UNCONVENTIONAL URANIUM RESOURCES
Challenges and opportunities

UNFC Workshop,
Santiago, Chile, 9-12 July 2013
Patrice BRUNETON
• “Unconventional resources” are resources from which uranium is only recoverable as a minor by-product, such as uranium associated with phosphate rocks, non-ferrous ores, porphyry copper, carbonatite, black shale and coal-lignite (Red Book 2012).

• Most of the unconventional uranium resources reported to date in the Red Book are associated with uranium in phosphate rocks.
“It is clear that stronger uranium prices and expectations of rising demand in recent years have stimulated investigation of a variety of projects and technologies by both governments and commercial entities in this area.”

“In particular, an interest in recovery of uranium from phosphates was highlighted, prompting a series of IAEA supported consultancies and technical meetings in 2010 and 2011.”
1. Intrusive anatetic and magmatic
2. Granite-related
3. Polymetallic iron-oxide breccia complex
4. Volcanic-related
5. Metasomatite
6. Metamorphite
7. Proterozoic unconformity
8. Collapse breccia pipe
9. Sandstone
10. Paleo-quartz pebble conglomerate
11. Surficial
12. Coal/lignite
13. Carbonate
14. Phosphate
15. Black shale
And also:

- **Sea water**
- Large uranium resources associated with *monazite-bearing coastal sands* (placers, paleoplacers) in Brazil, India, Egypt, Malaysia, Sri Lanka, USA, ...... mined mainly for REE-Zr-Ti
- **Tailings** from South Africa gold mines
Uranium in seawater

- Some **4.5 billion tons** of uranium, representing an enormous energy resource, are dissolved in the world's oceans, but at very low concentrations of about **3.3 ppb**.
The sea is the key to uranium bounty
(World Nuclear News, August 2012)

- The prospect of a vastly increased uranium resource has come closer with new technologies for extraction of uranium from seawater

- Tamada (2009) publish results obtained with a recovery system, based on a new type of polymer braid that enhanced U recovery by 3 times. About 1.5 gU/kg adsorbent were recovered over a 30-day period
The technology uses long mats of braided plastic fibres, embedded with an uranium absorbent to capture trace amounts of uranium in the ocean. The mats are placed 200 m underwater to soak up uranium before being brought to the surface. They are then washed in an acidic solution that captures U for future refinement.

The results show the new design cuts the production costs of a kilogram of uranium extracted from seawater from US $1230 to US $660.
In 2012, researchers of the University of North Carolina, USA, have designed a metal-organic framework (MOF) to collect common uranium-containing ions dissolved in seawater. In lab tests, the material was four times better than the conventional plastic adsorbent at drawing uranium from seawater.

The new techniques might reduce the cost of uranium to around US $135/lb ($350/kg). While this price remains uneconomic, the cost of nuclear fuel makes up only about 5% of the final cost of nuclear power.
HEAVY MINERALS SAND
(placers-paleoplacers)

Ti-Zr-REE

Monazite
REE-Th-U
WIM 150 deposit (Australia)

- Murray Basin, South Australia-Victoria
- 330,000 km²
- 1650 Mt with 3.7% heavy minerals
  - Ilmenite: 31%, 137 Mt
  - Zircon: 21%, 35 Mt ---> 10,500 t U, 10,500 t Th
  - Rutile: 12%, 29 Mt
  - Leucoxene: 6%
  - Monazite: 2%, 0.58 Mt ---> 3,000 t U, 35,000 t Th
  - Xenotime: 0.4%, 0.17 Mt ---> 1,700 t U, 1,700 t Th
Beach sand mining in India

- India’s Department of Atomic Energy (DAE) would permit private miners to process beach sand and supply monazite tailings to the government-owned Indian Rare Earths Limited (IREL) to extract Th and U (July 2012)

- Data from the Atomic Mineral Directorate for Exploration and Research has shown that India’s monazite reserve was estimated at 11 M t (60,000 t U, 700,000 t Th)
• Beach sand and river placer monazite occurs in plentiful supply in many countries outside of China. The rare earth oxide content of monazite is approximately 70 wt %

• The physical and chemical processing of monazite is well-known and can be handled

• The current perceived challenge to mining monazite is the presence of Th (and U) in the structure. If the thorium disposal problem can be solved economically, monazite mining can provide all of the necessary light and medium REEs to the marketplace without dependence on China
When Molycorp Inc. (Mountain Pass deposit) and Rhône-Poulenc (now Rhodia) were providing the bulk of the REEs to the marketplace, Rhône-Poulenc received all of its REEs from beach sands in Australia and South Africa. It transported the monazite sands to France and eventually compiled a large quantity of thorium. The French government forbade the company from continuing this, so it switched over to bastnasite and left the monazite.

