



RESSOURCES 21: Strategic metal resources for the 21st century



UNIVERSITÉ
DE LORRAINE



Strategic metal resources for the 21st century: beneficiation of low grade ores and fine particle separations

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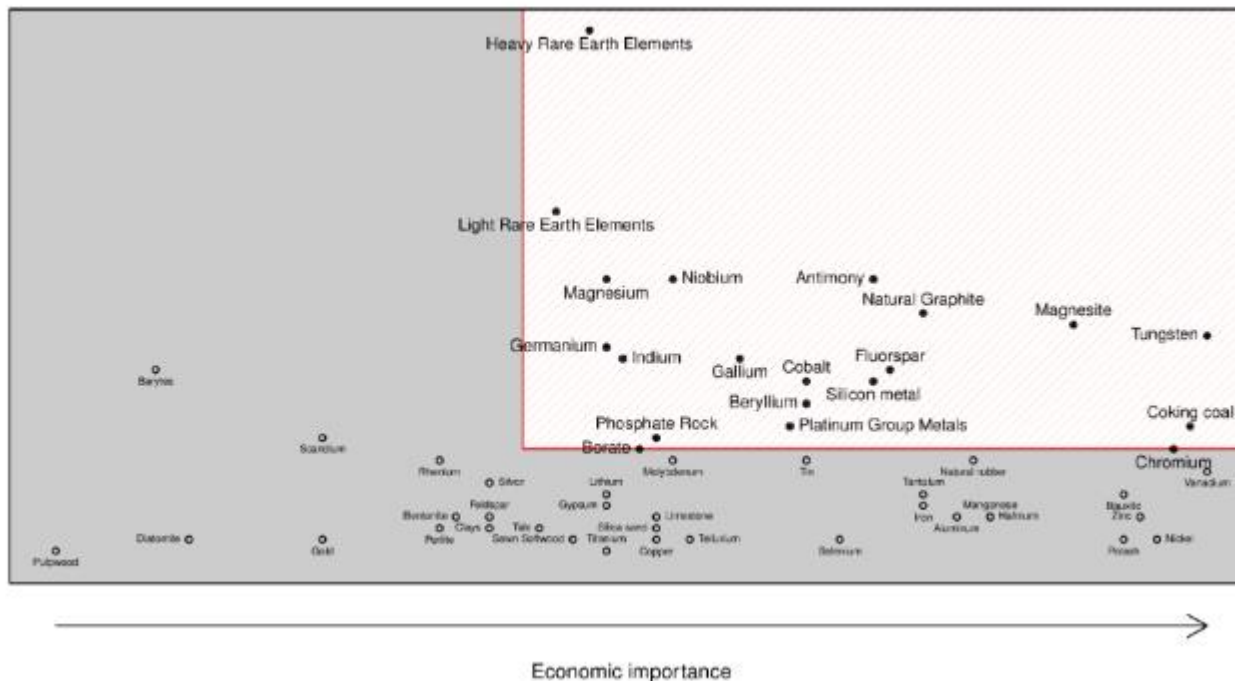


- Natural resources underpin the global economy and our quality of life. Energy Transition: Photovoltaic sector, Eolian energy, Clean cars
- If current trends continue, by 2050, i) the world population will have grown by 30%; ii) until 2050, as much metal will have to be produced as from the origin of humanity.



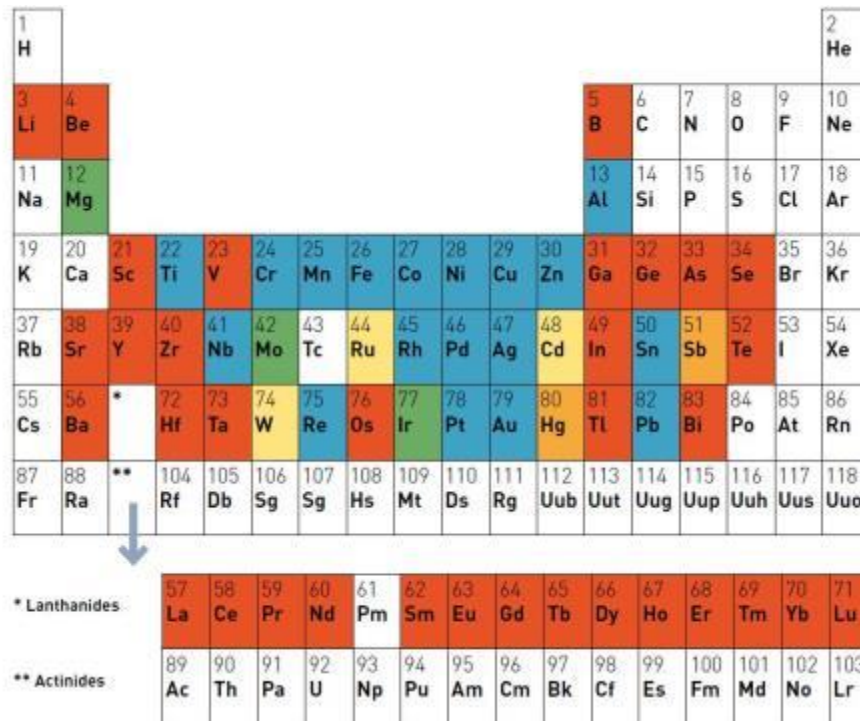
- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite
- Indium
- Magnesium
- Niobium
- PGMs (Platinum Group Metals)
- Rare earths
- Tantalum
- Tungsten
- + Borates
- + Chromium
- + Coaking coal
- + Fluorspar
- + ithium
- + Phosphate Rock
- + Silicon Metal

