COLLÈGE DE FRANCE
1530

CHAIRE DÉVELOPPEMENT DURABLE – ENVIRONNEMENT, ÉNERGIE ET SOCIÉTÉ

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Pr Georges Calas

Thursday January 22, 2015

Mineral Resources, the Basis of Our Industrial Civilization: Major Challenges for the 21st Century

Chaire créée avec le soutien de TOTAL


Tiébaghi nickel mine, New-Calédonia
© SLN, Nouméa

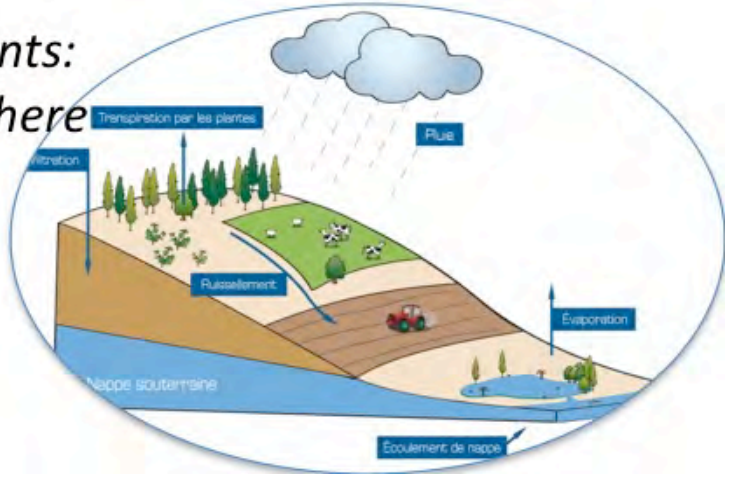
Natural resources

Mineral resources

Energetic resources

Biodiversity

Physical environments: water, soils, atmosphere



Food resources

Mineral resources

Between diamond and granite…

… prices vary as much as 7-9 orders of magnitude

Mineral resources

Ores for rare and strategic metals

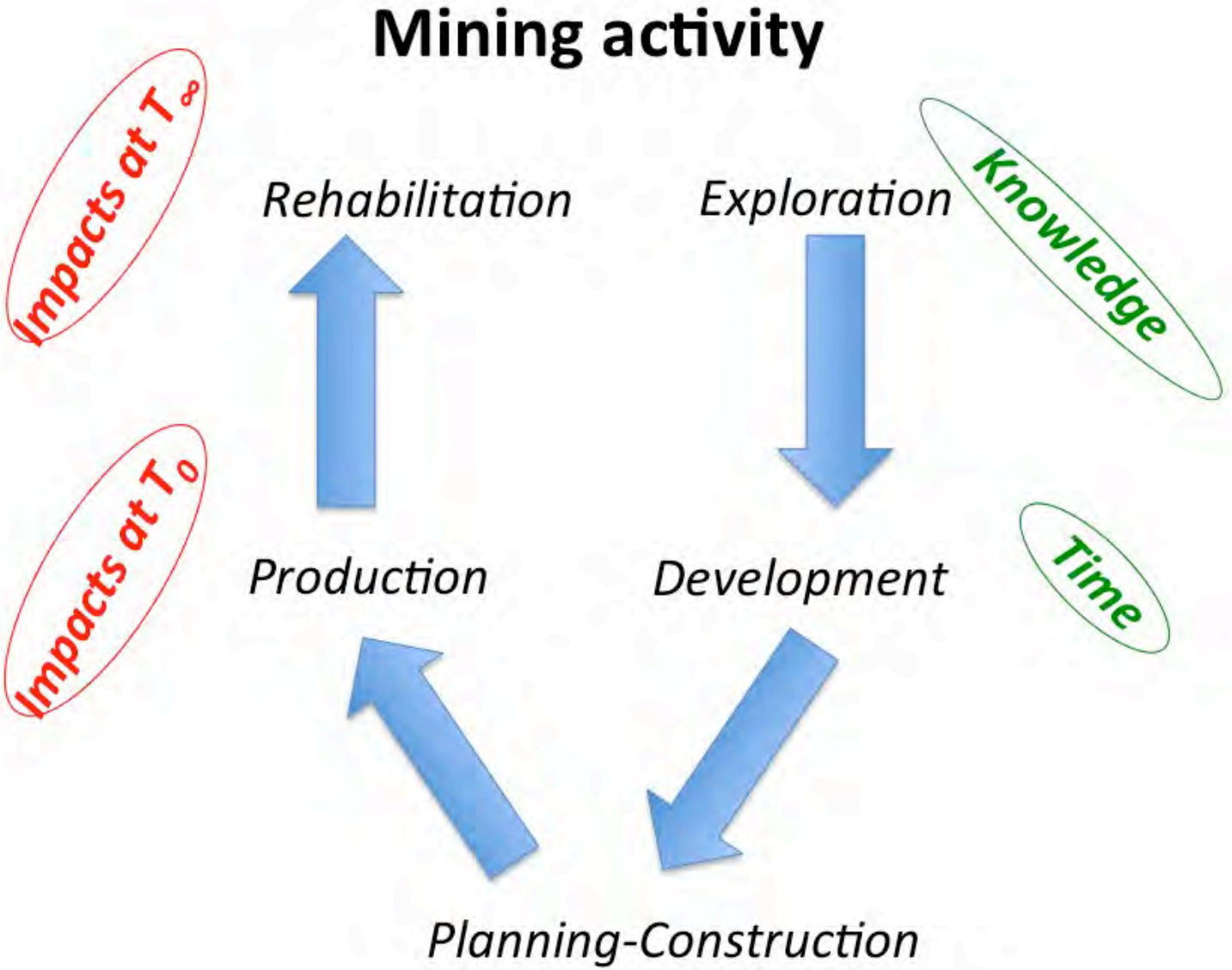
Building materials

Industrial minerals (paper, plastics…)

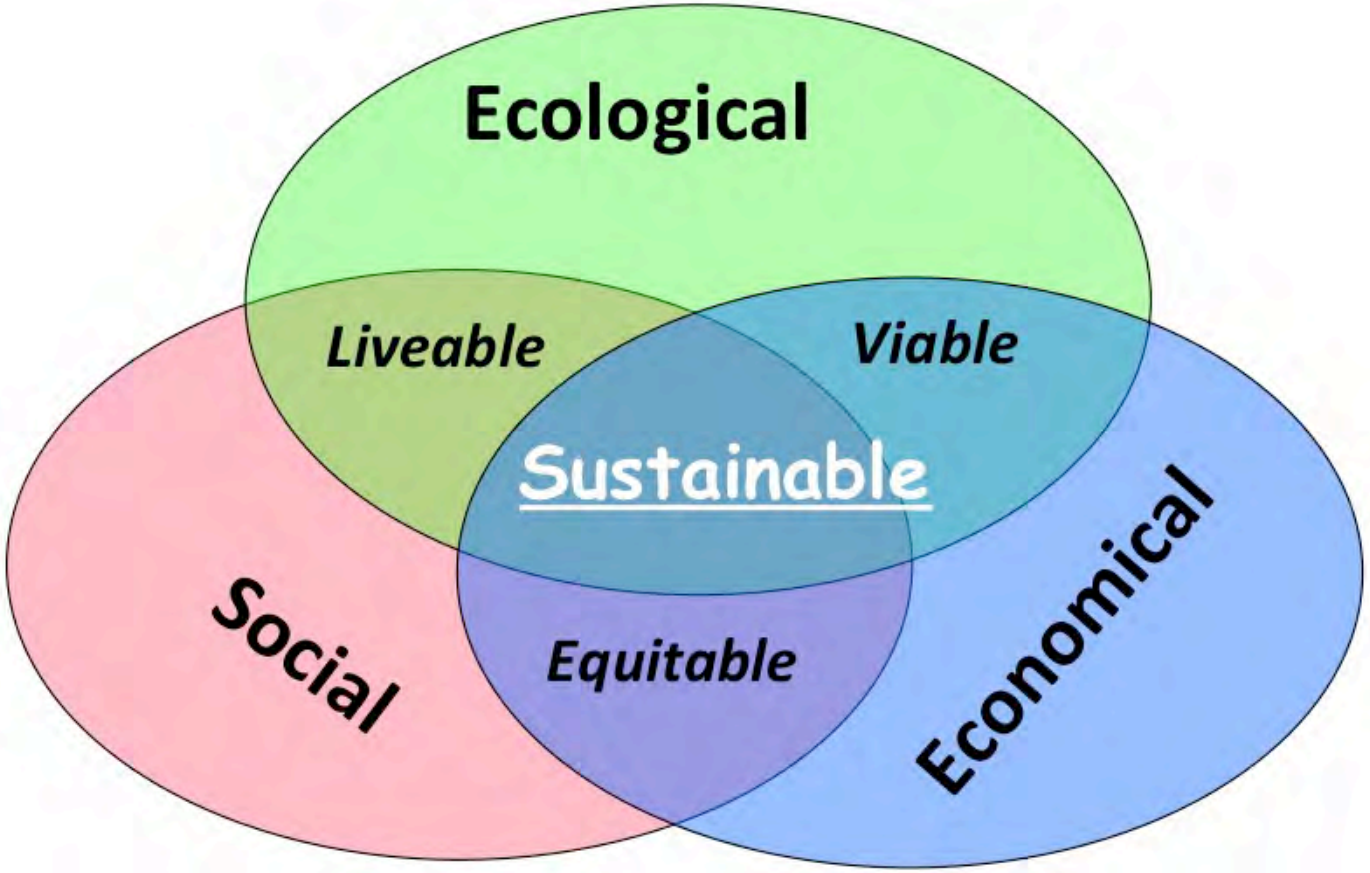
Raw materials (glasses, ceramics, cement)

Ores for base metals

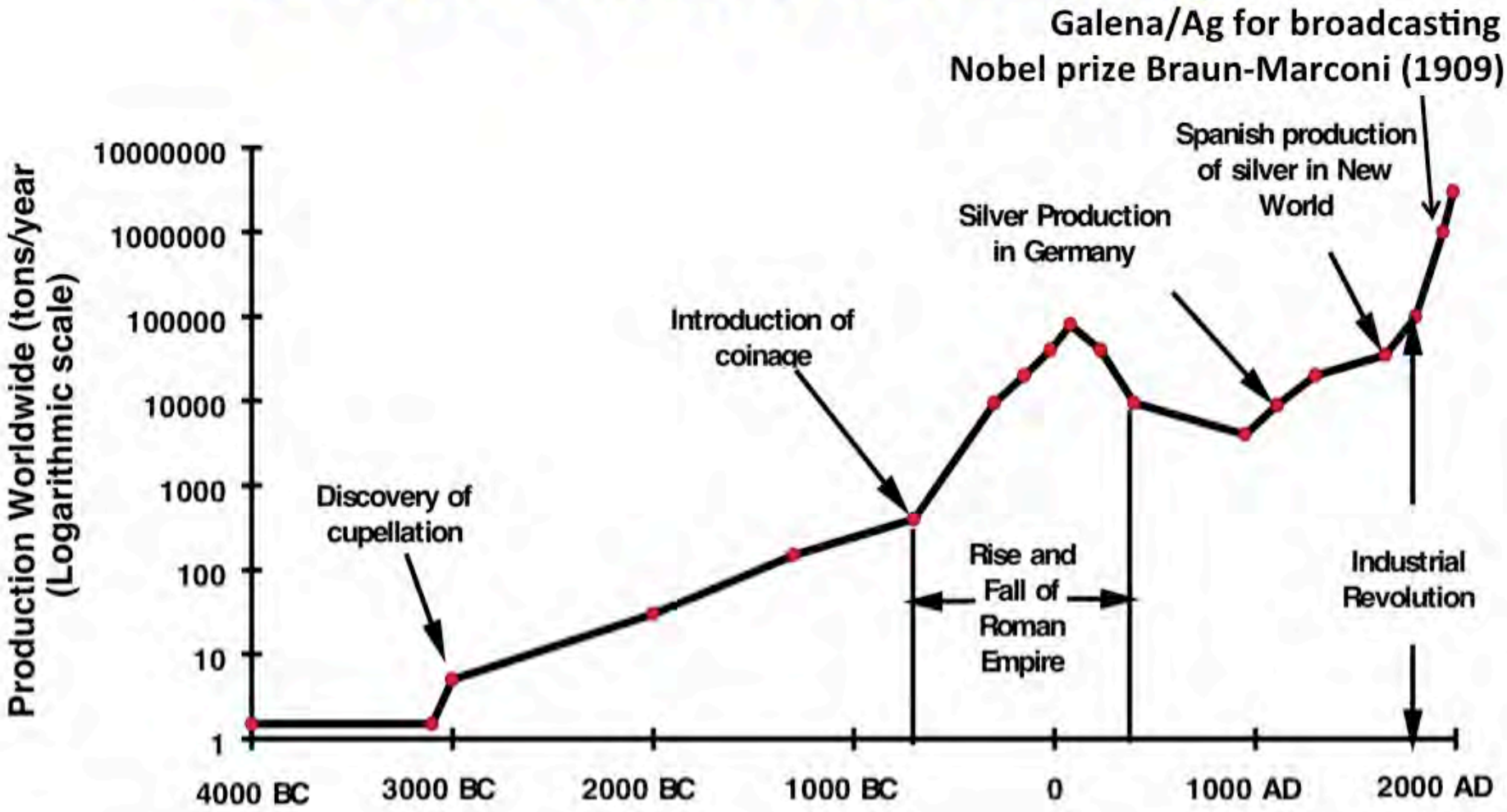
Mineral resources



A major questioning: sustainable development.



1. The lessons of History



World production of lead since 6 millenia (Hilts, 2001).

Since the dawn of humanity…

Flintstone of St Acheul
500 000/300 000 years BC.

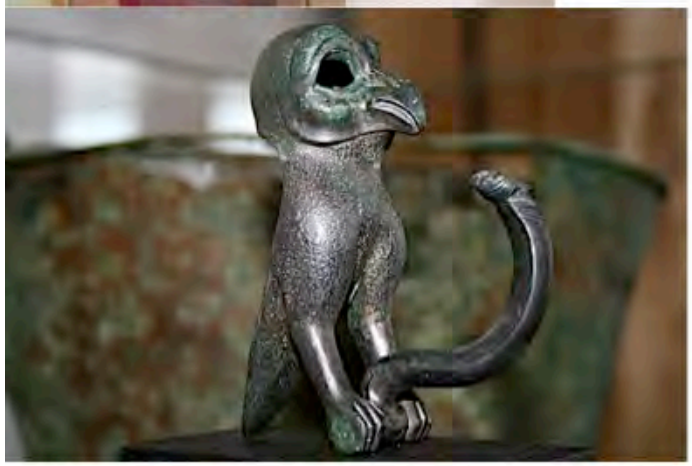
Natural Pigments (Fe, Mn oxides)
Lascaux Cave, about 18 000 years BC.

Collar of phosphates (variscite)
Carnac 4500/2000 years BC.

… marking the History of peoples…

Gallic Helmet
Alésia, France
Ist century BC.

Bracelets, Sainte-Colombe/Seine
500 years BC.



Gilt bronze, Batilly-en-Gâtinais, 200 years BC.

Extraction of gold in Spain and Gaul:
about 6500 kg gold per year…

… mineral ressources are used in their diversity…

Building materials
Antiques de Glanum, Saint Rémy de Provence,25-10 years BC.

Raw materials: elaboration of stained glasses, Chartres cathedral, around 1180.

… with myths ingrained in our memories.

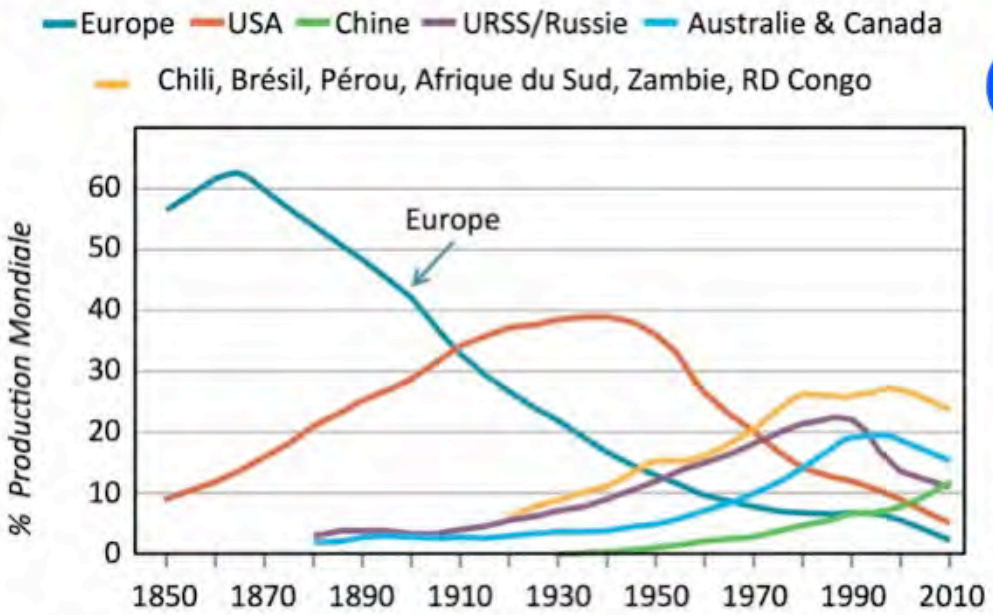
A founding region:
Erzgebirge (Saxony).
Kupfernickel, Kobolden, Marie Curie…

Jason and the Golden fleece

California, 1849: "Mother Lode"

Remembering decimated populations
(Potosi mines , goulags of Noril'sk
and Kolyma…)

