

Metals and Geology

Paul Stickland

What are metals?

- General criteria:
 - Opaque
 - Shiny
 - Silvery or grey
 - Can be drawn into wires
 - Can be shaped by hammering, bending, melting and casting
 - Can often be joined by rivetting, soldering, brazing or welding

What are they?

- To a physicist
 - Good conductors of heat
 - Good conductors of electricity
- To a chemist
 - Elements that form positive ions
- To an engineer
 - High strength materials

Metallurgists cover the science of extraction, physical and chemical properties, forming, joining, alloying, ageing, corrosion etc.

The Periodic Table

1

H

hydrogen

2

He

helium

3

Li

lithium

4

Be

beryllium

11

Na

sodium

12

Mg

magnesium

19

K

potassium

20

Ca

calcium

21

Sc

scandium

22

Ti

titanium

23

V

vanadium

24

Cr

chromium

25

Mn

manganese

26

Fe

iron

27

Co

cobalt

28

Ni

nickel

29

Cu

copper

30

Zn

zinc

31

Ga

gallium

32

Ge

germanium

33

As

arsenic

34

Se

selenium

35

Br

bromine

36

Kr

krypton

37

Rb

rubidium

38

Sr

strontium

39

Y

yttrium

40

Zr

zirconium

41

Nb

niobium

42

Mo

molybdenum

43

Tc

technetium

44

Ru

ruthenium

45

Rh

rhodium

46

Pd

palladium

47

Ag

silver

48

Cd

cadmium

49

In

indium

50

Sn

tin

51

Sb

antimony

52

Te

tellurium

53

I

iodine

54

Xe

xenon

55

Cs

caesium

56

Ba

barium

57

La

lanthanum

72

Hf

hafnium

73

Ta

tantalum

74

W

tungsten

75

Re

rhenium

76

Os

osmium

77

Ir

iridium

78

Pt

platinum

79

Au

gold

80

Hg

mercury

81

Tl

thallium

82

Pb

lead

83

Bi

bismuth

84

Po

polonium

85

At

astatine

86

Rn

radon

87

Fr

francium

88

Ra

radium

89

Ac

actinium

104

Rf

rutherfordium

105

Db

dubnium

106

Sg

seaborgium

107

Bh

bohrium

108

Hs

hassium

109

Mt

meitnerium

5

B

boron

6

C

carbon

7

N

nitrogen

8

O

oxygen

9

F

fluorine

10

Ne

neon

13

Al

aluminium

14

Si

silicon

15

P

phosphorus

16

S

sulphur

17

Cl

chlorine

18

Ar

argon

1

H

hydrogen

2

He

helium

3

Li

lithium

4

Be

beryllium

11

Na

sodium

12

Mg

magnesium

19

K

potassium

20

Ca

calcium

21

Sc

scandium

22

Ti

titanium

23

V

vanadium

24

Cr

chromium

25

Mn

manganese

26

Fe

iron

27

Co

cobalt

28

Ni

nickel

29

Cu

copper

30

Zn

zinc

31

Ga

gallium

32

Ge

germanium

33

As

arsenic

34

Se

selenium

35

Br

bromine

36

Kr

krypton

37

Rb

rubidium

38

Sr

strontium

39

Y

yttrium

40

Zr

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Ba

barium

57

La

lanthanum

72

Hf

hafnium

73

Ta

tantalum

74

W

tungsten

75

Re

rhenium

76

Os

osmium

77

Ir

iridium

78

Pt

platinum

79

Au

gold

80

Hg

mercury

81

Tl

thallium

82

Pb

lead

83

Bi

bismuth

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109

Mt

meitnerium

5

B

boron

6

C

carbon

7

N

nitrogen

8

O

oxygen

9

F

fluorine

10

Ne

neon

13

Al

aluminium

14

Si

silicon

15

P

phosphorus

16

S

sulphur

17

Cl

chlorine

18

Ar

argon

1

H

hydrogen

2

He

helium

3

Li

lithium

4

Be

beryllium

11

Na

sodium

12

Mg

magnesium

19

K

potassium

20

Ca

calcium

21

Sc

scandium

22

Ti

titanium

23

V

vanadium

24

Cr

chromium

25

Mn

manganese

26

Fe

iron

27

Co

cobalt

28

Ni

nickel

29

Cu

copper

30

Zn

zinc

31

Ga

gallium

32

Ge

germanium

33

As

arsenic

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Se

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8

O

oxygen

9

F

fluorine

10

Ne

neon

13

Al

aluminium

14

Si

silicon

15

P

phosphorus

16

S

sulphur

17

Cl

chlorine

18

Ar

argon

1

H

hydrogen

2

He

helium

3

Li

lithium

4

Be

beryllium

11

Na

sodium

12

Mg

magnesium

19

K

potassium

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calcium

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argon

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hydrogen

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He

helium

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Li

lithium

4

Be

beryllium

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sodium

12

Mg

magnesium

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K

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Ca

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V

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Cr

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manganese

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Co

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Ni

nickel

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Ge

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75

Re

rhenium

76

Os

osmium

77

Ir

iridium

78

Pt

platinum

79

Au

gold

80

Hg

mercury

81

Tl

thallium

82

Pb

lead

83

Bi

bismuth

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bohrium

108

Hs

hassium

109

Mt

meitnerium

5

B

boron

6

C

carbon

7

N

nitrogen

8

O

oxygen

9

F

fluorine

10

Ne

neon

13

Al

aluminium

14

Si

silicon

15

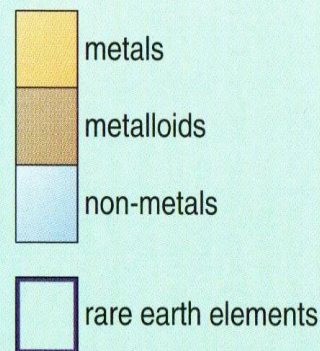
P

phosphorus

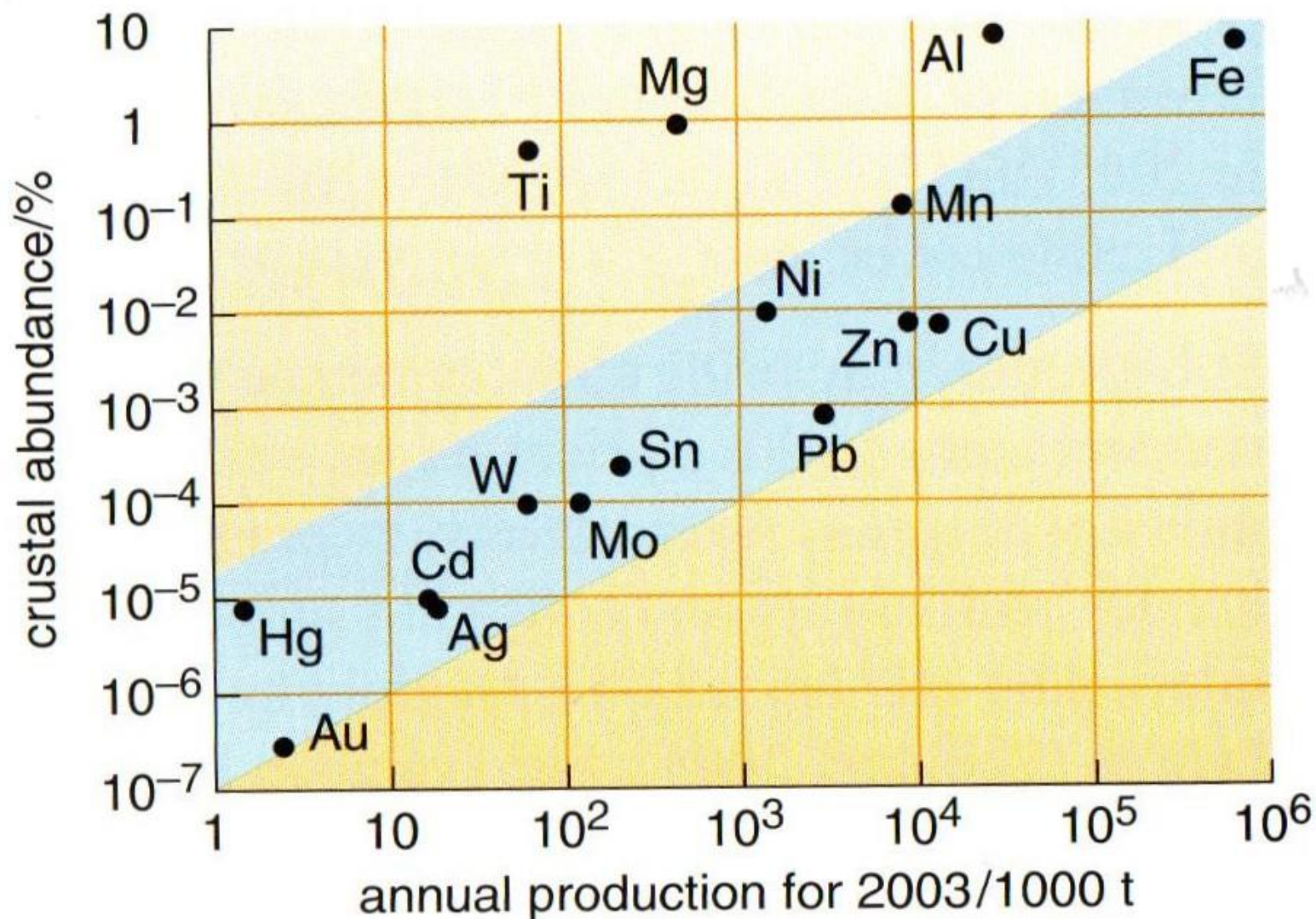
16

S</

58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium
90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium



Crustal abundance and production



Some metal properties

Table 1.2 Properties of selected metals involved in world trade.

Metal	Symbol	Density [†] /t m ⁻³	Melting temperature /°C	Tensile strength [‡]	Electrical conductivity [‡]	Thermal conductivity [‡]	Ease of atmospheric corrosion
aluminium	Al	2.70	660	**	***	***	oxide coating
chromium	Cr	7.19	1 860	****	**	**	very slow
copper	Cu	8.96	1 084	***	****	****	slow
gold	Au	19.3	1 064	**	***	****	does not corrode
iron	Fe	7.89	1 535	***	**	**	corrodes easily
lead	Pb	11.3	334	*	*	*	very slow
lithium	Li	0.53	181	*	**	**	oxide coating
magnesium	Mg	1.70	650	**	***	**	corrodes
mercury	Hg	13.5	-39	—	*	*	does not corrode
nickel	Ni	8.90	1 453	****	**	**	very slow
silver	Ag	10.5	962	***	****	****	tarnishes
tin	Sn	7.31	232	*	**	**	does not corrode
titanium	Ti	4.55	1 660	****	*	*	does not corrode
tungsten	W	19.3	3 410	****	**	***	does not corrode
zinc	Zn	7.13	420	*	**	**	very slow

[†] 1 t m⁻³ = 1 Mg m⁻³ = 10³ kg m⁻³ = 1 g cm⁻³.

[‡] Star rating: **** = high; * = low.

