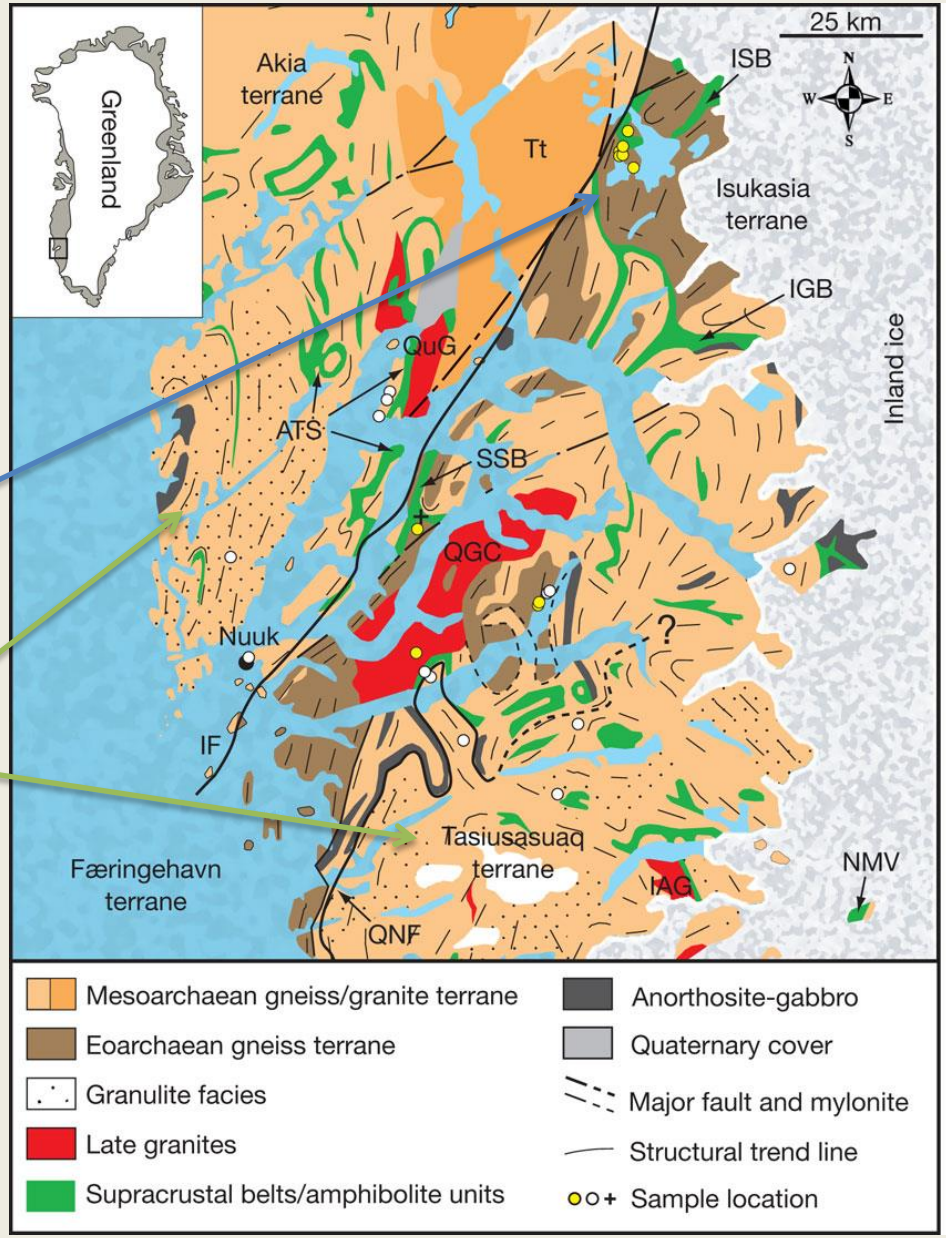
Greenland 14 Ma.



Miocene

The Archean basement

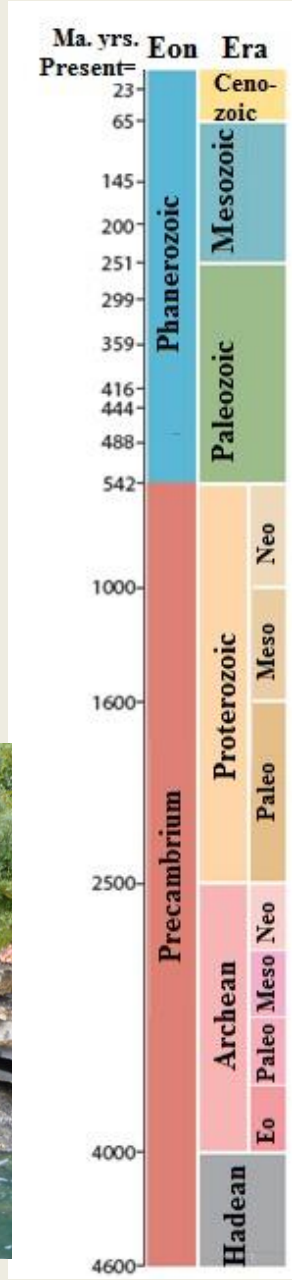
- In Nuuk-area you find the oldest rocks in Greenland and are among the oldest rocks on Earth.
- The area is split into different terranes which are rements of old continents.
- Amîtsoq gneis (S and E of Nuuk) was formed ~ 3900-3800 Ma.
- Gneiss i Tasiusarsuaq terrane og Akia terrane was formed ~3200-2900 Ma
- The different terranes where put together for approx. ~2720 Ma.



Næraa *et al.* (2012)

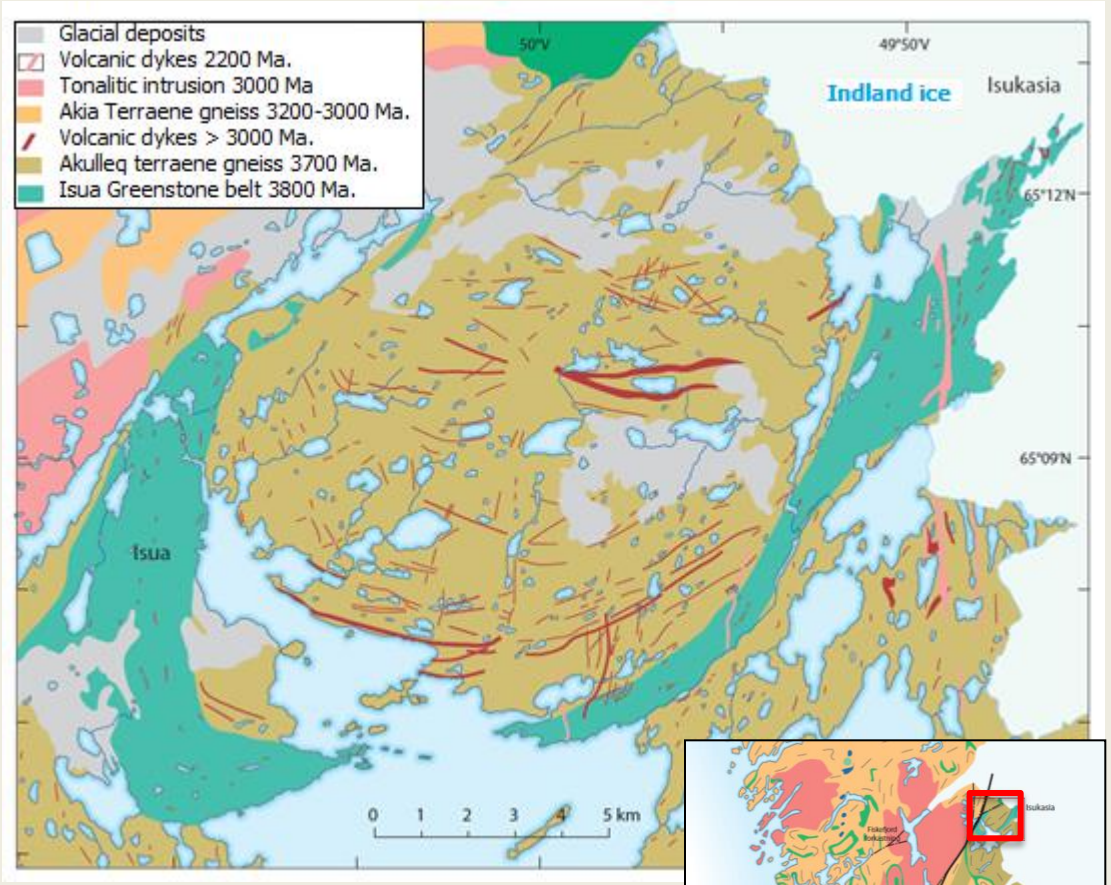
The Archean basement

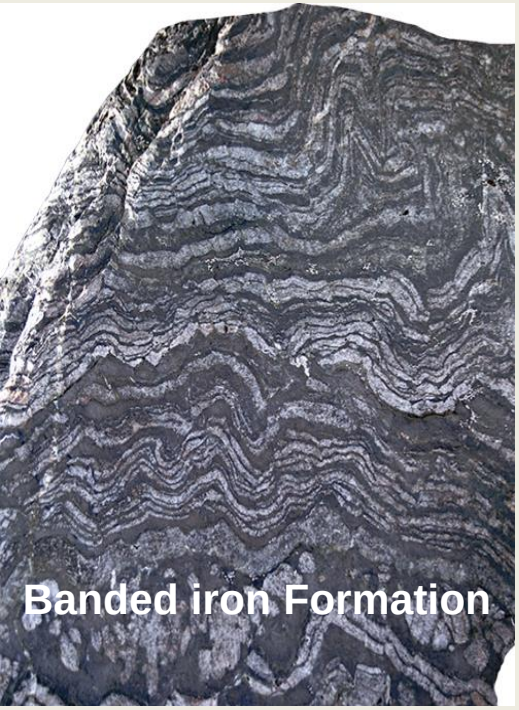
- A large blok in SW and SE Greenland
- **Craton (shield)**: stabil blok of the basement, which has been almost unaffected by the later events in the geological history.
- The Archean basement is part of the North Atlantic Craton
- The majority of rocks are gneiss, granite, metamorpic basalts (amphibolites) and sedimentary rocks (schists)



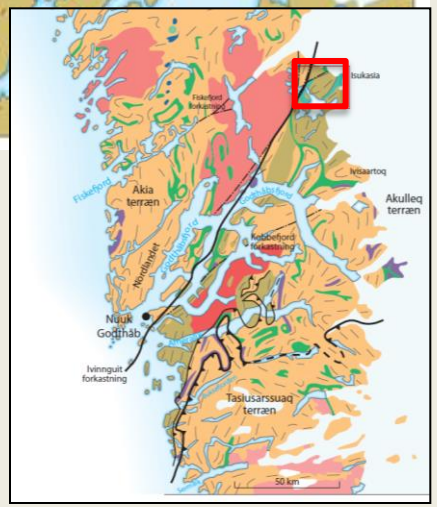
Isua greenstone belt

- The Earth's oldest sedimentary and volcanic rocks were formed c. 3900-3700 Ma, and forms the Isua greenstone belt