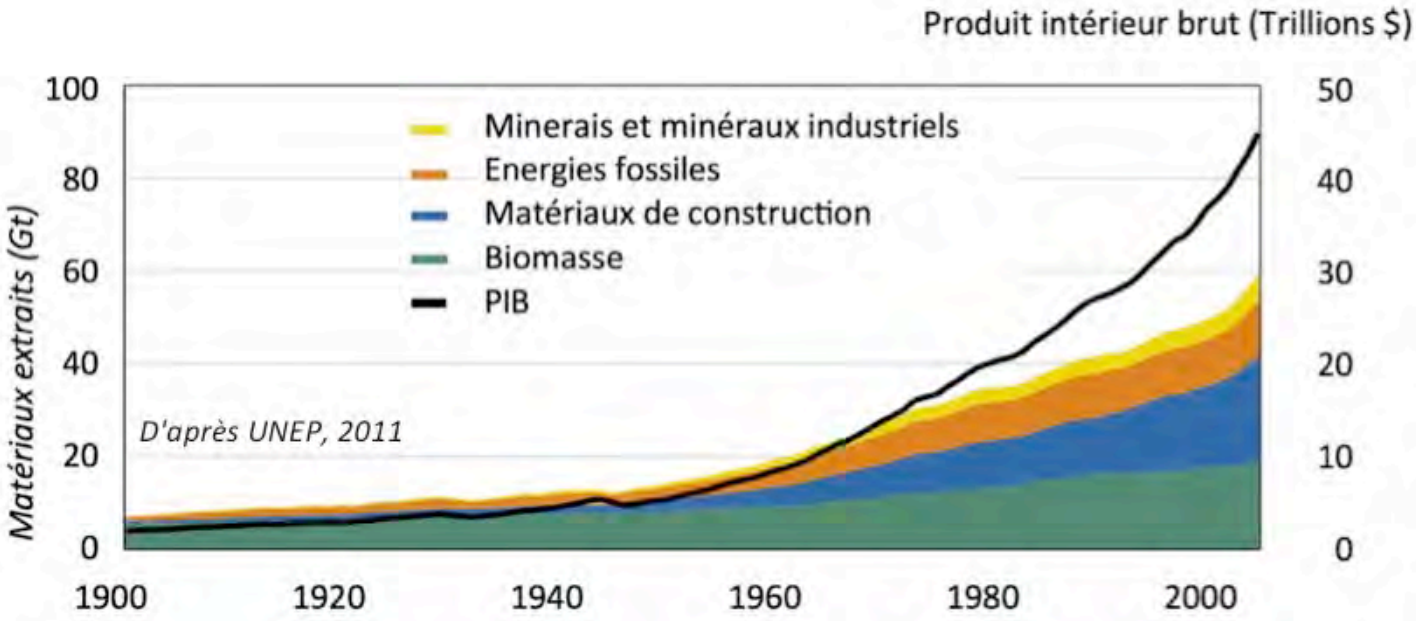
Changes in resource development



D'après ICMM, 2012

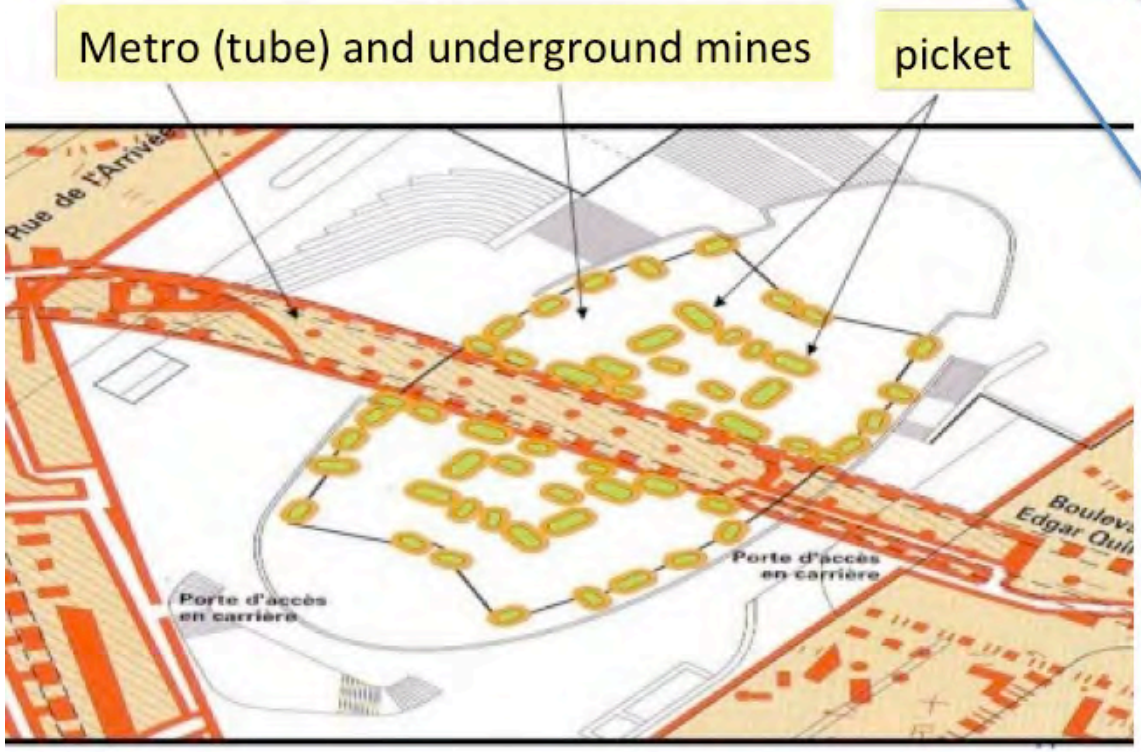
Decrease of mining activity in Europe…

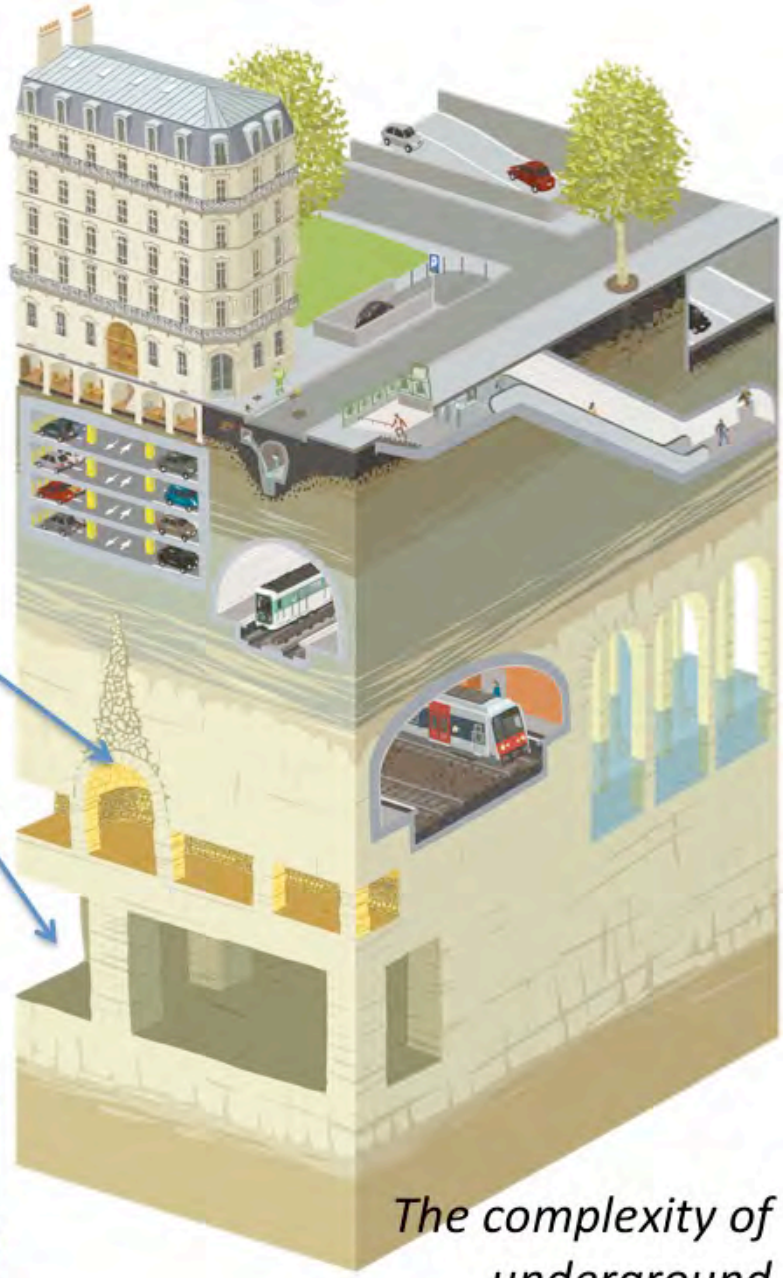
… in a context of larger extracted quantities, raising the question of resource sustainability.



Thinking to the future

Underground mining (2D) below Paris for extracting building stones: The past did not anticipate the future.





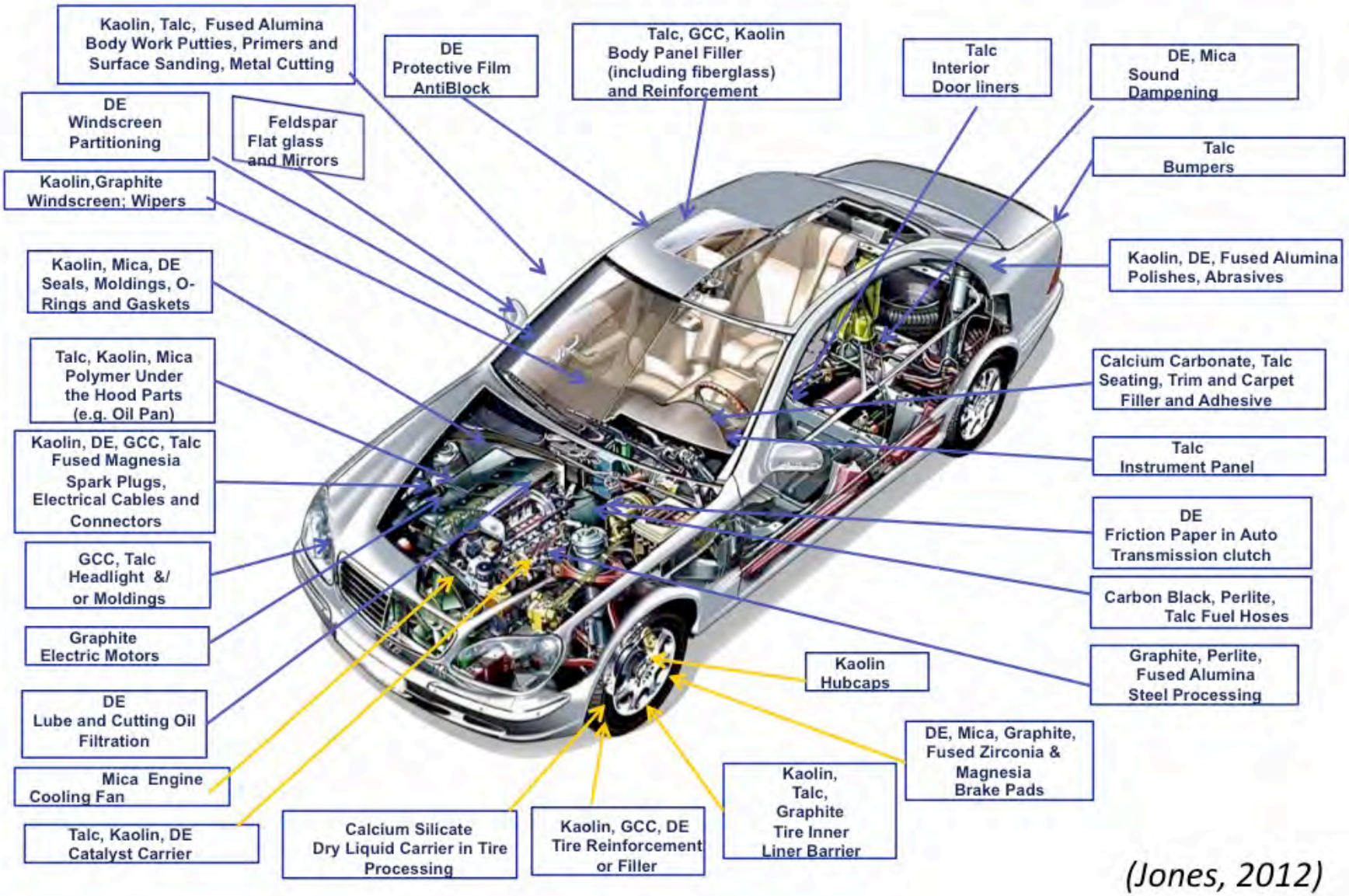
The complexity of underground Paris

Tour Montparnasse

2. Importance and current aspects of mineral raw materials

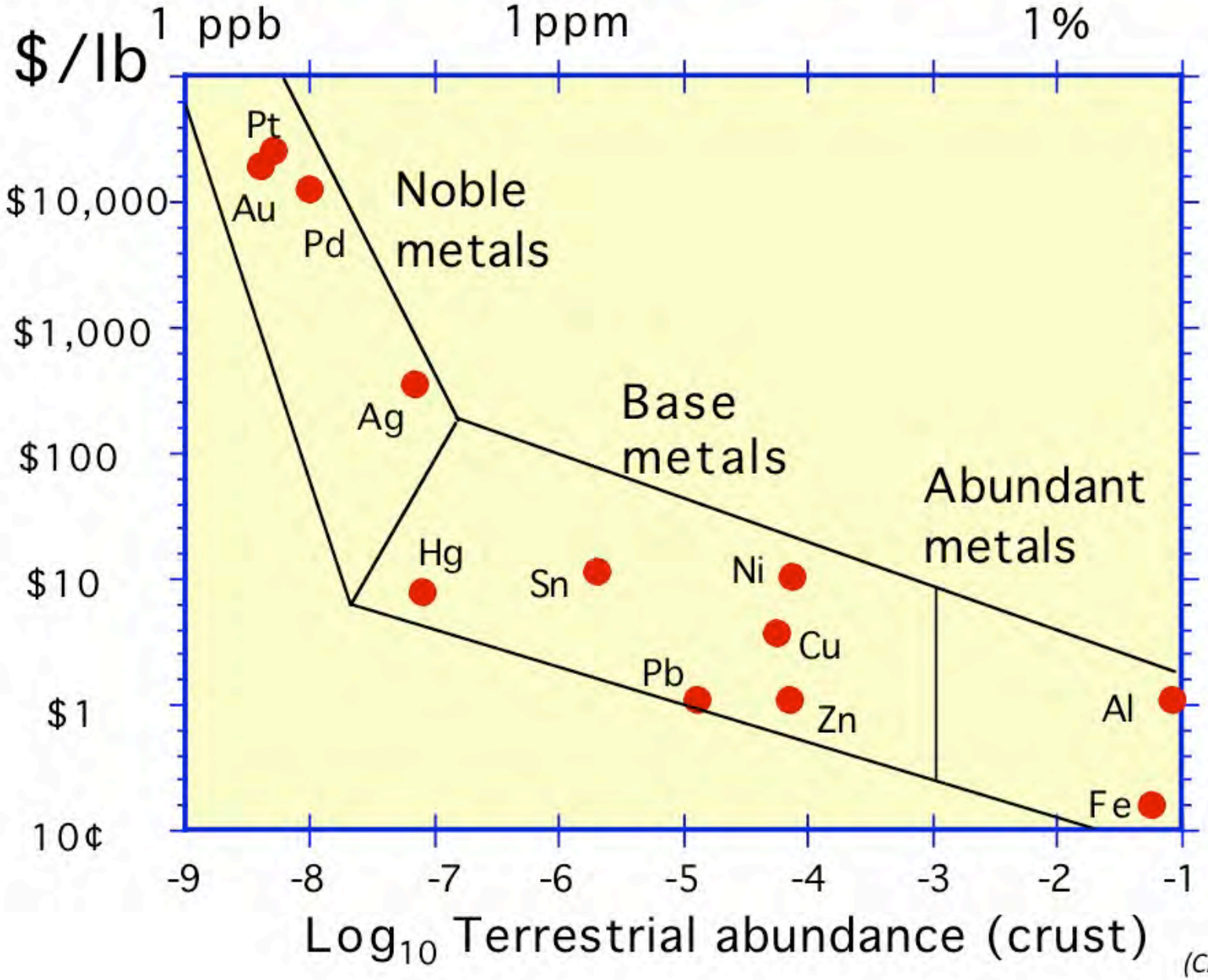
(Elements, 2014)

Minerals, in the everyday life



(Jones, 2012)

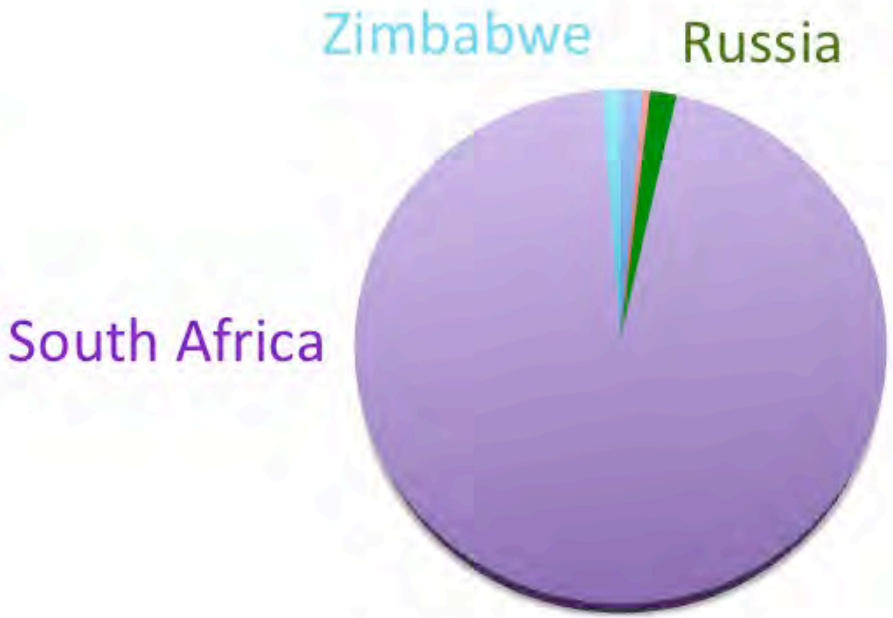
Metals, with contrasted values



(Criss, 2010)