Metal production

Table 1.4 The annual production, crustal abundance, price and notional value of selected metals. (Production data from USGS, 2005; prices data: see notes, Table 1.2)

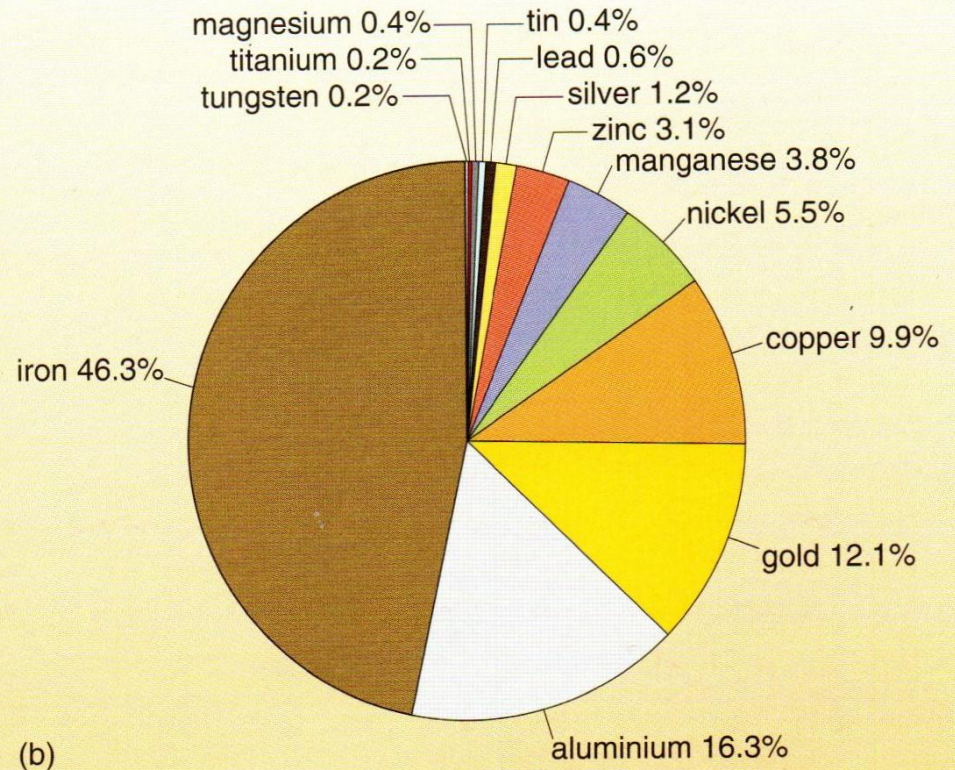
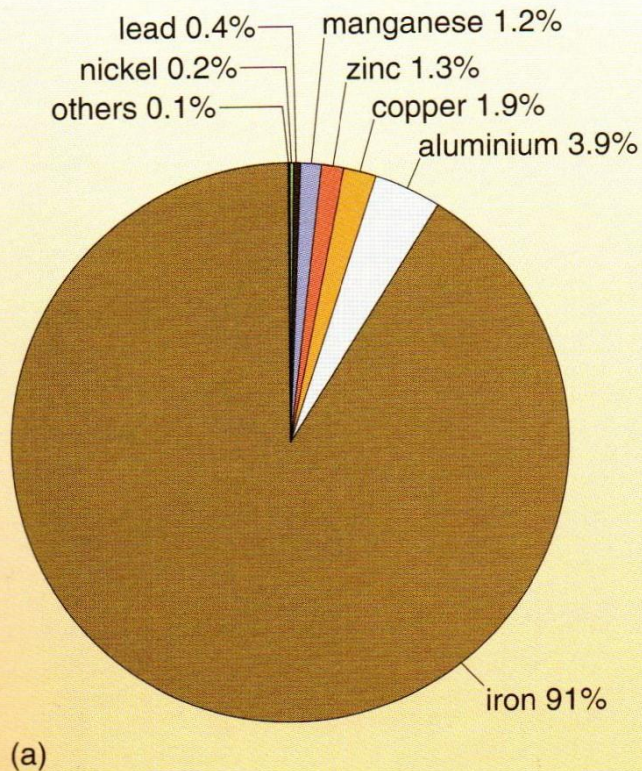
Metal	Production/1000 t (2003)	Abundance in continental crust/%	Price/US\$ t ⁻¹ (2003)	Notional value of world production/US\$ × 10 ⁹
iron	647 000	7.1	174	111.8
aluminium	27 700	8.4	1 430	39.6
copper	13 600	0.007 5	1 780	24.2
zinc	9 000	0.008	827	7.44
manganese	8 200	0.14	1 120	9.18
lead	2 950	0.000 8	515	1.52
nickel	1 400	0.011	9 630	13.5
magnesium	510	3.2	1 900	0.97
tin	210	0.000 25	4 890	1.03
titanium	65	0.54	8 800	0.57
tungsten	62	0.000 1	7 860	0.49
silver	18.8	0.000 008	157 000	2.95
gold	2.52	0.000 000 3	11 700 000	29.09
mercury	1.5	0.000 008	5 370	0.008

Main producers

Table 1.5 The main producers of iron, copper, zinc, lead, tin and gold in 1930 and 2000, in order of decreasing share of world mine production.

Year	Iron	Copper	Zinc	Lead	Tin	Gold
1930	USA France UK Sweden Russia Luxemburg	USA Chile Congo Canada Japan Mexico	USA Germany Mexico Australia Poland Canada	USA Mexico Australia Canada Spain India	Malaya Bolivia East Indies Thailand Nigeria China	South Africa USA Canada Russia Mexico Rhodesia
2000	China Brazil Australia Russia India USA	Chile USA Indonesia Australia Canada China	China Australia Canada Peru USA Mexico	China Australia USA Peru Canada Mexico	China Indonesia Peru Brazil Bolivia Australia	South Africa USA Australia China Canada Russia

Metal production by weight and value



Where do metals come from?

- Any rock you pick up contains just about every natural chemical element there is..
- Geological processes that have concentrated chemical elements are essential for metal extraction.
- A rock from which a metal can be extracted economically is an **ore**.

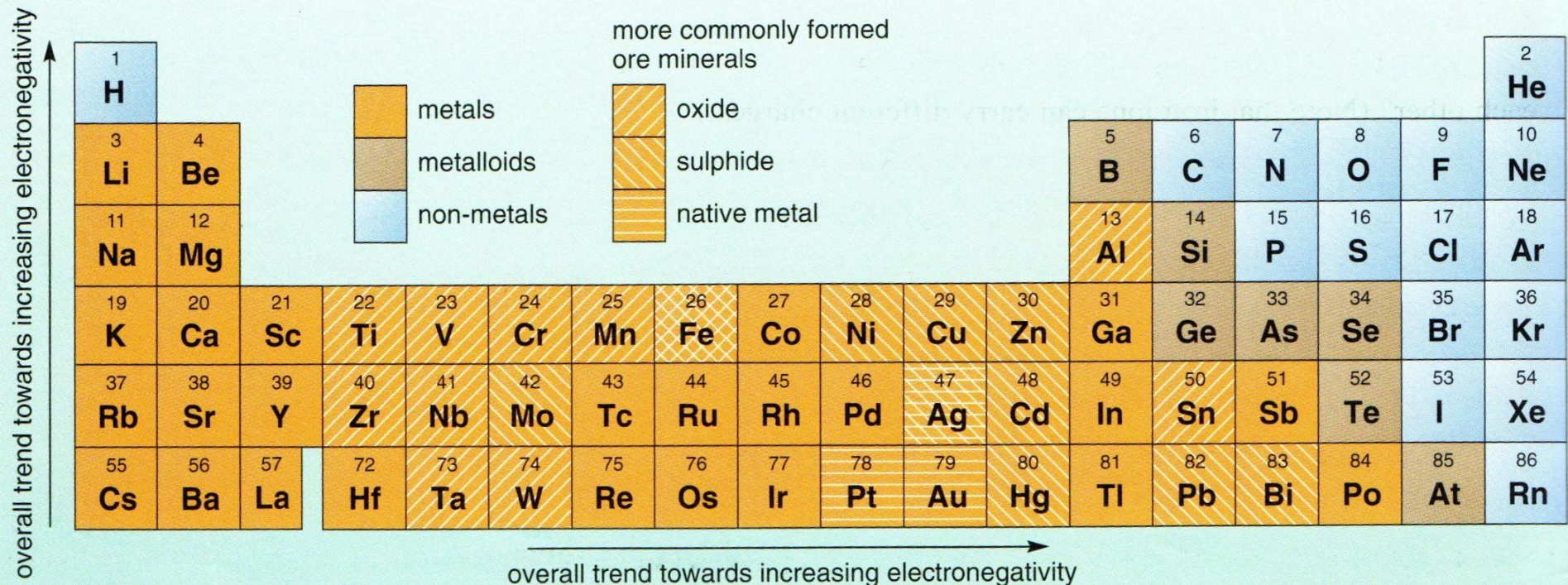
In what form do metals occur?

- A few, e.g Cu and Au, are found as metals.
- Most are combined with other elements in minerals.
- Though widespread, those in the rock-forming silicate minerals are difficult to extract.
- Less-common oxides, sulphides and carbonates have higher metal concentrations, and are easier to extract

Metal Ores

	Ore mineral, formula	Type of mineral
Major metals		
aluminium, Al	<i>gibbsite</i> , Al(OH) ₃	hydrated oxide
copper, Cu	<i>chalcopyrite</i> , CuFeS ₂ ; <i>bornite</i> , Cu ₅ FeS ₄ ; <i>covellite</i> , CuS; <i>chalcocite</i> , Cu ₂ S <i>malachite</i> , CuCO ₃ .Cu(OH) ₂ ; <i>azurite</i> , 2CuCO ₃ .Cu(OH) ₂ <i>cuprite</i> , Cu ₂ O native copper, Cu	sulphide carbonate/hydroxide oxide metal
iron, Fe	<i>magnetite</i> , Fe ₃ O ₄ ; <i>haematite</i> , Fe ₂ O ₃ <i>goethite</i> , FeO(OH) <i>siderite</i> , FeCO ₃ (<i>pyrite</i> , FeS ₂ ; <i>pyrrhotite</i> , FeS)*; <i>arsenopyrite</i> , FeAsS	oxide hydrated oxide carbonate sulphide
lead, Pb	<i>galena</i> , PbS	sulphide
zinc, Zn	<i>sphalerite</i> , ZnS	sulphide
Minor metals		
beryllium, Be	<i>beryl</i> , Be ₃ Al ₂ (SiO ₃) ₆	silicate
bismuth, Bi	<i>bismuthinite</i> , Bi ₂ S ₃	sulphide
cadmium, Cd	substitution of Cd for Zn in sphalerite	sulphide
cerium, Ce	<i>monazite</i> , (Ce,Th)PO ₄	phosphate
chromium, Cr	<i>chromite</i> , (Fe,Mg)Cr ₂ O ₄	oxide
lithium, Li	<i>spodumene</i> , LiAlSi ₂ O ₆	silicate
manganese, Mn	<i>pyrolusite</i> , MnO ₂	oxide
mercury, Hg	<i>cinnabar</i> , HgS	sulphide
molybdenum, Mo	<i>molybdenite</i> , MoS ₂	sulphide
nickel, Ni	<i>pentlandite</i> , (Ni,Fe) ₉ S ₈	sulphide
niobium, Nb	<i>columbite</i> , FeNb ₂ O ₆	oxide
tantalum, Ta	<i>tantalite</i> , FeTa ₂ O ₆	oxide
thorium, Th	<i>monazite</i> , (Ce,Th)PO ₄ <i>thorite</i> , ThSiO ₄	phosphate silicate
tin, Sn	<i>cassiterite</i> , SnO ₂	oxide
titanium, Ti	<i>ilmenite</i> , FeTiO ₃ ; <i>rutile</i> , TiO ₂	oxide
tungsten, W	<i>wolframite</i> , FeWO ₄	oxide
uranium, U	<i>uraninite</i> , UO ₂ (sometimes quoted as U ₃ O ₈)	oxide
vanadium, V	substitution of V for Fe in magnetite	oxide
zirconium, Zr	<i>zircon</i> , ZrSiO ₄	silicate
Precious metals		
gold, Au	native gold, Au, and gold–silver alloy, electrum	metal
platinum, Pt	native platinum, Pt	metal
silver, Ag	<i>acanthite</i> , Ag ₂ S; minor component in galena native silver, Ag; naturally alloyed with gold (electrum)	sulphide metal

Oxide or sulphide?



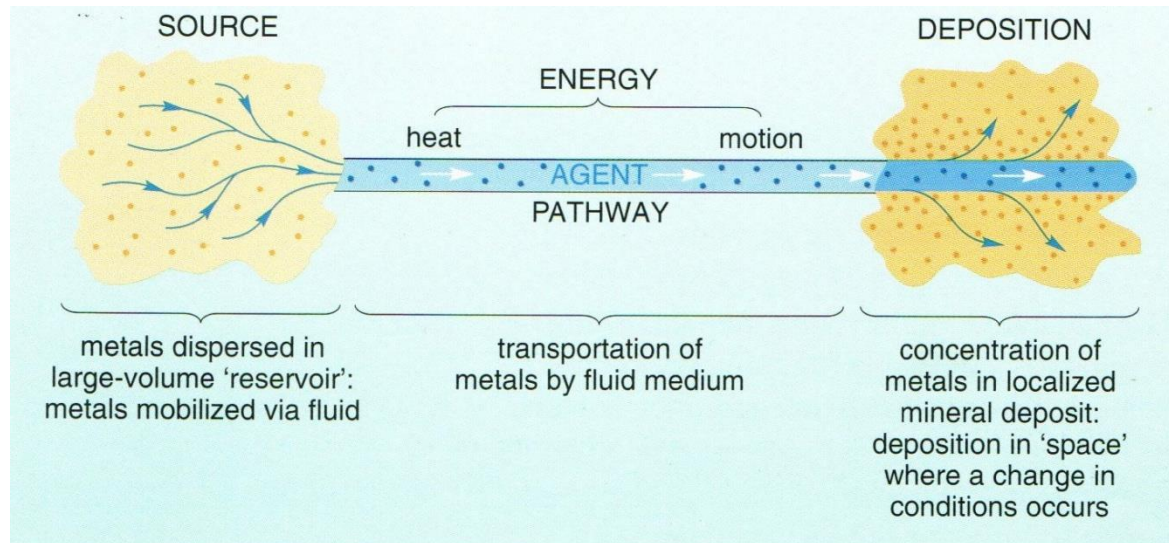
Exploitable ores

Metal	Average minimum exploitable grade/%	Abundance in continental crust/%	Concentration factor	Price 2003 /US\$ t ⁻¹
iron	55	7.1	7.7	174
aluminium	30	8.4	3.6	1 430
lead	5	0.000 8	6 250	515
zinc	3	0.008	315 ✓	827
nickel	1	0.011	90 ✓	9 630
copper	0.5	0.007 5	67 ✓	1 780
tin	0.5	0.000 25	2000 ✓	4 890
mercury	0.2	0.000 008	25 000	5 370
silver	0.01	0.000 008	1 250	157 000
gold	0.000 4	0.000 000 3	1330 ✓	11 700 000