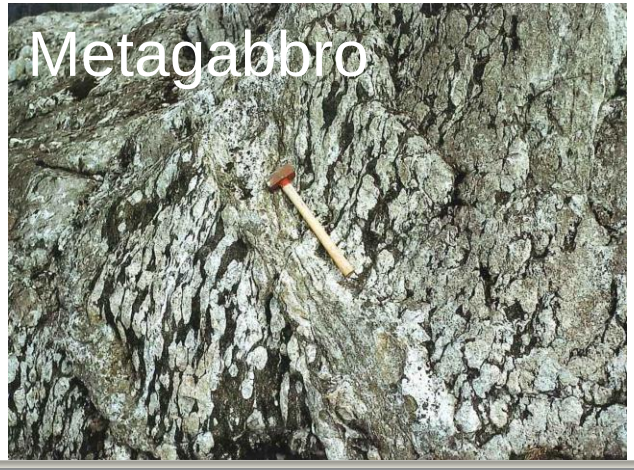


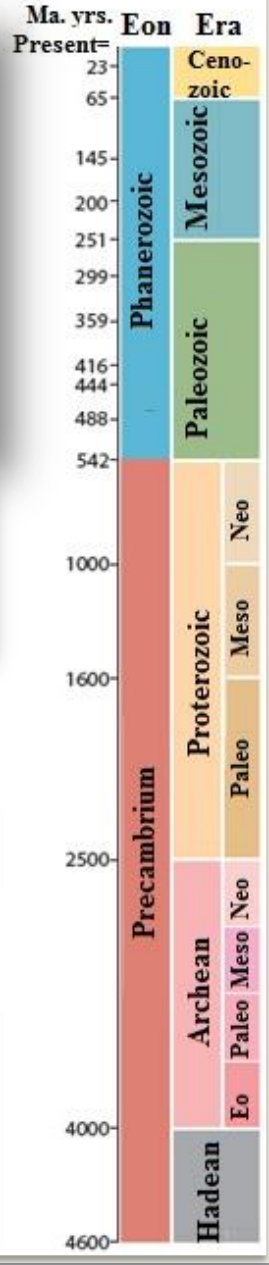
Photos ©Henriksen, GEUS



The Fiskenæsset Complex

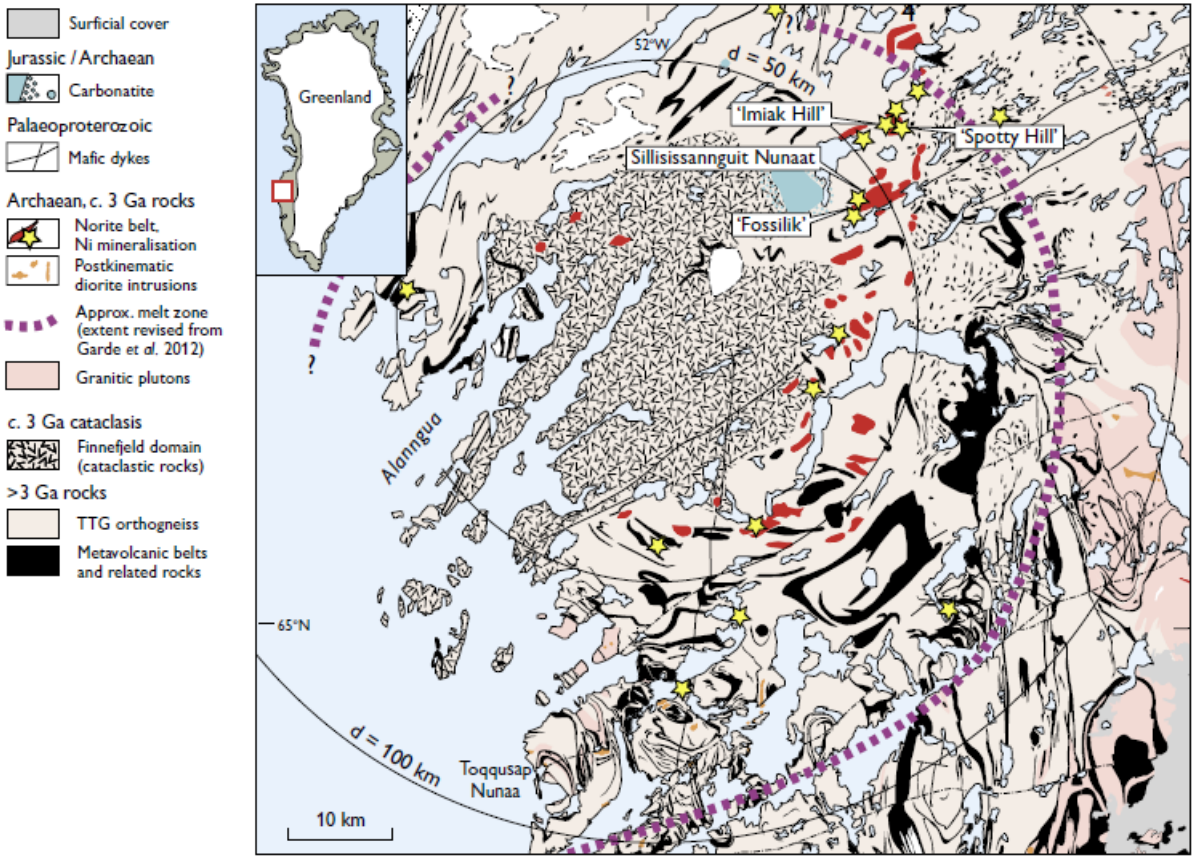
- The Fiskenæsset Complex (anorthosite-metagabbro) was intruded into amfibolites and basalts about 2.970-2.950 Ma.
- The Fiskenæsset Complex contains rubies and chromite.
- More than 40 localities with ruby and sapphires, but only few localities contains gemstone quality stones.

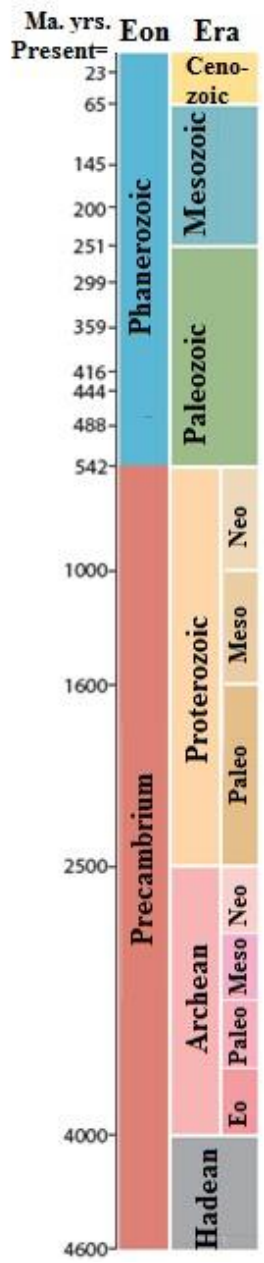




The Maniitsoq giant Meteorite impact area

- A giant Meteorite impact crater about 3000 Ma., and is the oldest and deepest crater structure in the world.
- The Finnefjeld Domain contains totally melted and crushed rocks.
- High Nickel concentrations
- Carbonatites (volcanic rocks with carbonate), which can carry diamonds

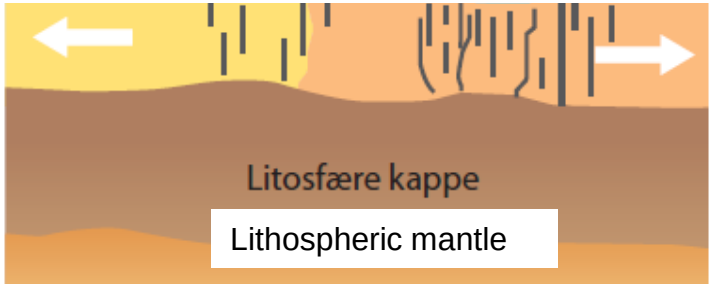




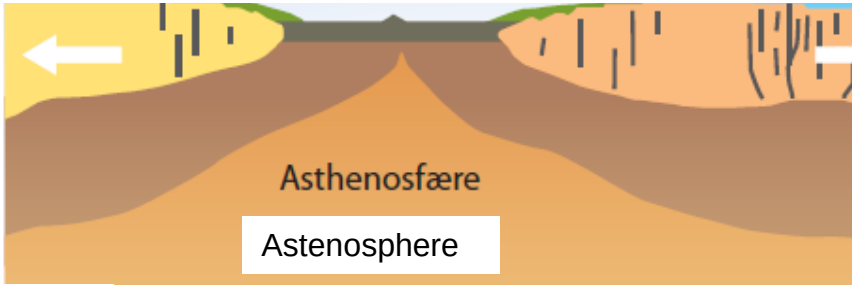
Garde *et al.* 2013

Nagssugtoqidian folding belt

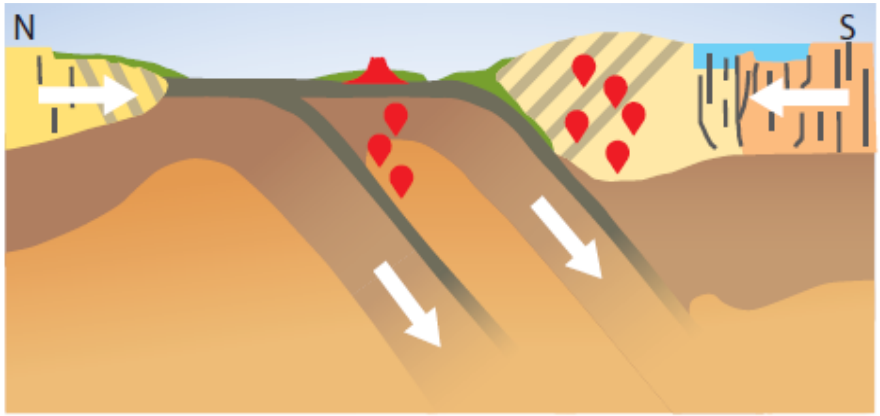
1) Rifting and intrusion of volcanic dikes (2040 Ma.)



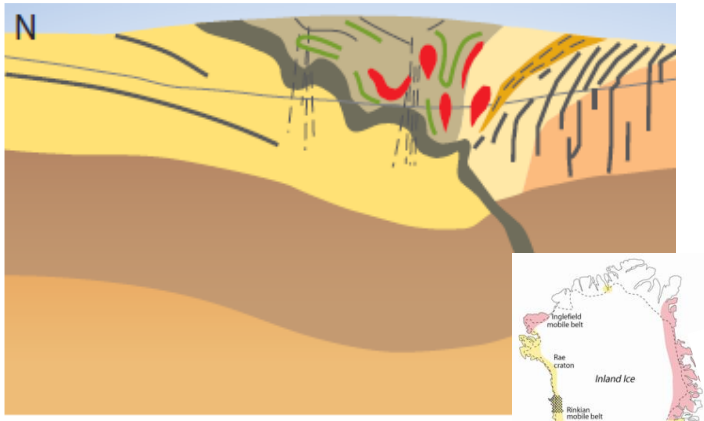
2) Further rifting and opening of a sea (2000-1920 Ma.)

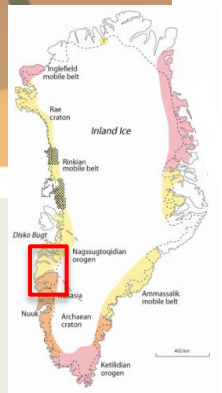


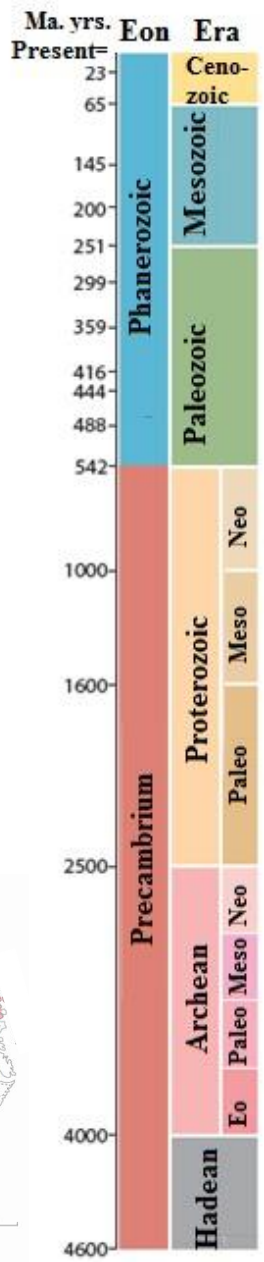
3) Closing of the ocean and intrusions forming events (1920-1870 Ma.)



4) Continent-continent collision = orogenese (1860-1825 Ma.)

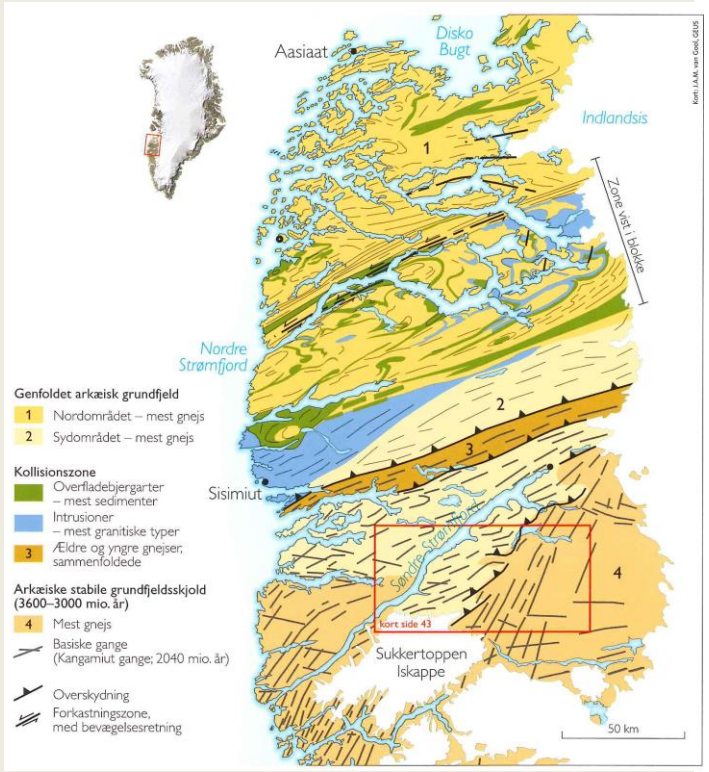


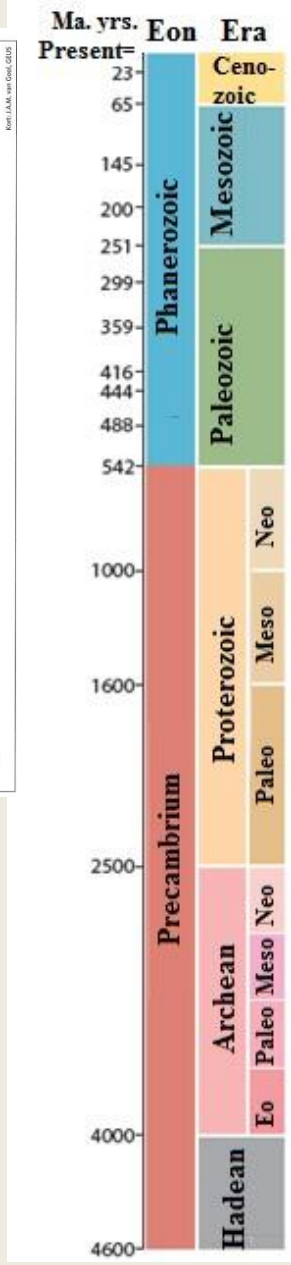




Kimberlites in the Nagssugtoqidian

- Kimberlites are volcanic rocks from 300-150 km depth.
- was formed between ~ 660 Ma and 170 Ma.
- Kimberlites can carry diamonds
- If the ascending of the magma towards the Earth's surface is too slow the diamonds become unstable and change into graphite.

