TU Clausthal

Economic Geology

Thomas Ulrich

Geochemistry, Petrology and Ore Deposit Research

Why this course?

- What are you expecting from this course?

- What I am expecting from you

- Knowing some basic geological processes that occur on Earth
- Being able to identify the major (ore) minerals
- Being able to explain the main ore forming processes
- Being able to distingusih different ore deposit types and their metallogeny
- Being able to explain the importance of mineralogical raw materials
- Being able to reflect on the sustainability of raw material extraction and use

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Content and structure

- **Module 1: Intro, element abundance, plate tectonics, economics**
- Module 2: Minerals, Rock types
- Module 3: Ore forming processes
- Module 4: Base metals and their ore deposit types
- Module 5: Precious and rare metals and their ore deposit types
- Module 6: Summary

The role and need of raw materials

Discuss in pairs/groups:

- What is in your opinion the most important raw material?
- Are there any challenges to get this raw material?

Different kinds of resources

- Metallic resources: Iron, copper, gold...
- Non-metallic resources: Salt, gypsum, limestone, sand
- Energy resources: Coal, petrolium, natural gas
- Water resources: Groundwater, surface water

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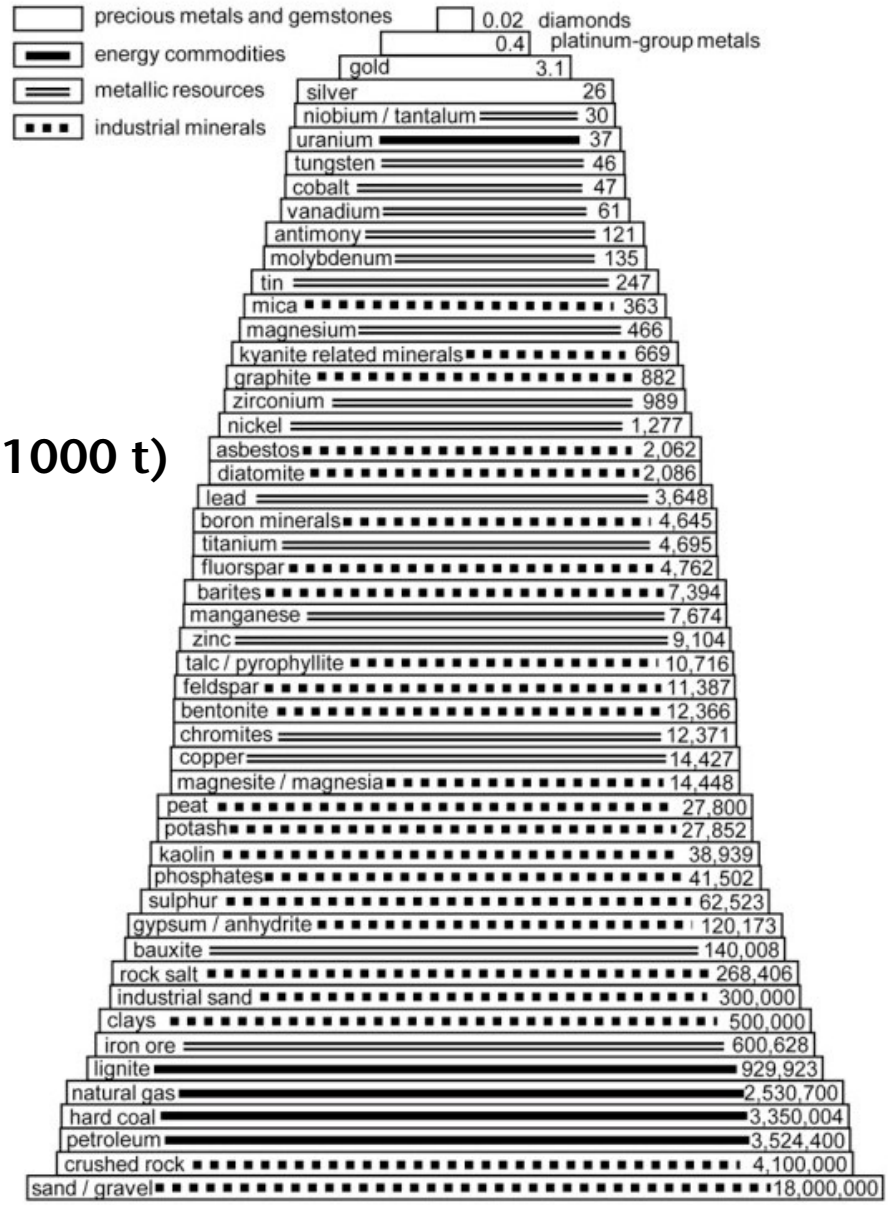
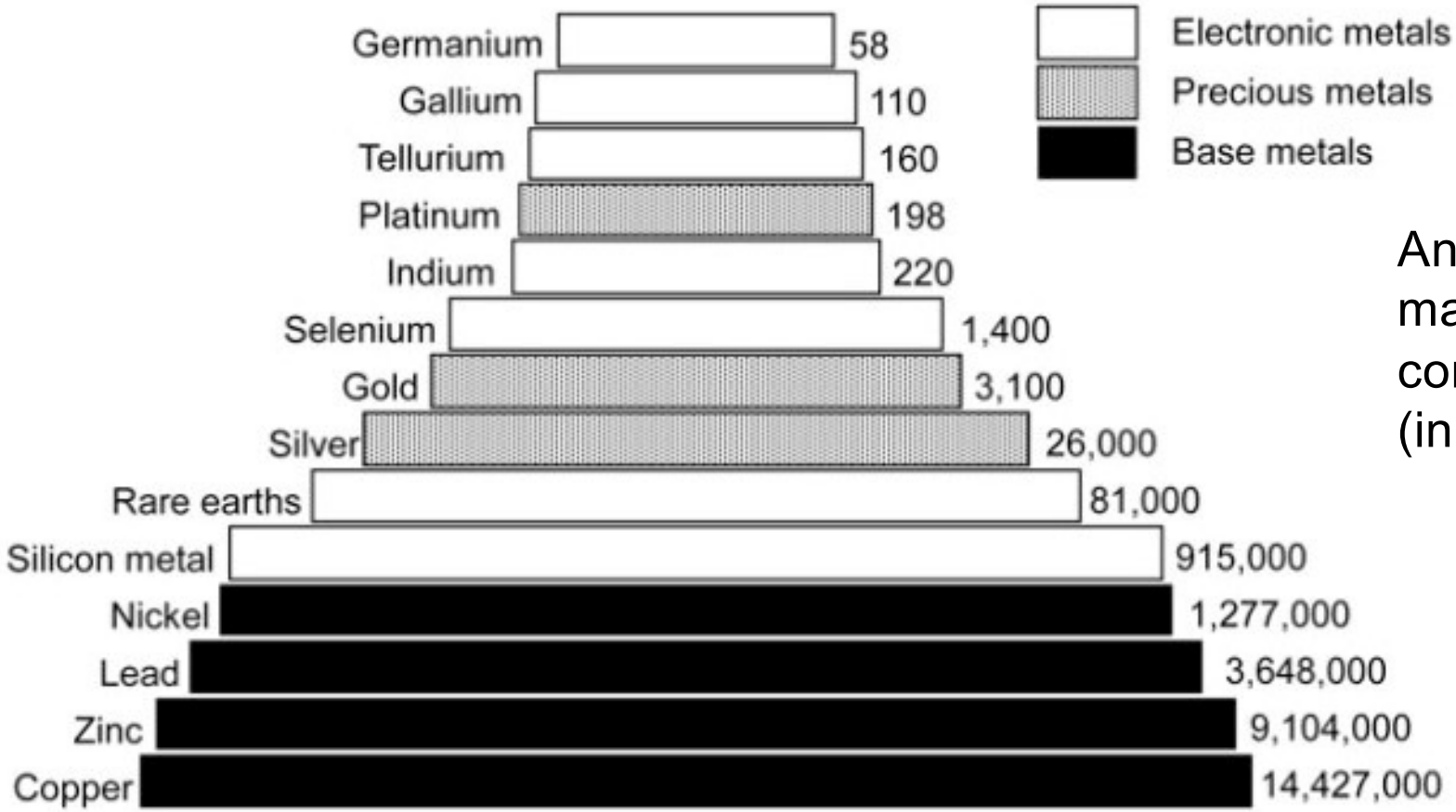
Annual raw materials consumption (in 1000 t)



In Wagner and Wellmer



Annual raw materials consumption (in t)

