From Geology to deposits
Critical Raw Materials

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Chair of EGS Mineral Resources Expert Group

RAW MATERIALS UNIVERSITY DAY, Athens, 19-06-2014
# Non-Energy Mineral Raw Materials

<table>
<thead>
<tr>
<th>Construction materials</th>
<th>Industrial minerals</th>
<th>Metallic minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates (crushed rock, sand &amp; gravel)</td>
<td>Barites</td>
<td>Bauxite</td>
</tr>
<tr>
<td>Ceramic tiles</td>
<td>Bentonite</td>
<td>Cadmium</td>
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<tr>
<td>Brick clays</td>
<td>Feldspar</td>
<td>Chromium</td>
</tr>
<tr>
<td>Pozzolan</td>
<td>Quartz</td>
<td>Copper</td>
</tr>
<tr>
<td>Gypsum</td>
<td>Kaolin</td>
<td>Lead (galena)</td>
</tr>
<tr>
<td>Stones (e.g. granite, marble, slate)</td>
<td>Magnesite</td>
<td>Zinc (sphalerite)</td>
</tr>
<tr>
<td></td>
<td>Perlite</td>
<td>Gold</td>
</tr>
<tr>
<td></td>
<td>Potash</td>
<td>Silver</td>
</tr>
<tr>
<td></td>
<td>Talc</td>
<td>Iron ore</td>
</tr>
<tr>
<td></td>
<td>Zeolites</td>
<td>Manganese</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mercury</td>
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<tr>
<td></td>
<td></td>
<td>Nickel</td>
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<tr>
<td></td>
<td></td>
<td>Tungsten</td>
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<tr>
<td></td>
<td></td>
<td>Tungsten</td>
</tr>
<tr>
<td></td>
<td></td>
<td>REE, PGM</td>
</tr>
</tbody>
</table>
Minerals make Geology become Economic

- there is a public and political awareness that minerals are raw materials vital to social well being and to any economy
- minerals, like other natural resources are of high strategic importance as their availability conditions influence the viability of a wide-range of value-adding downstream economic activities
Re-shaping the mineral industry

The growth of industrial economies, like for instance the Chinese and the Indian, led to a tremendous upward spiral of mineral Consumption. The demand is became so great that even low mineral concentrations and mining related waste can reasonably be considered ore deposits. This means the global mineral industry needs to be reshaped.

Doubling of used extraction from 2000 to 2030

Waste potential grows
MRM* value chain challenges

• enhance the accessibility to existing data/knowledge base on mineral resources (databases, statistics, prospectivity) to make an efficient tool in achieving high potential exploration areas and new mineral resources taking also into account competing land-uses

• exploration technologies (3D/4D) to locate deep-seated deposits; traditional/common metals are always needed but there is another challenge, in terms of getting much deeper than before

• mineral processing (environmentally friendly technologies, low grade deposits, bio-leaching etc)

• new mineral resources (e.g. CRM); a critical volume is needed to make the production of metals economically feasible

• both primary and secondary resources, in terms of re-use of by-products and mine wastes/tailings should be explored, evaluated and exploited

• waste management issues

• material technologies (mineral based nano-products e.g. ProMine project); with new metals and minerals a challenge is to find enough innovations for their use, and there we need continuous research

*MRM-Mineral Raw Materials
Documentation and spatial databases of reserves/deposit areas is of importance for influencing on the future land use!

To an increasing extent, extraction of mineral resources must compete with other interests

enhance the accessibility to existing data/knowledge base on mineral resources (databases, statistics, prospectivity) to make an efficient tool in achieving high potential exploration areas and new mineral resources taking also into account competing land-uses
Exploration focus

• Generating successful new projects is mainly based on three factors
  ▪ geologist explores where no one had explored before
  ▪ geologist identifies new mineralization features overlooked before
  ▪ geologist explores in areas of known mineralization based on geological knowledge gained from previous prospecting and mining activities
Exploration stages

- ideas based on conceptual studies e.g. regional metallogenetic features
- target generation and evaluation based on available information reviews and new exploration surveys carried out
- exploration drilling aimed to achieve ore intersections
- resource evaluation/definition drilling aimed to provide economic information in terms of grades, tonnes and mining processing/metallurgical characteristics
- feasibility study to assess all factors (geological, mining, environmental, political, economic) relevant to the decision to mine

The smart exploration geologist will generate the best quality prospects and test them in the most efficient and cost effective manner.
Conceptual genetic models guiding exploration

Adding resource potential and growth value

Challenging porphyry Cu-Au styles at deeper levels
Hellenic-Balkan Mineral Belt
Exploration methodology

• **geological mapping** is fundamental skill for any exploration geologist to choose the best scale, to be able to measure the structures and to evaluate remote sensed data, focusing more on evaluating the regional mineral potential and how to utilize the information more efficiently e.g. meeting the demand for new high-tech metals and the continuous need for base metals

