






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?

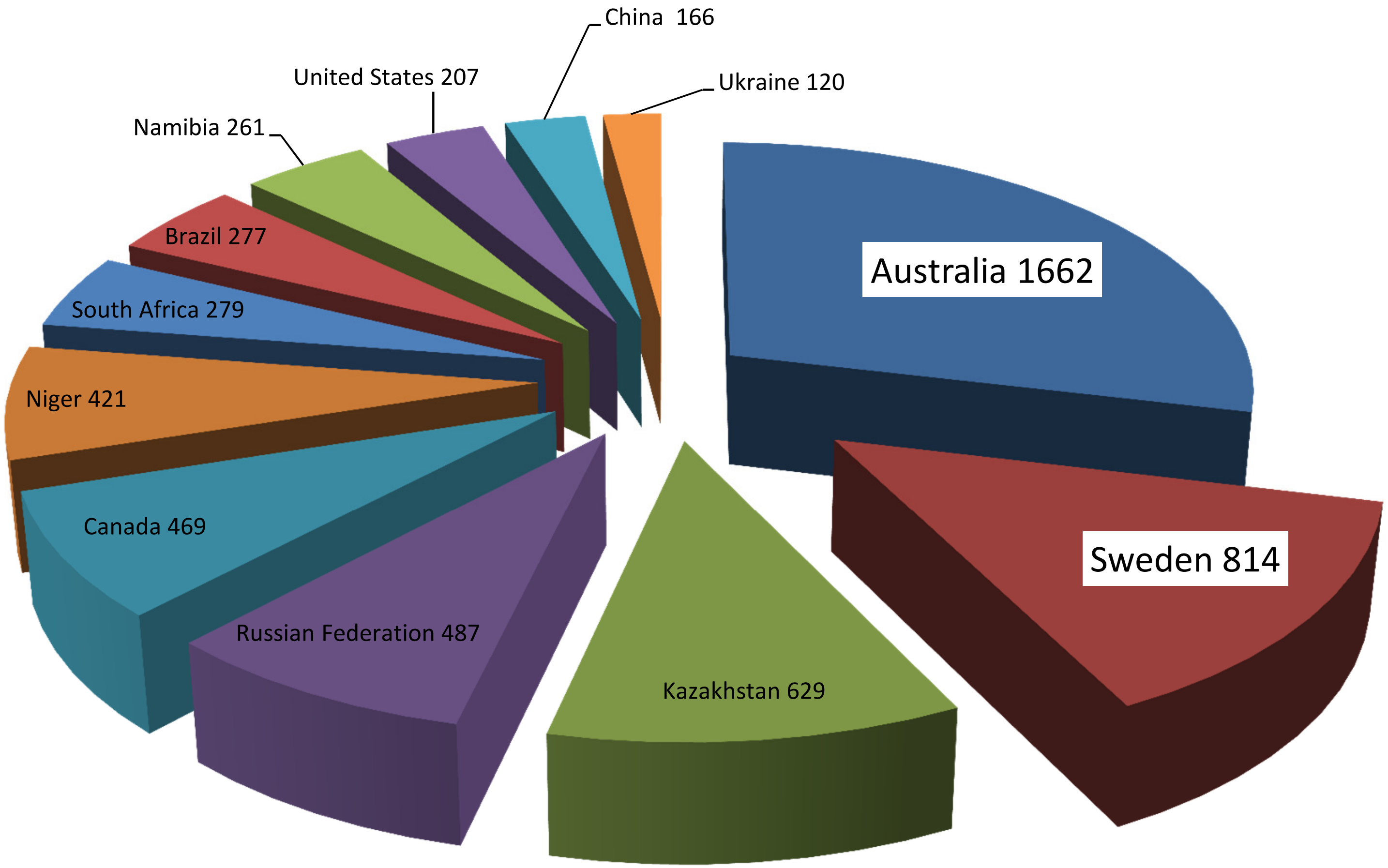
Bob Beeson, Will Goodall: Aura Energy Ltd

International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle:
Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues

IAEA
International Atomic Energy Agency

aura energy

Sweden - second largest resource base



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

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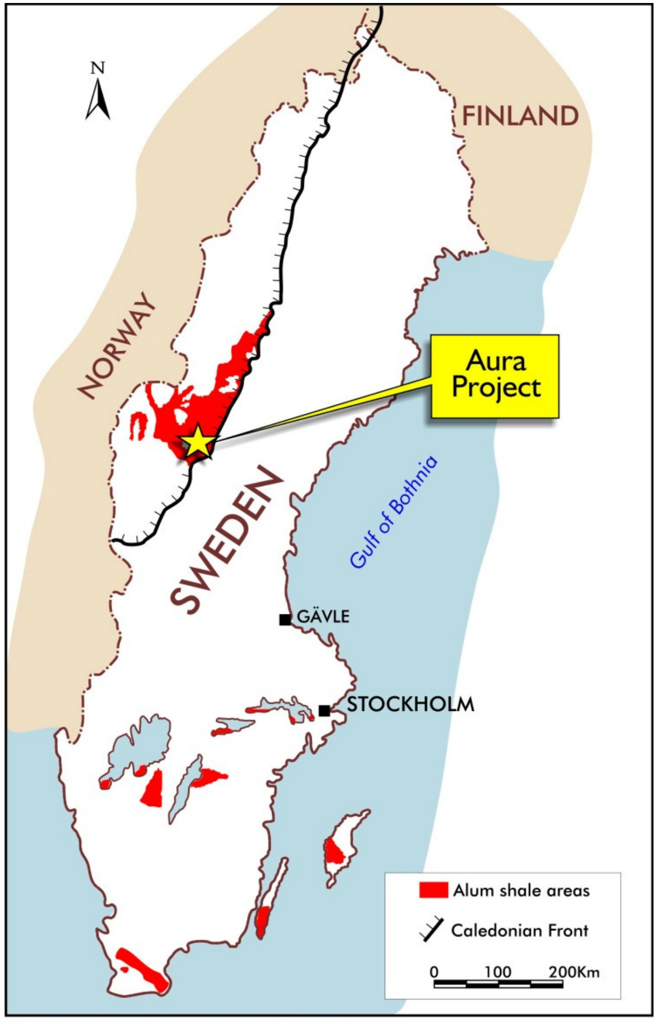
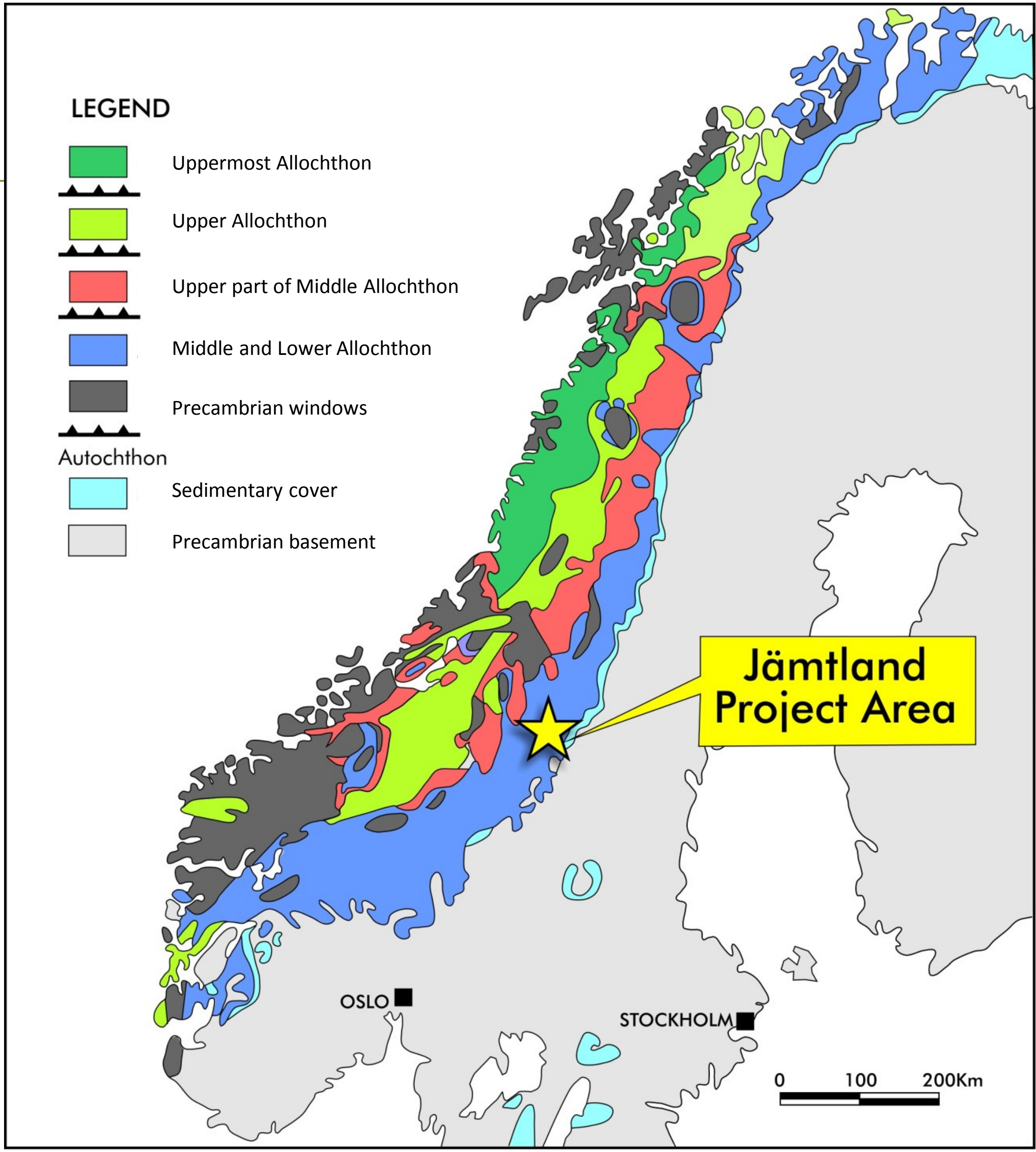
Alum Shale - host to major uranium deposits in the Baltic Region

- 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





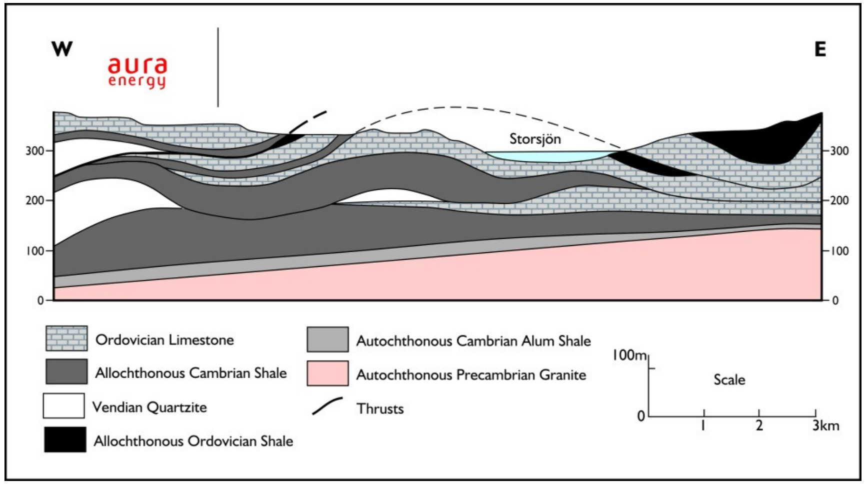
Tectonic map of the Scandinavian Caledonides