In 2011, agreement between Rhodia and AREVA to develop deposits containing U and REE and reprocessing of “waste” resources.
South Africa tailings reprocessing from gold mines

- Gold production since 1886: 50,000 t Au
- Uranium production: 160,000 t U
- 8 projects to reprocess tailings
- Resources: 8,000 to 75,000 t U per project
- Grade: 30-80 ppm
- Planned annual production: 70 to 400 t U per project -----> 500-1000 t U/year?
- ± Au recovery
15m bench height

Top cut bench

Undercut bench

Crawler mounted water cannon producing 10000 tonnes per day

Slurry trench

Figure 18-1

First Uranium Corporation
Buffelsfontein Project
South Africa
Typical Tailing Recovery Operation
Found in various types of deposits:

- Type 1.1. Intrusive magmatic
- Type 3. Polymetallic iron-oxide breccia complex (IOCG)
- Type 12. Coal-lignite
- Type 14. Phosphate
- Type 15. Black shale
Type 1.1 - Intrusive plutonic deposits

• Uranium deposits consist of disseminated primary uranium minerals in rocks of intrusive magmatic origin

• Deposits are generally low- to very low grade (10-400 ppm), but may contain substantial resources (5,000-50,000 t U)

• 31 intrusive deposits in UDEPO classified as “Unconventional resources »
1.2. INTRUSIVE PLUTONIC deposits

3 classes of deposits are separated:

1.2.1. Granites-monzonites (porphyry copper) *(Bingham Canyon, USA; Chuquicamata, Chile)* (7 deposits). U can be recovered as a by-product of Cu-Au-Ag-Mo

1.2.2. Peralcaline complexes *(13 deposits)* *(Kvanefjeld, Greenland)*

1.2.3. Carbonatites *(11 deposits)* *(Phalabora, South Africa)*

*U can be recovered as a by/co-product of Nb-Ta, Zr, REE, P, Zn, Y, Th,* ……….
1.2.1. Granite-monzonite: porphyry-copper

Bingham Canyon (USA)
Cu, Au, Ag, Mo

50 t U/year, 1978-1989
8-12 ppm U
Chuquicamata (Chile)
150-200,000 t U ? 15-20 ppm
Codelco-AREVA
85 t U/year production ?
1.2. Intrusive-plutonic deposits: peralcaline complexes and carbonatites

- **1.2.2.-1.2.3. Peralcaline complexes and carbonatites:**
  - Several of these intrusions are actively drilled around the world to recover P, F, REE, Zr, Ta, Nb, Y, .......
  - Most of them contain elevated (20-400 ppm) U and Th which are for now considered as radioactive “waste”, but could become by-products due to the reinforcement of environmental constraints and improvement of extraction.
  - Some historical production (640 t U, 30-40 ppm) at Phalabora (South Africa).
  - Advanced projects: Kvanefjeld (Greenland), Catalao and Araxa (Brazil), Nolans Bore and Toongi (Australia), ......
  - 24 deposits in UDEPO.
## Major peralcaline complex-carbonatite deposits