In Wagner and Wellmer

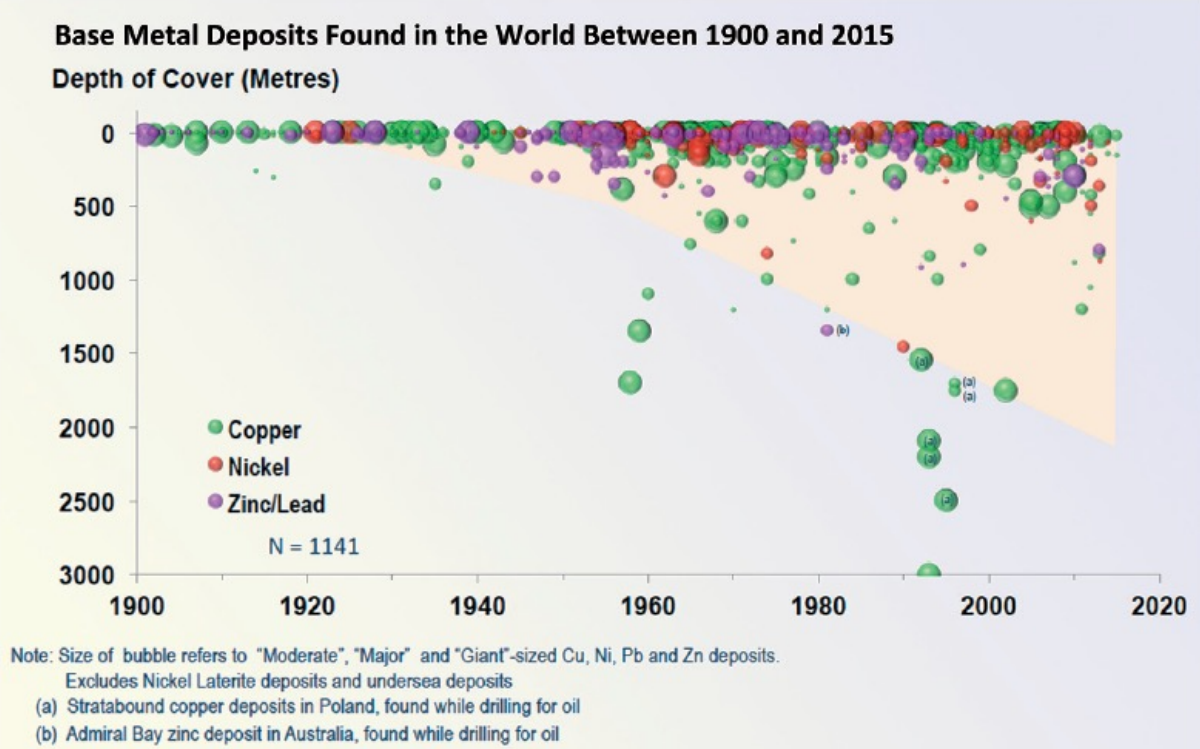
Distribution of ore deposits

- Ore deposit formation takes a long time (finite resource).
- Ore deposits are globally unequally distributed.

Arndt et al 2015

Distribution of ore deposits

- Only ore deposits close to the surface are (currently) economic.



Arndt et al 2017
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Some basic geology concepts

- Structure of the earth
- Plate tectonics
- Ore deposits and their geological setting

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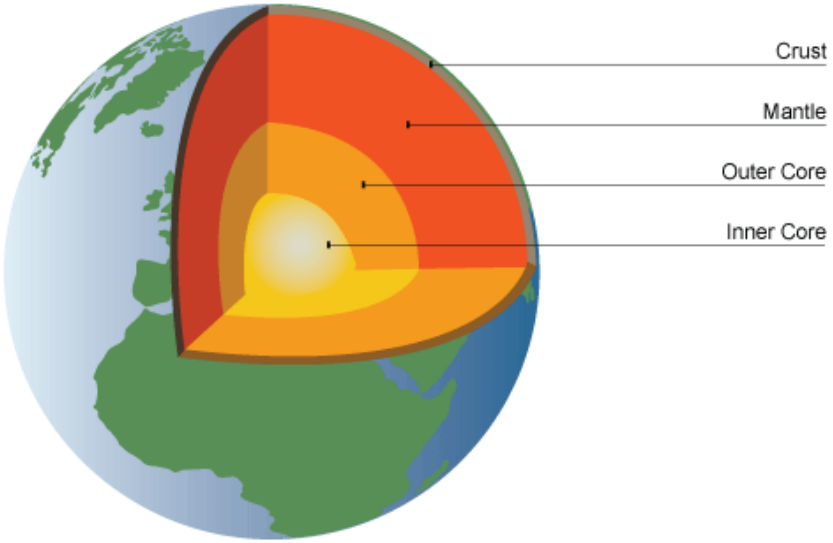
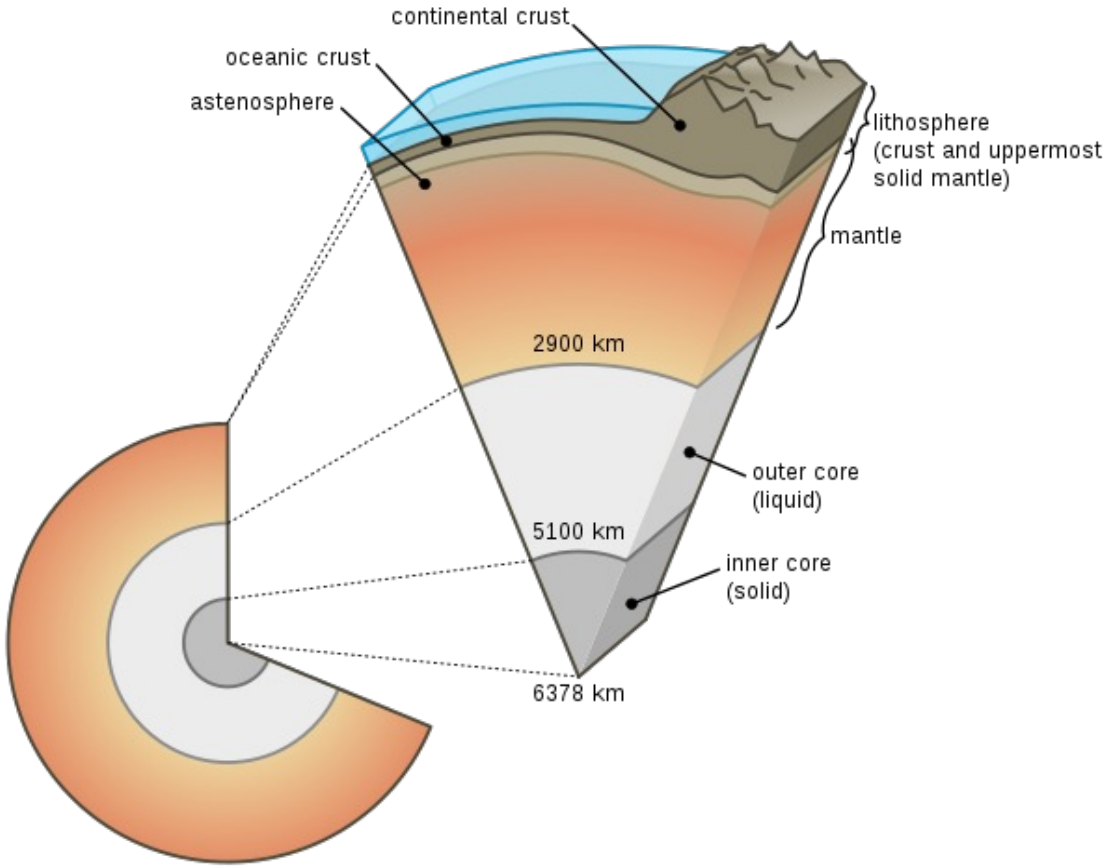
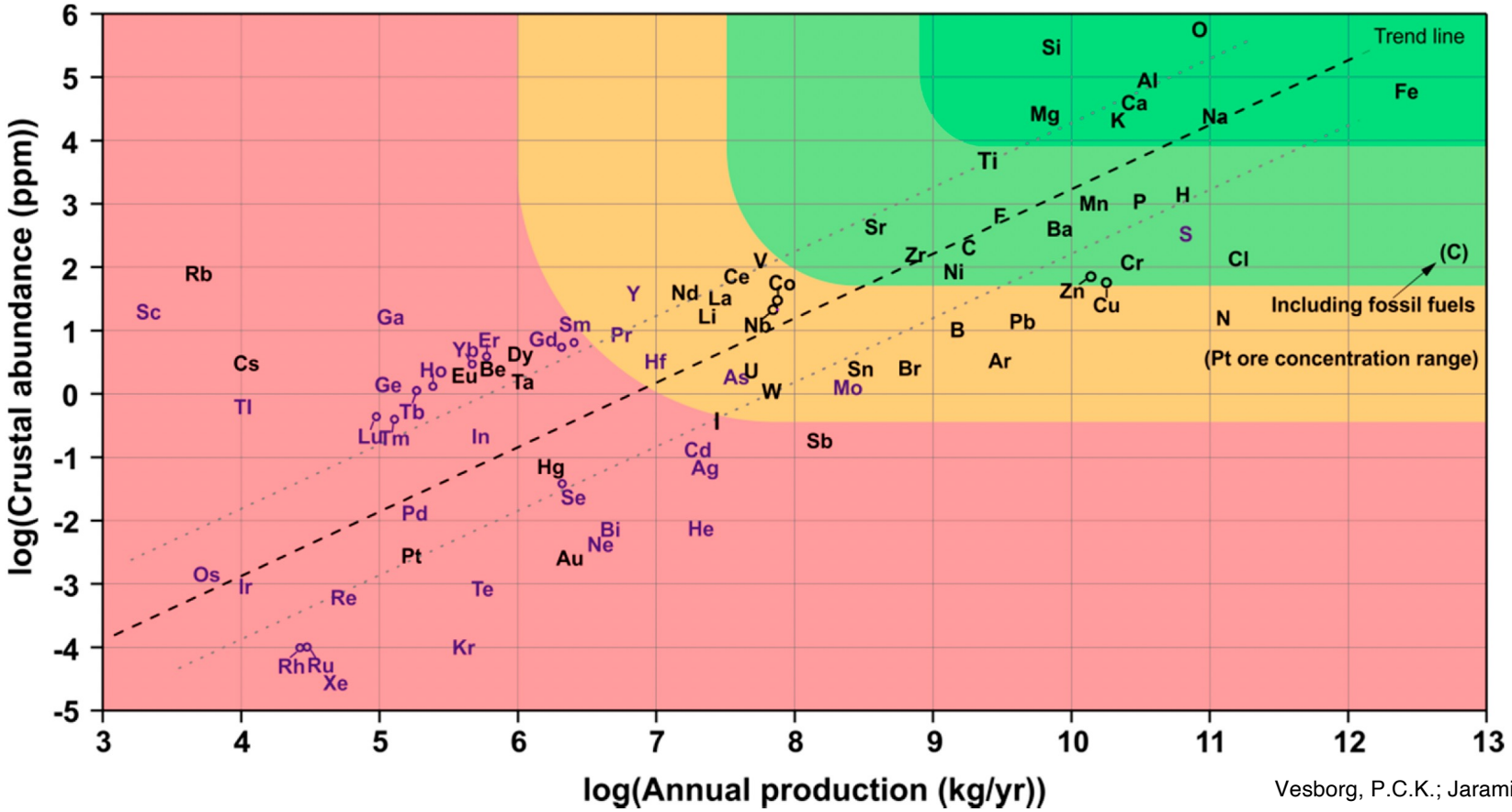
The structure of the Earth