(2014)



Securing the supply of raw materials is a major issue for industries

- The EU is dependent on the importation of most metals, as its domestic production is less than 5% of the world production.
- Mining is a key approach to tap Europe's unexploited minerals at a depth of 500–1,500 metres, including critical raw materials, with estimated value of about €100 billion. Europe also host several world class mining equipment providers.
- Recycling is another key way for reducing European demand for non-EU raw materials.



There is potential to extract sizeable quantities of raw materials from end-of-life industrial and consumer goods in Europe such as the rare earths found in computers, platinum found in car exhausts.

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- Recycling is another key way for reducing European demand for non-EU raw materials.
- Much of the material inputs used by European industry comes from secondary, or recycled, sources. Urban mine supplies are a considerable and valuable source of raw materials.
- **Innovation and research** is necessary improve resource efficiency (*A resource-efficient Europe is one of seven flagship initiatives of the Europe 2020 strategy*).
- Not only a matter of resource, but also energy consumption, environmental footprint and with economic, social and geopolitical issues
- *Earth, environmental, social sciences, chemistry, geophysics, biology, engineering, industrial processes, politics, lawyers, etc...*



>>> **New orebodies and mines ?**

Understand natural concentration processes

Where are the resources for the future?
New prospection tools

**Life cycle of strategic elements
(REE, Ge, In, Nb, Ta,)**

Numerous knowledge gaps

Improve clean and efficient extraction

How to minimize energy and mass fluxes ?

Evaluate the environmental impact and risks

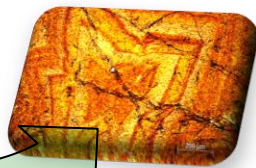
Preserve the environment
Clean contaminated soils

Source rock

**Transport
(fluid, magma)**



**Concentration
(ores)**



$\times 10^2$ to 10^5

**Exploitation (mine)
Extraction (mill)
Separation (plant)**



**Concentrate
Metal salt or alloy**

**Dispersion
transport
(waters)
Geo-availability**

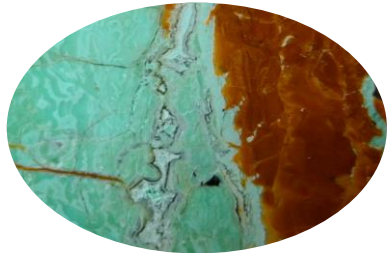
**Bio-concentration
Bio-availability
Eco-toxicity**



Where, Why, How ?
Understanding the process of
natural enrichment
In laterites (Fe-oxides and
silicates)

**Ex: Life cycle of Ni
and related chemical elements (Co, Sc, Mn)**

**Case of laterites on ultrabasites
(New Caledonia, Philippines)**



Ore processing of Ni-ores:
the fine grained ore problem



Extraction from soils
and plants:
Phytomining and
agromining of Ni



New Caledonia :

- the only French production (except Au in French Guiana)
- 10% of the world production of Ni
- French mining operators: ERAMET (SLN) and small producers