### 1.2.2. PLUTONIC-Peralcaline complex

<table>
<thead>
<tr>
<th>Location</th>
<th>Country</th>
<th>Population</th>
<th>Latitude</th>
<th>Deposit Type</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kvanefjeld</td>
<td>Denmark</td>
<td>134.750</td>
<td>0.023</td>
<td>Peralkaline syenite</td>
<td>Exploration</td>
</tr>
<tr>
<td>Twihinate</td>
<td>Morocco</td>
<td>75.000</td>
<td>0.025</td>
<td>Peralkaline complex</td>
<td>Dormant</td>
</tr>
<tr>
<td>Sorensen</td>
<td>Denmark</td>
<td>62 370</td>
<td>0.026</td>
<td>Peralkaline syenite</td>
<td>Exploration</td>
</tr>
<tr>
<td>Ghurayyah</td>
<td>Saudi Arabia</td>
<td>45.700</td>
<td>0.012</td>
<td>Peralkaline granite</td>
<td>Exploration</td>
</tr>
<tr>
<td>Ilimaussaq Zone 3</td>
<td>Denmark</td>
<td>24.260</td>
<td>0.025</td>
<td>Peralkaline syenite</td>
<td>Exploration</td>
</tr>
<tr>
<td>Pocos de Caldas</td>
<td>Brazil</td>
<td>22.700</td>
<td>0.29</td>
<td>Peralkaline syenite</td>
<td>Reclamation</td>
</tr>
<tr>
<td>Nolans Bore</td>
<td>Australia</td>
<td>5.160</td>
<td>0.018</td>
<td>Peralkaline complex</td>
<td>Exploration</td>
</tr>
</tbody>
</table>

### 1.2.3. PLUTONIC-Carbonatite

<table>
<thead>
<tr>
<th>Location</th>
<th>Country</th>
<th>Population</th>
<th>Latitude</th>
<th>Deposit Type</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalao</td>
<td>Brazil</td>
<td>72.175</td>
<td>0.0133</td>
<td>Carbonatite</td>
<td>Dormant</td>
</tr>
<tr>
<td>Glibat Lafhouda</td>
<td>Morocco</td>
<td>21.250</td>
<td>0.0425</td>
<td>Carbonatite</td>
<td>Dormant</td>
</tr>
<tr>
<td>Phalabora</td>
<td>South Africa</td>
<td>15-20.000</td>
<td>0.0040</td>
<td>Carbonatite</td>
<td>Operating</td>
</tr>
<tr>
<td>Araxa</td>
<td>Brazil</td>
<td>13.000</td>
<td>0.080</td>
<td>Carbonatite</td>
<td>Dormant</td>
</tr>
<tr>
<td>Toongi</td>
<td>Australia</td>
<td>8.690</td>
<td>0.012</td>
<td>Carbonatite</td>
<td>Exploration</td>
</tr>
</tbody>
</table>
Greenland Geology

Gardar Province – Alkaline intrusions emplaced in a continental rift setting (e.g. Ilimaussaq Complex)
South Greenland Geography

Narsaq
Ilmaussaq Complex
Narsuaq International Airport
To North Atlantic
Greenland Minerals and Energy Ilimaussaq project
(3 deposits, 221,400 t U, 230 ppm)
Greenland Minerals and Energy Ilimaussaq project

TREO-Y-Zn-U

185 m, 375 ppm U
Kvanefjeld Ore
(Lujavrite Mineralogy)

- Aegirine
- Arfvedsonite
- Bioitite

- Amphibole, pyroxene (Fe silicates)

- Albite
- Microcline
- Sodalite
- Analcime

- Feldspars/Feldspathoids (Silicates)

- Steenstrupine
  - U, REE
  - REE, Th
  - REE

- Monazite
- Vitusite

- Phosphates

- Cerite
  - REE
  - U

- Na-Zr-silicates

- Silicates

- Sphalerite
- Zn

- Sulphide
Comparison of Rare Earth Resources
Sources: IMCOA, Company Websites @ Q1 2011

Resources that are considered as compliant with international reporting codes, April 2011

Market capitalisation as of April 2011
The carbonatite is mined mainly for Cu with Fe, vermiculite and Ni-Au-Ag-U-Zr-Pt as by-products. Resources of apatite are enormous (6.700 Mt)
Glibat Lafhouda (Morocco)
(21,500 t U, 425 ppm)
3. Polymetallic iron-oxide breccia complex deposits (IOCG)

- **15** deposits in UDEPO
- 2 main provinces, Gawler Craton (Australia) and Carajas District (Brazil)
- One deposit, Olympic Dam (Australia) with the largest uranium resources in the world: **2,200,000 t U, 230 ppm**
- Within hematite-rich breccia complex
- Polymetallic: **Cu, Au, Ag, U, REE (53 Mt REO)**
- **3,386 t U** in 2012 as by-product of Cu-Au-Ag
### 3. Polymetallic iron-oxide breccia complex deposits

