Primary raw material extraction - challenges and needs: a geological perspective

Lluís Fontboté

Earth and Environmental Sciences, Univ. Geneva, Switzerland

Honorary Lecturer Society of Economic Geologists (SEG)

EIP Raw Materials

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Mineral Resources and Geofluids
Department of Earth Sciences

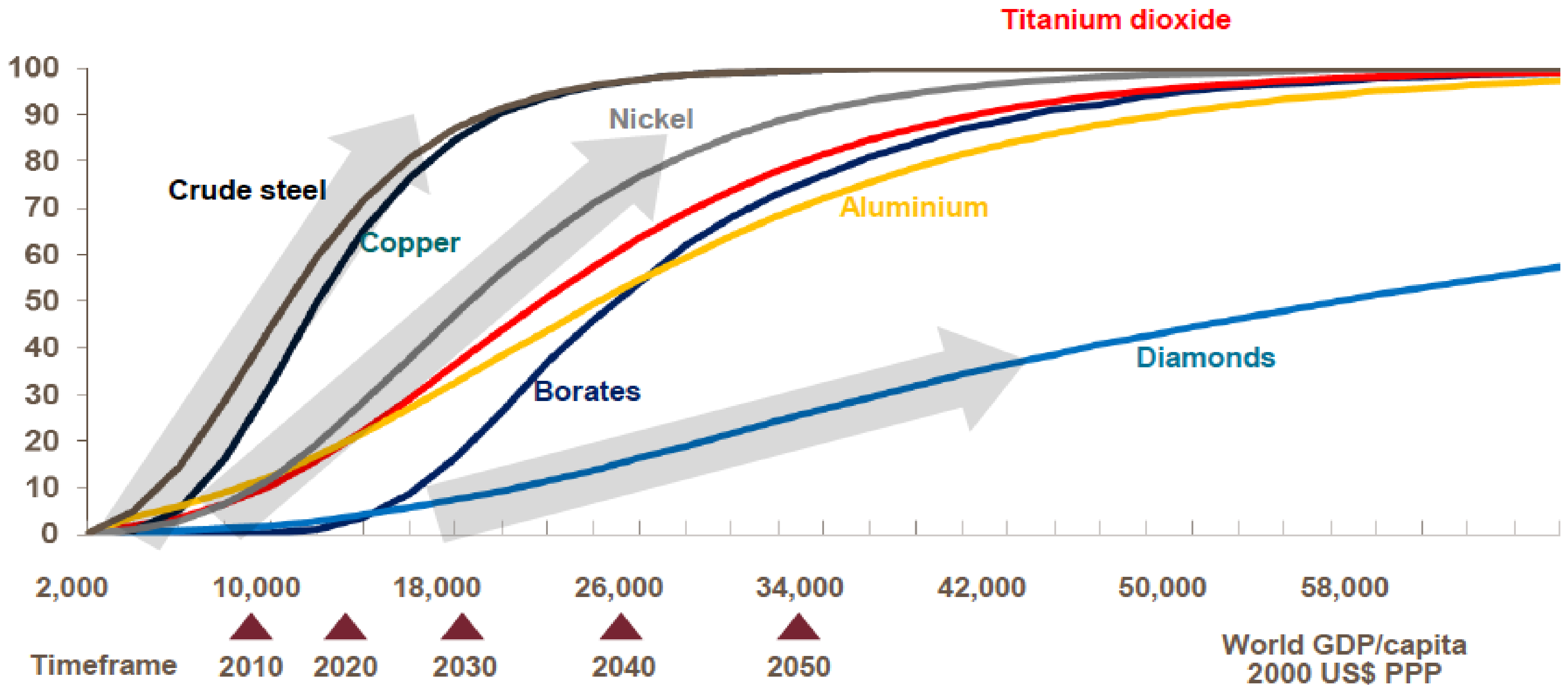
swissuniversity.ch

UNIVERSITÉ DE GENÈVE

Mine production by value

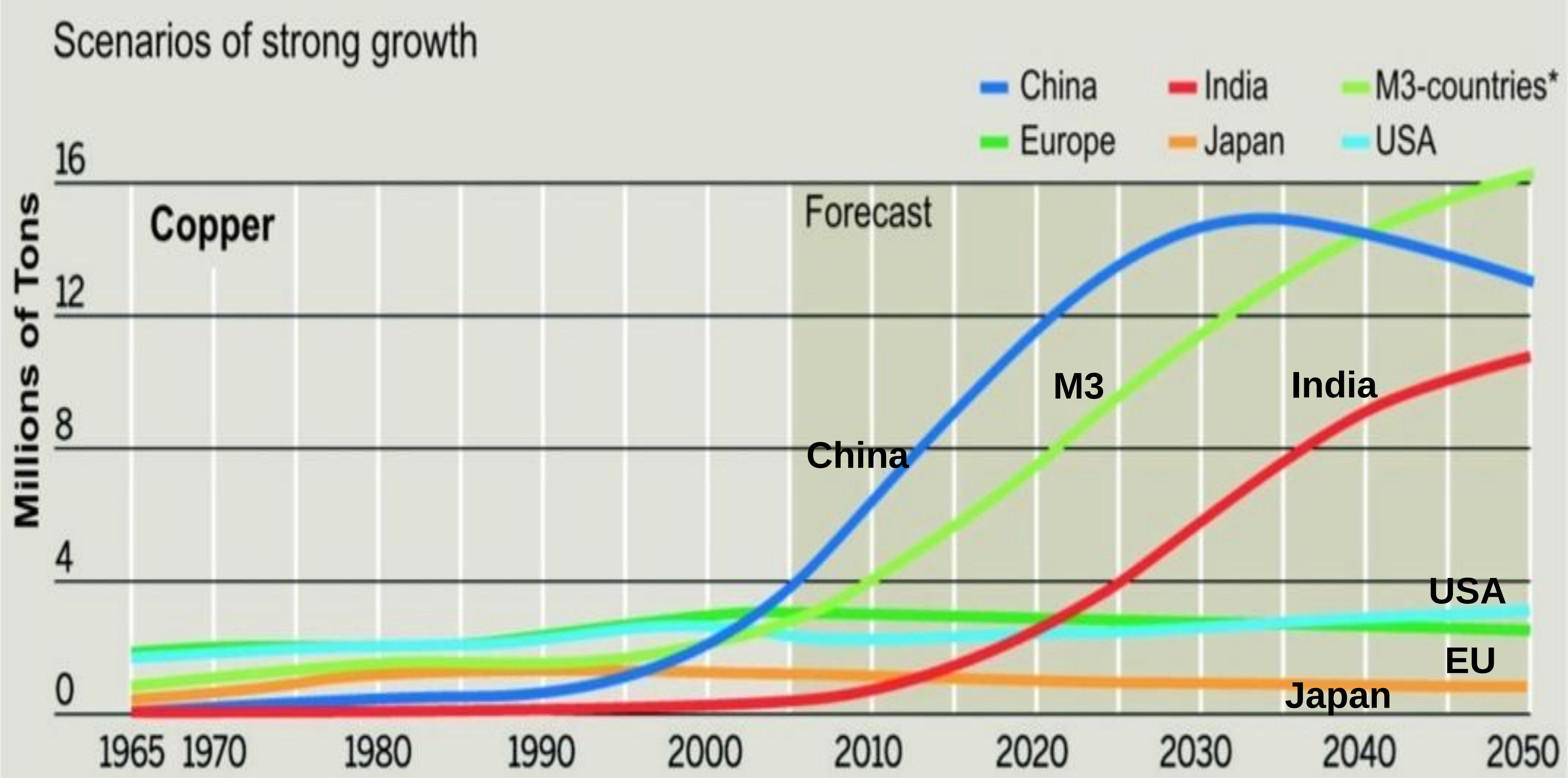
(approximate)	% in value (100% ~ 830 Bill USD, 2012)
Iron	37%
Copper	17%
Aluminium	10%
Au	17%
Pb-Zn	5%
Ni	4%
U	1.0%
Others	10% (includes ~0.3% REE)