Impact of Ni on
biosphere

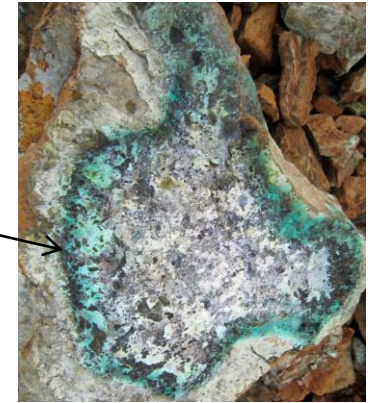
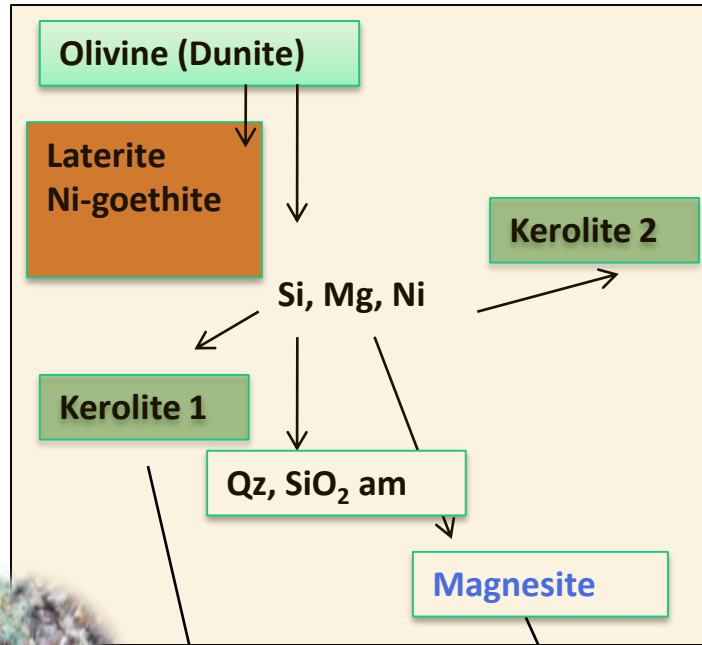
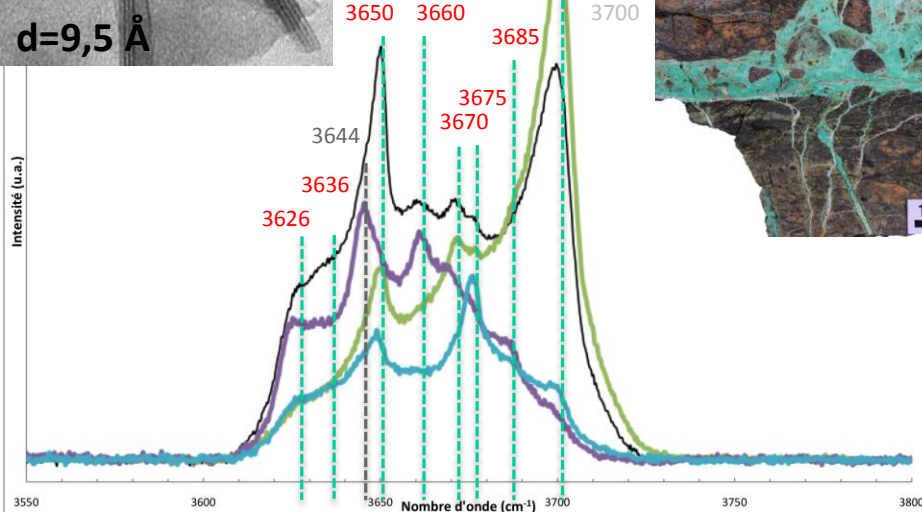
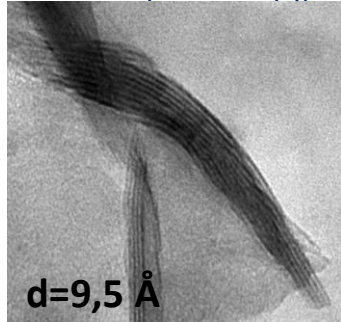


Understanding the process of natural enrichment: Life cycle of Ni and related elements (Co, Sc, Mn)

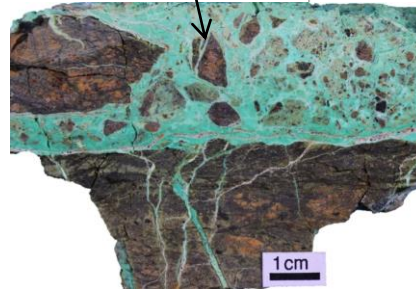
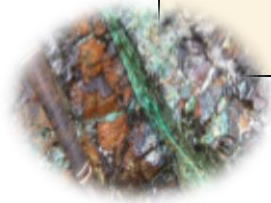
Relationships laterite- tectonic activity - water movements

A new model for the **kerolite** solid solution (Raman, TEM, QEMA)