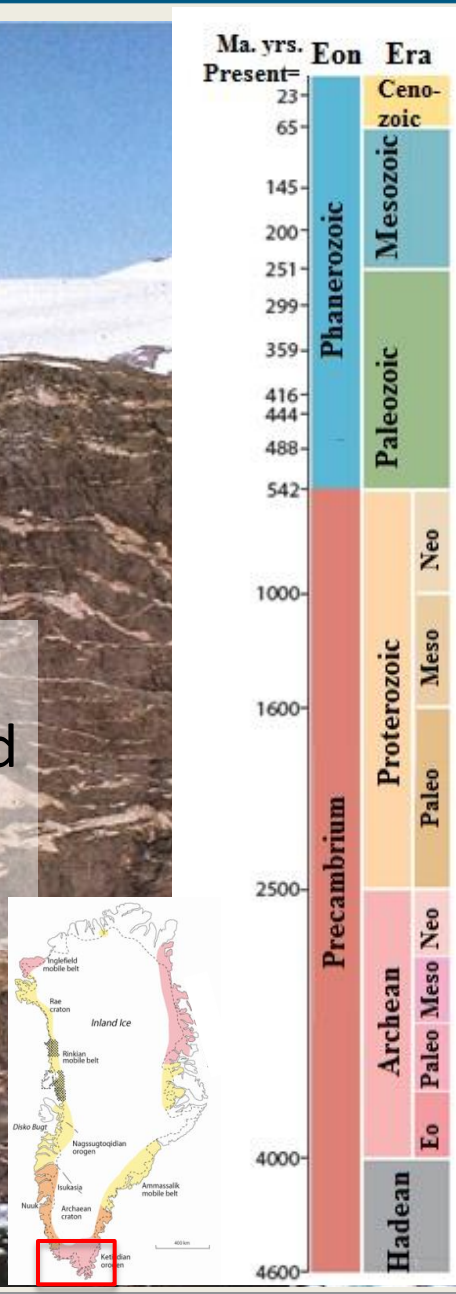




The Ketilidian mountain range

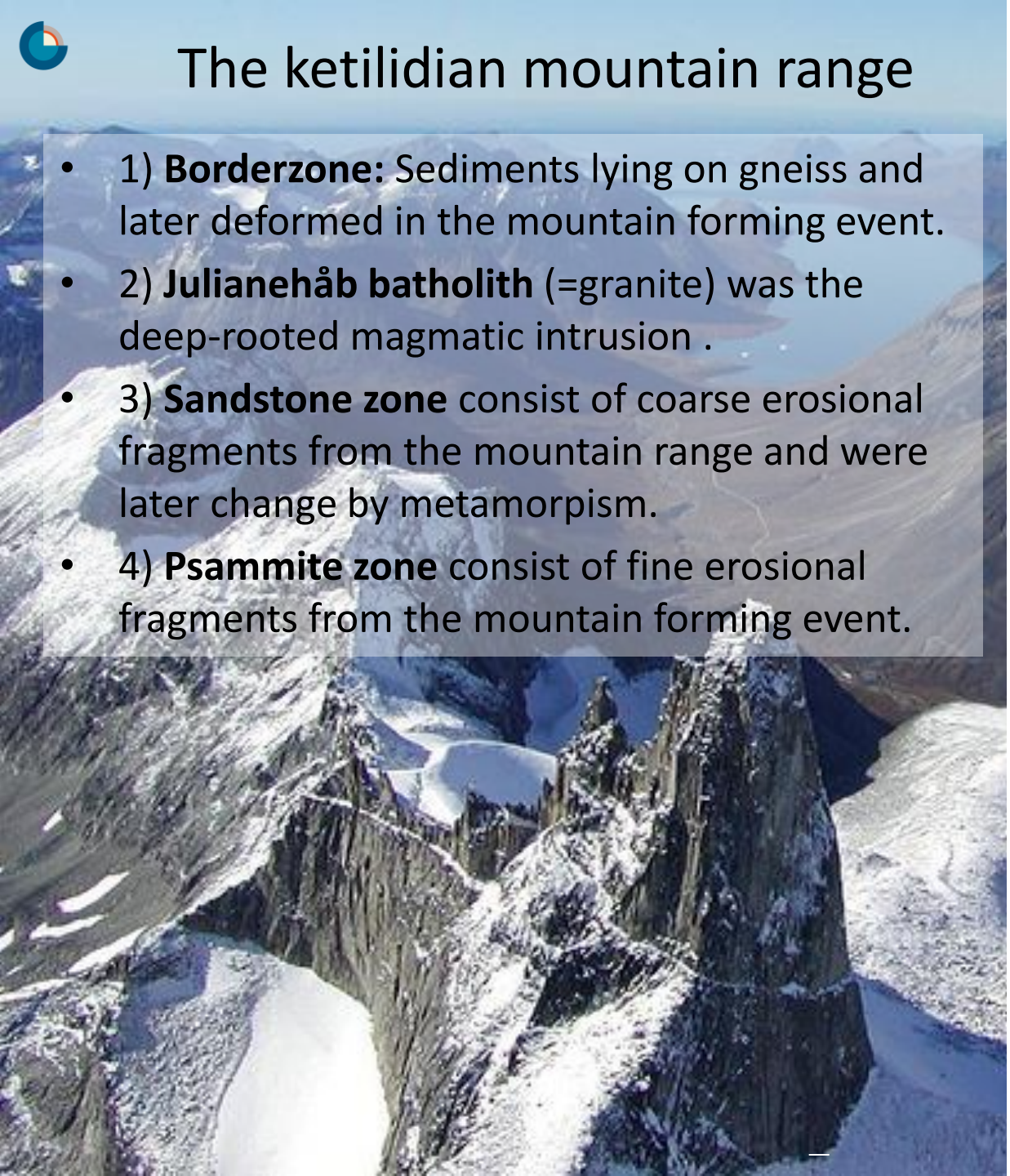
- 1850 Ma ~ the Southern border of the Archean basement collided with an oceanic plate and created subduction of the oceanic plate, and a mountain range started (similar to the Andes).

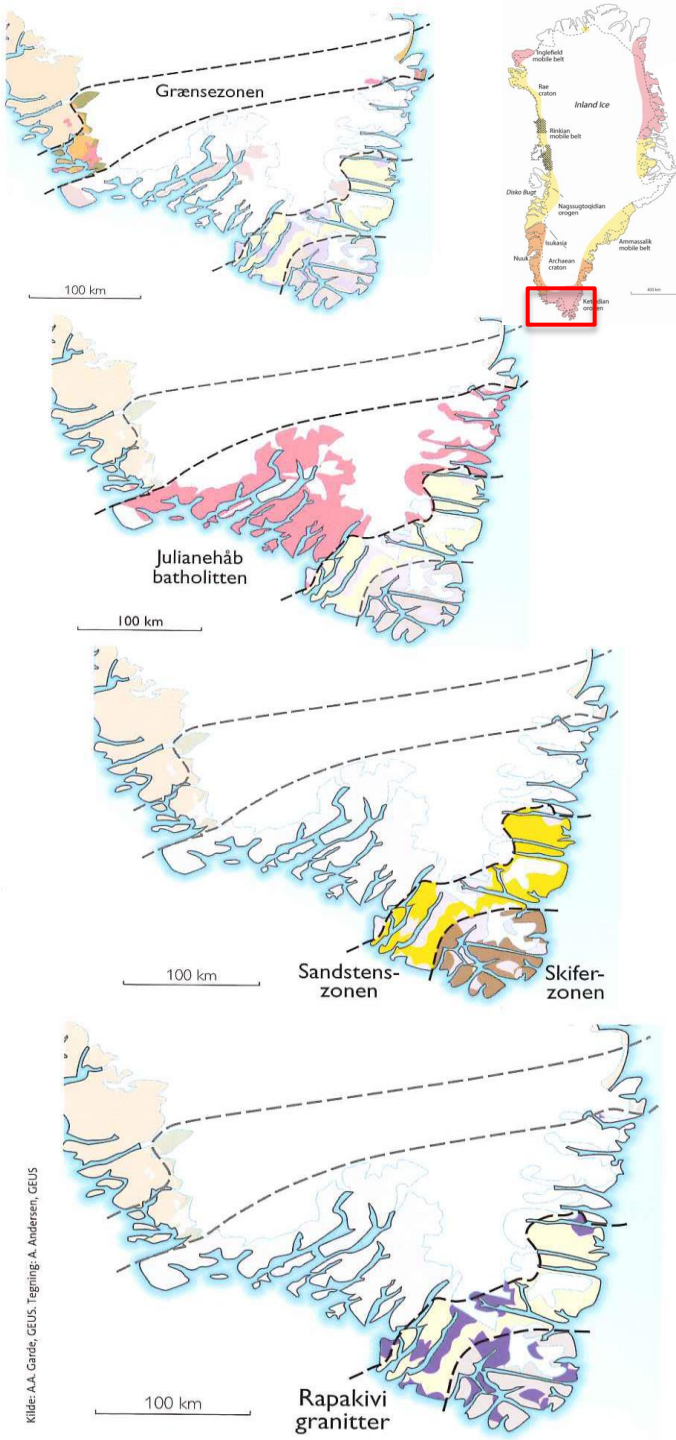
Photo © Henriksen, GEUS



The ketilidian mountain range

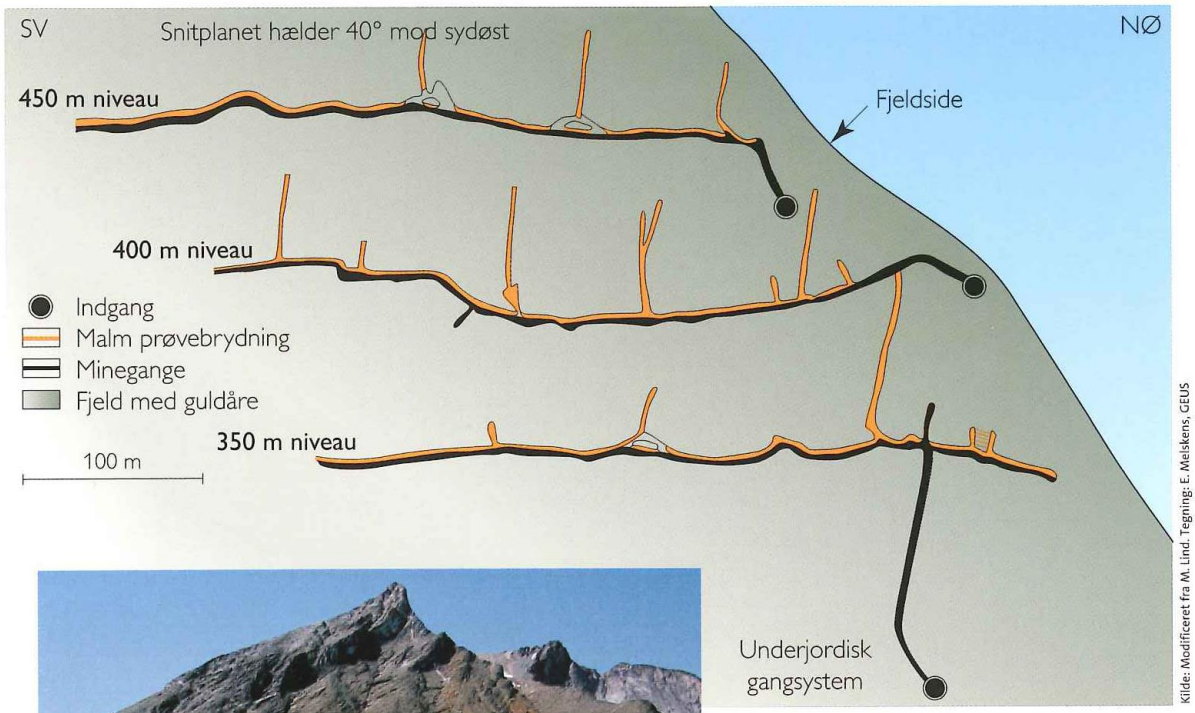
- 1) **Borderzone:** Sediments lying on gneiss and later deformed in the mountain forming event.
- 2) **Julianehåb batholith** (=granite) was the deep-rooted magmatic intrusion .
- 3) **Sandstone zone** consist of coarse erosional fragments from the mountain range and were later change by metamorpism.
- 4) **Psammite zone** consist of fine erosional fragments from the mountain forming event.

