Tungsten assessment Greenland
Results of resource assessment workshop 2013

Bo Møller Stensgaard, Diogo Rosa & Lars L. Sørensen
bmst@geus.dk; dro@geus.dk

Geological Survey of Denmark and Greenland
Ministry of Climate, Energy and Building, Government of Denmark

Greenland Day, Toronto 2014
March 3, 2014

With acknowledgements to members and observers in the MIM-GEUS Mineral Assessment Workshop 2013 on potential for undiscovered tungsten deposits in Greenland and special thanks to: L. Meinert, USGS; P. Pollard (consult, Australia), A. Steenfelt, N. Henriksen, GEUS; J. Pedersen (consultant).
Geological Survey of Denmark and Greenland (GEUS)

- Research and advisory institution in the Ministry of Building, Climate and Energy
- GEUS is collaborative partner to MIM/Government of Greenland as well as many other partners in Greenland, Denmark and international – both research institutions and industry
- Located in Copenhagen; with offices in Aarhus and Nuuk
- A total of about c. 350 full time specialists, technicians and administrative staff; ~120 of these works nearly full-time with Greenland
- Long history for geological work and data collection in Greenland; devoted to increase the geological knowledge base on Greenland for the benefit of society

- Come and visit us; at booth #417 or in Nuuk/Copenhagen
Why Tungsten?

Important industrial applications
• Cemented carbides – hard metals
• Tungsten in steel
• Lamp Industry
• Electronic and electrical industry
• Chemical applications

+ Supply risks

Main producing countries/regions
Increasing concentration of production
Low possibility substitution

Critical Mineral

Production


Tungsten – price...

APT = benchmark for tungsten concentrate is ammonium paratungstate (APT), which is the key intermediate product and most commonly traded tungsten material.

GFC = global financial crisis

mtu = metric ton units (mtu); 1 mtu of APT contains approximately 7.93kgs of tungsten.

Source: Schmidt et al. 2012 (ITIA)
What are we asked as (economic) geologist?

Resources…
- Where are the deposit(-s),
- how many
- how much,
- how do we find it?

Basically; the starting point…
as (economic) geologist…
- discriminate areas with mineral potential from those that are barren
Mineral Resource Assessment: tungsten in Greenland

Outline the regional locations, and estimate the probable amounts, of tungsten resources to a depth of one kilometer below the surface in Greenland.

Procedure:
Compile and use all available data and knowledge to facilitate a discussion of possibilities for undiscovered tungsten mineralizing systems/deposits from which estimated numbers of undiscovered deposits can be derived in a quantitative resource estimation.
Two models:

1. Tungsten Skarn Deposits
   (Cox 1986; SIDEX 2002)

1. Tungsten Veins
   (Cox & Bagby 1986; SIDEX 2002)

Fig. 4: Sketch showing the position of tungsten mineralized zone in section.

1. Slate mottled with mica, hornfelsed zone, hornfels zone.
2. Greisenized granite, potassic, sodic-feldspathized granite.
3. Tungsten-bearing quartz vein zone.
The procedure…

• Expert panel – 12 members
  ▪ Tungsten experts from US and Australia
  ▪ Economic and regional geologist, geochemists, geophysicists.
  ▪ Company, Survey and Academic; international
  ▪ Workshop observers

1. Areas with permissive geology are defined (tracts)
2. All data, maps, information, etc. is assessed and discussed – geology, exploration history, etc.
3. Individual bids on the number of undiscovered tungsten deposits in tracts at different confidence levels
4. Consensus bids on undiscovered
5. Estimation of resources [Monte Carlo simulation]

Mineral Assessment Workshop procedure; slightly modified version of the rules for the ‘3-part undiscovered mineral resource estimation methodology’ developed and used by USGS
Note: HMCs are obtained using different methods, hence W data are not directly comparable.
## Consensus undiscovered tungsten deposit estimates