J. Raman Spectroscopy, 2015



A new model of Ni redistribution as Ni silicate
Min. Dep. 2015

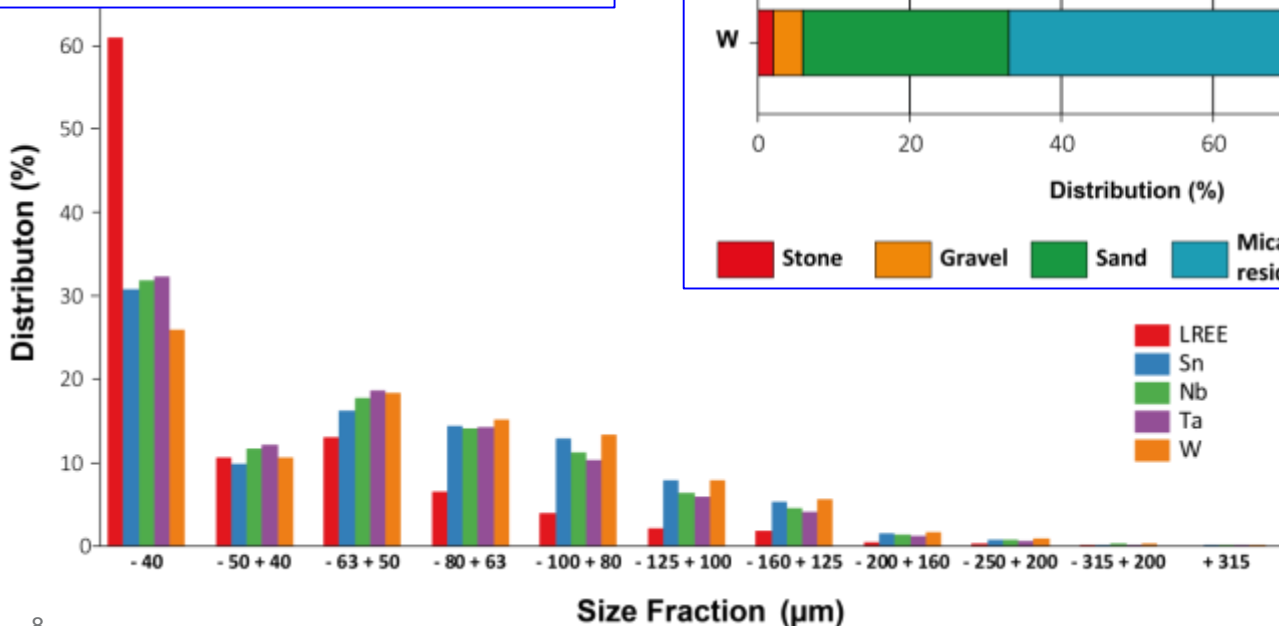


The fate of magnesium in the vicinity of Ni rich laterites
Syntectonic magnesite
Geology 2013

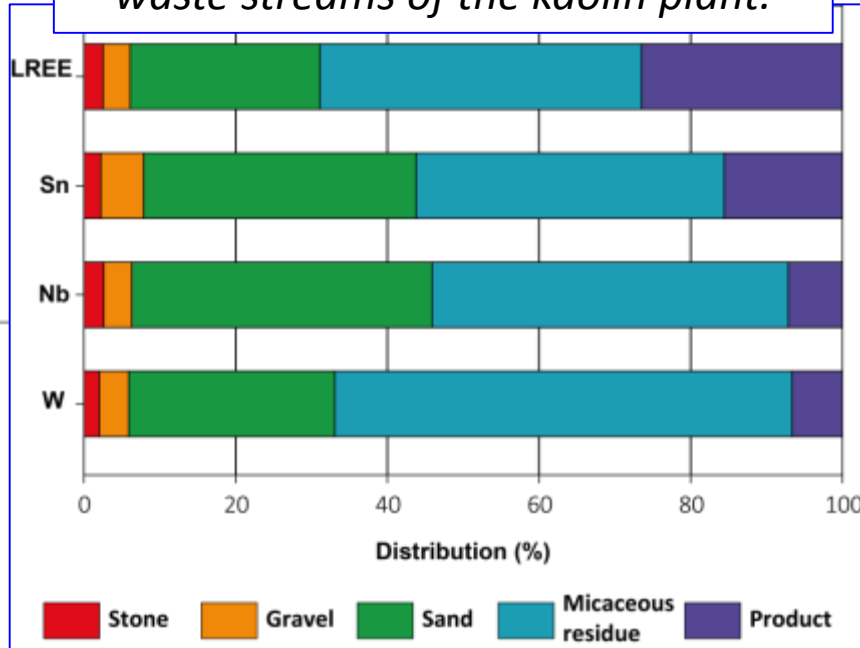
Magnesite formation after Specific serpentine polymorphs
Contrib. Mineral. Petrol. 2013

IDENTIFICATION AND CHARACTERISATION OF THE CRM BEARING MINERALS IN THE ALTERED GRANITE (*clay minerals*)

- Most of the LREE are concentrated in the -40 μm size fraction (61% LREE).



Distribution of the metals in the waste streams of the kaolin plant.

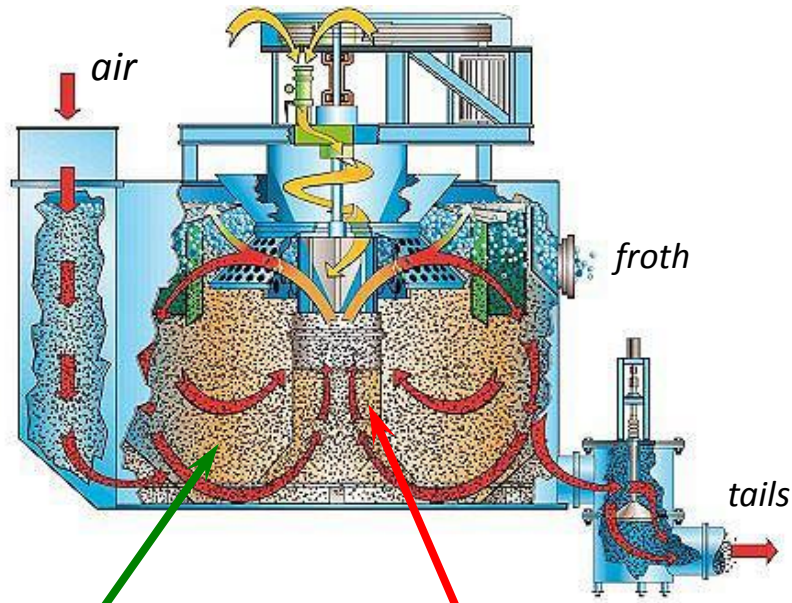


Size distribution of the metals within the micaceous residue.