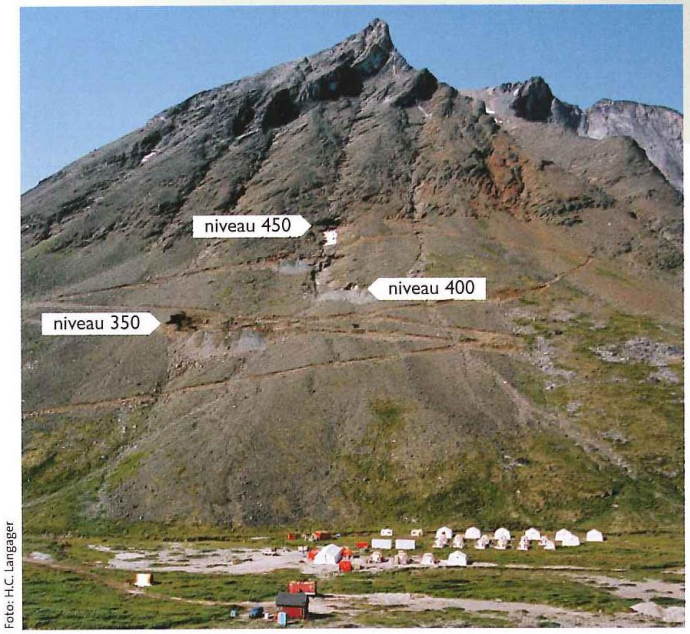


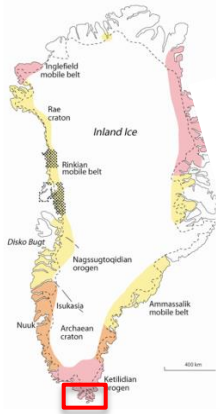


Gold ore in South Greenland

- Nalunaq Gold mine 2003 – closed December 2013
- Owned by Angel Mining Plc.
- Underground Mine
- More than 9,8 tons gold has been extracted, with a conc. per ton 25.5 ppm.



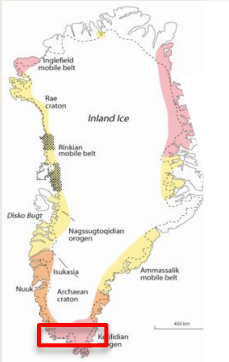


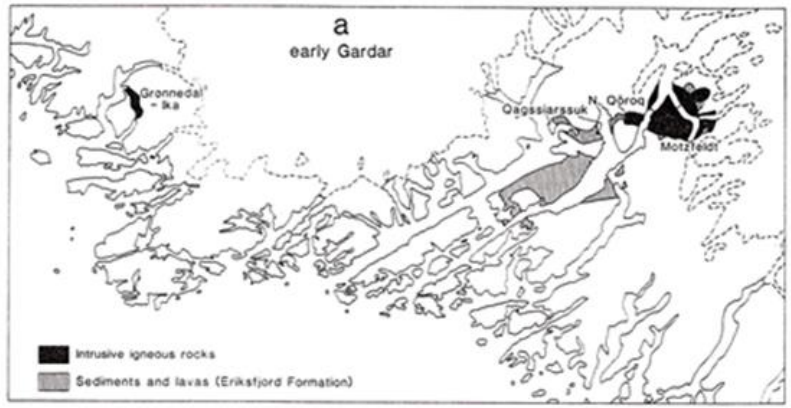


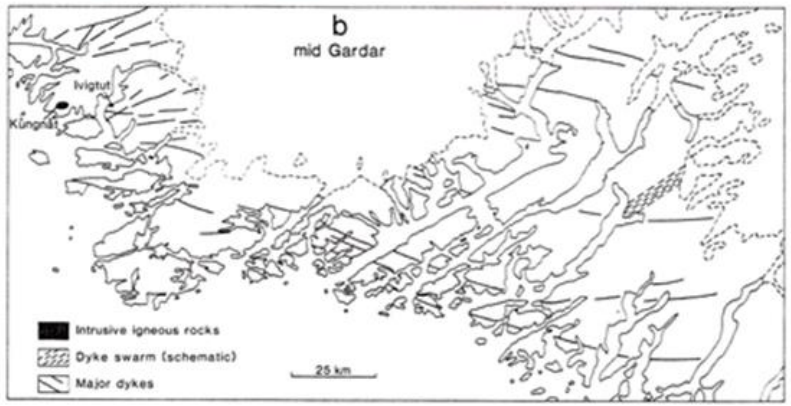
The Gardar Province

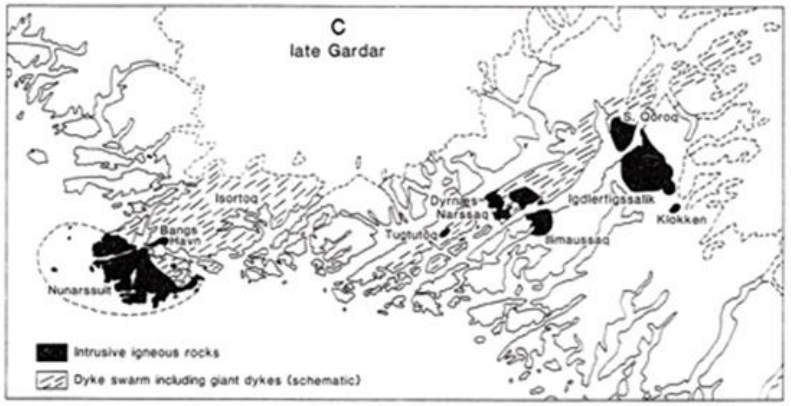
- **1350-1125 Ma.**
- Riftzone with volcanic dykes, rocks and sediments. The same riftzone are found 4000 km away. There are three phases:

- **Early Gardar (1350-1260 Ma):** Motzfeldt sø intrusion, Grønnedal og Erikson Fjord Fm (Igaliko Sandstone)
- **Mellem Gardar (1250- 1200 Ma):** Ivittuut Cryolite, rifting and dykes forming in a NV-SE direction
- **Late Gardar (1185- 1125 Ma)**: Klokken intrusion, Tuttutooq, South and North Qoroq intrusion, Nunarsuit, Illímausaq intrusion and dykes with a NE-SV direction.









Caledonian folding belt

- Continent - continent collision ~ 480-417 Ma. and a major mountain range was formed

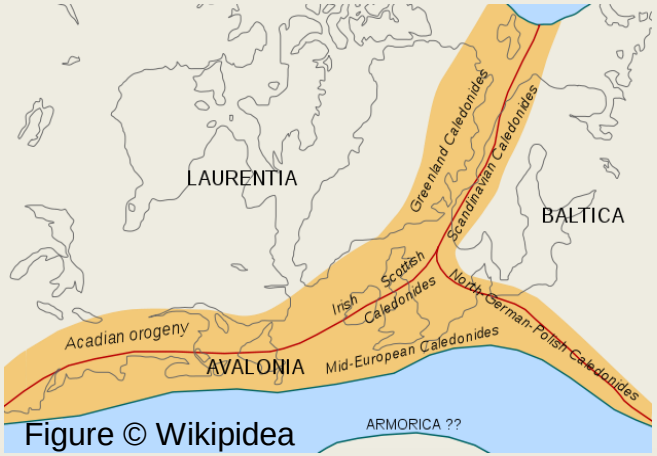


Figure © Wikipidea

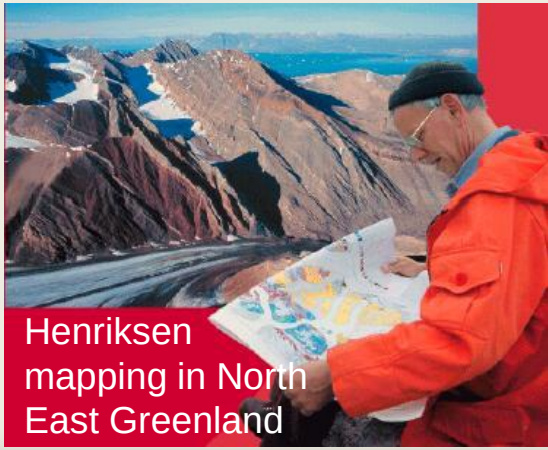
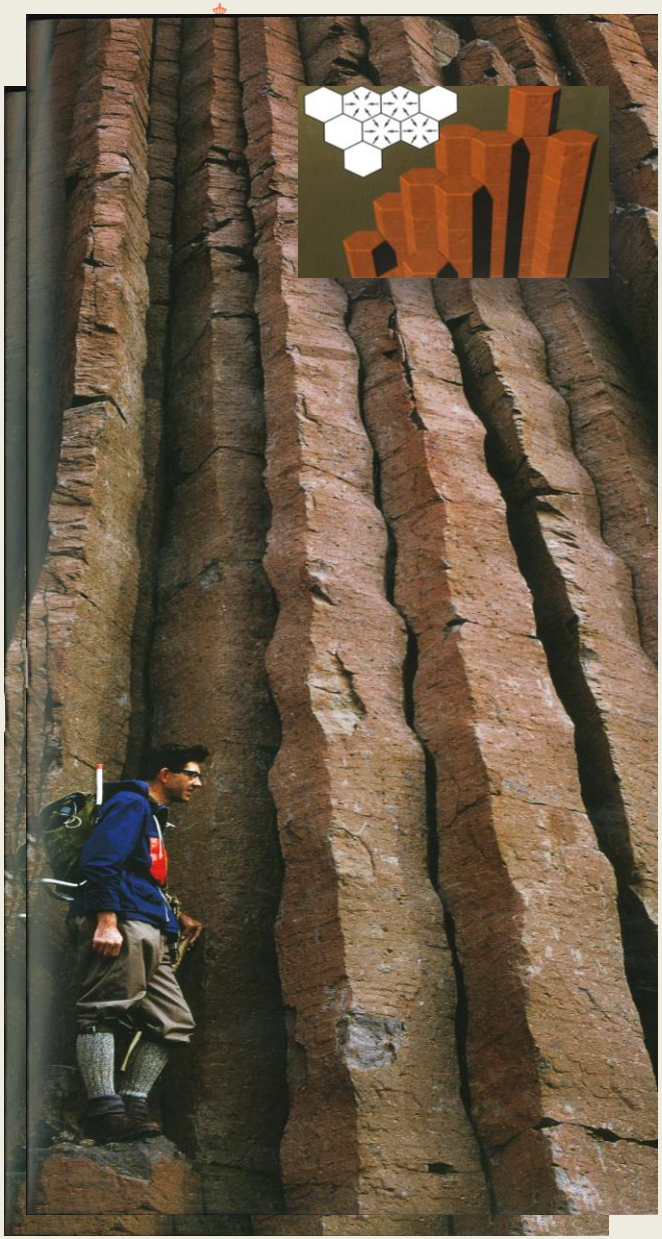

Henriksen mapping in North East Greenland


Photo shows the Eleonore Bay Supergroup ©Henriksen, GEUS

Palaogene volcanism



65.5-23 Ma.