Geological Concentration Processes

SPADE

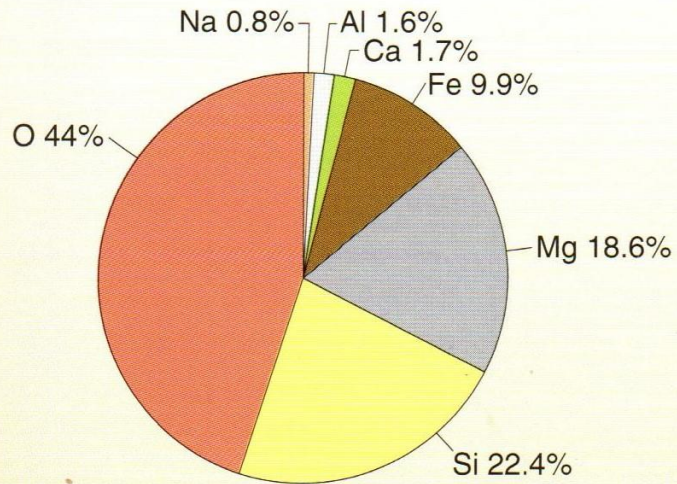
Need a **S**ource of the metal
a **P**athway
an **A**gent
a **D**eposition site
and **E**nergy



Geological Concentration Processes

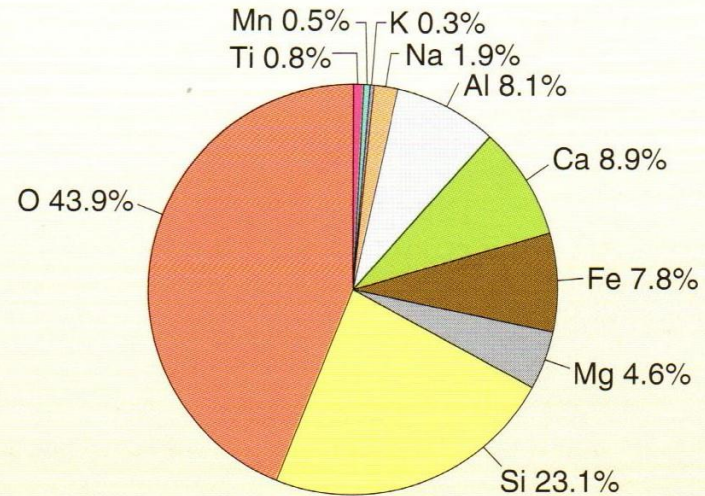
- We shall look at examples of ore bodies derived from three areas:
- 1 Igneous Processes **IP**
- 2 Processes at the Earth's surface **SP**
- 3 Hydrothermal Processes **HP**

SOURCES



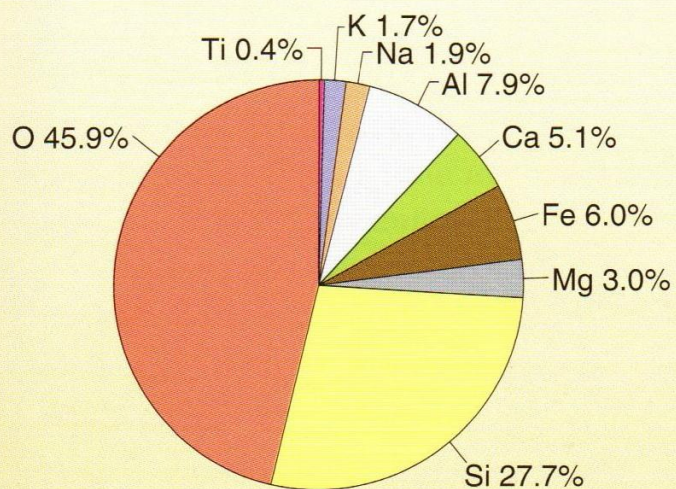
(a)

mantle



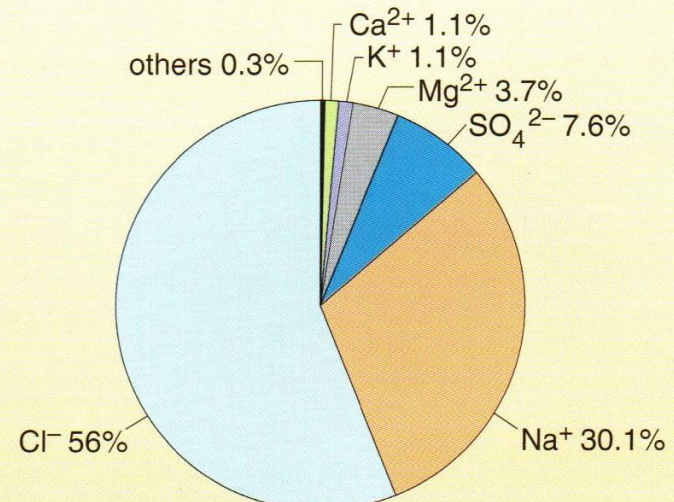
(b)

oceanic crust



(c)

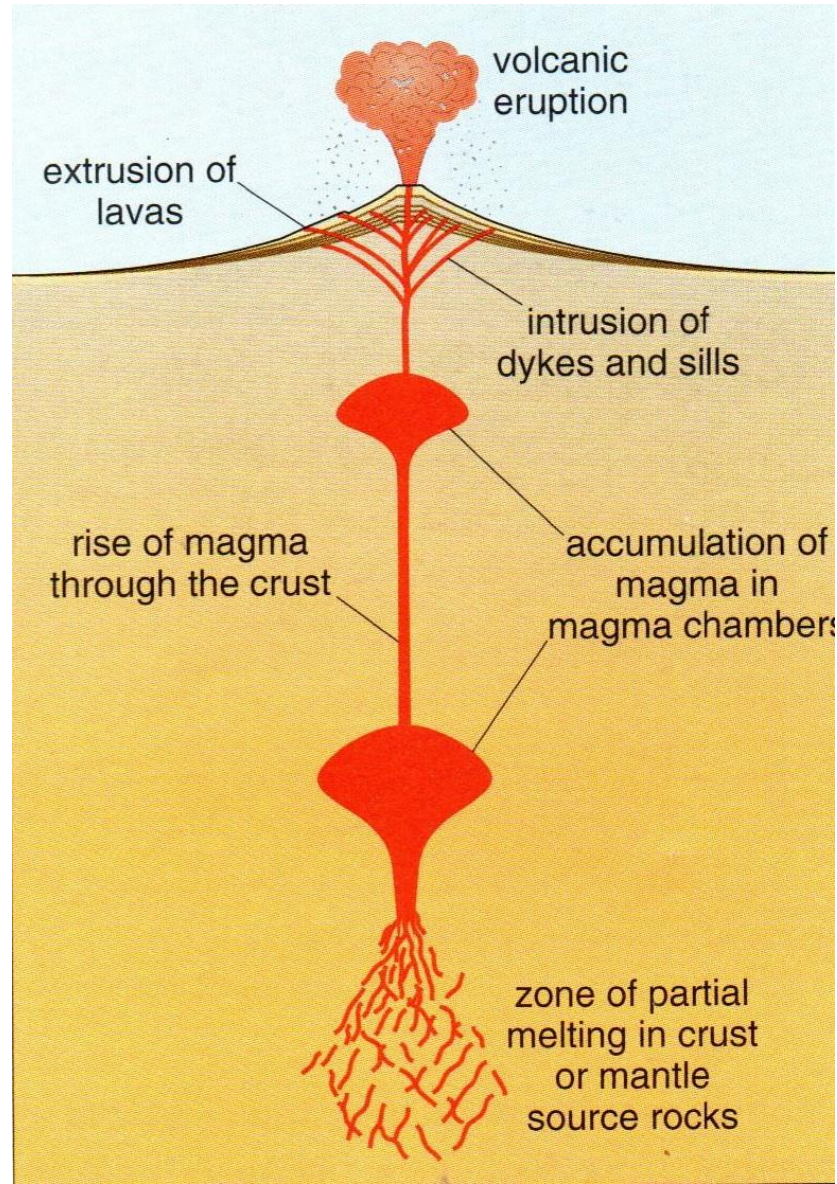
continental crust



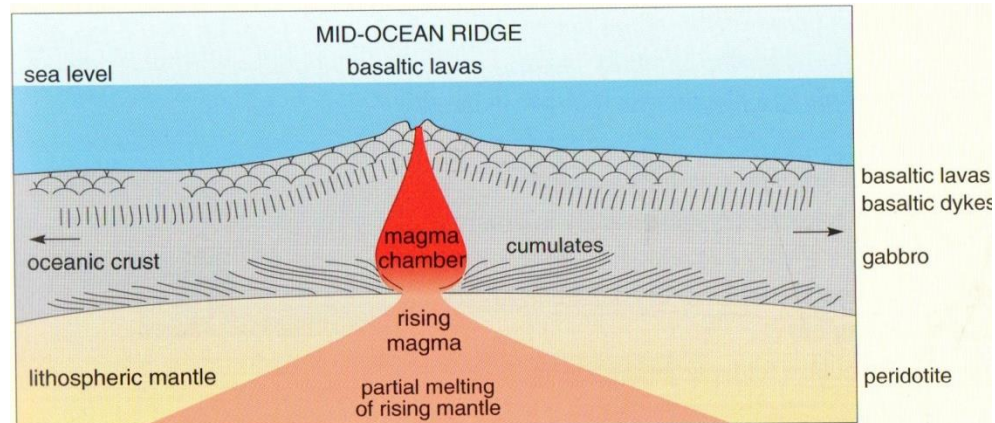
(d)