Conventional flotation cells vs Reactor-separator

Conventional flotation cell

All flotation subprocesses at the same averaged hydrodynamic conditions



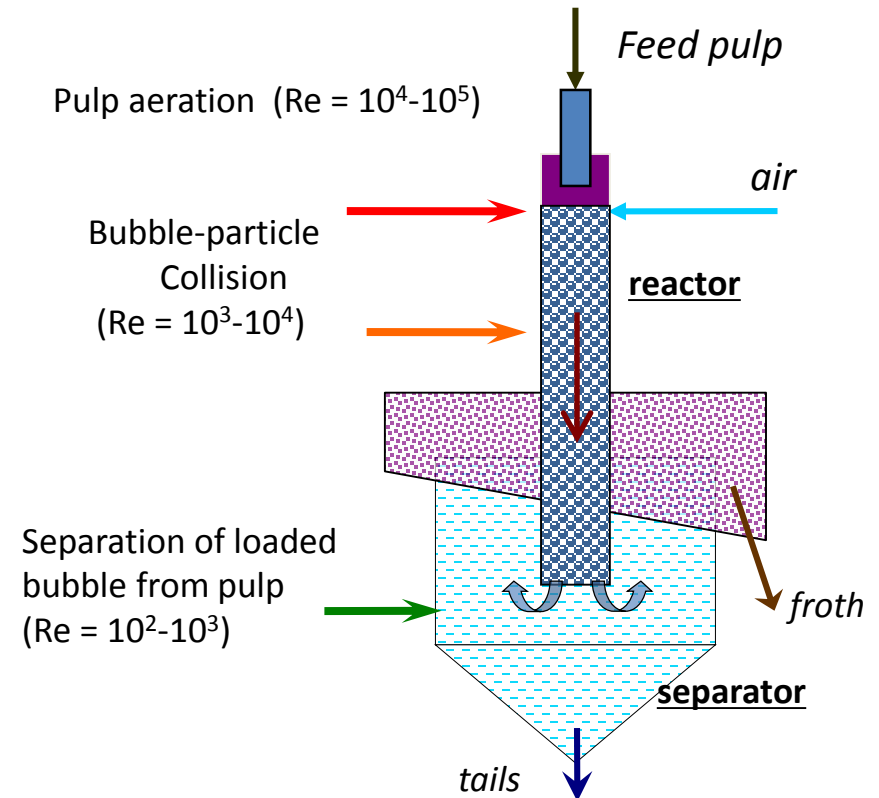
Separation of loaded bubble from pulp

Bubble-particle Collision

While designing impeller blocks the main aim was to reach optimal hydrodynamic conditions for particle mixing and air dispersion.

Reactor-separator

special zone for each subprocesses



Separation of loaded bubble from pulp
(Re = 10²-10³)

Pulp aeration (Re = 10⁴-10⁵)

Bubble-particle Collision
(Re = 10³-10⁴)

Contact dependent flotation machine. Optimal hydrodynamic conditions to reach maximum efficiency in each step

Low grade and Fine size distribution

Tailings from a phosphate ore processing plant (apatite, calcite, dolomite, quartz, mica and other Fe-bearing silicates).