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Country</th>
<th>Resources (t U)</th>
<th>Grade (%U)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olympic Dam</td>
<td>Australia</td>
<td>2,125,230</td>
<td>0.023</td>
<td>Production</td>
</tr>
<tr>
<td>Carrapateena</td>
<td>Australia</td>
<td>46,585</td>
<td>0.023</td>
<td>Exploration</td>
</tr>
<tr>
<td>Salobo</td>
<td>Brazil</td>
<td>35,500</td>
<td>0.0045</td>
<td>Cu-Au</td>
</tr>
<tr>
<td>Igarape Bahia</td>
<td>Brazil</td>
<td>30,000</td>
<td>0.0135</td>
<td>Cu-Au</td>
</tr>
<tr>
<td>Mount Gee</td>
<td>Australia</td>
<td>26,380</td>
<td>0.052</td>
<td>Exploration</td>
</tr>
<tr>
<td>Sossego</td>
<td>Brazil</td>
<td>22,000</td>
<td>0.006</td>
<td>Cu-Au</td>
</tr>
<tr>
<td>Prominent Hill</td>
<td>Australia</td>
<td>10,280</td>
<td>0.010</td>
<td>Cu-Au</td>
</tr>
<tr>
<td>Moran Lake C-Zone</td>
<td>Canada</td>
<td>3,680</td>
<td>0.030</td>
<td>Exploration</td>
</tr>
<tr>
<td>E1 North and South</td>
<td>Australia</td>
<td>3,460</td>
<td>0.012</td>
<td>Exploration</td>
</tr>
<tr>
<td>Anna Lake</td>
<td>Canada</td>
<td>1,890</td>
<td>0.059</td>
<td>Exploration</td>
</tr>
<tr>
<td>Radium Ridge</td>
<td>Australia</td>
<td>1,845</td>
<td>0.050</td>
<td>Exploration</td>
</tr>
<tr>
<td>Armchair-Streiberg</td>
<td>Australia</td>
<td>1,540</td>
<td>0.085</td>
<td>Exploration</td>
</tr>
<tr>
<td>Queens Gift</td>
<td>Australia</td>
<td>910</td>
<td>0.024</td>
<td>Exploration</td>
</tr>
</tbody>
</table>
Olympic Dam expansion

3.500 ----> 16.000 tU
12. LIGNITE-COAL deposits

- **12.1. Stratiform**: stratiform syngenetic uniformly disseminated U. Very low (20-150 ppm) to medium (0.05-0.10%) grade mineralization (North Dakota, USA; Nizhne Iliskoye, Kazakhstan) (**30 deposits**)

- **12.2. Mixed stratiform/fracture-controlled**: spotty and irregularly distributed epigenetic mineralization with strong tenor variations (0.02-0.25%) (Freital type, Germany) (**2 deposits**)

*(Dahlkamp 2009)*
## Major lignite-coal deposits

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Country</th>
<th>Resources (t U)</th>
<th>Grade (% U)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Great Plains</td>
<td>USA</td>
<td>5-7,000,000</td>
<td>0.001-0.010</td>
<td>Dormant</td>
</tr>
<tr>
<td>East Ebro Valley</td>
<td>Spain</td>
<td>102,000</td>
<td>Unknown</td>
<td>Dormant</td>
</tr>
<tr>
<td>Springbok Flats</td>
<td>South Africa</td>
<td>81,920</td>
<td>0.042</td>
<td>Exploration</td>
</tr>
<tr>
<td>Nizhne-Iliyskoye</td>
<td>Kazakhstan</td>
<td>60,000</td>
<td>0.098</td>
<td>Dormant</td>
</tr>
<tr>
<td>Koldzhat</td>
<td>Kazakhstan</td>
<td>37,000</td>
<td>0.162</td>
<td>Dormant</td>
</tr>
<tr>
<td>Mulga Rock deposits</td>
<td>Australia</td>
<td>20,780</td>
<td>0.043</td>
<td>Exploration</td>
</tr>
<tr>
<td>Stepnovskoye</td>
<td>Russia</td>
<td>19,100</td>
<td>0.005</td>
<td>Dormant</td>
</tr>
<tr>
<td>Min-Kush Basin</td>
<td>Kyrghystan</td>
<td>7,000-13,000</td>
<td>0.10</td>
<td>Mined-out to dormant</td>
</tr>
<tr>
<td>Luena Basin</td>
<td>Dem. Republic of the Congo</td>
<td>5,000-10,000</td>
<td>0.01-0.05</td>
<td>Dormant</td>
</tr>
<tr>
<td>Serres Basin</td>
<td>Greece</td>
<td>4,000</td>
<td>0.01</td>
<td>Dormant</td>
</tr>
<tr>
<td>Freital-Gittersee</td>
<td>Germany</td>
<td>3,690</td>
<td>0.10</td>
<td>Mined-out</td>
</tr>
</tbody>
</table>
U-bearing coal deposits and occurrences of Middle Asia (Seredin and Finkelman 2008)
Nizhne Iliskoye deposit