Mass of earth crust: 2.8×10^{22} kg
Mass of earth mantle: 4.0×10^{24} kg
Mass of earth core: 2.9×10^{24} kg

The element abundance in the Earth crust

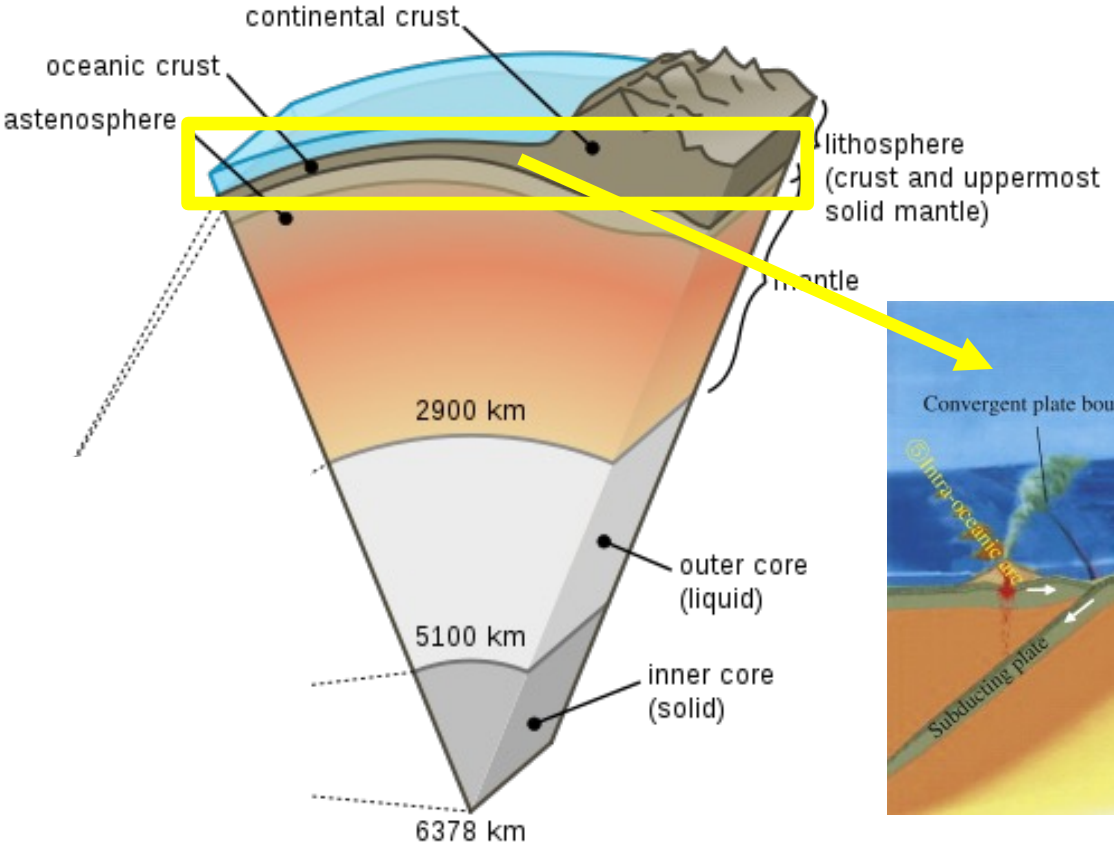


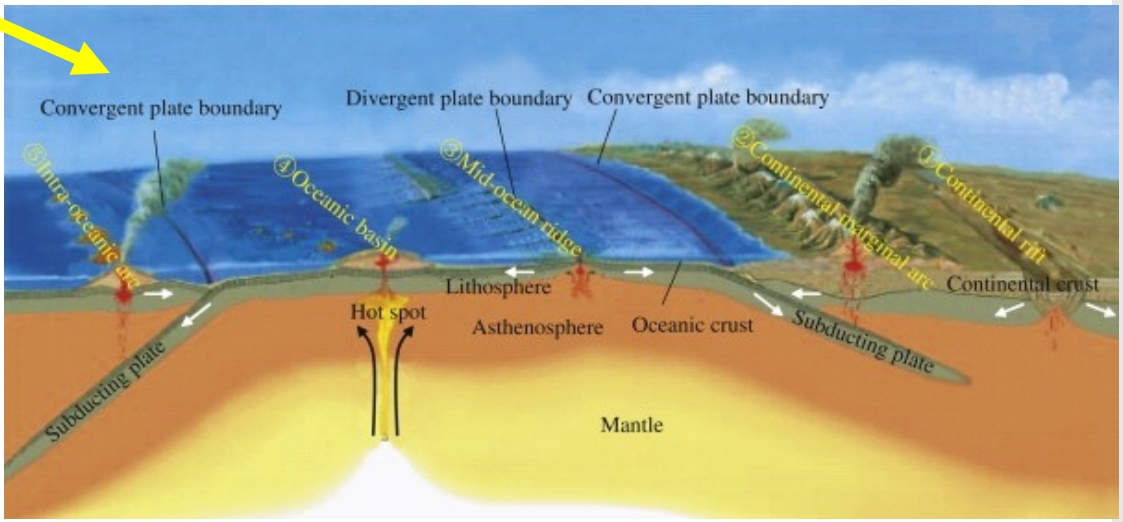
Vesborg, P.C.K.; Jaramillo, T.F. (2012)

