I giacimenti minerari: anomalie della distribuzione degli elementi nella Terra

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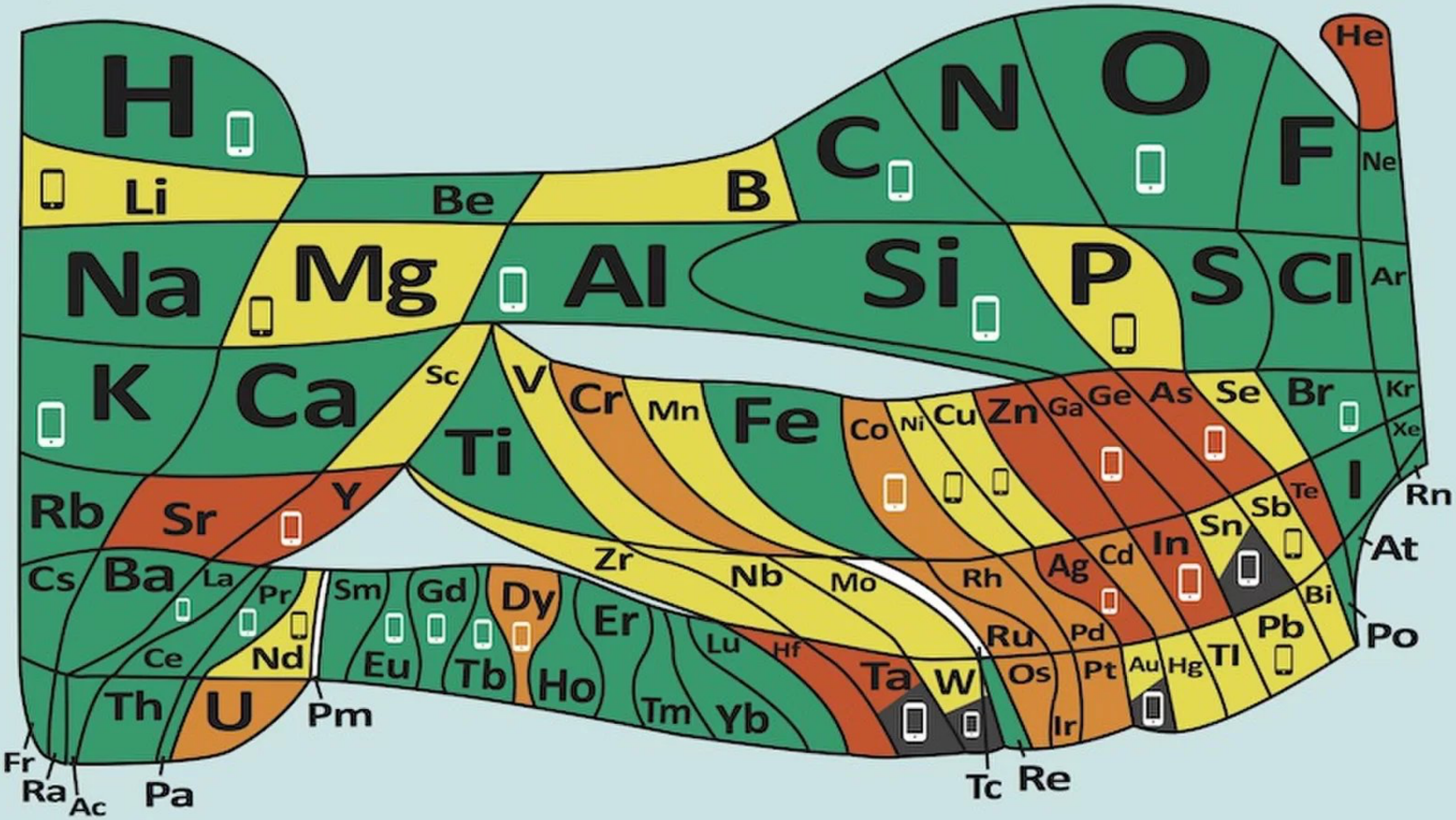
DiSTAR Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse

United Nations Educational, Scientific and Cultural Organization

2019 IYPT
International Year of the Periodic Table of Chemical Elements

The 90 natural elements that make up everything

How much is there? Is that enough?



Serious threat in the next 100 years

Rising threat from increased use

Limited availability, future risk to supply

Plentiful Supply

Synthetic

From conflict minerals

Elements used in a smart phone

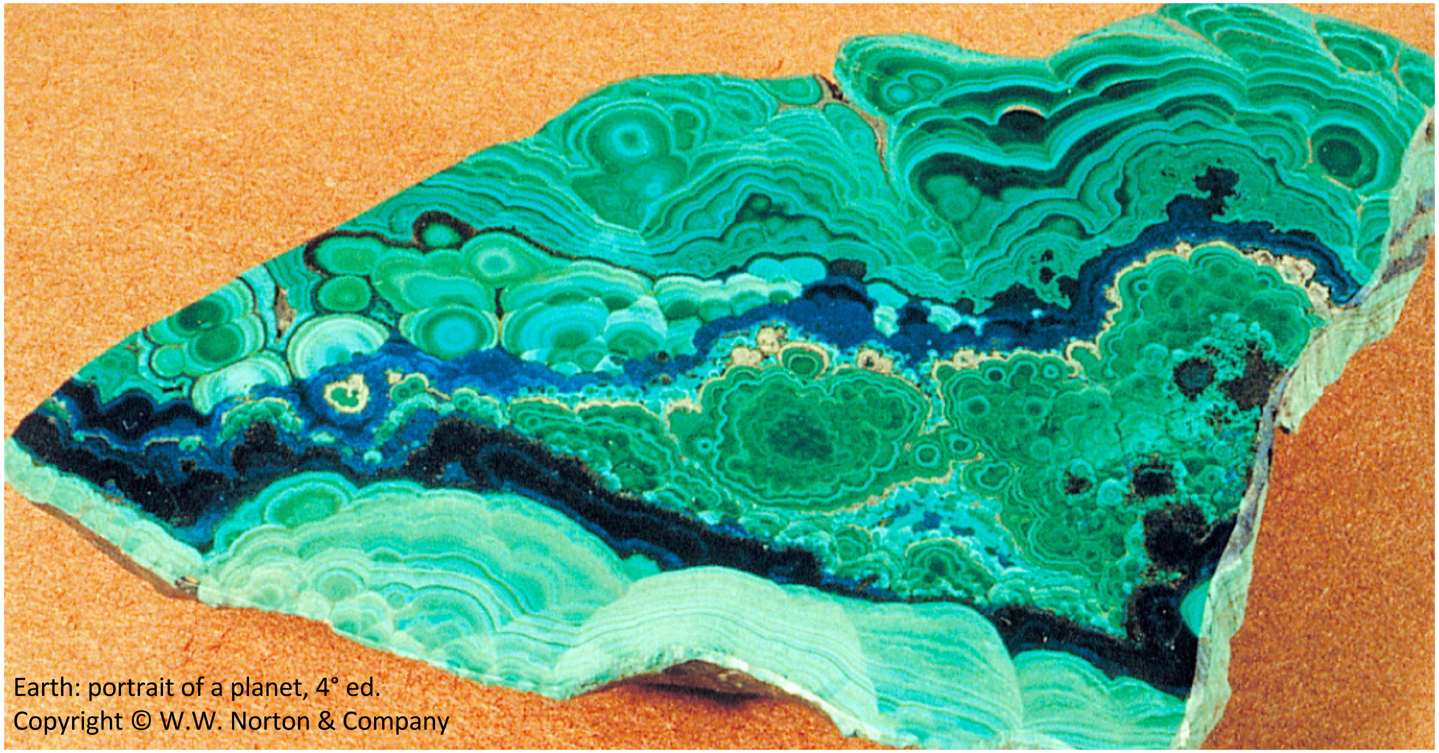
Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'

Read more and play the video game **http://bit.ly/euchems-pt**

EuChemS
European Chemical Society

Giacimenti minerari

Accumuli naturali di minerali o metalli nella crosta terrestre che, per dimensione, concentrazione e localizzazione, sono sfruttabili con profitto.
I metalli devono essere recuperati a costi relativamente bassi.

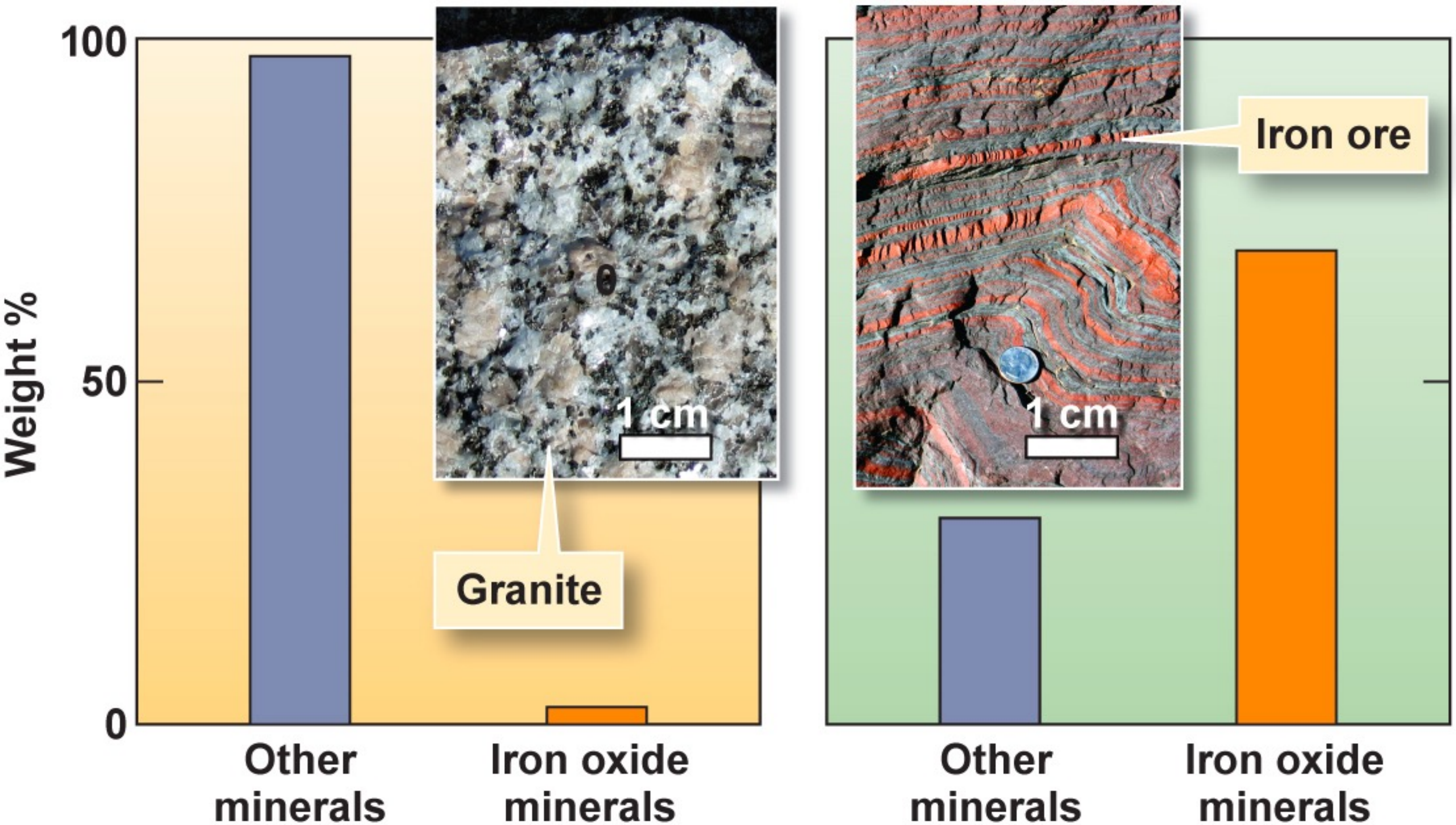


Maschera funeraria
di Tutankhamon,
XIII sec. a.C.

Bronzi di Riace, V secolo a.C.

… e tanti metalli presenti negli “smartphone”!

Giacimenti minerari



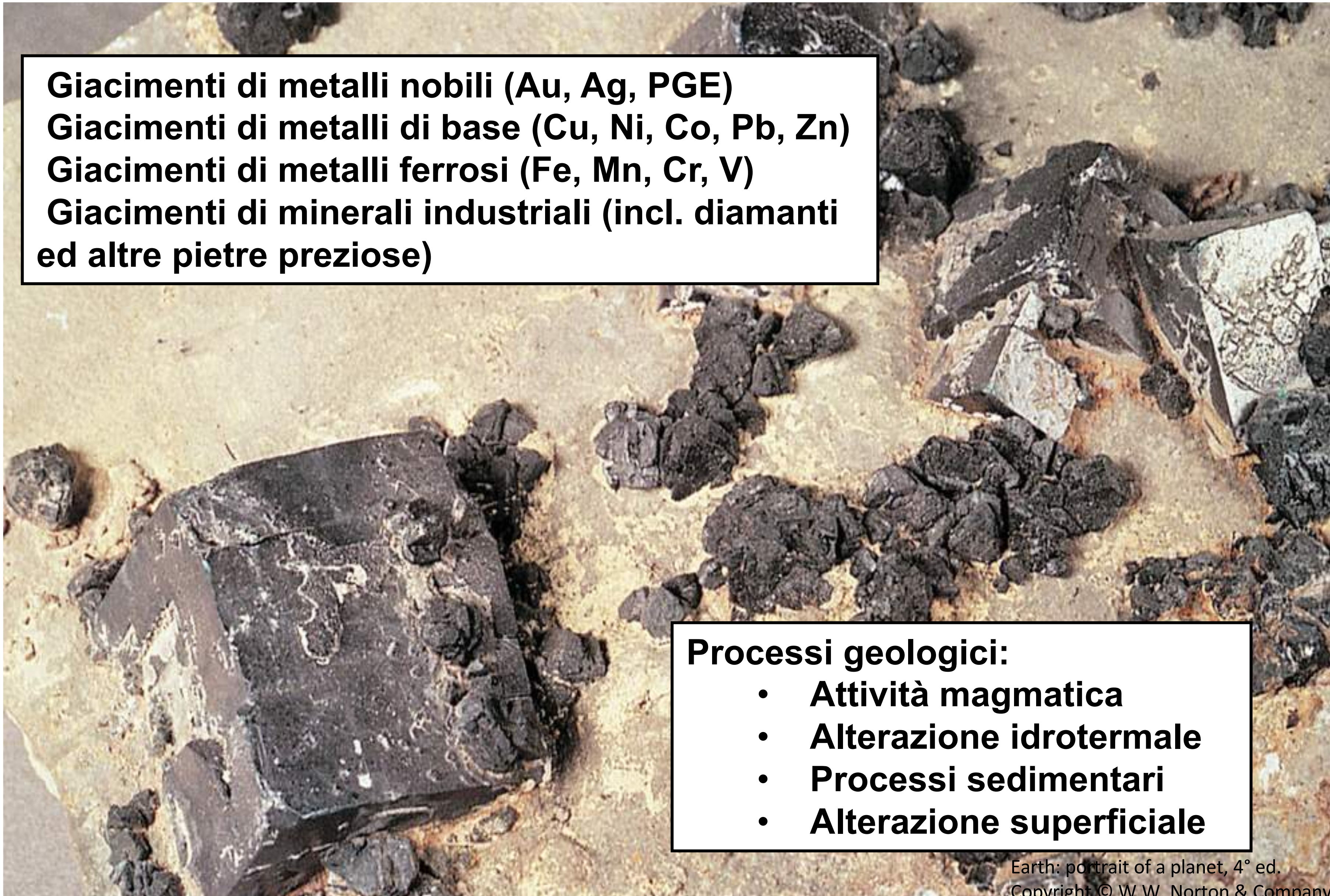
La differenza tra un giacimento e altre rocce risiede nel fatto che, nel primo, i metalli sono concentrati. Questa concentrazione è il **risultato di processi geologici** che avvengono solo in determinati ambienti tettonici. **Ciò comporta che i giacimenti minerari non siano uniformemente distribuiti sulla crosta terrestre**.

Giacimenti minerari = anomalia!

Abbondanza media crostale (Clarke) vs. concentrazione economica di alcuni elementi					
Elemento	valore Clarke	Tenore limite (cut-off)		Clarke di concentrazione	
	[wt.%]	Superficie [wt.%]	Sotterraneo [wt.%]	Superficie	Sotterraneo
Al	8	30	40	3.75	5
Fe	5	50	60	10	12
Mn	0.09	35	40	389	444
Cu	0.005	0.15	1	30	200
Ni	0.007	0.5	1	71	142
Zn	0.007	4	5	571	714
Sn	0.0002	0.5	1	2500	5000
Cr	0.01	30	40	3000	4000
Pb	0.001	3	4	3000	4000
Au	0.004 ppm	1 ppm	5 ppm	250	1250
Pt	0.005 ppm	1 ppm	5 ppm	200	1000

Tenore limite = Concentrazione minima per una coltivazione economica

Giacimenti minerari: come si formano?



Giacimenti di metalli nobili (Au, Ag, PGE)
Giacimenti di metalli di base (Cu, Ni, Co, Pb, Zn)
Giacimenti di metalli ferrosi (Fe, Mn, Cr, V)
Giacimenti di minerali industriali (incl. diamanti ed altre pietre preziose)

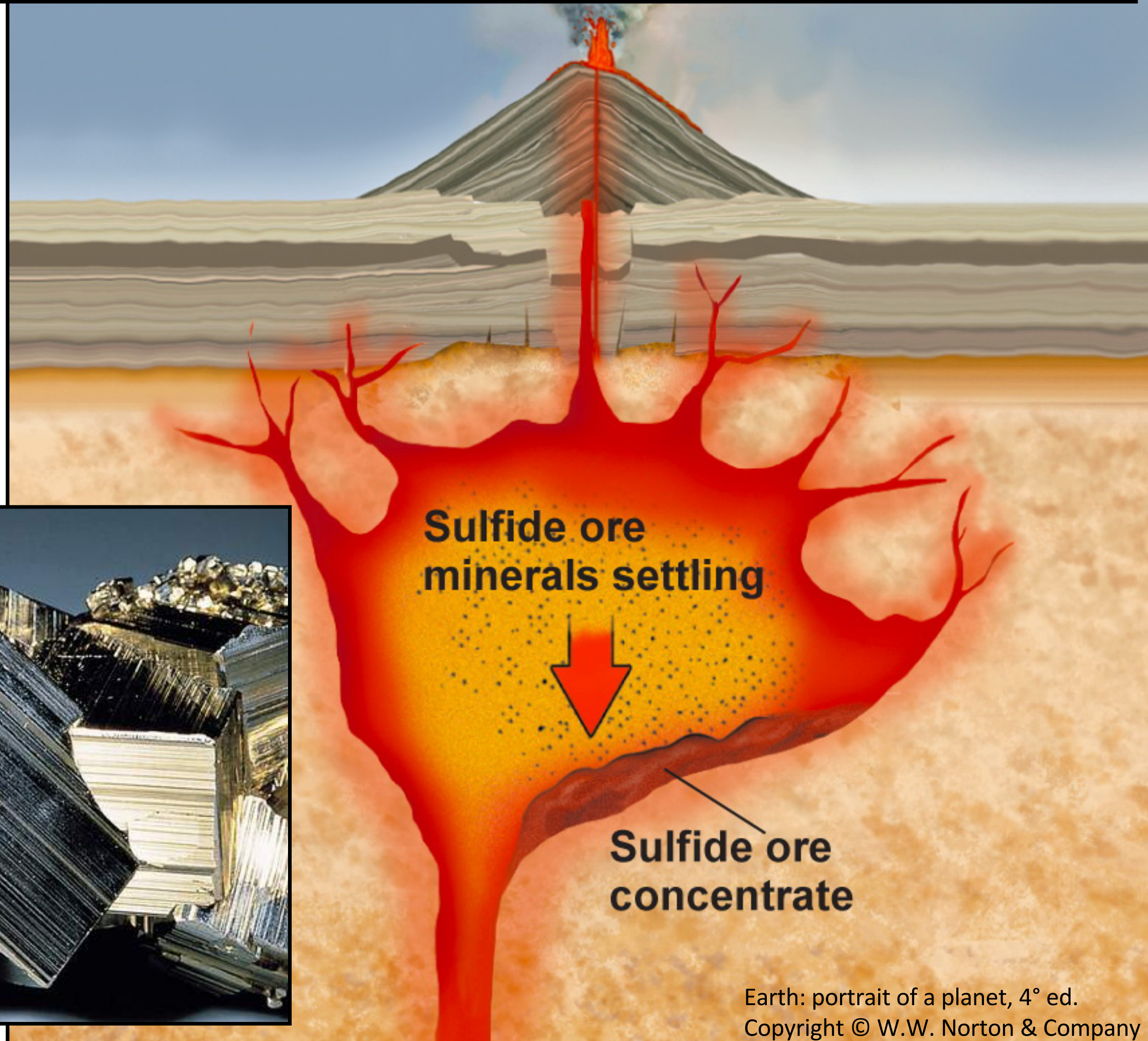
Processi geologici:

- **Attività magmatica**
- **Alterazione idrotermale**
- **Processi sedimentari**
- **Alterazione superficiale**

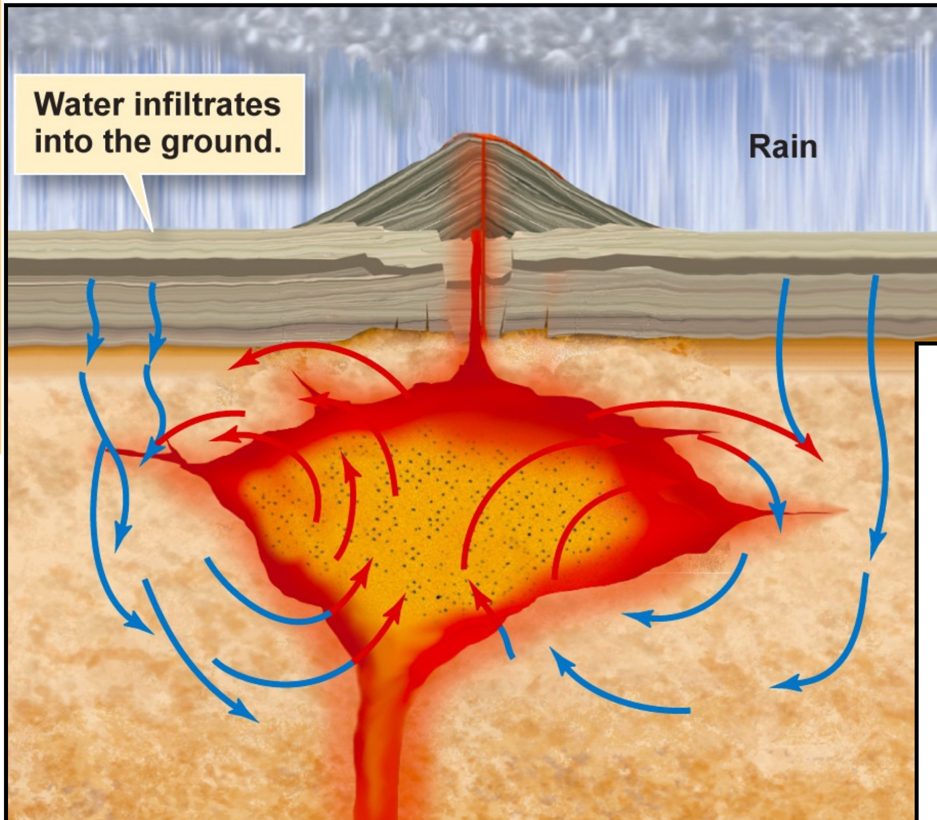
Giacimenti minerari – come si formano?

I **depositi magmatici** si formano in seguito al raffreddamento di un plutone.

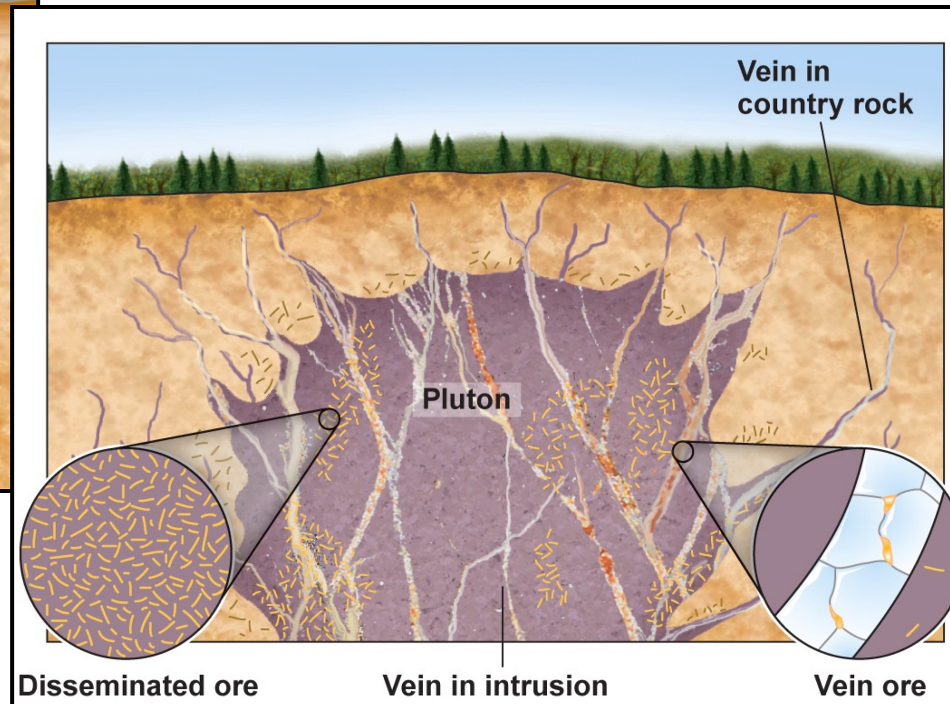
I minerali metallici (solfuri e ossidi) cristallizzano direttamente nella camera magmatica.
I minerali tipici di questi giacimenti sono: cromite, calcopirite, platinoidi e diamanti.



Giacimenti minerari – come si formano?

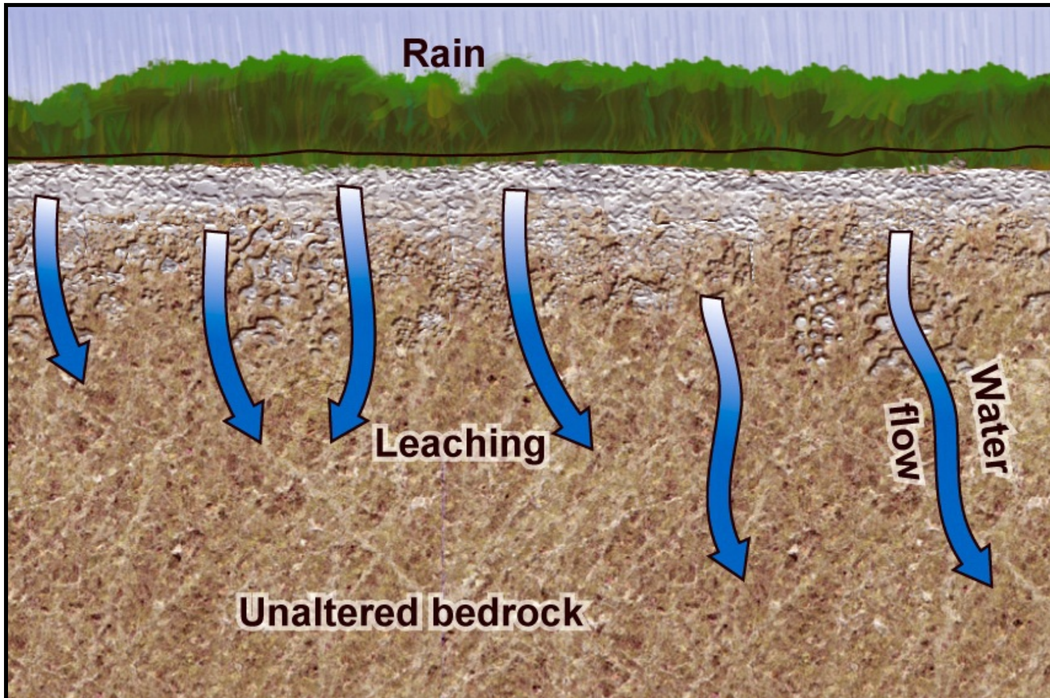


I **depositi idrotermali** si formano per precipitazione dei minerali di interesse economico da soluzioni acquose ad alta temperatura (>150°C).



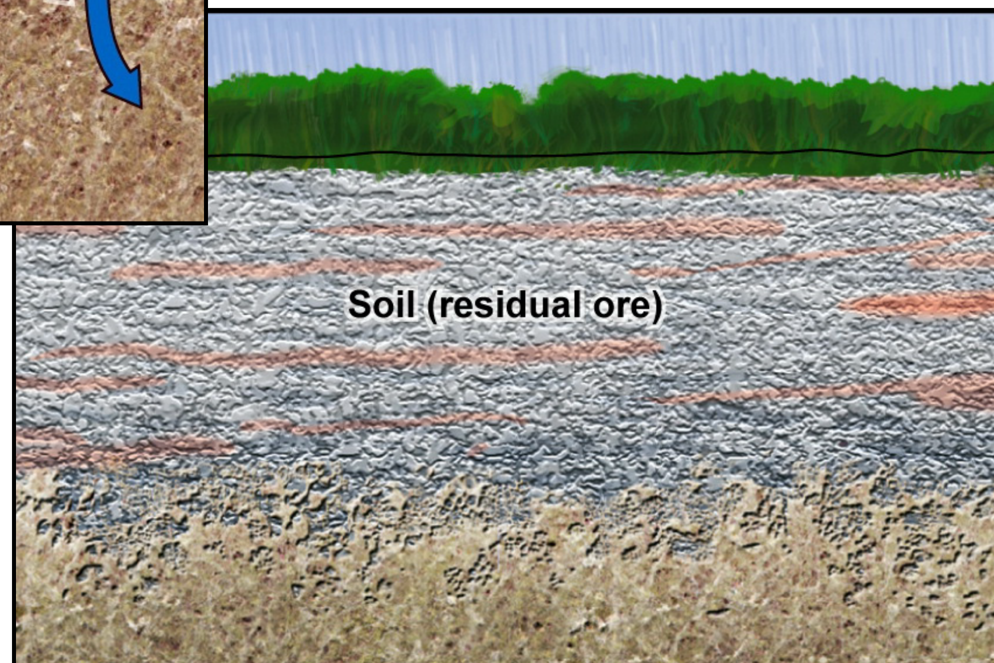
Il fluido idrotermale può essere di **origine magmatica**, se rilasciato direttamente da un'intrusione magmatica che sta raffreddando, o di **origine meteorica /superficiale**, se acqua di falda viene riscaldata da intrusioni ignee ed è in grado di solubilizzare e precipitare metalli.

Giacimenti minerari – come si formano?



I **depositi superficiali residuali** si formano in ambienti caratterizzati da un'estrema alterazione superficiale di tipo chimico e da clima caldo-umido tropicale.

Un'intensa alterazione chimica elimina quasi tutte le componenti di un suolo, lasciando in posto solo gli elementi meno solubili.
Gli elementi comunemente più conosciuti sono **Al e Fe**, che si concentrano in suoli "residuali" detti **bauxite**.