Consumption according GDP



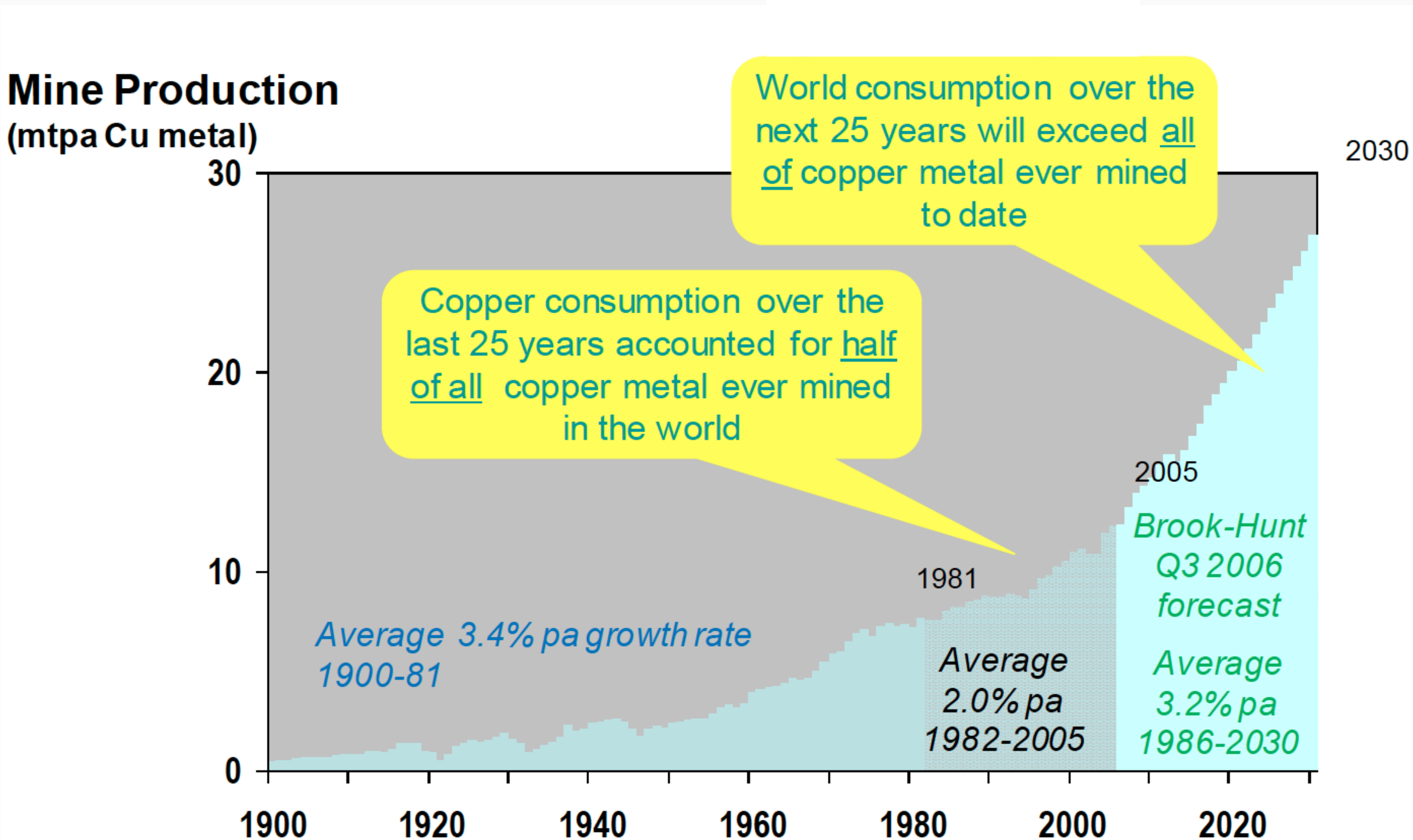
Rio Tinto (2012)

Now China, tomorrow India, M3 countries



(NZZ, Nov. 2006, mod.)

Recycling and use efficiency are good but not enough. We must continue to explore and mine



BHP Billiton (2007)

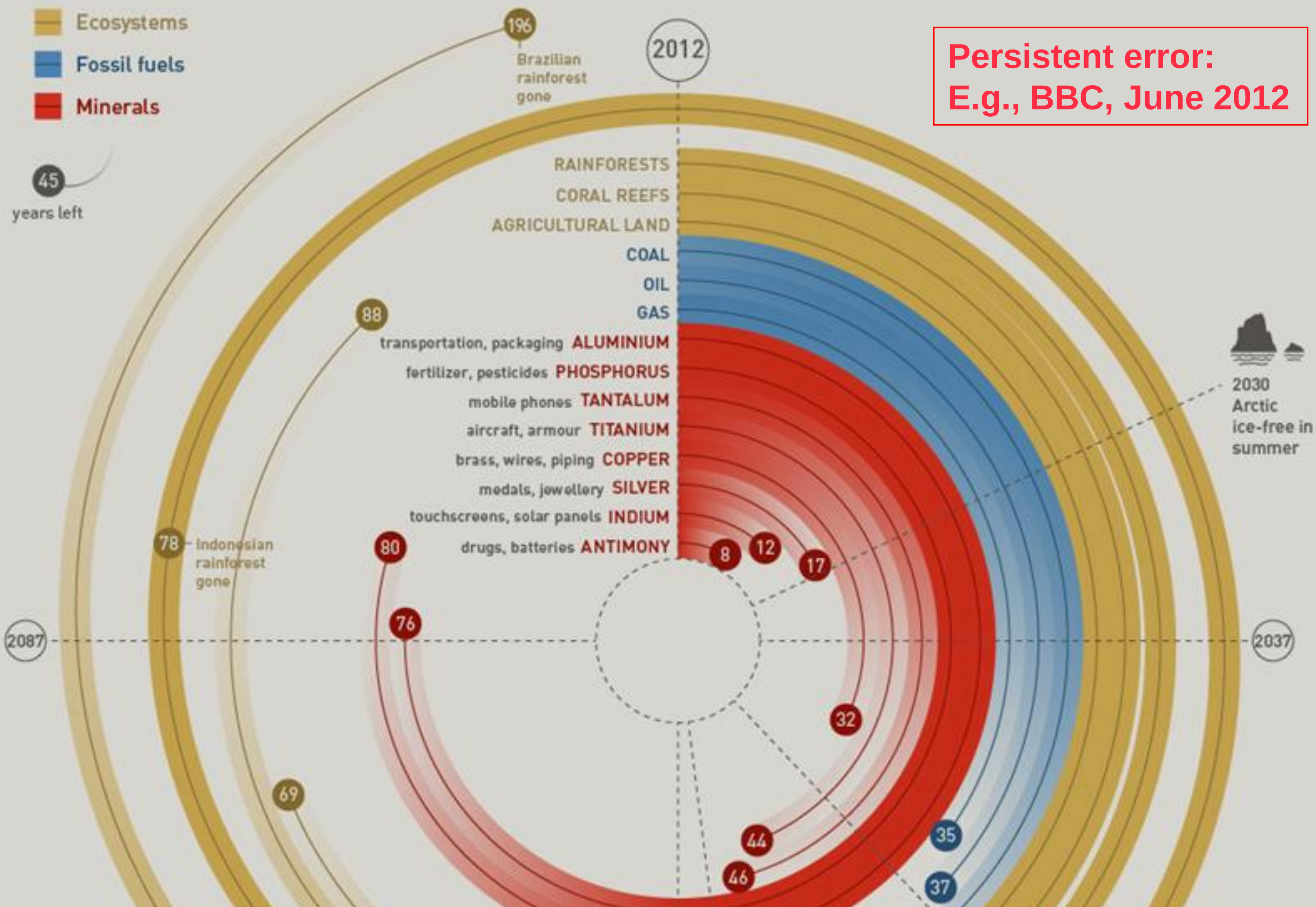
If we have to mine… How long can we?

- **Even if metals are not renewable resources we are far away from a "metal peak"**

- **Most alerts are just wrong and essentially derived from a confusion between resources and reserves**

Stock Check

Estimated remaining world supplies of non-renewable resources



Persistent error:
E.g., BBC, June 2012

Reserve life time depends mainly on investment and type of commodity, NOT on geology!

(in years)	1969	1981	1994	2001	2011
Cu	51	**72**	33*	27*	38*
Zn	16	**40**	20	21	21
Au			21	19	19
Fe	238	**191**	152*	140*	60*