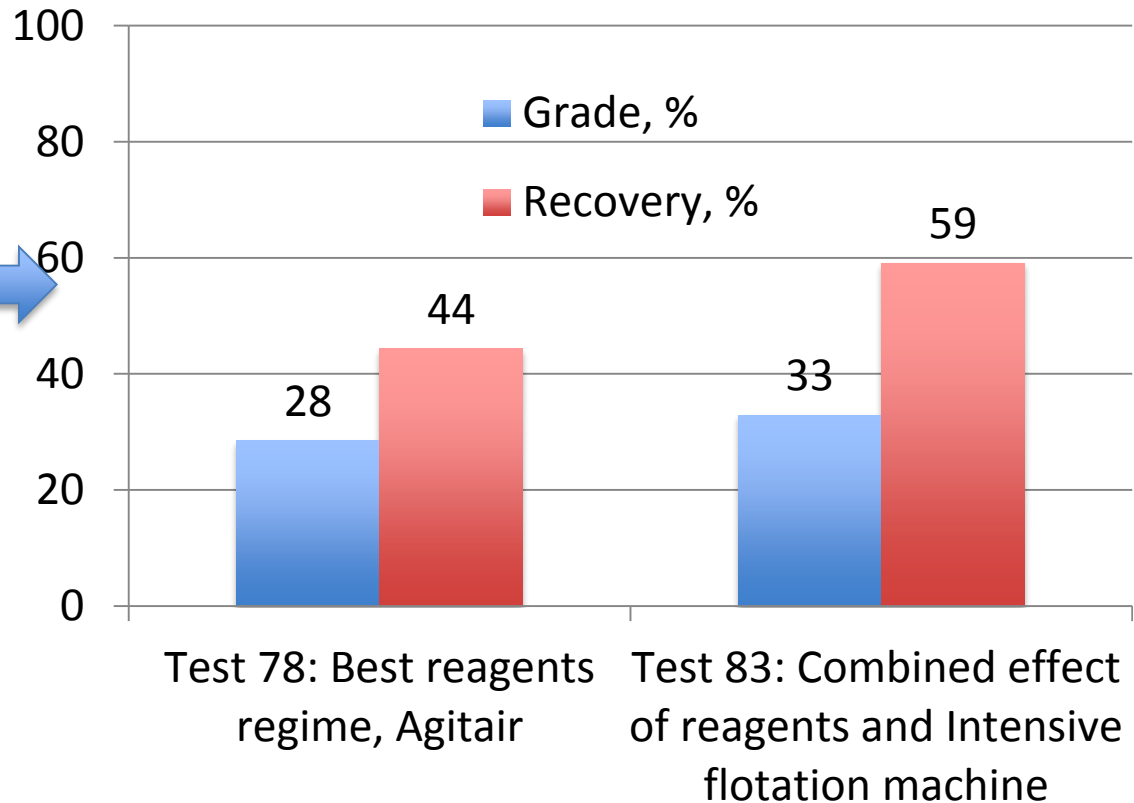
Minerals are altered. REE are enclosed in the apatite

Chemical composition

FeO	3.92 %
P ₂ O ₅	8.95 %
CaO	25.92

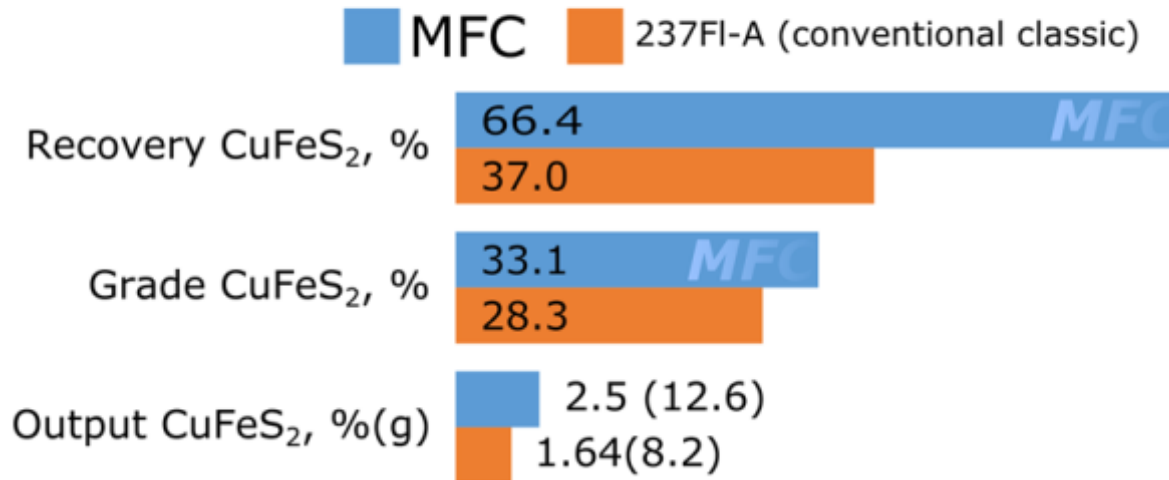
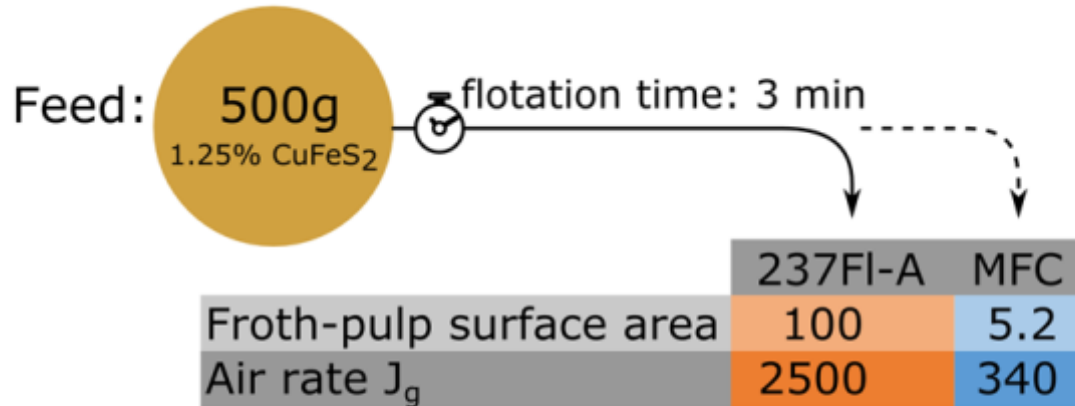
95 % below 63 μm