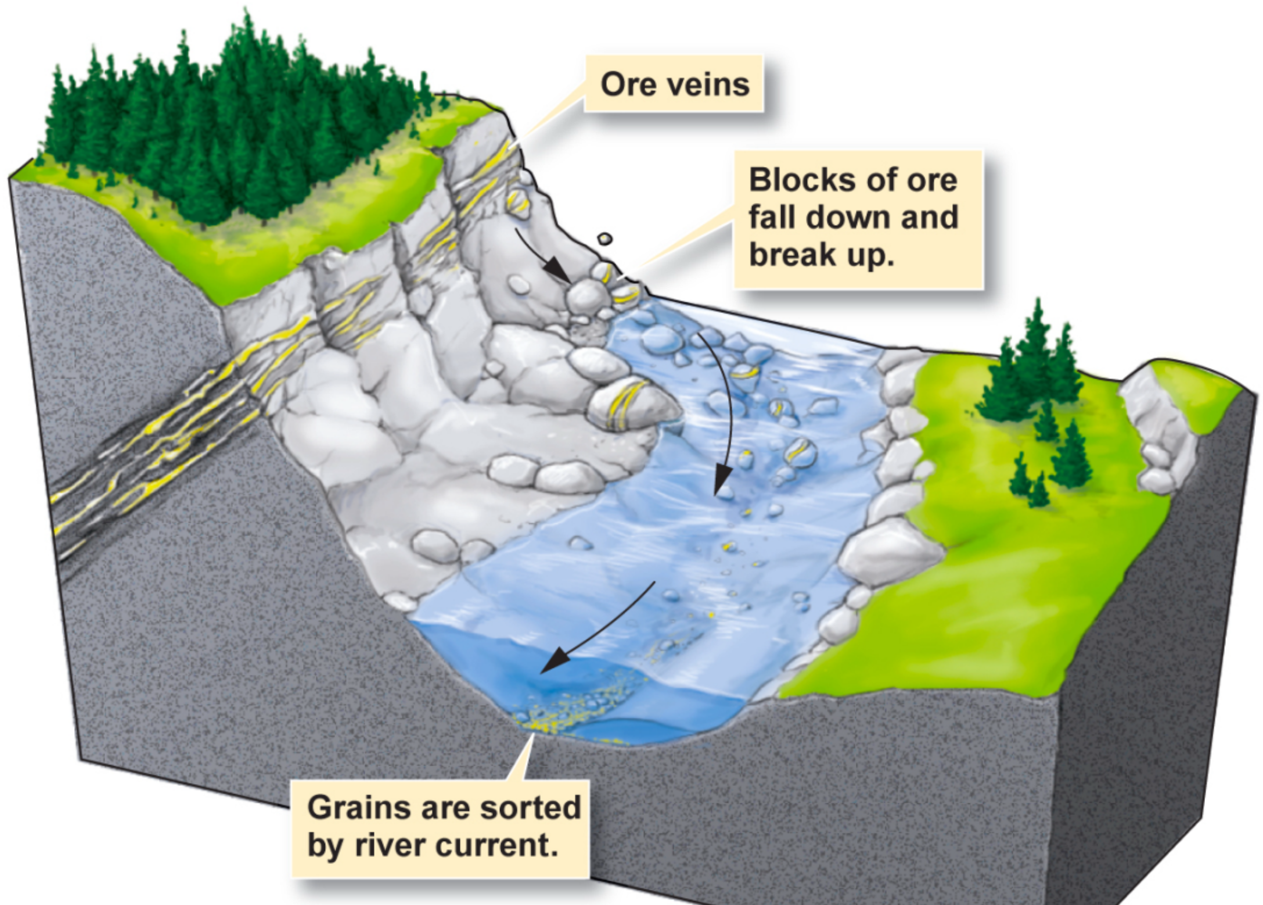


Earth: portrait of a planet, 4° ed.

Giacimenti minerari – come si formano?

I **depositi superficiali detritici (placer)** si formano per processi di selezione/setacciatura idraulica in ambienti fluviali, deltizi o marini ad alta energia.

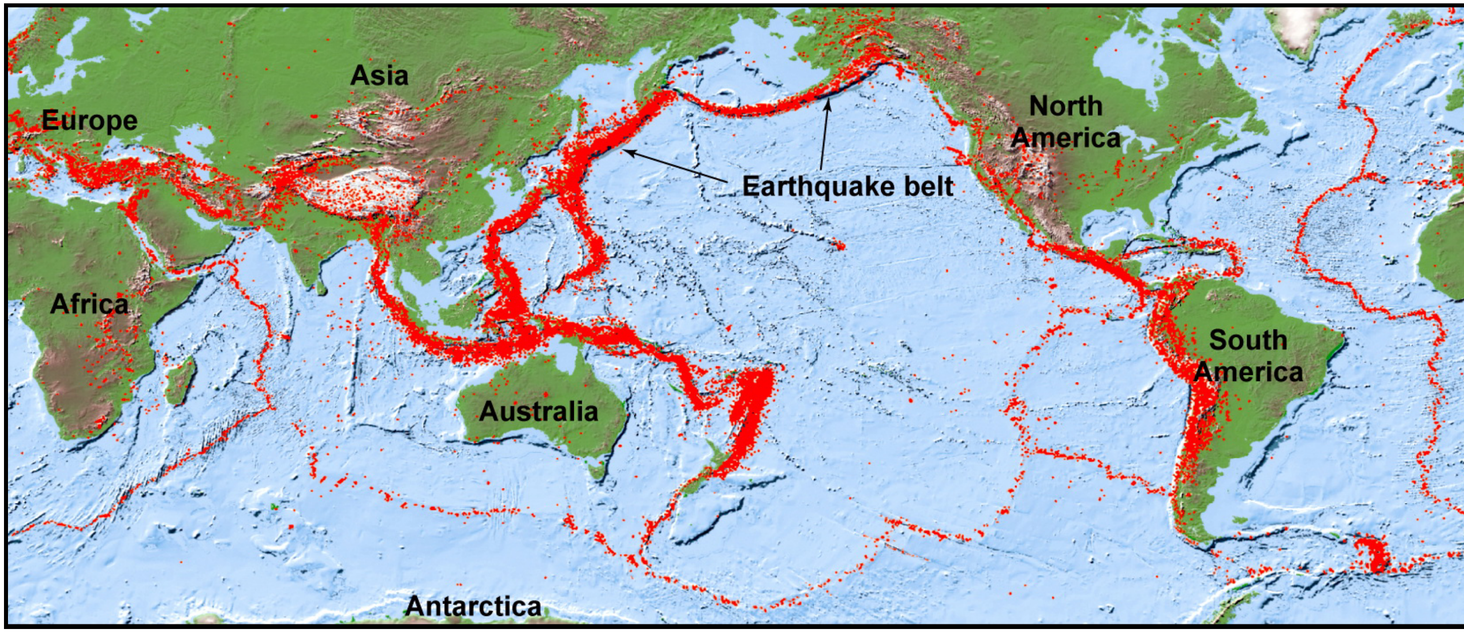
I minerali a bassa densità vanno in sospensione e vengono dilavati, mentre **i grani più pesanti sono concentrati per sedimentazione**. La selezione idraulica è un importante meccanismo di concentrazione per l'oro, lo stagno e i diamanti.
La sorgente originaria dei minerali di interesse economico può essere individuata risalendo la corrente.

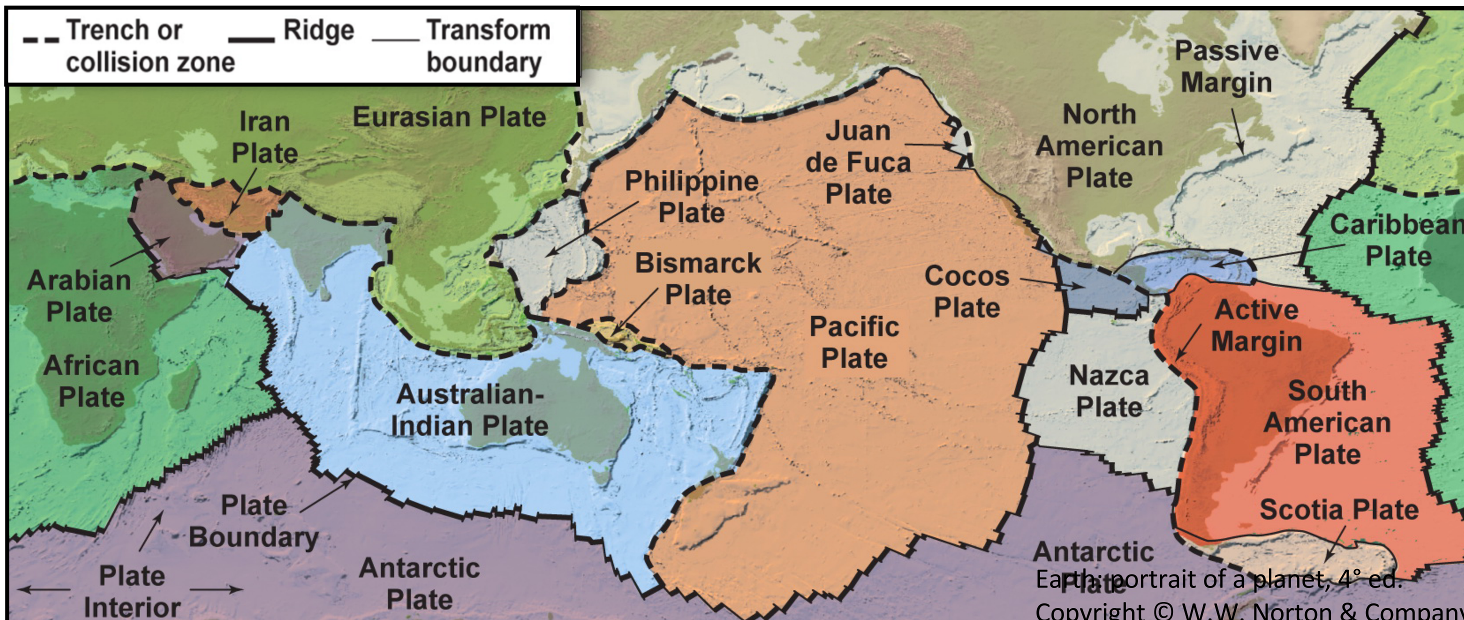


Earth: portrait of a planet, 4° ed.

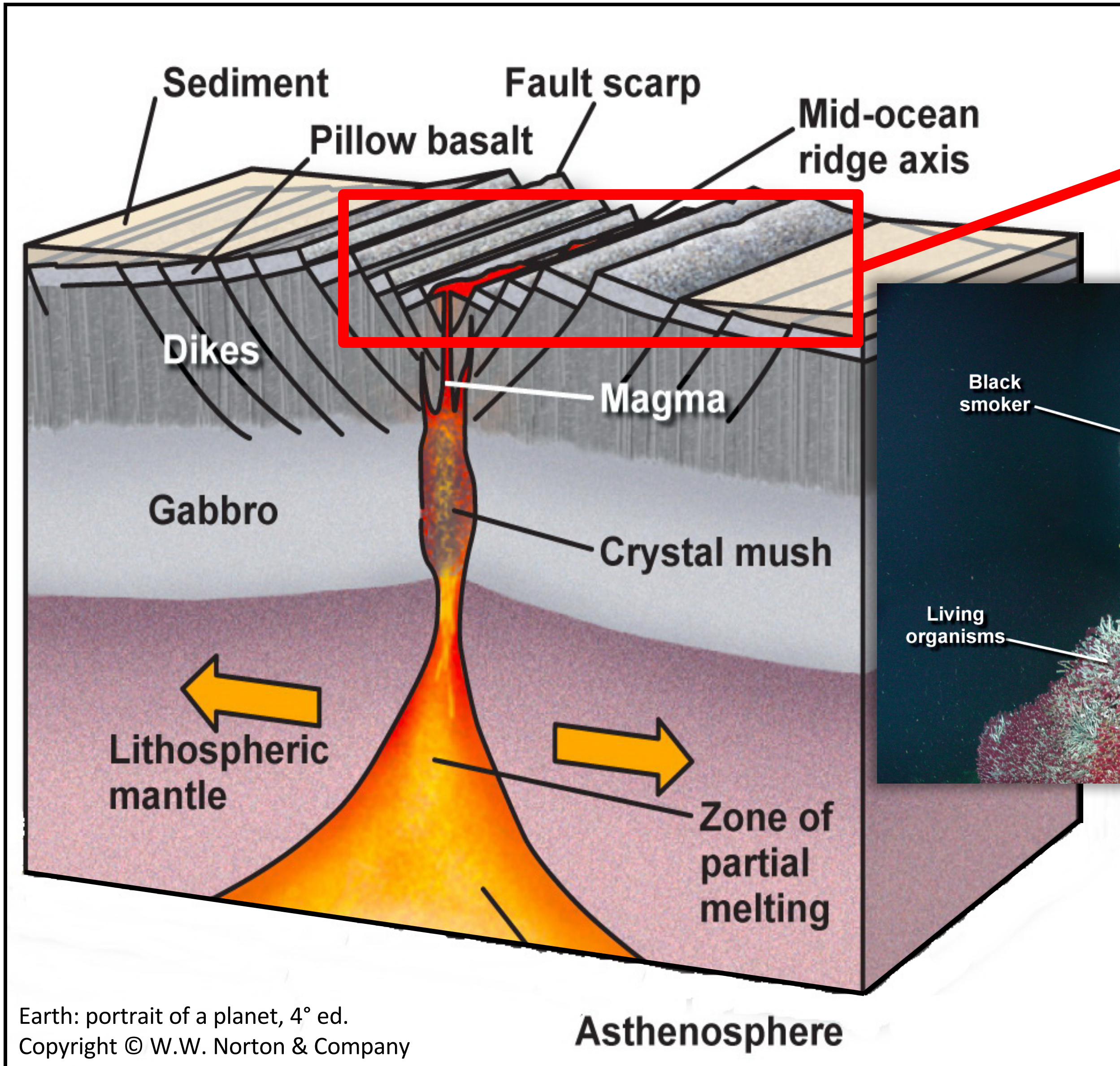
Giacimenti minerari – dove si formano?

I processi tettonici hanno il controllo principale sulla posizione dei giacimenti minerari. **Attività ignea e idrotermale si sviluppano lungo i margini delle placche, lungo i sistemi di rift e hot spot.** Questi **sono i luoghi dove si formano la maggior parte delle risorse minerarie.**



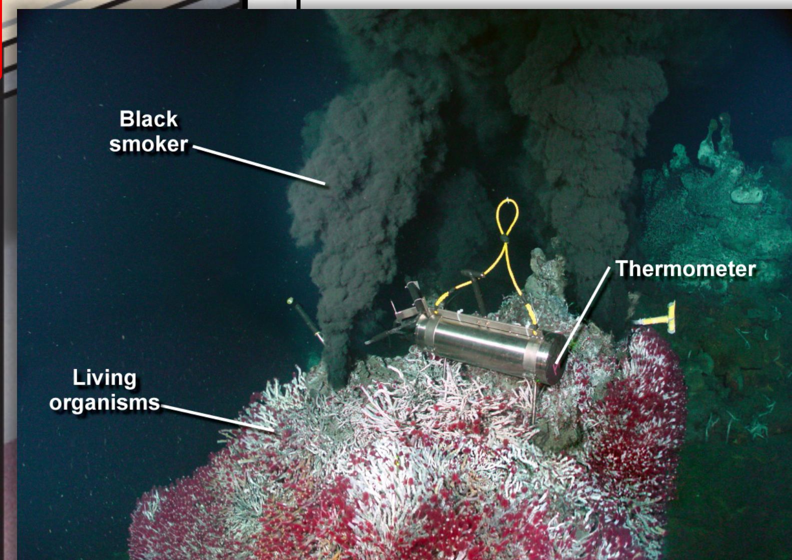


Giacimenti minerari su margini divergenti



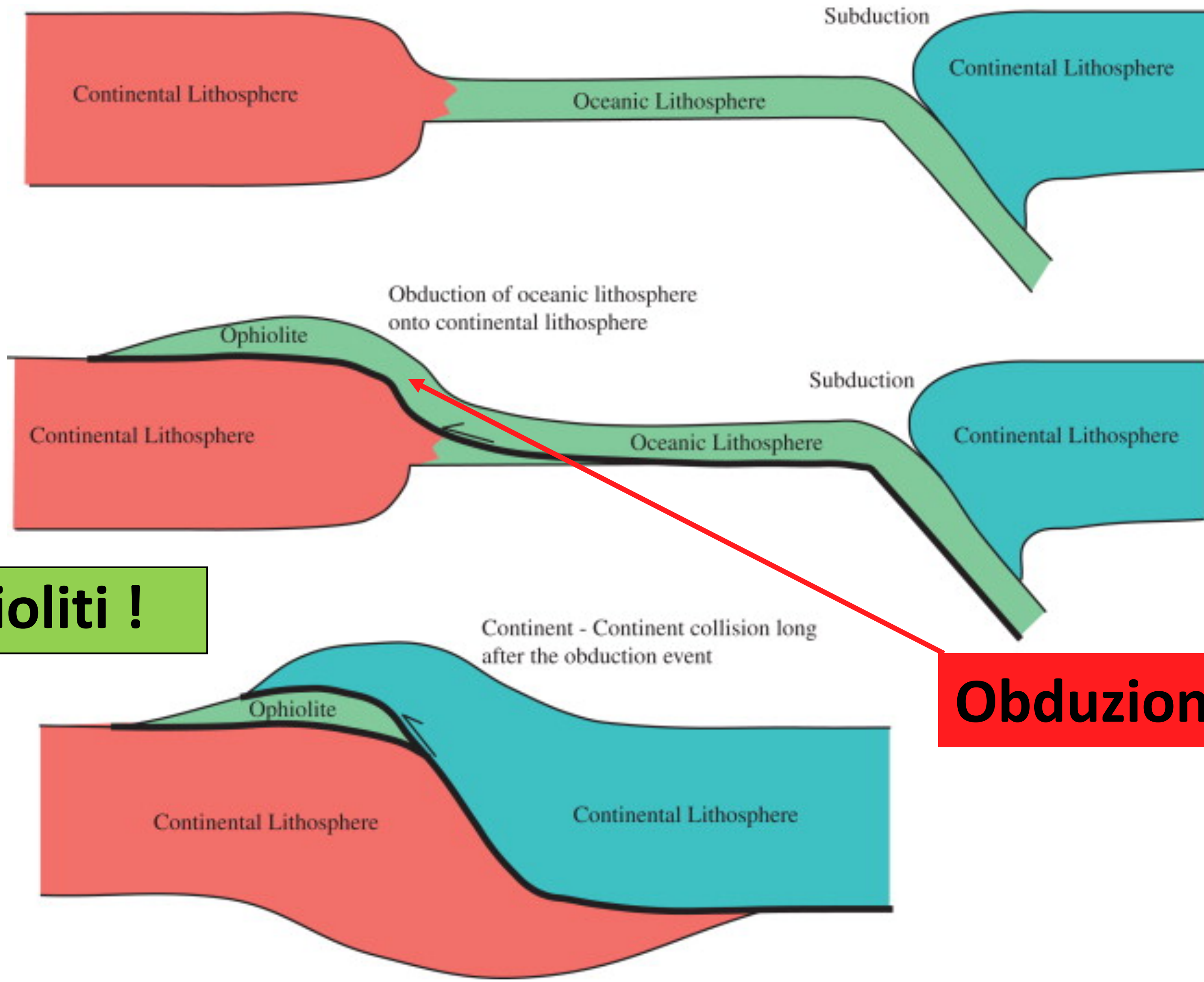
Earth: portrait of a planet, 4° ed.

Ambiente al di sopra della dorsale



Depositi di rame

Margini divergenti fossili

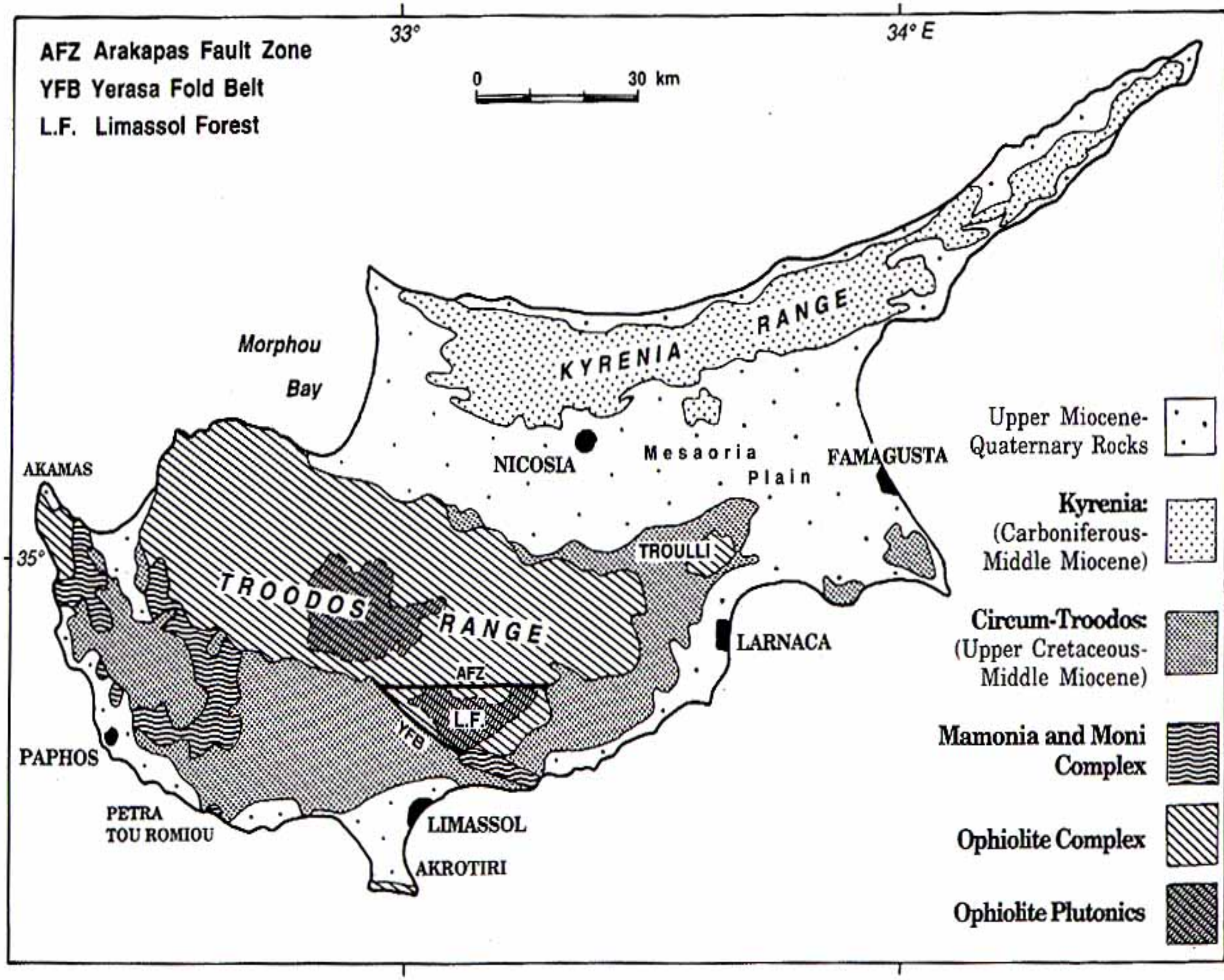


Ofioliti !

Obduzione!!!

DiPietro 2013

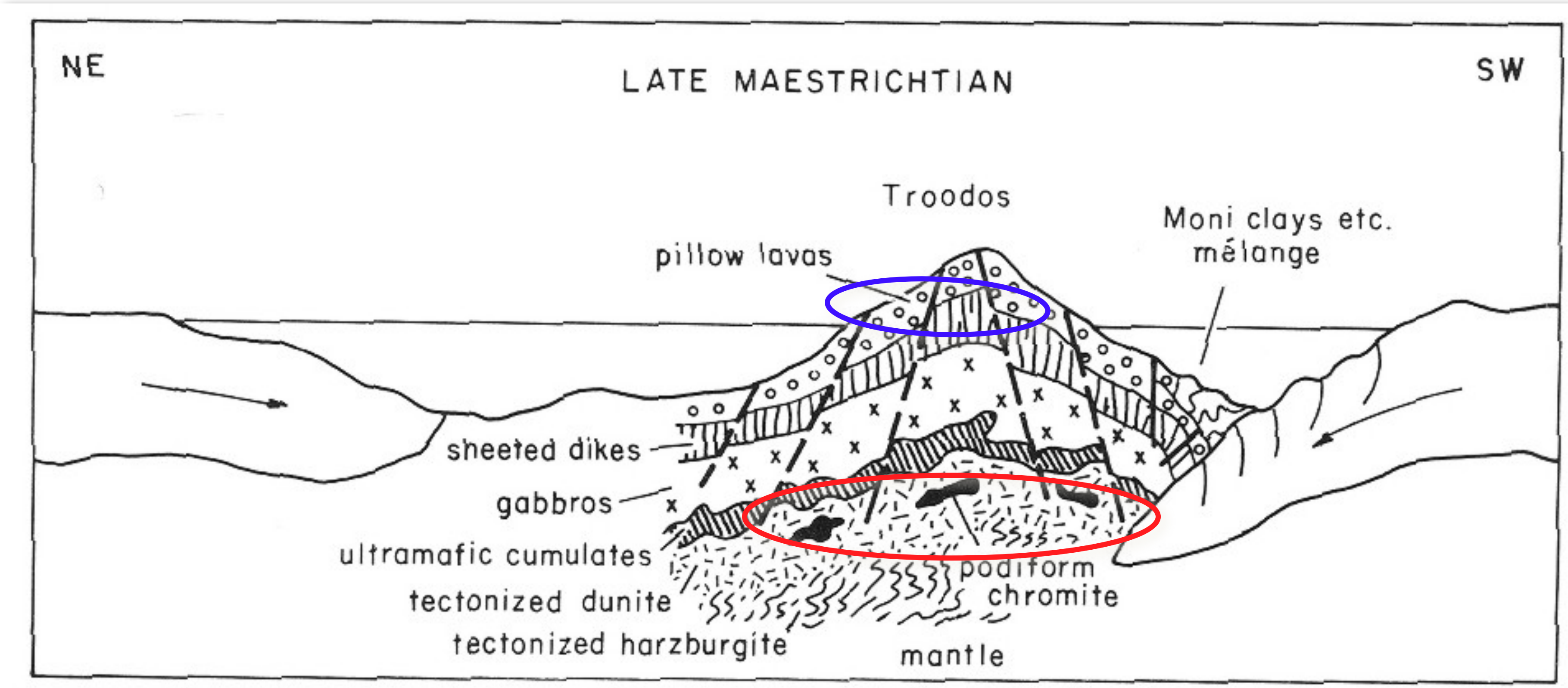
Margini divergenti fossili



Cipro

Source: Sawkins (1984)

Complesso ofiolitico del Monte Troodos, Cipro



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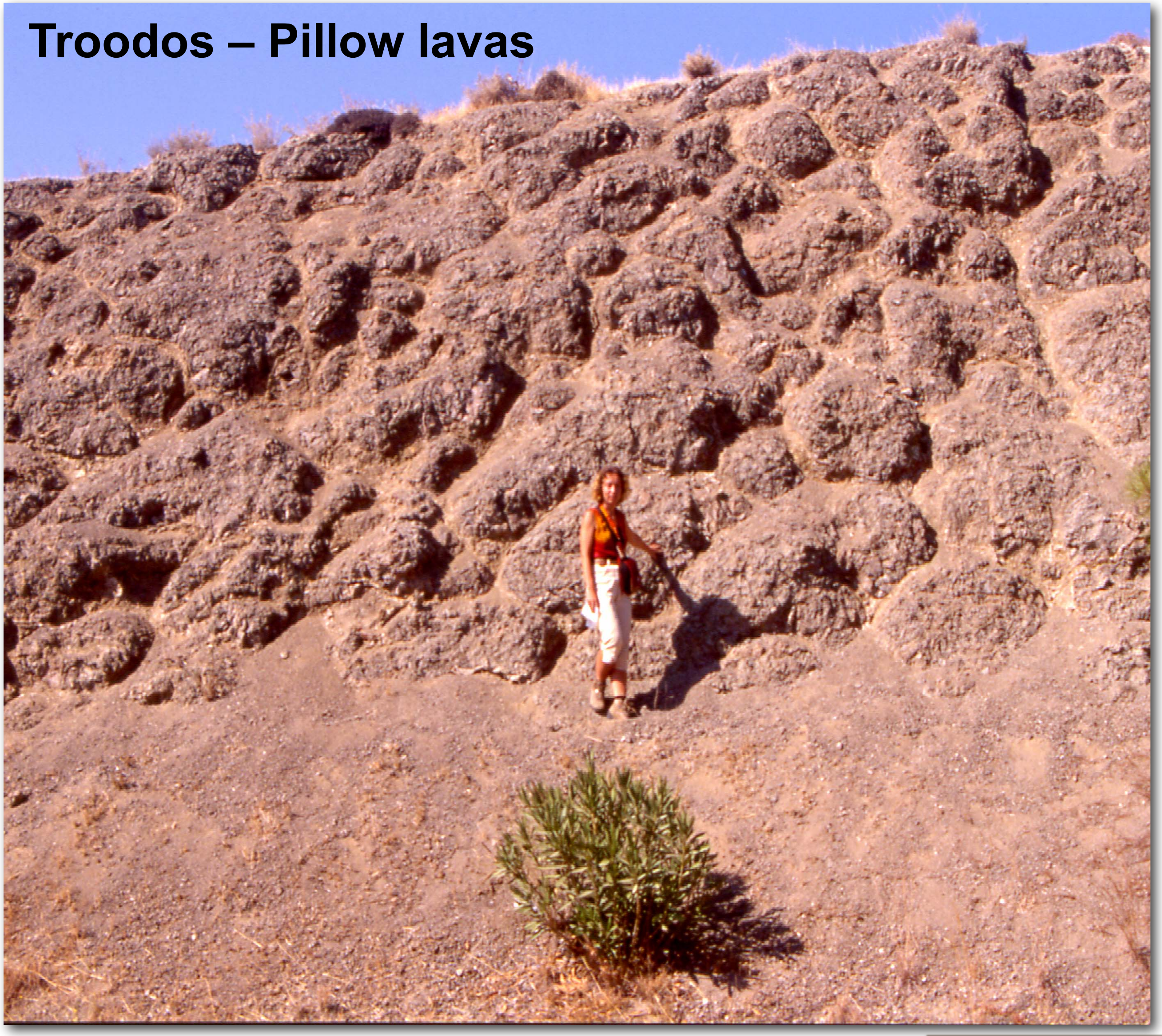
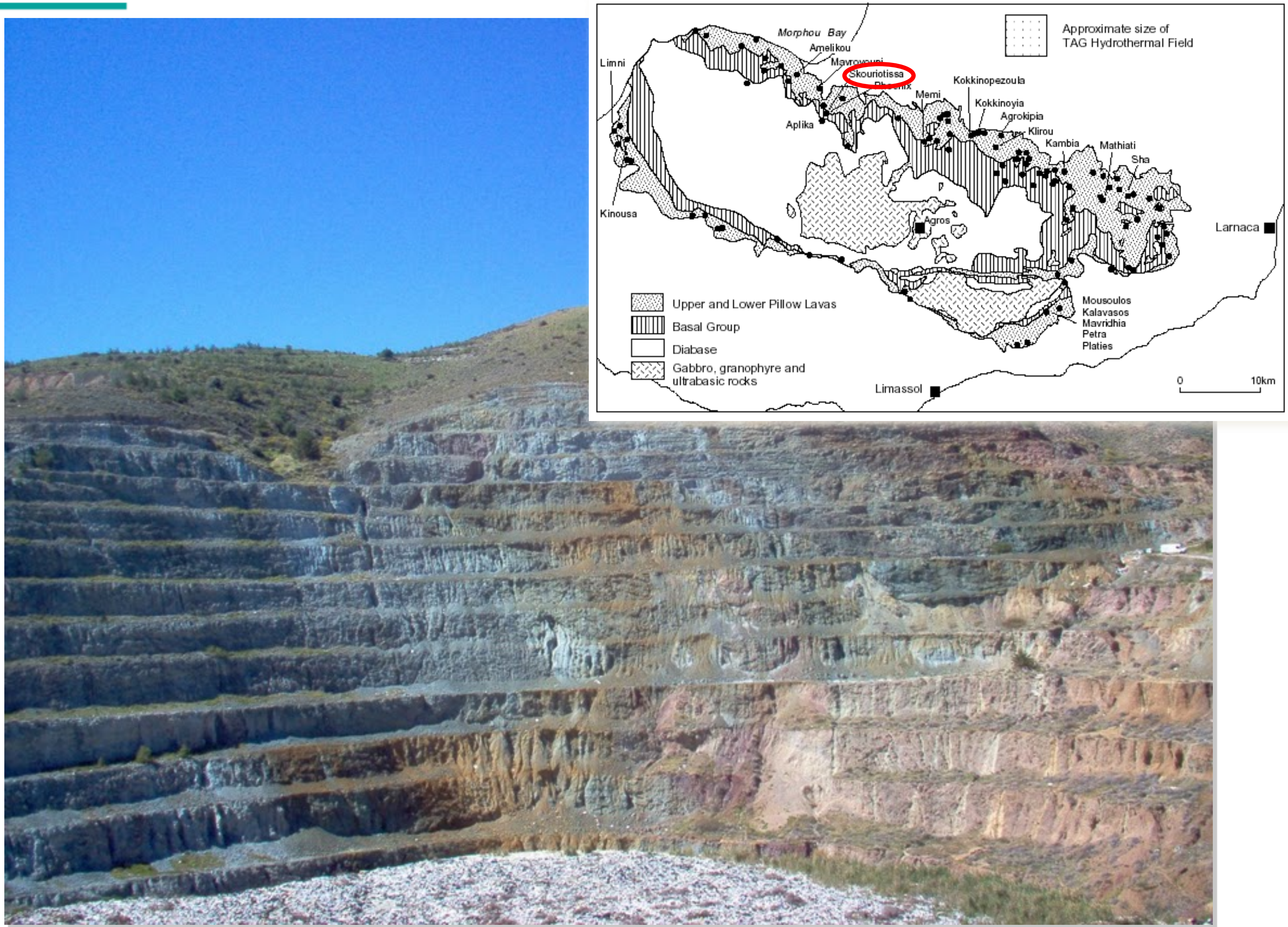


