The giant Alum Shale polymetallic deposits of Jämtland, Sweden - a potential major low cost supplier of Uranium for the future

Unconventional in 2014, conventional in 2024?

Bob Beeson, Will Goodall: Aura Energy Ltd

International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues
Sweden - second largest resource base

Source: World Nuclear Association 2012 Known Recoverable Resources, plus stock exchange reports for Sweden
Acknowledgements

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SGS Laboratories, Perth
Alum Shale – host to major uranium deposits in the Baltic Region

- historically exploited resource in Southern Sweden for uranium, oil and alum

- the unit extends from Finnmark in northern Norway to Scania in southernmost Sweden

- non-metamorphosed Shale in southern Sweden

- deformed Shale in the Caledonide nappes
- large areas of outcropping Alum Shale along the Caledonide Front

- in the Lower Allochthon (medium blue)
Alum Shale in the Storsjön area, Jämtland

- Tectonically repeated Alum Shale units have resulted in increased thickness (in excess of 250 m)

- SGU’s early investigations as a model - can now improve this in the poorly exposed western areas where Aura has been drilling
Alum Shale in Jämtland
A low metamorphic grade black schist

- carbonaceous black schist
- carbon metamorphosed to a semi-anthracitic form (10-15%)
- strong schistosity, and local folding of core
- abundant pyrite (5-10%)
- quartz - calcite veining
- local limestone bands
Alum Shale mineralogy

• Alum Shale is very fine-grained and requires Electron Probe Microanalysis to detect minerals present

• groundmass of quartz, muscovite and carbonaceous material

• pyrite - several generations

• quartz veins

CSIRO Process Science and Engineering Division Report to Aura Energy Ltd
Uranium mineralisation

- uranium very fine grained (generally <1-2µm)
- evenly distributed throughout the mica-carbon matrix
- no evidence that the mineralisation has been re-distributed or concentrated by later events, so CSIRO considers that mineralisation is syngentic or diagenetic
Examples of metal distributions

- warm colours (red, yellow) indicate relative abundance of elements
- uranium, vanadium, molybdenum in the groundmass
- nickel and iron in pyrite
Laterally continuous, thick mineralisation

**Haggn Permit Alum Shale - East-West Section**

**Haggn Permit Western Area - North-South Section**

Vertical exaggeration x2
803Mlbs U₃O₈ resource

- resources estimated by H&S Consultants

**Uranium Inferred Resources**

- 803Mlbs U₃O₈ inferred resource with 2.35Bn tonnes @ 155 ppm U₃O₈

- plus co-products:
  
  - nickel - 0.74 million tonnes
  - zinc - 1.0 million tonnes
  - molybdenum - 0.48 million tonnes
  - vanadium - 3.6 million tonnes

- plus major Exploration Target that could add 50-100% to resources if converted

<table>
<thead>
<tr>
<th>U₃O₈ (100ppm Cut-off)</th>
<th>Tonnes (Bt)</th>
<th>U₃O₈ (ppm)</th>
<th>Mo (ppm)</th>
<th>V (ppm)</th>
<th>Ni (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inferred</td>
<td>2.35</td>
<td>155</td>
<td>207</td>
<td>1,519</td>
<td>316</td>
<td>431</td>
</tr>
</tbody>
</table>
Thick western zone potential starting point for a multi-decade operation
Exceptionally large resources, but can the mineralisation be processed economically?

2011 Red book:

By the late 1980s however, the cost of production was considered too high for economic production with uranium prices of the time and these deposits were no longer reported in the Red Book.
Leaching evaluation - phase 1

- Conventional acid leach gave excellent recovery but high acid consumption
- Conventional carbonate leach gave less uranium recovery

<table>
<thead>
<tr>
<th>Method</th>
<th>Extraction</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U (%)</td>
<td>Ni (%)</td>
</tr>
<tr>
<td>Conventional acid leach</td>
<td>93.9%</td>
<td>22.7%</td>
</tr>
<tr>
<td>Conventional carbonate leach</td>
<td>76.9%</td>
<td>0%</td>
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</tbody>
</table>
**Bacterial leaching**

- bacterial leaching identified as a method to obtain similar high U recovery as conventional acid leaching whilst minimising impact of acid consuming gangue minerals

- insoluble metal sulphides converted into water-soluble metal sulphates

- micro-organisms produce leaching chemicals catalysing oxidation of ferrous to ferric ions

- implementation at Talvivaara, Finland on similar ore for Ni, Cu and Zn recovery
Pyrite

- pyrite typically 5-10% of the mode of the Alum Shale
- pyrite often has a framboidal texture
- small individual pyrite crystals (white) arranged into larger spheres up <5µm diameter
- considered to be sygenetic to diagenetic in origin
- plus distinct metamorphic pyrite
Two broad generations of pyrite present: syngenetic/diagenetic and metamorphic.