46.5 below 10 μm



Cu bearing old tailings: Increase of the selectivity

Fine size fraction from an Old sulphide tailings resulting from gravity concentration with 1.25 % of CuFeS_2



Increase of the recovery and grade in the concentrate means the increased efficiency of flotation equipment with better selectivity of separation

- Liège
- Trier
- Kaiserslautern
- Saarbrücken
- Metz
- Nancy



INTER
MAT



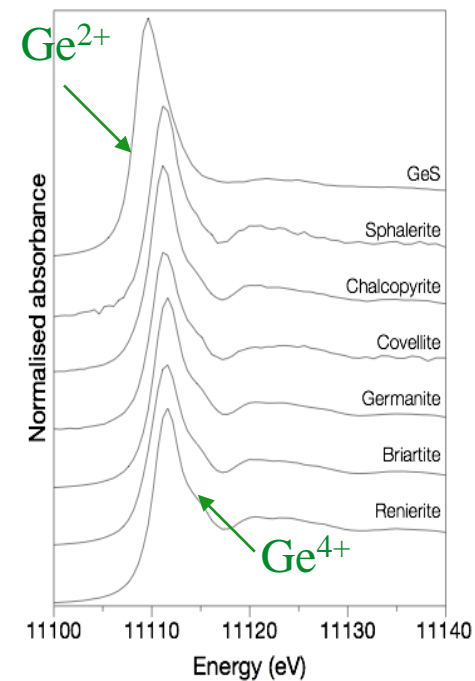
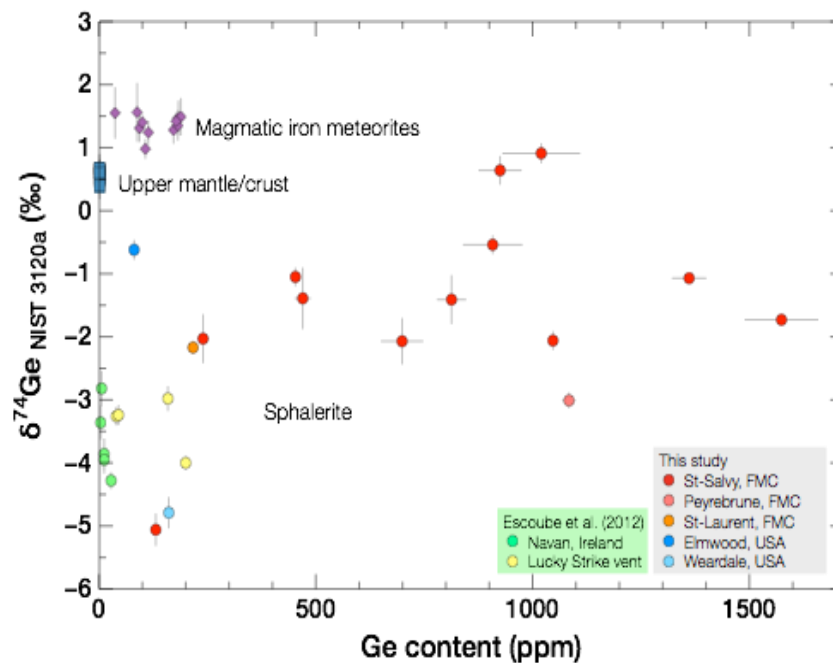
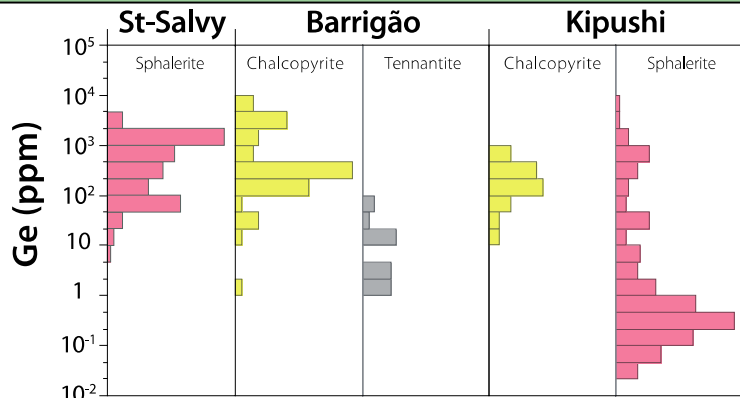
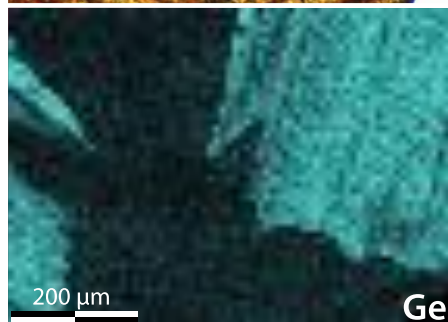
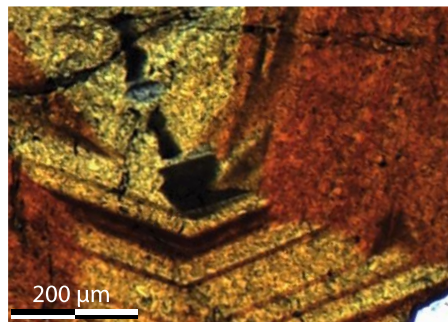
June 2015