The definition of an ore deposit

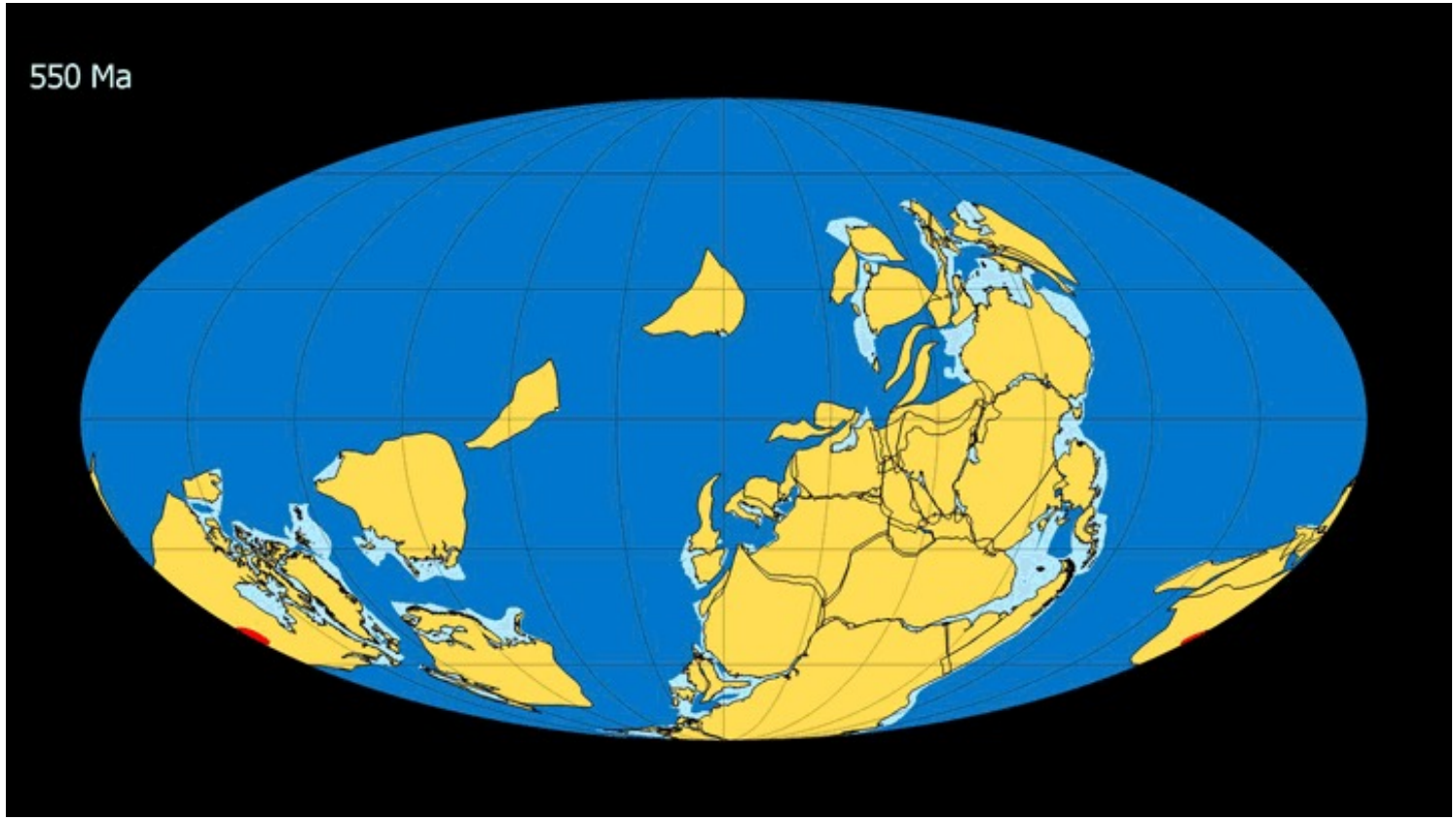
- The accumulation of a chemical element (metal) that can be economically extracted with the present technology.

Geological processes: Plate tectonics





Geological processes: Plate tectonics



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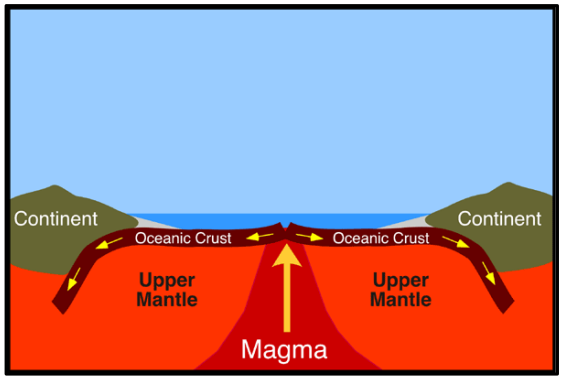
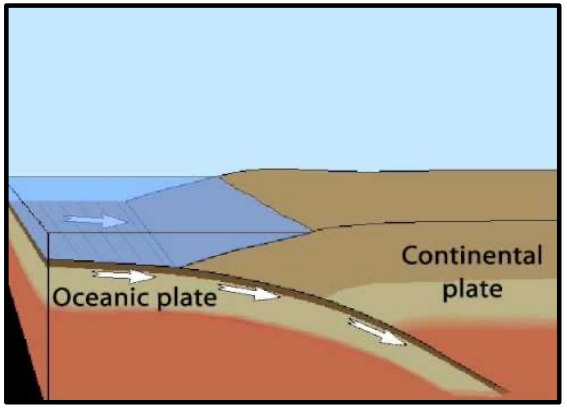
Geological processes: Plate tectonics

- Divergent plate boundaries



- Convergent plate boundaries



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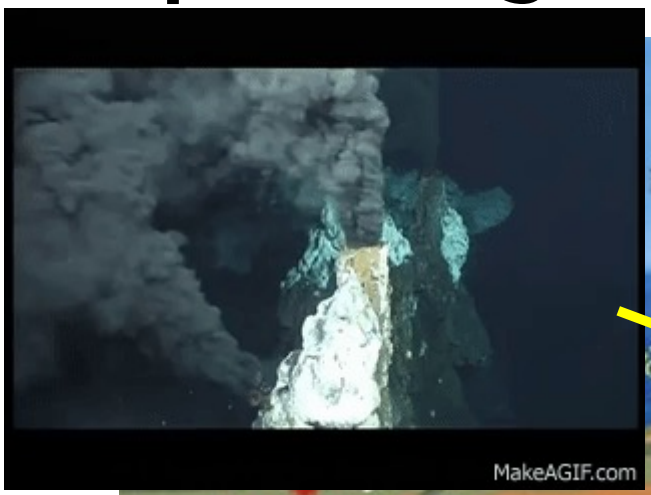
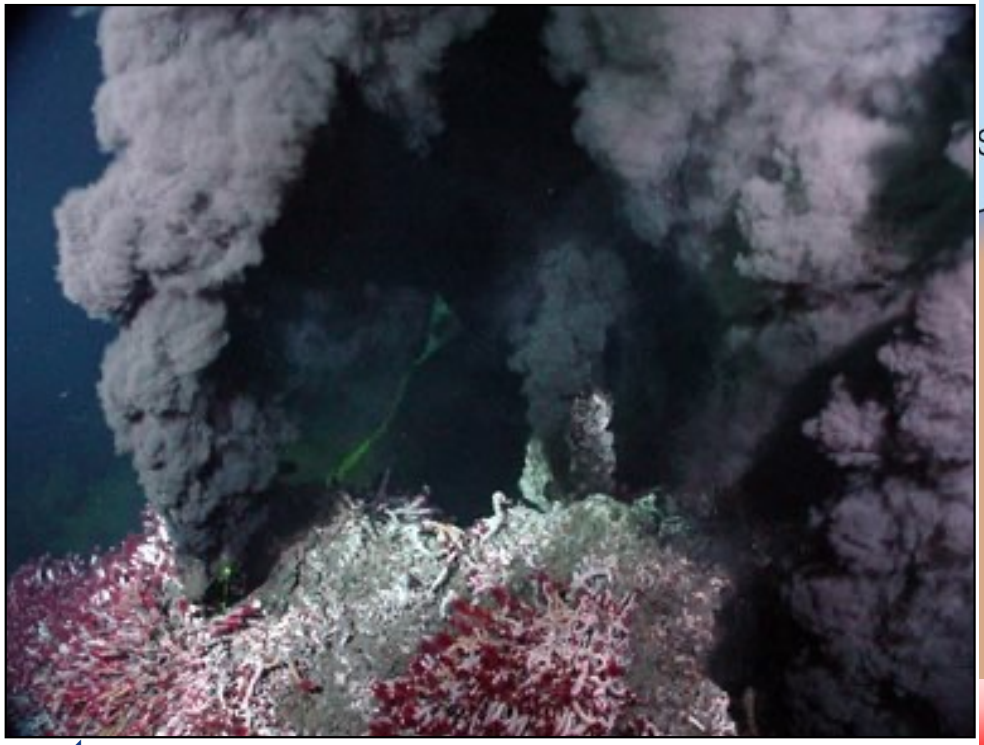
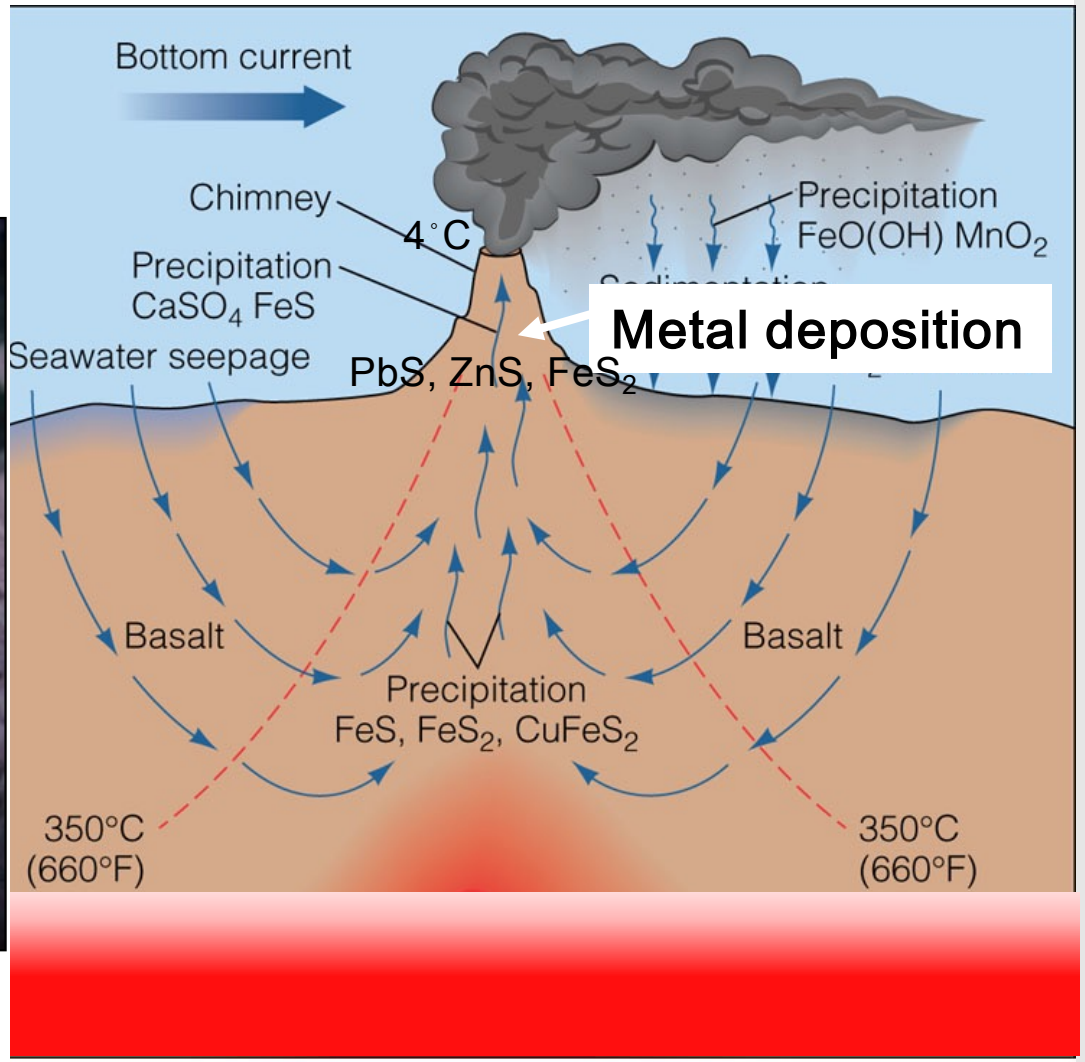
Spreading ridge (divergent plates)