From: Gee, D.G., et al., 2010: Collisional Orogeny of the Scandinavian Caledonides. GFF 132, 29-44

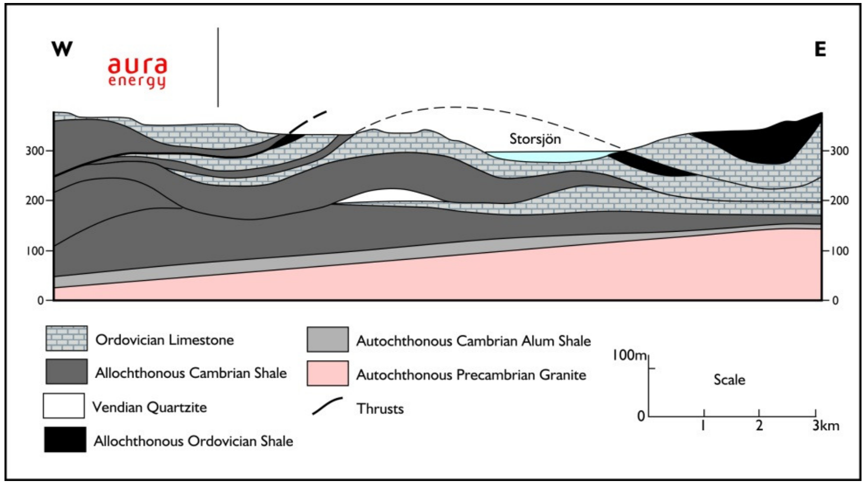
- large areas of outcropping Alum Shale along the Caledonide Front
- in the Lower Allochthon (medium blue)

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



Original SGU cross section from 1985



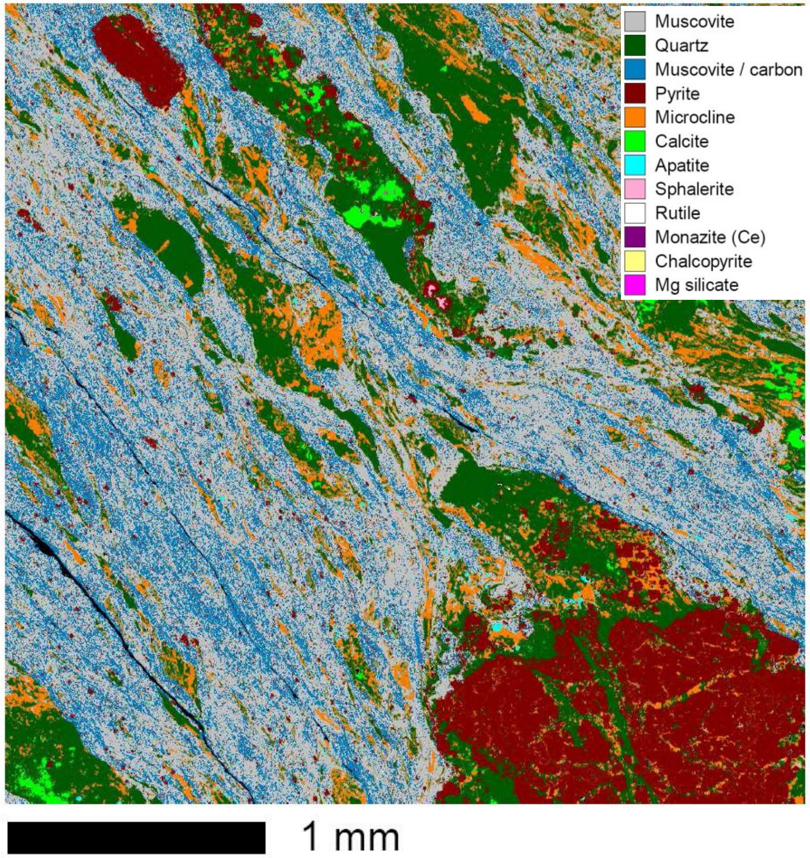
Revised cross section after Aura drilling

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



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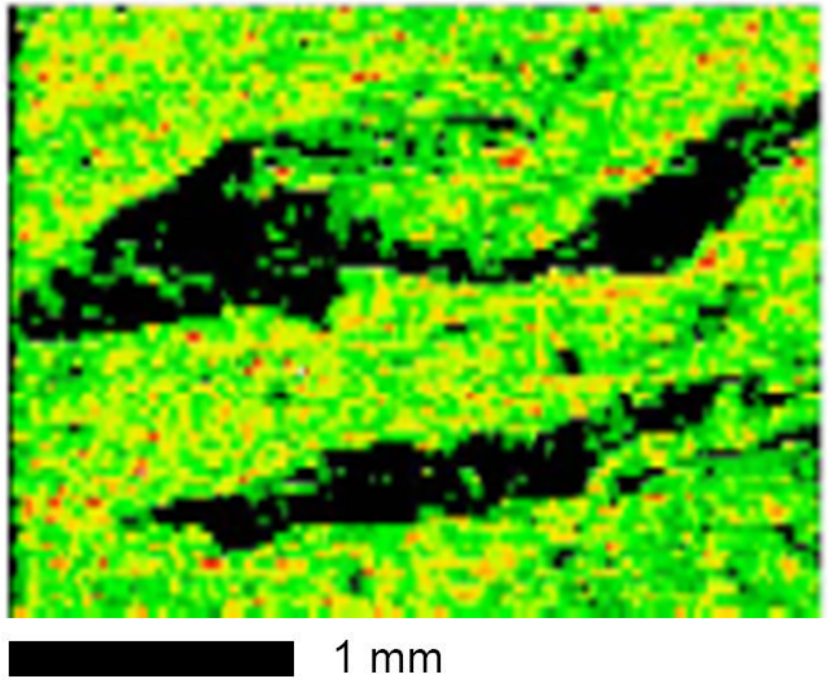
Uranium mineralisation