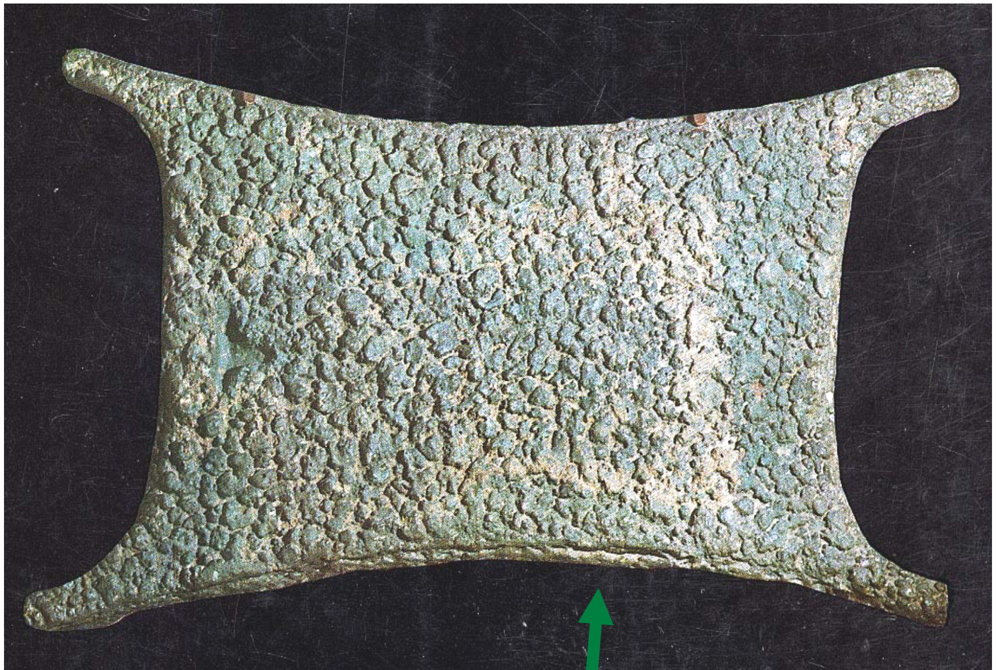
M. Boni



Cipro Skouriotissa Miniera di rame

M. Boni

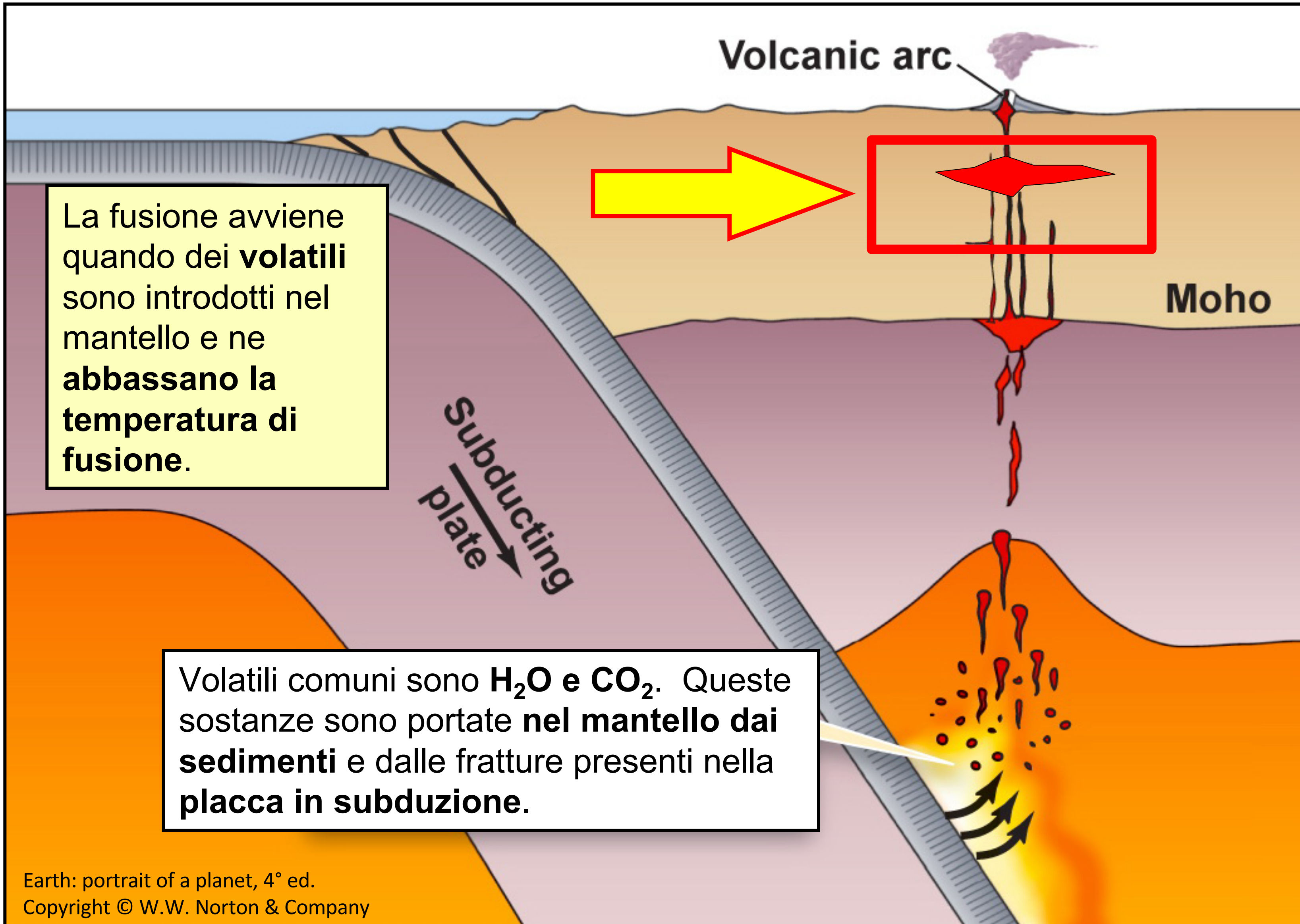
Depositi di rame su margini divergenti



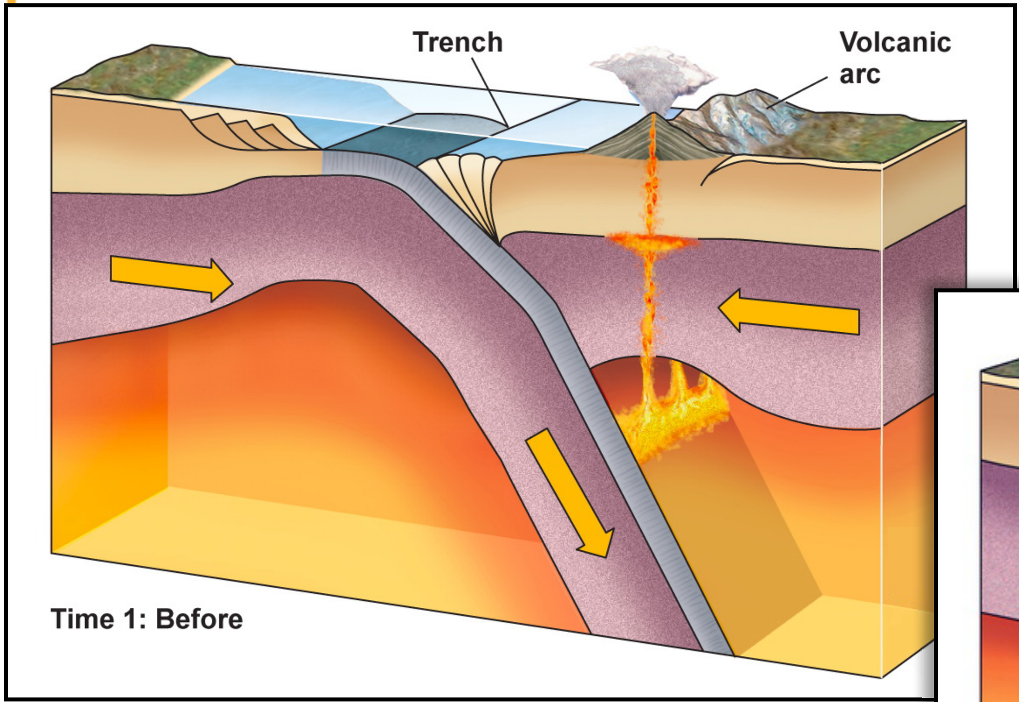
Cipro - Cu-lingotto

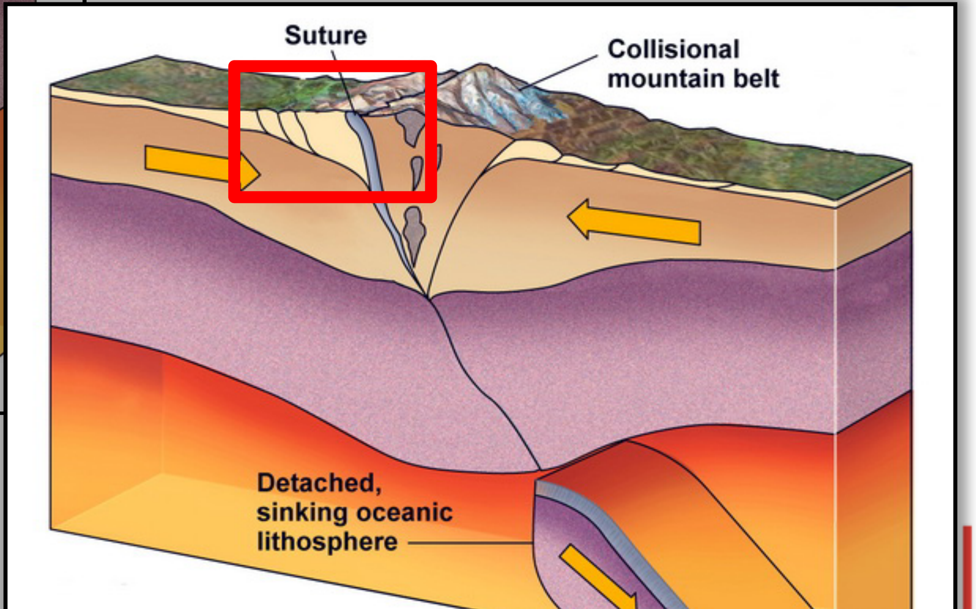
Statua di rame

Giacimenti minerari su margini convergenti
Margini continentali attivi



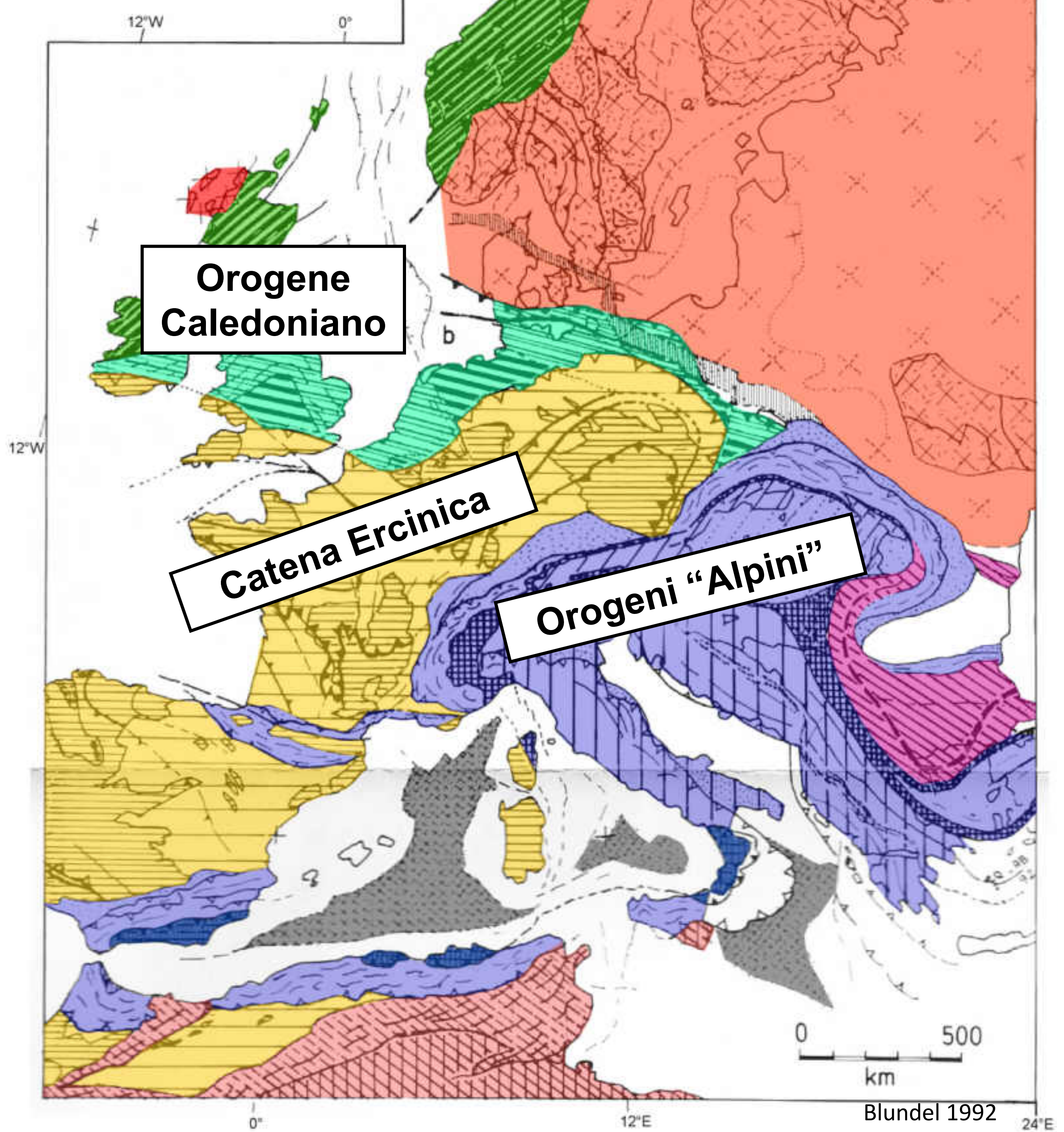
Giacimenti minerari su margini convergenti
Catene montuose





Earth: portrait of a planet, 4° ed.

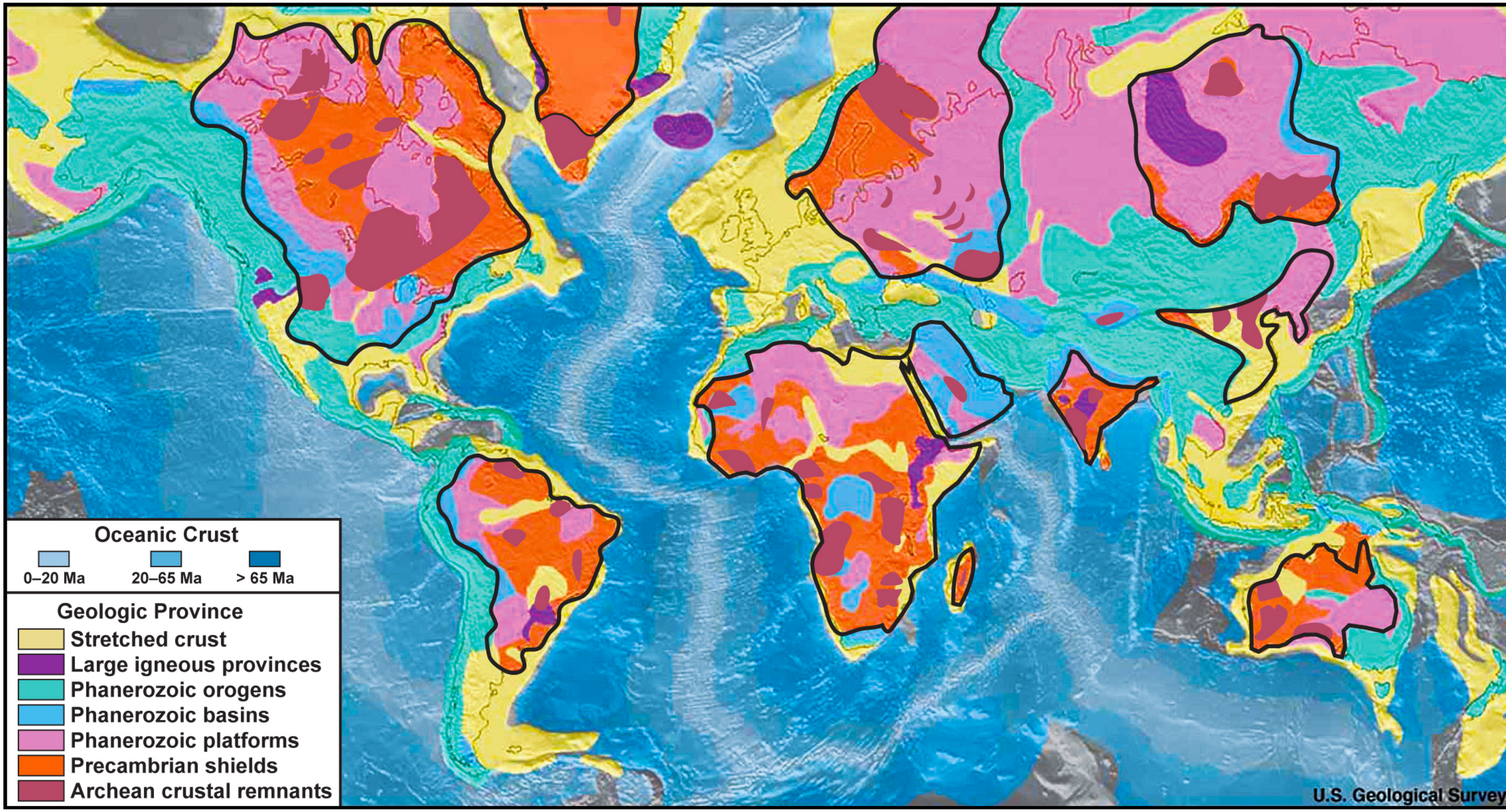
Margini collisionali inattivi



Blundel 1992

Carta tettonica dell'Europa

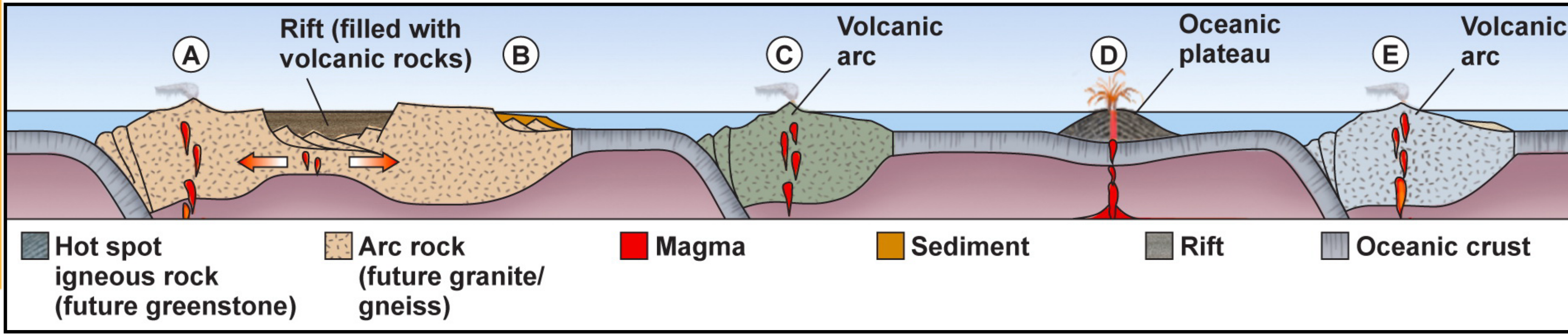
Aree cratoniche

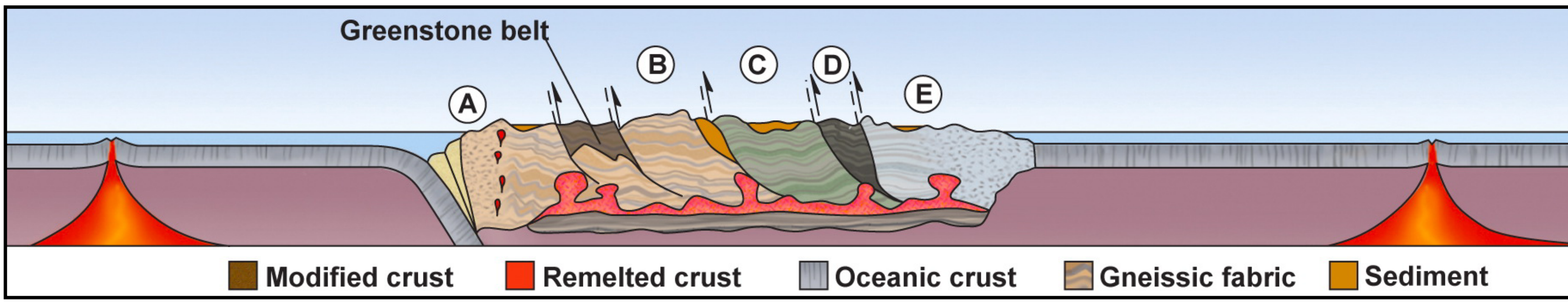


Cratone = blocco di crosta continentale molto antico (età anche > 2.5 Ga)

Earth: portrait of a planet, 4° ed.

Hot spot e *Mantle plumes* in aree cratoniche





Cicli orogenetici

Cratone = blocco di crosta continentale molto antico (età anche > 2.5 Ga)

Monopolio “geologico” delle risorse

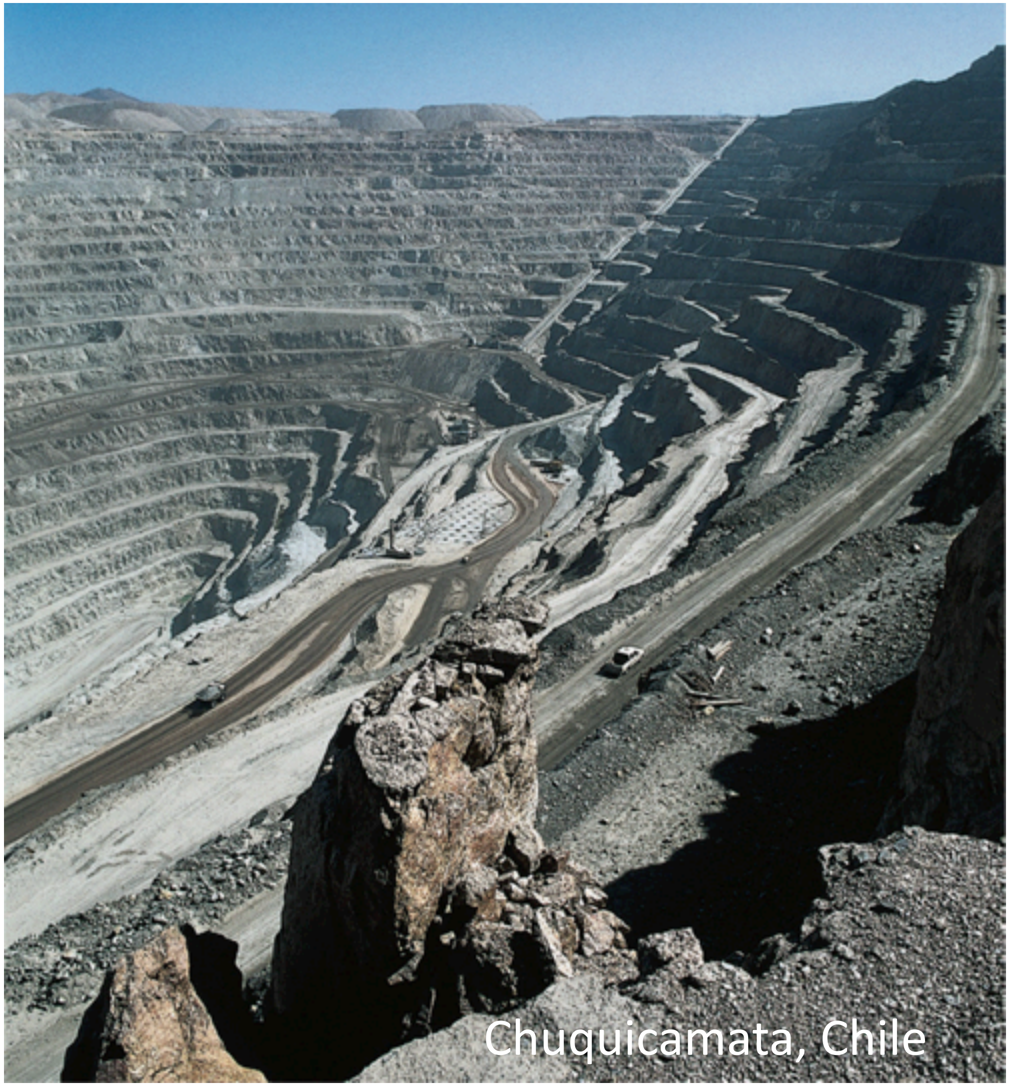


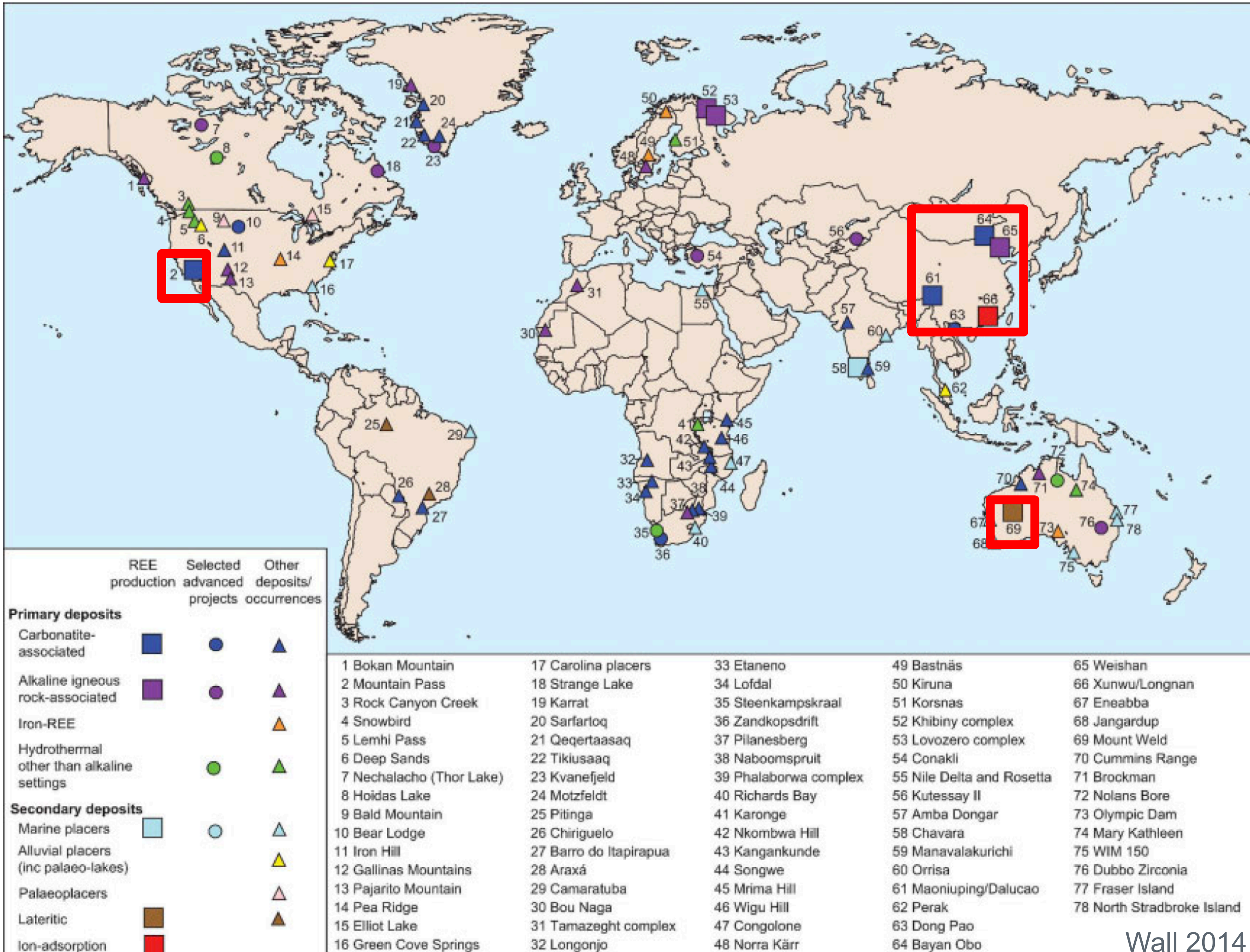
Table 1 | Geographical restrictions on non-energy commodity supply

Commodity	Producer	Market share %
Rare Earths	China	97
Antimony	China	91
Gallium	China	83
Platinum	South Africa	80
Germanium	China	79
Tungsten	China	75
Indium	China	58
Silicon	China	58
Tantalum	Australia	53
Rhenium	Chile	53
Chromium	South Africa	45
Cobalt	Congo	45
Lithium	Chile	44
Iron Ore	China	43
Palladium	Russia	43
Vanadium	South Africa	38
Copper	Chile	31

Compilation table showing commodities where one country is responsible for >30% of the world mine production, showing the percentage market share (2008–2012 figures)[17,18].