60,000 t U, 0.098%

Polymetallic mineralization: Ag, Cd, Co, Ga, Ge, Mo, Ni, Pb, Se, Re, Tl, Zn, Cu, Sc, V, Y, Zr, REE

(Dahlkamp 2009)
U concentrations in US coal basins

U is enriched in ashes produced by coal power plants
• Sparton Resources project in China:

• reprocessing of ashes from coal power plants
• ash-rich coal (20-30%) with 20-315 ppm U (average 65 ppm).
• planned production: 85 t U/year
14. Phosphate deposits

3 sub-types are recognized:

• **14.1. Microchemical phosphorites**
  • *Bedded* phosphorites: North Africa (8-15 Mt U, 100-150 ppm), Phosphoria Formation, USA (7 Mt U, 50-100 ppm)
  • *Land pebble* phosphorites (Florida): 800,000 t, 90-100 ppm

• **14.2. Organic phosphorites (Caspian Sea):** 145,000 t, 0.05-0.10%

• **14.3. Continental phosphate (Bakouma):** 50,000 t, 0.15-0.30%
<table>
<thead>
<tr>
<th>Deposit</th>
<th>Country</th>
<th>Resource (t U)</th>
<th>Grade (% U)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphoria Formation</td>
<td>USA</td>
<td>6-7.000.000</td>
<td>0.006-0.020</td>
<td>Dormant</td>
</tr>
<tr>
<td>Oulad Abdoun Basin</td>
<td>Morocco</td>
<td>3.220.000</td>
<td>0.012</td>
<td>P</td>
</tr>
<tr>
<td>Meskala Basin</td>
<td>Morocco</td>
<td>2.043.000</td>
<td>0.010</td>
<td>P</td>
</tr>
<tr>
<td>Gantour Basin</td>
<td>Morocco</td>
<td>1.206.000</td>
<td>0.015</td>
<td>P</td>
</tr>
<tr>
<td>East Florida</td>
<td>USA</td>
<td>270.000</td>
<td>0.010</td>
<td>Dormant</td>
</tr>
<tr>
<td>Central Florida</td>
<td>USA</td>
<td>225.000</td>
<td>0.010</td>
<td>P</td>
</tr>
<tr>
<td>Northeast Florida</td>
<td>USA</td>
<td>180.000</td>
<td>0.010</td>
<td>Dormant</td>
</tr>
<tr>
<td>North Florida</td>
<td>USA</td>
<td>90.000</td>
<td>0.010</td>
<td>Dormant</td>
</tr>
<tr>
<td>Precaspian Region</td>
<td>Kazakhstan</td>
<td>85.000</td>
<td>0.080</td>
<td>Dormant</td>
</tr>
<tr>
<td>Shidiya Eshidia</td>
<td>Morocco</td>
<td>83.000</td>
<td>0.007</td>
<td>Exploration</td>
</tr>
<tr>
<td>Abu Tartur</td>
<td>Somalia</td>
<td>60.000</td>
<td>0.01-0.05</td>
<td>Dormant</td>
</tr>
<tr>
<td>Ergeninsky Region (12 deposits)</td>
<td>Russian Federation</td>
<td>60.000</td>
<td>0.03-0.10</td>
<td>Dormant</td>
</tr>
</tbody>
</table>
Tethys sea location 20 Ma ago compared to present day (Ragheb 2010)
14.1. Microchemical phosphorite: land-pebble phosphorites from Florida (USA)