- 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 syngenetic or diagenetic



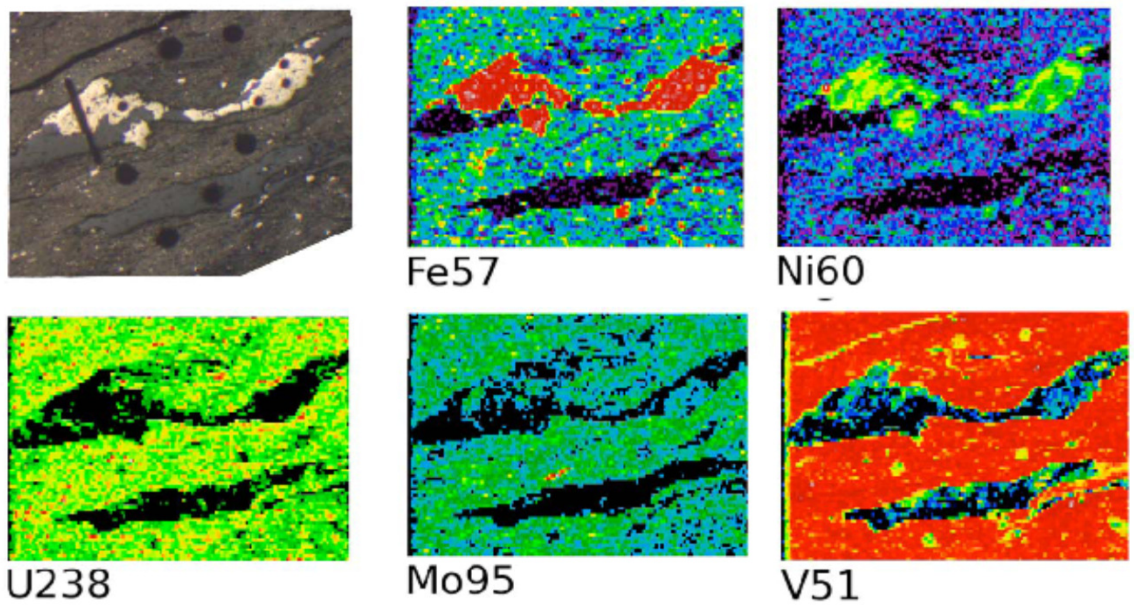
Presence of uranium indicated by the red and yellow colouring in this image

CODES – ARC Centre of Excellence in Ore Deposits, University of Tasmania Report to Aura Energy Ltd

Examples of metal distributions

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

slide15



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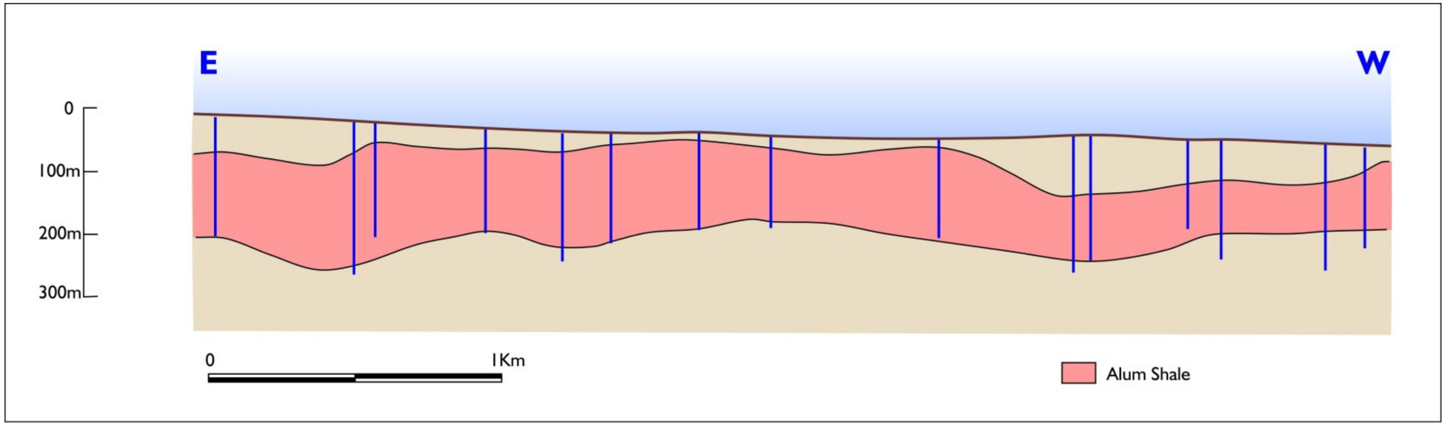
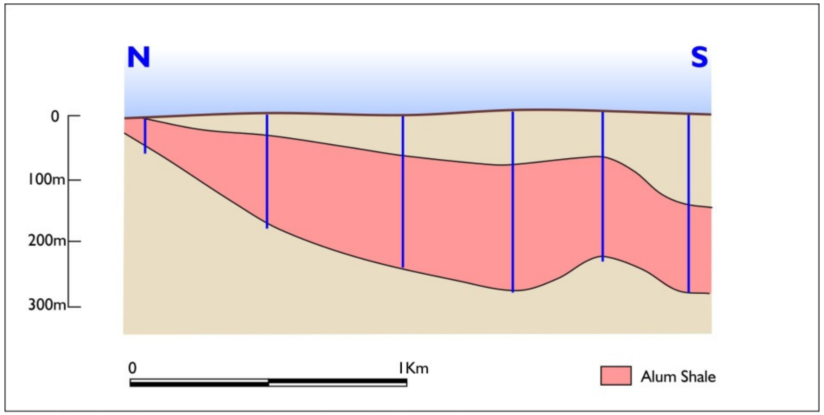
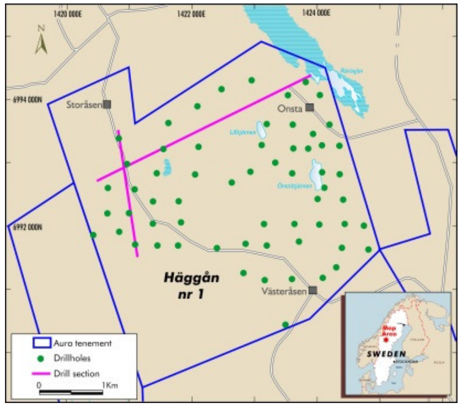
Laterally continuous, thick mineralisation