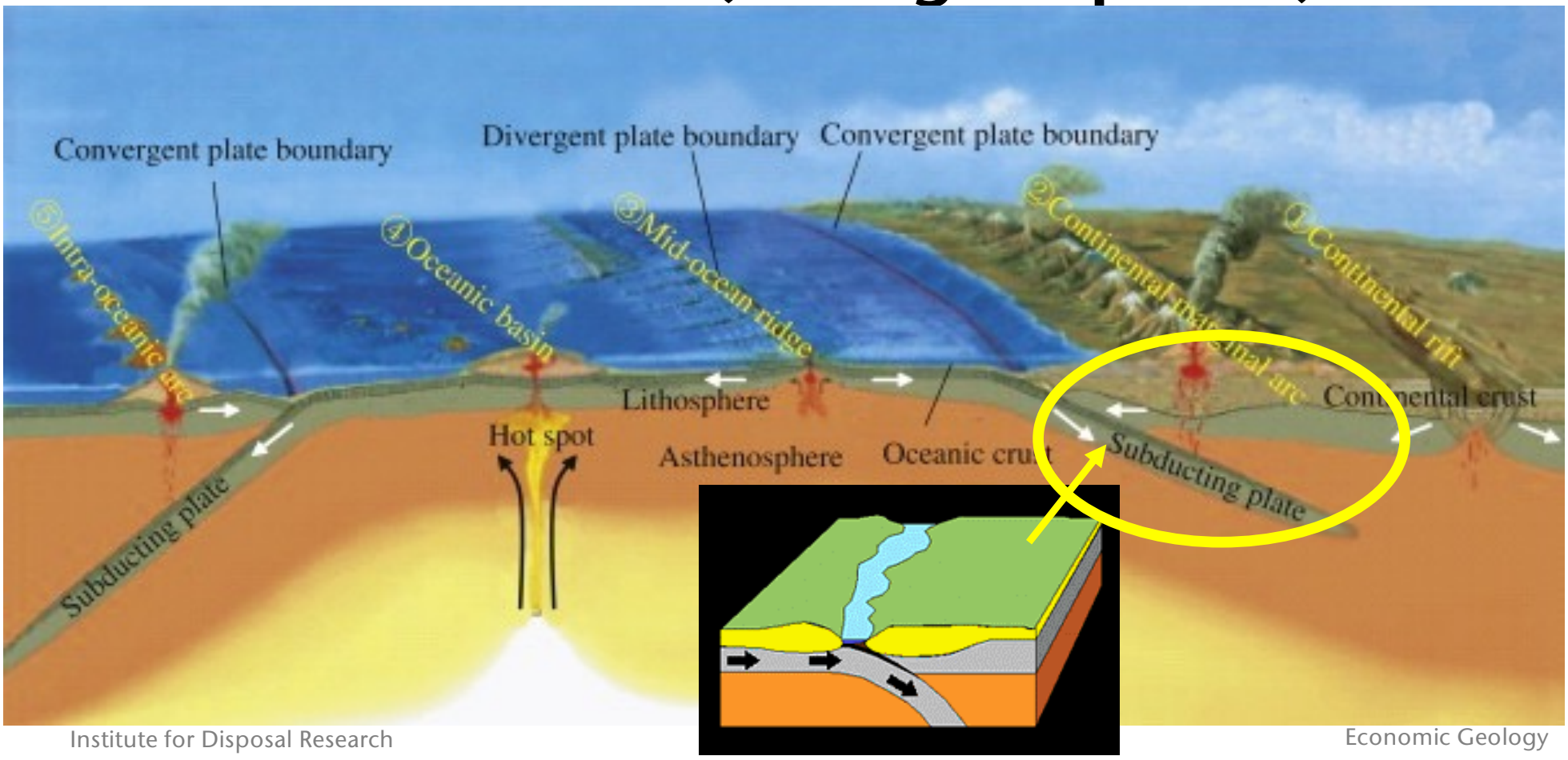


Black smokers (Pb, Zn, ±Cu)



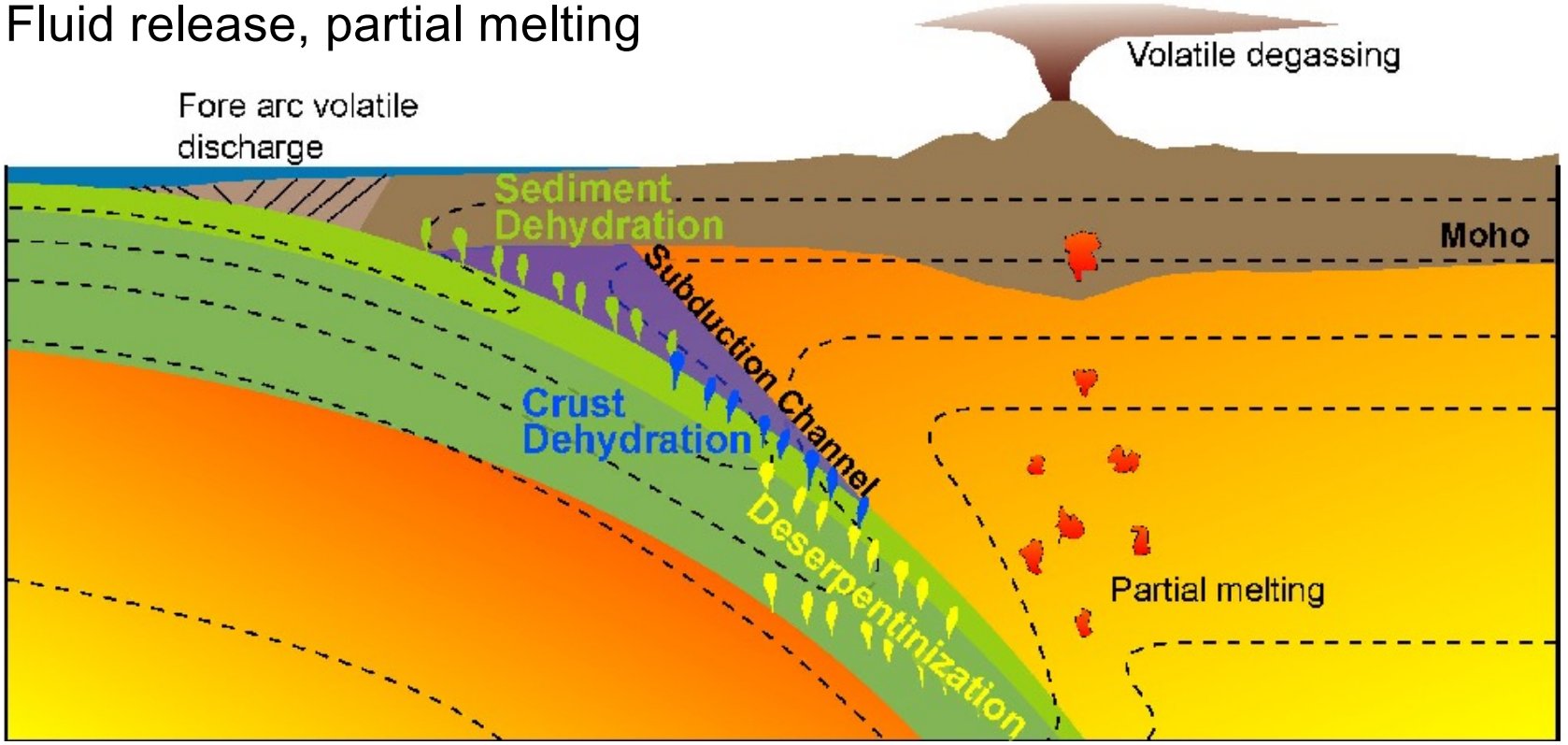


Subduction zones (divergent plates)