Poorly shared resources

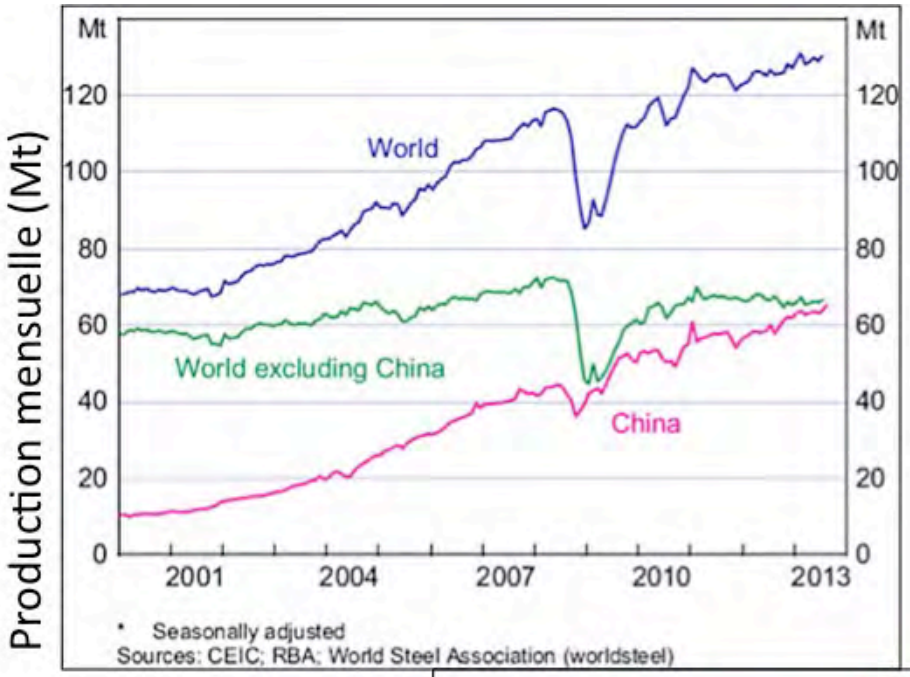
Platinum annual production (192 t)



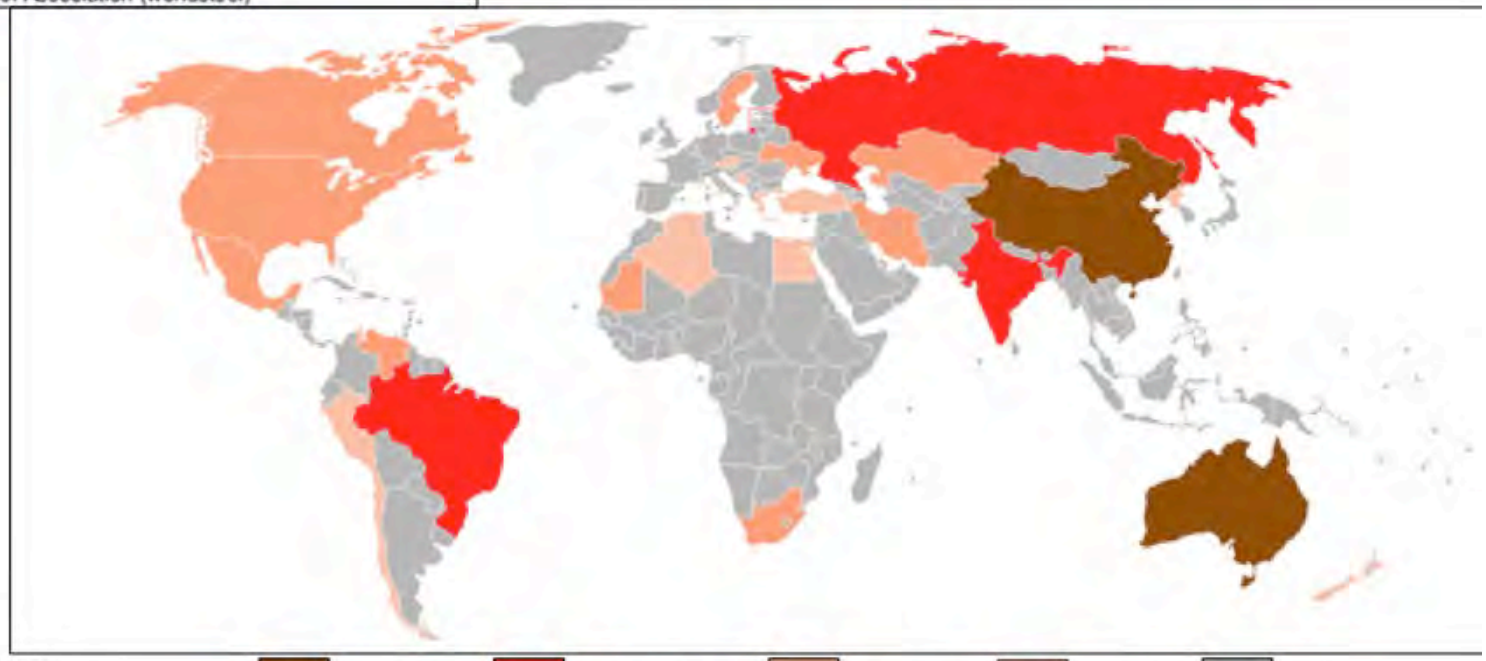
Platinoid Reserves (66 000 t)

Niobium : Araxa mine (Brazil: 75% world production)
Rare earths: Bayan Obo mine (China: 45% world production)

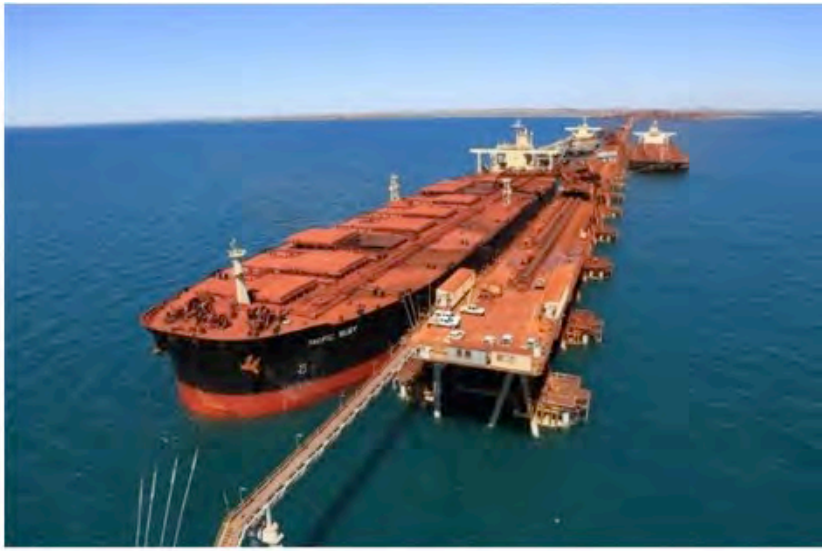
21st century: rise in power of China



Steel Production

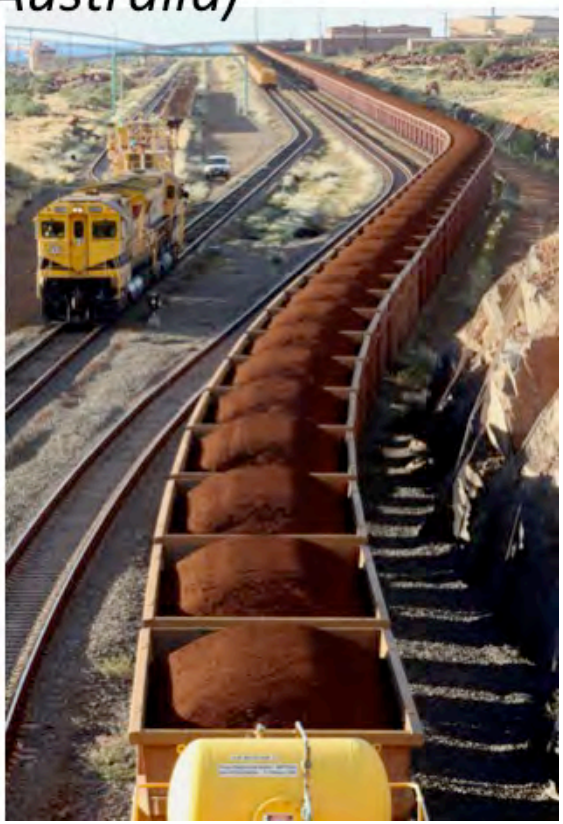


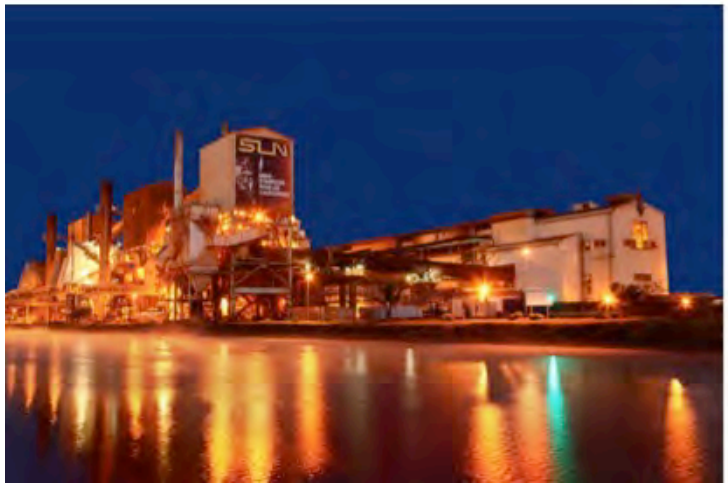
Fe-ore production
(Mt: 2008)



Iron ore mining (Pilbara, Australia)

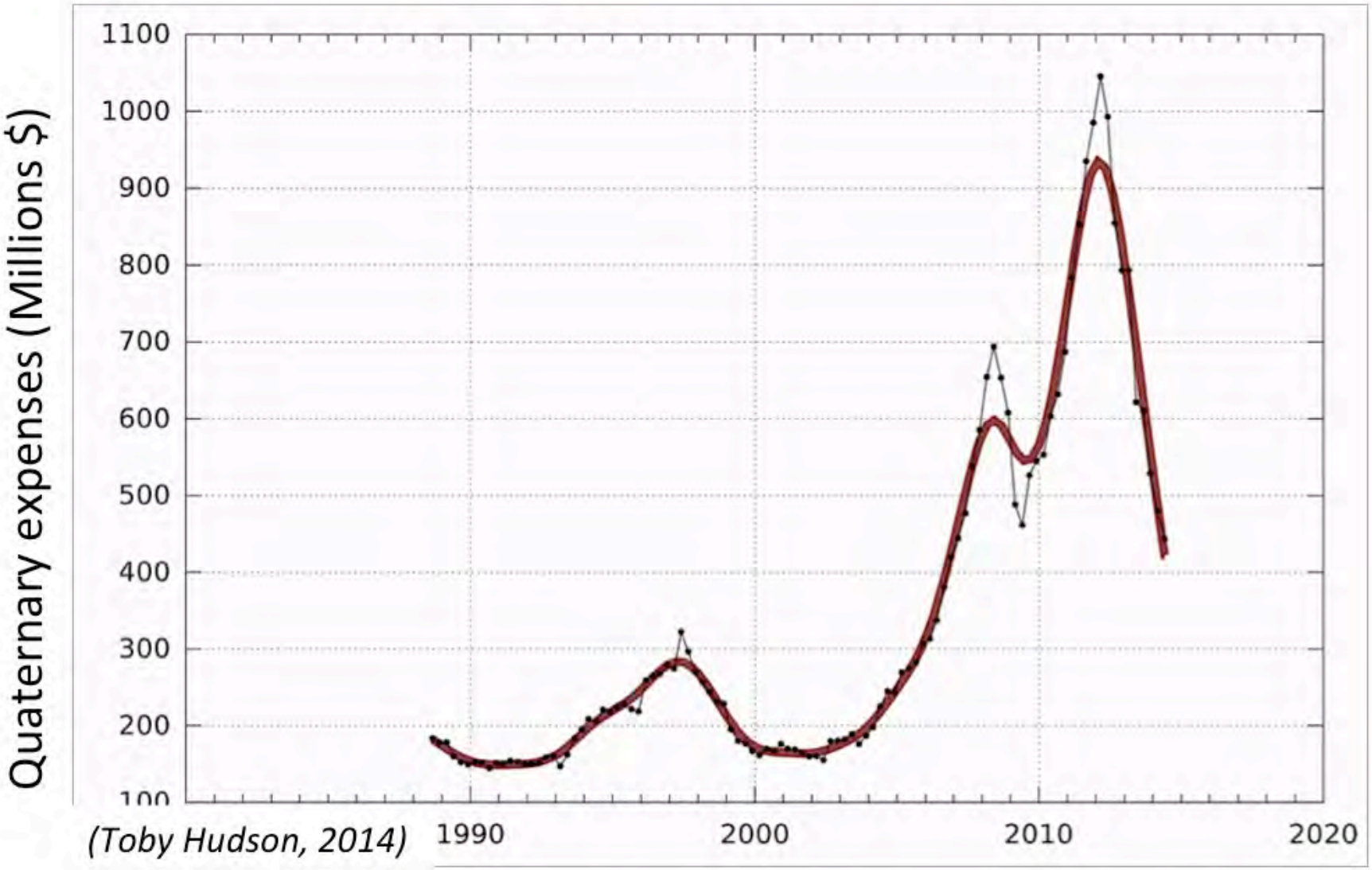
Mine, metallurgy, trade:
a vertical integration …





Le Nickel Company:
Smelters at Doniambo
(New Caledonia)

Fast growth reversals.

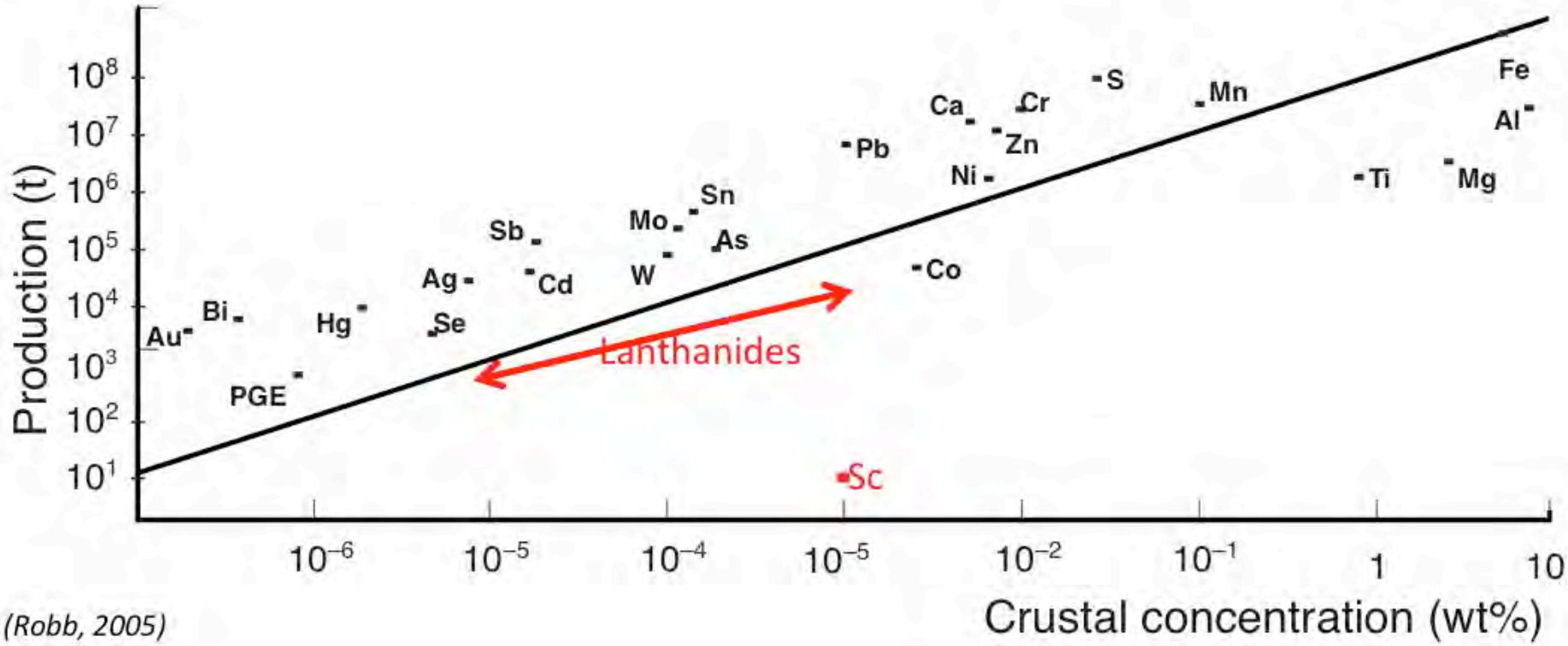


Exploration expenses for Fe-mining in W-Australia

Ressources mined according to their abundance

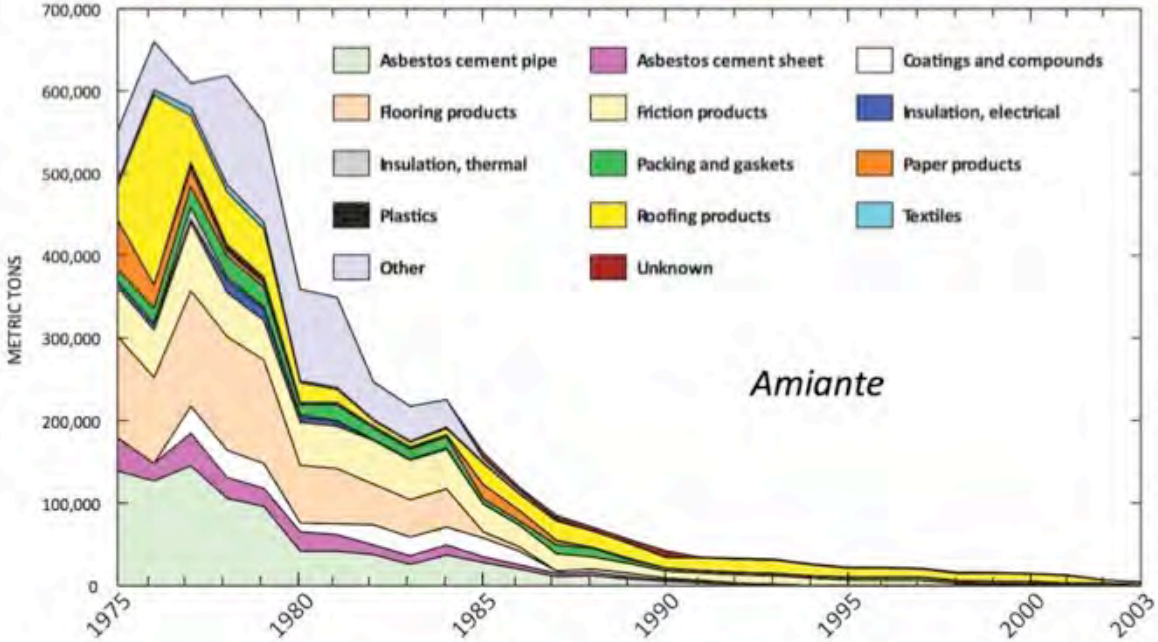
The ores must be concentrated enough to be economical: their grades may be more that 1000 times larger that the geochemical concentrations (Au, Sn…).