Häggån Permit Alum Shale - East-West Section



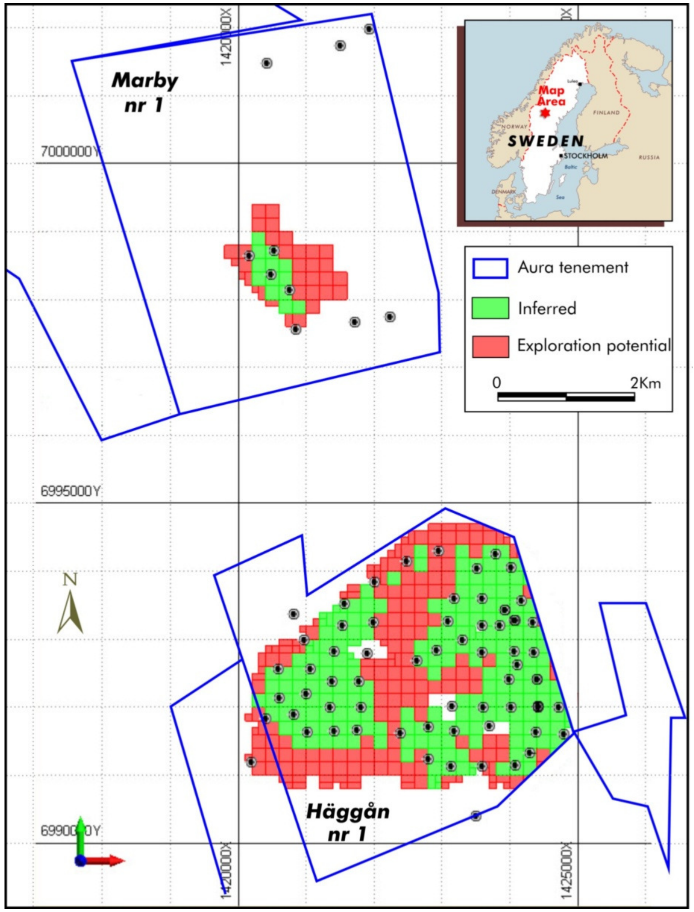
Häggån Permit Western Area - North-South Section



Vertical exaggeration x2

803Mlbs U_3O_8 resource

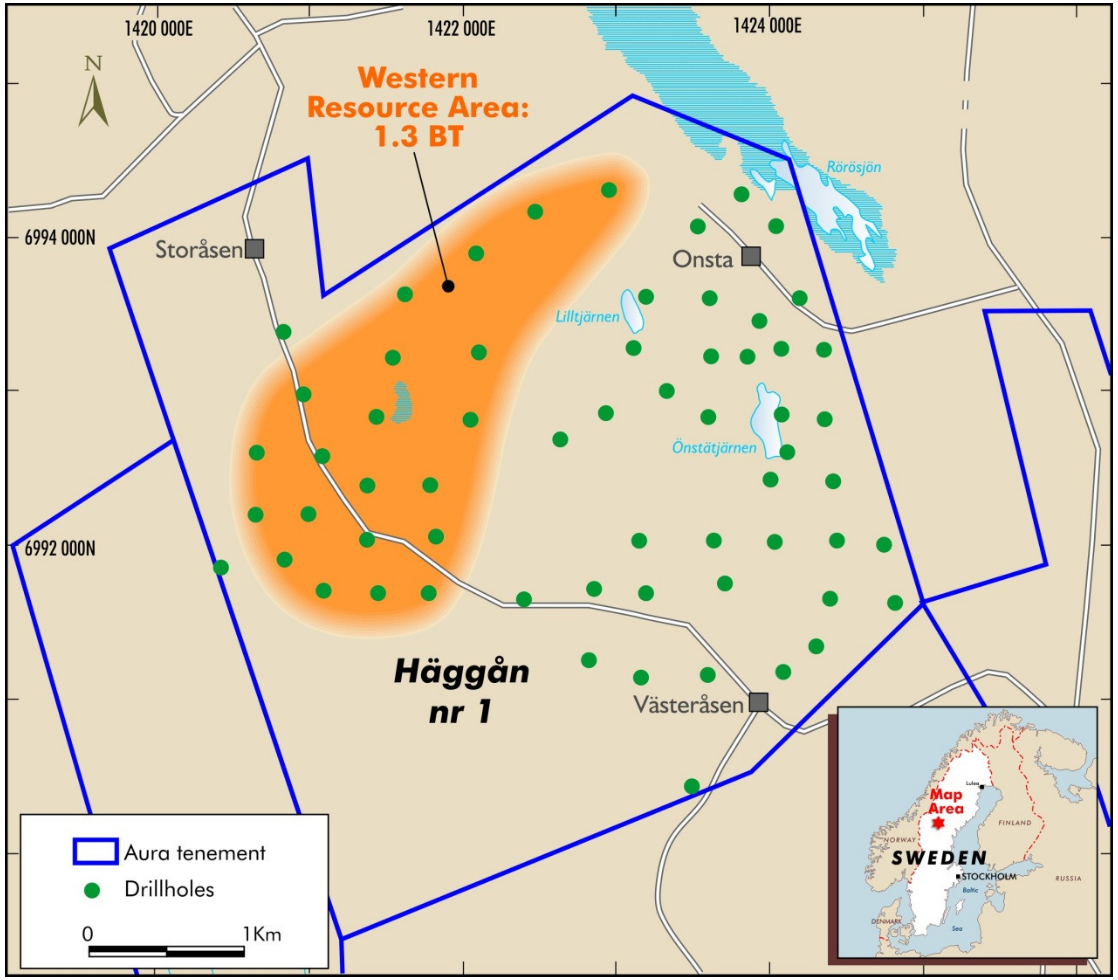
- resources estimated by H&S Consultants
- **Uranium Inferred Resources**
  - **803Mlbs U_3O_8 inferred resource with 2.35Bn tonnes @ 155 ppm U_3O_8**
- plus co-products:
  - nickel – 0.74 million tonnes
  - zinc – 1.0 million tonnes
  - molybdenum – 0.48 million tonnes
  - vanadium - 3.6 million tonnes
- plus major Exploration Target that could add 50-100% to resources if converted