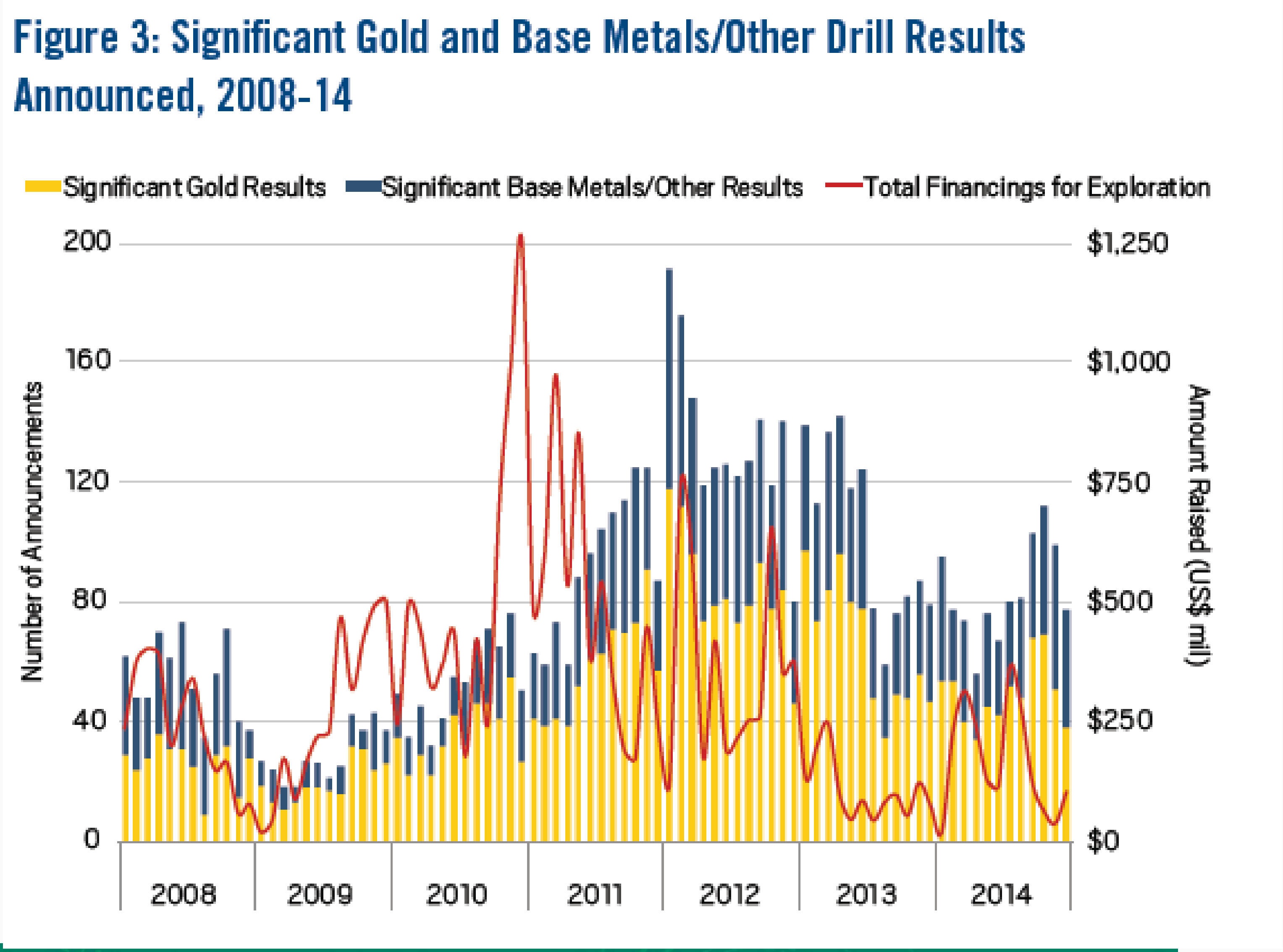
USGS

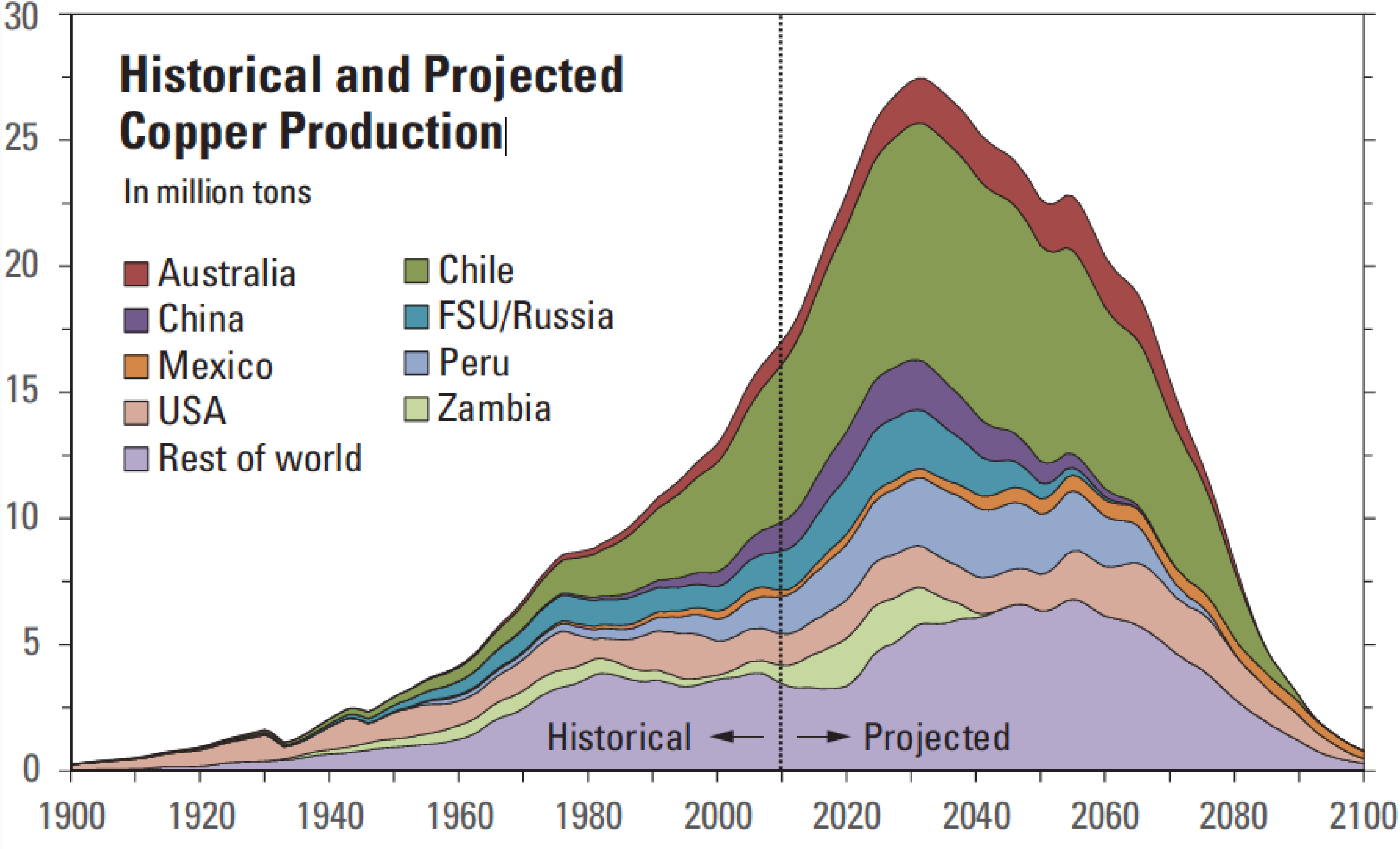
*Reserves 1994. Cu: 310 Mt Fe: 150.000 Mt

*Reserves 2001. Cu: 340 Mt Fe: 140.000 Mt

*Reserves 2011 . Cu: 690 Mt Fe: 170.000 Mt

Investment and Exploration Results





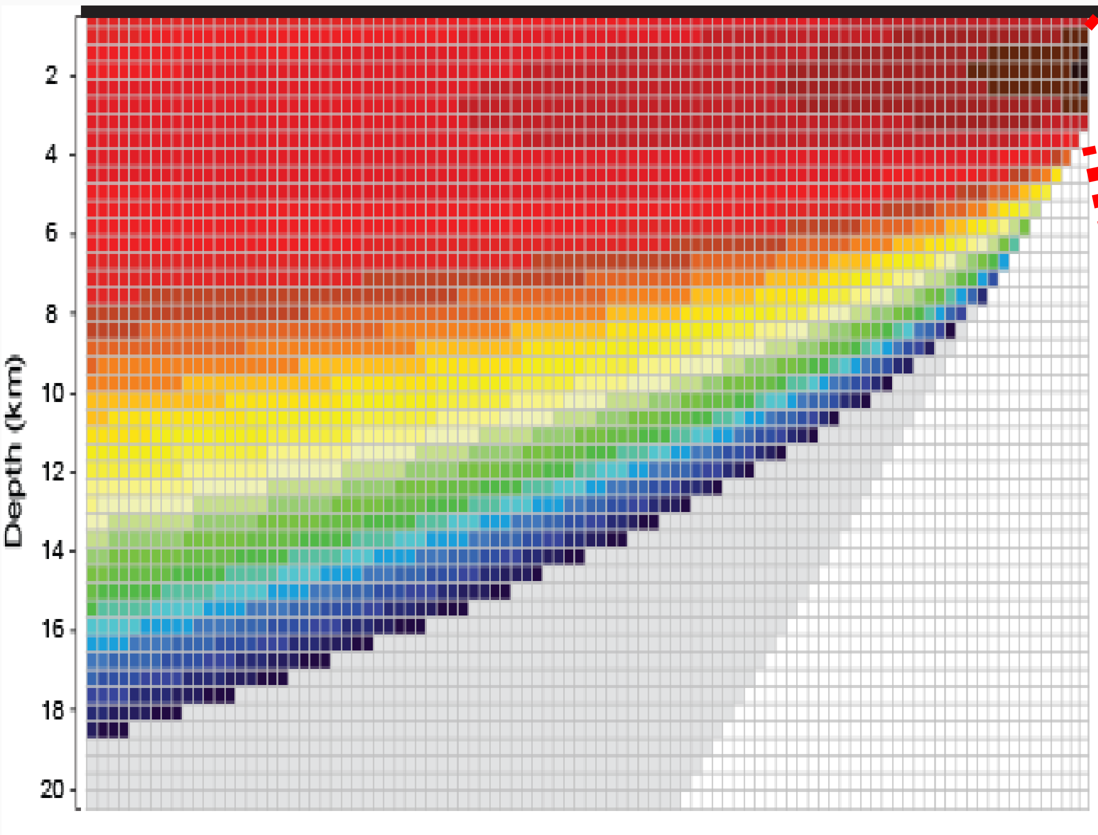
Mohr et al. in Kerr, Science (2014)