Herrington 2013

Dove si trovano i depositi di REE



Wall 2014

Tipi di deposito

Le REE sono arricchite in:

- Rocce ignee alcaline (sottosature in SiO_2, ricche in Na_2O),
- Carbonatiti (rocce ignee costituite da minerali carbonatici)

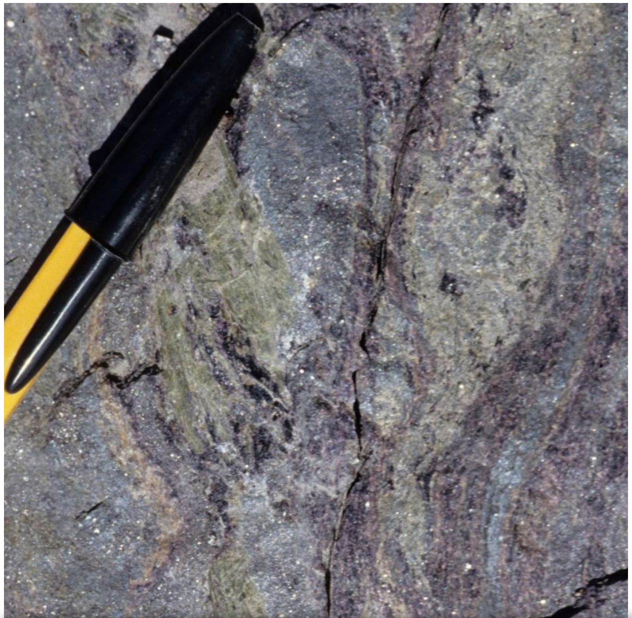
I depositi “primari” sono rari (i.e. il processo magmatico da solo non è in grado di “fare un giacimento”). Per incrementare i tenori di REE, sono necessari processi di arricchimento secondario:

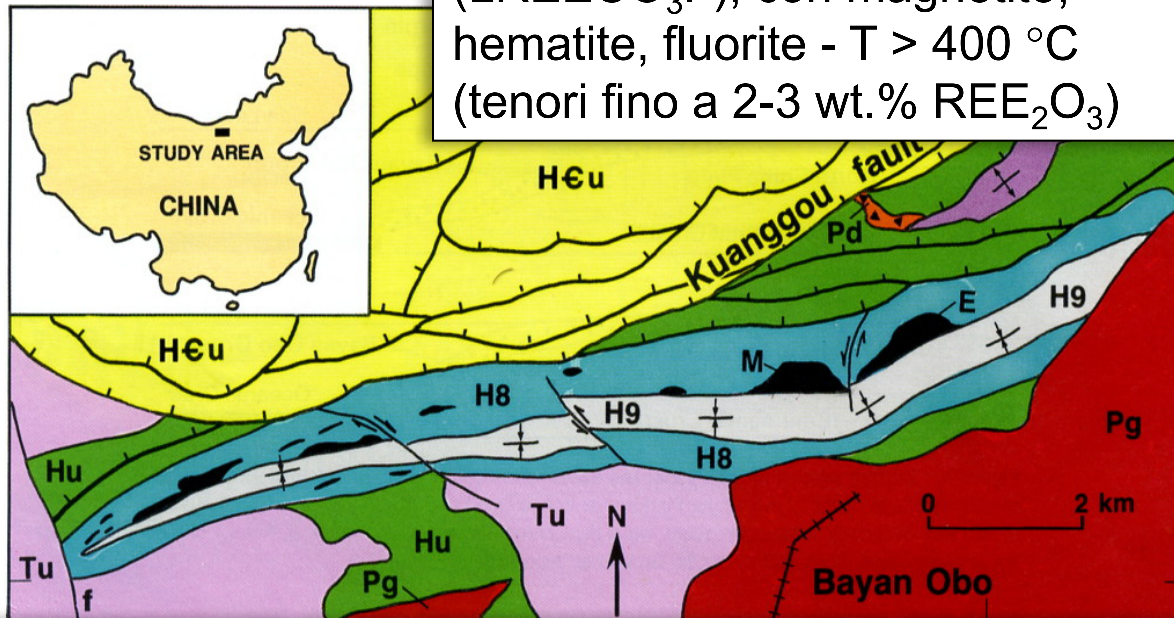
- Idrotermali
- Superficiali

e.g. Wall 2014

Bayan Obo, Cina

Monazite ($LREEPO_4$) & bastnäsite ($LREECO_3F$), con magnetite, hematite, fluorite - T > 400 °C (tenori fino a 2-3 wt.% REE_2O_3)



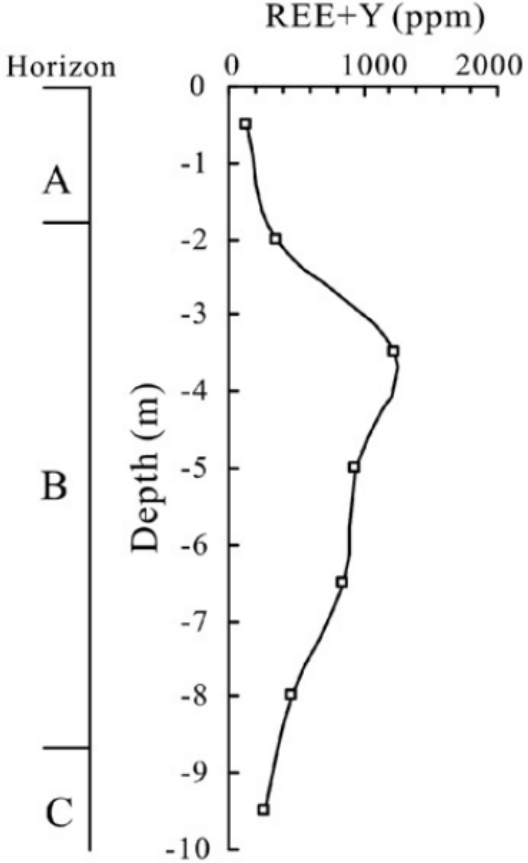


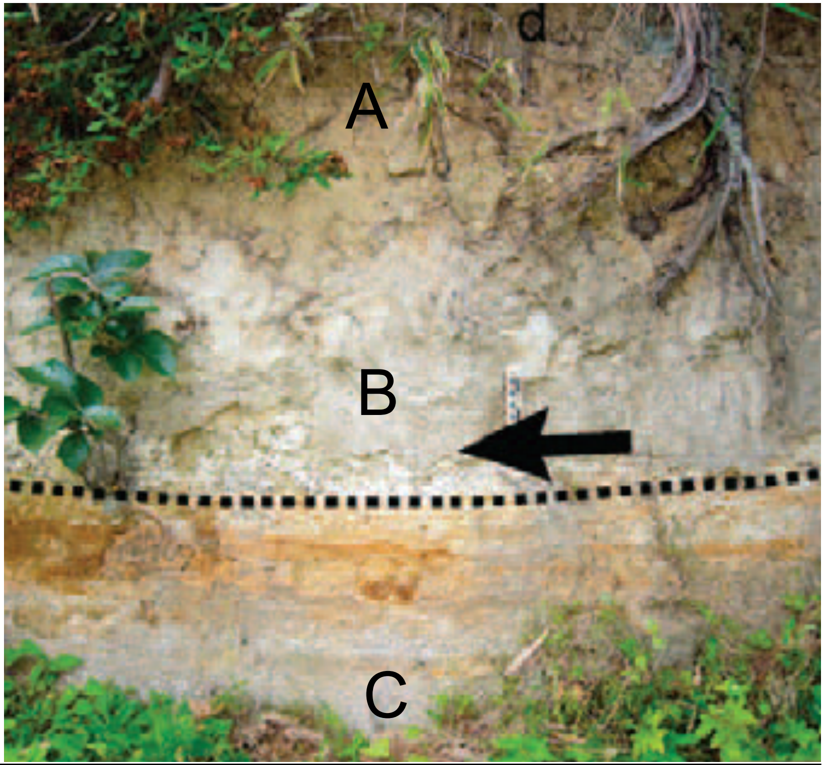
Smith & Henderson (2000)

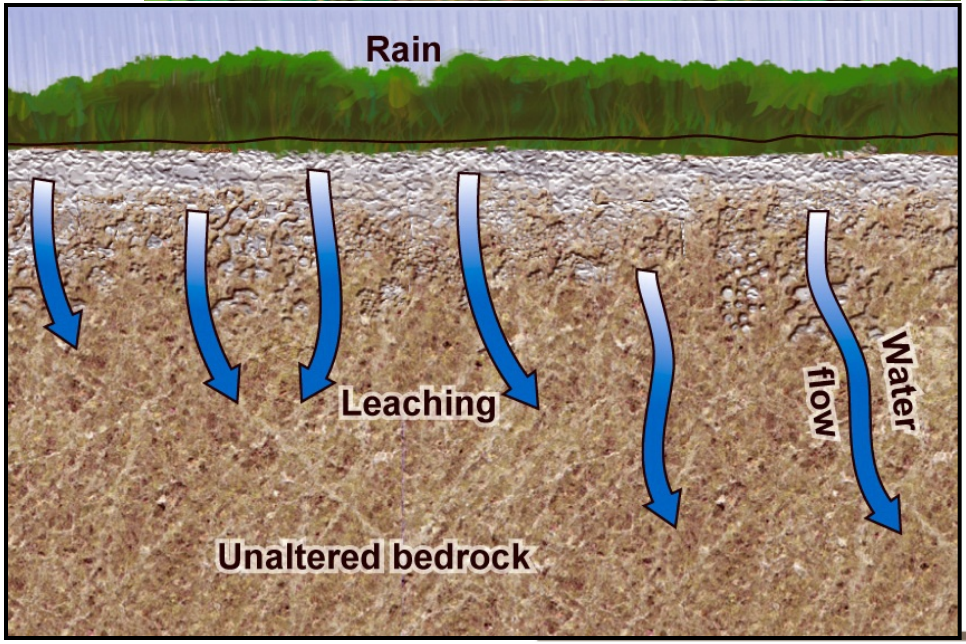
Carbonatite con alterazione idrotermale

Longnan, Cina

Depositi superficiali –
REE concentrate in suoli lateritici al di sopra di graniti, grazie ad un fenomeno di adsorbimento su argille (tenori 0.2 - 0.35 wt.% REE_2O_3).







A. Williams-Jones

Longnan, Cina

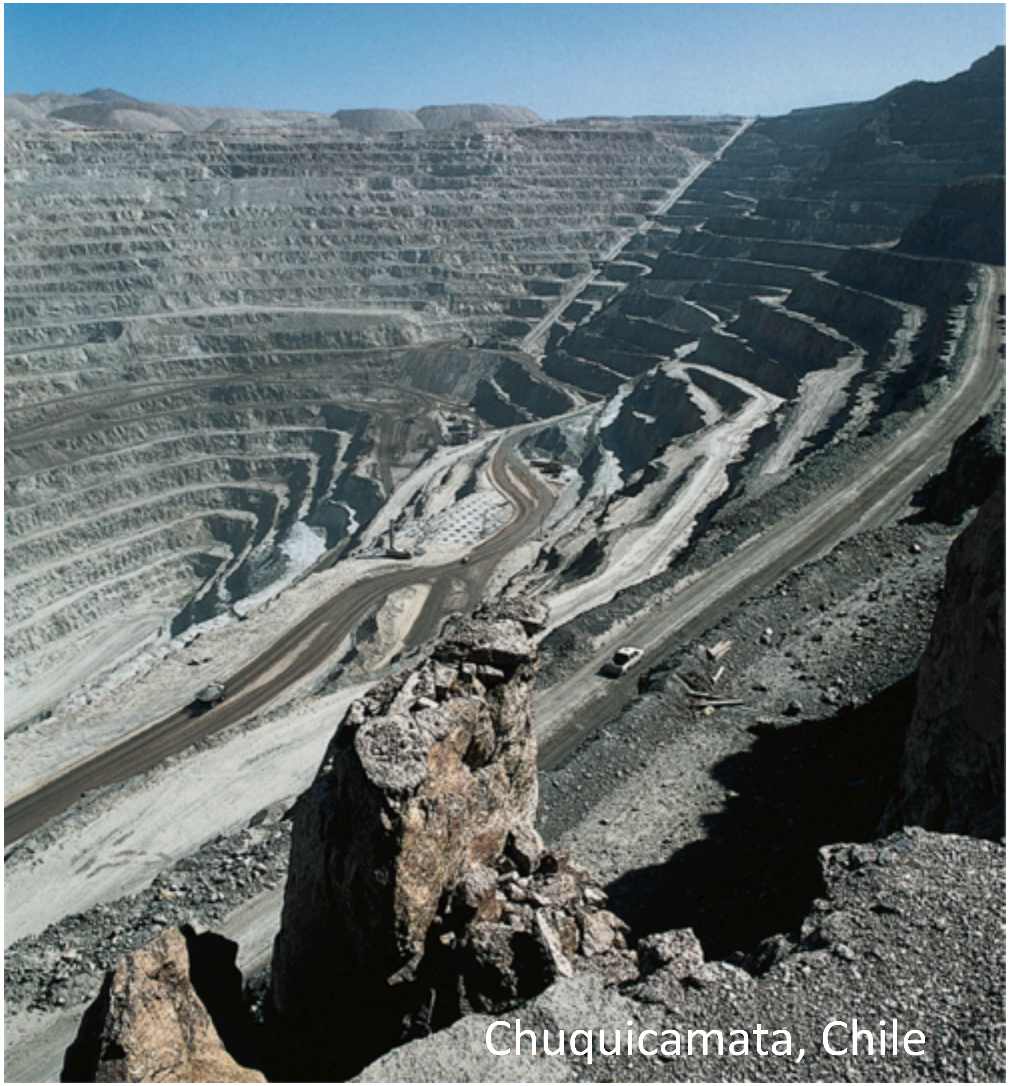
Processo di estrazione:
leaching acido in situ!!

A. Williams-Jones

Bayan Obo, Cina

Bayan Obo, China - REE mine and processing plant

Monopolio "geologico" delle risorse



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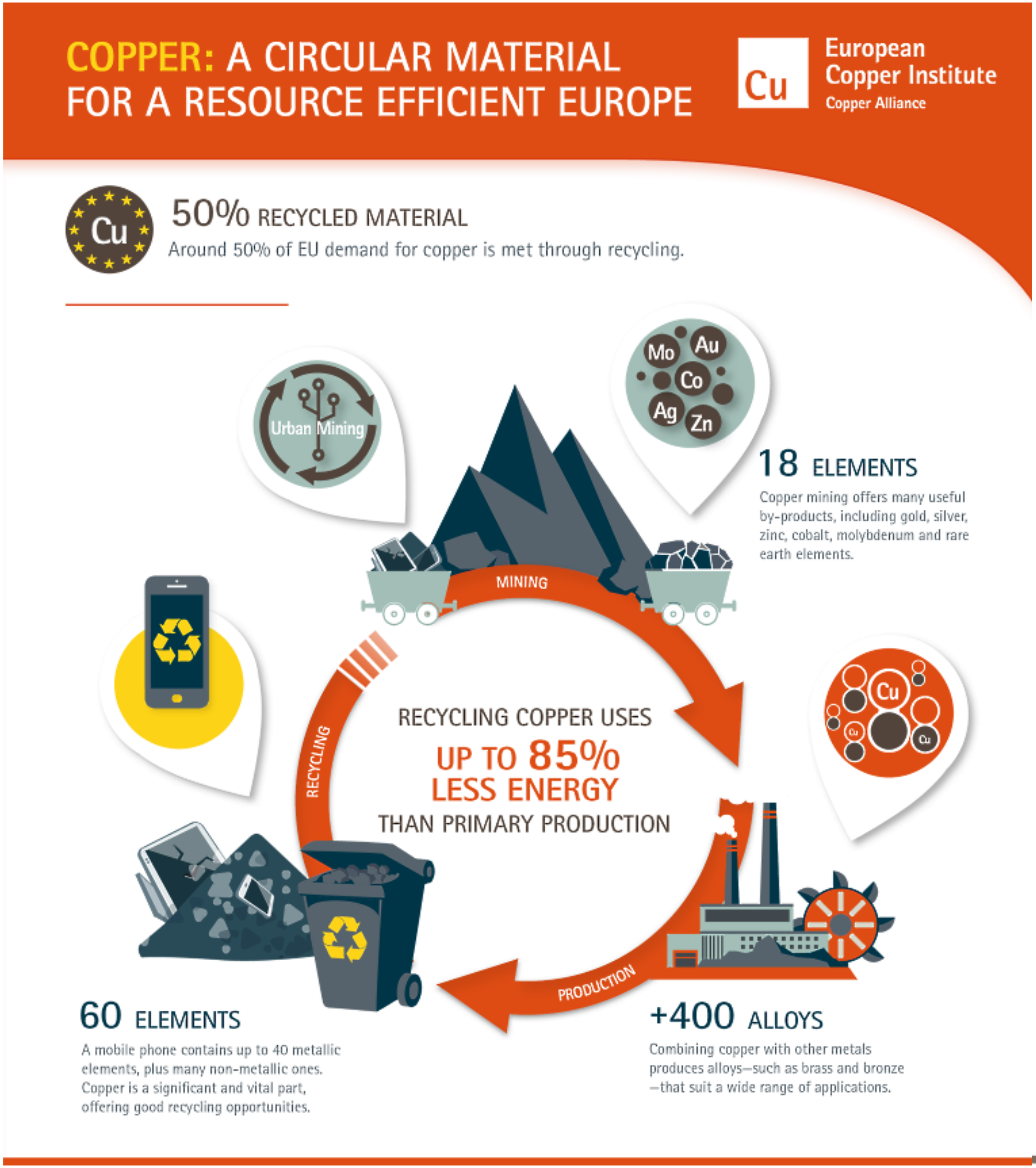
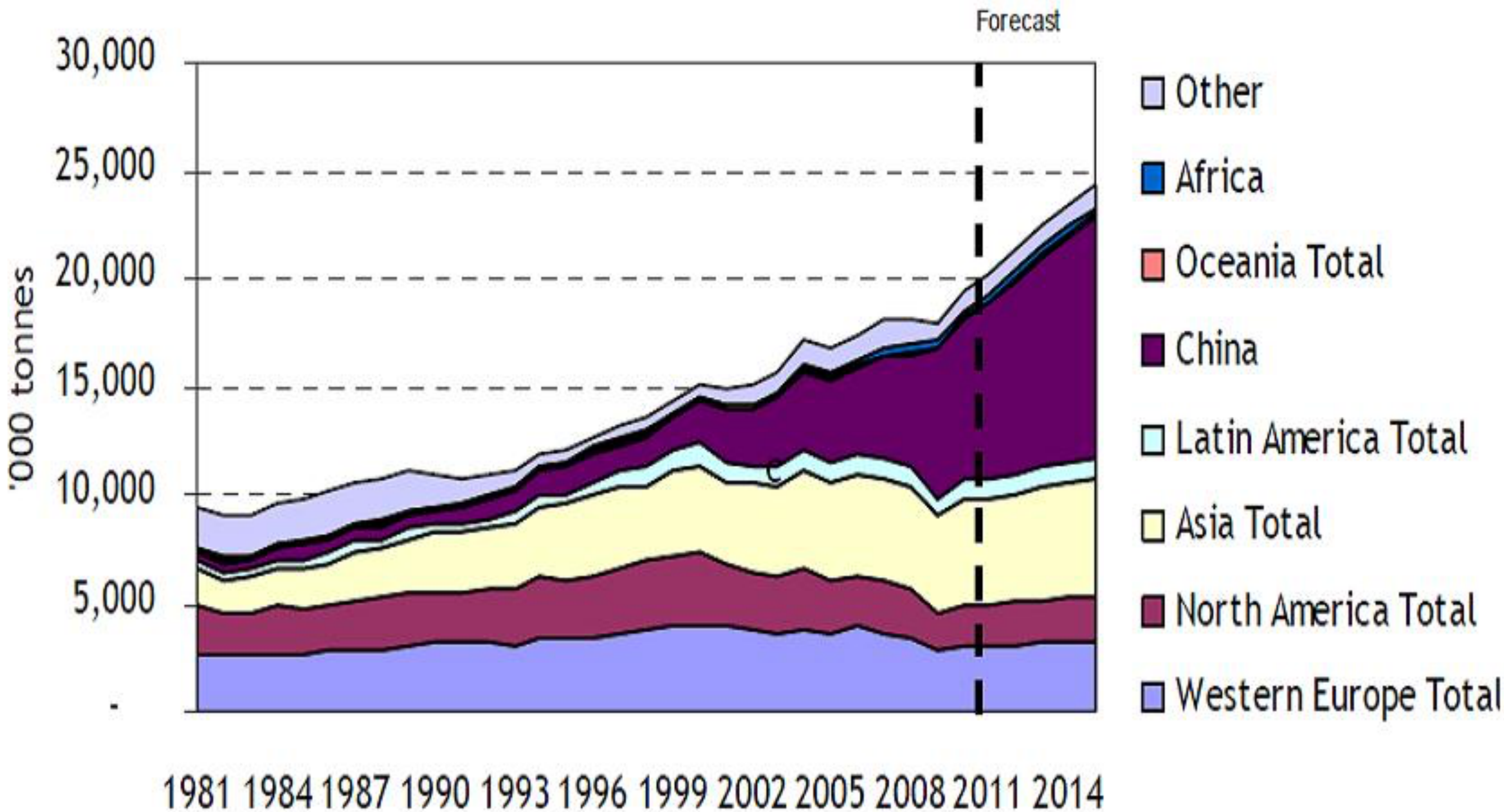

COPPER: A CIRCULAR MATERIAL
FOR A RESOURCE EFFICIENT EUROPE
Cu
European
Copper Institute
Copper Alliance
Cu
50% RECYCLED MATERIAL
Around 50% of EU demand for copper is met through recycling.
Urban Mining
Mo
Au
Co
Ag
Zn
18 ELEMENTS
Copper mining offers many useful by-products, including gold, silver, zinc, cobalt, molybdenum and rare earth elements.
MINING
RECYCLING
RECYCLING COPPER USES
UP TO 85%
LESS ENERGY
THAN PRIMARY PRODUCTION
Cu
PRODUCTION
60 ELEMENTS
A mobile phone contains up to 40 metallic elements, plus many non-metallic ones. Copper is a significant and vital part, offering good recycling opportunities.
+400 ALLOYS
Combining copper with other metals produces alloys—such as brass and bronze—that suit a wide range of applications.