• **geophysical and geochemical data** should be integrated and co-evaluated along with geological mapping

• **geophysical methods** based on magnetic, gravity, radiometric, electromagnetic, electric measurements interpreted using advanced data modelling e.g. 3D

• **geophysical methods penetrating** and providing information on structures at depths of several kms, reflection sounding, are expensive and they should be used in regions with well-known ore potential

• **geochemical methods** - stream sediments, heavy mineral concentrates, rock, weathered zones

• **drilling techniques properly selected**, and abilities to execute geological logging, geochemical sampling and structural analysis

Geophysical and geochemical surveys aim at measuring anomalous features of rocks that directly reflect and have close spatial relationships to economic mineralization
3D modeling makes dynamic tool

- 3D modeling in combination to existing data and in connection with ore exploration applications it is better to consider more than one geological model. As ore genetic understanding, theories and interpretations change with time, geological models have to be updated accordingly.
- Suggestions for different 3D models down to depths of about 3 km.
- 3D exploration enable geologists to locate new mineral deposits and secure supplies for generations to come
More effective exploration

- better understand ore genesis and direct exploration at deeper (down to 150-4000 meters), unexploited levels of the bedrock

- 3D/4D modeling to locate deep-seated deposits using highly efficient and cost-effective exploration technologies, such as 3D geophysical.

- new geo-models of mineral deposits interpreting in a useful form the data obtained from integrated geological, geophysical, geochemical and other methods to facilitate finding of new mineral deposits on the continent and in the sea-bed.
3D modeled ore structures

- better understand ore genesis and direct exploration at deeper, unexploited levels of the bedrock
- What was thought to be two ore bodies belong to the same and only one displaced by a late stage NE striking fault up to a >100m vertical descent
Minerals Raw Materials in Europe
(based on total number of 13,686 records)

Anthropogenic concentrations (mine wastes)
<table>
<thead>
<tr>
<th>Number</th>
<th>Deposit types</th>
<th>Commodity Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alkaline &amp; Peralkaline intrusions</td>
<td>Nb, REE, P, (Ta, Zr, Sc, F, U, Fe)</td>
</tr>
<tr>
<td>2</td>
<td>Epithermal</td>
<td>Au, Ag, Sb, Hg, Te, Cu, In</td>
</tr>
<tr>
<td>3</td>
<td>Igneous Felsic</td>
<td>Sn, W, Ta, Nb, (Mo, Li, Be, B, In, F)</td>
</tr>
<tr>
<td>4</td>
<td>Igneous Intermediate</td>
<td>Cu, Mo, Au, (Re)</td>
</tr>
<tr>
<td>5</td>
<td>Igneous Replacement</td>
<td>Fe, W, Pb, Zn, Cu, Au</td>
</tr>
<tr>
<td>6</td>
<td>IOCG</td>
<td>Fe, Cu, Au, (P, REE, U, Co)</td>
</tr>
<tr>
<td>7</td>
<td>Mafic intrusion</td>
<td>Fe, Ti, V</td>
</tr>
<tr>
<td>8</td>
<td>Mafic or Ultramafic</td>
<td>Ni, Cr, Cu, PGE, (Co, Bi, U, Ag)</td>
</tr>
<tr>
<td>9</td>
<td>Orogenic Gold</td>
<td>Au, (Ag, As, W, Cu, Sb, Bi)</td>
</tr>
<tr>
<td>10</td>
<td>Pegmatites</td>
<td>Nb, Ta, Sn, Li, Be, (U, REE)</td>
</tr>
<tr>
<td>11</td>
<td>Carbonate-hosted deposits</td>
<td>Zn, Pb, Ag, Ba</td>
</tr>
<tr>
<td>12</td>
<td>Sandstone- and shale-hosted deposits</td>
<td>Cu, U, Pb, (Ni, Co, Zn, V, PGE, Re)</td>
</tr>
<tr>
<td>13</td>
<td>Sedimentary deposits</td>
<td>Fe, Mn, Ba, K, Na, Sr</td>
</tr>
<tr>
<td>14</td>
<td>VMS</td>
<td>Cu, Zn, Pb, (Ag, Au, Te, Sn, In)</td>
</tr>
<tr>
<td>15</td>
<td>Residual deposits</td>
<td>Fe, Al, Ni, Cu, (Mn, Au, P, REE)</td>
</tr>
<tr>
<td>16</td>
<td>Base metals veins</td>
<td>Pb, Zn, Cu, U, (Ba, F)</td>
</tr>
</tbody>
</table>
Mineral deposits and exploration potential for associated commodities