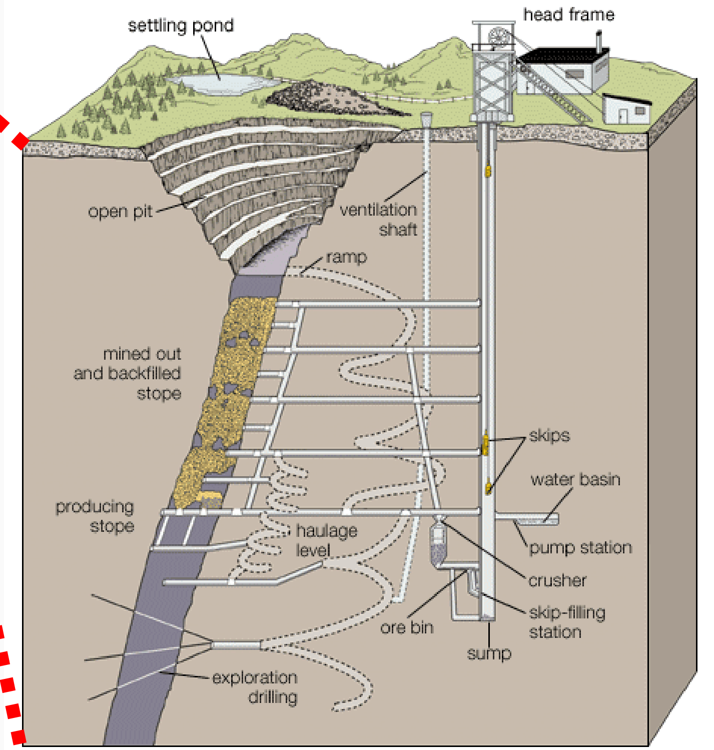
Mohr's model is based on "a database of the extractable copper at all known mine sites" compiled by Mudd and Weng (2012) and on increase of consummation of 1.6% per annum + a 50% increase to account not discovered resources . **Is this a realistic model?**

A more realistic model

(Kesler, Wilkinson, Univ. Michigan, 2005, 2010)

If we can find and mine 50% of resource above 3 km
we can maintain PRESENT PRODUCTION RATE for
~1000 years for Au
~2500 years for Cu
(only magnitude order, same ore deposit types, similar grades and metallurgical processes: potential to improve!)





Business as usual?
NO!

Several critical issues:

- **Social acceptance - NIMBY**
- **Environmental impact**
- **Exploration is increasingly difficult: deeper**
- **Lack of investment**
- **New needs**
- **Better Ore Deposit Models**
- **Creation and transfer of technical know-how (geophysics, mineralogy, drilling, data integration)**

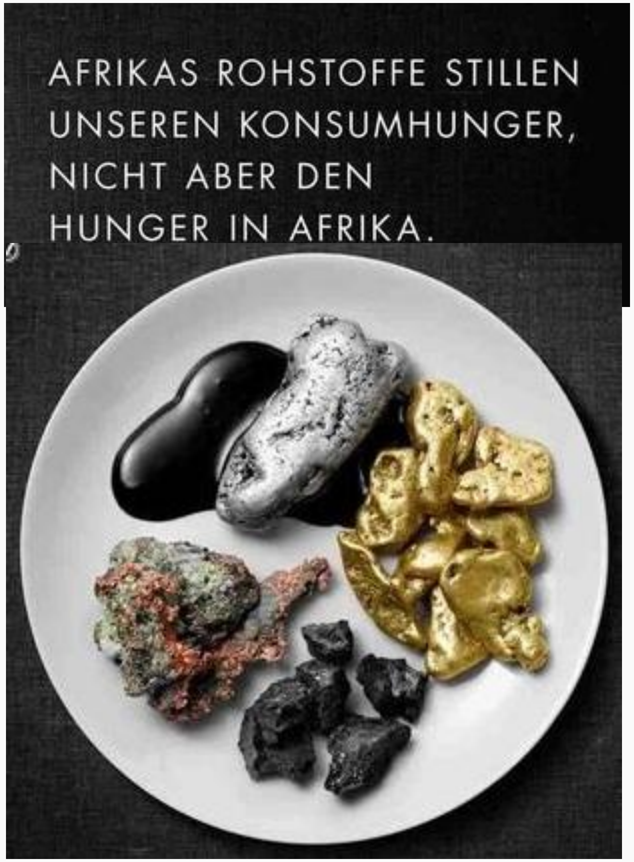
Challenges

- Mineral exploration & mining: reduce costs, better efficiency, higher success rate, reduced environmental and social impact during
- Smaller footprint, less invasive, more predictive
- Less waste, better use of by-products, improve mineral ore dressing efficiency
- New geo-models (mineral deposits and belts)
- Data integration and interpretation

Environmental Impact - Social Licence

Tambogrande, Peru, 2001

Clashes corporate giants



Switzerland, March 2011

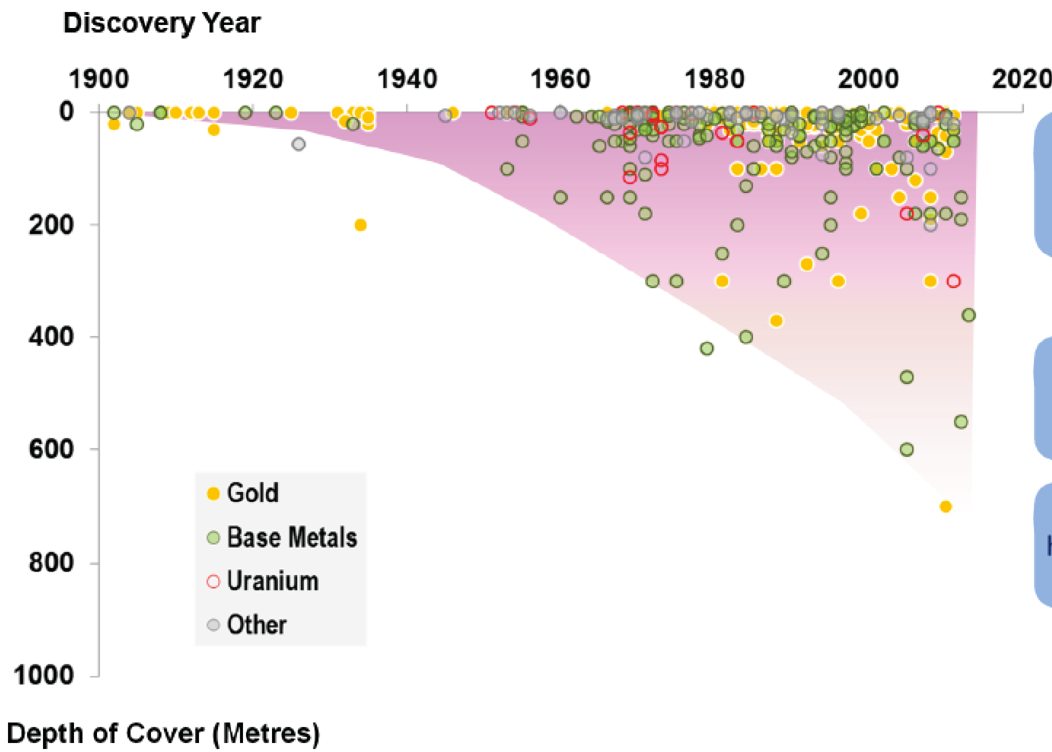
Swiss campaign of churches-related ONG: "Raw materials of Africa feed our consumption desires but not hunger in Africa"