Aura's Häggån resource and exploration target

U_3O_8 (100ppm Cut-off)	Tonnes (Bt)	U_3O_8 (ppm)	Mo (ppm)	V (ppm)	Ni (ppm)	Zn (ppm)
Inferred	2.35	155	207	1,519	316	431

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

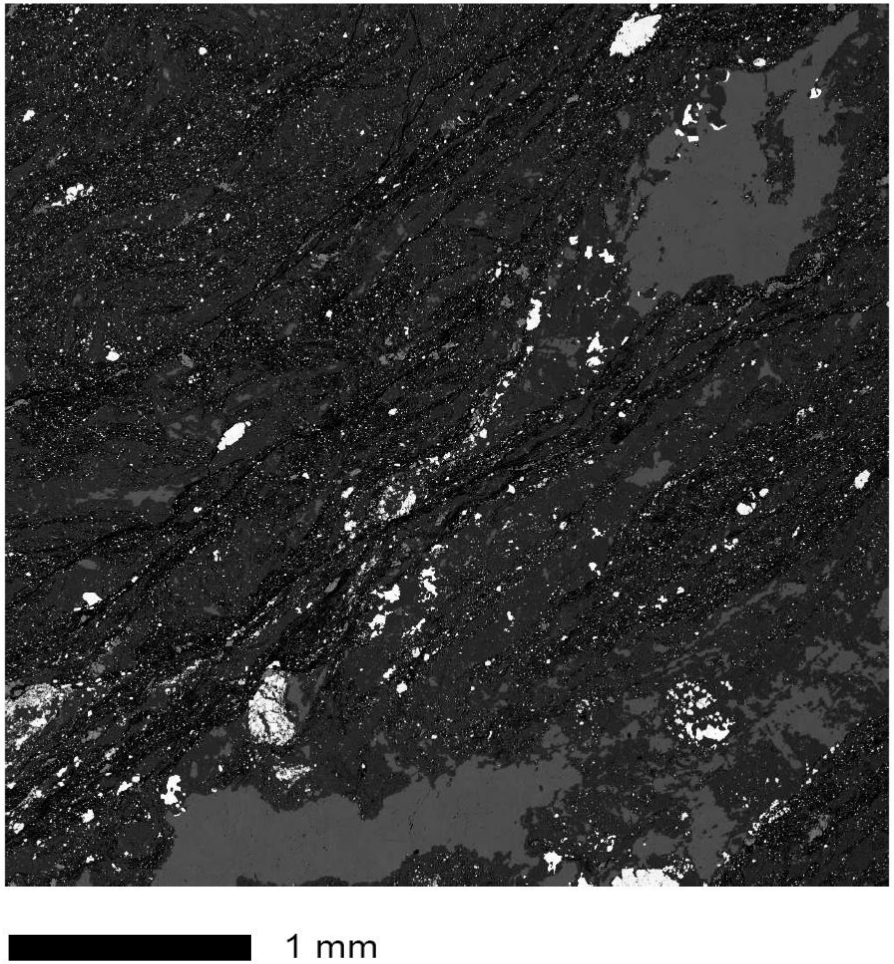
Method	Extraction				Consumption	
	U (%)	Ni (%)	Mo (%)	V (%)	H_2SO_4 kg/t ore	Total carbonate kg/t ore
Conventional acid leach	93.9%	22.7%	12.2%	4.7%	87	
Conventional carbonate leach	76.9%	0%	29.8%	0%	-	9.4

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 syngenetic to diagenetic in origin
- plus distinct metamorphic pyrite