800,000 to 1,000,000 t U minimum, 80-120 ppm
Phosphate mining in Florida
Fluoride-contaminated acidic wastewater on top of phosphogypsum stack (Polk County, Florida)
Phosphate ore can contain significant quantities of uranium. (IMC Agrico - New Wales Plant, Polk County, Florida)
Recovery of U from phosphate

- **USGS 2012 resources:** 71,000 Mt (77% in Morocco)
- **IFDC 2010 resources:** 290,000 Mt
- **World 2012 production:** 191 Mt
- **Average grade:** 100 ppm U
- **72% P production devoted to phosphoric acid**
- **84% U recovery**
- **Maximum U production around** 11,000 t U/year
- **Cost of recovery as by-product:** 60-200 US $/kg U
- **Cost of recovery as main product:** 1300-6300 US $/kg U!
“Success for uranium-from-phosphate plant”
(WNA, Sept 2012)

- By-product uranium from the phosphate industry was a major source of uranium production in the 1980s, but the solvent extraction process used at the time had become uneconomic by the 1990s and production ceased.
- A portable demonstration plant has achieved "exceptional results" with uranium recoveries of over 90% during steady state operations.
- Uranium Equities’ PhosEnergy demonstration plant uses a refined ion exchange process to recover uranium from phosphate streams from the production of fertilizers.
- Operating costs are currently estimated to be $25-30/lb $U_3O_8 (65-80/kg U).
- Future planned production in Florida: 2-3.000 t U.
MINJINGU mine - Tanzania

- Biogenic phosphate deposit (guano)
- Annual production: 165,000 t
- Resources: 8-10 Mt
- U grade: 300-1100 ppm (average 410 ppm)
- U resources: 3,000-4,000 t U
15. BLACK SHALES deposits

- Black shale-related uranium mineralization consists of marine organic-rich shale or coal-rich pyritic shale, containing syn-sedimentary disseminated uranium adsorbed onto organic material.

- The size of the mineralization is highly variable from small deposits to very large districts and grades are usually very low to low (20-500 ppm) with notable structural enrichments (0.10-0.20 %) in some deposits.

- 43 black shales deposits/districts are listed in the UDEPO Database.
### Major black shales deposits

<table>
<thead>
<tr>
<th>Deposit/district</th>
<th>Country</th>
<th>Resources (t U)</th>
<th>Grade (% U)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chattanooga Shale</td>
<td>USA</td>
<td>4-5,000,000</td>
<td>0.0057</td>
<td>Dormant</td>
</tr>
<tr>
<td>MMS Vicken</td>
<td>Sweden</td>
<td>403,000</td>
<td>0.0144</td>
<td>Exploration</td>
</tr>
<tr>
<td>Ranstad</td>
<td>Sweden</td>
<td>254,000</td>
<td>0.030</td>
<td>Dormant</td>
</tr>
<tr>
<td>Haggan</td>
<td>Sweden</td>
<td>243,000</td>
<td>0.0137</td>
<td>Exploration</td>
</tr>
<tr>
<td>Schmirchau-Reust</td>
<td>Germany</td>
<td>73 410</td>
<td>0.085</td>
<td>Mined-out</td>
</tr>
<tr>
<td>Auminzatau Ore Field (5 deposits)</td>
<td>Uzbekistan</td>
<td>56,600</td>
<td>0.05</td>
<td>Dormant</td>
</tr>
<tr>
<td>Altyntau Ore Field (5 deposits)</td>
<td>Uzbekistan</td>
<td>44,300</td>
<td>0.02-0.10</td>
<td>Dormant</td>
</tr>
<tr>
<td>Ogcheon Metamorphic Belt (13 deposits)</td>
<td>South Korea</td>
<td>33,350</td>
<td>0.029</td>
<td>Exploration</td>
</tr>
<tr>
<td>Drosen</td>
<td>Germany</td>
<td>29,995</td>
<td>0.085</td>
<td>Mined-out</td>
</tr>
<tr>
<td>Paitzdorf</td>
<td>Germany</td>
<td>28,750</td>
<td>0.085</td>
<td>Mined-out</td>
</tr>
<tr>
<td>Zeitz-Baldenhain</td>
<td>Germany</td>
<td>16,000</td>
<td>0.080</td>
<td>Dormant</td>
</tr>
<tr>
<td>Chanziping</td>
<td>China</td>
<td>10,000</td>
<td>0.20</td>
<td>Exploration</td>
</tr>
</tbody>
</table>
15. 1. Stratiform black shale deposits (Randstad type)