Extracted quantities are consistent with crustal concentrations.

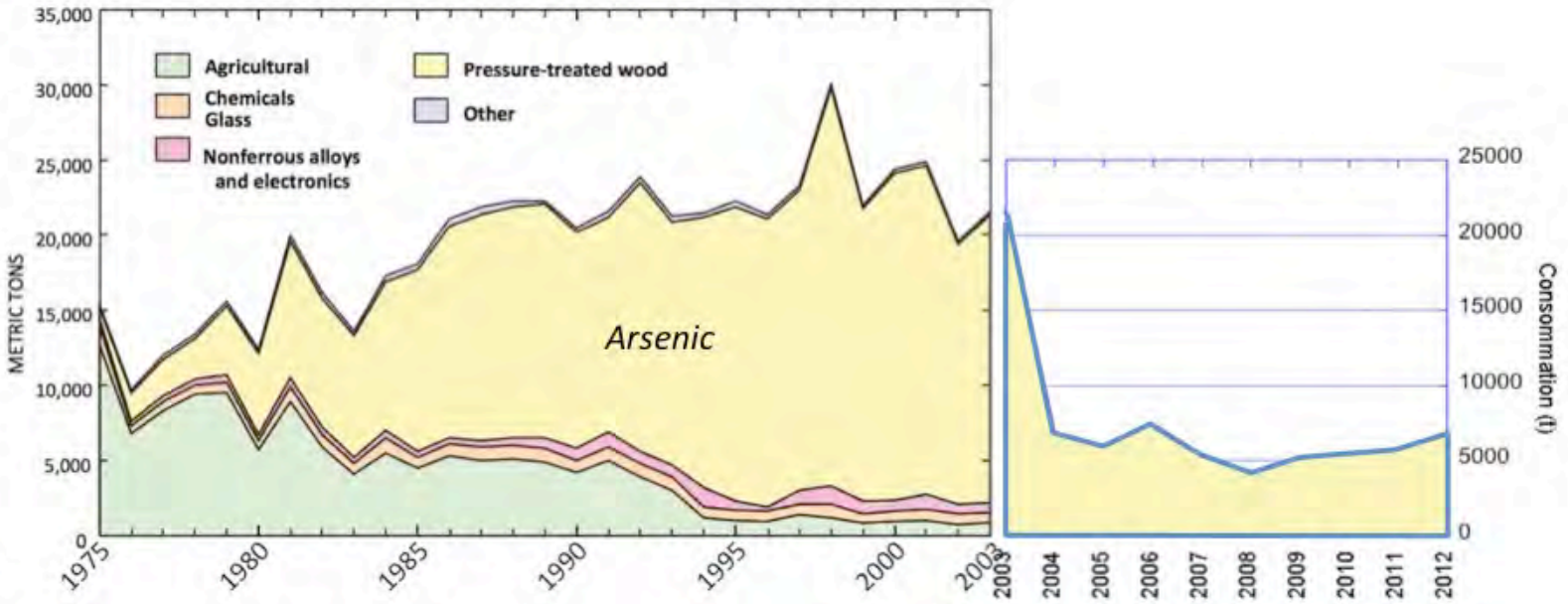


(Robb, 2005)

Impact of regulations: asbestos, arsenic.

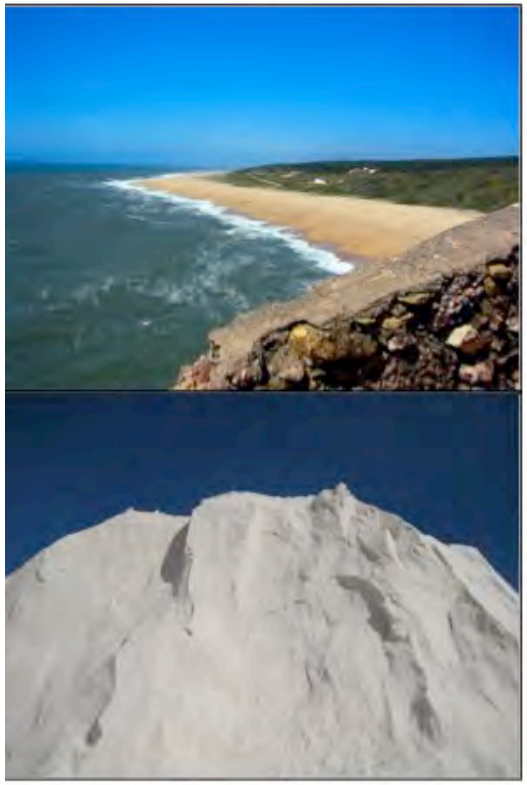


2003: ban on wood preservatives containing arsenic.



(USGS, 2011)

3. Quality and variability : the exemplary cas of industrial minerals



Beach

Quartz sand

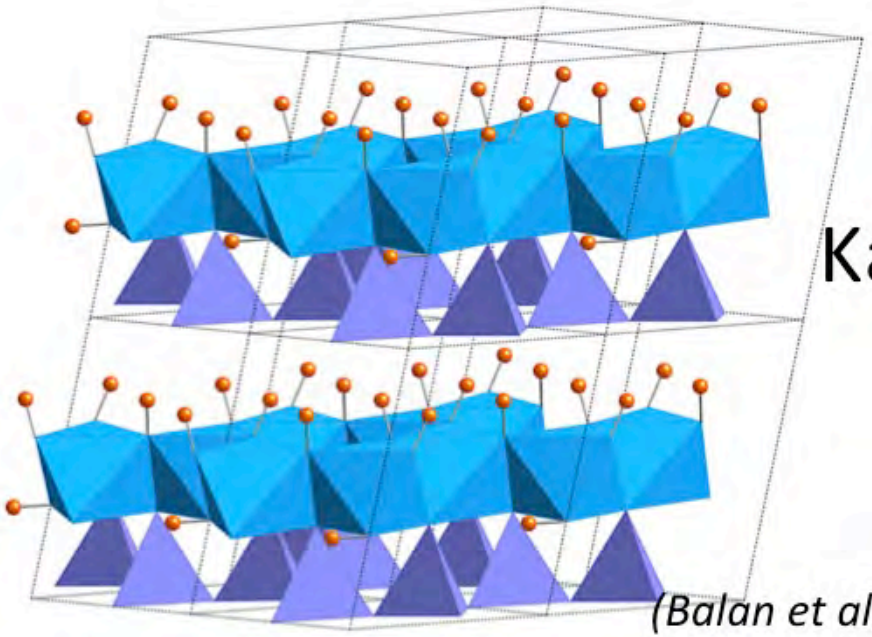
Lateritic soil

Kaolin

Clay minerals

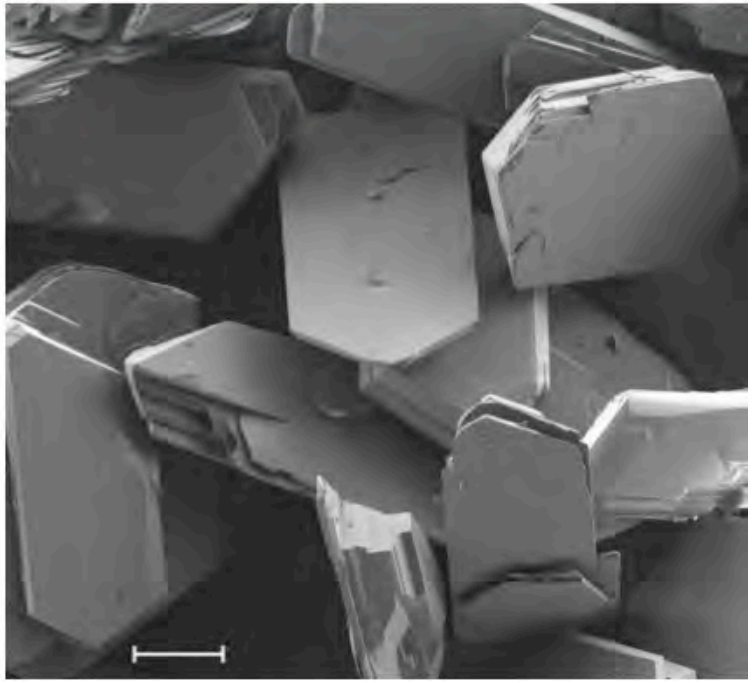
Clays, materials used since the beginning of time.

Under the same name name, very different qualities, uses and values.



Kaolinite

(Balan et al., 2011, 2014)



Structure-properties relations in clay minerals

Resins, Wax
25- 40 mJ/m²

Water 73 mJ/m²

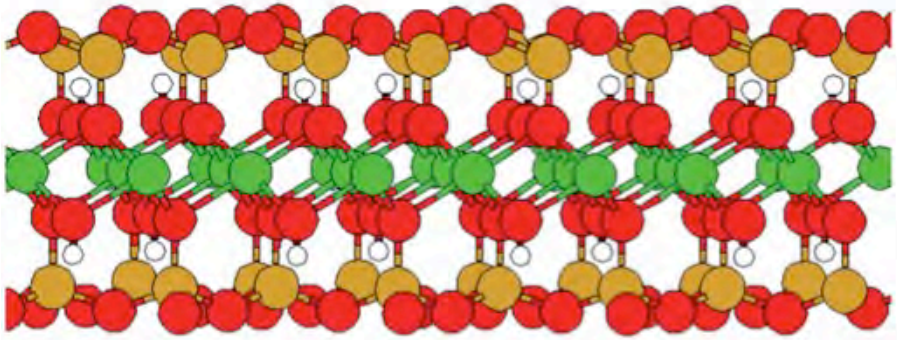
Cellulose
200-300 mJ/m²

Talc
25-55 mJ/m²

Carbonates
75-80mJ/m²

Kaolin
500-600 mJ/m²

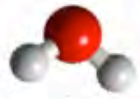
Hydrophobic **Surface energy** **Hydrophilic**



(Geysermans & Noguera, 2009)

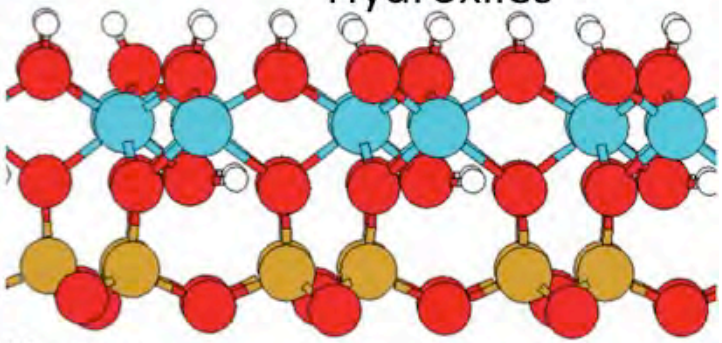
Siloxanes

Siloxanes



H_2O

Hydroxiles



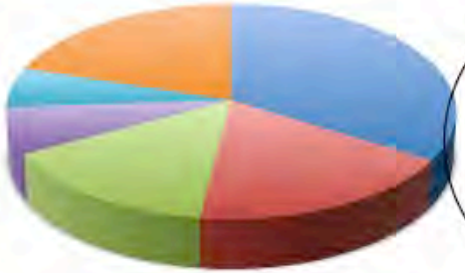
Talc

Kaolinite

Siloxanes

Uses and quality of the resource

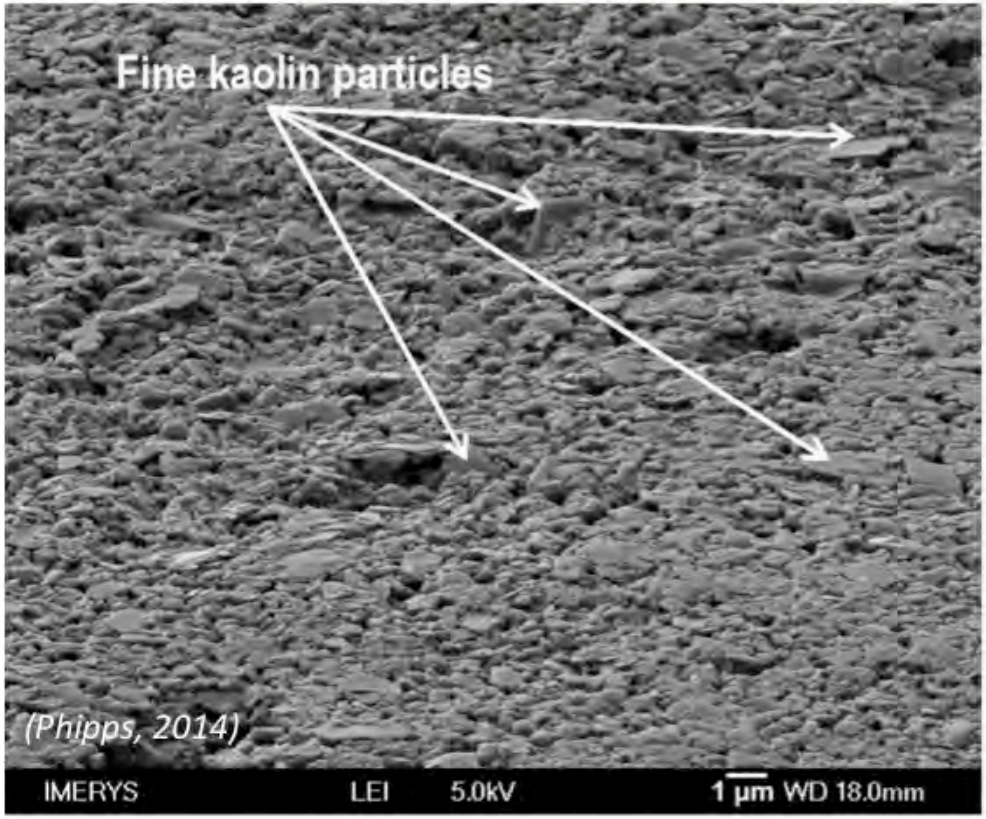
Kaolin



- *Papier* → Industrial mineral
- Réfractaires
- Céramiques
- Fibres verre → Raw materials
- Catalyse
- *Various (cosmetics, fillers, paints…)*

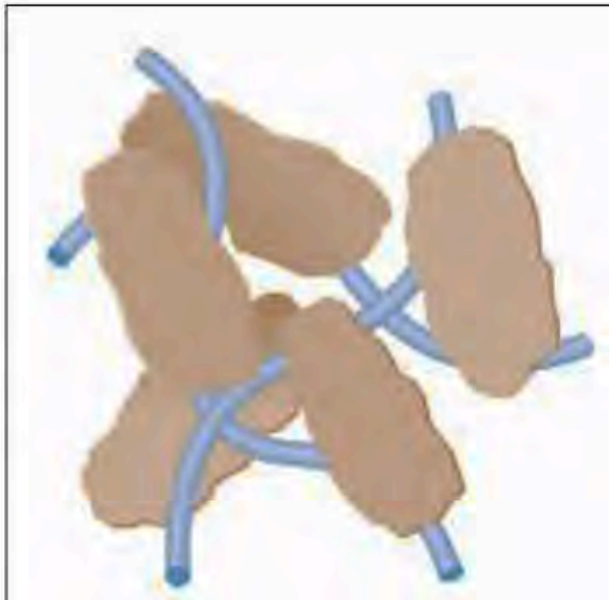
Importance of impurities as Fe^{3+} (concentration, speciation) on kaolin properties : morphology of the particles, color, surface properties …
… but an importance which depends whether the material is used raw or transformed.

The importance of morphology: paper



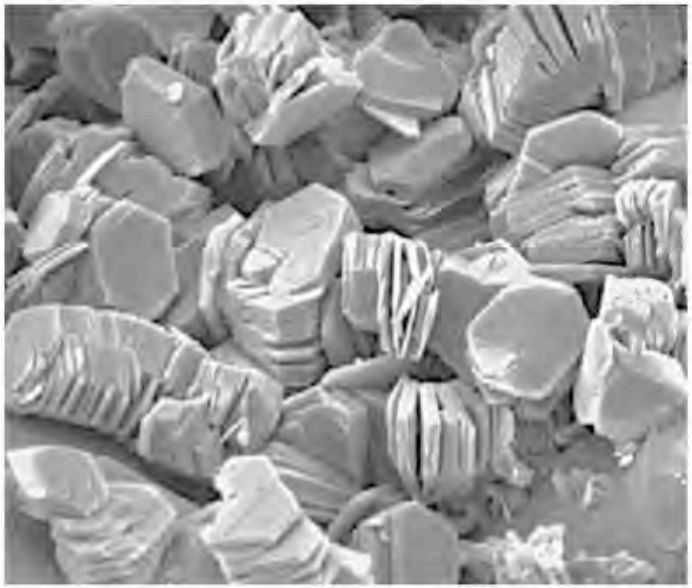
At the surface of the paper sheet : materials for coatings (2D)

In the bulk: association modified kaolin / modified cellulose. Hybrid nanomaterials.