seawater

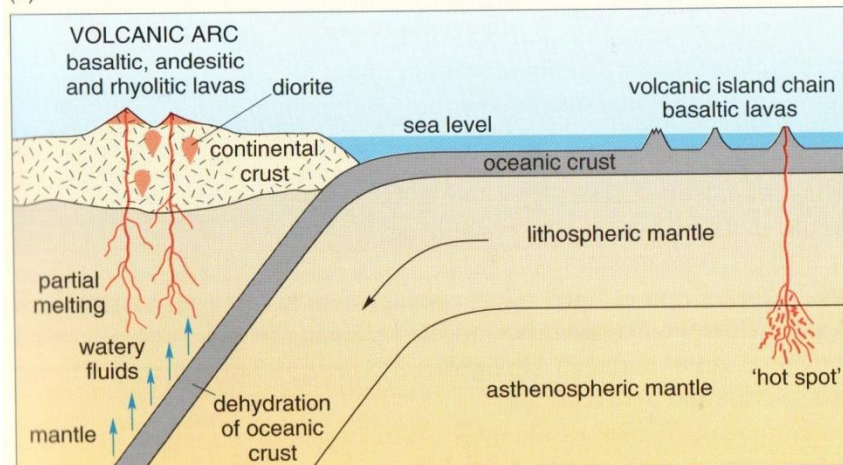
IP Magma Melting - General



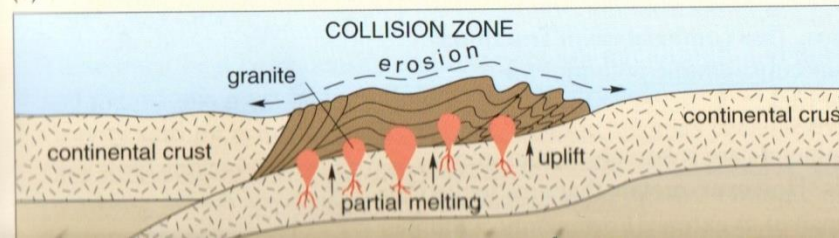
IP Magma Melting and Crystallisation



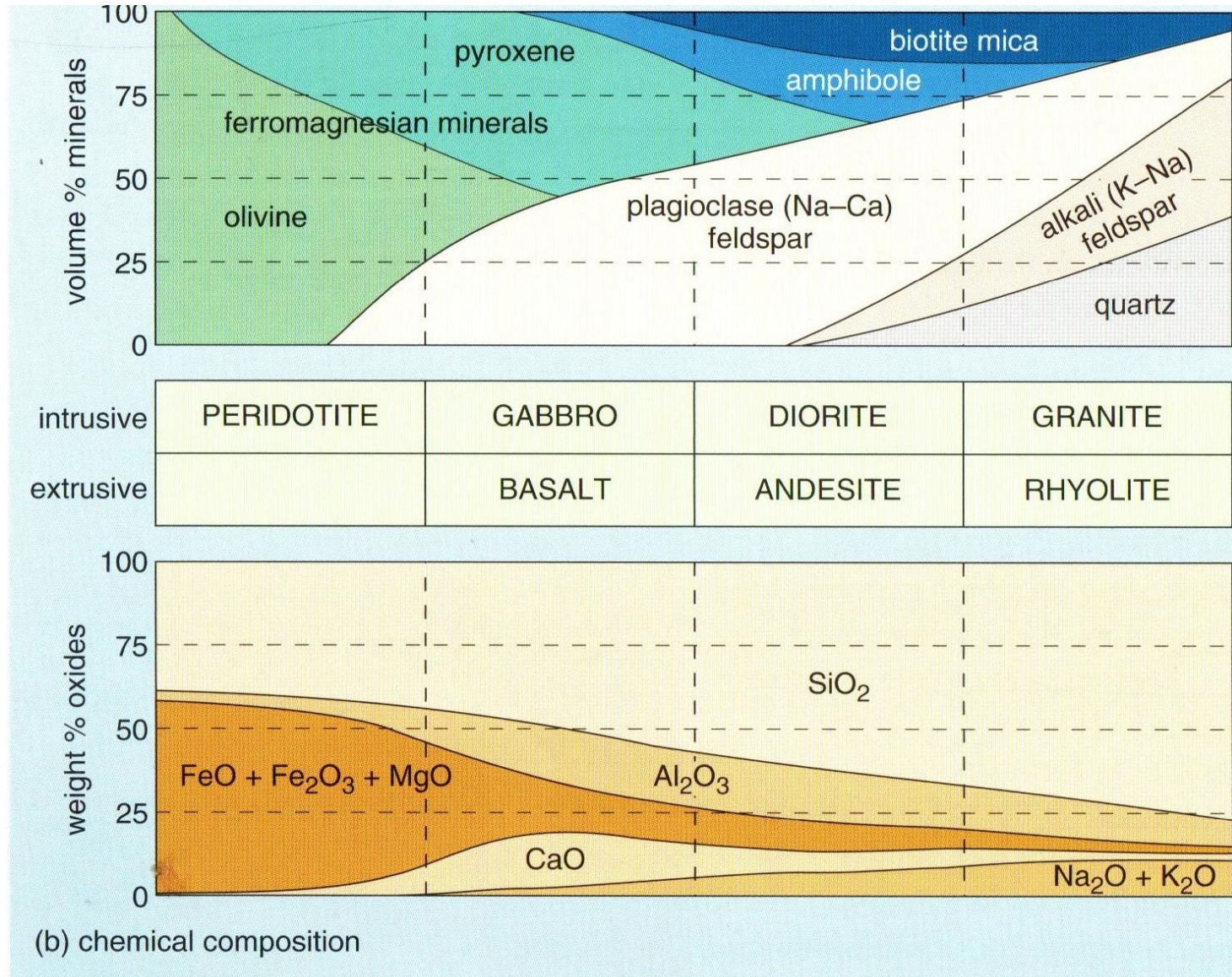
(a)



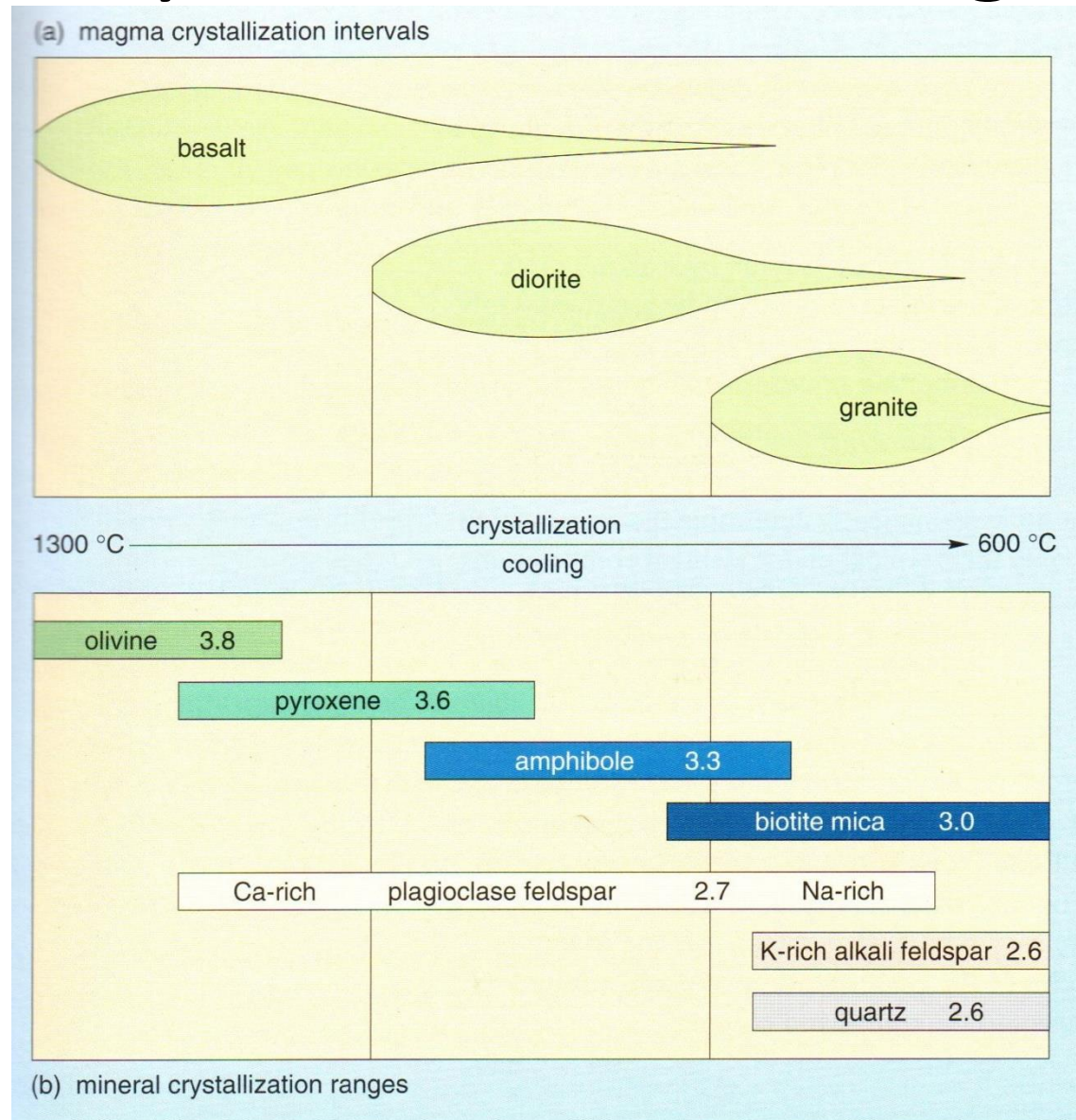
(b)



IP Mineral and chemical composition



IP Crystallisation of magmas



IP Magma Fractionation

- As the magma melts the lower melting and less dense materials rise in the column, and from the mantle ultra-mafic material peridotite you develop the mafic material gabbro, then intermediate diorite and finally felsic granite, which crystallise in turn.
- Thus you have a pathway and an agent.

IP Trace metals

- If metals cannot enter the structure of early crystallising minerals they are INCOMPATIBLE (because of their ionic size and charge) and concentrate in the melt, eventually rising to diorite and granite layers.
- COMPATIBLE metals do enter the structure of crystallising minerals, and remain in peridotite and gabbro layers

IP Trace elements in Igneous Rocks



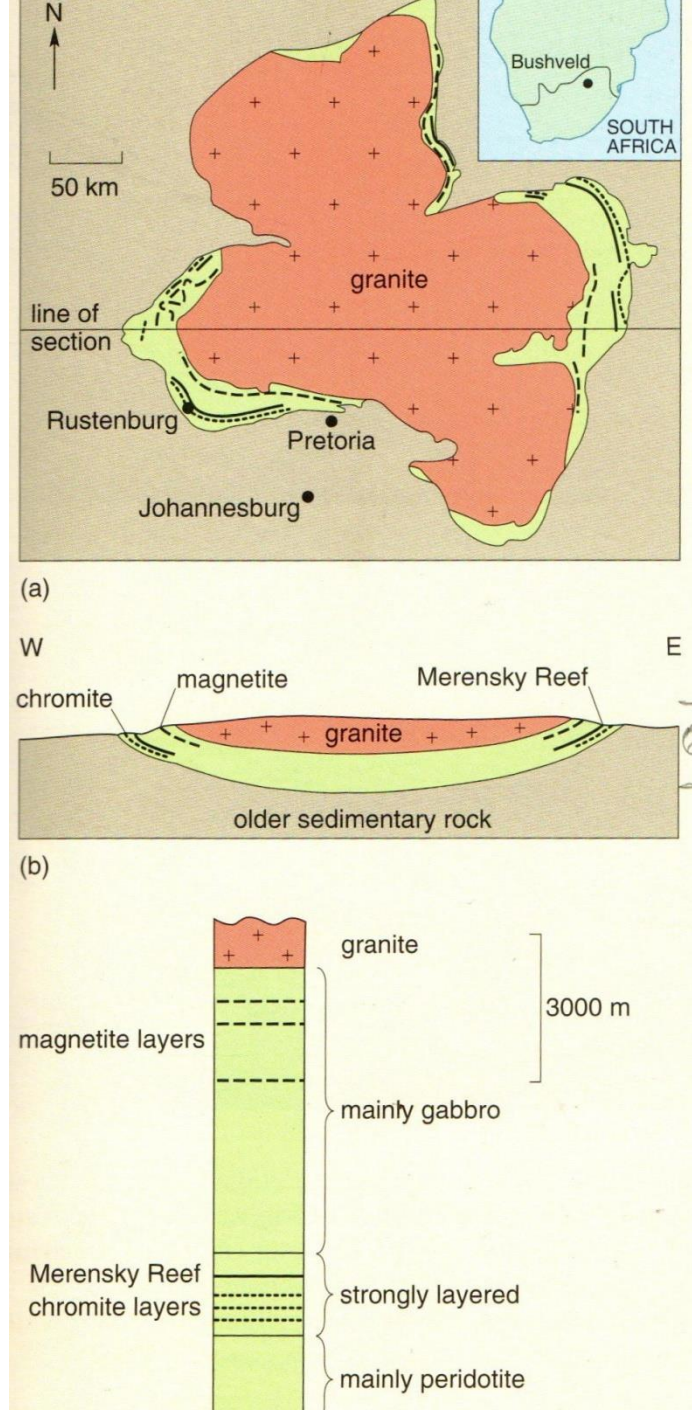
Metal	<u>Peridotite</u> ppm	<u>Gabbro</u> ppm	<u>Diorite</u> ppm	<u>Granite</u> ppm	Max abundance in	Min <u>Epl</u> grade ppm	Min <u>conc</u> factor
Cr	3,000	300	30	10	<u>Peridotite</u>	300,000	150
Cu	20	70	50	10	<u>Gabbro</u>	3,000	31
Li	0.5	10	22	40	Granite	20,000	500
Ni	2000	130	10	3	<u>Peridotite</u>	10,000	5
<u>Nb</u>	5	15	25	40	Granite	1,000	25
Pt	0.05	0;01	0.005	0.001	<u>Peridotite</u>	5	100
Ta	0.25	0.75	1.5	3.5	Granite	500	200
<u>Sn</u>	0.5	1.0	1.5	2.0	Granite	5,000	1430
Ti	5	10,000	5,000	1,000	<u>Gabbro</u>	30,000	3
W	0.5	1.0	1.5	2.0	Granite	5,000	2,500
U	0.005	1,0	2.0	3.5	Granite	350	100
V	60	40	100	30	<u>Gabbro</u>	20,000	50

IP A magmatic segregation deposit

- The Bushveld complex is the most valuable ore deposit in the world, valued at over £2 trillion. It is mainly peridotite and gabbro containing compatible elements Cr, V, Pt group elements, Cu and Ni, with a capping layer of granite.
- Its very large extent is attributed to repeated pulses of magma injection and mixing.

Bushveld complex

About 250km
across – worked
at the margins of
the granite cap.
Intruded into
stable continental
crust in pre-
Cambrian times.



IP Pegmatites

- Very coarse grained granitic rocks arising from late crystallisation of water saturated magmas that can be mineralised with incompatible metals.
- Deposits are not generally very large, but worked in Australia for Li, and in Canada for Ta, Li and Ni.