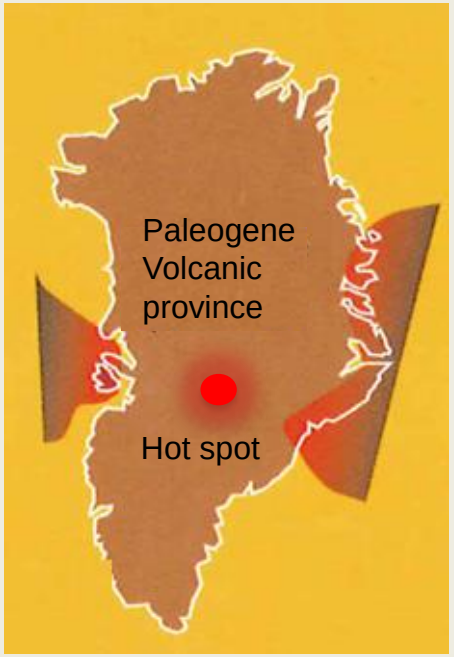
West Greenland (Disko)

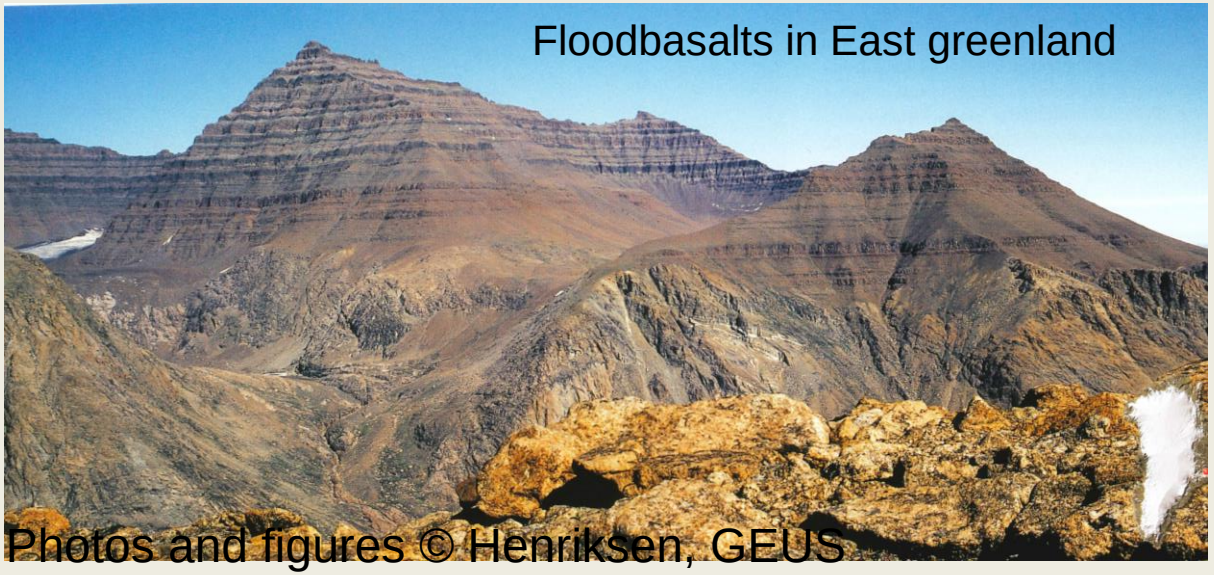
East Greenland

Skaergaard + many other intrusions

Hot spot related volcanism

The Hot spot is situated underneath Iceland today.



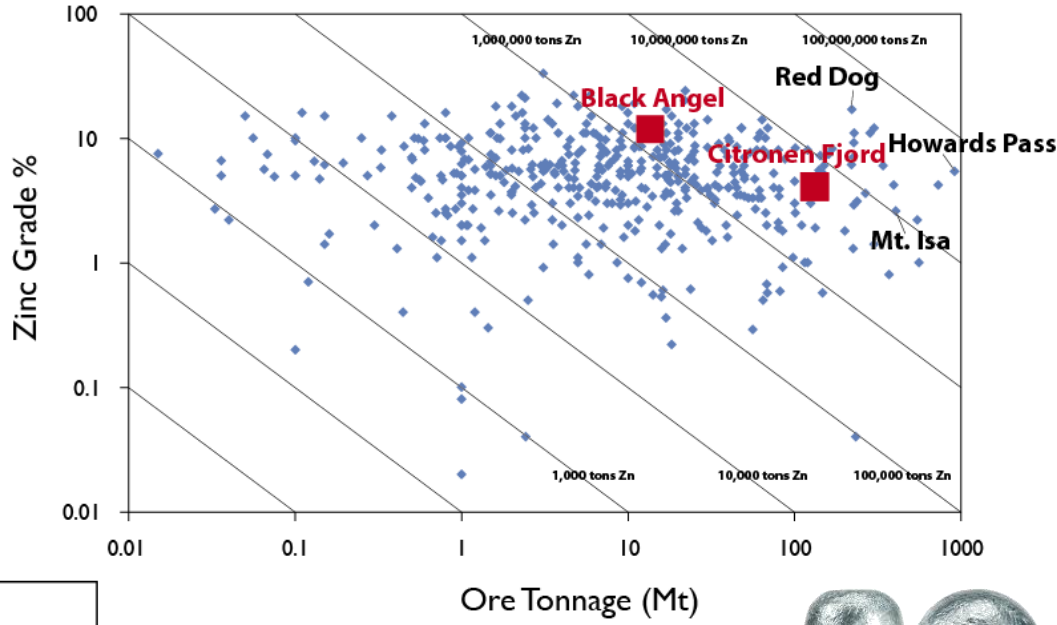


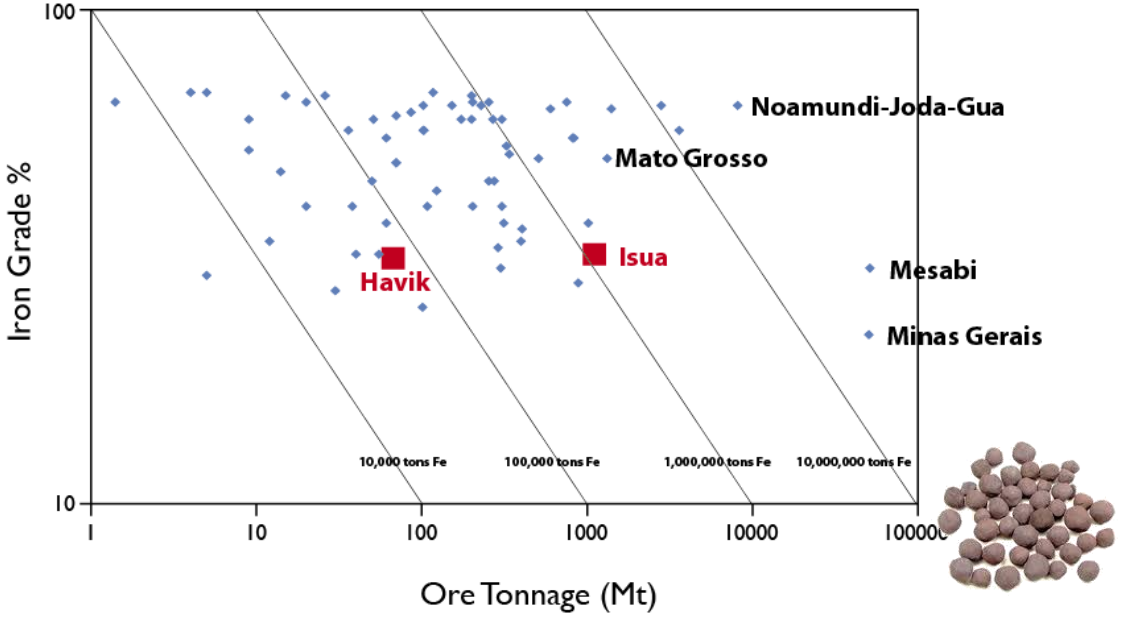
Mineral resources in Greenland

Giant deposits are present…

Proven potential; but historical limited activity compared to similar geological regions…

Giant deposits are present…

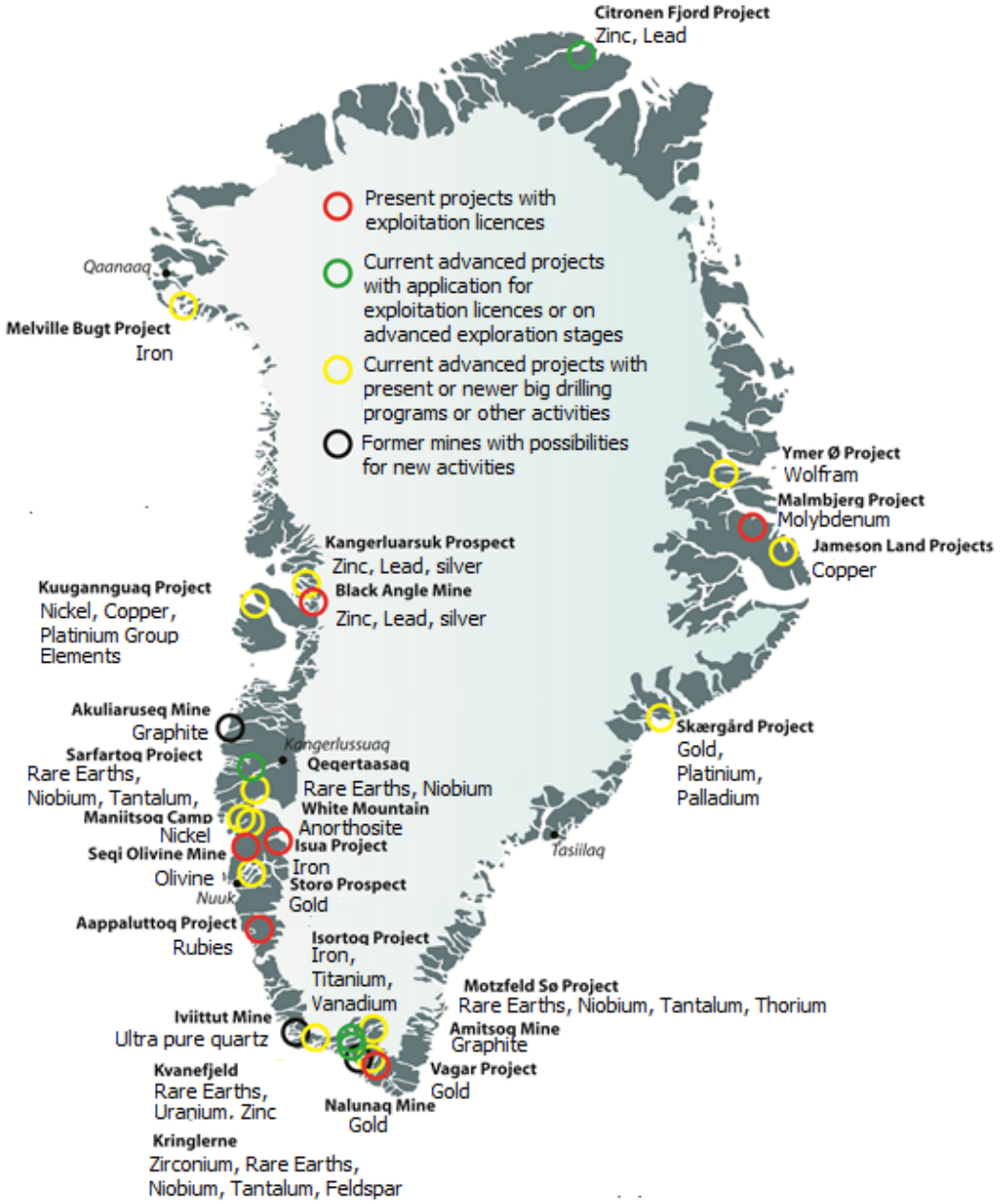




Status on exploration and exploitation projects

Status by April 2015:

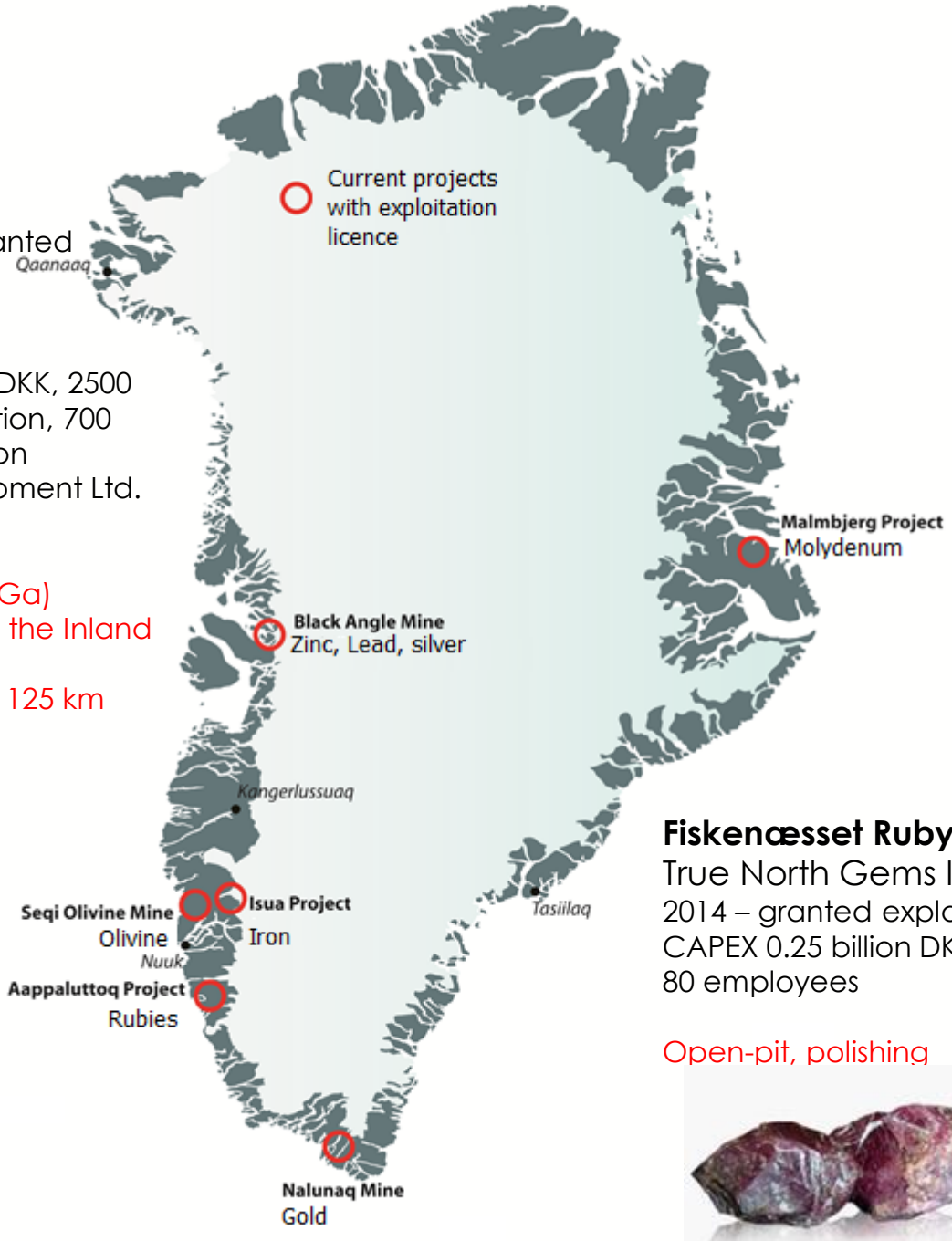
- Only a selection of the more advanced or 'hot' projects
- Quick changes
- There are about 138 mineral exploration licenses now
- Mostly small junior companies (Canada, Australia and Great Britain)
- No mines at present