<table>
<thead>
<tr>
<th></th>
<th>N90</th>
<th>N50</th>
<th>N10</th>
<th>N05</th>
<th>N01</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_Vein</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>S2_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>S3_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E1_Vein</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>E2_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E3_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E4_Vein</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>NW1_Vein</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>N90</th>
<th>N50</th>
<th>N10</th>
<th>N05</th>
<th>N01</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>S2_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S3_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E1_Skarn</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>E2_Skarn</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E3_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E4_Skarn</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>NW1_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
Central East Greenland
- Archean and Proterozoic basement and crystalline complexes
- Mesoproterozoic metasediments – Eleonore Bay Supergroup
- 930 Ma granites
- North Atlantic Caledonies – thrusting
- Caledonian / Devonian granites
- Post-caledonian sedimentary basins
- Palaeogene intrusions
- Many known tungsten occurrences
Neoproterozoic - Palaeozoic metasediments
Eleonore Bay Supergroup

14 km of shelf and carbonate platform metasediments

Eleonore Bay Supergroup; Ymer Ø Group, Geologfjord [cliff-face 1 km]
Caledonian / Devonian granites
Caledonian / Devonian granites
Granites worldwide

From Baker et al. 2005:

Granites from central East Greenland

From Baker et al. 2005:

Summary:
W anomalies are associated with extensional faulting and
1) late Caledonian leucogranites, where emplaced in lower EBS,
2) Devonian acid magmatism,
3) Palaeogene acid magmatism
Ymer Ø
Tungsten vein structure at south-side of Noa Dal

1979 Outcrops with scheelite located in S. and N. Margeries Dal by Nordisk Mineselskab. Presently licensed by NunaMinerals A/S.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Tonnage</th>
<th>Grade WO₃ %</th>
<th>Tonnes per strike metre</th>
</tr>
</thead>
<tbody>
<tr>
<td>S Margeries Dal W</td>
<td>75.000</td>
<td>2.5 %</td>
<td>350</td>
</tr>
<tr>
<td>N Margeries Dal W</td>
<td>42.000</td>
<td>0.7 %</td>
<td>330</td>
</tr>
</tbody>
</table>

Nordisk Mineselskab, 1984
Alpefjord Tungsten vein:
Quartz veins; 5 km²
- Oldest veins carry scheelite
- Younger veins: arsenopyrite, galena, chalcopyrite, pyrrhotite, bismuthinite
- 0.1% W, 0.2% As

Garnet-hbl.-px. skarnoid
- Scheelite, fluorite, sphene, apatite
- 0.1 0.8% W + Be, Sn, Bi

Kalkdal Tungsten Skarn:
Biotite granite and granodiorite (434 Ma) skarn in marble within granite contact
- Scheelite in actinolite, diopside and garnet skarn
- Sericitization and scapolite formation
- 500 ppm W (max. 2% W)
Consensus undiscovered tungsten deposit estimates

<table>
<thead>
<tr>
<th></th>
<th>N90</th>
<th>N50</th>
<th>N10</th>
<th>N05</th>
<th>N01</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_Vein</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>S2_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>S3_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E1_Vein</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>E2_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E3_Vein</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E4_Vein</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>NW1_Vein</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>N90</th>
<th>N50</th>
<th>N10</th>
<th>N05</th>
<th>N01</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S2_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>S3_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E1_Skarn</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>E2_Skarn</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E3_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>E4_Skarn</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>NW1_Skarn</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
Tungsten mineralization in Greenland
Preliminary results of a resource assessment workshop

Bo Møller Stensgaard, Diogo Rosa & Lars L. Sørensen
bmst@geus.dk; dro@geus.dk

Geological Survey of Denmark and Greenland
Ministry of Climate, Energy and Building, Government of Denmark

Thank you!

Come and visit us at booth #417; or in our offices in Nuuk and Copenhagen

Next assessment workshop: Intrusion-related gold deposits – November/December 2014
Get in contact if interested.
Devonian granites

Geologist trying to solve the riddle of the west face of Parkinson Bjerg, Hudson Land.

A reddish Devonian granite is seen at the top of the slope. Relief is c.1000 m.

Geochemical Sn, W, Mo, Nb etc. anomalies in the surrounding drainage systems
Ymer Ø
South Margeries Dal
1979 Outcrops with scheelite located in S. and N. Margeries Dal by Nordisk Mineselskab