IP Metals in Pegmatites

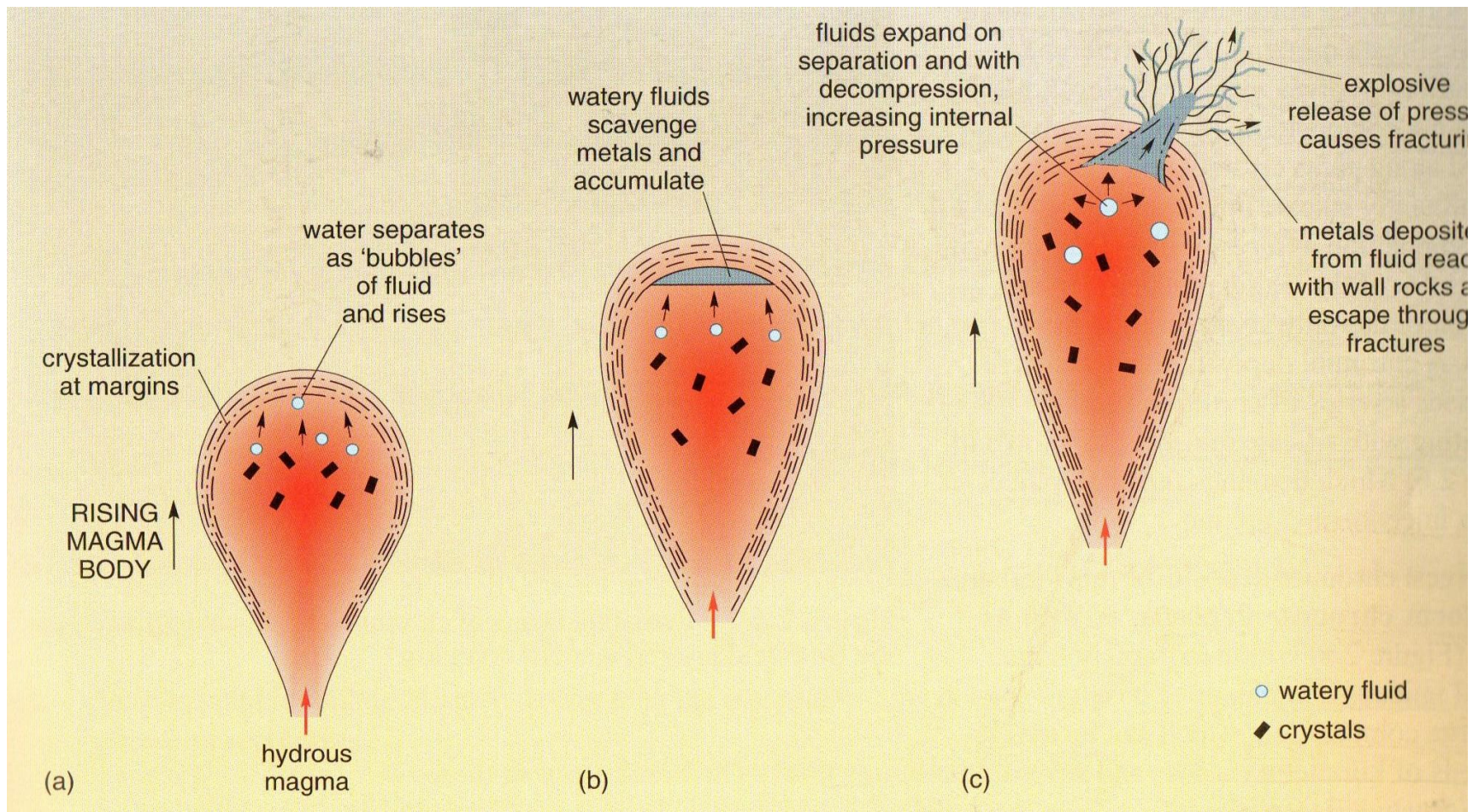
Table 2.2 Some metals that can be obtained from pegmatites: their minerals, uses and properties. (Note: m.t. = melting temperature.)

Metal	Mineral/formula	Important uses	Notable properties
beryllium, Be	beryl, $\text{Be}_3\text{Al}_2(\text{SiO}_6)_{18}$ (Figure 2.9b)	brake discs for jet aircraft; windows of X-ray tubes	low density; high m.t. (1279 °C); resistant to metal fatigue; a good heat insulator; transparent to X-rays; toxic
caesium, Cs	pollucite, $(\text{Cs}, \text{Na})_2\text{Al}_2\text{Si}_4\text{O}_{12} \cdot \text{H}_2\text{O}$	atomic clocks and light- sensitive detectors	nuclei of caesium atoms have different energy states
cerium, Ce	monazite, CePO_4	coatings for high-definition TV tubes; lighter 'flints'	phosphorescence; high-friction alloy
lithium, Li	spodumene, $\text{LiAlSi}_2\text{O}_6$	low-density alloys; batteries; coolant in nuclear reactors	low density; high thermal conductivity; low m.t. (181 °C)
tantalum, Ta	tantalite, FeTa_2O_6	military warheads; electronic capacitors (as in mobile phones); surgical implants	high density; machinable; high resistivity; very high m.t. (2996 °C); resistant to corrosion
tin, Sn	cassiterite, SnO_2	tinplate; float glass; alloys (bronze, pewter, solder, gunmetal)	low m.t. (232 °C); resistant to corrosion
tungsten, W	wolframite, FeWO_4	abrasive and cutting tools (tungsten carbide); high-speed steel; darts; light bulb filaments	high density; very high m.t. (~3400 °C); low thermal expansion
uranium, U	uraninite, UO_2	fuel for nuclear reactors	fissile isotopes

IP Porphyry Ore deposits

- Porphyry is a textural term for an intrusive igneous rock comprising large crystals set in a matrix of smaller crystals.
- The ores are large low grade deposits associated with such rocks. They include Cu, Mo, Ag, Au and W ores.
- Now provide 50% of the world's Cu, and 70% of the Mo.
- Associated with granodiorites, above subduction zones.

IP Mechanism for porphyrytic ores



IP The South American Copper Belt

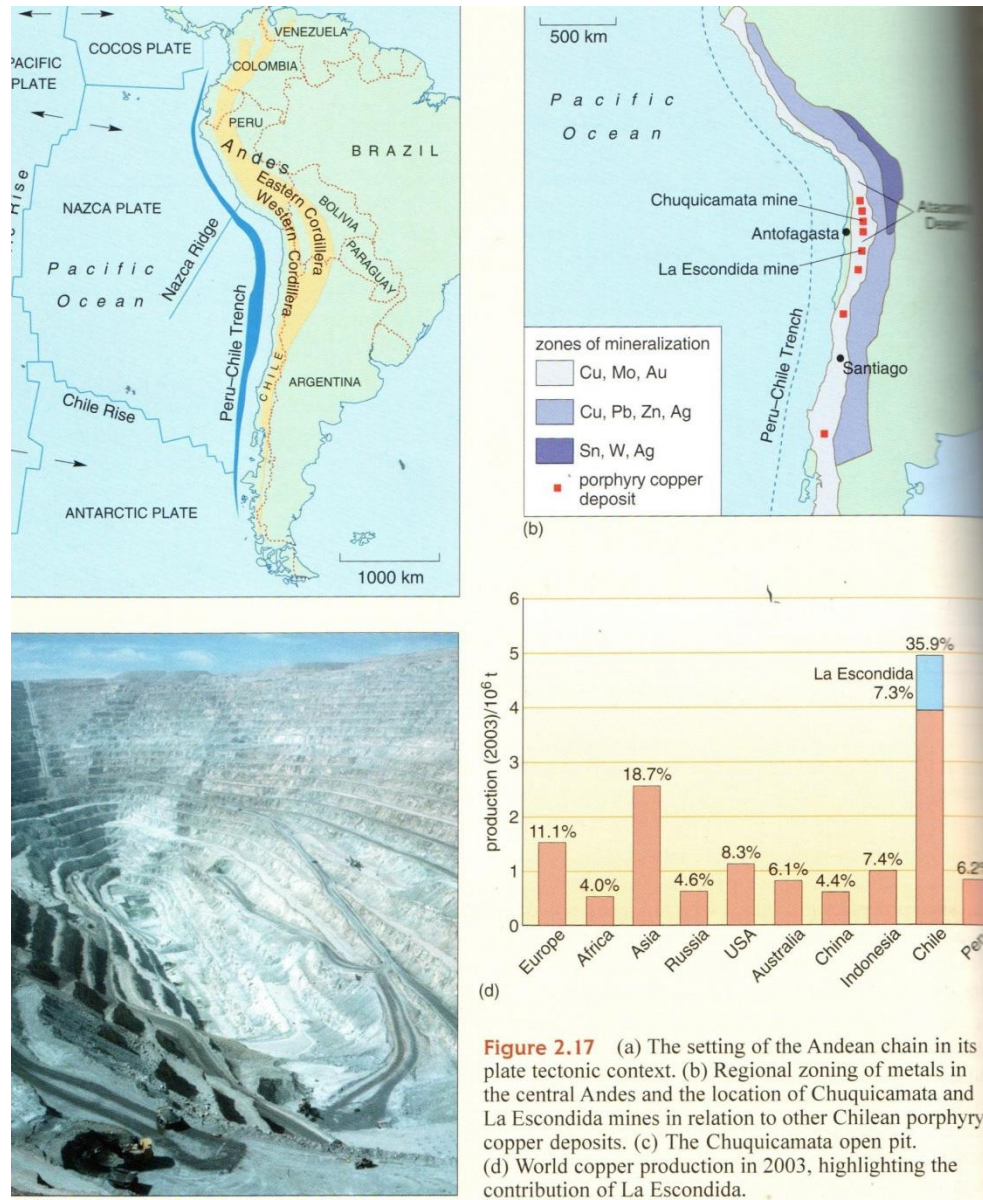
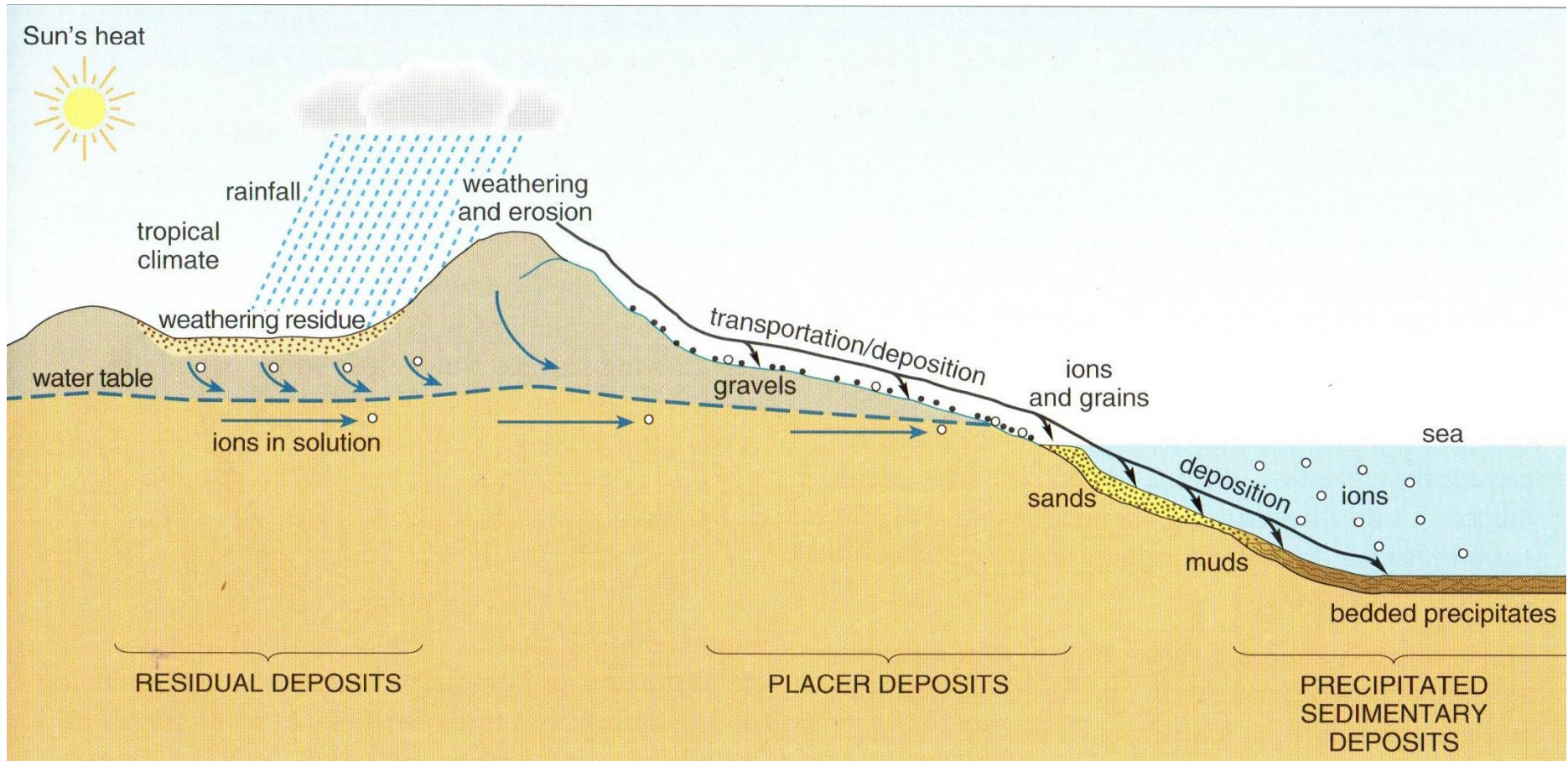


Figure 2.17 (a) The setting of the Andean chain in its plate tectonic context. (b) Regional zoning of metals in the central Andes and the location of Chuquicamata and La Escondida mines in relation to other Chilean porphyry copper deposits. (c) The Chuquicamata open pit. (d) World copper production in 2003, highlighting the contribution of La Escondida.