Isua Fe

2013: London Mining granted exploitation
(London Mining; under administration 2014)
Isua Plans: CAPEX 14 billion DKK, 2500 employees during construction, 700 employees during production
2015: General Nice Development Ltd. takes over license

Banded iron formation (3.8 Ga)
Situated near the margin of the Inland Ice
Open-pit mining, slurry-pipe 125 km



Fiskenæsset Ruby
True North Gems Inc.
2014 – granted exploitation
CAPEX 0.25 billion DKK
80 employees

Open-pit, polishing

Fingerprinting of the rubies

- A small part of GEUS work involve assisting the Government of Greenland with fingerprinting the Greenlandic rubies

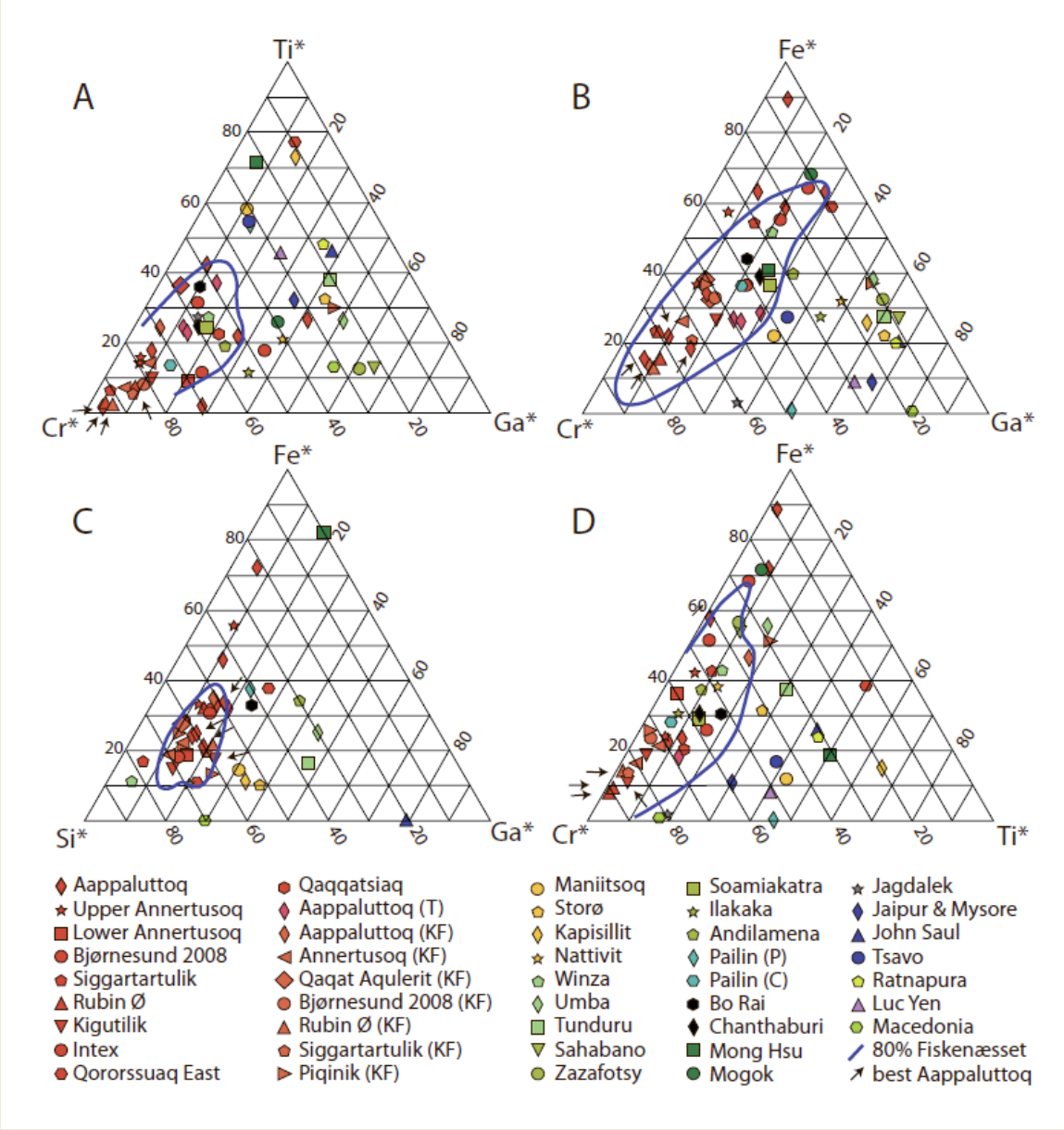
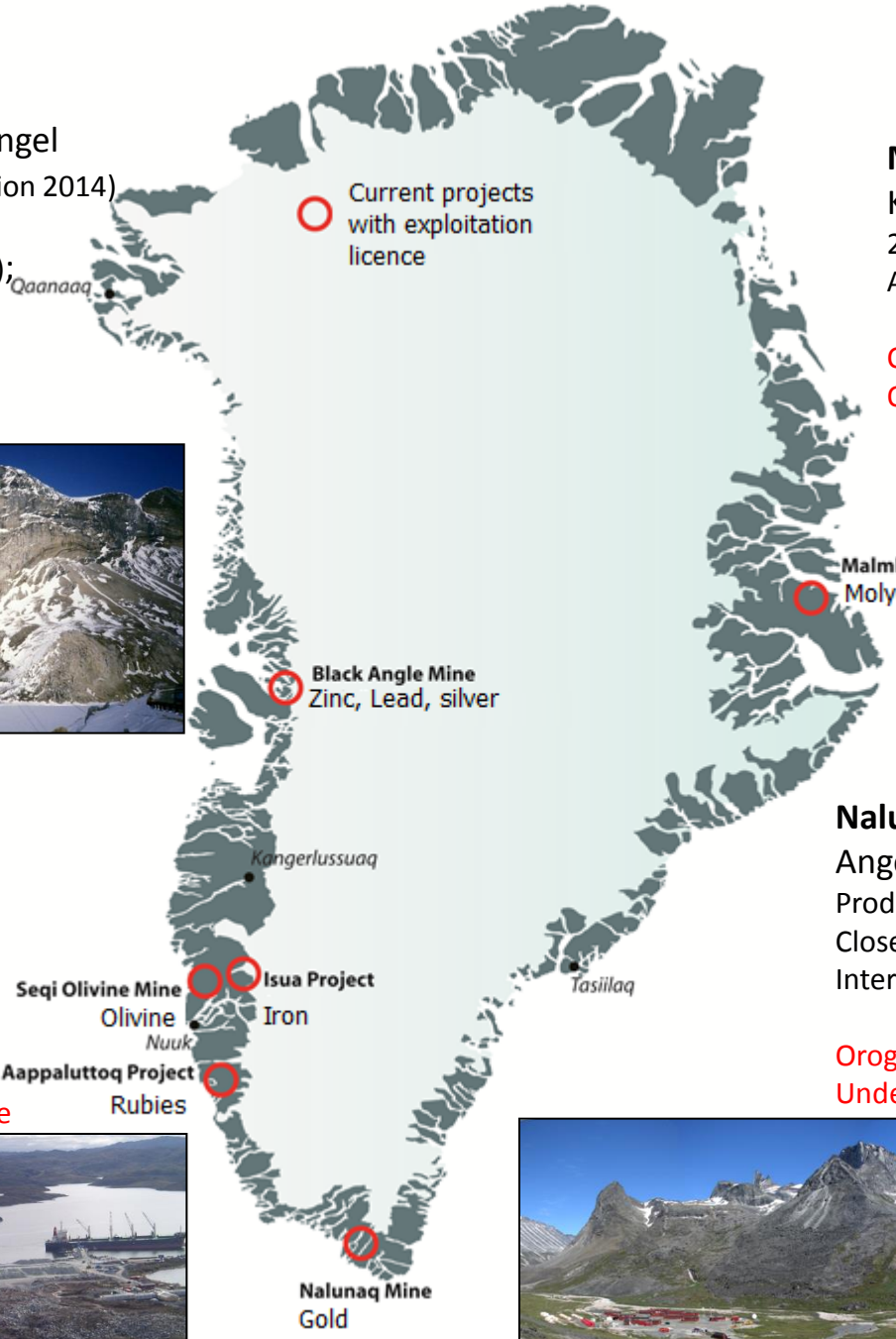


Figure from Keulen & Kalvig 2013. Data for international ruby occurrences are from Calligaro et al. 1999; del Castillo et al. 2009; Kalvig & Frei 2010; Pornwilard et al. 2011; Rakontondrazafy et al. 2008; Schwarz et al. 2008; Thirangoon 2008

Black Angel Zn-Pb

2010: exploitation license (Angel Mining Plc. – under administration 2014)
2015: license taken over by FBC Mining (?exploitation license);
Exploration activities

MVT type deposit



Malmbjerg Mo

KGHM International
2008: exploitation license
Awaiting market improvements?

Climax-type porphyry Mo deposit
Open-pit, long haul-road

Seqi Olivine Mine

LKAB
2005: exploitation license
Production from 2005-09
Closed (2009)
Interest from other parties?

Ultramaifc body – 150 Mt olivine
Open-pit

Nalunaq Gold Mine

Angel Mining (Gold) Plc.
Production (2004 - 2012)
Closed (2014)
Interest from other parties?

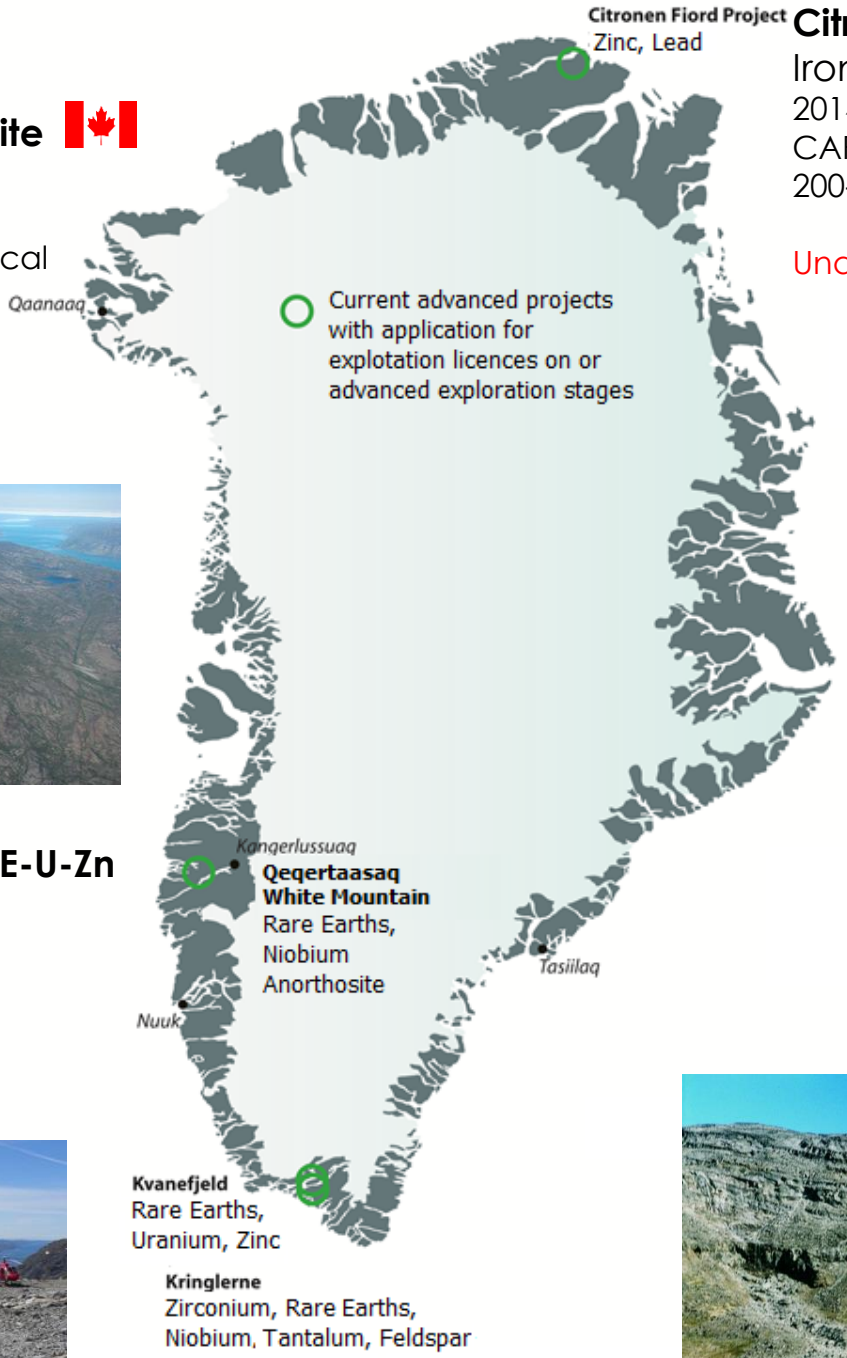
Orogenic gold / hydrothermal vein
Underground