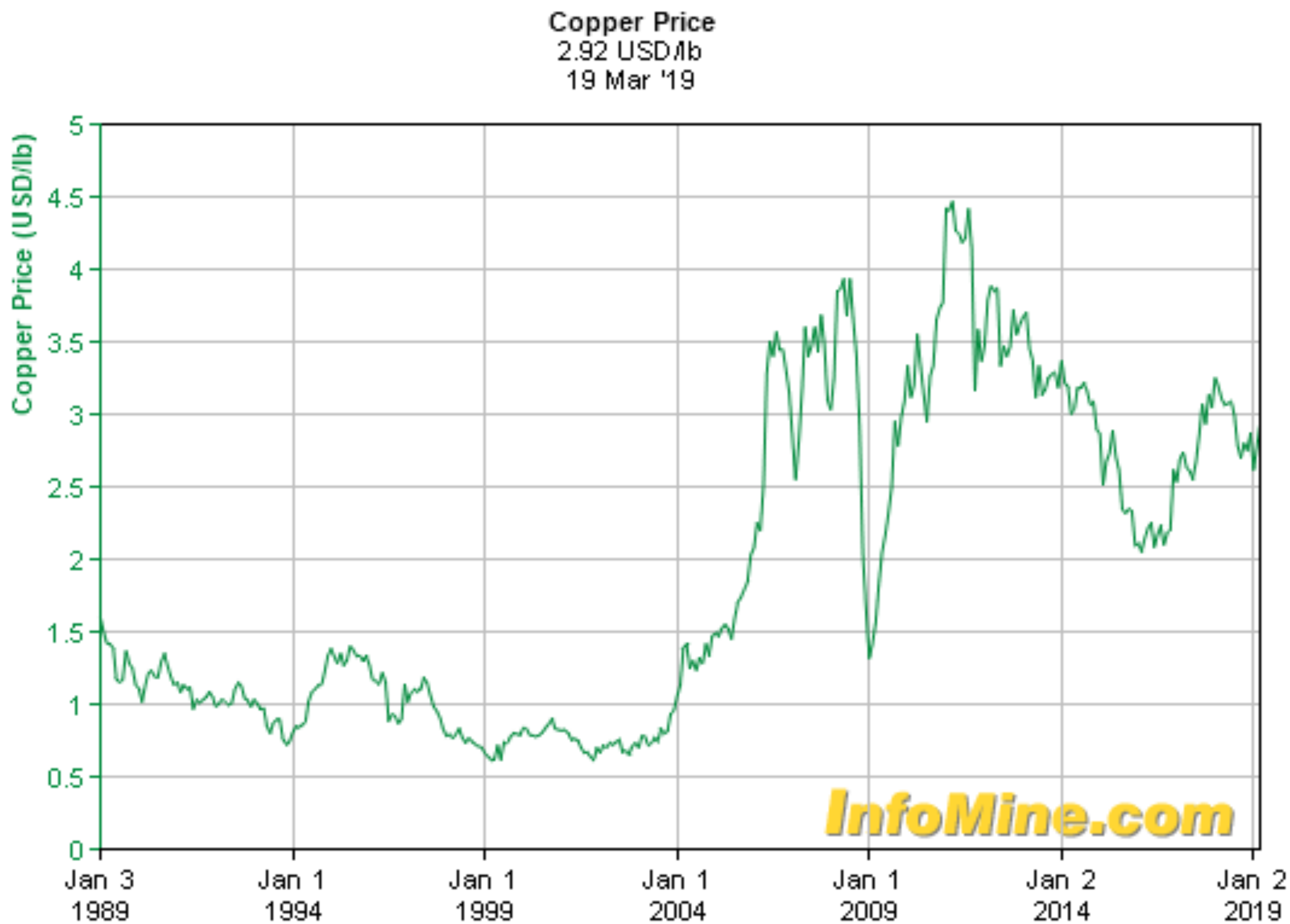
La domanda di rame è cresciuta…



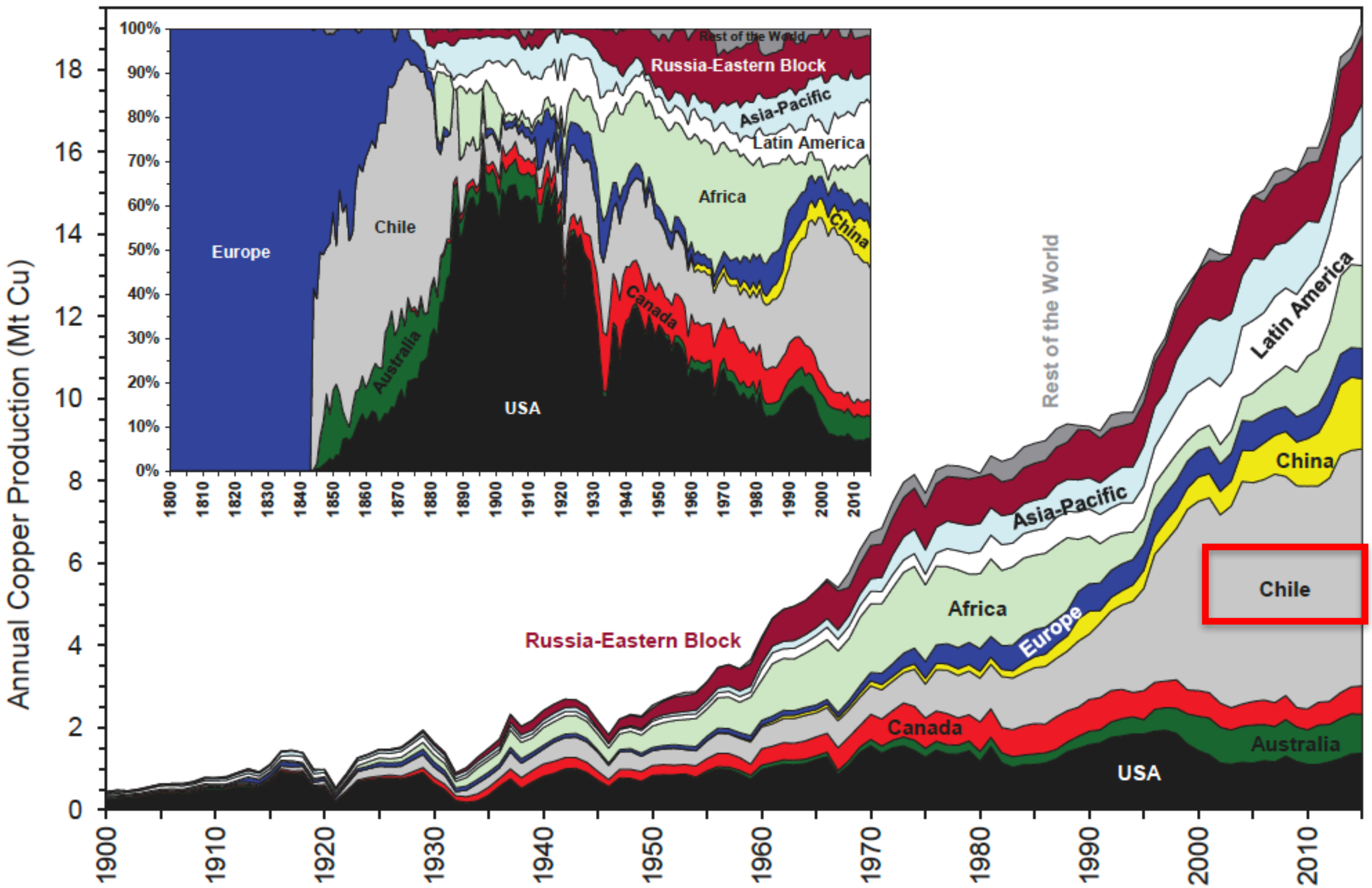
- China's copper demand boom…

Source: RBC 1-23-12, Brook Hunt, ICSG

Il prezzo del rame è salito…



La produzione “mineraria” di rame è aumentata…



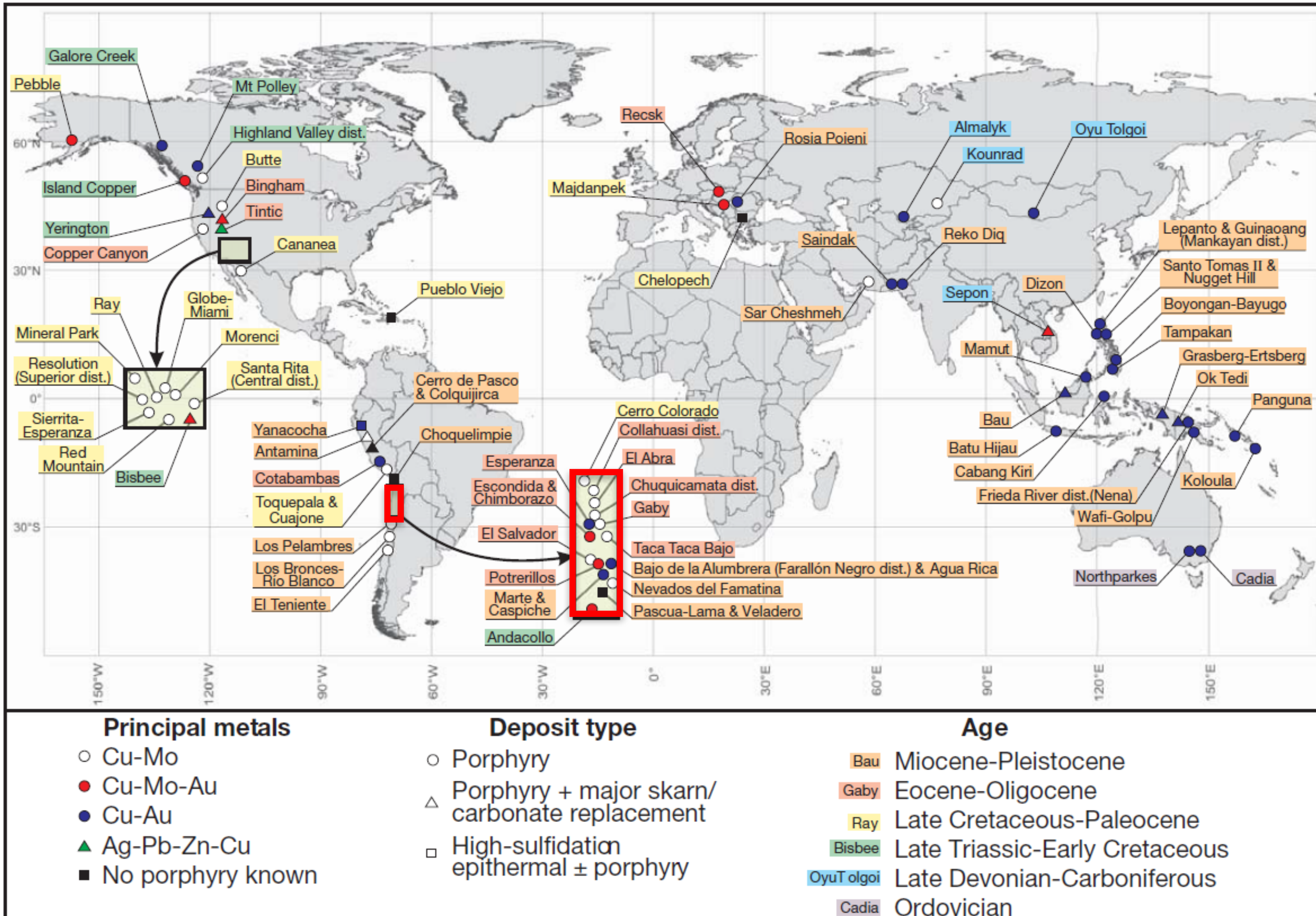
Mudd & Jowitt 2018

Risorse minerarie di rame su scala globale

Mineral deposit type	Basis	Mineral resources (inclusive of reserves)				Mineral reserves				2010 study[1]
		Count	Mt	% Cu	Mt Cu	Count	Mt	% Cu	Mt Cu	(Mt Cu at % Cu)
Porphyry	C	385	443,508.8	0.42	1,842.8	139	109,873.3	0.45	489.0	1,316.5 at 0.45%
	NC	342	96,524.9	0.43	417.6	1	27.0	0.26	0.070	
Sediment-hosted stratiform/stratabound Cu	C	126	18,632.4	1.48	275.9	48	5,856.4	1.18	69.3	165.5 at 1.52%
	NC	65	3,414.8	0.89	30.4	2	345.6	0.78	2.68	
Iron oxide Cu-Au (IOCG)	C	76	19,362.3	0.71	138.1	23	3,776.7	0.80	30.3	125.1 at 0.71%
	NC	12	221.9	1.24	2.75	0	-	-	-	
Volcanogenic massive sulfide (VMS)	C	246	6,556.3	0.73	47.9	59	1,023.8	0.91	9.3	31.6 at 0.78%
	NC	366	3,618.0	1.23	44.5	10	178.7	1.54	2.75	
Magmatic sulfide	C	186	34,397.6	0.24	83.6	65	5,186.2	0.37	19.2	76.2 at 0.29%
	NC	52	3,178.7	0.54	17.2	0	-	-	-	
Skarn	C	82	8,096.2	0.63	50.7	28	2,696.1	0.63	17.0	34.5 at 0.70%
	NC	46	1,049.1	0.65	6.86	0	-	-	-	
Epithermal	C	83	8,278.5	0.27	22.2	20	762.1	0.24	1.81	4.9 at 0.18%
	NC	58	1,550.6	0.74	11.5	0	-	-	-	
Sediment-hosted Pb-Zn	C	26	7,243.0	0.15	10.6	4	46.5	1.56	0.73	10.7 at 0.39%
	NC	51	1,413.3	0.34	4.81	0	-			
Sea floor polymetallic nodule	C	1	553.0	1.14	6.32	0	-			-
	NC	3	670.1	1.09	7.28	0	-			
Orogenic Au	C	24	352.3	0.70	2.48	9	60.7	0.99	0.60	0.5 at 0.41%
	NC	10	201.8	0.41	0.83	0	-	-	-	
Manto Cu	C	5	130.3	1.23	1.60	1	3.1	0.07	0.002	1.02 at 1.41%
Tailings	C	26	2,113.6	0.19	4.02	5	145.0	0.10	0.14	0.26 at 0.88%
	NC	7	255.1	0.09	0.24	0	-			
Native Cu	C	1	2.2	2.87	0.063	0	-			-
	NC	2	117.1	1.08	1.27	0	-			
Intrusion-related Au	C	5	446.7	0.17	0.75	1	149.0	0.10	0.15	0.84 at 0.12%
Miscellaneous[2]	C	10	5,665.3	0.03	1.61	1	35.0	0.54	0.19	0.74 at 0.37%
	NC	3	5.6	0.21	0.012	0	-	-	-	
Stockpiles and waste rock dumps	C	2	646.4	0.10	0.67	0	-	-	-	-
Subtotal	C	1,284	555,985.1	0.45	2,489.4	403	129,613.8	0.49	637.6	1,780.9 at 0.49%
	NC	1,017	112,221.0	0.49	545.3	4	394.2	0.82	3.22	
Grand total	-	2,301	668,206.1	0.45	3,034.7	407	130,008.0	0.49	640.9	1,780.9 at 0.49%

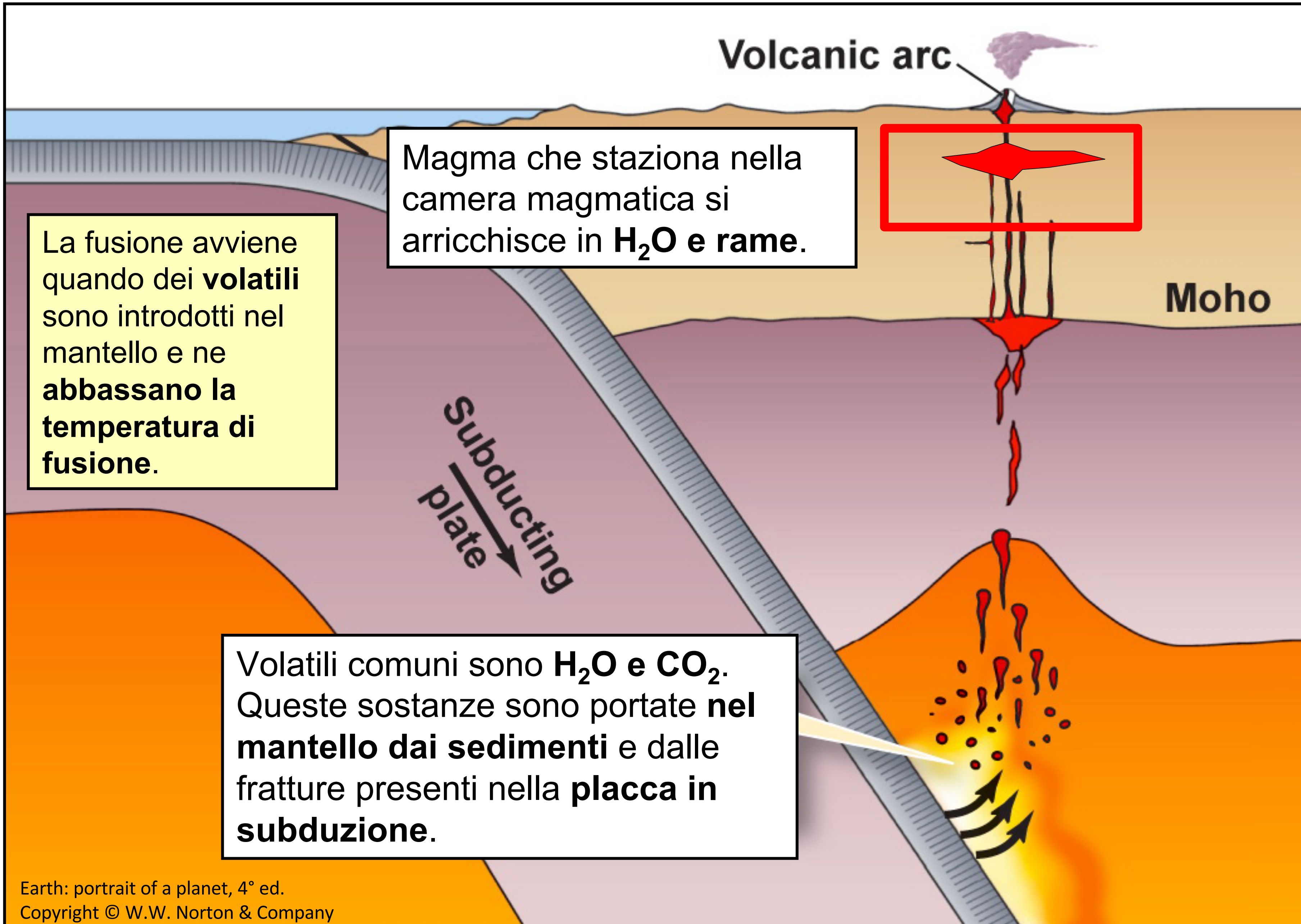
Mudd & Jowitt 2018

Distribuzione spaziale dei *porphyry*-Cu

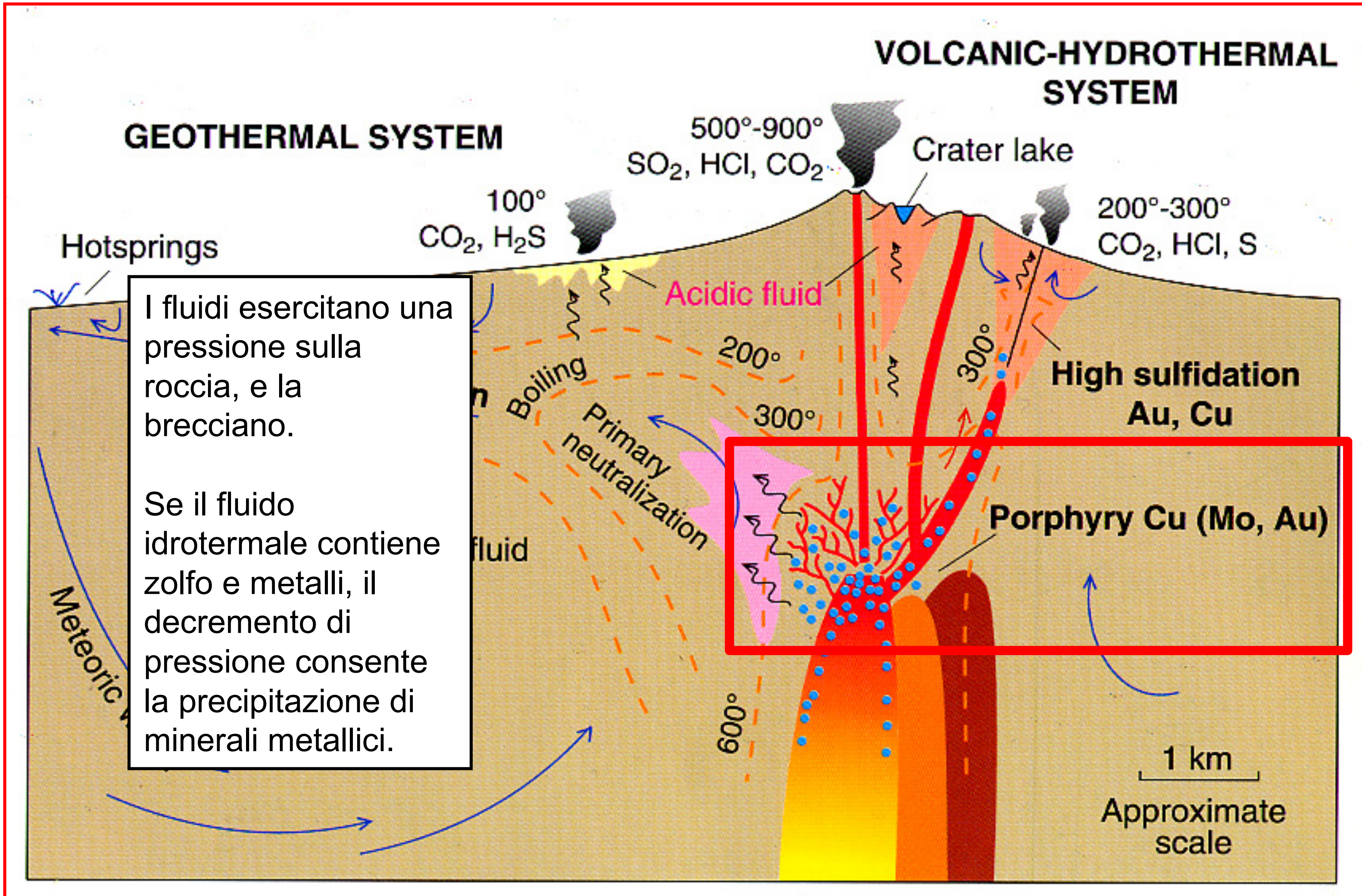


Sillitoe 2010

Genesi dei porphyry-Cu



Genesi dei porphyry-Cu

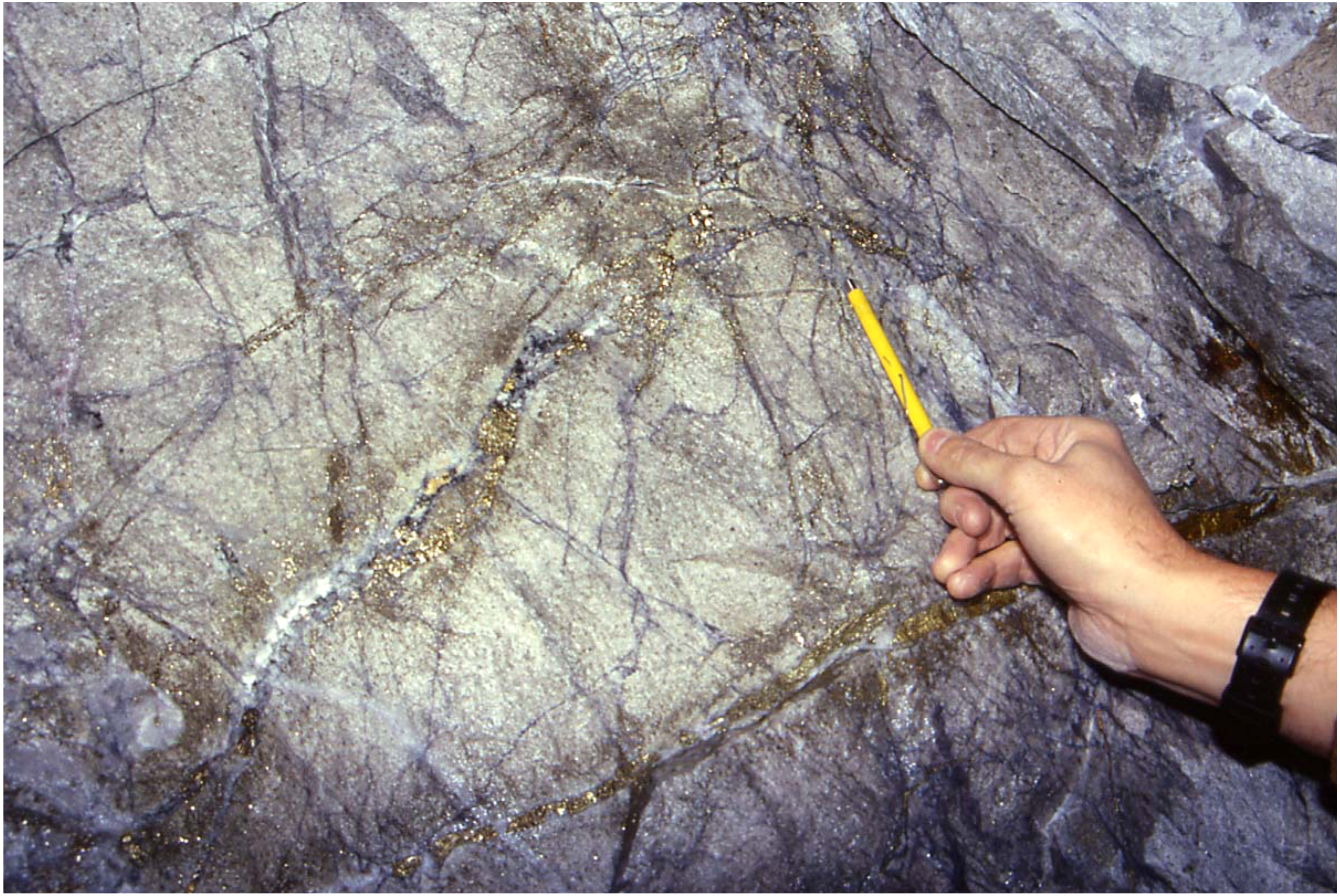


I fluidi esercitano una pressione sulla roccia, e la brecciano.

Se il fluido idrotermale contiene zolfo e metalli, il decremento di pressione consente la precipitazione di minerali metallici.

Hedenquist et al. 1996

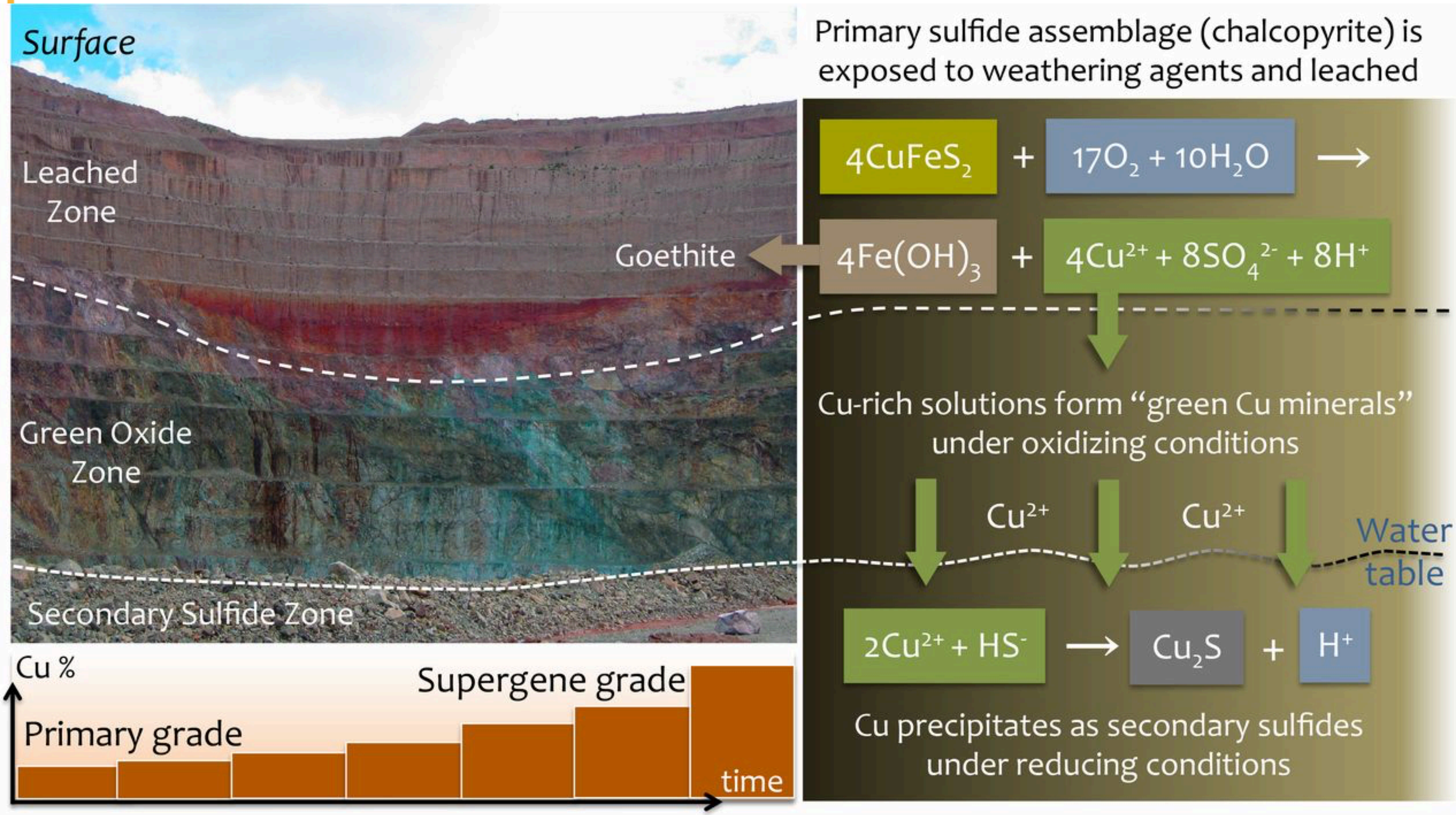
Porphyry-Cu



M. Boni

Chuquicamata

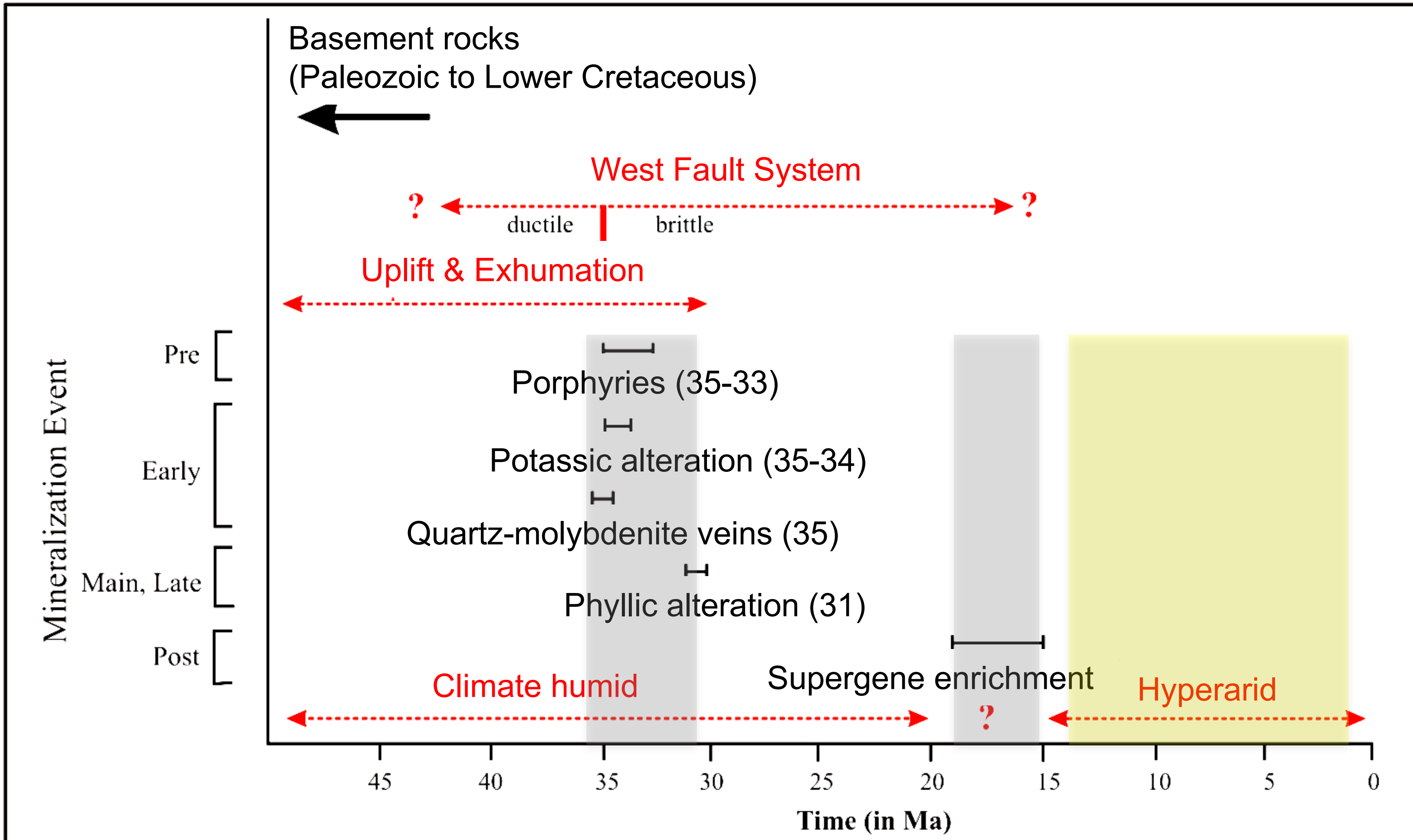
Porfidi a rame: arricchimento supergenico



Incremento dei tenori di Cu!

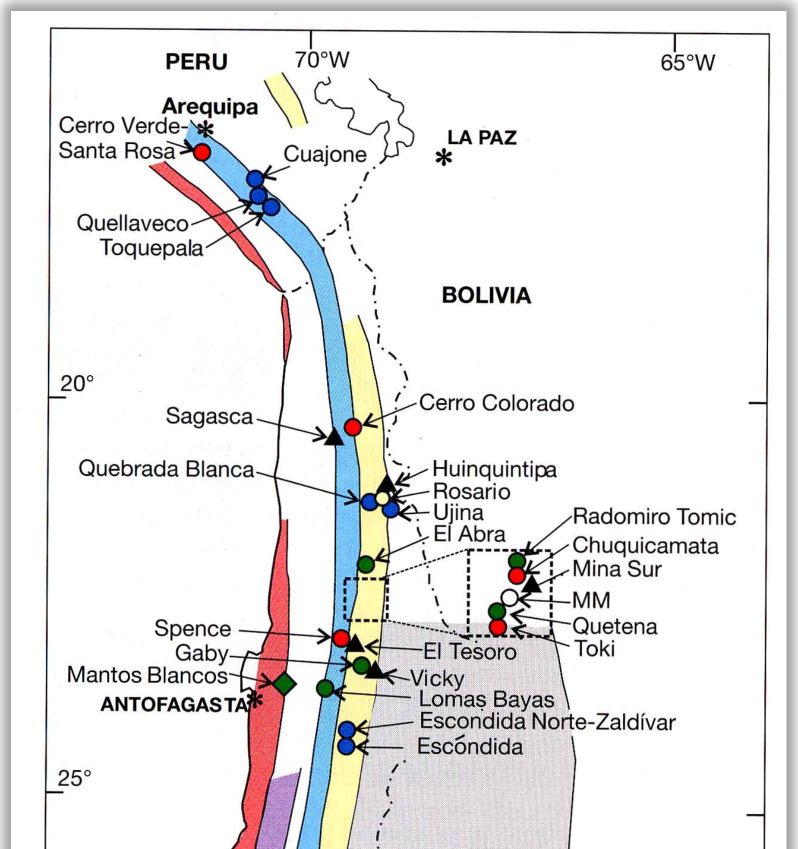
Reich & Vasconcelos 2015

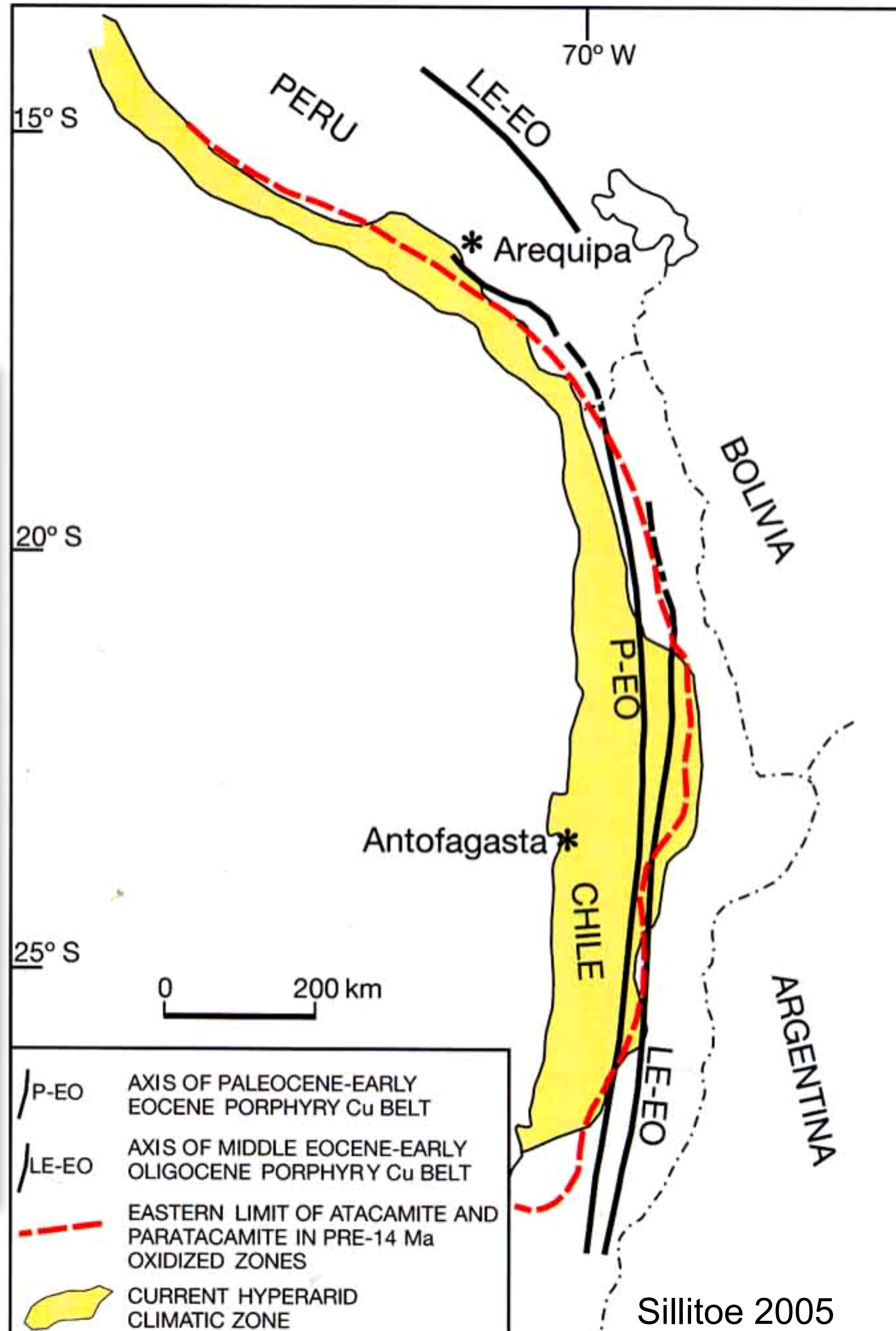
Chuquicamata:
evoluzione dei porphyry-Cu del Cile



Sillitoe 2005

Zone climatiche attuali





Zone climatiche attuali

Salar de Atacama, Chile

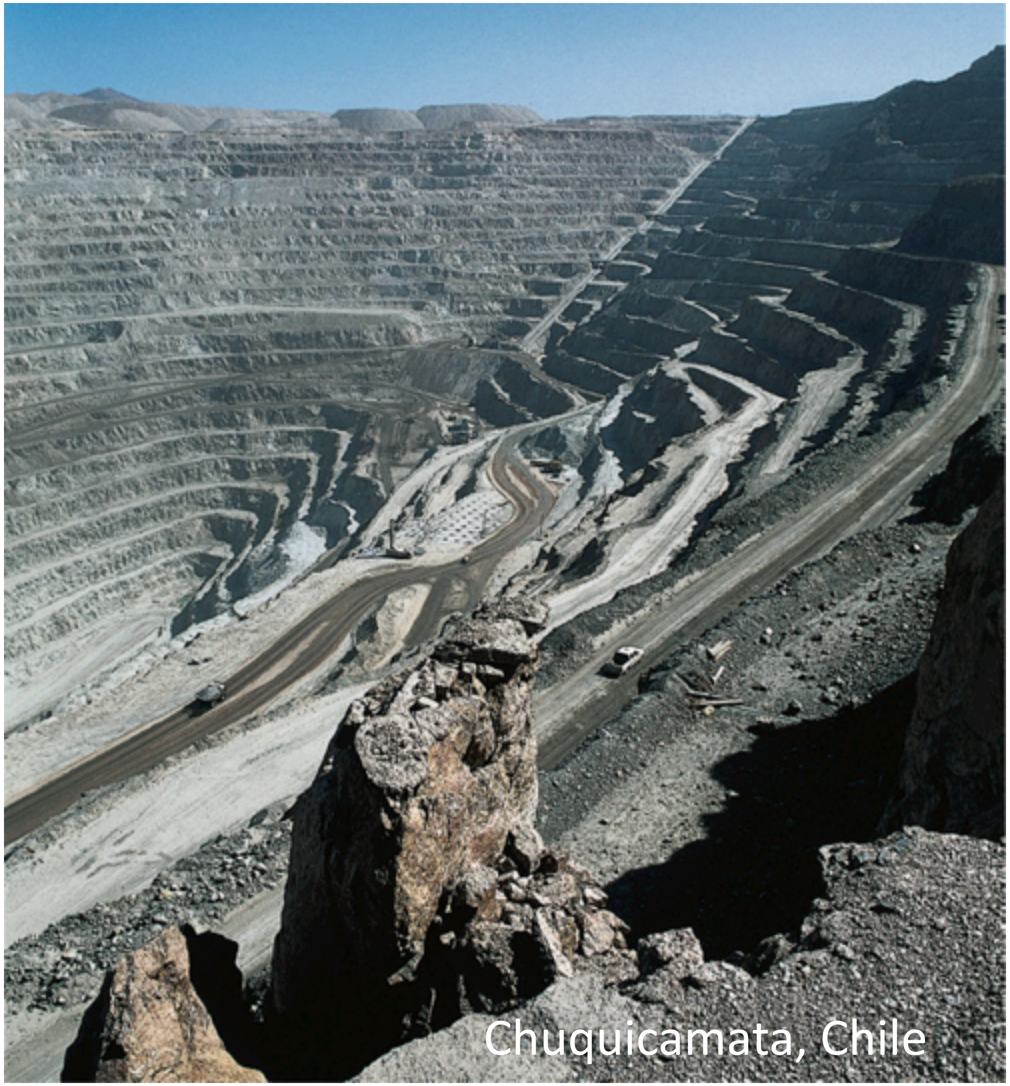
The world's largest and purest active source of lithium!