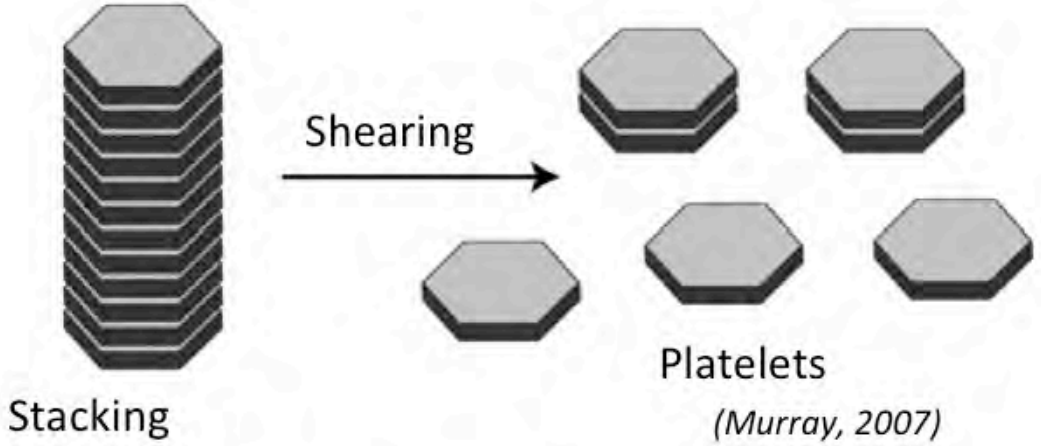


The importance of morphology: develop the resource

- Favor coating materials /fillers.
- Improve the resource quality : physical and chemical treatments of kaolins if their properties (or defects) so permit.



Pilings ("booklets") of kaolinite platelets



(Murray, 2007)

Transformation 3D → 2D by delamination

4. Ore deposits: unique witnesses of Earth history

Black smoker,
Hydrothermal site Rainbow (IFREMER)

Ore deposits form through efficient concentration processes.

Trilogy: mobilisation-transport-deposition

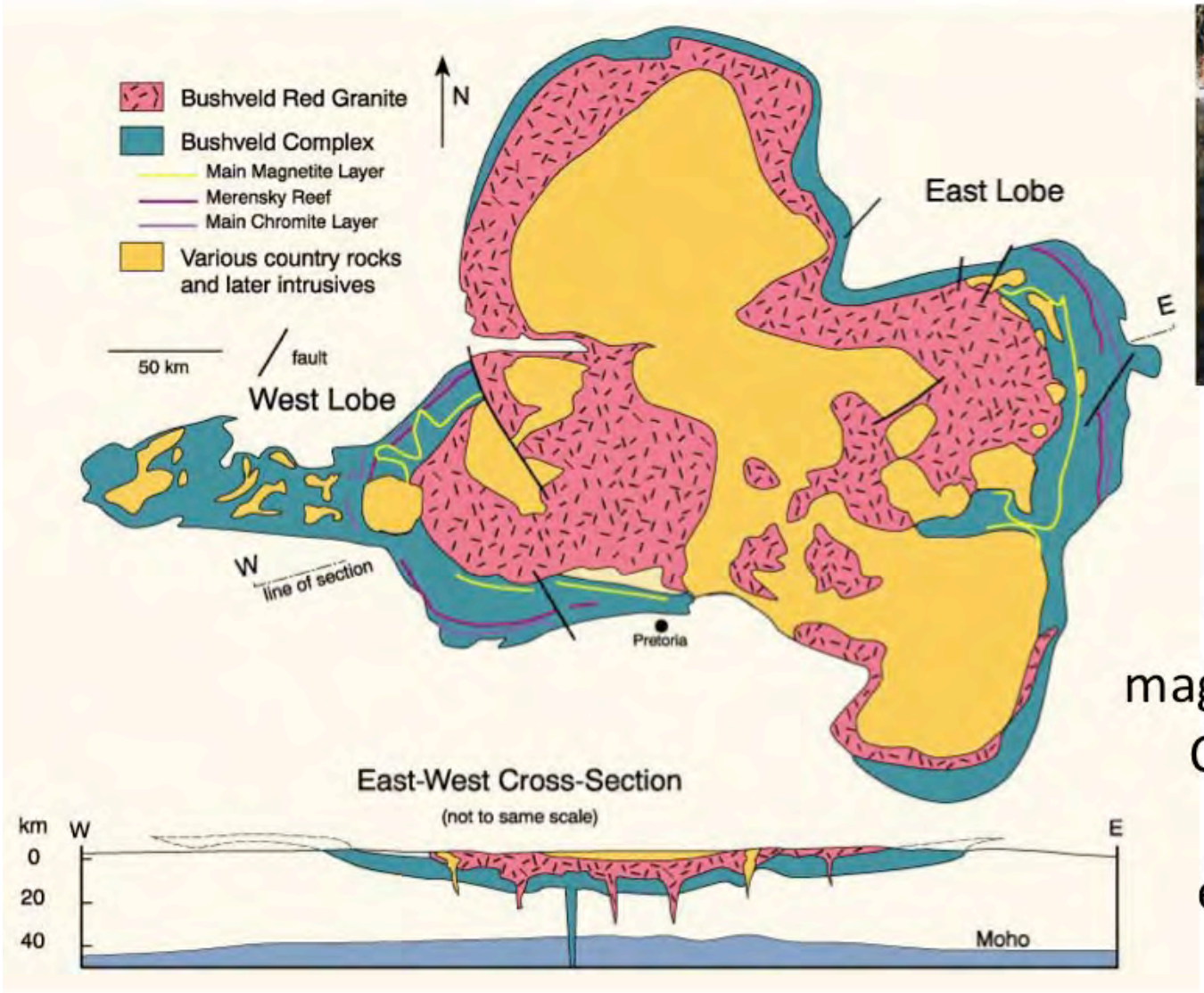
Some physico-chemical parameters :

- Solubility/precipitation (activity of mineral phases)
- Redox: affects directly element solubility ($Mn^{2+/4+}$…)
- Metal complexation (chlorides, sulfides, organic matter…)
- Biological activity

Geological parameters:

- Nature of the geological levels
- Coherent tectonics
- Heat sources
- Local geochemistry (S, organic matter…)

Bushveld: one of the largest (67000 km^2) and the richest magmatic complex in the world (2 Ga)

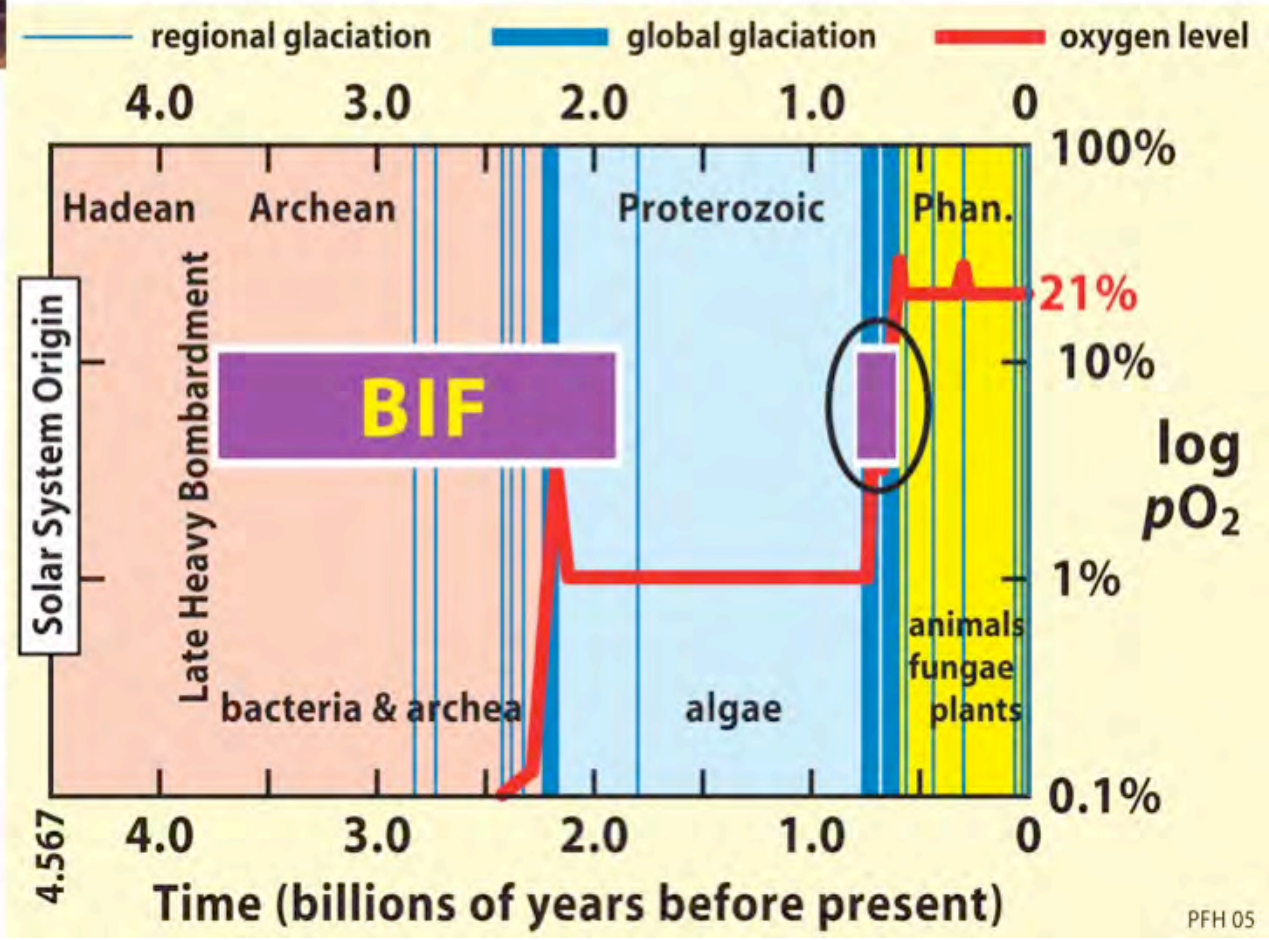


Formation at high temperature, during magmatic crystallization. Considerable reserves of high value elements (Cr, V, Pt…).

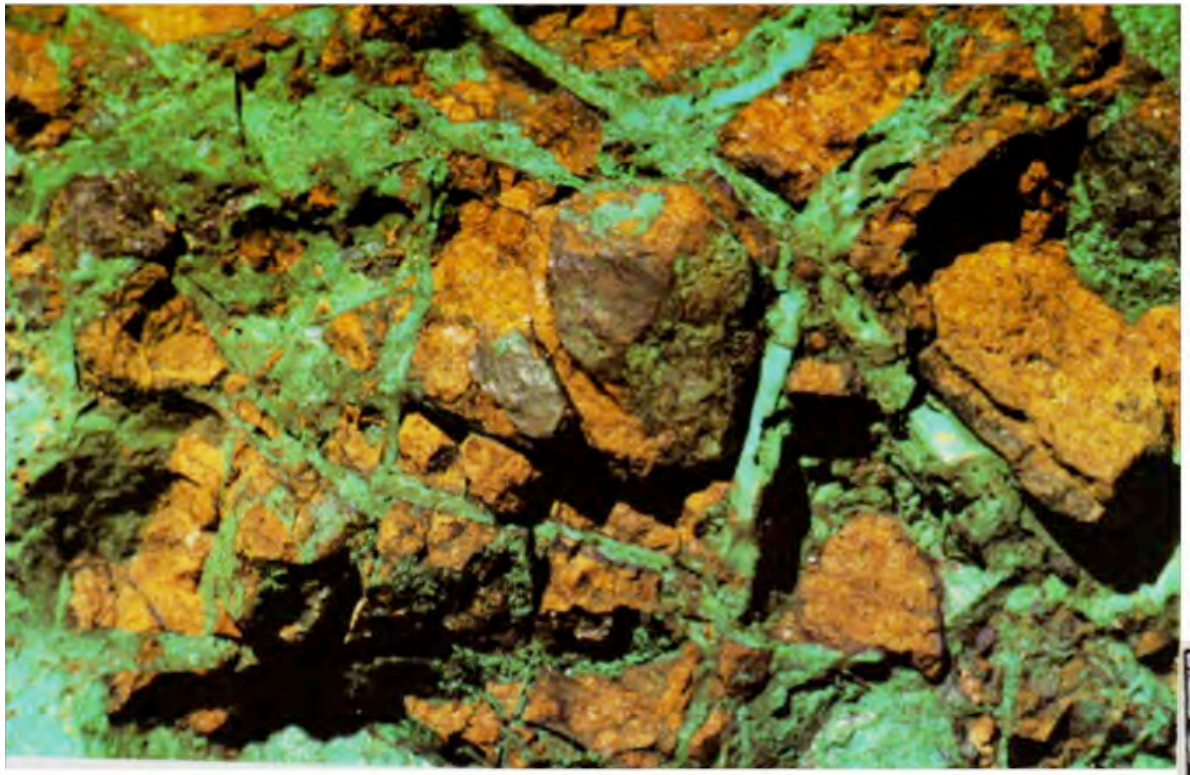
Banded iron formations (3,5-2 Ga), witnesses of the evolution of terrestrial atmosphere.

Carajas Mine , Brazil: the most important iron mine in the world (reserves evaluated at 7 Gt Fe_2O_3)

Fe^{2+} (soluble) oxidized as Fe^{3+} (low solubility in neutral conditions) : a result of the photosynthetic activity in oceans.



Ores from New Caledonia



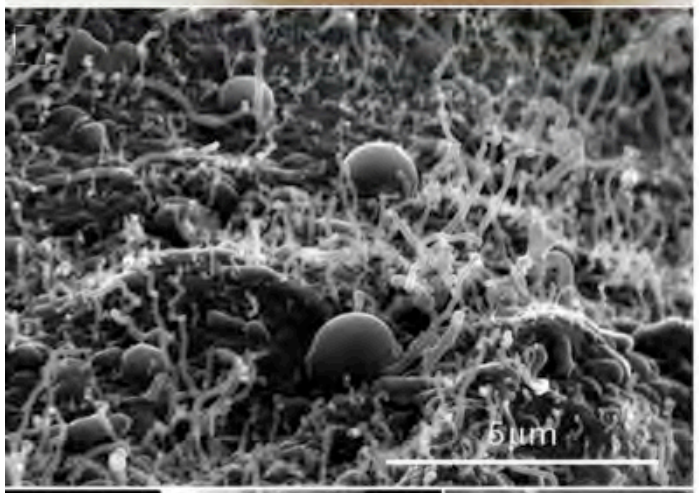
Nickeliferous phyllosilicate (Ni ore: green).

Nickel ore minerals are processed by pyrometallurgy. New technologies needed to process the "new" resource in laterites: Ni+ Co +…

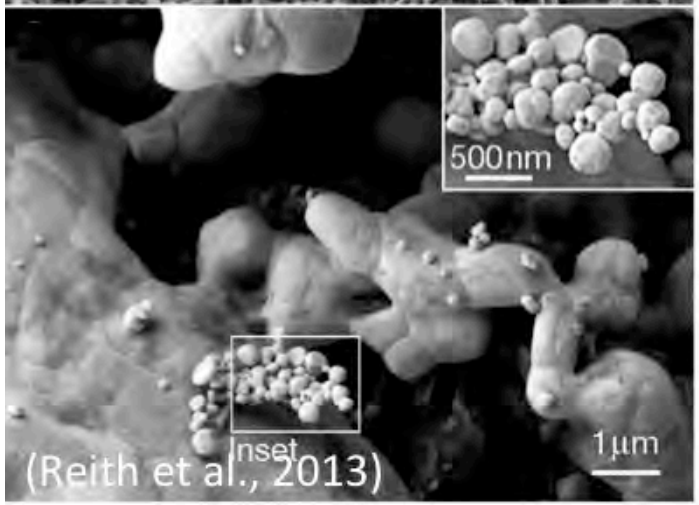
"Cobaleur", 19th century

Native gold is not immobile: the importance of bacterial activity.

"The Camel", 9.3 kg nugget (Russian Diamond Fund);

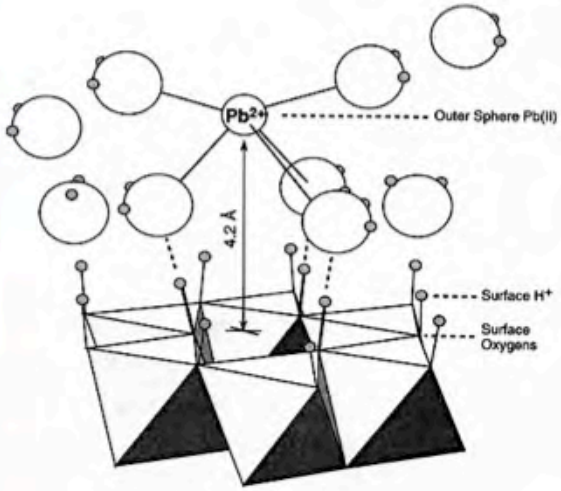


Presence of biofilms at the surface of native gold particles.



Formation of nanoparticulate gold inside biofilms.