NZZ 20-3-2010

New scientifical and technical know-how needed

Depth of cover for discoveries in Australia: 1900-2013

Australia 2002-2012:reduction of discovery versus $ spent by 60%



Most of the gold discoveries are still being made under shallow cover

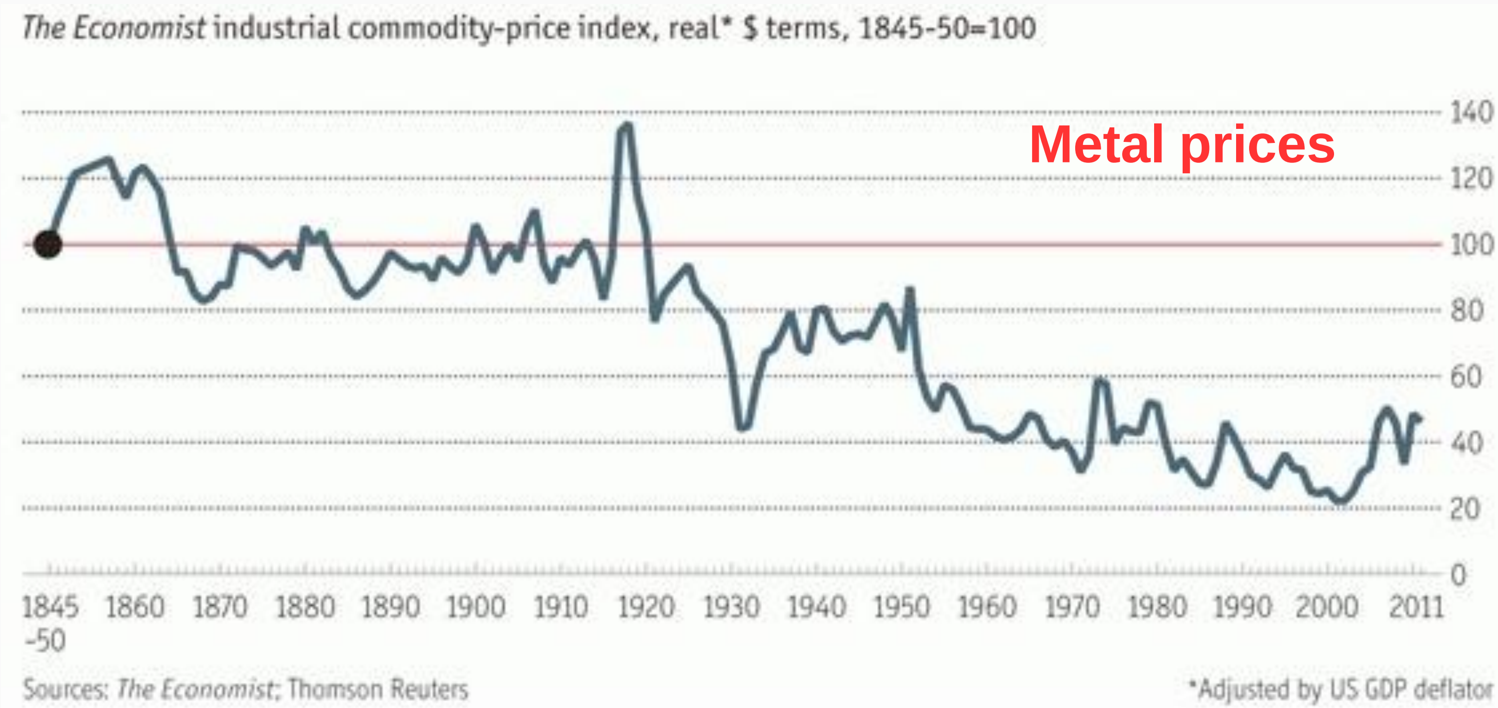
It is difficult to find deposits under deep cover

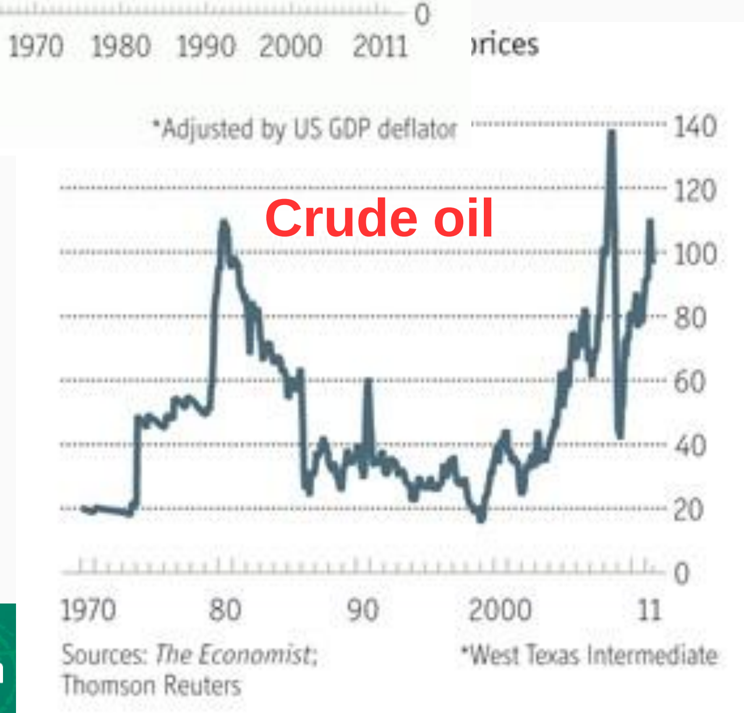
... end-result is that we have to drill more metres per discovery

Note: Excludes satellite deposits within existing Camps. Also excludes Bulk Mineral discoveries.. Analysis based on Moderate-, Major- and Giant-sized deposits

Source: MinEx Consulting © November 2013

Metal prices after 1845



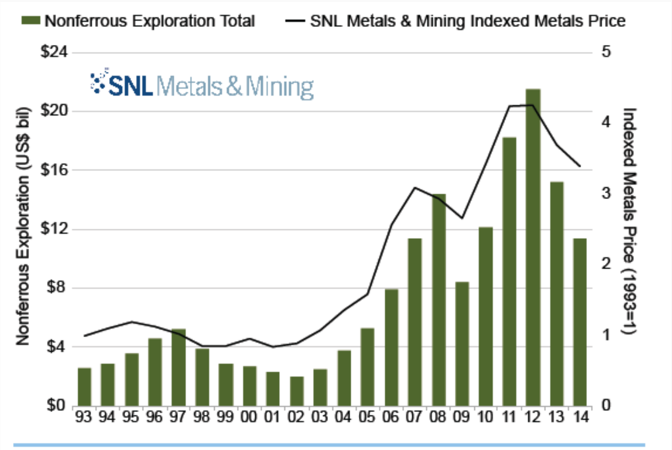


Metal prices consistently decreased since 1900. Since 2002 they tend to increase: change of tendency? Just an "irregularity"?

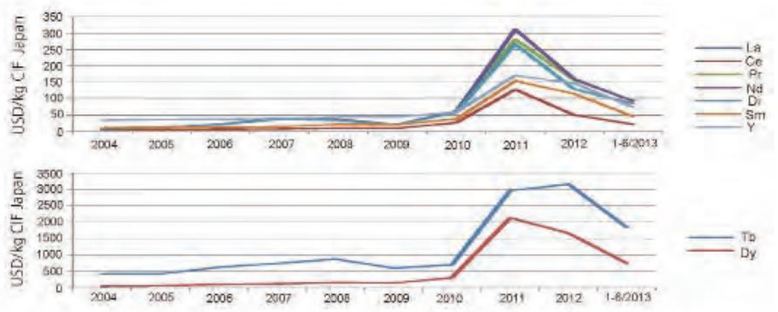
(Different beahaviour than for oil!)

The Economist 24-9-2011
http://www.economist.com/node/21528986

Lack of investments: new RM crisis will come as from exploration to mining ~15 years