Subduction zones (divergent plates)

Fluid release, partial melting



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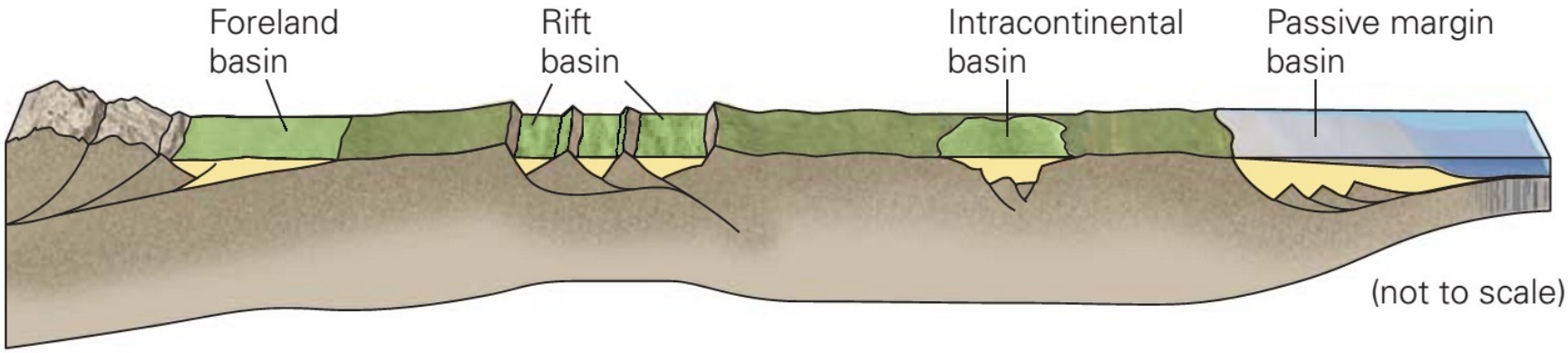
Basin formation



Weight of the mountain belt pushes down the crust's surface.

Downward slip on faults produces narrow troughs.

The basin forms in the interior of a continent, perhaps over an old rift.

Subsidence occurs over thinned crust at the edge of an ocean basin.

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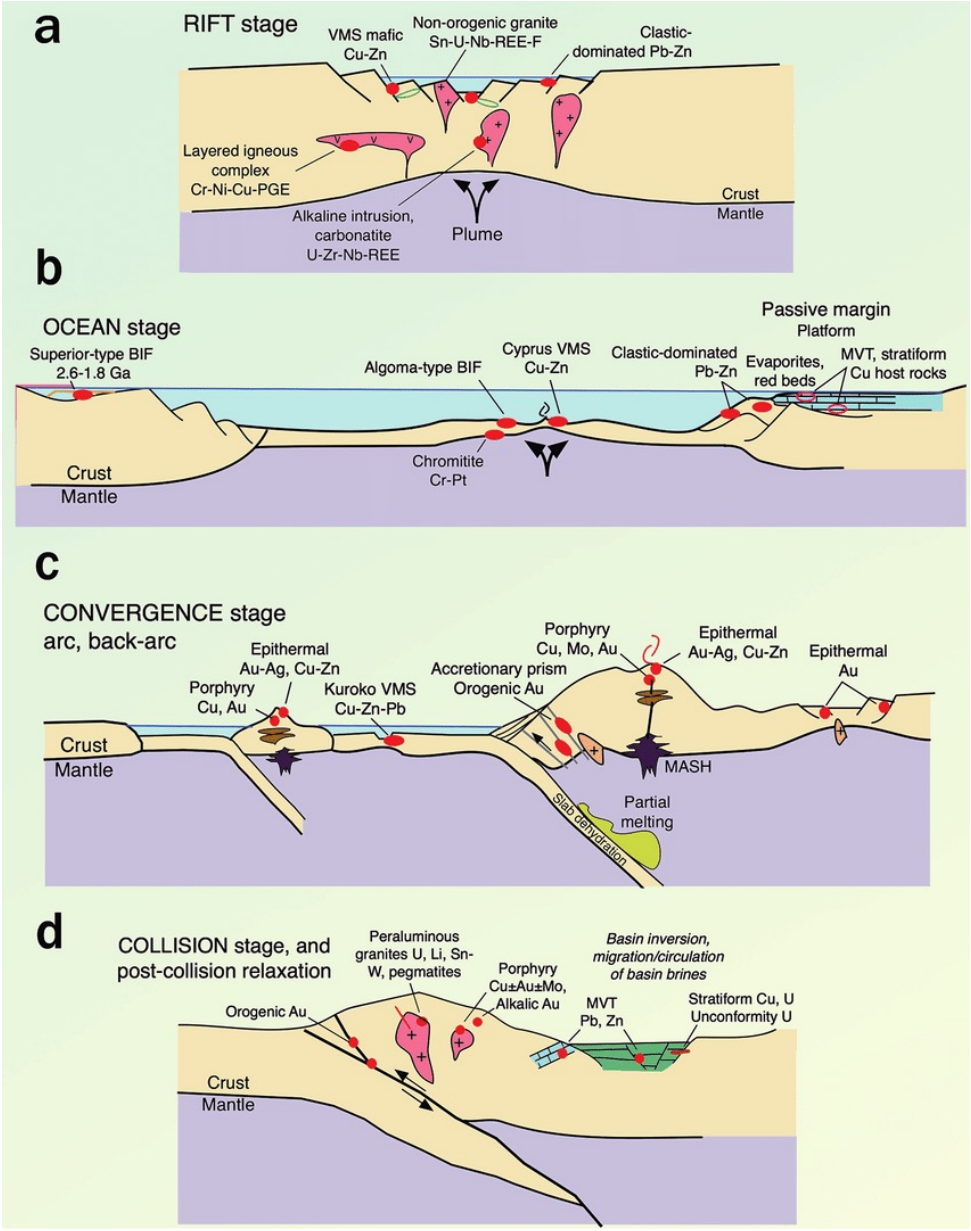
Ore deposits related to plate tectonics

A combination of geological processes leads to exceptional concentration of certain metals to form a potential ore deposit.

Relatively rare occasion, because several processes and conditions need to coincide.