- Epithermal
- Igneous Intermediate

EuroGeoSurveys - The Geological Surveys of Europe
Commodity predictivity mapping

- Copper (Cu)
- Antimony (Sb)
Predictive map for indium

Predictive map for gallium
Rare Earth Elements (REE)

Periodic table highlighting the Light Rare Earth Elements, Heavy Rare Earth Elements and (Y, Sc)

Forecast average annual demand growth to 2020 for critical raw materials (% per year)

Source: Roskill Information Services (September 2013) and other data in the extended profiles

End-of-life recycling rates for REE

EuroGeoSurveys - The Geological Surveys of Europe
Named deposits are subjects of active exploration.
Europe needs to focus on more effective exploration of critical MRM including REE

It all starts with understanding where mineral deposits occur, how they are formed, and how they can be sustainably extracted!

and

Innovation is needed in the whole value chain as many REE-based critical products are available as by-products of primary mined mineral resources.

Both primary and secondary resources, in terms of re-use of by-products and mine wastes/tailings should be explored, evaluated and exploited.
More efficient REE exploration

• Mineral exploration is the only way to ensure secure and sustainable supply of raw materials. Even in the case of 100% recycling efficiency there will never be able to meet the increasing supply demand for REE.

• There is today a need to understand better the REE ore forming processes of any of the primary and secondary deposit types, to be able developing the right exploration guides in order to apply them to respective European geological settings and make the discoveries of new ore deposits possible.

• Carbonatites and alkaline rocks may be of high priority but other types such as the granitic pegmatite, IOA & IOCG ones need to be explored more efficiently. Examples of required end products might be,
  ▪ Distribution of REE (total, HREE, LREE and individual elements) occurrences in Europe (Map)
  ▪ Reserves and resources in Europe and in individual countries (Reports, Excel spreadsheets, maps)
Belts of REE exploration potential?

Rifts

• What can we learn from older rifts that are exposed in Scandinavia and Greenland that we can use to understand Cenozoic rifts
  • E.g. Turkey – carbonatitic/alkali volcanism along Cenozoic rifts
  • How are these focused? Along structures? – can we identify these structures? How – regional geophysics?
• Can this data be used to focus exploration targeting?
• Can we create an “exploration matrix” that we can deliver on eurare.eu?
Agricultural soil geochemistry
guiding mineral exploration

EuroGeoSurveys GEMAS project
(http://gemas.geolba.ac.at/)

Ore deposits: 1, 3, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 21, 24, 25, 26, 27, 20, 31, 33, 34, 35, 36, 37, 38, 39, 42, 44, 47, 53
Geology: 5, 20, 28, 29, 40, 41, 43, 46, 48
Cities: 2, 10, 11, 23, 49
Contamination: 6, 17, 32, 50, 51, 52
Unexplained: 4, 22, 45
Minerals exploration tools (?)
Source: GEMAS project (http://gemas.geolba.ac.at/)

Geophysical exploration  Geochemical exploration
Concluding remarks

- Mineral resources are drivers of development and growth in many countries, but need also to consider,
  - sustainable development and use of mineral resources
  - added value industries located close to RM
  - R&D problem analysis, high performance, capacity building, software solutions
  - Enhanced exploration and geological maps of mineral resources e.g. Critical Mineral Raw Materials
  - high level of mineral resources expertise
  - closure of mine and related environmental aspects
  - mining operations as the core of regional development creating economic multiplying effects and taking care of the environmental responsibilities
  - geological basic and expertise on mineral resources should be connected with socio-economic and political expertise
Thank you for your attention

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Exploitation potential

• Based on the geological and compositional characteristics of the major REE mineralisation types in Europe and Greenland, it is obvious there is an exploration potential and high prospective interest for
  ▪ primary HREE-enriched deposits in Greenland, the Nordic countries and the British islands, and
  ▪ secondary LREE-enriched deposits in mainly NW France, Greece and west Balkans.

• Following the global developments and their HREE-enriched and U-Th deficient grades, the primary REE deposits have a clear exploitation preference, and in this respect
  ▪ the carbonatites and alkaline rocks geotectonic settings and metallogenetic belts are of high exploration potential and priority.

• However, the potential of secondary REE deposit types will need to be taken into account whenever there is an issue on estimating Europe’s REE mineral resources.
The GEMAS periodic table
of mineralisation & mineral deposits in Europe

Aimou Demetriades, Clemens Reinsch, Manfred Bitter & The GEMAS Project Team

http://gemas.geofba.ac.at/
“Hot” metallic commodities for Greece
Potential REE mineral belts

HREE enrichment trends
LREE enrichment trends

REE occurrences in Europe
- Alkaline igneous rock
- Carbonatite
- Hydrothermal
- Iron REE deposit
- Laterite/Bauxite
- Pegmatite/Granite
- Phosphorite
- Placer
- Canary islands

EuroGeoSurveys - The Geological Surveys of Europe