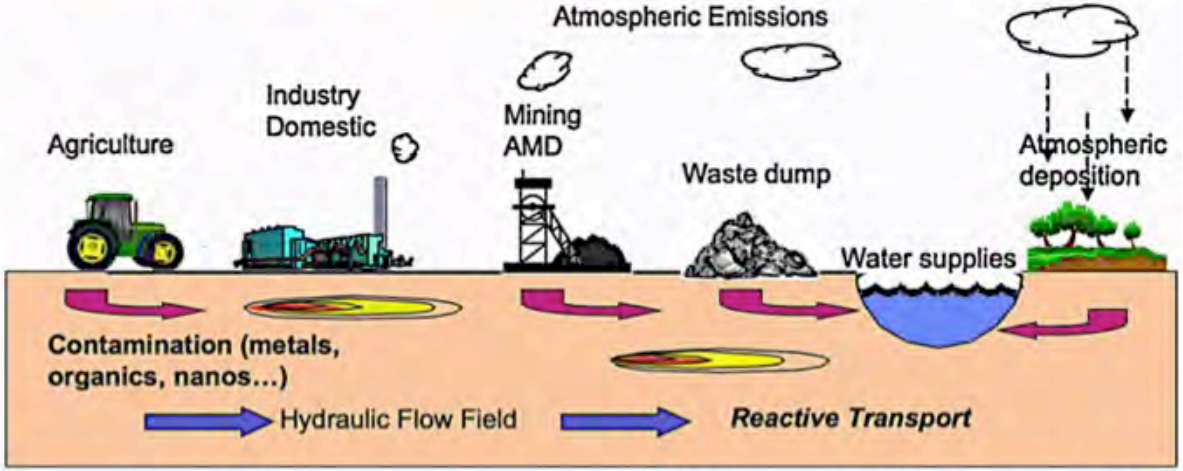
5. Sustainable development: the environmental impacts



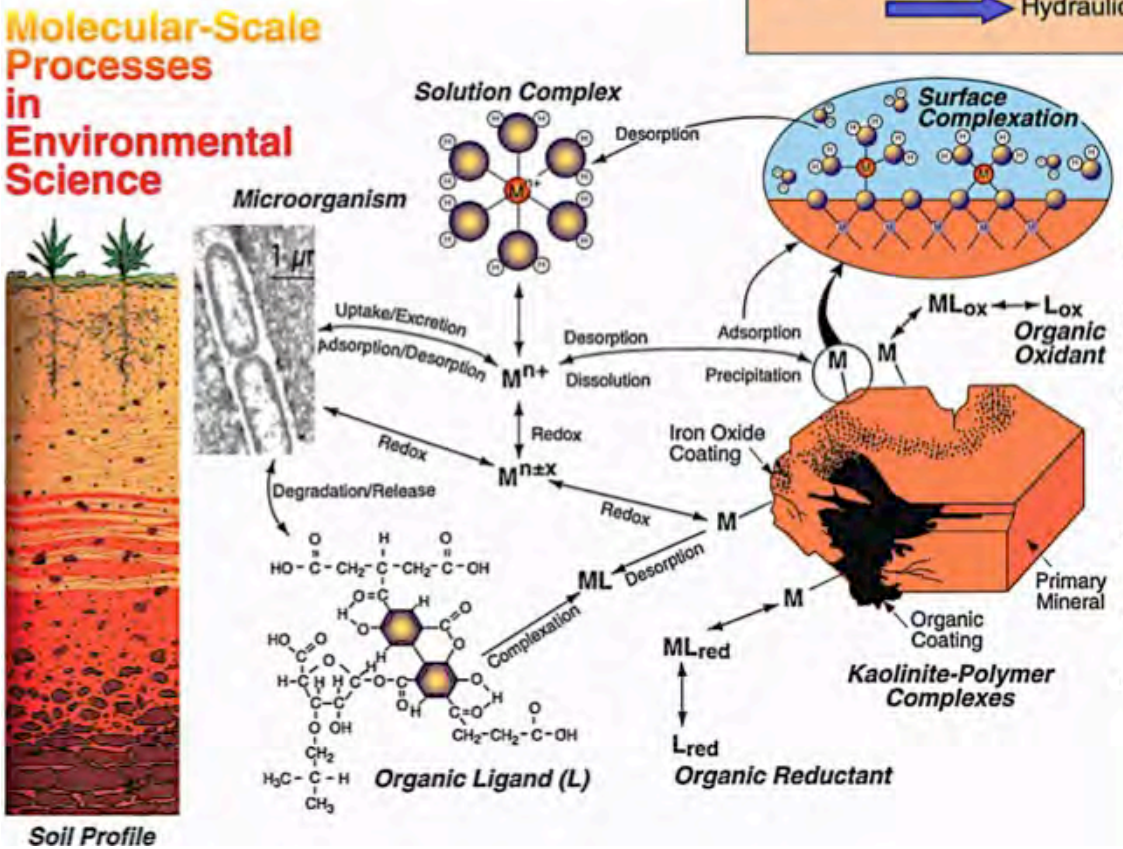
Pb^{2+} trapped at the α-Al_2O_3 (0001) surface

(Brown and Calas, 2012; Bargar et al., 1997)

Soil contamination by heavy metals



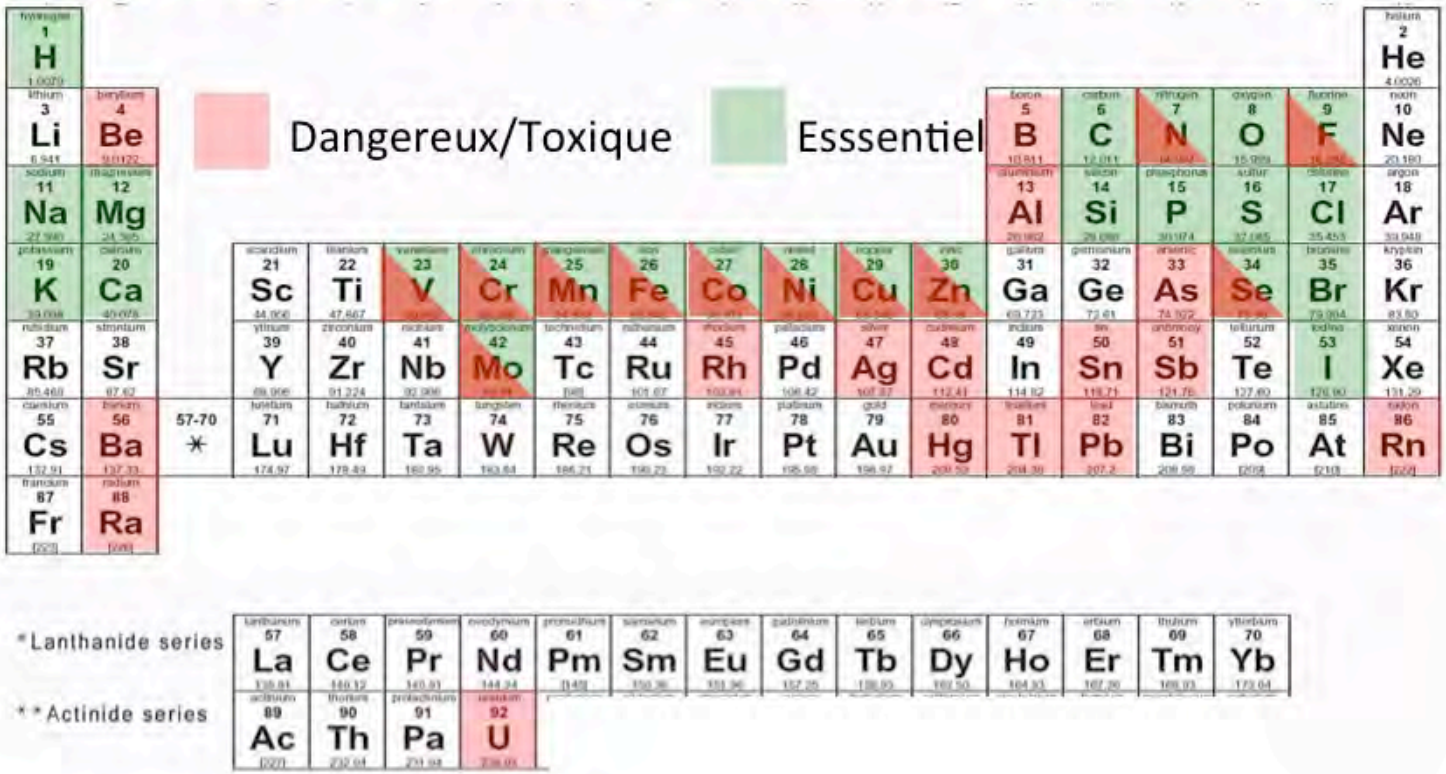
(Brown and Calas, 2011)

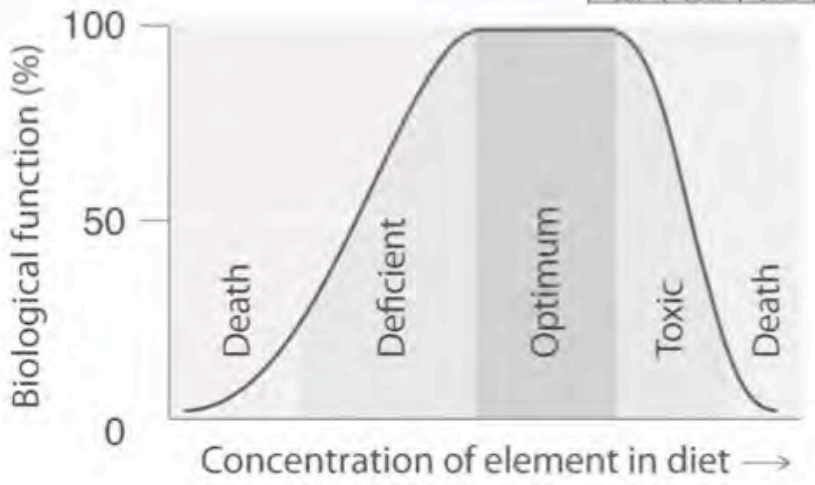


Evolution of physical environments and the contaminating forcing:

- multi-scale processes
- the time paraeter
- diverse stakeholders
- new jobs.

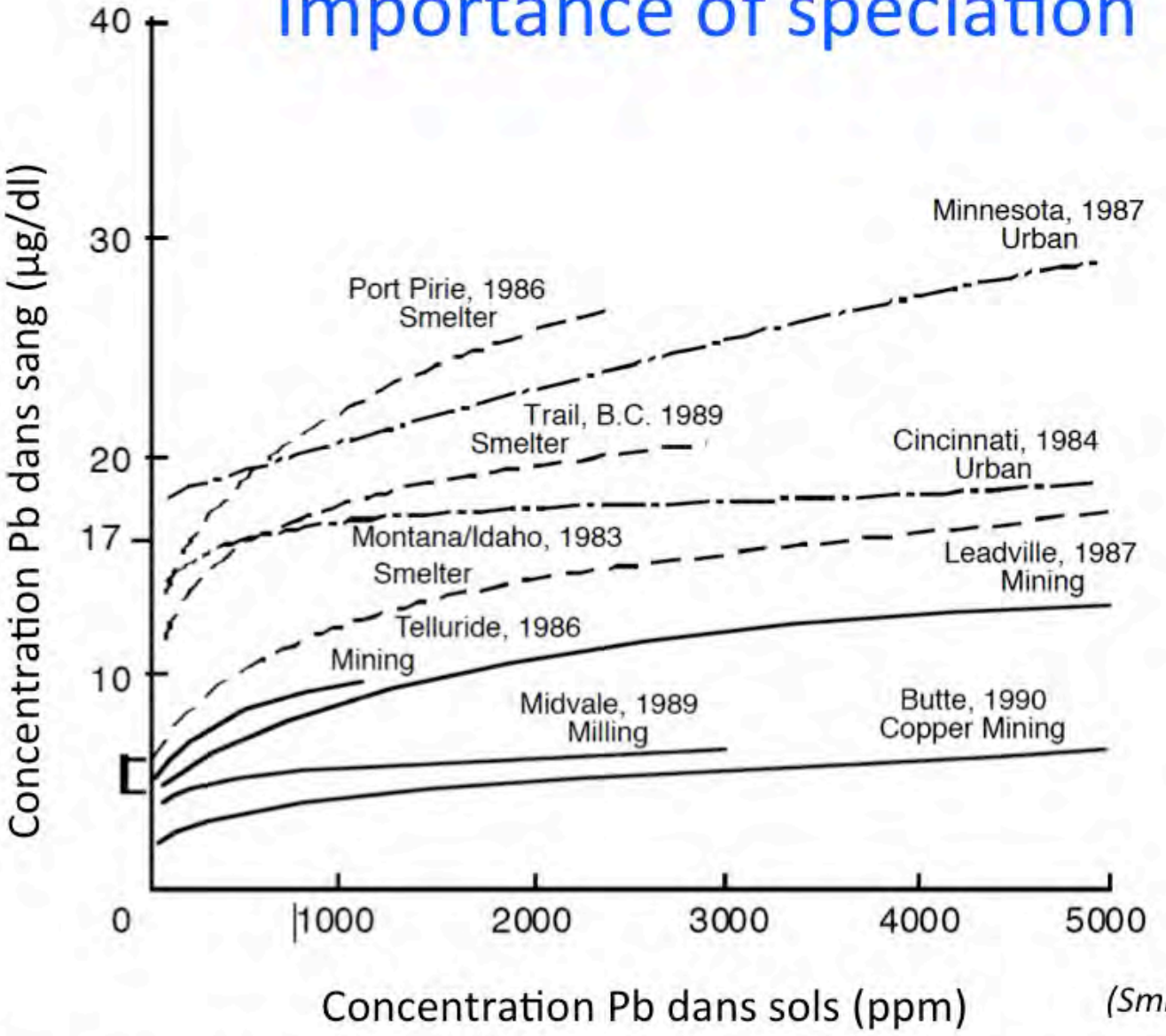
The impact of trace metallic elements





"All is poison, nothing is poison, it is the dosage which makes the poison"
(Paracelse)

Importance of speciation



(Smith&Huyck, 1999)

The health impact of contamination depends on speciation (crystal chemical environment of elements).

Trace metallic elements and mining activity

"Instant" Action

Environnemental disasters (e.g., Aznalcollar, 1998).
Short and medium term impacts.
Regional scale.

Geological Times

Naturally high concentrations: **geochemical anomalies**.
Stable, low solubility minerals.

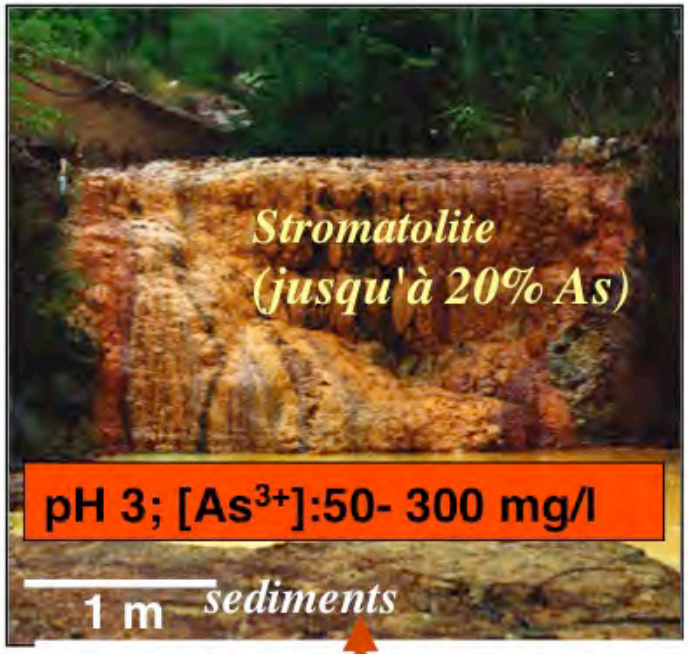
As, Cd, Pb, Hg, Sb, Cr…

Transferts in rivers (Garonne…), from former mining sites.
Delayed Impacts. Regional scale.

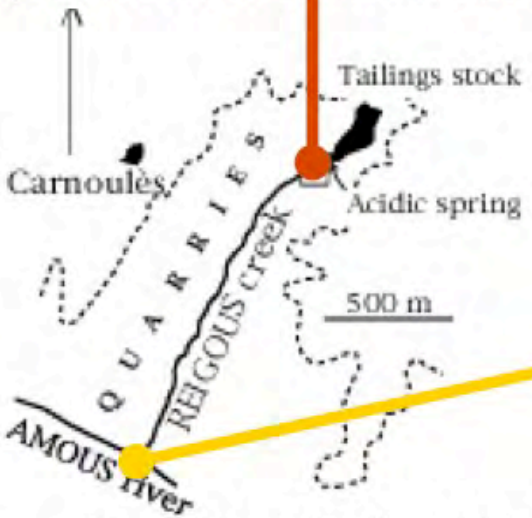
Evolution of historical mining wastes.
Delayed Impacts. Local scale.

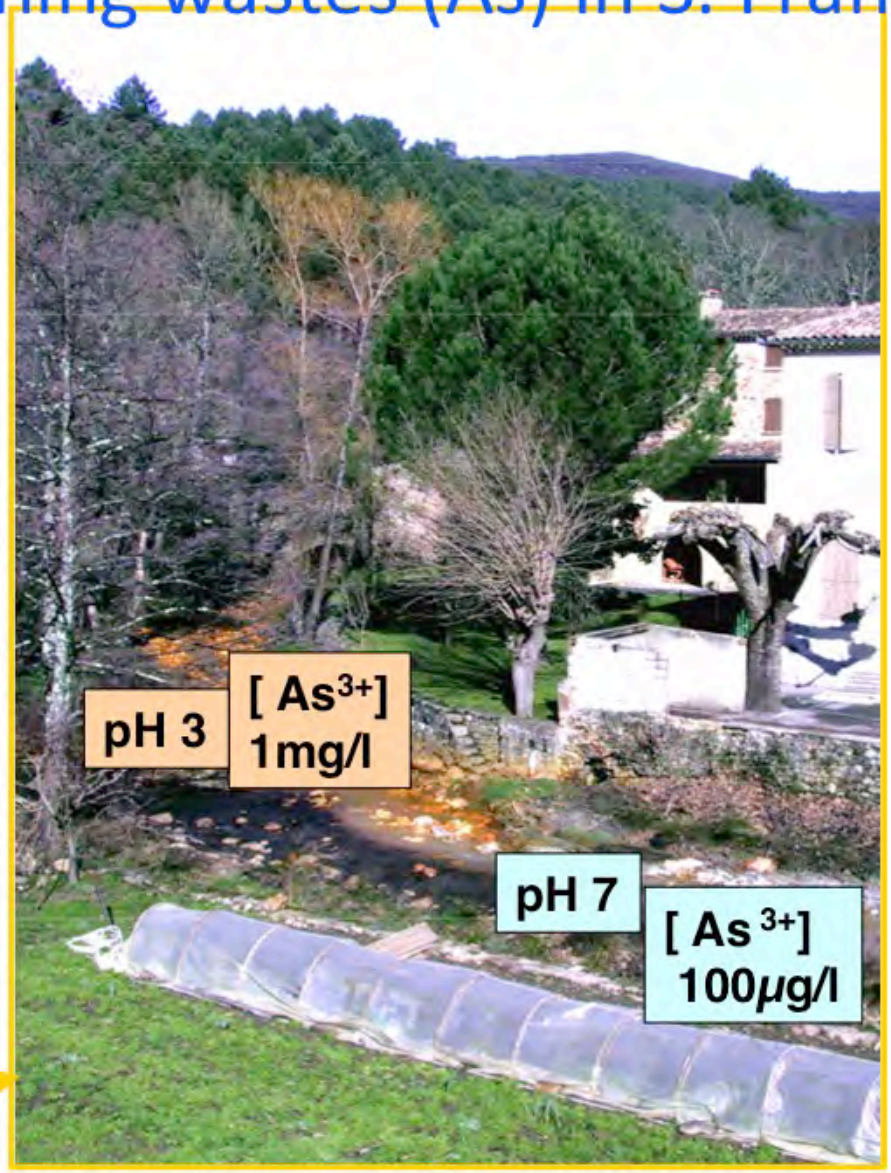
"Time Bombs"