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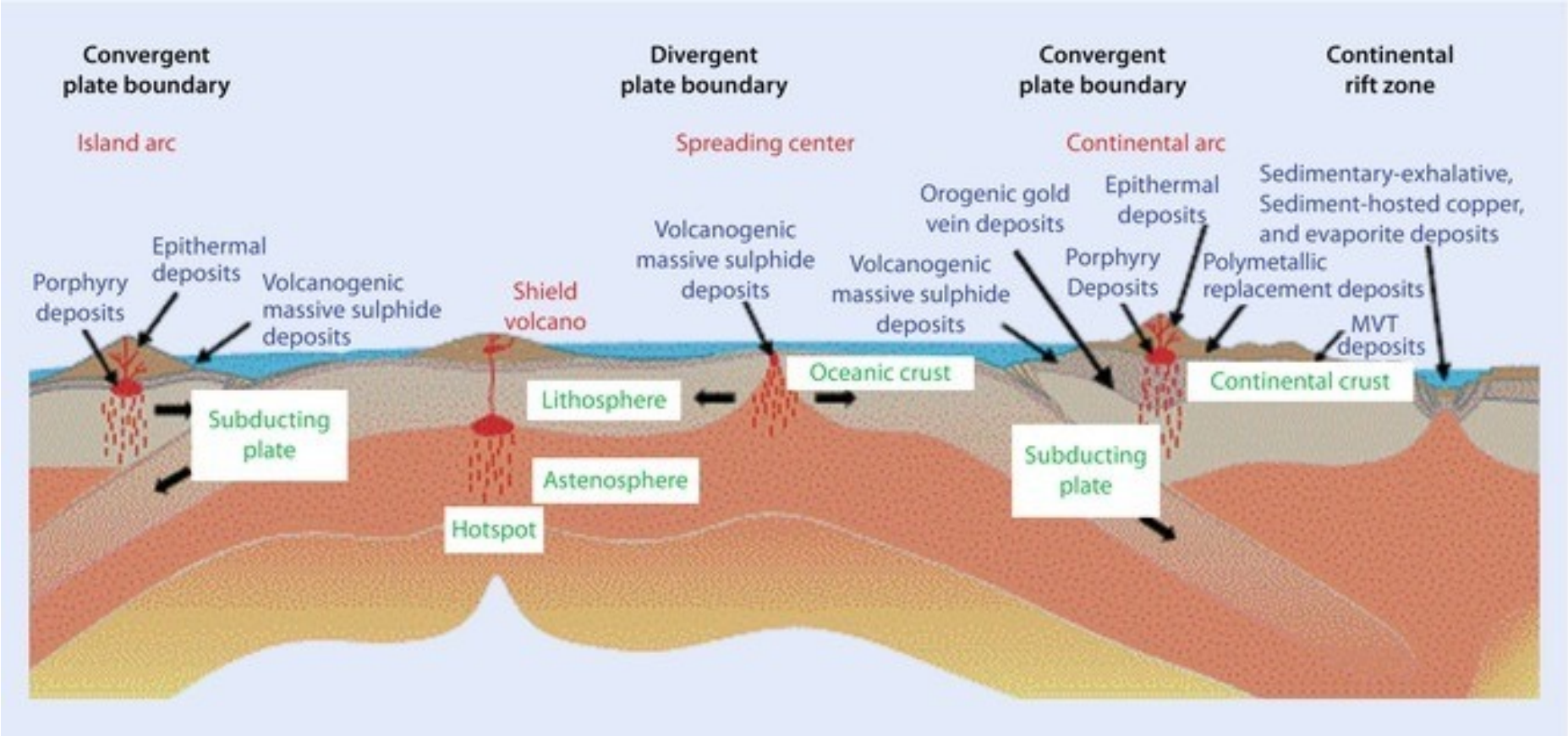
Ore deposits related to plate tectonics



Definitions

- Economic geology:

- Deals with Earth materials that can be used for economic or industrial purpose.

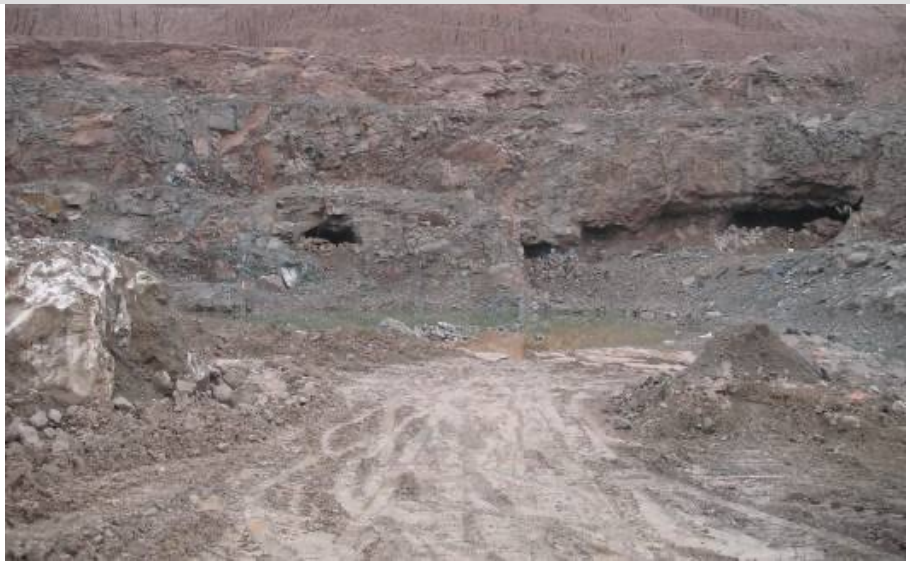
- Ore deposit geology:

- The geology of economic concentrations of metals.

- *Ore deposits not just about geology*....this is the geology of economic concentrations of metals.

- Many factors will control the price of a commodity and thus whether it is to be an ore deposit or not. Thus, an ore deposit is constantly moving target!

- Open pit operation but with old underground workings visible



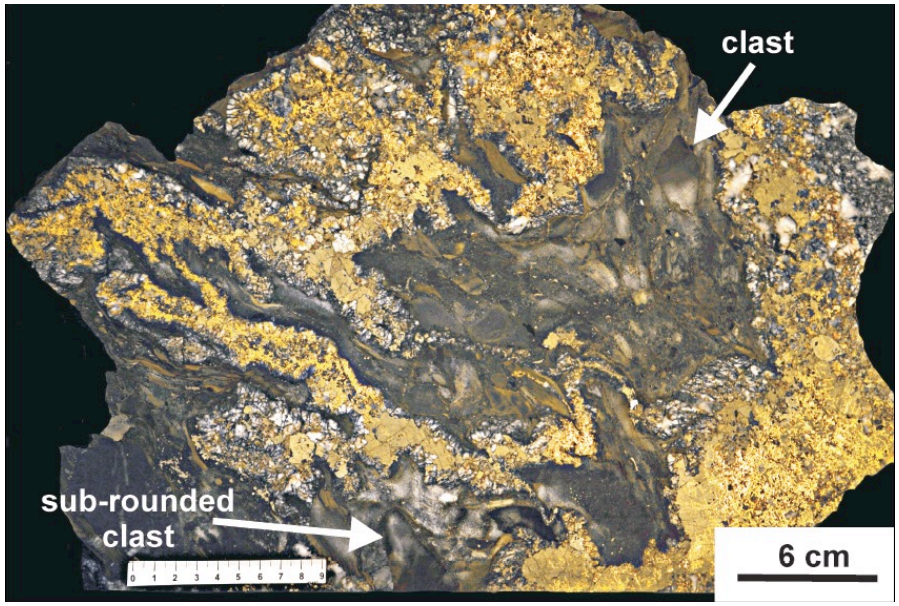
- Gays River Zn-Pb deposit, N.S.
- Carbonate hosted MVT deposit.
- Discovered 1971 and mined unsuccessfully in 1978 & 1988
- Reopened 2007 with $40M/year profit projected
- Closed in fall 2009 due to depressed Zn market.

Ore Deposit is defined by socio-economic factors and there are many variables which contribute to whether it will or will not be a deposit:

Ore Deposit = A + B + C +D +E + F + ...

Where:

A = metal price
B = infrastructure
C = exchange rate
D = metallurgical issues
E = environmental issues
F = political issues



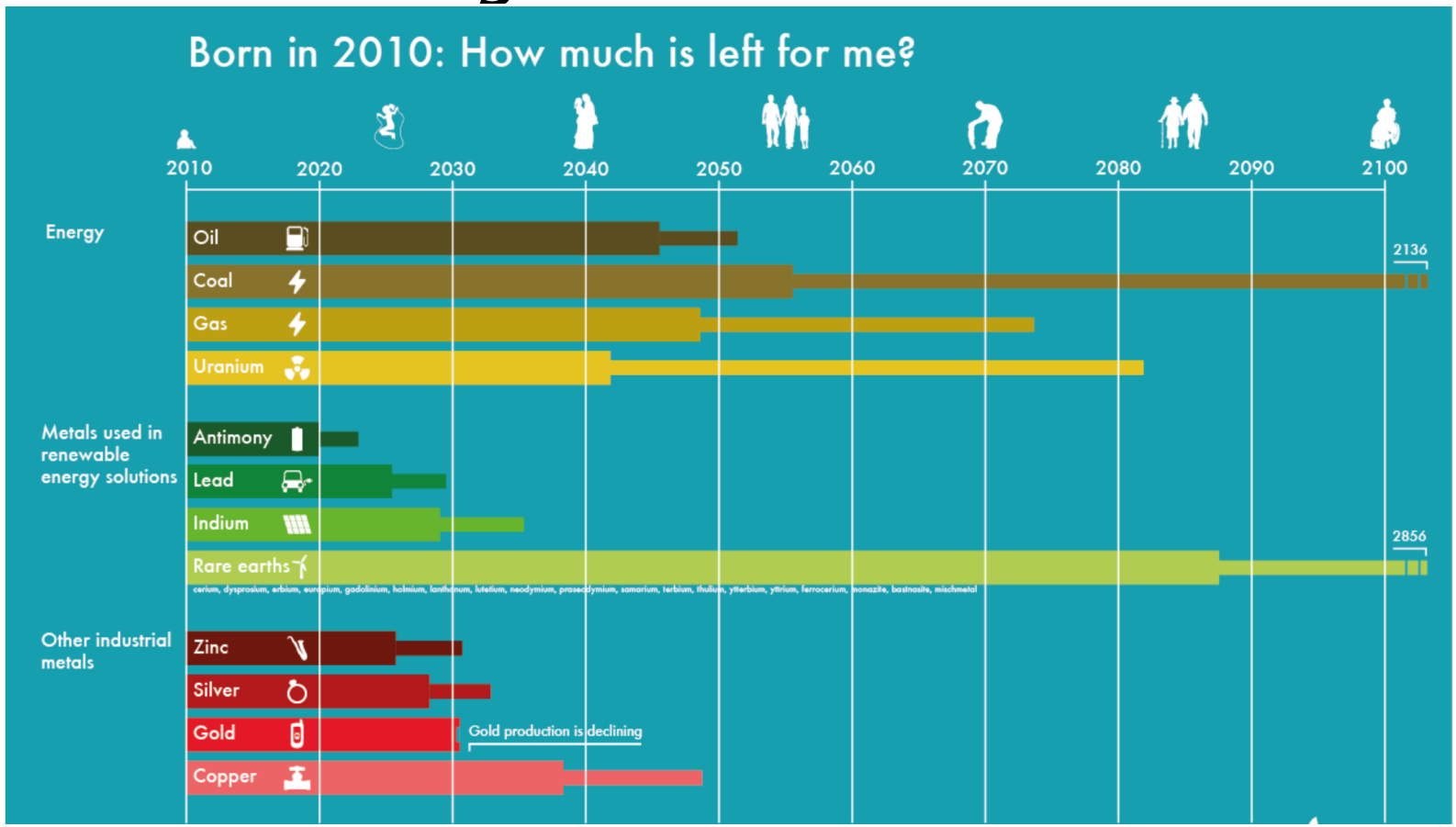
Change these and it can make or break a deposit!