IP Back to SPADE

- The Pathway is the vertical column of magma, the Agent is the molten magma, abetted by the water content in hydrous magma, and the Deposition site is where the magma finally crystallises, or in the case of porphyritic ores in the fracture zone above.
- Energy comes from Earth's radioactive heating.

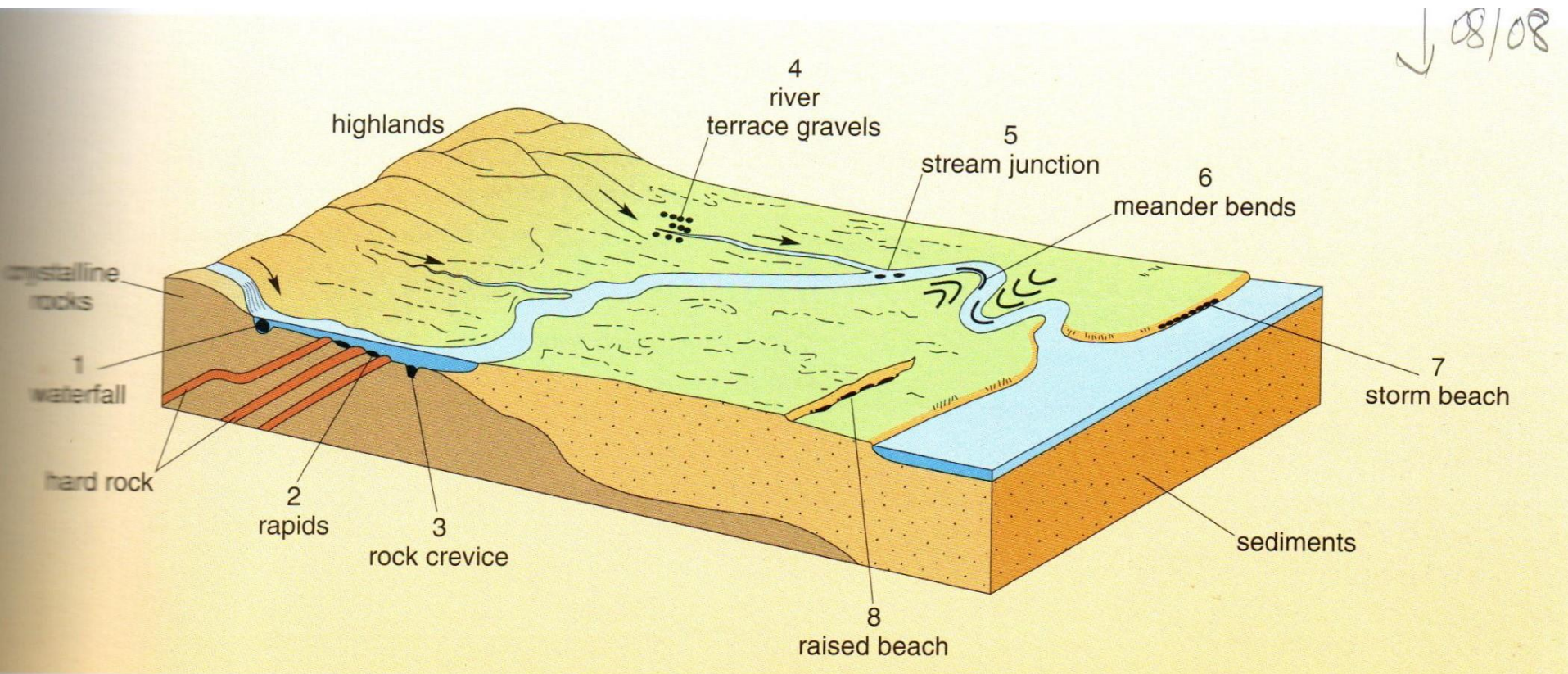
SP Surface Processes



SP Surface Processes

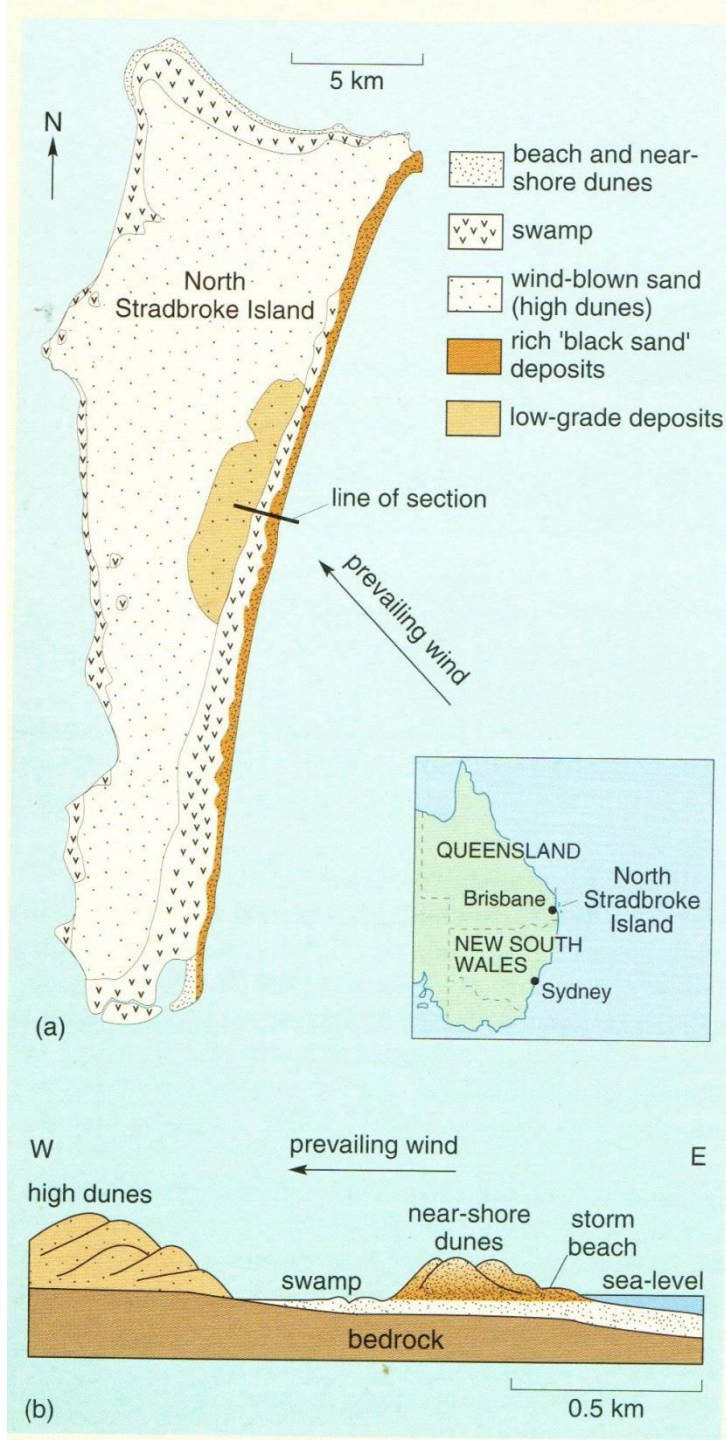
- The source is chemical and physical weathering of crystalline igneous rocks in which metals will have been concentrated by magmatic processes.
- The pathway is flowing water from rainfall.
- The agent is water.
- The energy source is the sun.

SP Placer Material Deposits



SP Beach Placer Deposits

(Ti, Zr and
Monazite, sorted
by wave and
wind action)



SP Placer Material Characteristics

- Mineral grains are hard, chemically stable and dense, and will be deposited where transport conditions change.
- Recent, unconsolidated placer deposits can be mined by dredging, or with high-pressure water jets. Because of this lower-grade ores are economical to work.

SP Placer Ores

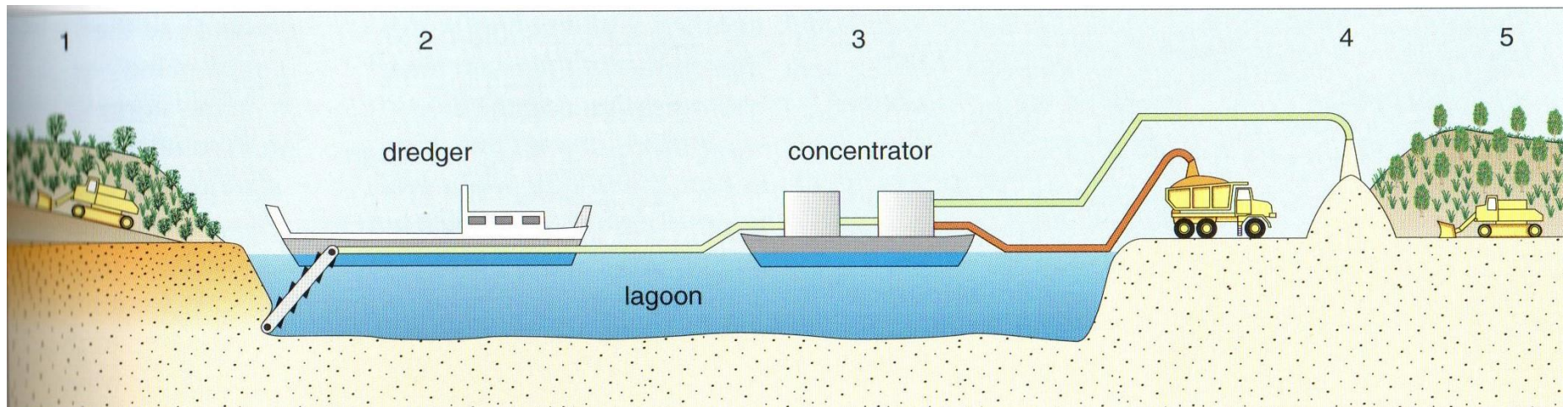
Table 3.2 Ore minerals commonly recovered from placer deposits.