Table1 | Geographical restrictions on non-energy commodity supply

Commodity	Producer	Market share %
Rare Earths	China	97
Antimony	China	91
Gallium	China	83
Platinum	South Africa	80
Germanium	China	79
Tungsten	China	75
Indium	China	58
Silicon	China	58
Tantalum	Australia	53
Rhenium	Chile	53
Chromium	South Africa	45
Cobalt	Congo	45
Lithium	Chile	44
Iron Ore	China	43
Palladium	Russia	43
Vanadium	South Africa	38
Copper	Chile	31

Compilation table showing commodities where one country is responsible for >30% of the world mine production, showing the percentage market share (2008–2012 figures)[17,18].

Monopolio “geologico” delle risorse



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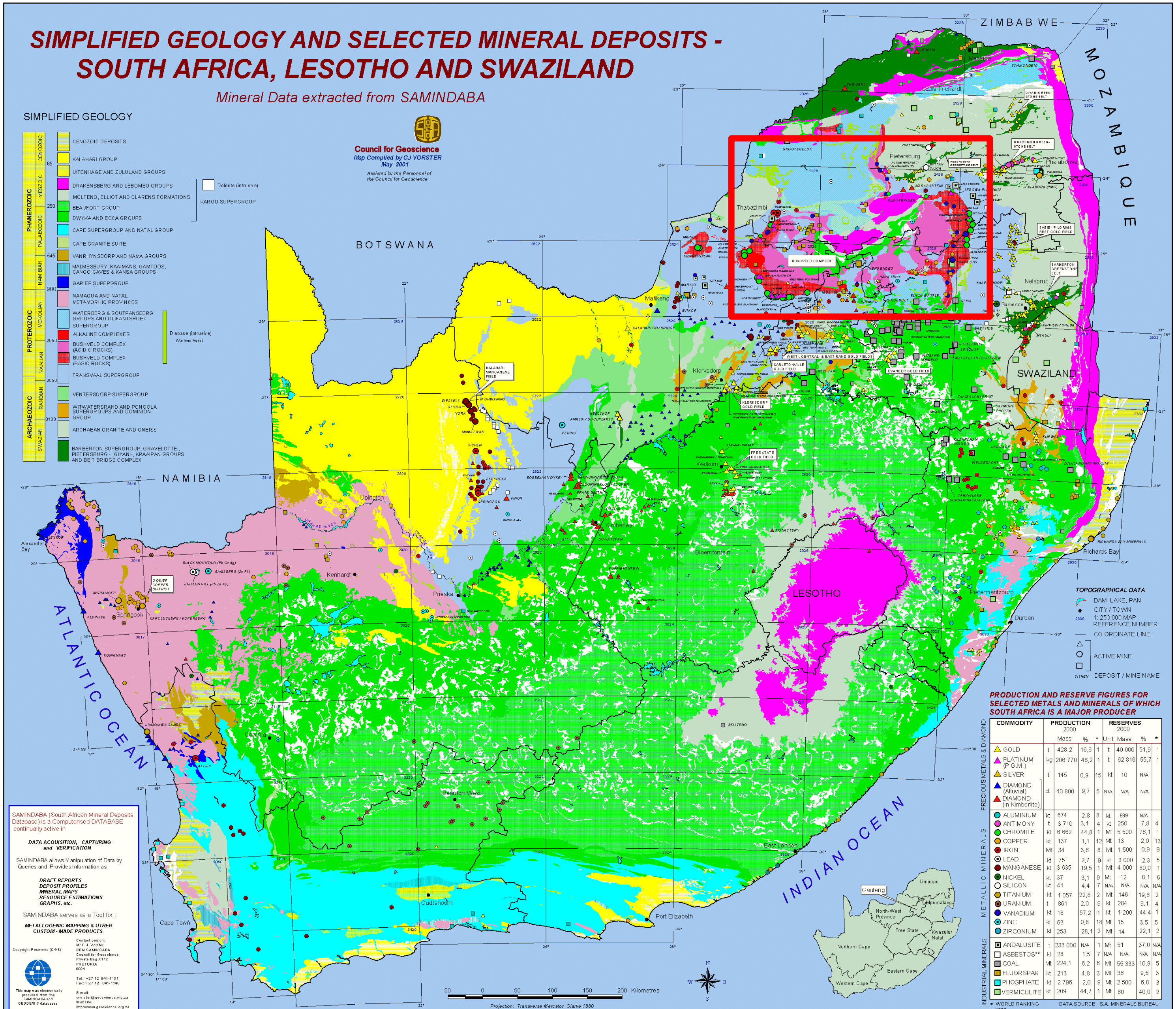
Herrington 2013

South Africa

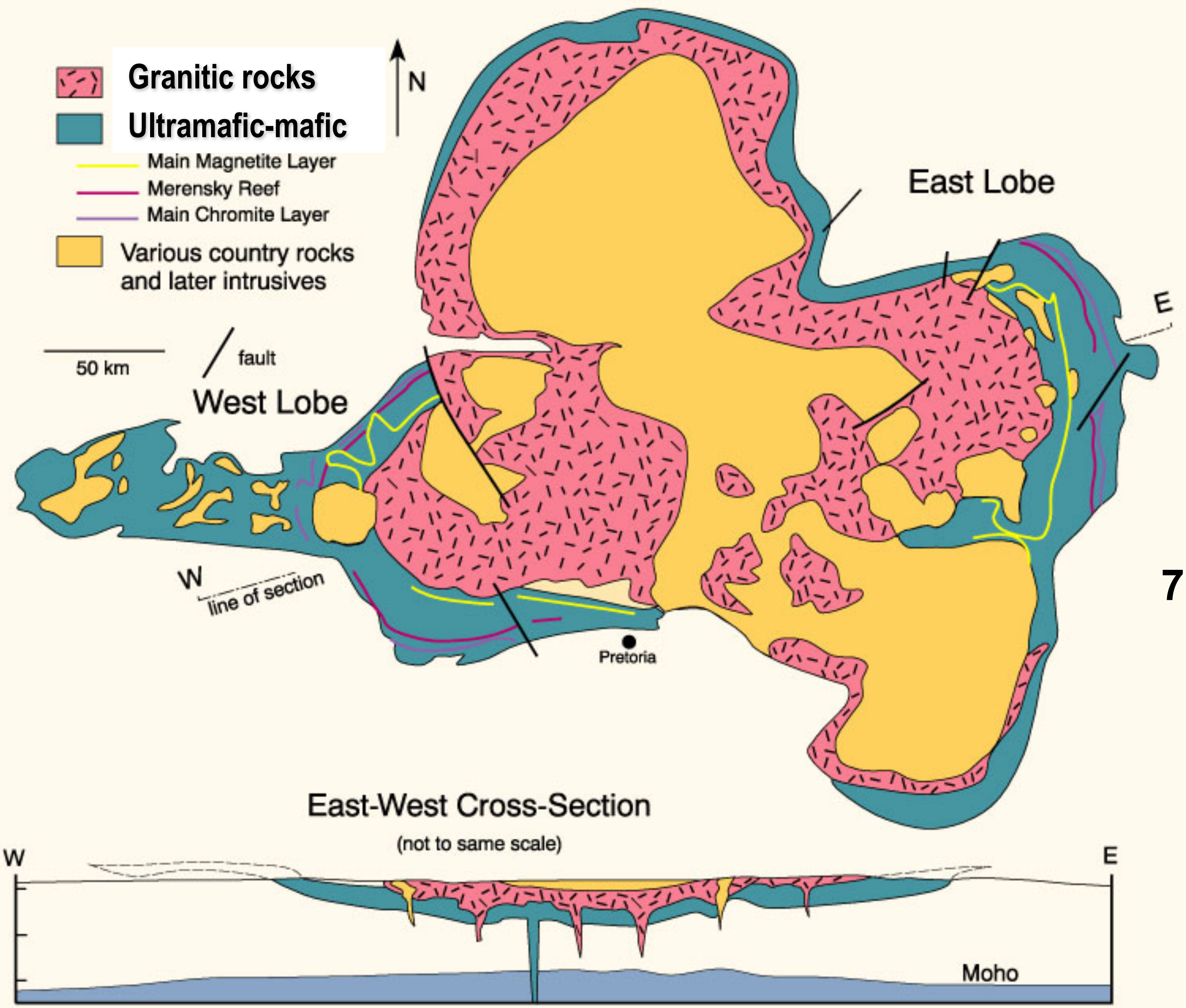


PRODUCTION AND RESERVE FIGURES FOR SELECTED METALS AND MINERALS OF WHICH SOUTH AFRICA IS A MAJOR PRODUCER

	COMMODITY	PRODUCTION 2000				RESERVES 2000			
			Mass	%	*	Unit	Mass	%	*
PRECIOUS METALS & DIAMOND	GOLD	t	428,2	16,6	1	t	40 000	51,9	1
	PLATINUM (P.G.M.)	kg	206 770	46,2	1	t	62 816	55,7	1
	SILVER	t	145	0,9	15	kt	10	N/A	
	DIAMOND (Alluvial) / DIAMOND (in Kimberlite)	ct	10 800	9,7	5	N/A	N/A	N/A	
METALLIC MINERALS	ALUMINIUM	kt	674	2,8	8	kt	689	N/A	
	ANTIMONY	t	3 710	3,1	4	kt	250	7,8	4
	CHROMITE	kt	6 662	44,8	1	Mt	5 500	76,1	1
	COPPER	kt	137	1,1	12	Mt	13	2,0	13
	IRON	Mt	34	3,6	8	Mt	1 500	0,9	9
	LEAD	kt	75	2,7	9	kt	3 000	2,3	5
	MANGANESE	kt	3 635	19,5	1	Mt	4 000	80,0	1
	NICKEL	kt	37	3,1	9	Mt	12	8,1	6
	SILICON	kt	41	4,4	7	N/A	N/A	N/A	N/A
	TITANIUM	kt	1 057	22,8	2	Mt	146	19,8	2
	URANIUM	t	861	2,0	9	kt	284	9,1	4
	VANADIUM	kt	18	57,2	1	kt	1 200	44,4	1
	ZINC	kt	63	0,8	18	Mt	15	3,5	5
	ZIRCONIUM	kt	253	28,1	2	Mt	14	22,1	2
INDUSTRIAL MINERALS	ANDALUSITE	t	233 000	N/A	1	Mt	51	37,0	N/A
	ASBESTOS**	kt	28	1,5	7	N/A	N/A	N/A	N/A
	COAL	Mt	224,1	6,2	6	Mt	55 333	10,9	5
	FLUORSPAR	kt	213	4,8	3	Mt	36	9,5	3
	PHOSPHATE	kt	2 796	2,0	9	Mt	2 500	6,8	3
	VERMICULITE	kt	209	44,7	1	Mt	80	40,0	2

* WORLD RANKING
**1998
DATA SOURCE: S.A. MINERALS BUREAU

Bushveld Complex



Intrusione magmatica ultrabasica stratificata

2.06 Ga (Proterozoic)

66,000 km^2 estensione

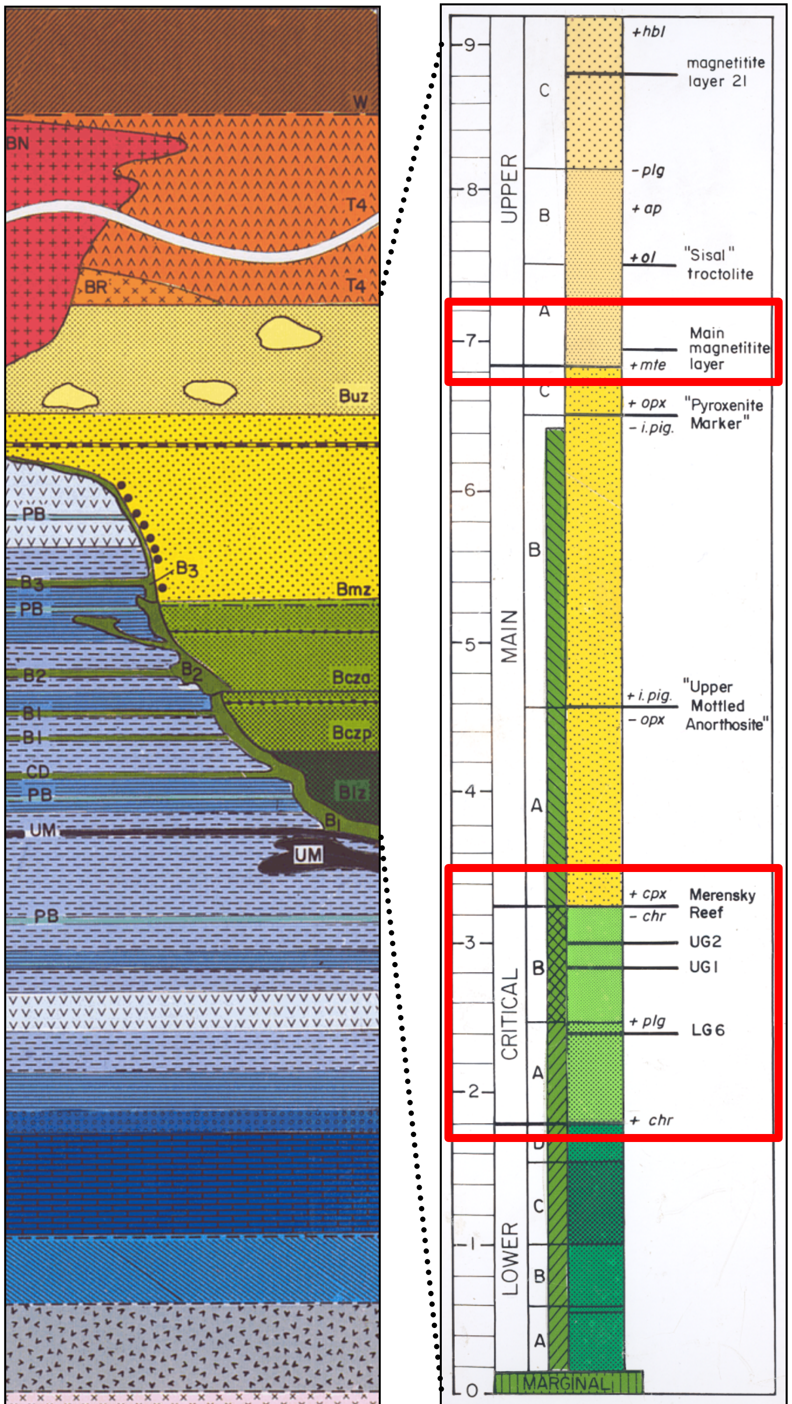
7 km spessore massimo

Simplified geologic map and cross section of the Bushveld complex. After Willemse (1964), Wager and Brown (1968), and Irvine *et al.* (1983).

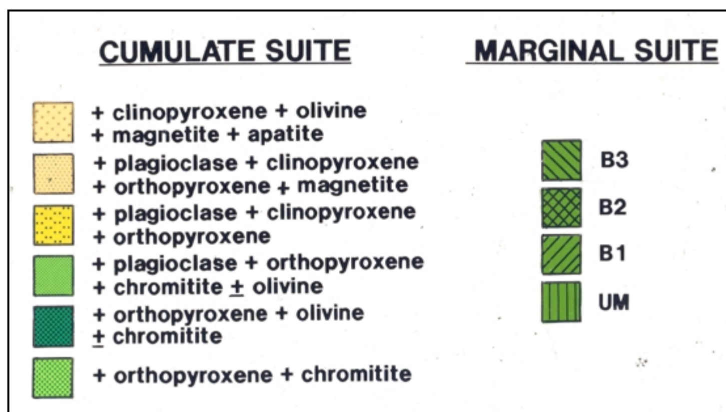
Bushveld Complex

Magma ultra-basico cristallizza molto lentamente all'interno di una camera magmatica profonda. La **cristallizzazione frazionata** si sviluppa in maniera **estrema** e i minerali si separano in maniera tanto efficace **da accumularsi in "strati" ben definiti** all'interno della roccia intrusiva risultante.

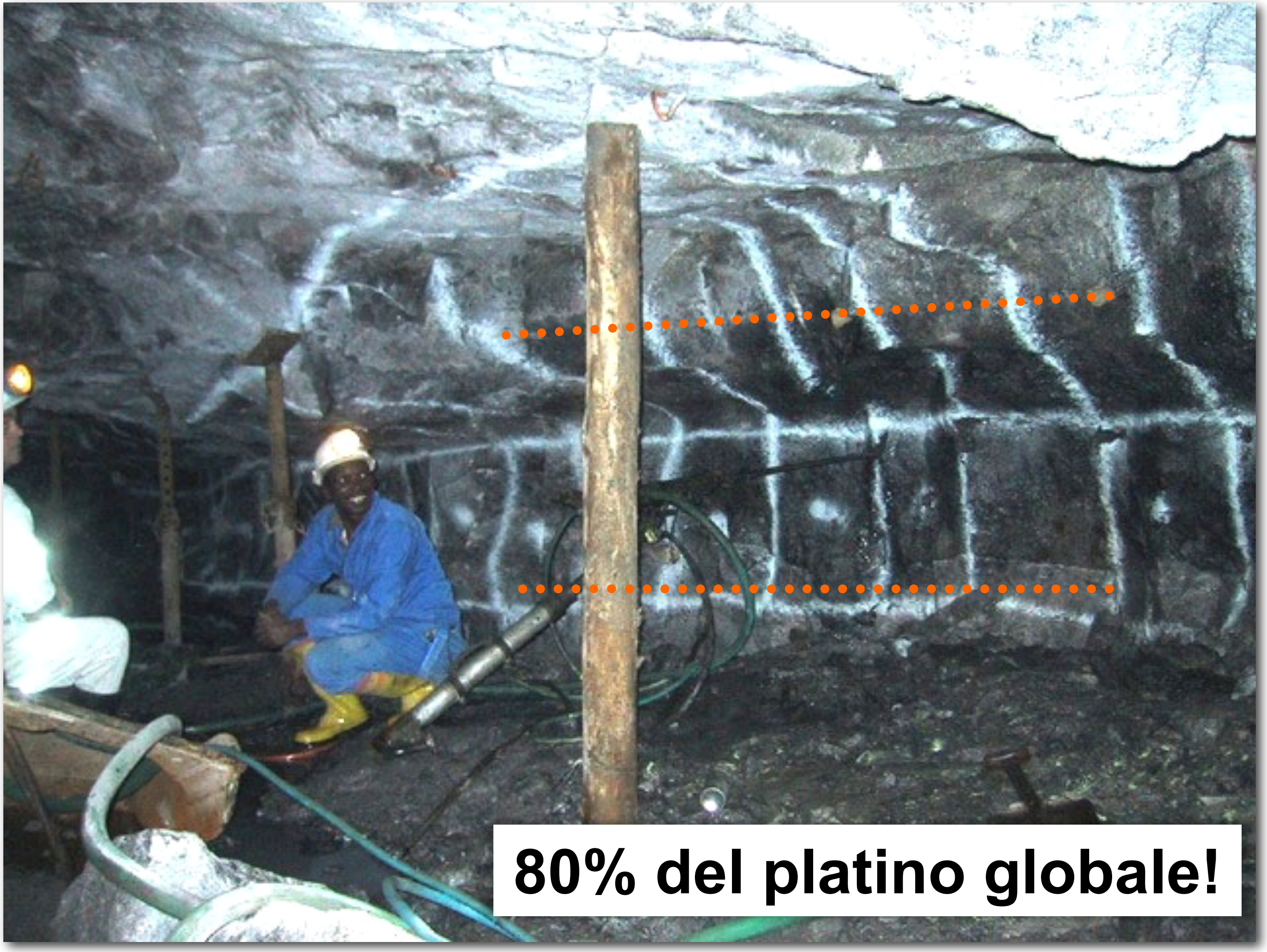
Bushveld Complex - Critical Zone



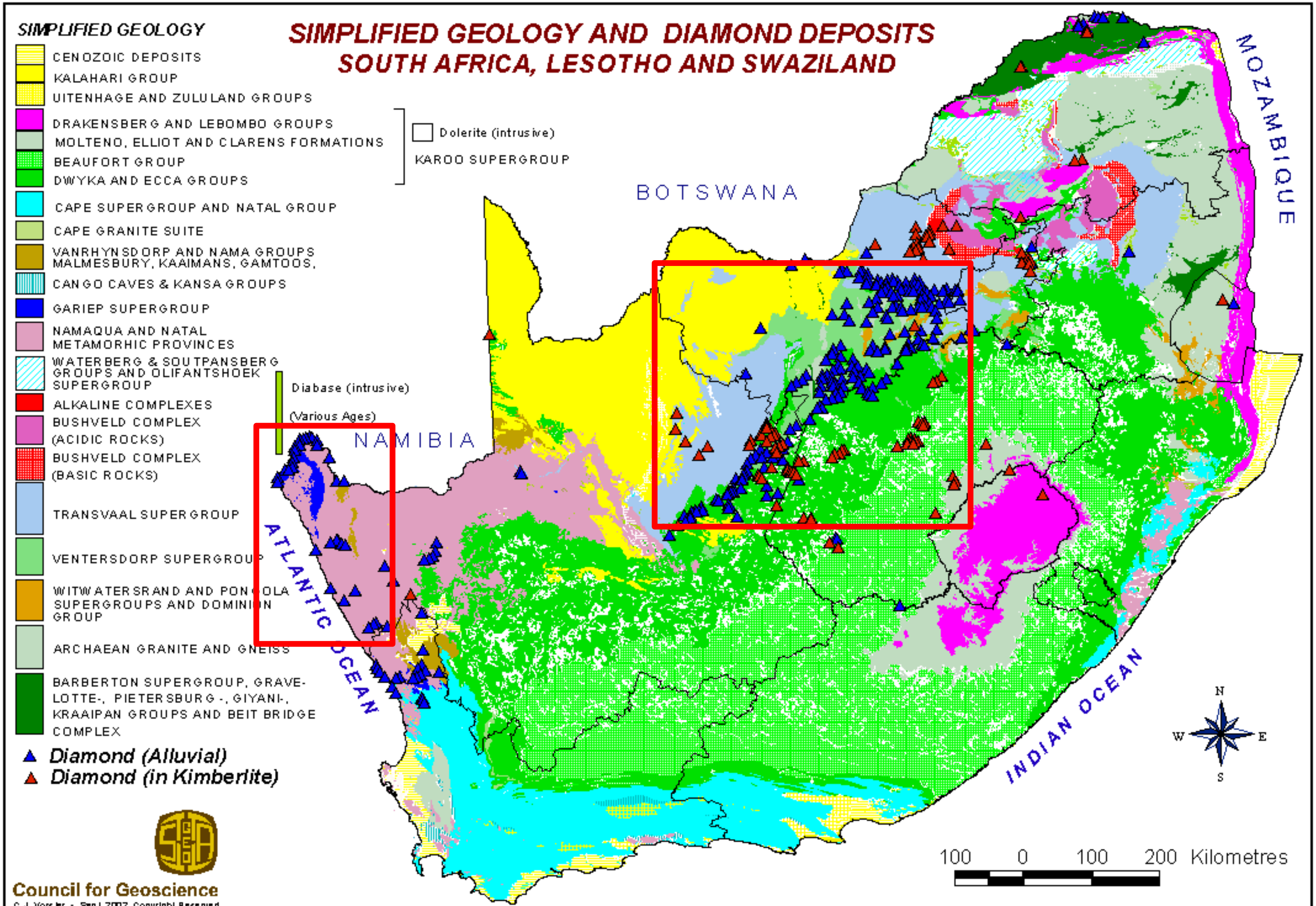
- Lower Critical zone (mostly pyroxenite) & Upper Critical zone (mostly norite)
- 13 major chromitite layers, in 3 clusters:
  - ➢ Lower group: 7 layers (LG1-LG7) in Lower Critical zone
  - ➢ Middle group: 4 layers (MG1-MG4)
  - ➢ Upper group: 2 layers (UG1 & UG2) in Upper Critical zone
- 60 to 90 % **chromite** grains
- Anomalously enriched in **PGE**
- PGEs economically enriched in **Merensky reef** (overlying UG2)
- **V-bearing Ti-magnetite** in the upper zone