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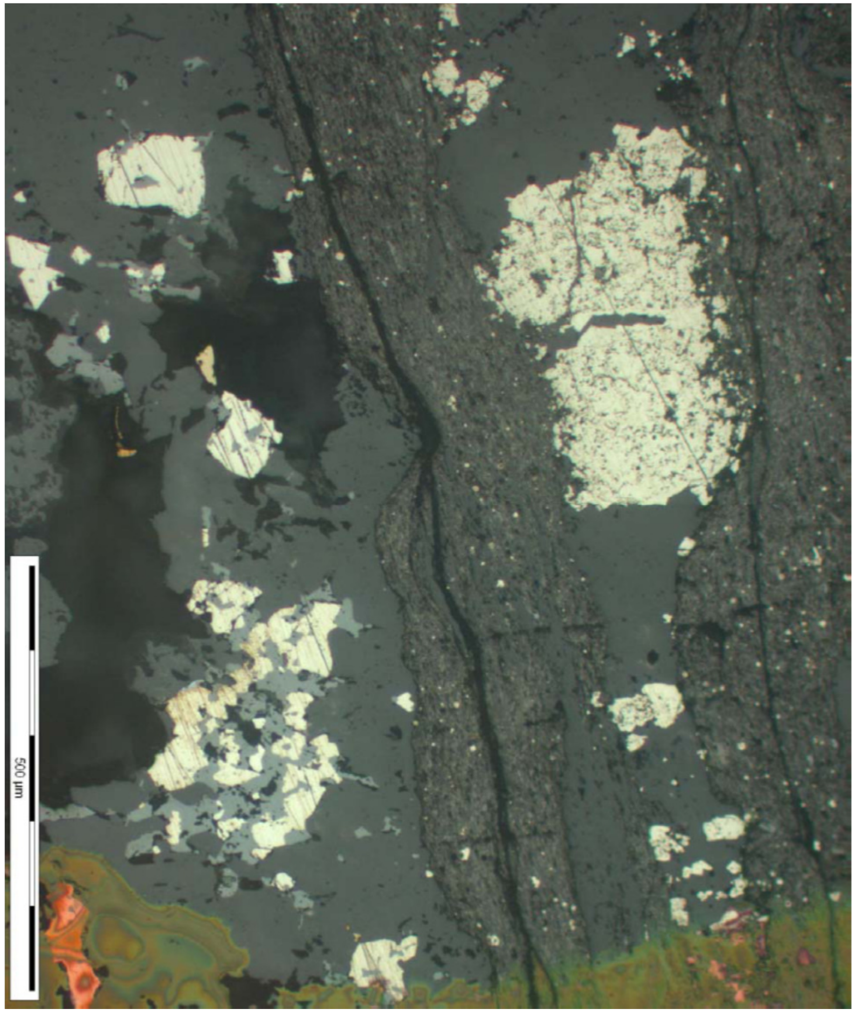
Two broad generations of pyrite present: syngenetic/diagenetic and metamorphic

Clear subhedral metamorphic pyrite intergrown with sphalerite (left)



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

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

Method	U %	Mo %	Ni %	Acid consumption
Bacterial tank leach	83%	18%	45%	-11 kg/t

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

Method	U %	Mo %	Ni %	Zn %
Bacterial column leach	85%	22%	66%	51%

Bacterial agitated tank leaching vs. Bacterial heap leaching

Bacterial Heap Leach

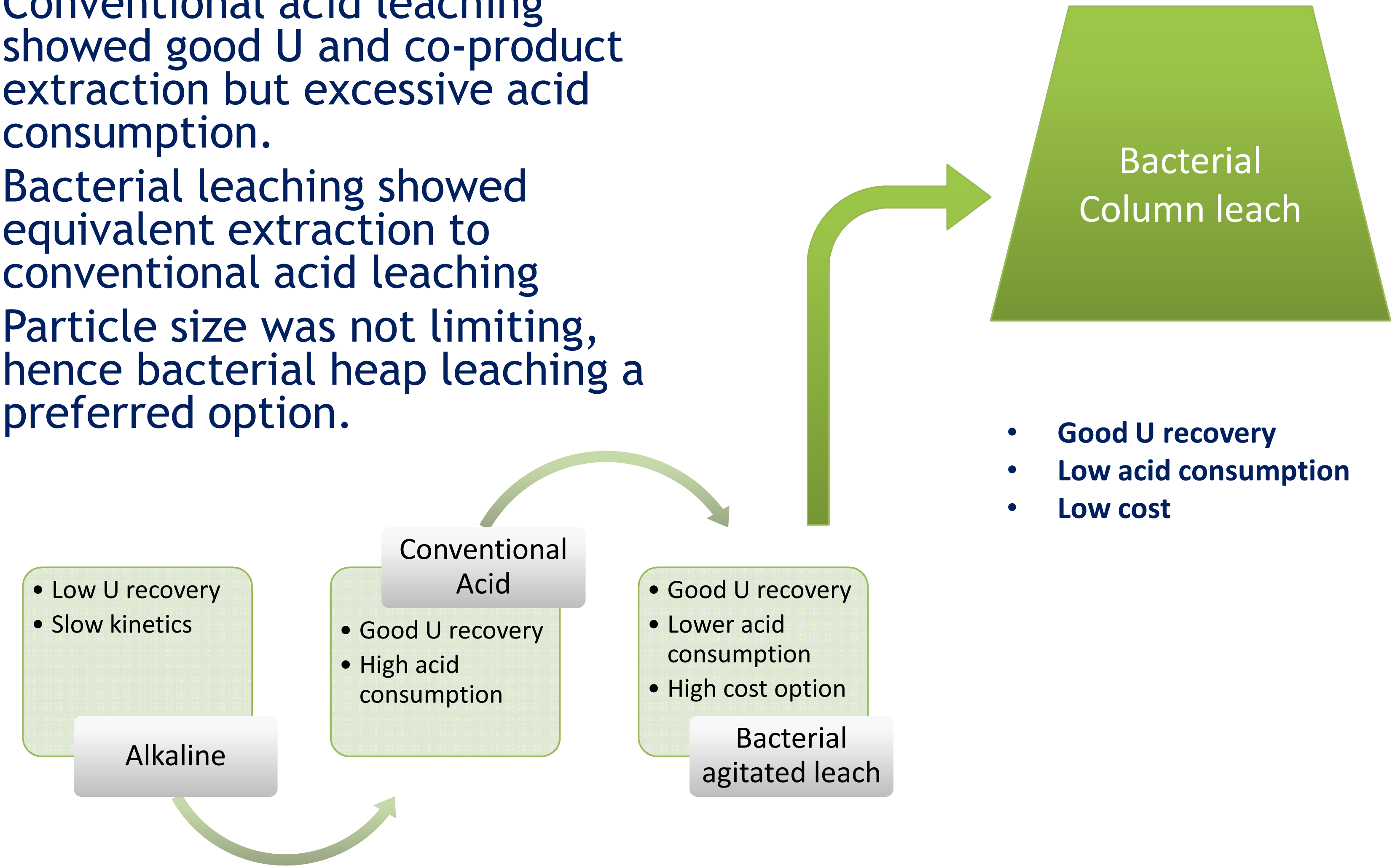
- Low CAPEX
- Low OPEX
- Low acid consumption
- Dependent on consistent material characteristics
- Established technology in other commodities
- No grinding required
- Long residence time