Metal/element	Ore mineral	Density/t m⁻³	Main environment
carbon	diamond, C	3.5	beach sand and alluvial
titanium	rutile, TiO ₂	4.2	beach sand
zirconium	zircon, ZrSiO ₄	4.6–4.7	beach sand
titanium	ilmenite, FeTiO ₃	4.7	beach sand
rare earth elements	monazite, CePO ₄	4.8–5.5	beach sand
iron	magnetite, Fe ₃ O ₄	5.2	beach sand
niobium	columbite, FeNb ₂ O ₆	5.2–7.9	alluvial
tin	cassiterite, SnO ₂	6.8–7.1	alluvial
tantalum	tantalite, FeTa ₂ O ₆	7.9–8.2	alluvial
gold	native metal, Au	15.0–19.3	alluvial
platinum	native metal, Pt	14.0–19.0	alluvial

Many heavy minerals were formed originally as accessory minerals in igneous rocks.

granite granite - aabb

SP Placer Mining (1)

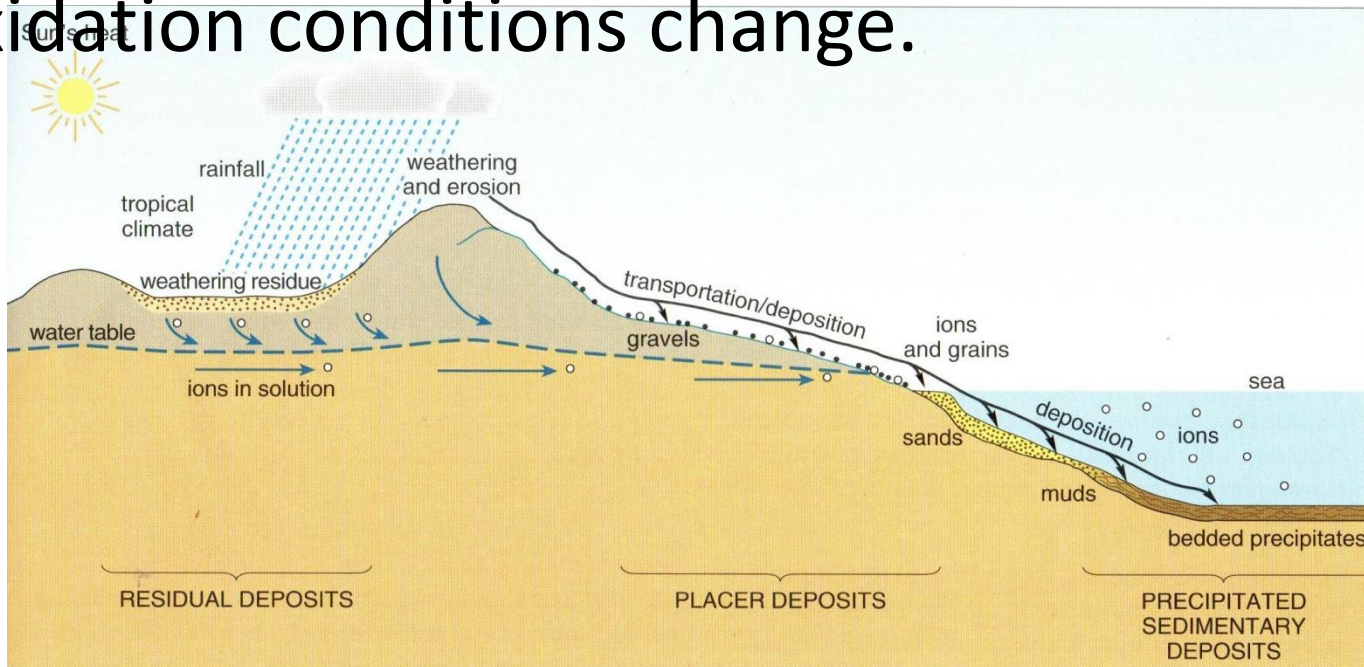


SP Placer Mining (2)



SP Ocean, or Bedded Deposits

Particles going past sea level will end up as sands, muds and precipitated sedimentary, or bedded deposits. Metals transported as ions, or as colloids may also be deposited when salinity or oxidation conditions change.



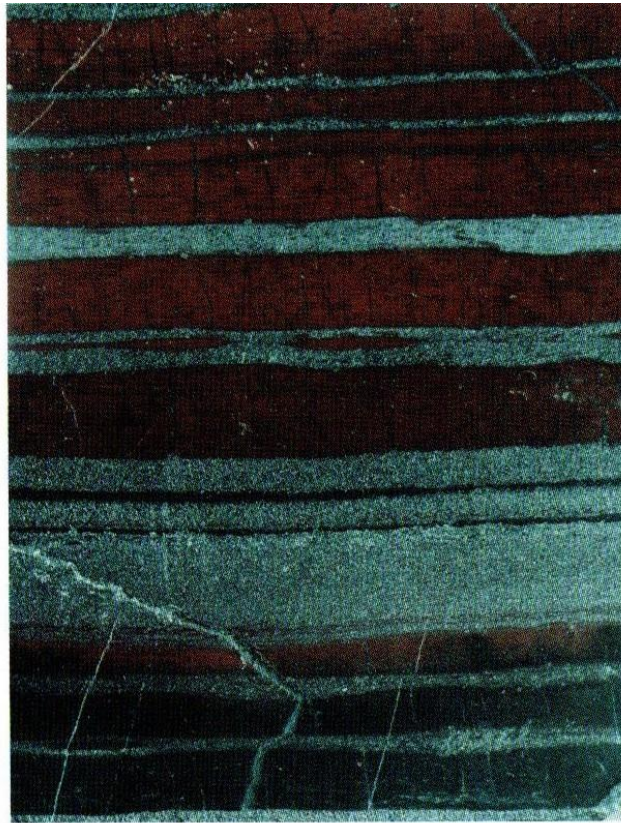
SP Iron Ores

- Iron and its alloys are by far the most common metals in use.
- The Industrial Revolution in Europe depended on the proximity of coal and 'bog iron ores' (FeCO_3) arising from the Carboniferous period.
- Later Jurassic ironstones used in UK until the 1970s were interbedded limestones, mudstones and sandstones.

SP Banded Iron Ores

- Before 2 Bn years ago, there was no free oxygen in Earth's atmosphere, and an abundance of Fe^{2+} ions in the seas. However, appearance of plant life in the form of photosynthetic bacteria gave rise to free oxygen in the seas, precipitating layers of insoluble Fe^{3+} oxides and hydroxides, interbedded with silica.
- Such BIFs contain ca 30% Fe, but where silica has been leached out, this can rise to 60%

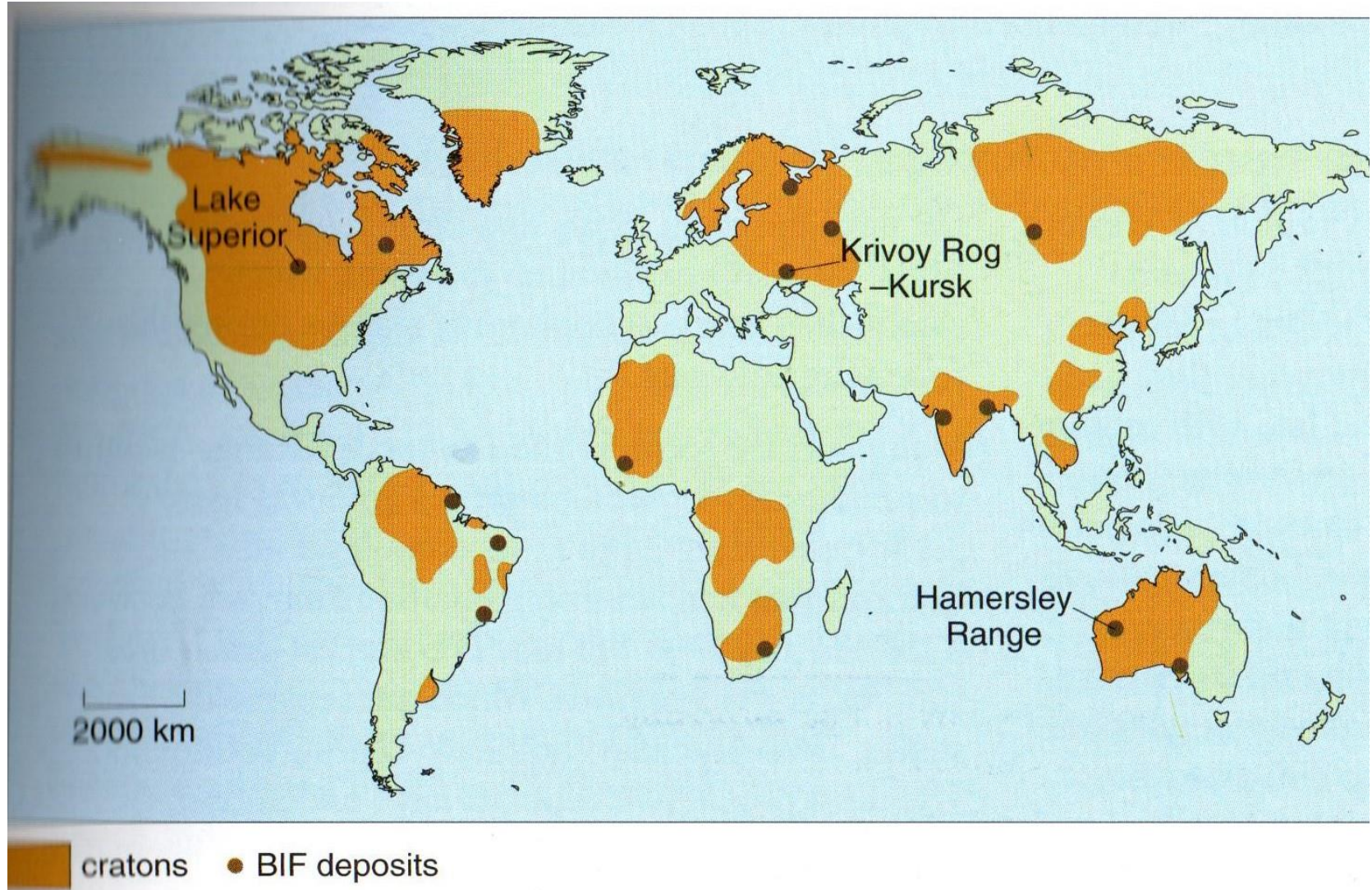
SP A BIF Structure



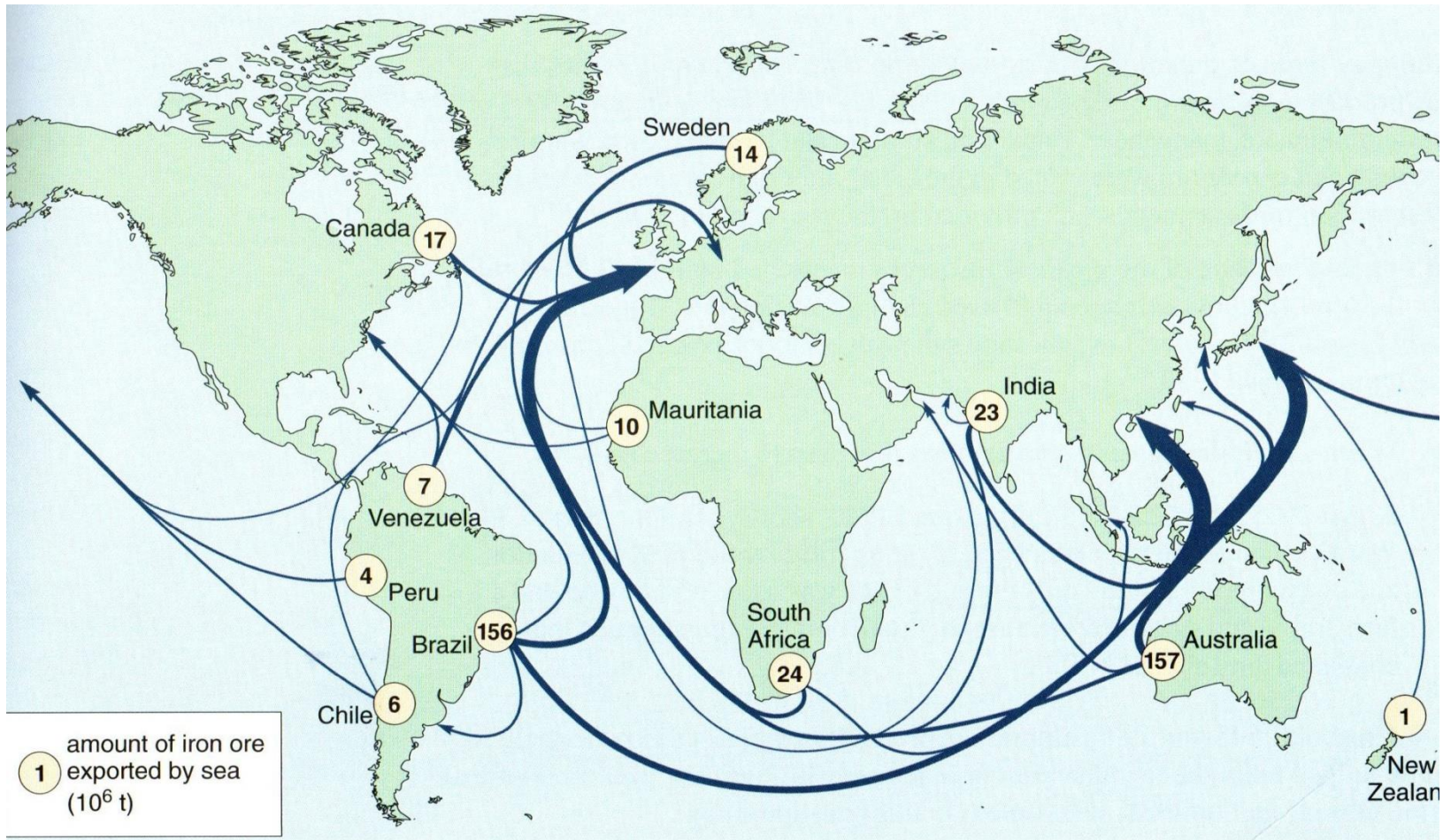
1 cm

Figure 3.12 Sedimentary iron ore: alternating bands (2–8 mm wide) of chert and iron oxide in a polished specimen of banded iron formation.