Bushveld Complex - Critical zone - Merensky Reef

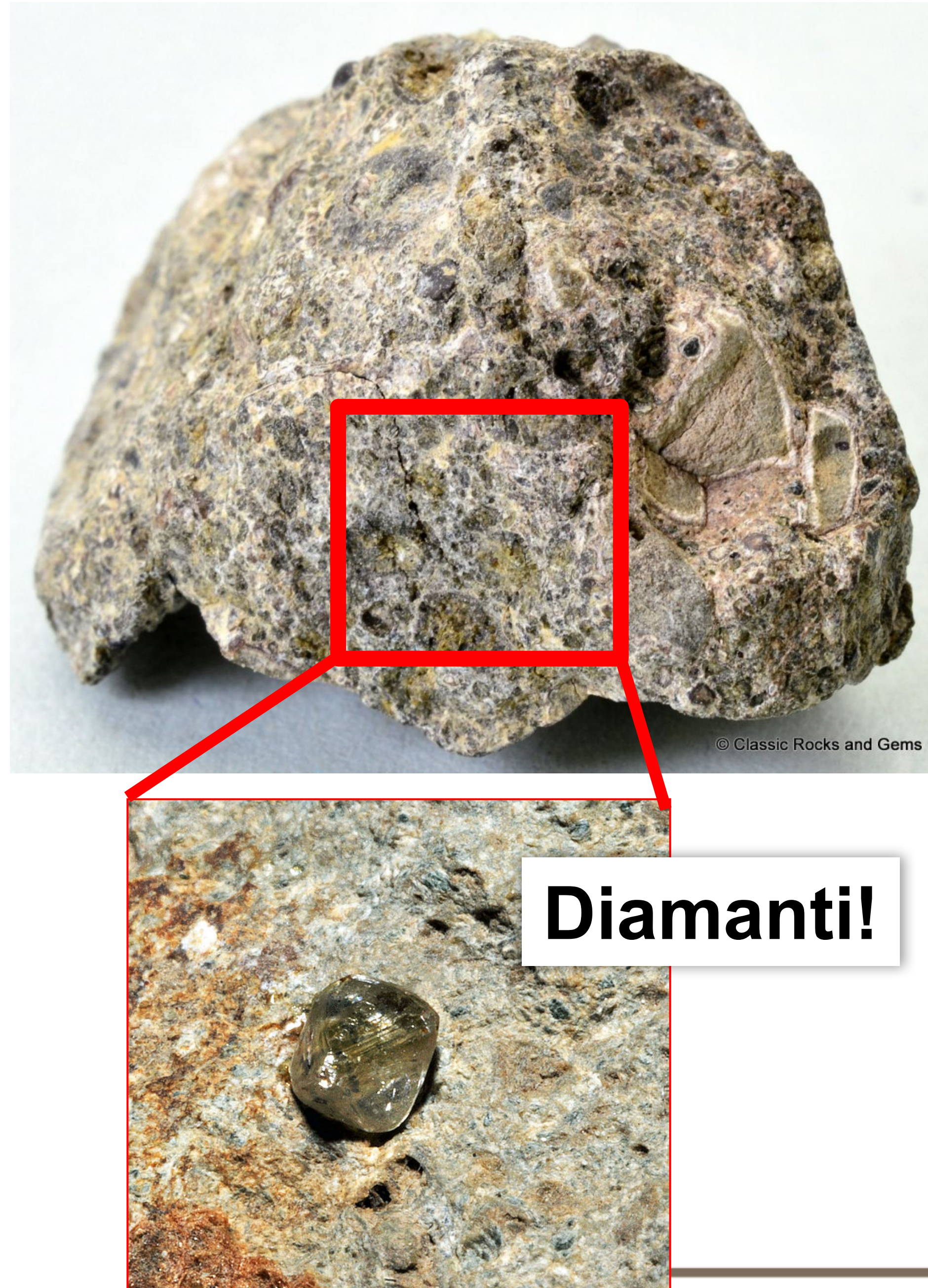


Diamanti

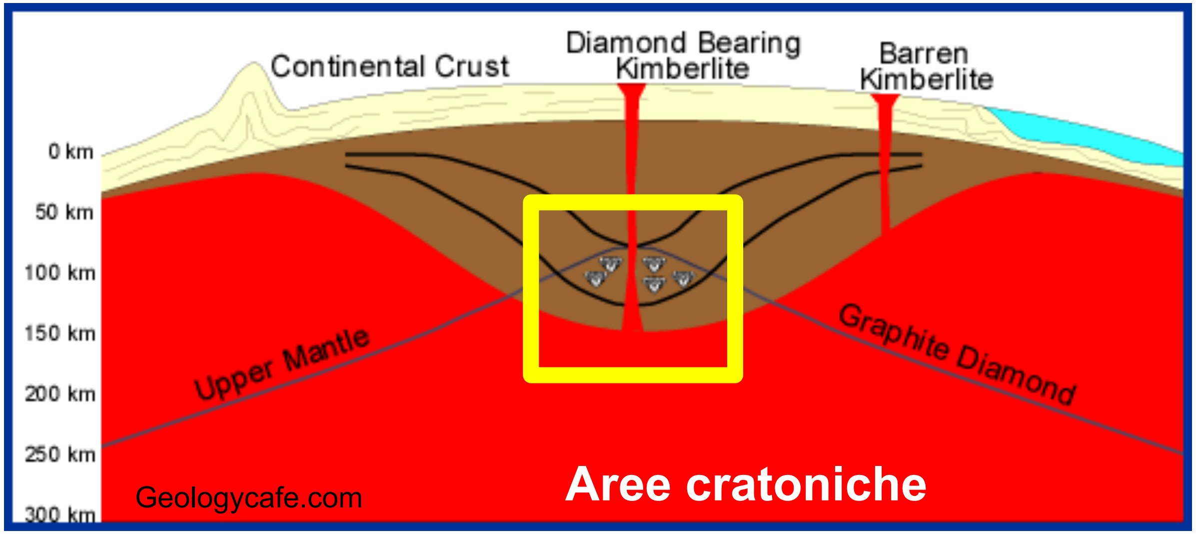


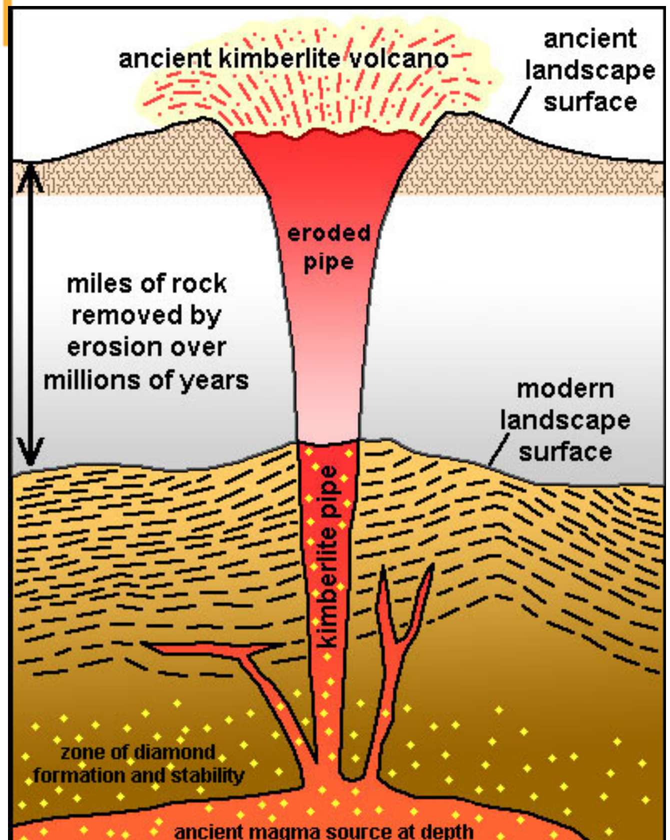
SIMPLIFIED GEOLOGY AND DIAMOND DEPOSITS
SOUTH AFRICA, LESOTHO AND SWAZILAND
SIMPLIFIED GEOLOGY
CENOZOIC DEPOSITS
KALAHARI GROUP
UITENHAGE AND ZULULAND GROUPS
DRAKENSBERG AND LEBOMBO GROUPS
MOLTENO, ELLIOT AND CLARENS FORMATIONS
BEAUFORT GROUP
DWYKA AND ECCA GROUPS
Dolerite (intrusive)
KAROO SUPERGROUP
CAPE SUPERGROUP AND NATAL GROUP
CAPE GRANITE SUITE
VANRHYNSDORP AND NAMA GROUPS
MALMESBURY, KAAIMANS, GAMTOOS,
CANGO CAVES & KANSA GROUPS
GARIEP SUPERGROUP
NAMAQUA AND NATAL METAMORHIC PROVINCES
WATERBERG & SOUTPANSBERG GROUPS AND OLIFANTSHOEK SUPERGROUP
Diabase (intrusive)
(Various Ages)
ALKALINE COMPLEXES
BUSHVELD COMPLEX (ACIDIC ROCKS)
BUSHVELD COMPLEX (BASIC ROCKS)
TRANSVAAL SUPERGROUP
VENTERSDORP SUPERGROUP
WITWATERSRAND AND PONGOLA SUPERGROUPS AND DOMINION GROUP
ARCHAEAN GRANITE AND GNEISS
BARBERTON SUPERGROUP, GRAVELOTTE-, PIETERSBURG-, GIYANI-, KRAAIPAN GROUPS AND BEIT BRIDGE COMPLEX
Diamond (Alluvial)
Diamond (in Kimberlite)
BOTSWANA
NAMIBIA
MOZAMBIQUE
ATLANTIC OCEAN
INDIAN OCEAN
N
W
E
S
100 0 100 200 Kilometres
Council for Geoscience
C.J. Vorster - Sept. 2002 Copyright Reserved

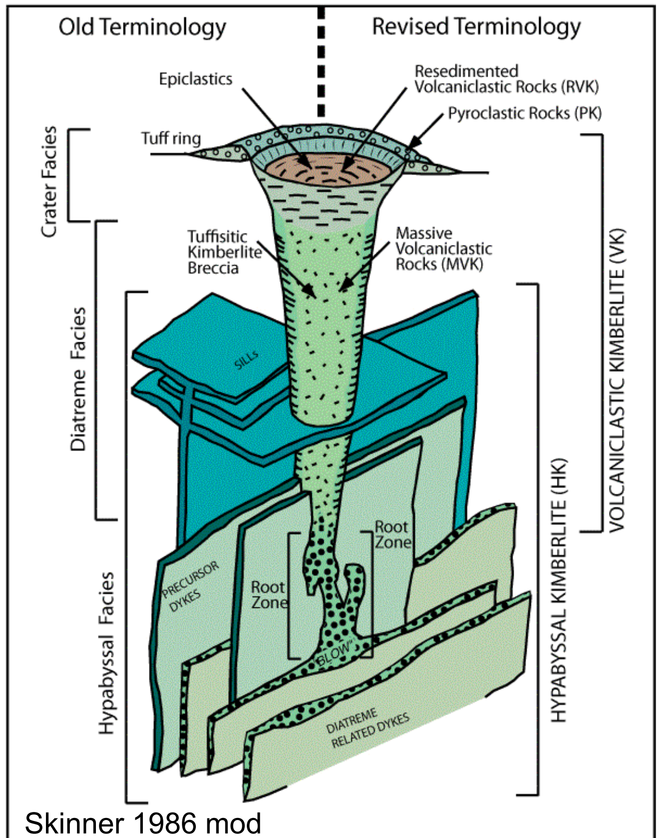
Depositi di diamanti in kimberlite



Depositi di diamanti in kimberlite



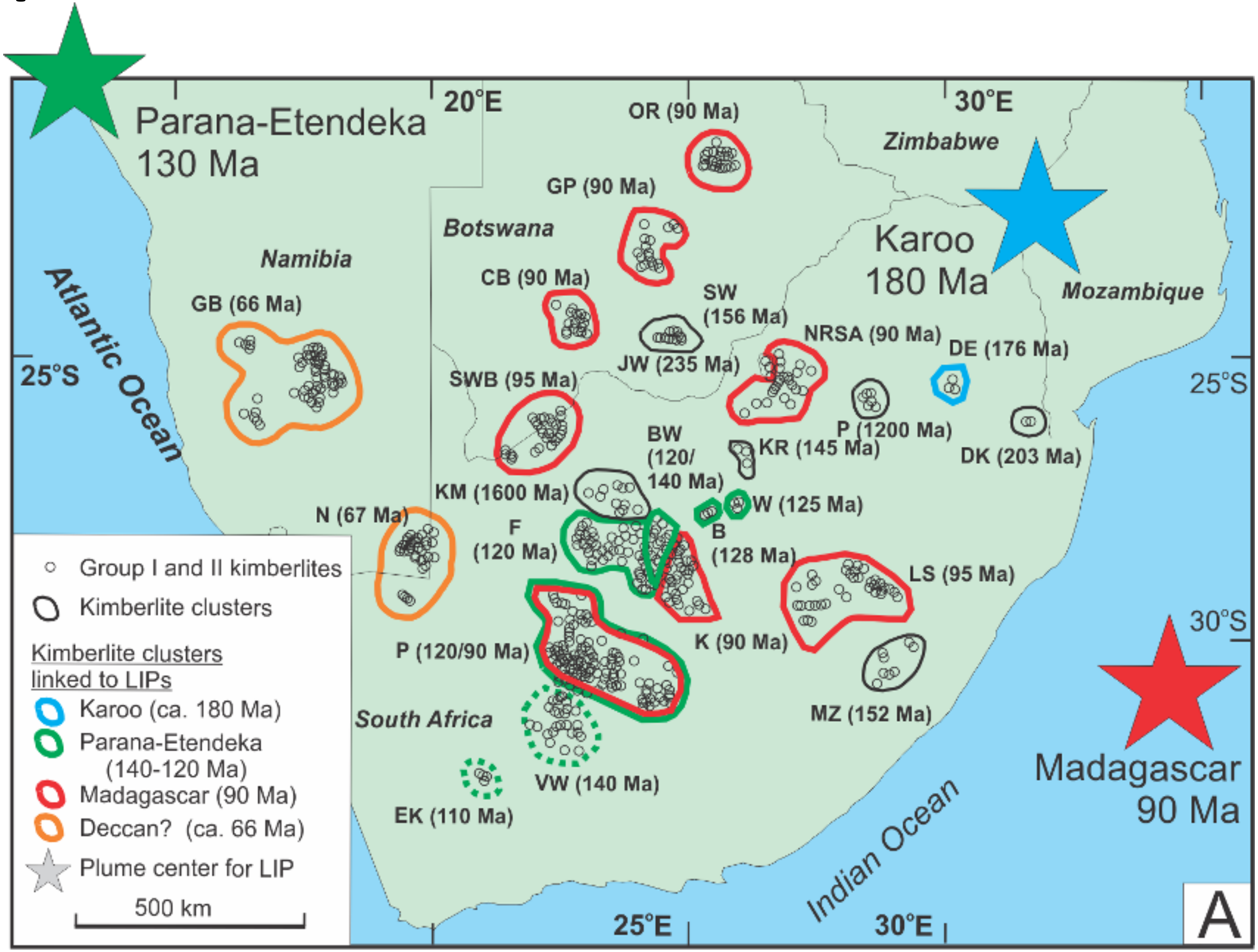




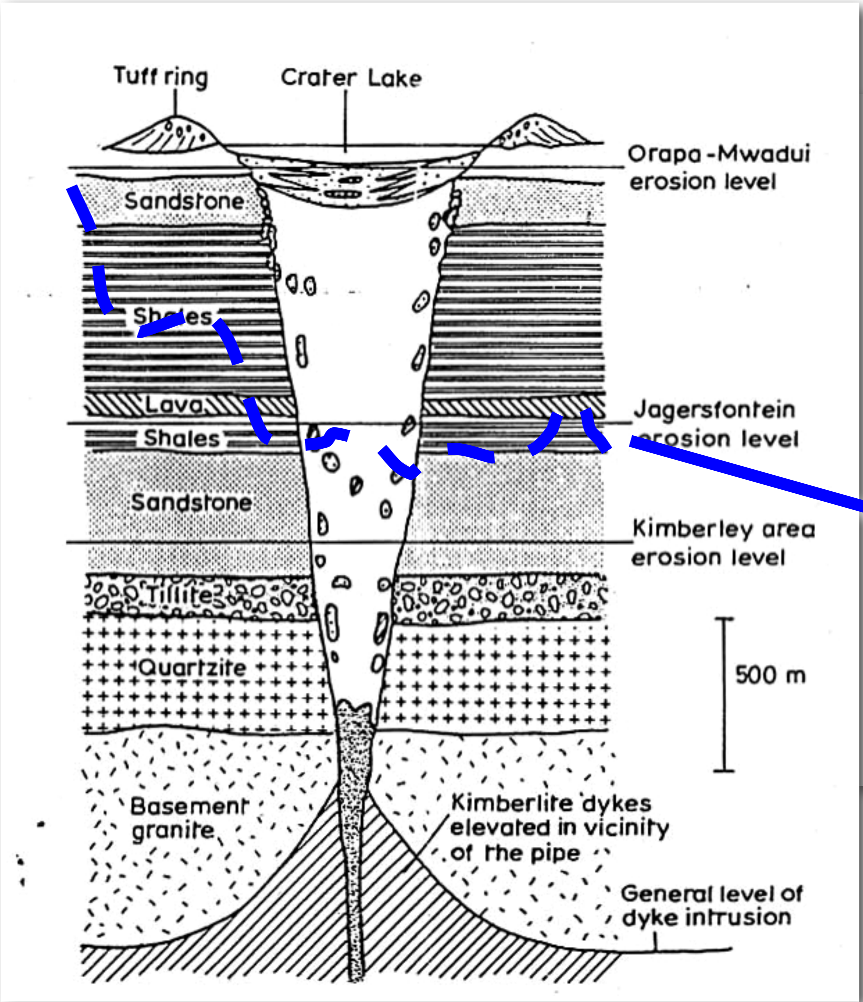
Al di sotto dei cratoni si raggiungono **pressioni litostatiche tali da permettere la formazione di diamanti**.

I diamanti raggiungono la superficie quando sono trasportati da **magmi che risalgono rapidamente** attraverso la spessa crosta del cratone. Se stazionano nella crosta, i diamanti vengono riassorbiti dal magma.

Depositi di diamanti in kimberlite

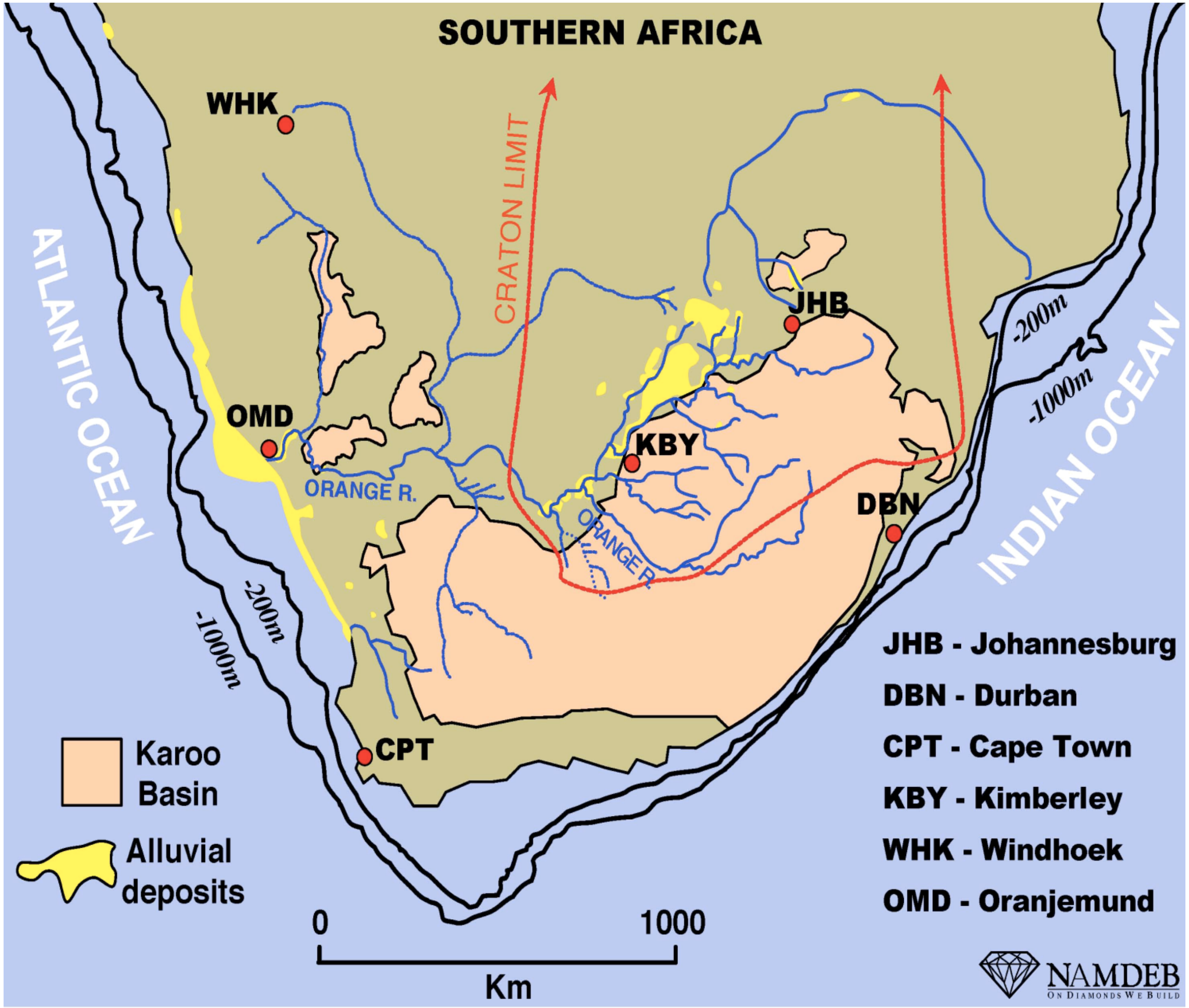


Depositi di diamanti “alluvionali”



Erosione delle kimberliti

Depositi di diamanti “alluvionali”



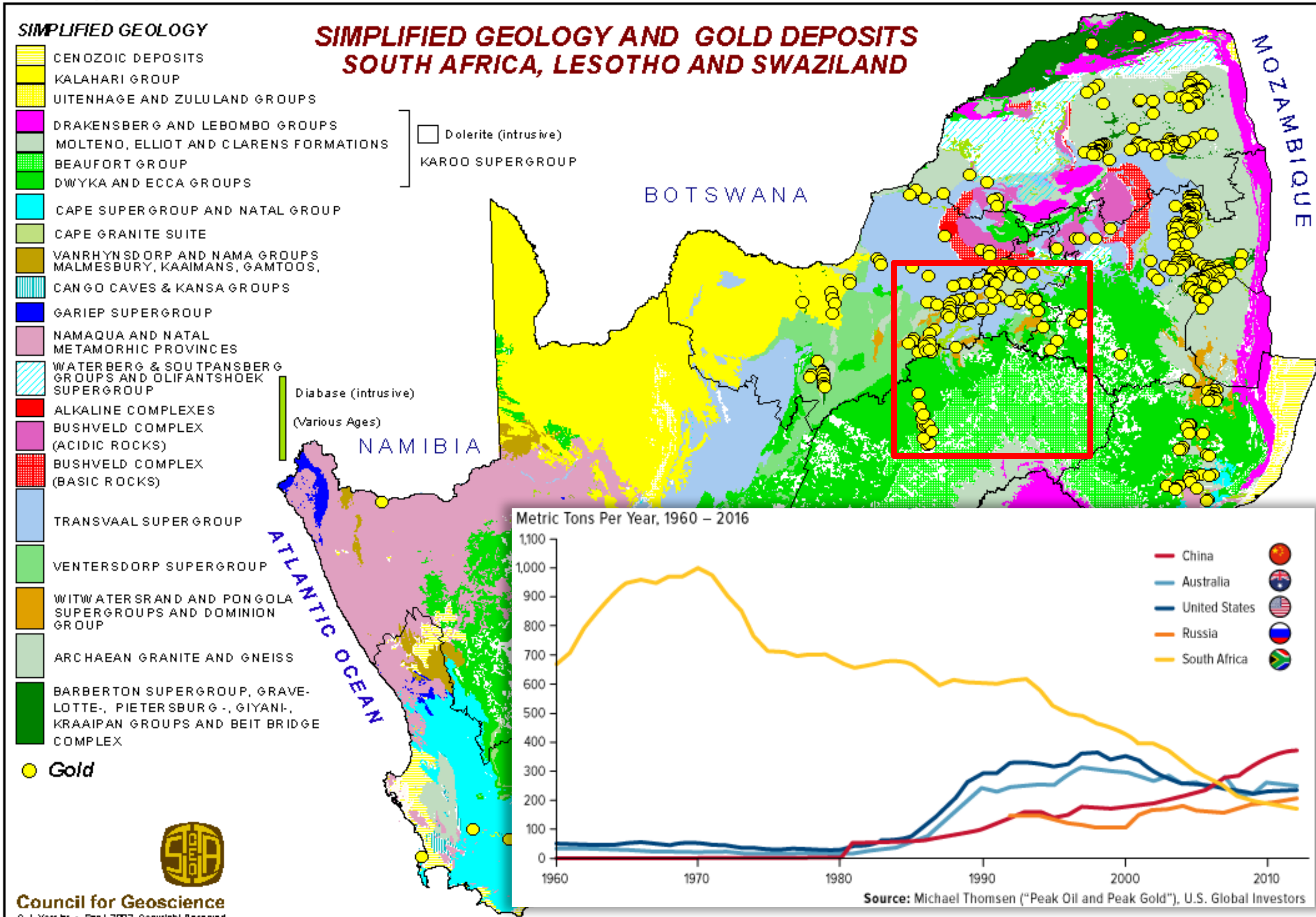
Depositi di diamanti "alluvionali"

Orange river (Namibia-South Africa border)

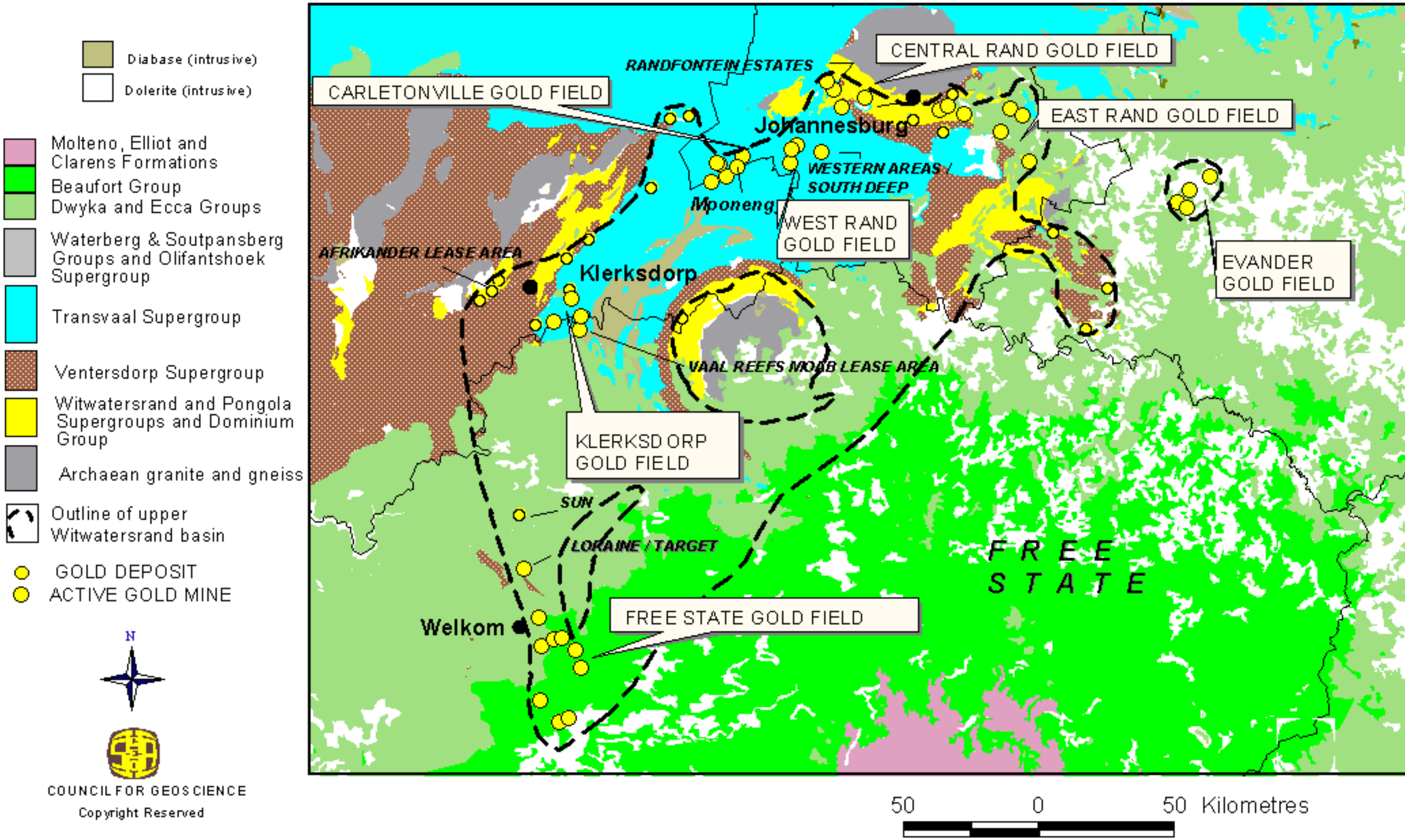
Depositi di diamanti "alluvionali"

Orange river (Namibia-South Africa border)

Depositi di oro



GOLD DEPOSITS OF THE WITWATERSRAND BASIN



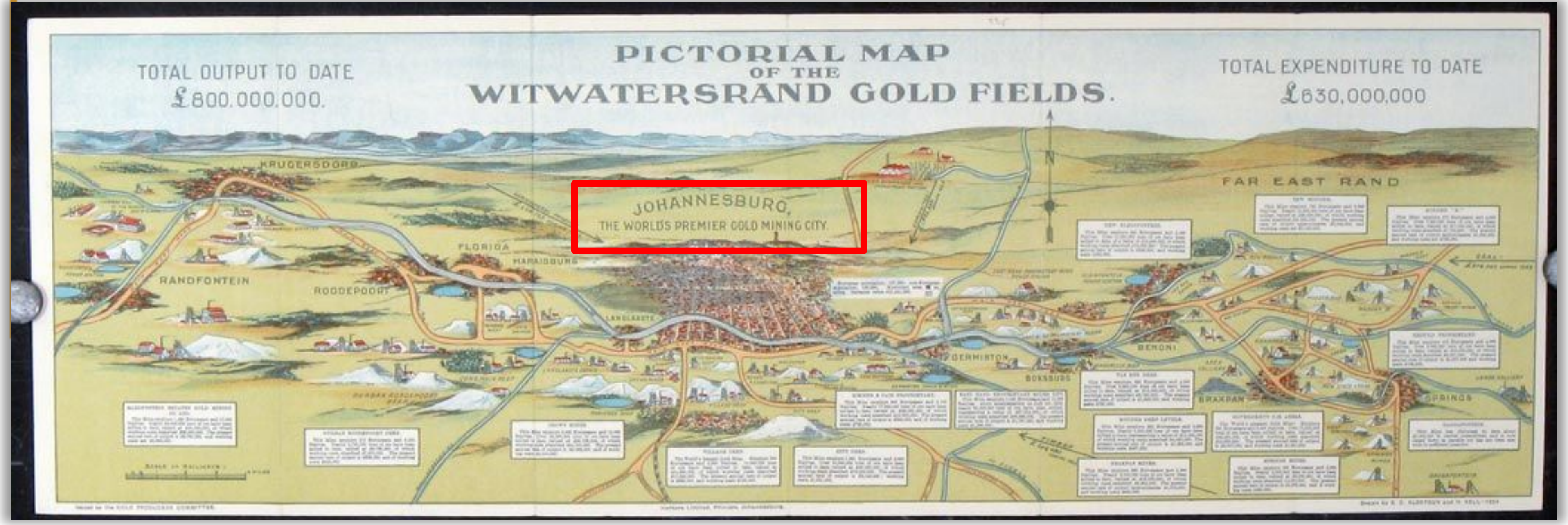
COUNCIL FOR GEOSCIENCE

CJ Vorster June 2000

Depositi di oro nel bacino del Witwatersrand

Johannesburg (South Africa)

Depositi di oro nel bacino del Witwatersrand



“Johannesburg, the World's Premier Gold Mining City” (1924)

La scoperta dell’oro nel bacino del Witwatersrand nel 1880 rese Johannesburg una delle città più popolose e grandi del mondo.

Si stima che dai depositi del Sud Africa derivi circa il 40% di tutto l’oro estratto nella storia dell’umanità.