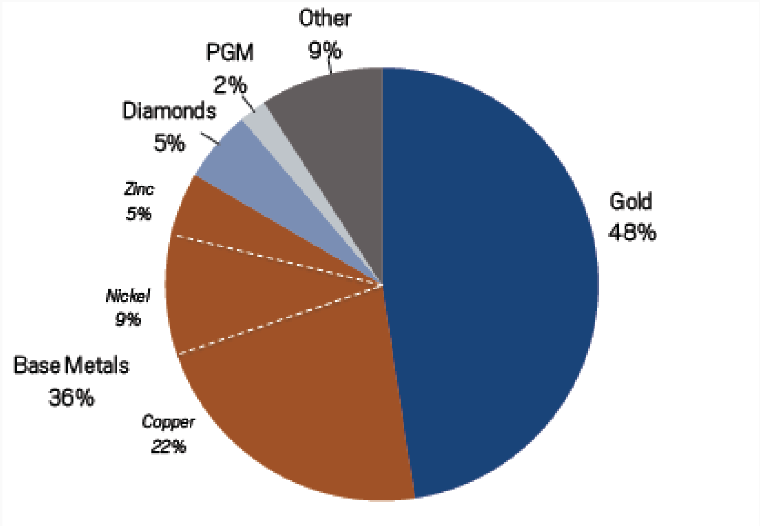


SNL Metal Exploration trends 2015



Watanabe, 2014

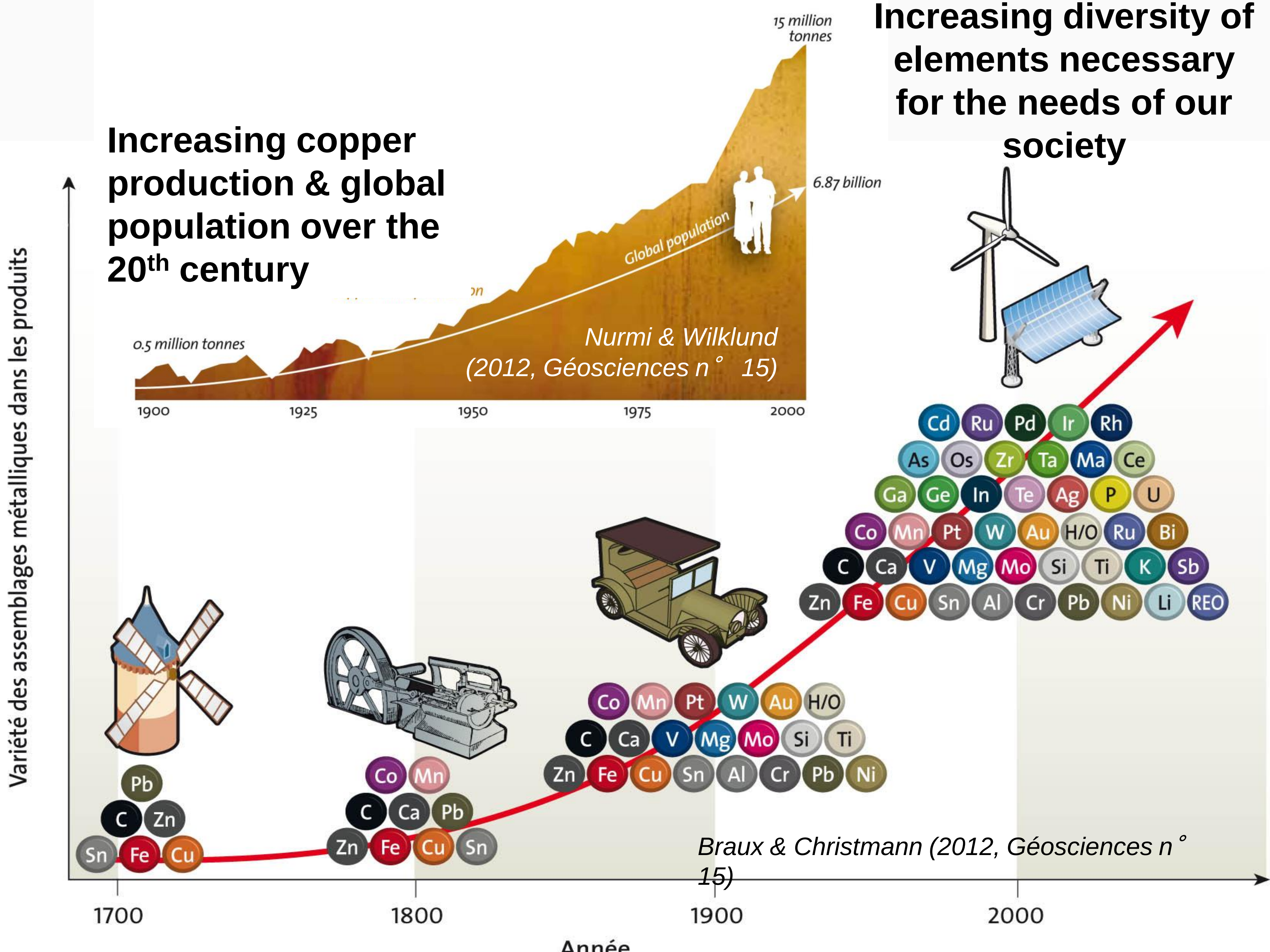
- Most exploration investment is short-term minded and follows metal prices
- Investment trends and societal need do not coincide



SNL Metal Exploration trends 2010

Increasing copper production & global population over the 20th century

Increasing diversity of elements necessary for the needs of our society



Nurmi & Wilklund (2012, Géosciences n° 15)

Braux & Christmann (2012, Géosciences n° 15)

Challenges

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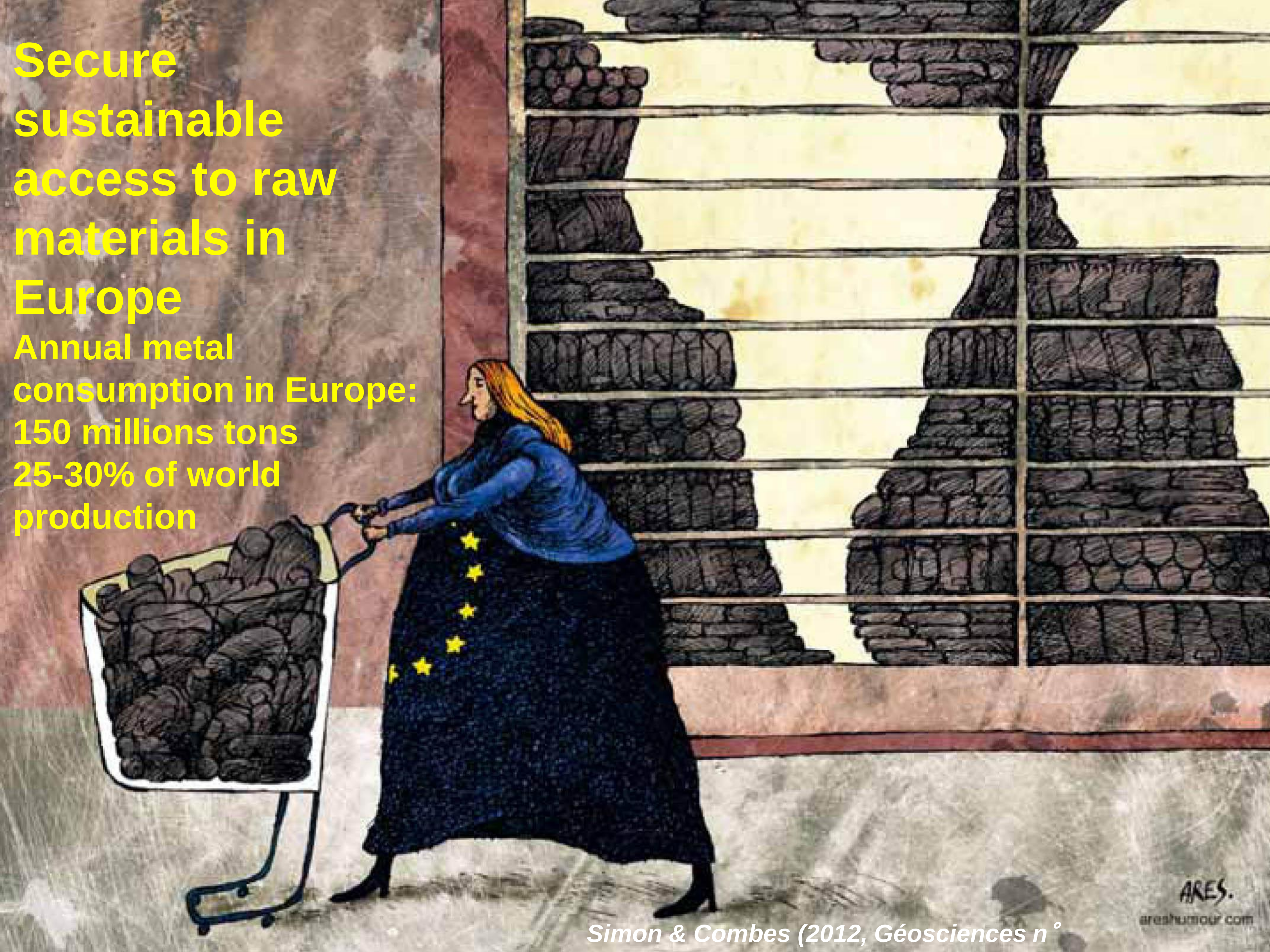
Secure sustainable access to raw materials in Europe