Porous, inclusion-rich pyrite: syngenetic/diagenetic with minor metamorphic re-crystallisation (right).

Clear subhedral metamorphic pyrite intergrown with sphalerite (left).
Bacterial leaching results - Stage 1

- Sighter shake tests showed great promise.
- Uranium recovery confirmed by tank leaching
- Acid consumption greatly reduced
- By-product recovery increased

<table>
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<tr>
<th>Method</th>
<th>U %</th>
<th>Mo %</th>
<th>Ni %</th>
<th>Acid consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial tank leach</td>
<td>83%</td>
<td>18%</td>
<td>45%</td>
<td>-11 kg/t</td>
</tr>
</tbody>
</table>
Bacterial leaching results - column leaching

- technical breakthrough for the Project - previously considered not viable
- uranium extraction confirmed with up to 85% achieved
- scale up gives similar extraction levels
- low acid consumption

<table>
<thead>
<tr>
<th>Method</th>
<th>U %</th>
<th>Mo %</th>
<th>Ni %</th>
<th>Zn %</th>
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</thead>
<tbody>
<tr>
<td>Bacterial column leach</td>
<td>85%</td>
<td>22%</td>
<td>66%</td>
<td>51%</td>
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</tbody>
</table>
Bacterial agitated tank leaching vs. Bacterial heap leaching

**Bacterial Heap Leach**
- Low CAPEX
- Low OPEX
- Low acid consumption
- Dependent on consistent material characteristics
- Established technology in other commodities
- No grinding required
- Long residence time

**Bacterial Tank Leach**
- Lower acid consumption than conventional leach
- High CAPEX
- Mid OPEX
- Throughput restrictions
- Grinding required
- Marginally higher recovery
Leaching option assessment

- Conventional acid leaching showed good U and co-product extraction but excessive acid consumption.
- Bacterial leaching showed equivalent extraction to conventional acid leaching.
- Particle size was not limiting, hence bacterial heap leaching a preferred option.

- Low U recovery
- Slow kinetics

- Conventional Acid
  - Good U recovery
  - High acid consumption
  - Good U recovery
  - Lower acid consumption
  - High cost option

- Alkaline

- Bacterial agitated leach

- Bacterial Column leach
  - Good U recovery
  - Low acid consumption
  - Low cost
Low cost, low risk, large mining project

Independent scoping study:

- initial pit shells contain >741 Mt
- nominal 30 Mtpa operation with 25 year initial mine life
- low mining costs - strip ratio of 0.75:1
- target initial annual production of 7.8Mlbs (3,538t) U₃O₈
- IRR of 49%; payback <5 years, ($65/lb uranium price)

- Häggån operating costs $9.30/t
- directly comparable with large bioheap leach copper projects in South America: e.g. Barrick’s Zaldivar project - $9.00/t
- operating costs: US$13.50/lb U₃O₈ when nickel & molybdenum treated as by-products
Smaller throughput options also economically attractive

<table>
<thead>
<tr>
<th>MTPA</th>
<th>APPROX CAPEX*</th>
<th>OPCOST</th>
<th>U3O8</th>
<th>Mo</th>
<th>Ni</th>
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<tbody>
<tr>
<td></td>
<td>$m</td>
<td>US$/lb.</td>
<td>Mlbs</td>
<td>Mlbs</td>
<td>Mlbs</td>
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<tr>
<td>3.5</td>
<td>150</td>
<td>21.00-25.00</td>
<td>1.0</td>
<td>0.4</td>
<td>1.7</td>
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<tr>
<td>5</td>
<td>190</td>
<td>18.00-22.00</td>
<td>1.4</td>
<td>0.6</td>
<td>2.4</td>
</tr>
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<td>7.5</td>
<td>250</td>
<td>18.00-22.00</td>
<td>2.1</td>
<td>1.0</td>
<td>3.6</td>
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<tr>
<td>30.0</td>
<td>540</td>
<td>13.50</td>
<td>7.8</td>
<td>4.3</td>
<td>14.8</td>
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Summary of the Häggån Project

- giant Inferred Resource of uranium mineralisation
- valuable and extractable co-products
- low cost, open pit mining
- low cost bioheap leaching testwork very positive
- rural environment, chiefly commercial forestry on private land
- in a stable first-world country with a long mining tradition