Bacterial Tank Leach

- Lower acid consumption than conventional leach
- High CAPEX
- Mid OPEX
- Throughput restrictions
- Grinding required
- Marginally higher recovery

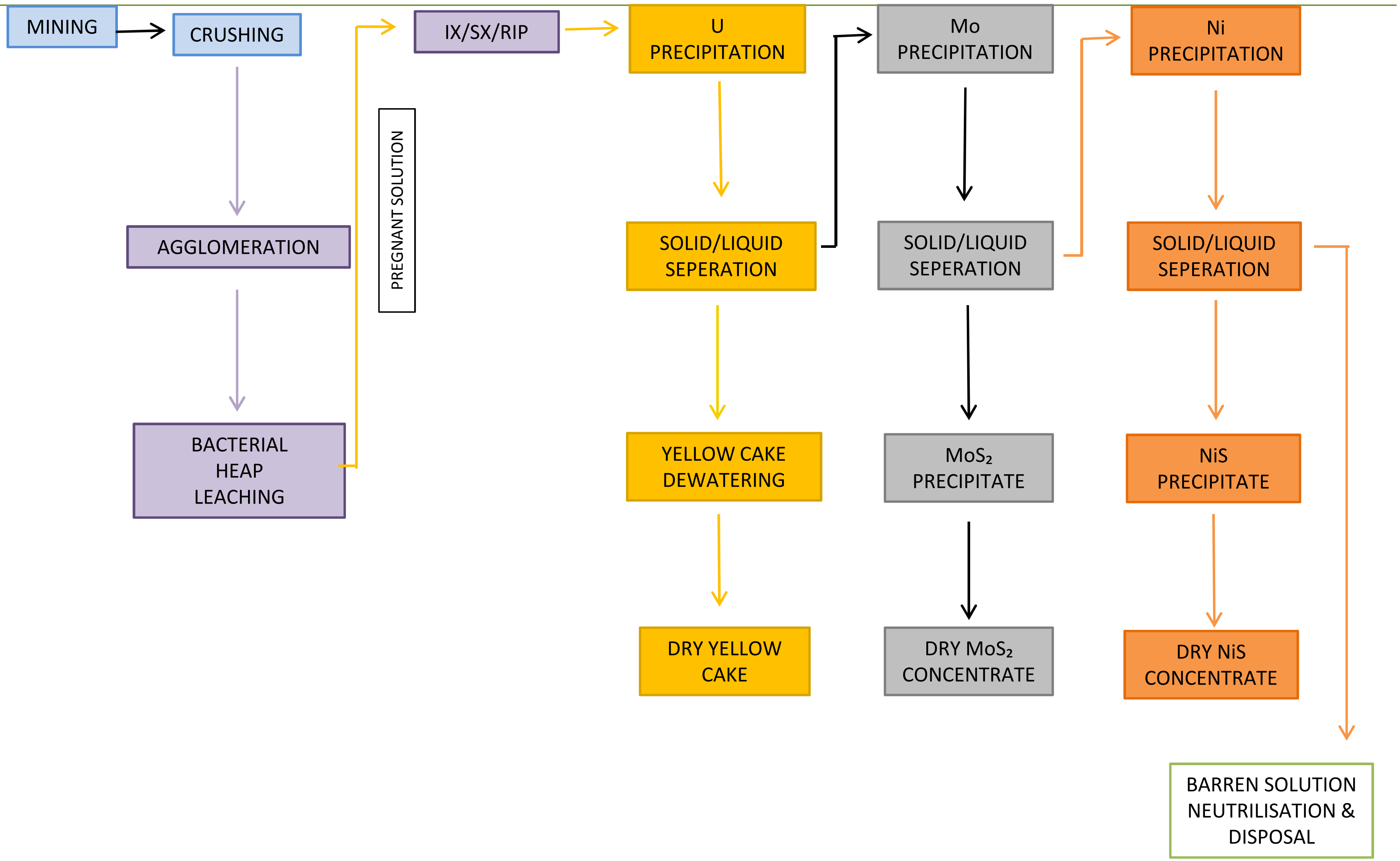
Leaching option assessment

- 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.



- **Good U recovery**
- **Low acid consumption**
- **Low cost**

Heap leach circuit used in Scoping Study



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) U_3O_8
- 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 U_3O_8 when nickel & molybdenum treated as by-products

Smaller throughput options also economically attractive

MTPA	APPROX CAPEX*	OPCOST	U3O8	Mo	Ni
	$m	US$/lb.	Mlbs	Mlbs	Mlbs
3.5	150	21.00-25.00	1.0	0.4	1.7
5	190	18.00-22.00	1.4	0.6	2.4
7.5	250	18.00-22.00	2.1	1.0	3.6
30.0	540	13.50	7.8	4.3	14.8

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