Annual metal consumption in Europe: 150 millions tons 25-30% of world production



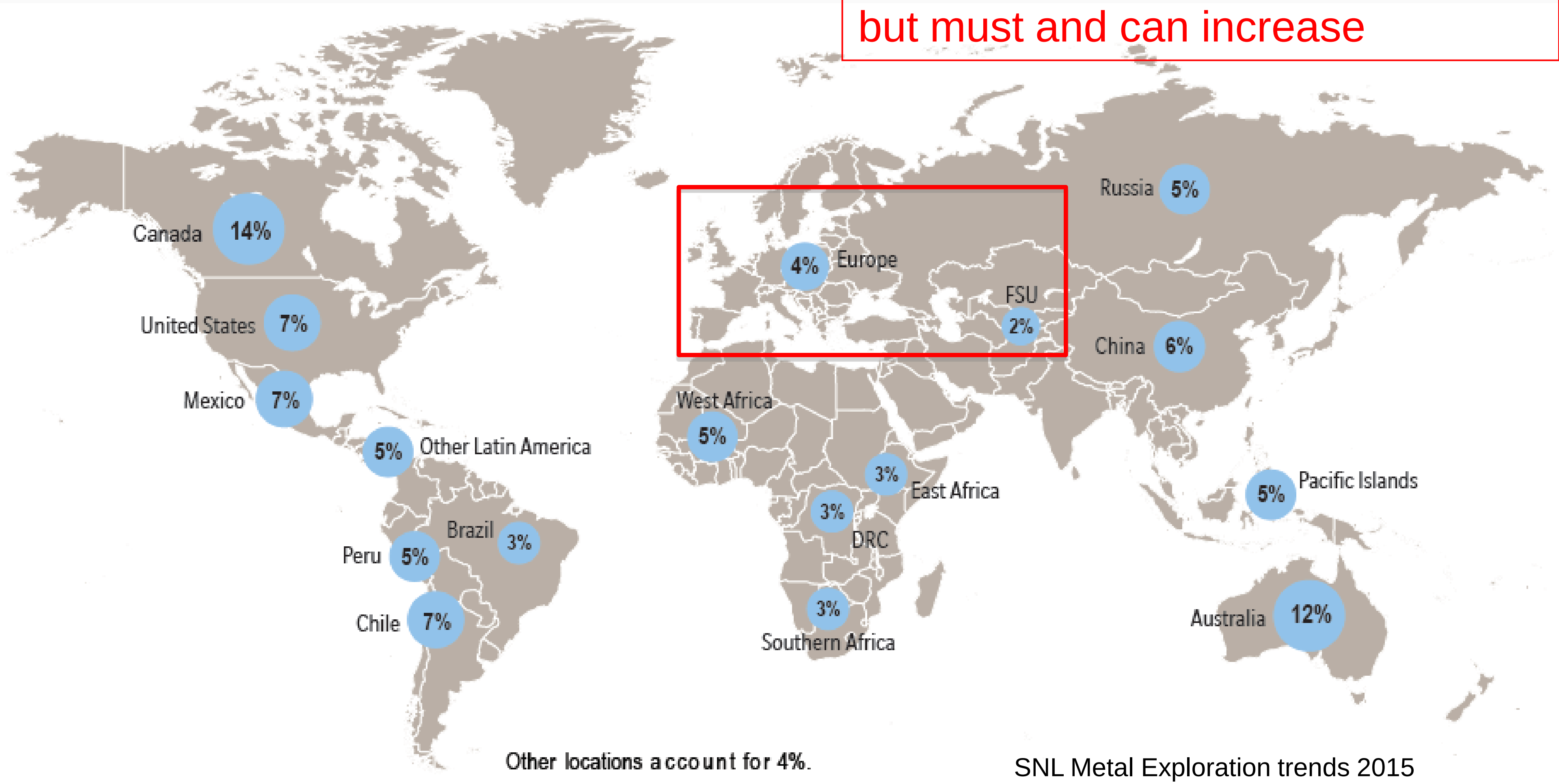
Simon & Combes (2012, Géosciences n°

Challenges - EU

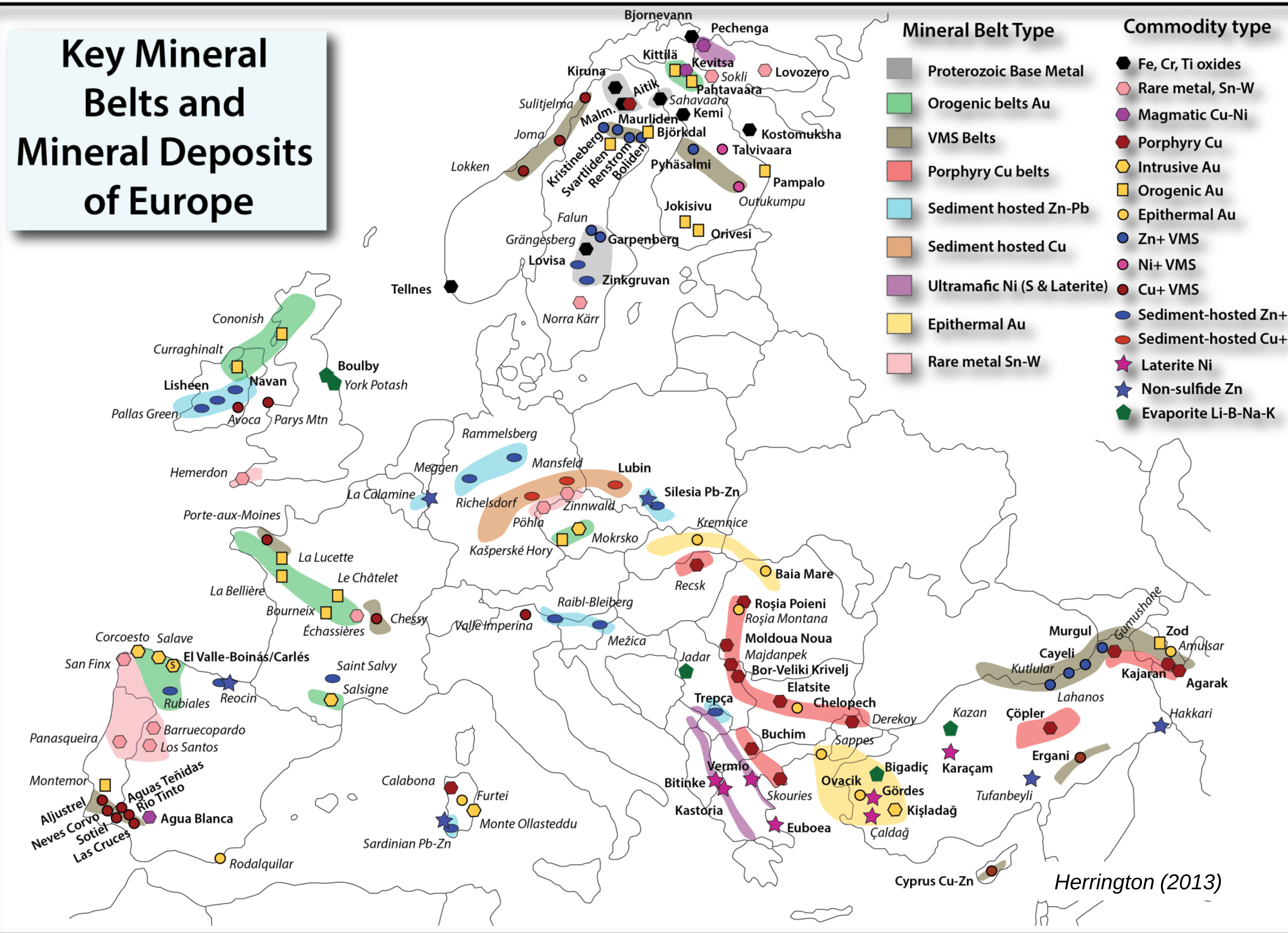
- EU strong dependency on imports of critical raw materials
- Need of sustainable access to raw materials
- Populated area (difficult access to land)
- Old mining districts / Deep mining / Small deposits
- Know how (for a long time raw materials were not "important")