Depositi di oro nel bacino del Witwatersrand

Kloof mine - Witwatersrand

M. Boni

Il bacino del Witwatersrand 3.0-2.9 Ga

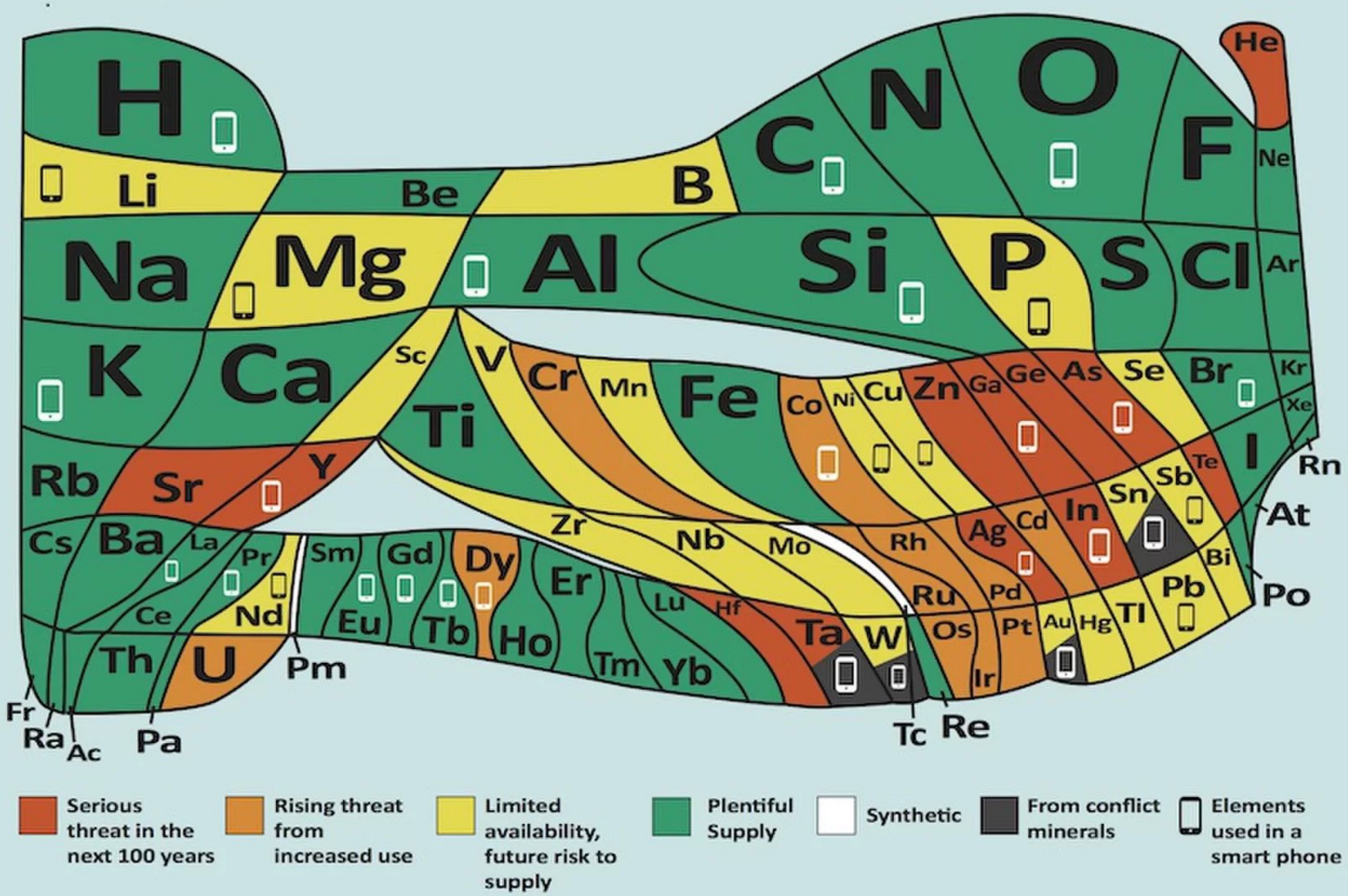
Reproduced from Antrobus (1986)

United Nations Educational, Scientific and Cultural Organization

2019 IYPT International Year of the Periodic Table of Chemical Elements

The 90 natural elements that make up everything

How much is there? Is that enough?

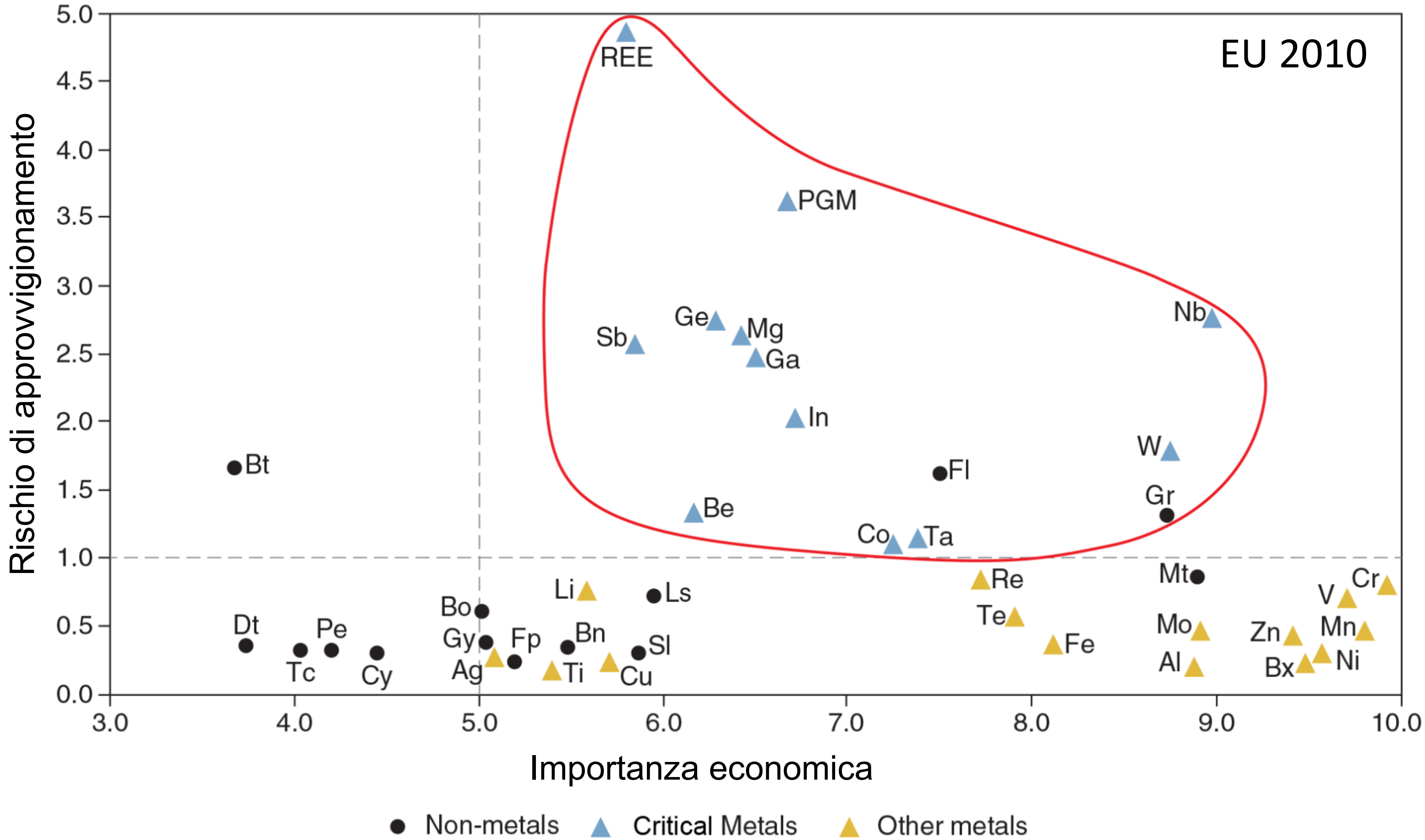


Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'

Read more and play the video game **http://bit.ly/euchems-pt**

EuChemS European Chemical Society

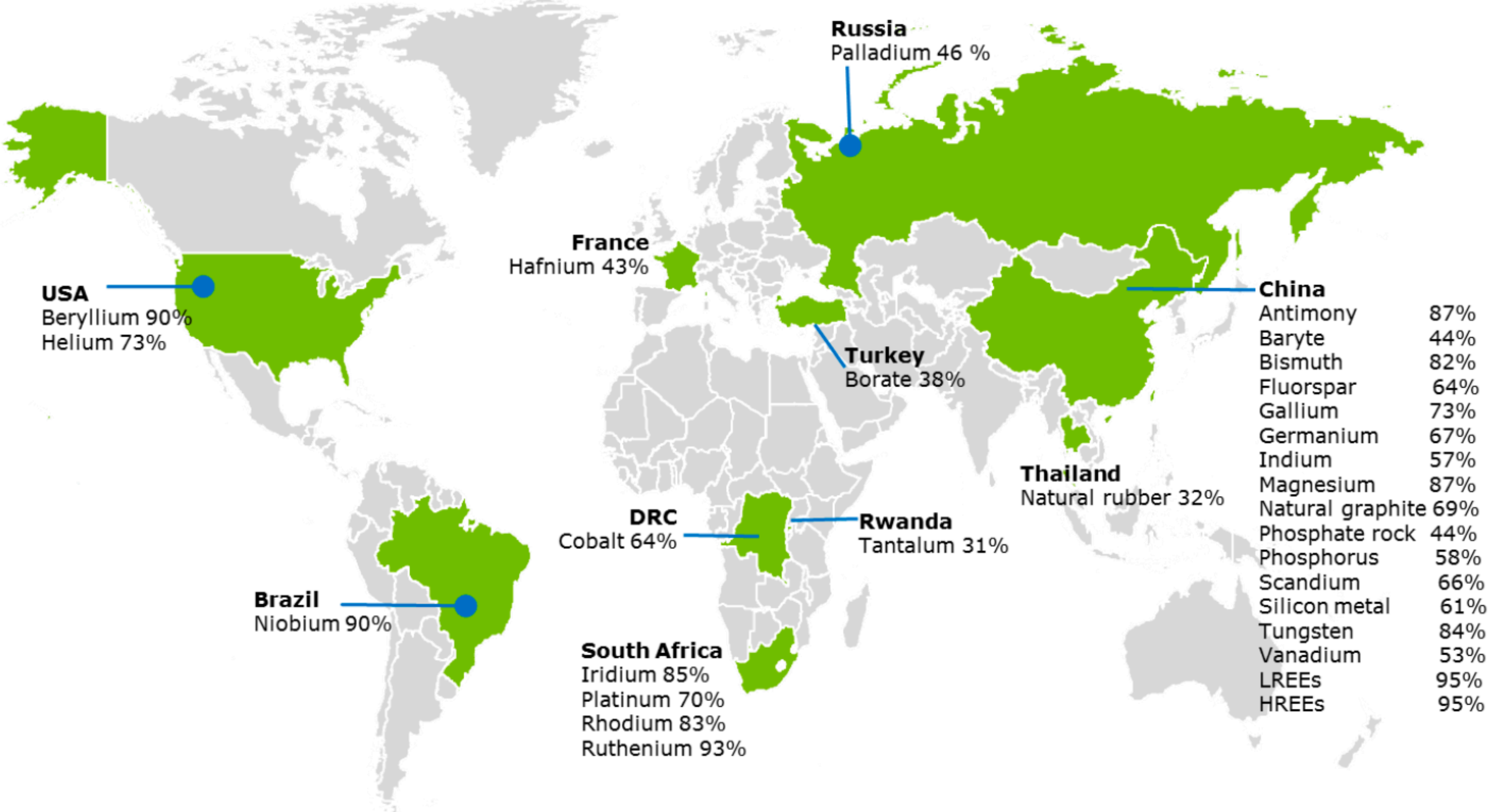
La ‘Criticità’ dei metalli high-tech per l’UE



Ag, silver; Al, aluminium; Be, beryllium; Bt, barytes; Bx, bauxite; Bn, bentonite; Bo, borate; Co, cobalt; Cr, chromium; Cu, copper; Cy, clays; Dt, diatomite; Fe, iron; Fp, feldspar; Fl, fluorspar; Ga, gallium; Ge, Germanium; Gr, graphite; Gy, gypsum; In, indium; Li, lithium; Ls, limestone; Mg, magnesium; Mn, manganese; Mo, molybdenum; Mt, magnesite; Nb, niobium; Ni, nickel; Pe, perlite; PGM, platinum-group metals; Re, rhenium; REE, rare earth elements; Sb, antimony; Sl, silica; Ta, tantalum; Tc, talc; Te, tellurium; Ti, titanium; V, vanadium; W, tungsten; Zn, zinc.

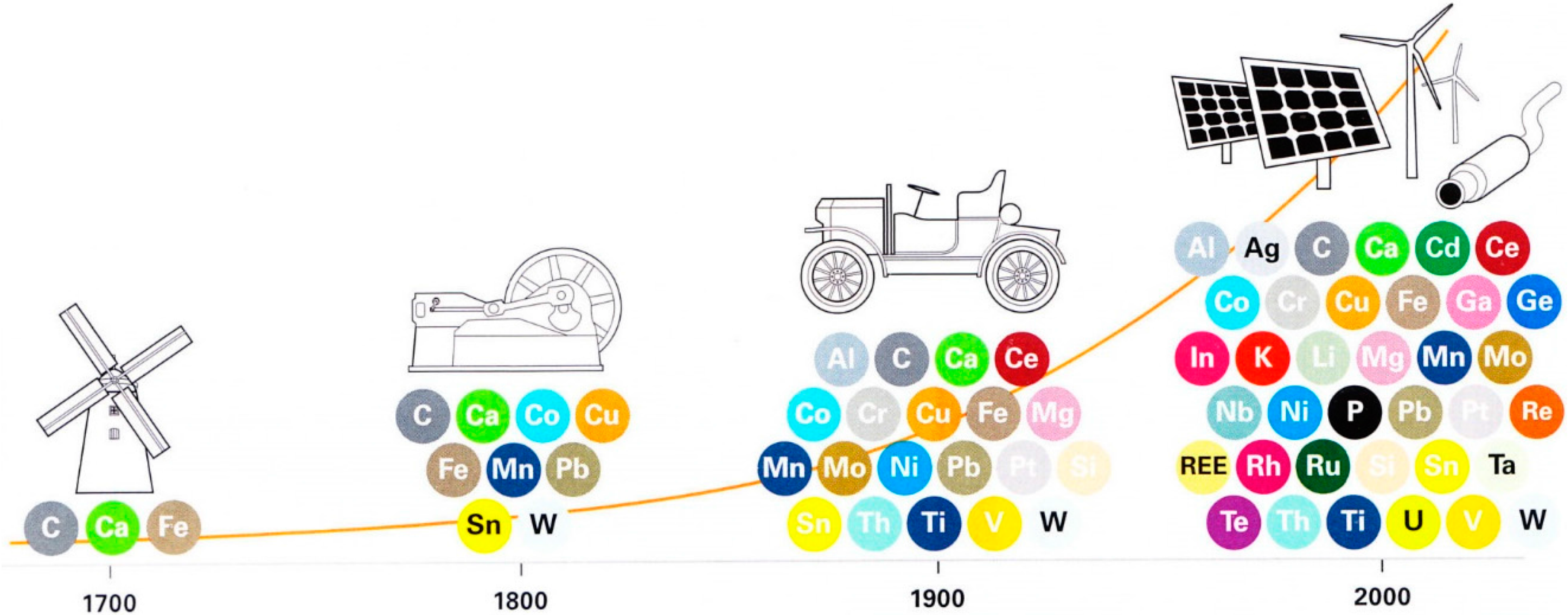
La 'Criticità' dei metalli high-tech

Provenienza delle materie prime "critiche" per l'Unione Europea



EU Commission 2017

La lista dei metalli critici “cambia” nel tempo …



Sviluppo delle tecnologie energetiche negli ultimi 300 anni

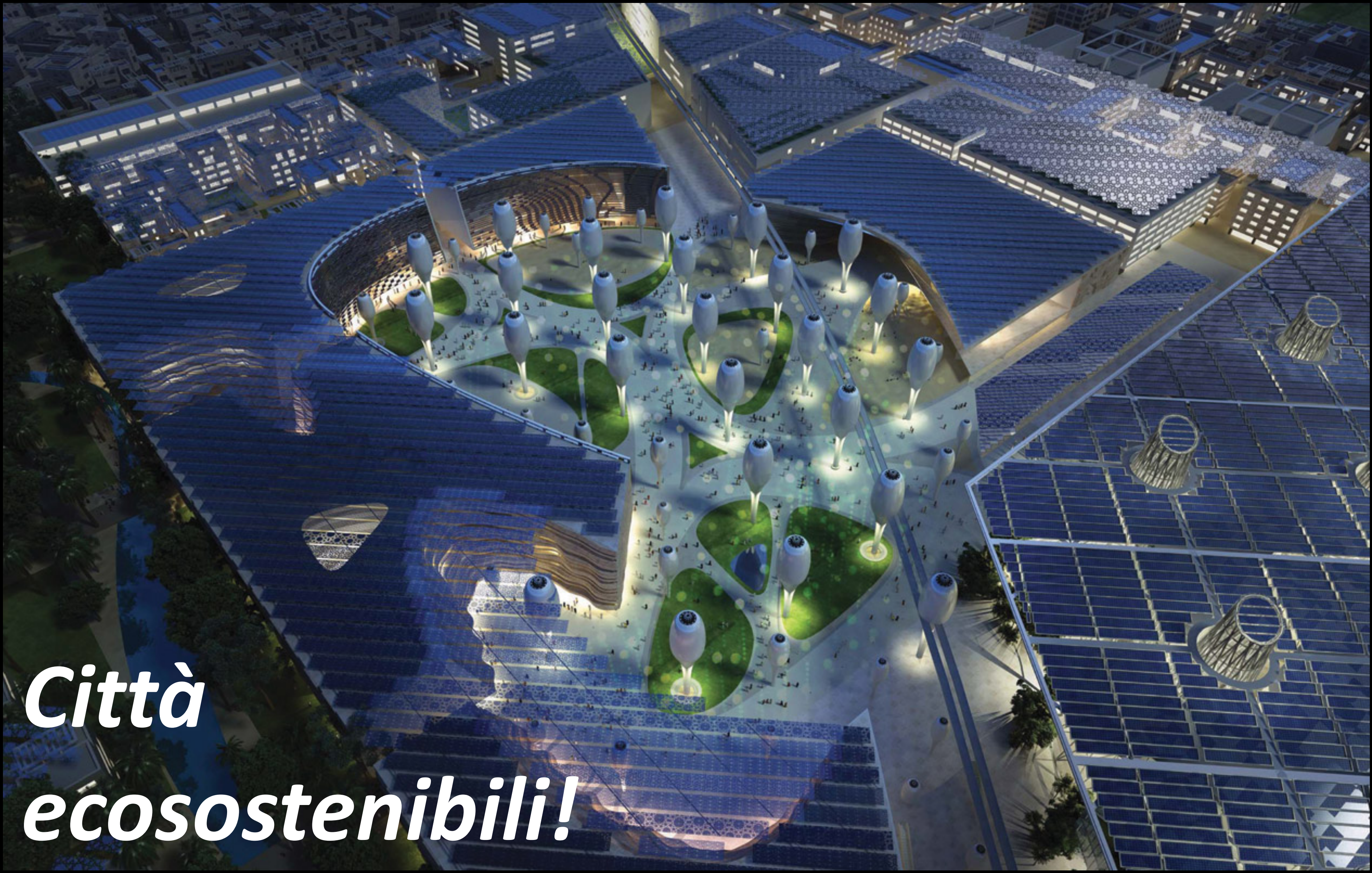
Zepf et al. 2014

2005

2013


IN HONOREM PRINCIPIS APOST PAVLVS V BVRGHESIVS ROMANVS PONT MAX AN MDCXII PONT VII

Cosa ci riserva il futuro?

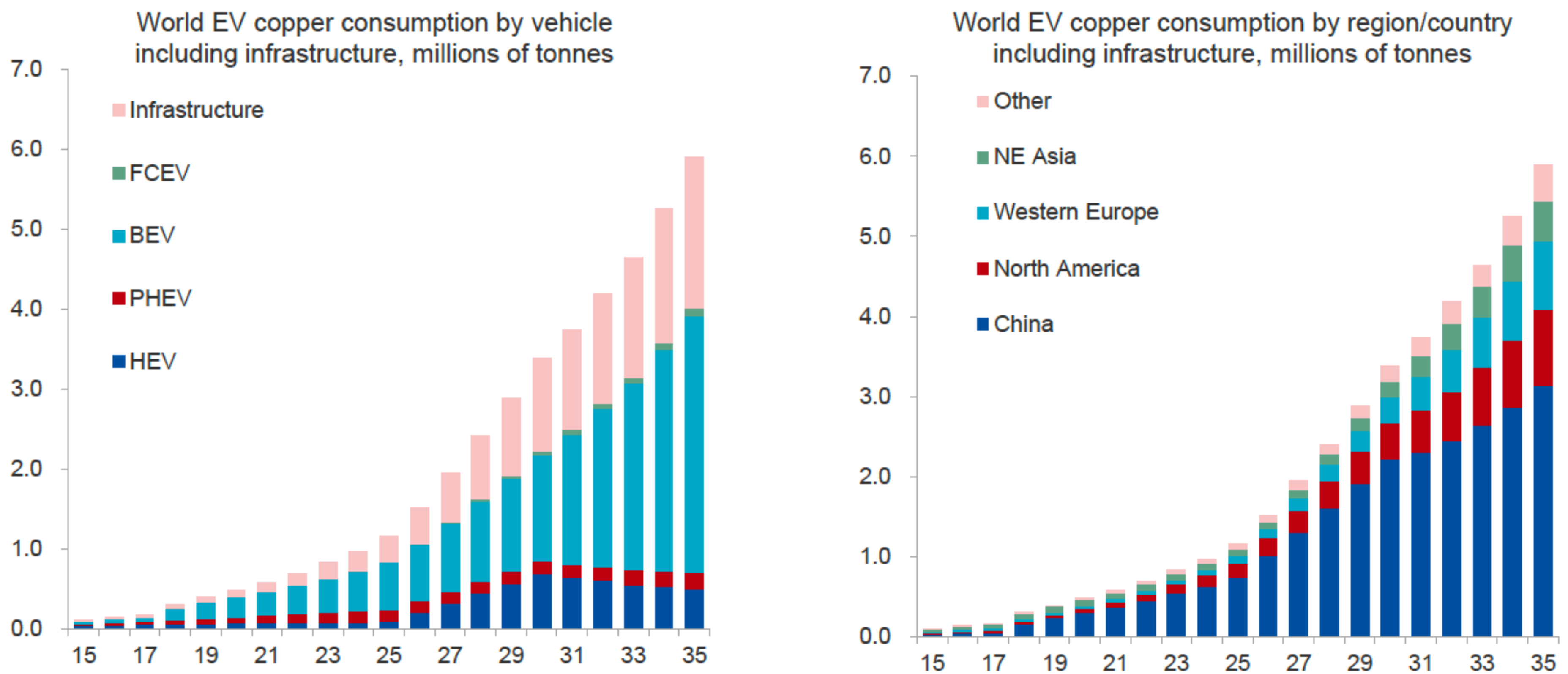

Città
ecosostenibili!

Prototipo di città ecosostenibile Masdar city – Abu Dhabi!

http://www.masdar.ae/

Grande uso di metalli!

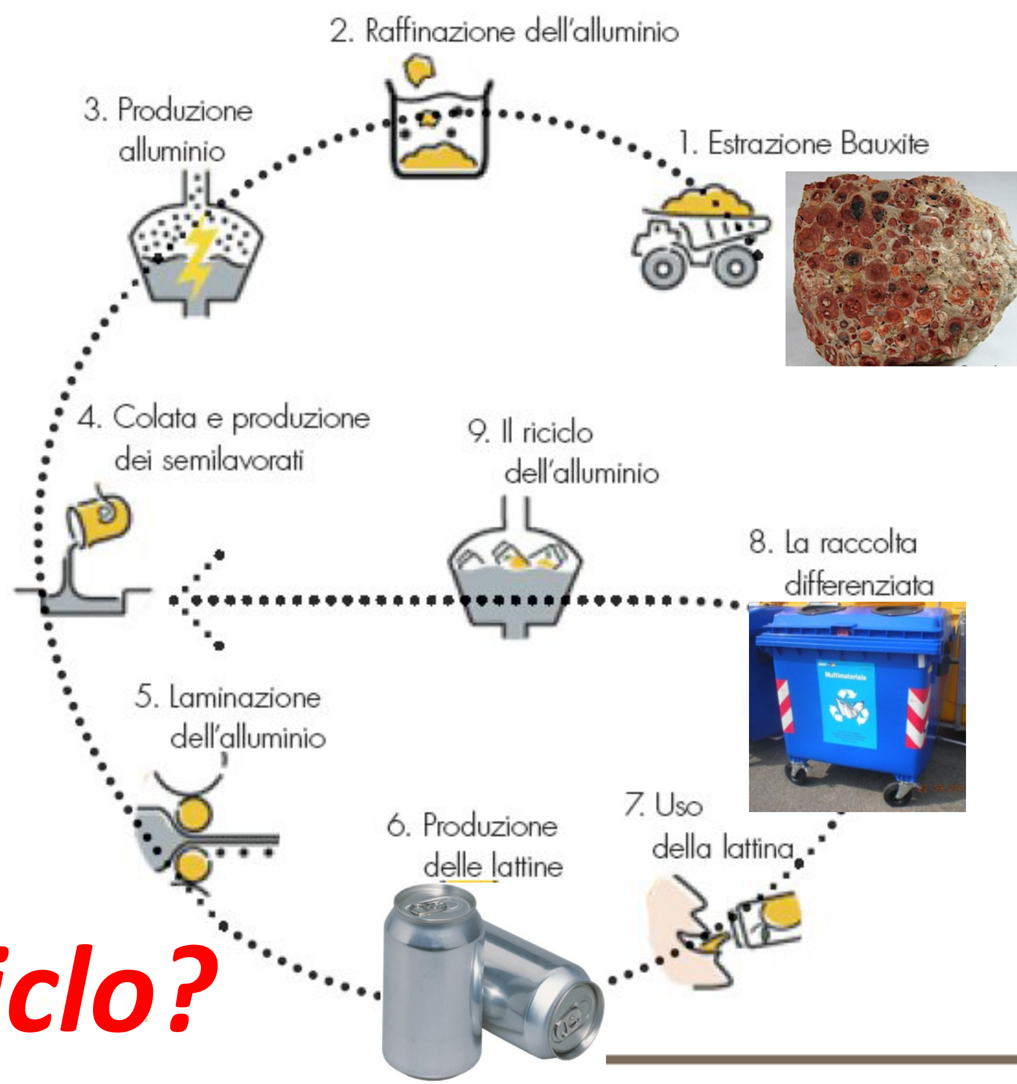
Crescita della domanda di rame…
…nel caso sostituissimo completamente le auto attuali con veicoli elettrici (EV)!



Notes: FCEV = Fuel cell electric vehicles, BEV = Battery electric vehicle, PHEV = Plug-in hybrid electric vehicle, HEV = Hybrid electric vehicle

Davidson 2018

Come soddisferemo la domanda di metalli?



Riciclo?

Elementi in uno smartphone!

SCREEN

- 49 In Indium
- 50 Sn Tin
- 8 O Oxygen

- 13 Al Aluminium
- 14 Si Silicon
- 8 O Oxygen
- 19 K Potassium

- 39 Y Yttrium
- 57 La Lanthanum
- 65 Tb Terbium
- 59 Pr Praseodymium
- 63 Eu Europium
- 66 Dy Dysprosium
- 64 Gd Gadolinium

BATTERY

- 3 Li Lithium
- 27 Co Cobalt
- 6 C Carbon
- 13 Al Aluminium
- 8 O Oxygen

ELECTRONICS

- 29 Cu Copper
- 47 Ag Silver
- 79 Au Gold
- 73 Ta Tantalum

- 28 Ni Nickel
- 66 Dy Dysprosium
- 59 Pr Praseodymium
- 65 Tb Terbium
- 60 Nd Neodymium
- 64 Gd Gadolinium

- 14 Si Silicon
- 8 O Oxygen
- 51 Sb Antimony
- 33 As Arsenic
- 15 P Phosphorus
- 31 Ga Gallium

- 50 Sn Tin
- 82 Pb Lead

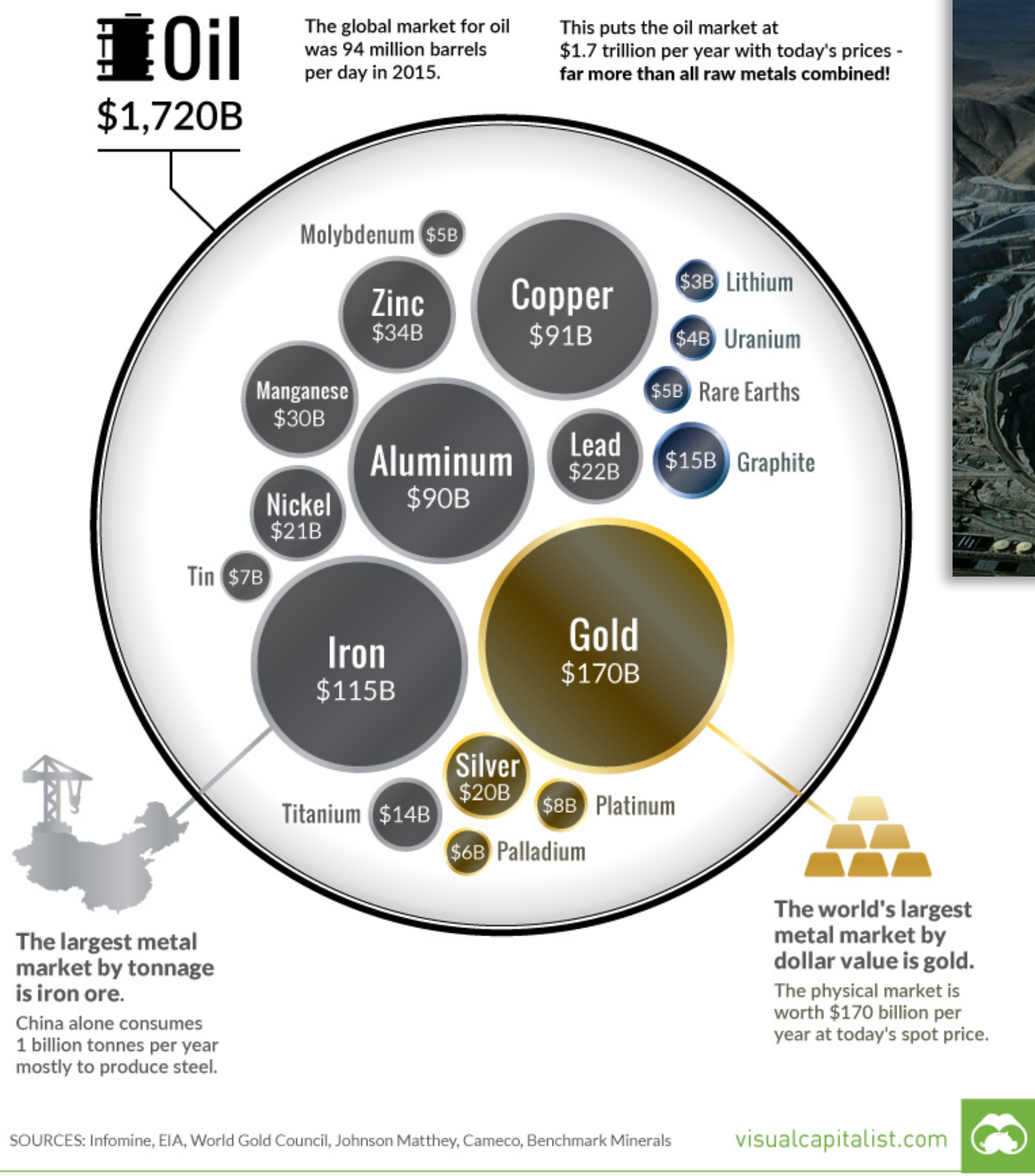
CASING

- 6 C Carbon
- 12 Mg Magnesium
- 35 Br Bromine
- 28 Ni Nickel

Molti metalli high-tech non sono riciclabili…

● = not recyclable!

Mercato delle risorse metalliche naturali



… la ricerca di metalli continua!