White Mountain Anorthosite
Hudson Resources Inc.
2014: Submitted application
Anorthosite – feldspar; chemical compound - alumina, silicon and calcium

Open-pit, simple operation
E-fiber glass, fillers, alumina

Kvanefjeld (Ilímaussaq) REE-U-Zn
Greenland Minerals and Energy Ltd.
CAPEX 4.5 billion DKK;
500-700 employees

Open-pit, handling of uranium



Citronen Fjord Zn-Pb
Iron Bark Zinc Ltd.
2014: Submitted application
CAPEX 2.8 billion DKK
200-300 employees

Underground, mining in high arctic

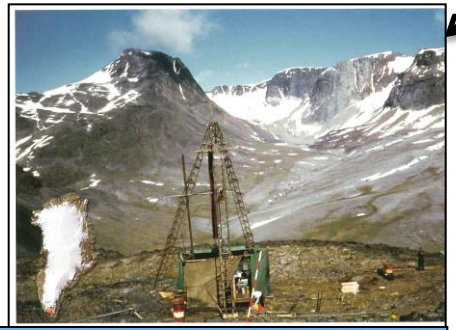
Kringlerne Zr-Nb-Ta-REE
Tanbreez Ltd.
2013: Submitted application
CAPEX 1.2 billion DKK
60-80 employees

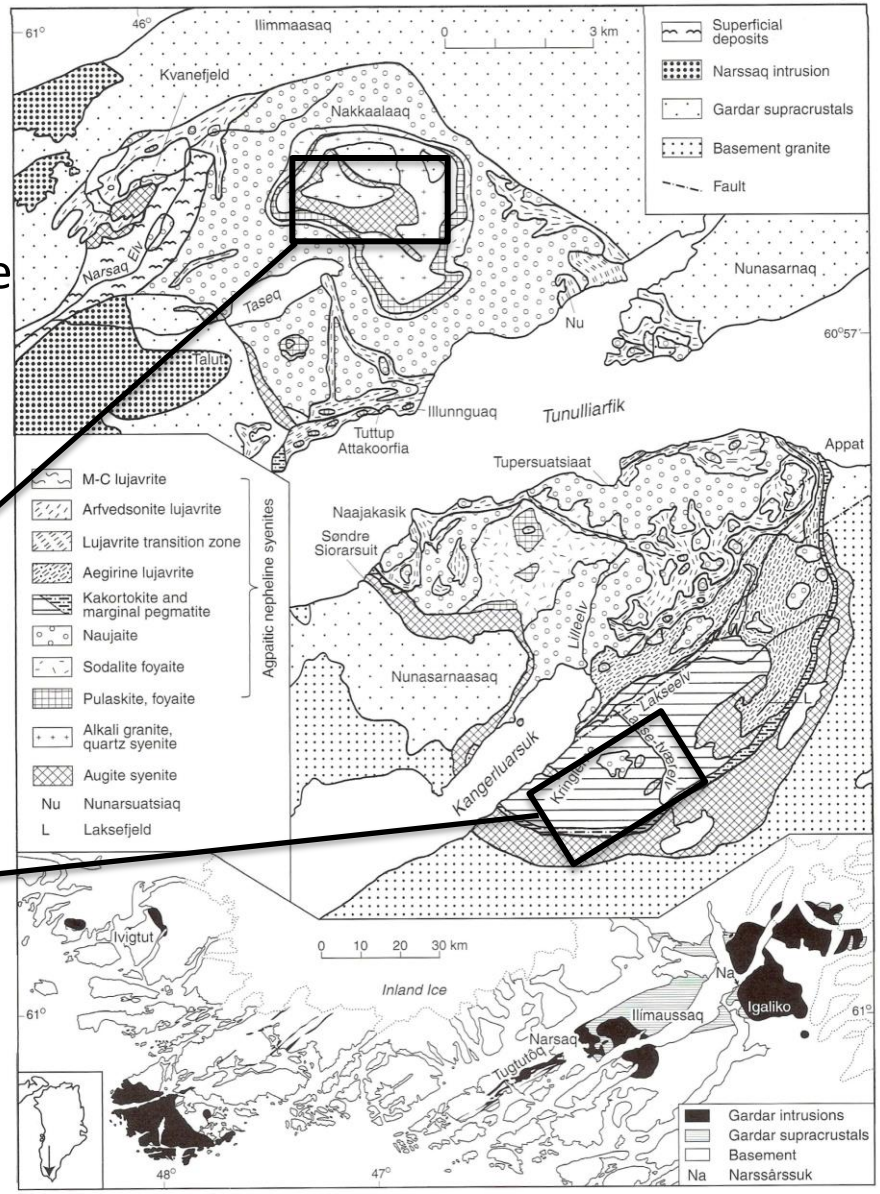
Alkaline-intrusion hosted
Open-pit mining

Illímaussaq Intrusion

Ilímaussaq Intrusion

- Ilimaussaq complex: contains REE + Uranium and locally up to 1400g/ton ore.
- A Magma chamber originally burried about 2-5 km in the continental crust.
- 200 different minerals, rare minerals, where 30 of them were first described here, and 12 have only been found in Ilímaussaq.
- 2 world-Class deposits of Rare Earth Metals





Melville Bay Ltd.
2012: drill activity
Market conditions

Avannaa Resources Ltd.
2011-13: drill targets defined.
Restructuring, financial situation, investors

Hudson Resources Ltd.
Since 2009-12:
>30 km drill on REE
Market conditions

North American Nickle Ltd.
Since 2011
Ongoing activity, geophysical surveys and drilling

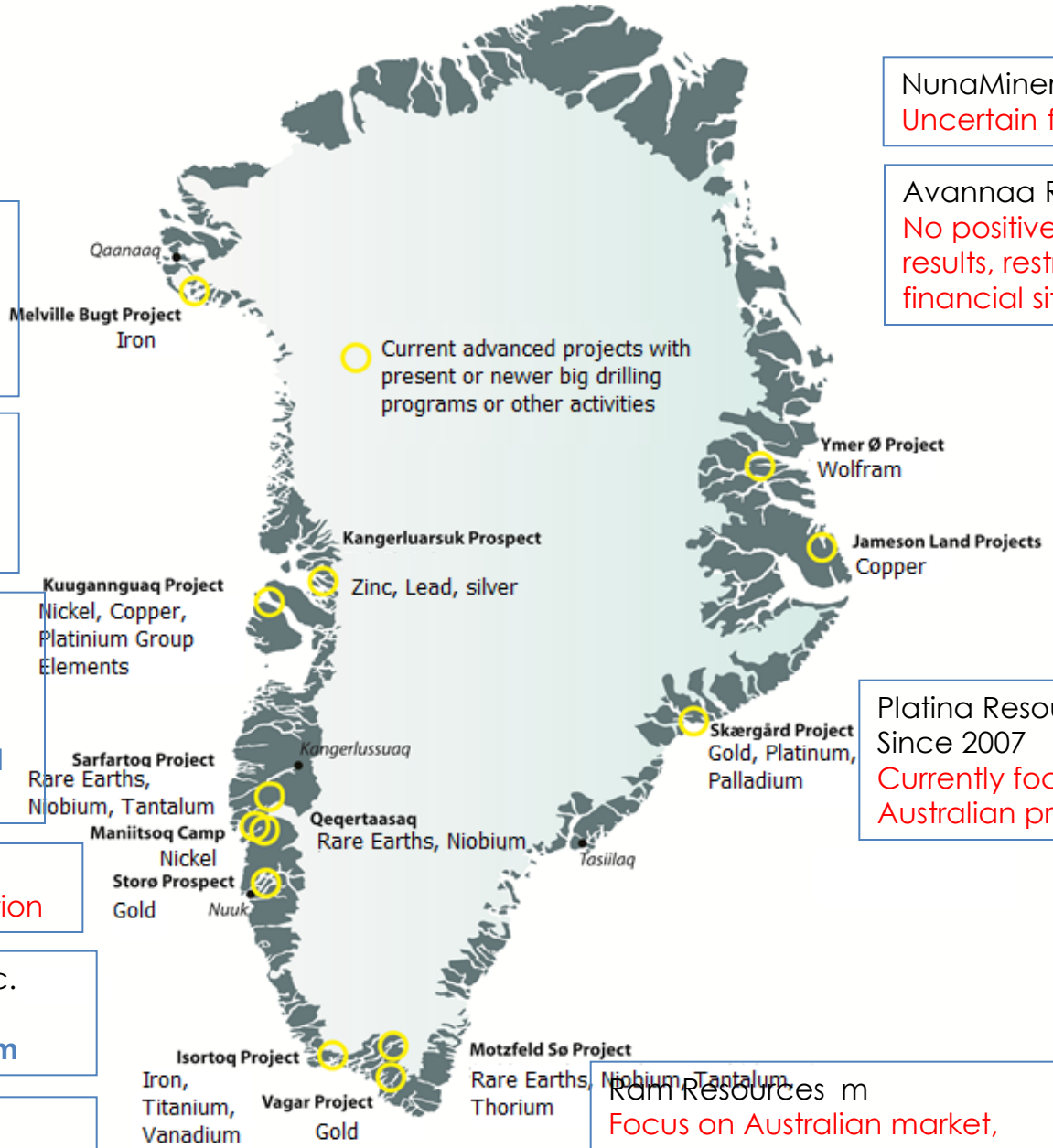
NunaMinerals A/S
Uncertain financial situation

Greenland Resources Inc.
Since 2014
Plan 2015 drilling program

West Melwill Metals Inc.
Since 2012
Metallurgical investigations, market conditions

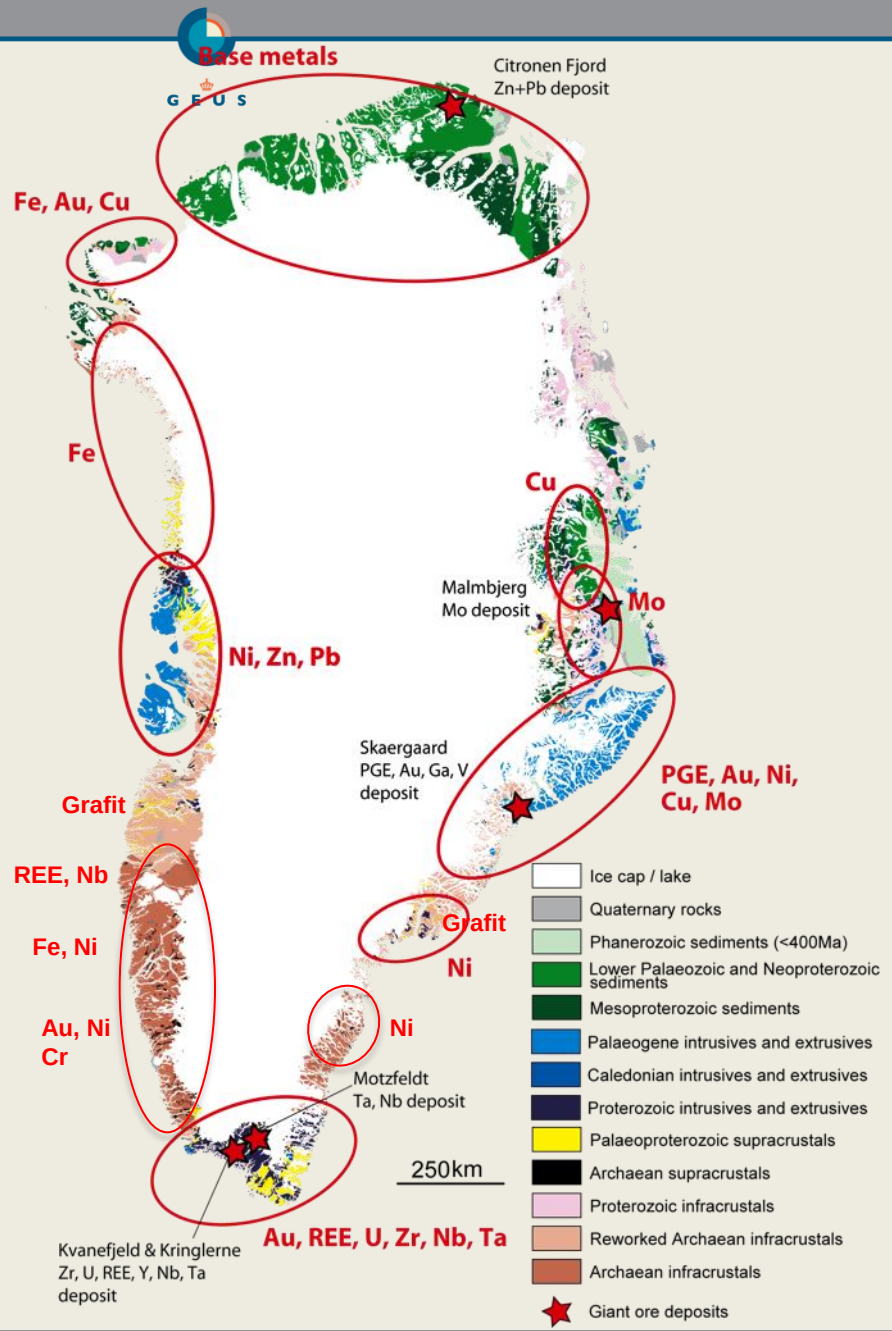
NunaMinerals A/S
Uncertain financial situation