Top destinations nonferrous exploration 2014

Exploration in Europe not negligible
but must and can increase



SNL Metal Exploration trends 2015

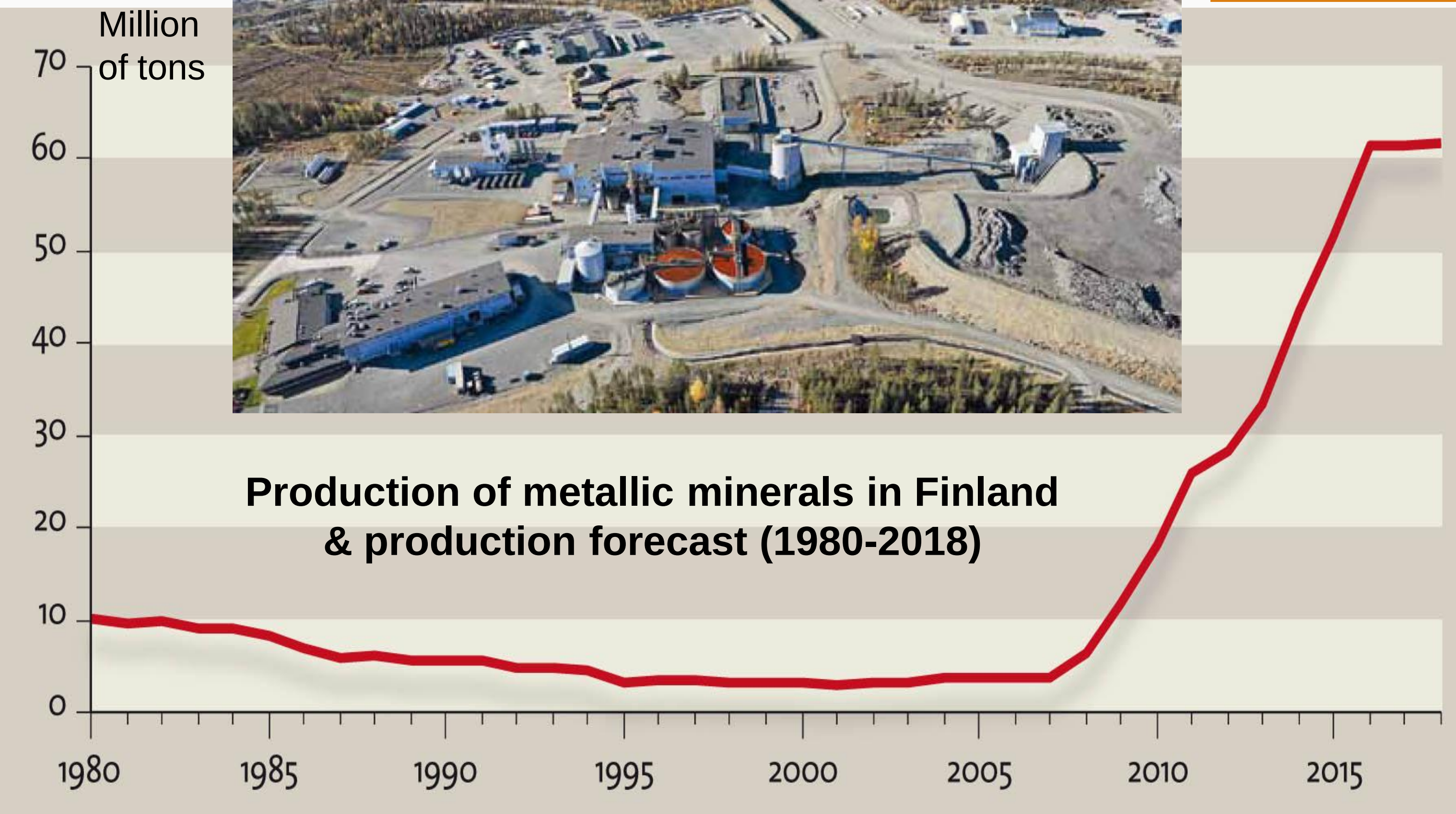

Key Mineral Belts and Mineral Deposits of Europe
Mineral Belt Type
Proterozoic Base Metal
Orogenic belts Au
VMS Belts
Porphyry Cu belts
Sediment hosted Zn-Pb
Sediment hosted Cu
Ultramafic Ni (S & Laterite)
Epithermal Au
Rare metal Sn-W
Commodity type
Fe, Cr, Ti oxides
Rare metal, Sn-W
Magmatic Cu-Ni
Porphyry Cu
Intrusive Au
Orogenic Au
Epithermal Au
Zn+ VMS
Ni+ VMS
Cu+ VMS
Sediment-hosted Zn+
Sediment-hosted Cu+
Laterite Ni
Non-sulfide Zn
Evaporite Li-B-Na-K
Bjornevann
Pechenga
Kittilä
Kevitsa
Lovozero
Sokli
Pahtavaara
Kiruna
Aitik
Sahavaara
Kemi
Sulitjelma
Malm.
Maurliden
Björkdal
Kostomuksha
Joma
Kristineberg
Svartliden
Renstrom
Boliden
Talvivaara
Pyhäsalmi
Lokken
Pampalo
Outukumpu
Jokisivu
Falun
Orivesi
Grängesberg
Garpenberg
Lovisa
Zinkgruvan
Tellnes
Norra Kärr
Cononish
Curraghinalt
Boulby
York Potash
Lisheen
Navan
Pallas Green
Avoca
Parys Mtn
Rammelsberg
Meggen
Mansfeld
Lubin
Hemerdon
La Calamine
Richelsdorf
Silesia Pb-Zn
Zinnwald
Porte-aux-Moines
Pöhla
Kremnice
Mokrsko
Kašperské Hory
La Lucette
Baia Mare
Recsk
Le Châtelet
La Bellière
Raibl-Bleiberg
Roşia Poieni
Bourneix
Chessy
Valle Imperina
Roşia Montana
Échassières
Mežica
Moldoua Noua
Murgul
Gumushane
Zod
Corcoesto
Salave
Majdanpek
Cayeli
Amulsar
Jadar
El Valle-Boinás/Carlés
San Finx
Saint Salvy
Bor-Veliki Krivelj
Kutlular
Kajaran
Agarak
Salsigne
Elatsite
Reocin
Trepça
Chelopech
Lahanos
Rubiales
Derekoy
Kazan
Çöpler
Hakkari
Barruecopardo
Buchim
Sappes
Panasqueira
Los Santos
Vermio
Bigadiç
Karaçam
Ergani
Montemor
Ovacik
Bitinke
Calabona
Aguas Teñidas
Rio Tinto
Furtei
Gördes
Tufanbeyli
Aljustrel
Skouries
Kastoria
Kişladağ
Neves Corvo
Sotiel
Las Cruces
Agua Blanca
Monte Ollasteddu
Euboea
Çaldağ
Sardinian Pb-Zn
Rodalquilar
Cyprus Cu-Zn
Herrington (2013)

Mining "in our backyard" ….

… is essential not only for **directly assuring raw materials necessary for our society** but also for several critical issues

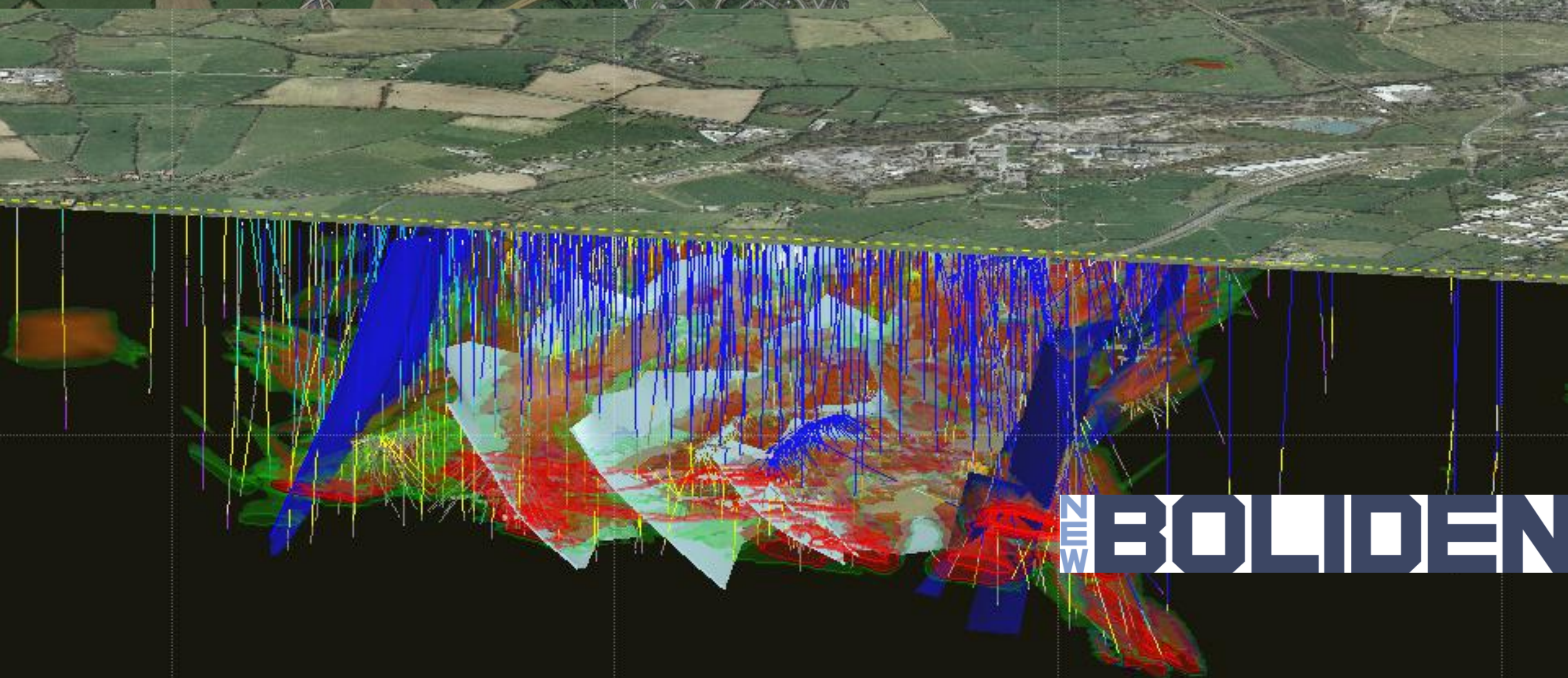
- Share of benefit and burden
- Creating models of sustainable mining (necessary to increase social acceptance and decrease environmental impact). Already good examples exist.
- Increasing know-how (science and technical): e.g., deposits under cover!
- Increasing social awareness that our society depends on metal supply

Reduce environmental impact of mining



Nurmi & Wilklund (2012, Géosciences n° 15)

Mining in Europe



NEW BOLIDEN

Dependency of the European Union (2009) on import of critical elements and other raw materials

Antimoine	100 %
Béryllium	100 %
Bore	100 %
Cobalt	100 %
Molybdène	100 %
Niobium	100 %
Platinoïdes	100 %
Terres rares	100 %
Tantale	100 %
Titane	100 %
Germanium	100 %
Vanadium	100 %

Phosphates	92 %
Rhénium	90 %
Nickel	86 %
Fer	83 %
Aluminium	80 %
Zinc	80 %
Tungstène	76 %
Plomb	76 %
Cuivre	74 %
Chrome	53 %

Braux & Christmann (2012, Géosciences n° 15)

Contribution to world production by China in 2009