Evolution of historical mining wastes (As) in S. France



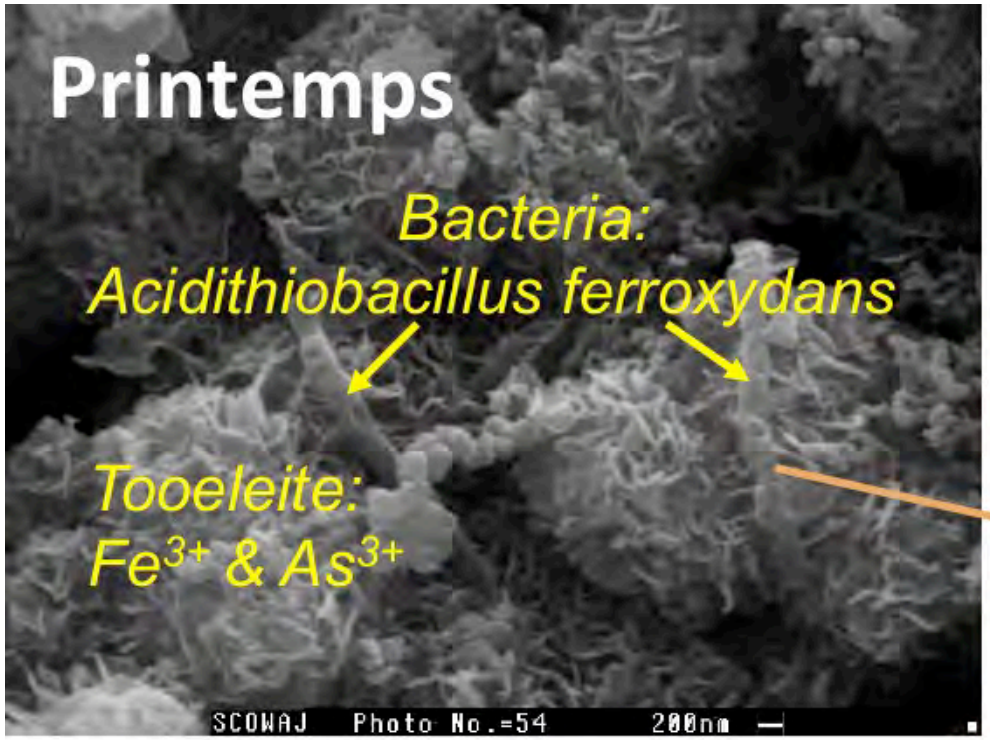
(Carnoules site: Morin et al., 2003)

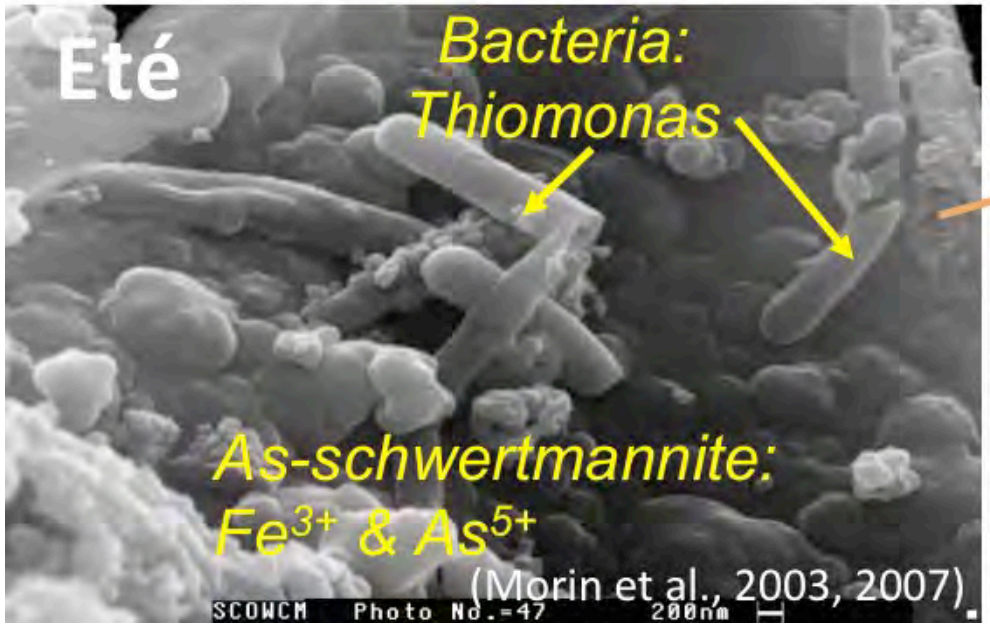




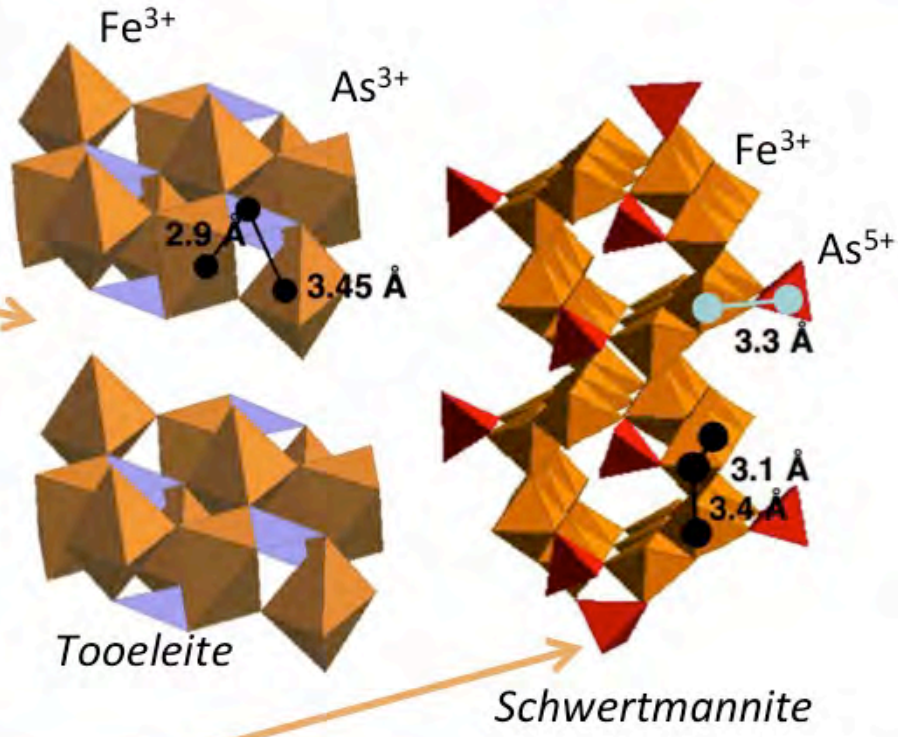
50 years of waste aging: oxidation of sulfides (+As).

As concentration decreases downstream but stays above standards (10 µg/l)





Crystal structures able to trap $As^{3+/5+}$



Spring: As^{3+} co-precipitates with Fe^{3+} (Thiobacillus Ferrooxydans only oxidizes Fe^{2+}: As^{3+}-Fe^{3+} minerals)

Summer: Thiobacillus (Fe^{2+}) +Thiomonas (As^{3+})= As^{5+}-Fe^{3+} minerals + As-adsorption

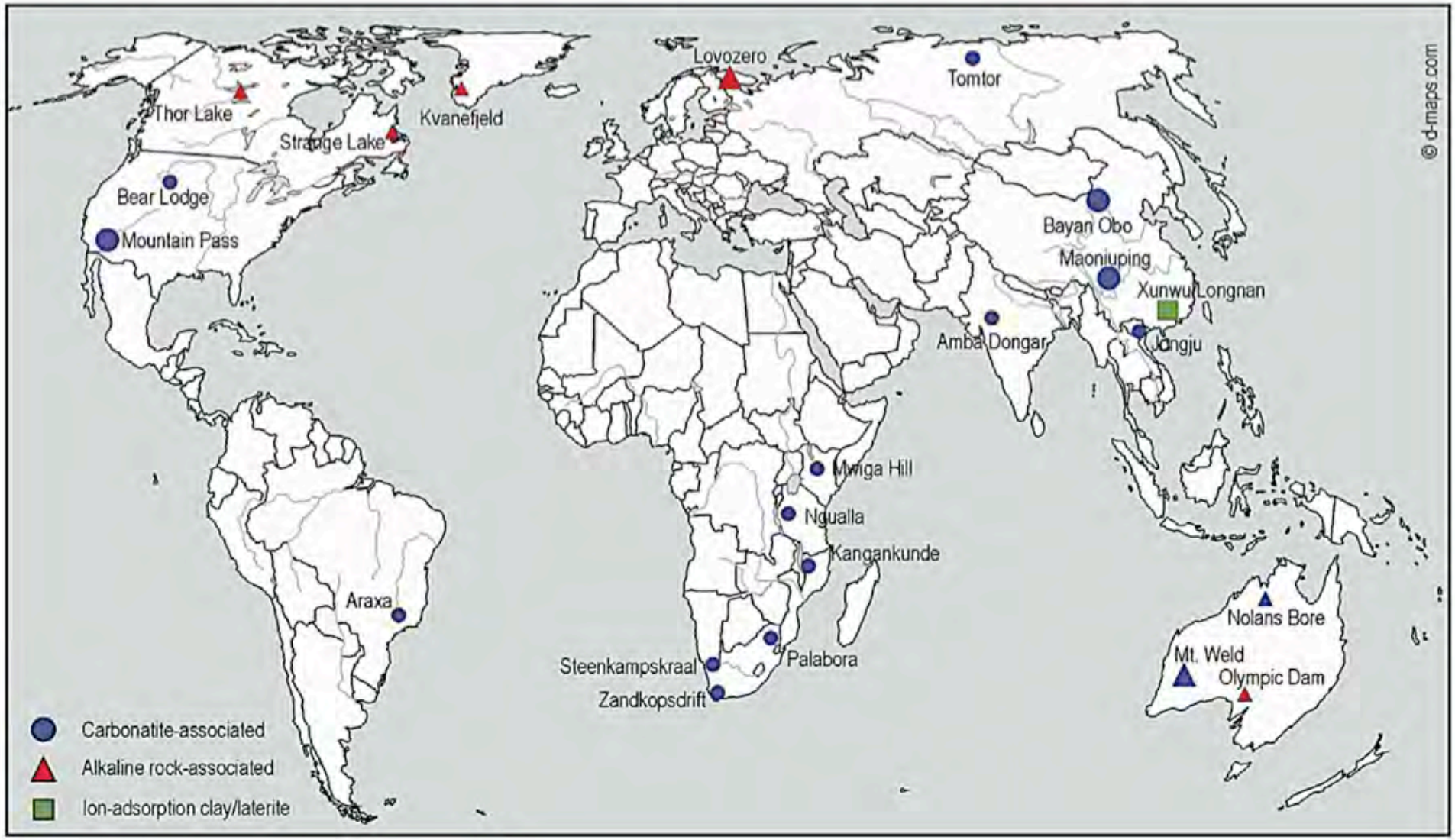
6. Sustainable development, critical metals : short-term vs. long-term

(Calas, 2012)

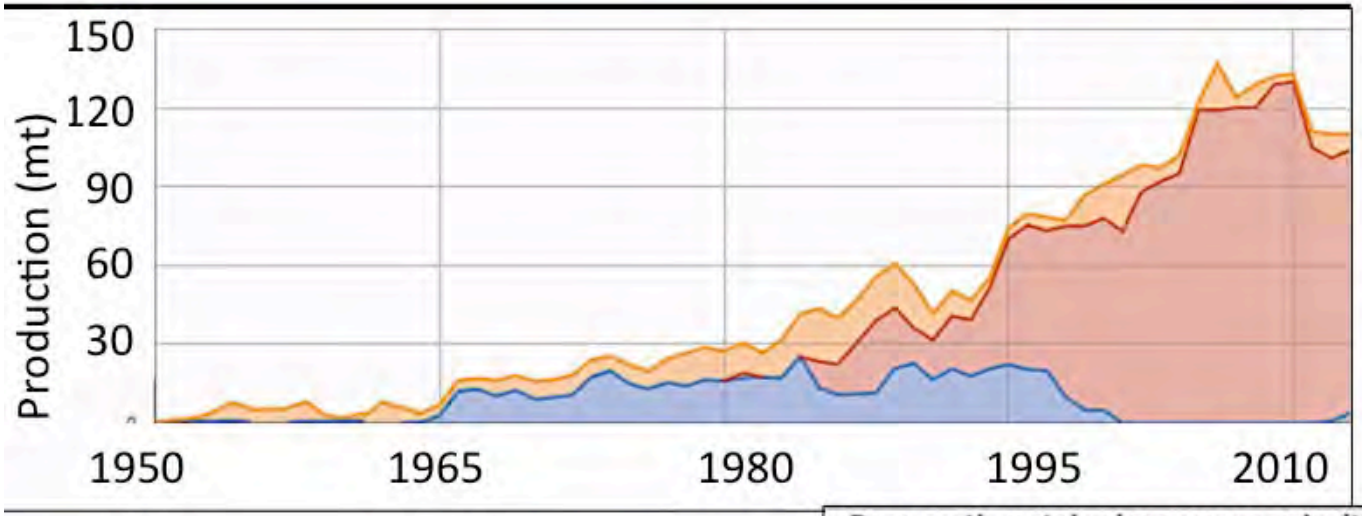
- *What? A gram of dysprosium! You're gone overboard!*
- *We rather wanted to offer you lanthanum, but we did notn't find any!*

(Cabu – Le Canard enchaîné – Dec. 2010).

Poorly distributed ressources : rare earth deposits

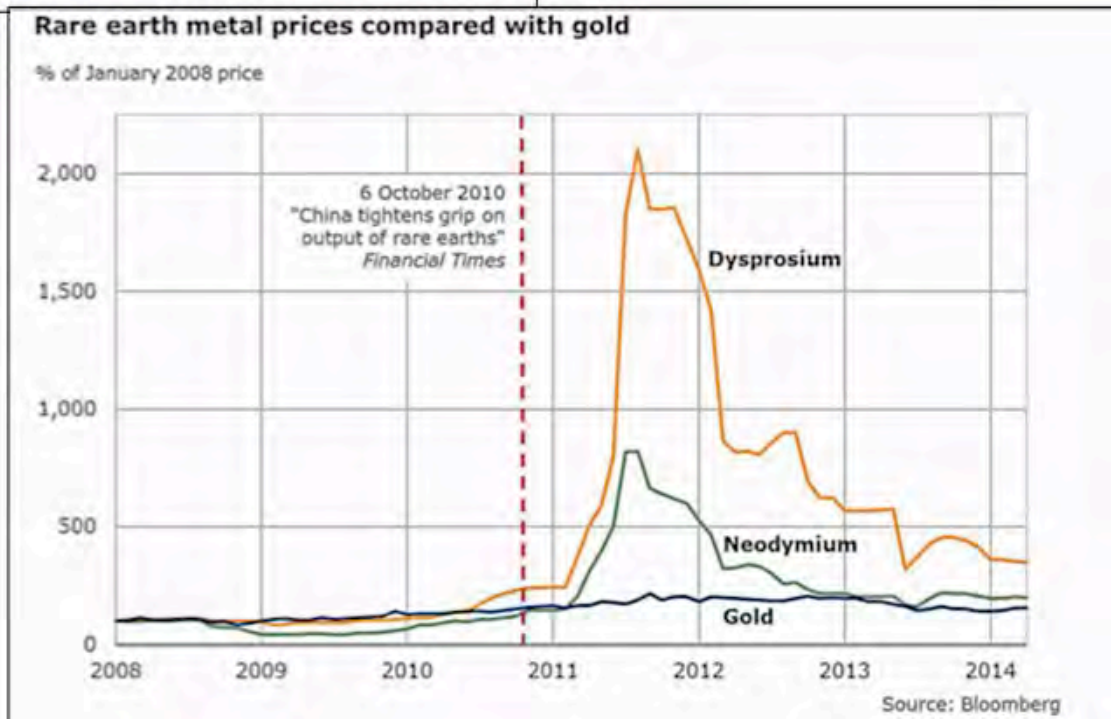


Rare earths: criticality of the resource?



A high-profile crisis:
the 2010 incidents and their consequences on the rare earth market.

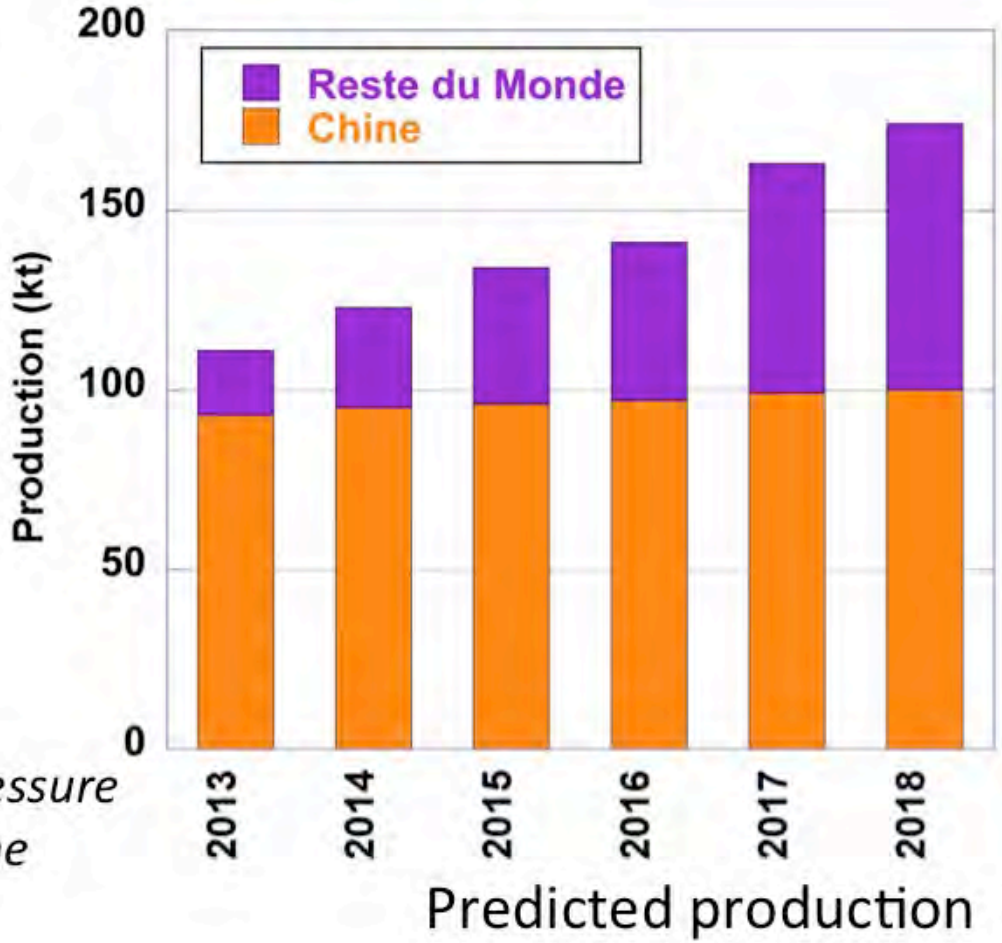
Rare earth prices: the short-term.