Understanding the process of metal transfer at the local scale and incorporation of strategic elements as traces in minerals

In situ techniques coupled to geochemistry on micro-samples

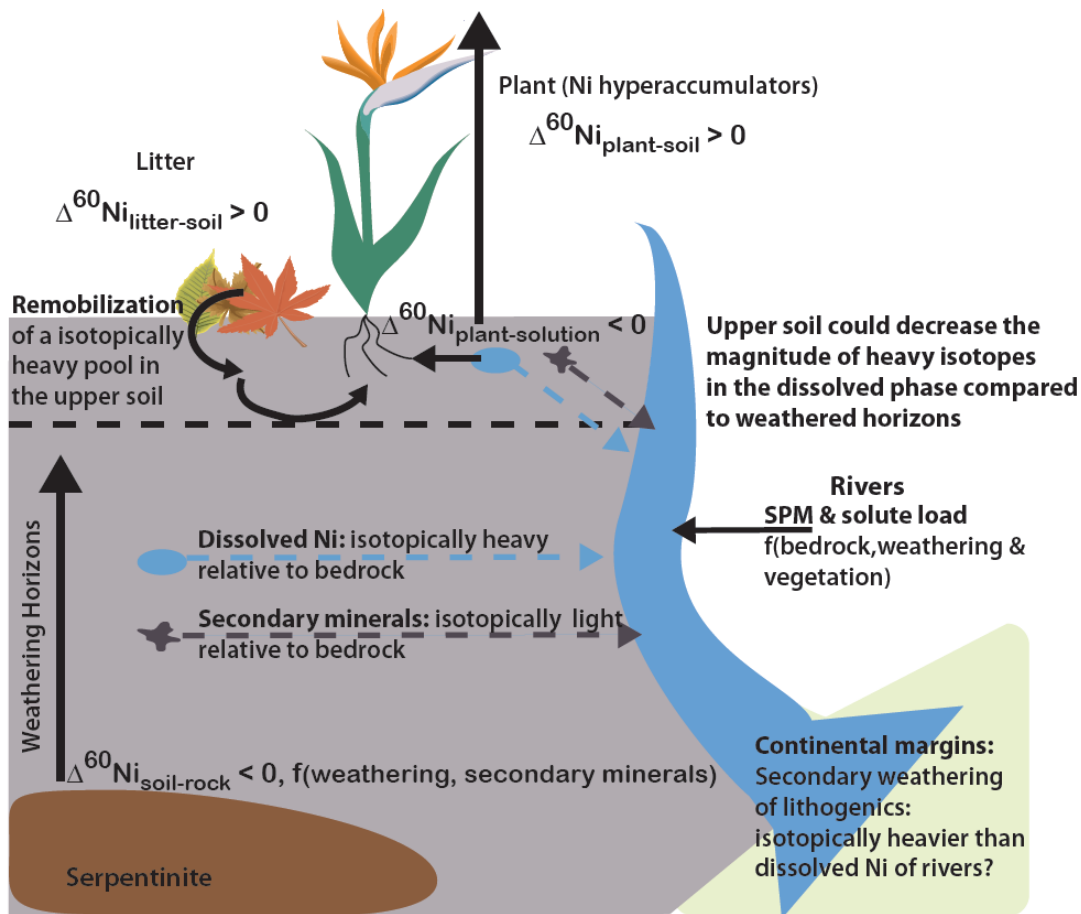
Coupling on minerals

- LA-ICP-MS (conc. down to 0.1 ppm)
- Ion probe (isotopes)
- MC-ICP-MS (isotopes on trace elements)
- Synchrotron (EXAFS)-speciation, valence



Belissant et al., 2014
Geoch. Cosmochim Acta

Belissant et al., 2015
GCA in review



Phytomining, agromining

From soil to biomass
 From biomass to Ni salt



(Ni-hydr. Amm. Sulfate)
 T. Deng, PhD thesis
 >> patent

Estrade et al. 2015 *New methodology of Ni isotope measuring by double spike- Ni isotopic fractionation from soil to plant.* *EPSL*

Inventory of hyperaccumulative plants,
 Bani et al , 2013, *Env. Mon. Ass*, 2014,

Van der Ent, 2015 *Agromining* , *Env Sci Tech*
 Deng et al., 2014, *Ni and Zn fractionation*, *Env Sci Tech*