Avannaa Resources Ltd.
No positive 2014 drilling results, restructuring, financial situation



Platina Resources Plc.
Since 2007
Currently focusing on Australian projects

Ram Resources m
Focus on Australian market, marked conditions



Potential for much more…

- North
  - Pb-Zn-Cu
  - *Potential ones: Ga*
- East
  - Mo, Cu, Zn,
  - PGE, Au, Ni
  - *Potential ones: W, Sn, In, Sb, Fe, Ga, V, Ti, Ag, REE, U, graphite*
- South
  - Au, REE, Zr Nb, Ta, U, Th, F
  - Fe, V, Co
  - *Potential ones: Sn, W, PGE*
- West
  - Au, Ni, Fe, ruby, diamond
  - REE, Nb
  - Zn, Pb, Ag
  - *Potential ones: Cr, V, Ti, PGE, graphite*

…Others

- *Dimension/building stones, aggregates, industrial minerals*

List of critical metals and geological potential in Greenland

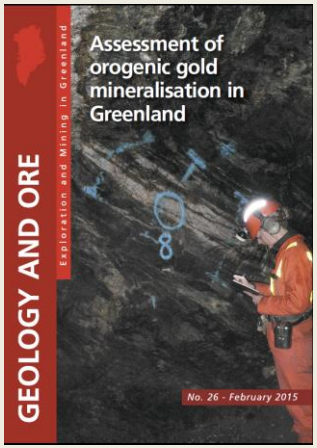
	Current critical raw material (EU 2010, 2013)	Future critical material?	Potential in Greenland	Primary product ● or by-/co-product ○
Antimony	X		Moderate	●/○
Borates	X		Low (unknown)	●
Beryllium	X		High	●/○
Chromium	X		Moderate	●/○
Cobalt	X		Moderate	○
Fluorspar	X		Moderate	○ of REE
Gallium	X		Moderate	○ of PGE
Germanium	X		Low (unknown)	○ of Zn
Graphite	X		Moderate - High	●
Indium	X		Low	○
Lithium		X	Low - Moderate	○
Magnesium	X		Low	
Molybdenum		X	High	●
Niobium	X		High	●/○
PGE's	X		Moderate - High	●
Rhenium		X	Low	○
REE's heavy / light	X		High	●
Silver		X	Low - Moderate	●?/○ of Zn/Pb
Tantalum	X		High	○
Tin		X	Moderate	●
Tungsten	X		Moderate	●
Vanadium		X	High	○ of Fe

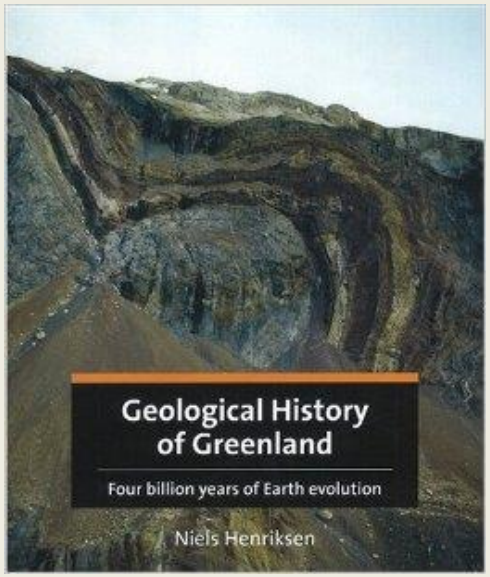
Useful Links and information

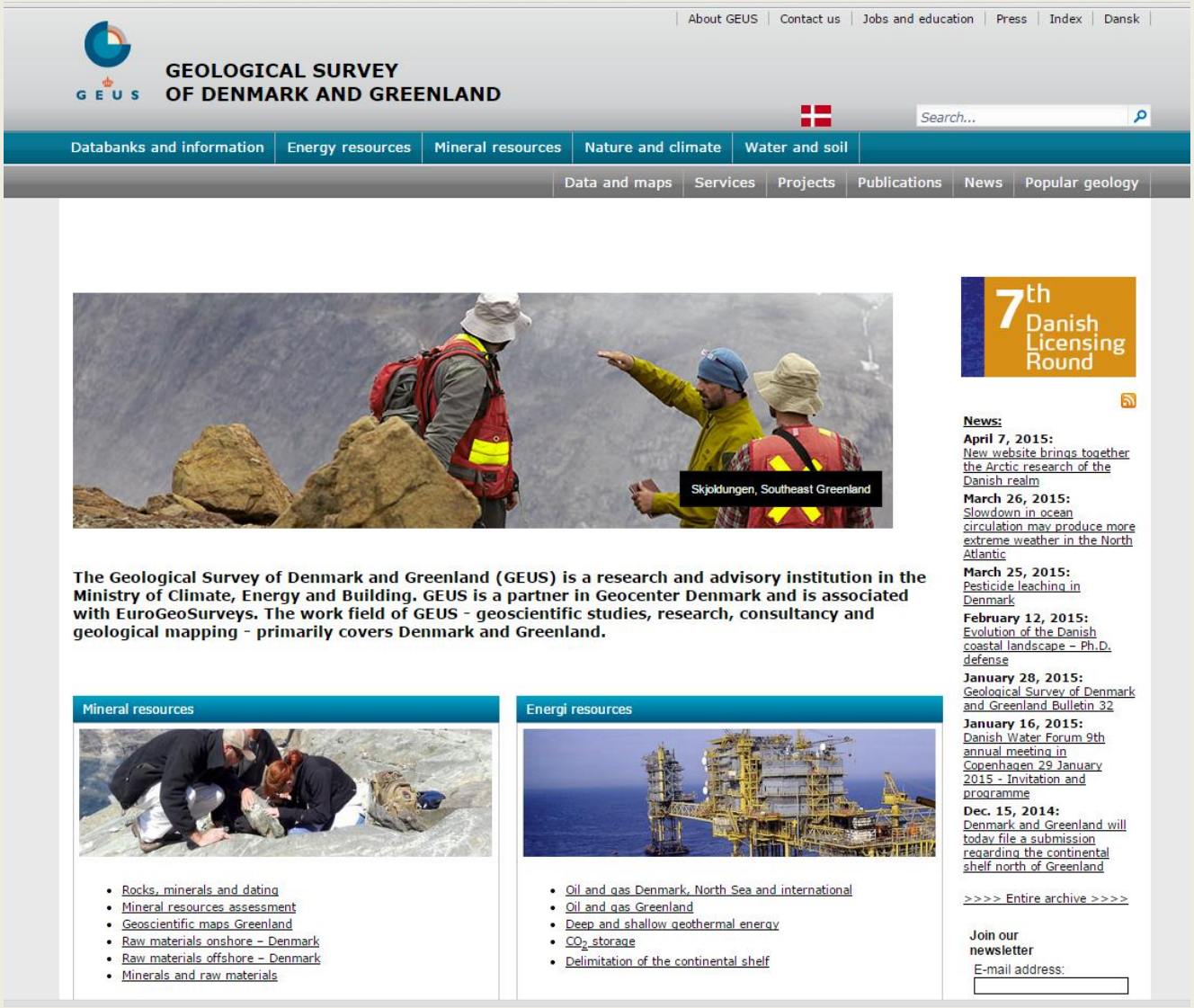
GEUS homepage and literature

www.geus.dk

- www.geus.dk

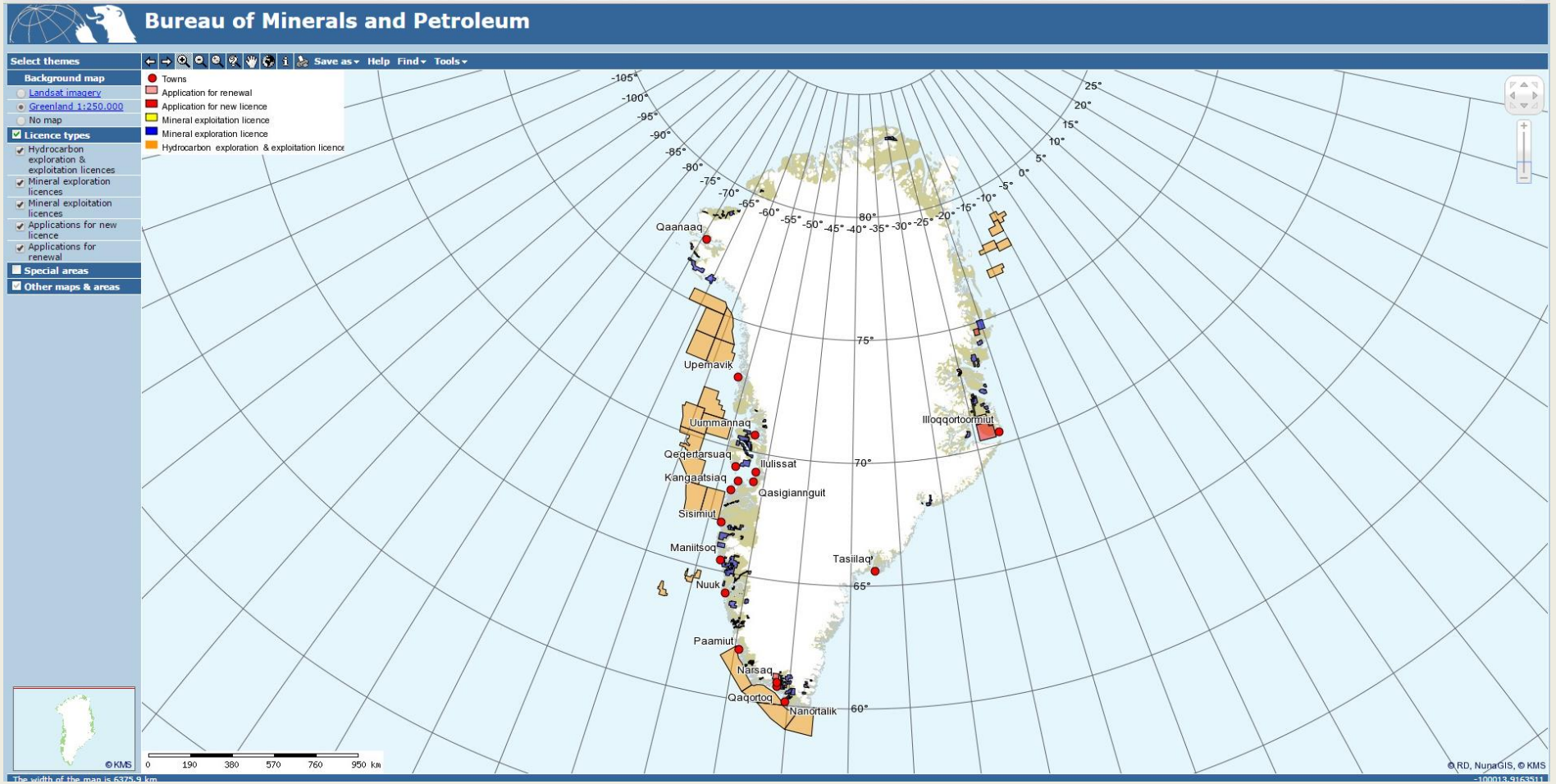






Government of Greenland

- Government of Greenland and the Ministry of Mineral Resources:
- www.govmin.gl
- www.nanoq.gl
- Information about licence holders



Thank You