Rare earth: after the crisis

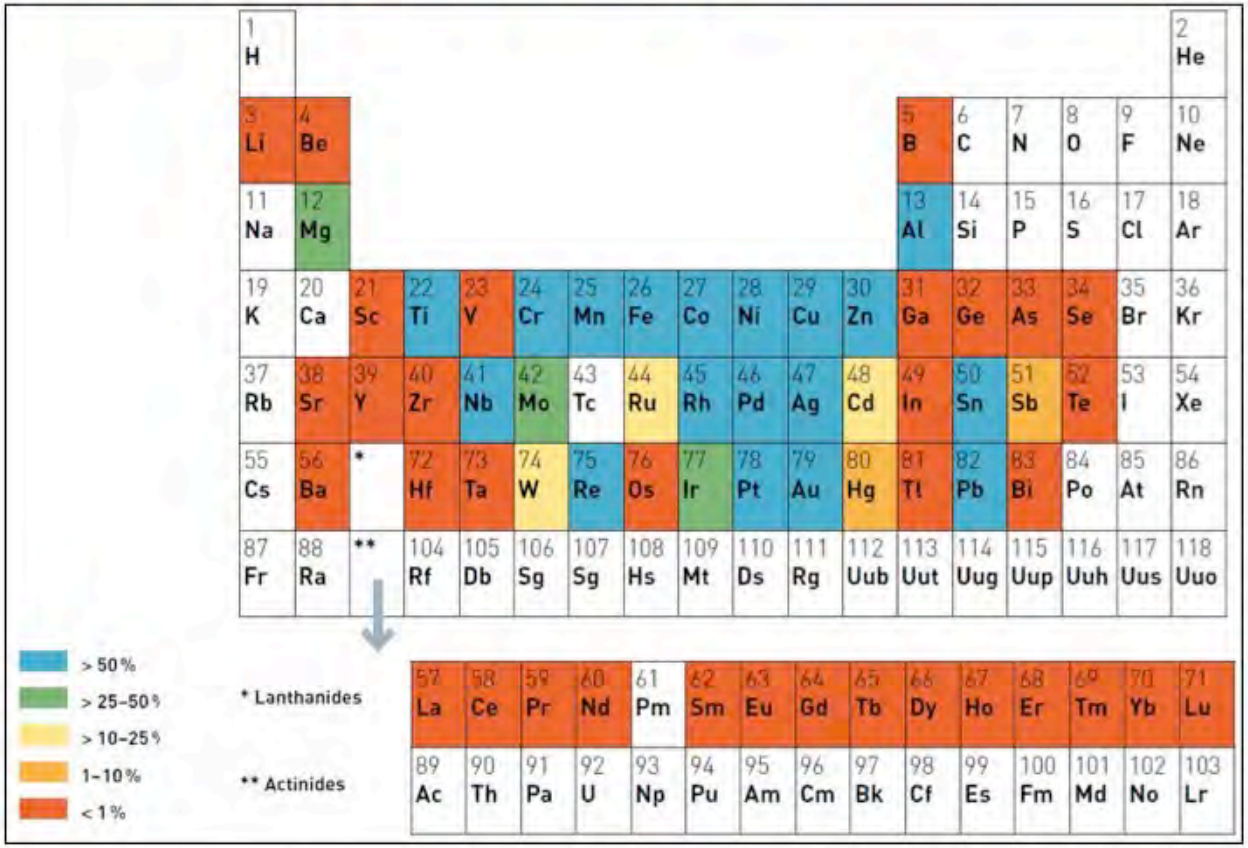
World reserves (140 Mt)

An answer at medium/long term to the economic forcing.



"Policymakers should not succumb to pressure to act too quickly or too expansively in the face of raw materials threat" (E. Gholz)

Recycling, reusing: the new horizons

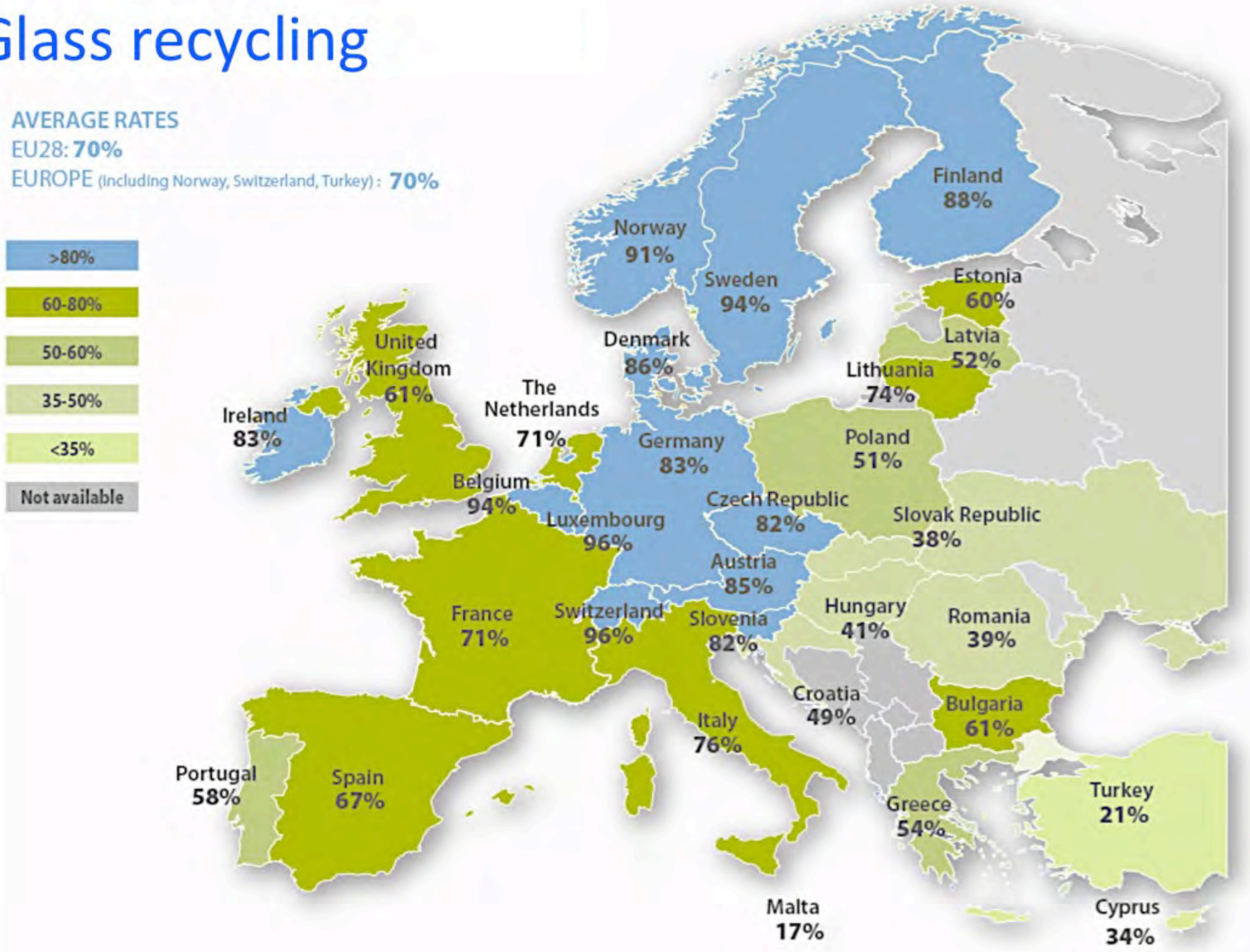


Recycling rates of chemical elements (mostly metals).

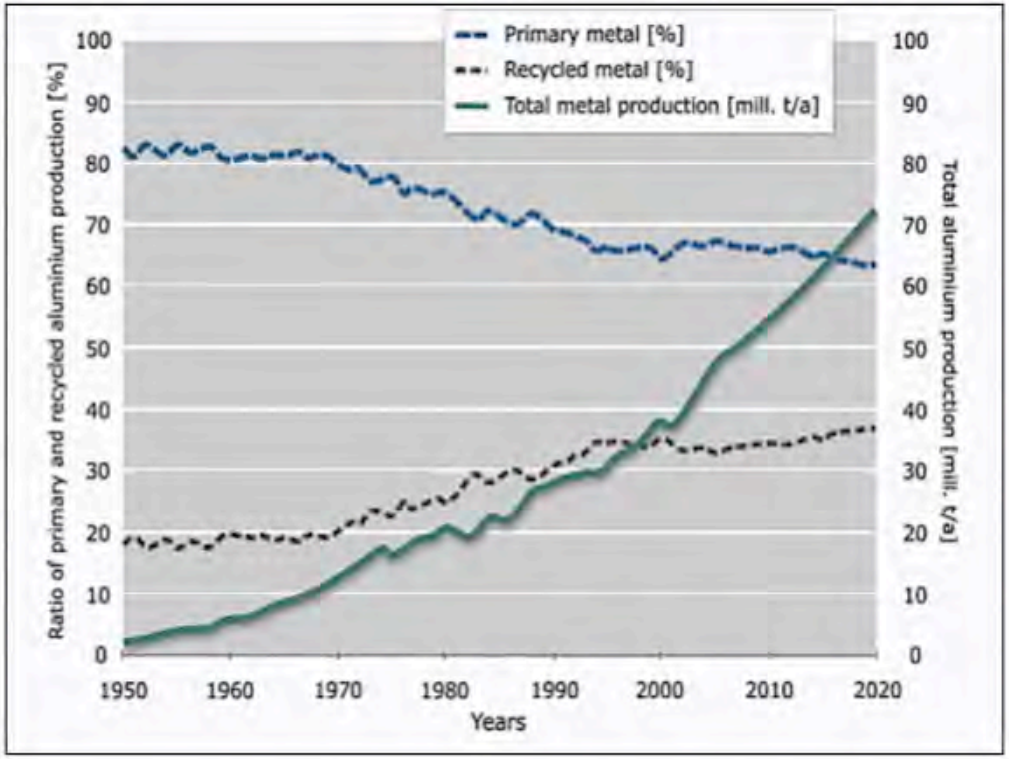
- Large contrasts among elements, varied technological possibilities.
- Limitations to tackle since the manufacturing stage.
- Job diversification for using the "deposits" of secondary raw materials (public buildings and works …).

Glass recycling

AVERAGE RATES
EU28: **70%**
EUROPE (including Norway, Switzerland, Turkey) : **70%**



Is the evolution of mining activity sustainable without recycling?

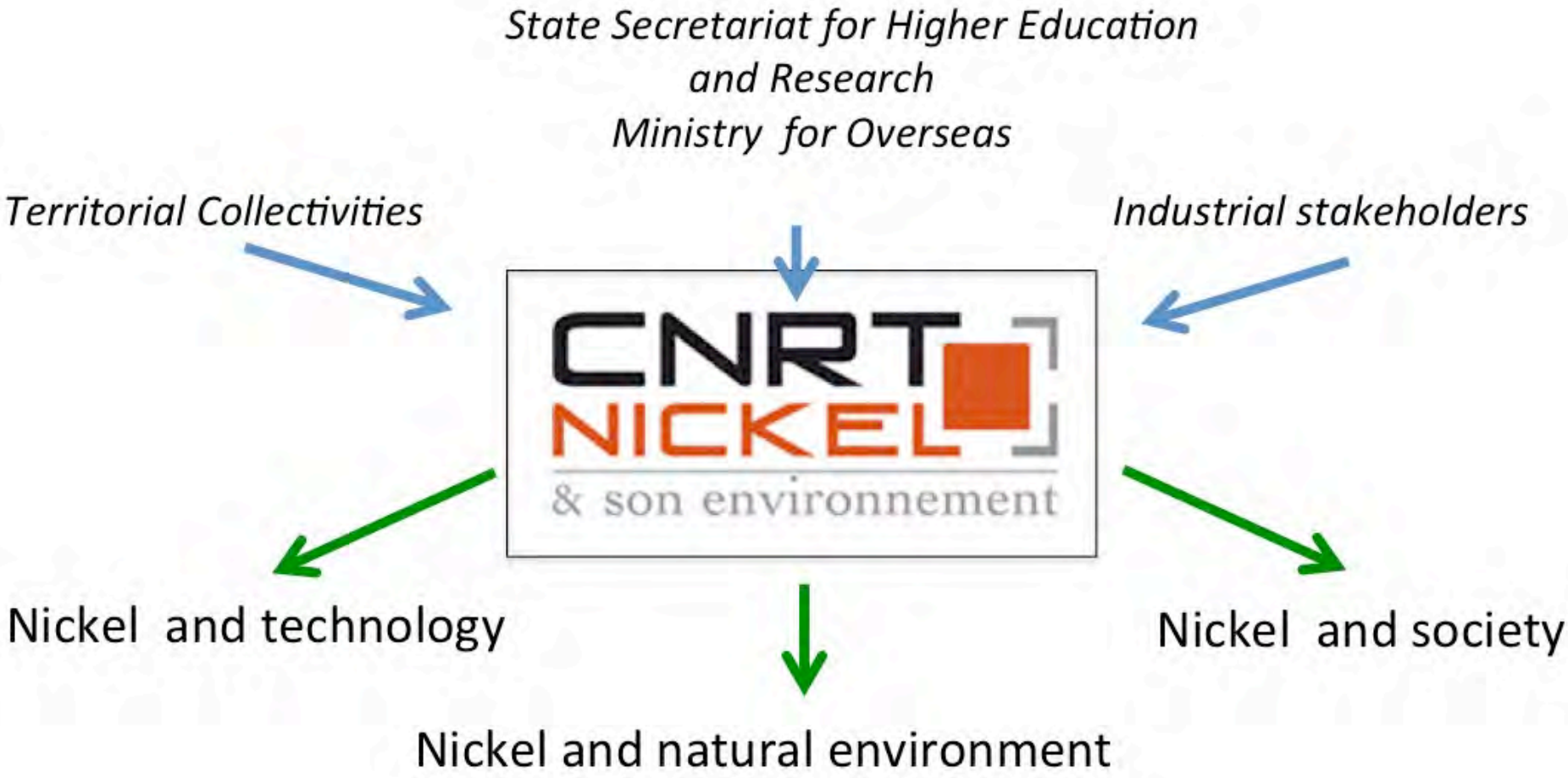


Aluminum

A progressive decrease of the direct mining activity.

"Primary metal production fills the gap between the availability of secondary material and total demand." (ICMM, 2006)

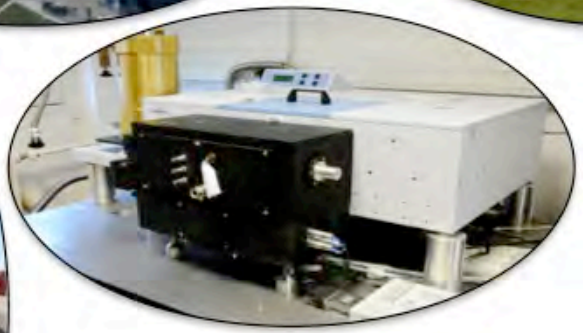
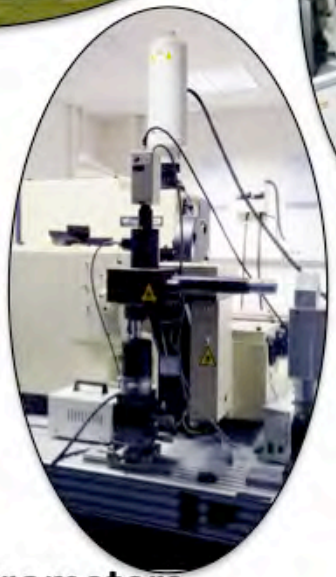
Un example of think tank on sustainable mining activity : the National Center for Technological Research "Nickel and its environment", Nouméa



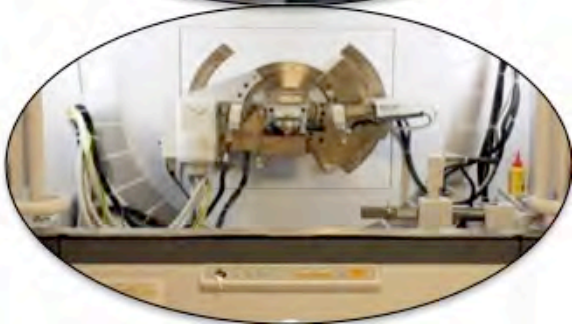
7. Tools adapted to "track" chemical elements









User facilities

Solid-state spectrometers

Electron Microscopes

Diffractometers

Numerical Simulation

As a conclusion

- Formation of ore deposits: a unique conjonction of geological events in a broad range of P/T/bio conditions;
- The future : positive revaluation of deposits, though often located in a difficult context; new processing technologies of the resource; recycling…
- Need for long-term research/R&D;
- Keep a high level of Research and Education in this discrete but vital domain.

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Thanks…

… to the personnalities who participated to the Seminars and to the Symposium;

… to the organisms and Universities whom I belonged to;

… to my family and relatives.