Concept of ore and ore deposit and issues/factors dictating what is an ore deposit.

1. Ore vs. ore deposit
2. Metallic vs. industrial minerals
3. Grade vs. tonnage
4. Shape, size, depth of ore body
5. Enrichment of elements
6. Non-geological factors relevant to ore
7. Metals through time ($$, supply)
8. Markets (cartels vs. free markets)
9. Sustainability
10. Reclamation

These are some of the more important factors that dictate what will be explored for and where you will explore, and what will and will not be an ore deposit.

Are we running out of metallic resources?



https://visual.ly/community/infographic/environment/born-2010-how-much-left-me

Reserves vs. Resources

- **Reserves:**
  - The amount that can be economically extracted at a given time
- **Resources:**
  - The overall known amount of the metal (economic and uneconomic concentrations)

Remember: these figures change continuously

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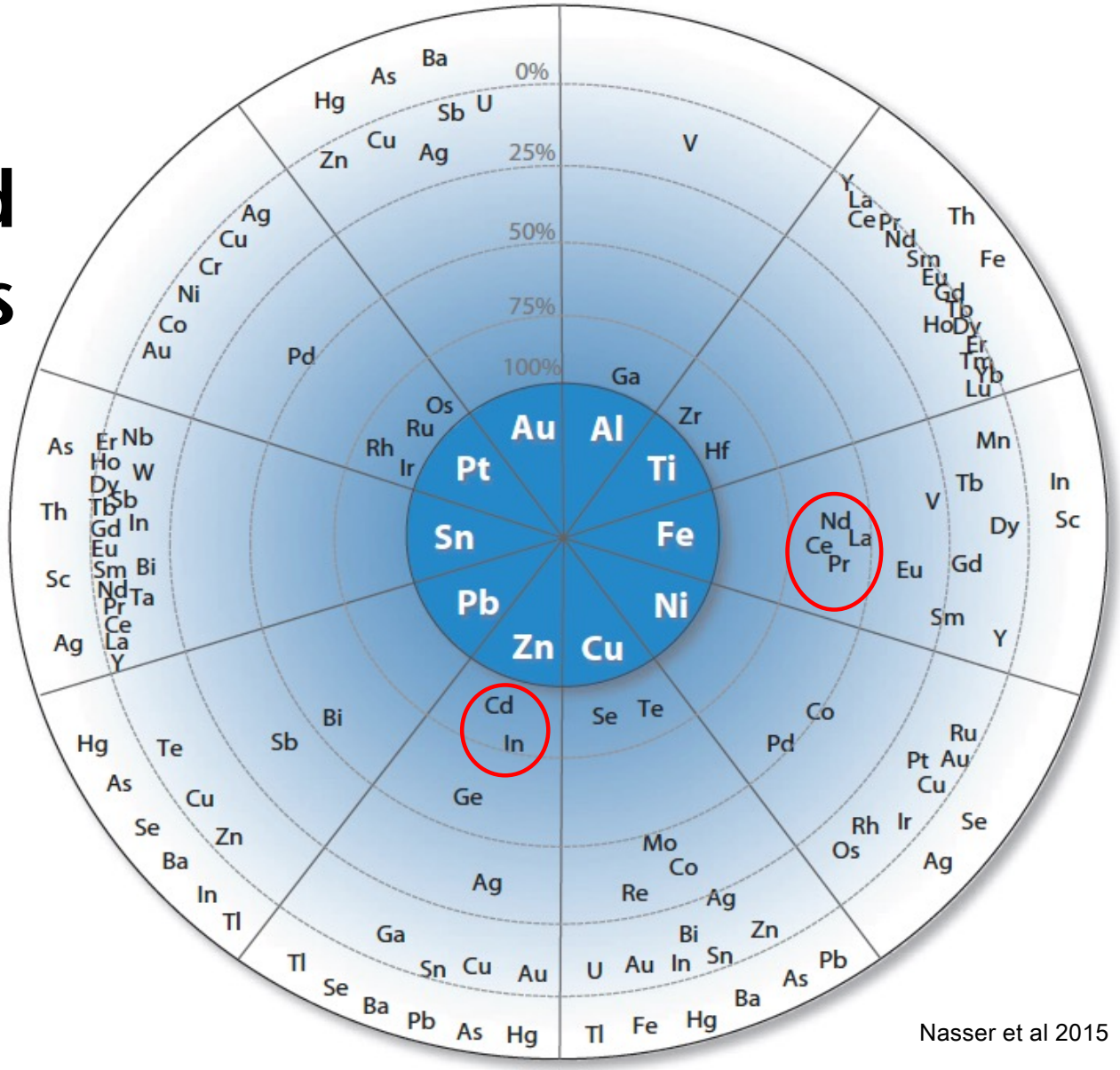
Major metals and their by-products

‘Critical’ metals are commonly used in small quantities only

‘Critical’ metals occur as minor by-products and thus are directly dependent on the market of the main ores or may not even be recovered.

Difficult to estimate the resources

What could be the challenges?



Nasser et al 2015

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Reserves vs. Resources: copper (in 1000t)

World Mine and Refinery Production and Reserves: Reserves for Australia, Canada, Chile, China, Peru, Poland, the United States, and Zambia were revised based on company and Government reports.

	Mine production		Refinery production		Reserves[6]
	2021	2022[e]	2021	2022[e]	
United States	1,230	1,300	971	1,000	44,000
Australia	813	830	385	380	[7]97,000
Canada	550	530	287	310	7,600
Chile	5,620	5,200	2,270	2,100	190,000
China	1,910	1,900	10,500	11,000	27,000
Congo (Kinshasa)	1,740	2,200	1,450	1,700	31,000
Germany	—	—	615	620	—
Indonesia	731	920	290	300	24,000
Japan	—	—	1,510	1,600	—
Kazakhstan	510	580	500	510	20,000
Korea, Republic of	—	—	647	660	—
Mexico	734	740	473	470	53,000
Peru	2,300	2,200	336	290	81,000
Poland	391	390	578	590	30,000
Russia	[e]940	1,000	981	1,100	62,000
Zambia	842	770	354	350	19,000
Other countries	2,850	3,400	3,170	3,000	200,000
World total (rounded)	21,200	22,000	25,300	26,000	890,000

(USGS 2023)

World Resources:[6] A U.S. Geological Survey study of global copper deposits indicated that, as of 2015, identified resources contained 2.1 billion tons of copper, and undiscovered resources contained an estimated 3.5 billion tons.[8]

Reserves vs. Resources: zinc (in 1000t)

World Mine Production and Reserves: Reserves for Australia, Bolivia, Canada, China, India, Kazakhstan, Mexico, Peru, Sweden, the United States, and "Other countries" were revised based on company and Government reports.

	Mine production[10]		Reserves[11]
	2021	2022[e]	
United States	704	770	7,300
Australia	1,320	1,300	[12]66,000
Bolivia	500	520	NA
Canada	310	250	1,800
China	4,140	4,200	31,000
India	777	830	9,600
Kazakhstan	194	200	7,400
Mexico	724	740	12,000
Peru	1,530	1,400	17,000
Russia	280	280	22,000
Sweden	234	240	4,000
Other countries	1,960	2,000	30,000
World total (rounded)	12,700	13,000	210,000

World Resources:[10] Identified zinc resources of the world are about 1.9 billion tons. (USGS 2023)

Summary: Module 1

- Formation of ore deposits requires special and coinciding geological processes.
- Ore deposits are not evenly distributed globally.
- Plate boundaries (divergent, convergent) play some role in the location of ore deposits.
- Many factors (not only geological) affect the economy of a potential deposit.
- Several metals are mined only as by-products.