15.2. Stockwork black shale deposits (Ronneburg type)
Scandinavian black shales
Haggan Project
(Aura Energy Ltd)
308,000 t U, 130 ppm
207 ppm Mo, 316 ppm Ni
430 ppm Zn, 1520 ppm V

Marby Project
23,000 t U, 115 ppm
185 ppm Mo, 250 ppm Ni,
353 ppm Zn, 1170 ppm V

MMS Vicken Project
(Continental Precious Metals)
403,000 t U, 145 ppm
V, Ni, Mo
The Talvivaara deposits (Finland)

- **Operator:** Talvivaara Mining Company Plc
- **Two large deposits:** Kuusilampi and Kolmisoppi
- **The Ni-Cu-Co-Zn mineralization is hosted almost entirely by high grade metamorphosed and intensively folded Proterozoic black schists.**
- **Main sulphides are:** pyrrhotite, pyrite, pentlandite, sphalerite and chalcopyrite
The black schist ore at Talvivaara contains uranium in concentrations ranging from 1 to 40 ppm U.

Talvivaara Mining Company has built a processing plant in collaboration with Cameco to recover U from its Zn-Ni-Co-Cu deposits in Finland.

Annual production will be 350 t U/year from ore averaging 16-18 ppm!

Bio heap leaching

Geological resources: Kuusilampi (15,000 t U) and Kolmisoppi (120,000 t U)
Talvivaara: Environmental Disaster in Finland (November 2012)
<table>
<thead>
<tr>
<th>Deposit type-subtype</th>
<th>Resources</th>
<th>Grade (ppm)</th>
<th>UDEPO deposits</th>
<th>World deposits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porphyry copper</td>
<td>100.000 t</td>
<td>10-40</td>
<td>7</td>
<td>691</td>
</tr>
<tr>
<td>Peralcaline complexes</td>
<td>400.000 t</td>
<td>50-250</td>
<td>13</td>
<td>125</td>
</tr>
<tr>
<td>Carbonatites</td>
<td>125.000</td>
<td>30-300</td>
<td>11</td>
<td>848</td>
</tr>
<tr>
<td>IOCG</td>
<td>2.3 Mt</td>
<td>30-250</td>
<td>15</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Coal-lignite</td>
<td>7.4 Mt</td>
<td>1-500</td>
<td>32</td>
<td>1600</td>
</tr>
<tr>
<td>Black shale</td>
<td>1.5 Mt</td>
<td>10-200</td>
<td>43</td>
<td>Several hundreds</td>
</tr>
<tr>
<td>Phosphate</td>
<td>13 Mt</td>
<td>50-150</td>
<td>41</td>
<td>1635</td>
</tr>
<tr>
<td></td>
<td>25 Mt</td>
<td></td>
<td>164</td>
<td>5-6000</td>
</tr>
</tbody>
</table>
CONCLUSIONS (1)

- Very large « unconventional resources »
- Multiple unconventional resources in various geological contexts
- Several projects to extract U as a by-or co-product from porphyry copper, alcaline complexes, carbonatites, IOCG, ashes from coal-lignite, phosphorites, black shales, monazite placers, ........
- Sea water if desperate !!
CONCLUSIONS (2)

- Economics driven by:
  - Presence of other metals: By-product co-product
  - Cost of production,
  - Improvement of extraction processes,
  - Environmental constraints: radioactive element associated to Th
  - Tensions on some metals (REE)
Near future production of uranium in unconventional resources

- **Most likely production (per year):**
  - Phosphates: $5,000-10,000$ t
  - Black shale: $350$ t (Finland), $1,000-2,000$ t (Sweden)
  - Porphyry copper: $85$ t
  - Alcaline complexes: $1,000$ t (Greenland)
  - Carbonatites: ?
  - Lignite-coal ashes: $85$ t
  - SA tailings: $500-1,000$ t
  - Monazite: ? (dependant on Th production)
THANK YOU