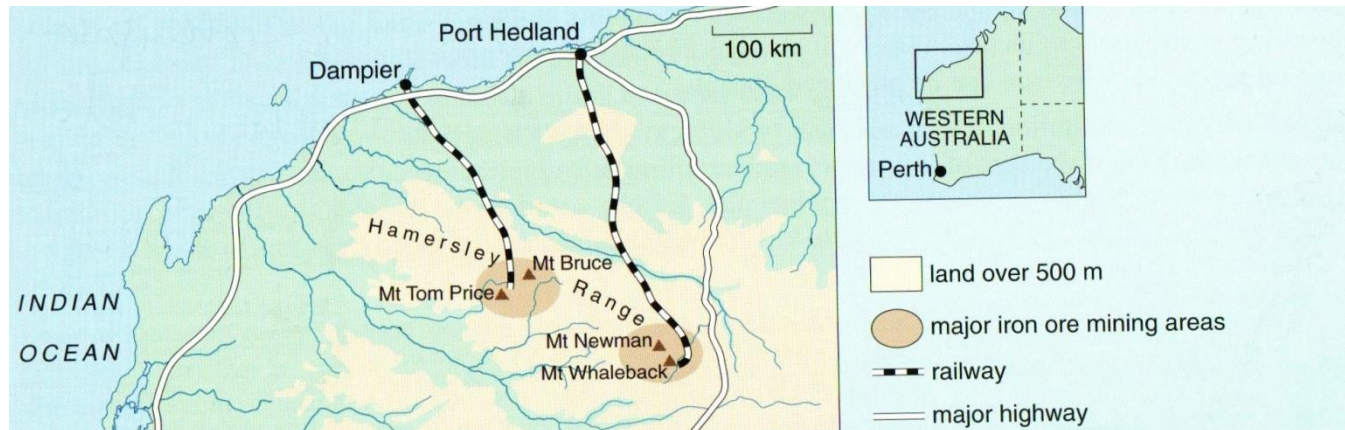
SP BIF Locations (in stable cratons)



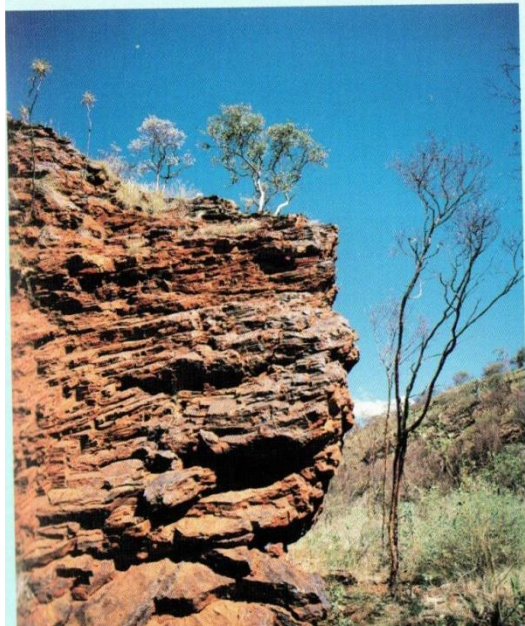
SP Seaborne Iron Ore Trade



SP The Hammersley Range

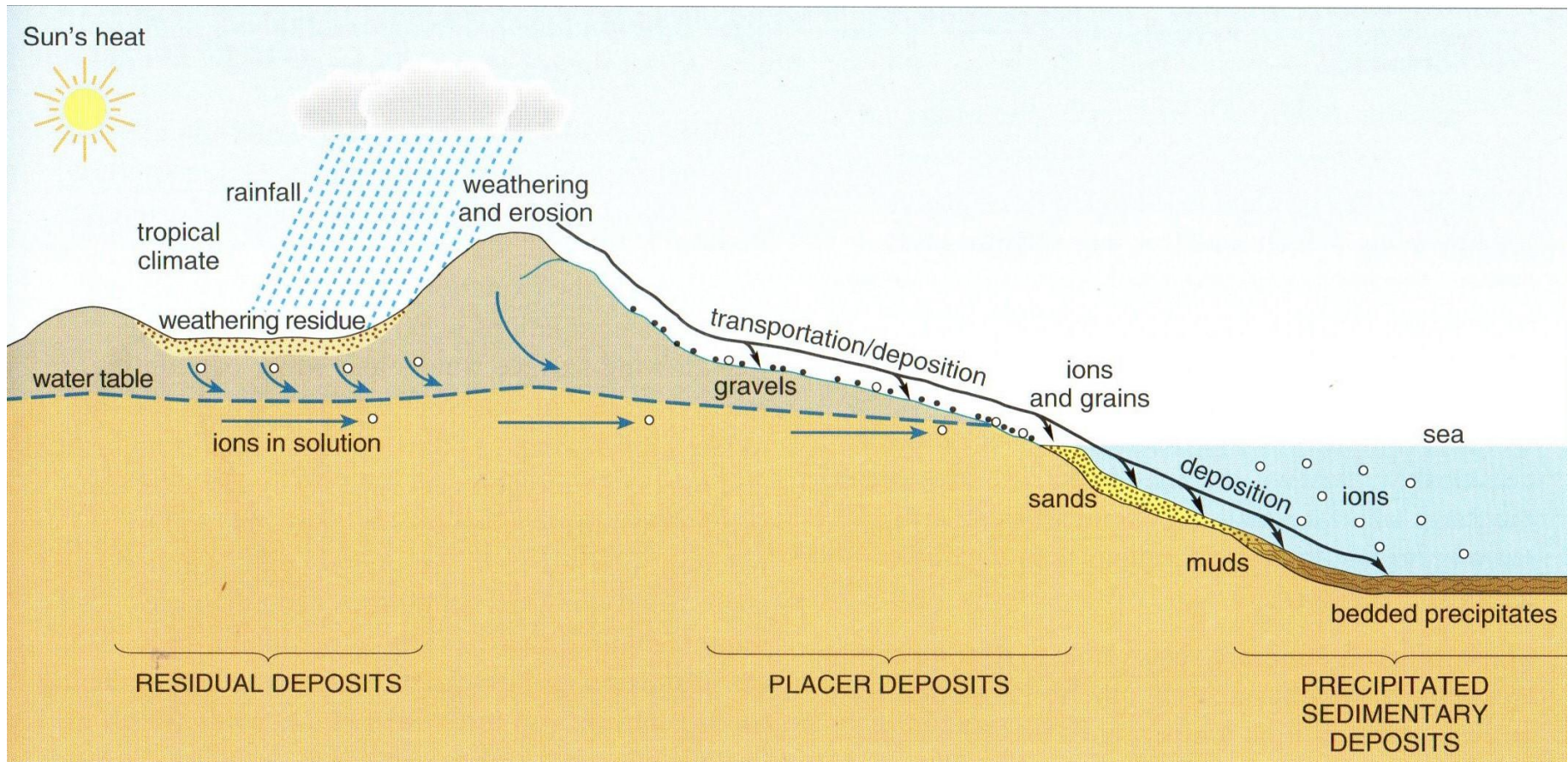


(a)



SP Residual Weathering Deposits

- (Back to a previous slide)

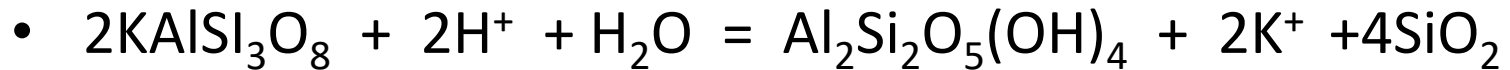
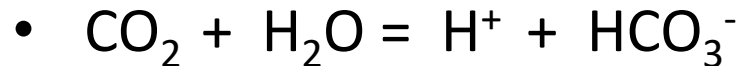


SP Laterites

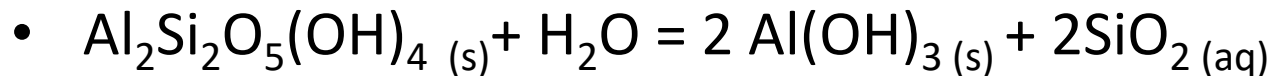
- In tropical climates, warm and humid conditions promote chemical weathering of surface rocks.
- If erosion is minimal, weathering products accumulate as thick residual soils or Laterites, especially over permeable rocks through which water can drain.
- Laterites often consist of Kaolinite and insoluble hydrated oxides of Al.

SP Kaolinite, Gibbsite and Bauxite

- We have seen how chemical weathering of the alkali feldspars (22% Al_2O_3) in granite forms kaolinite (40% Al_2O_3):



Then intense tropical weathering involving hot climate, heavy rainfall, with periodic changes from wet to dry conditions, breaks down the kaolinite to gibbsite (65% Al_2O_3). The silica is more soluble than alumina so drains away with other metal ions:



- A mixture of kaolinite and gibbsite is known as Bauxite, after the village of Les Baux in the south of France. Easily mined bauxite is the principal ore of aluminium.

SP Jamaica

Recently produced 60% of world bauxite output, still 10%

Source??

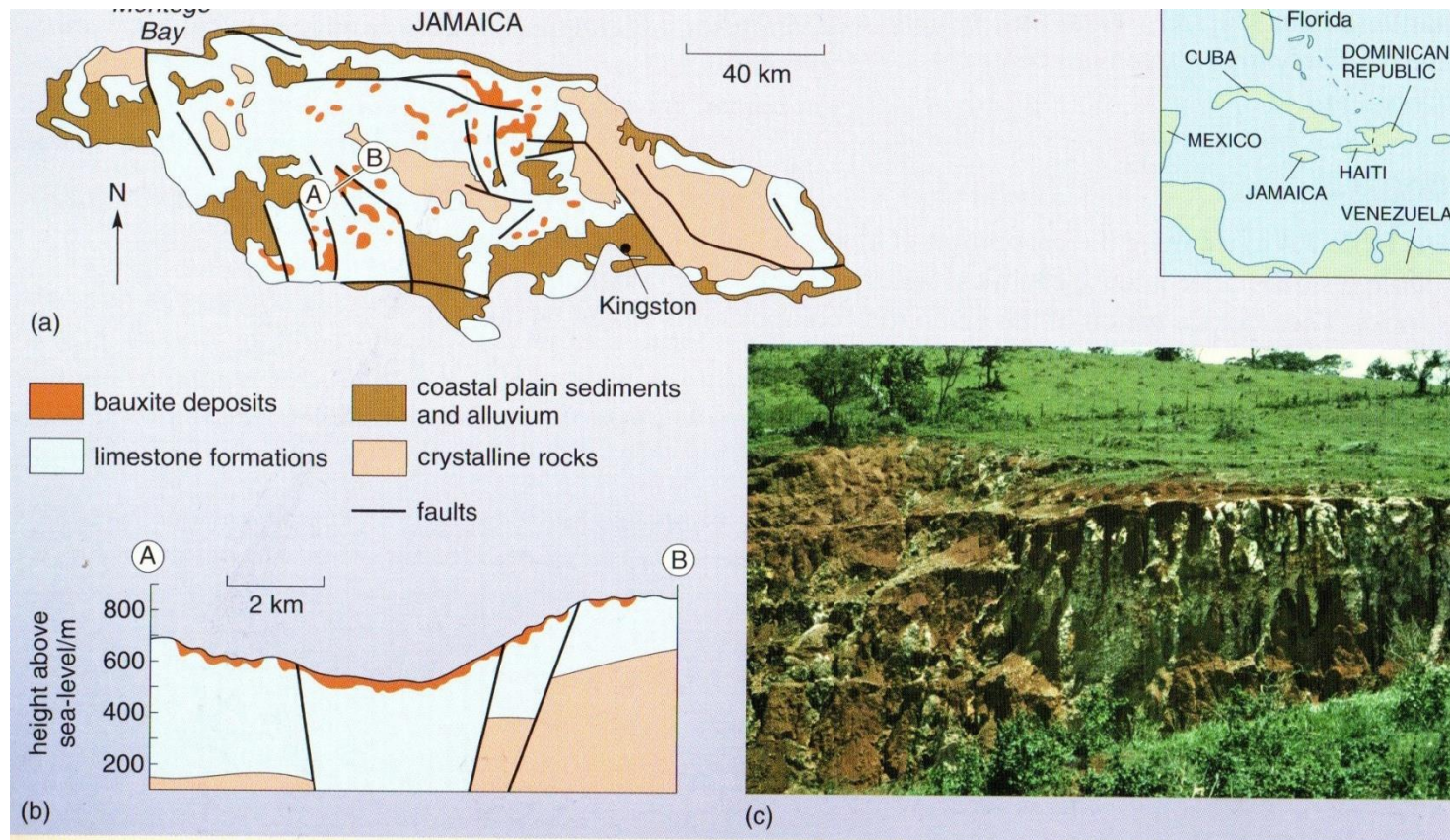
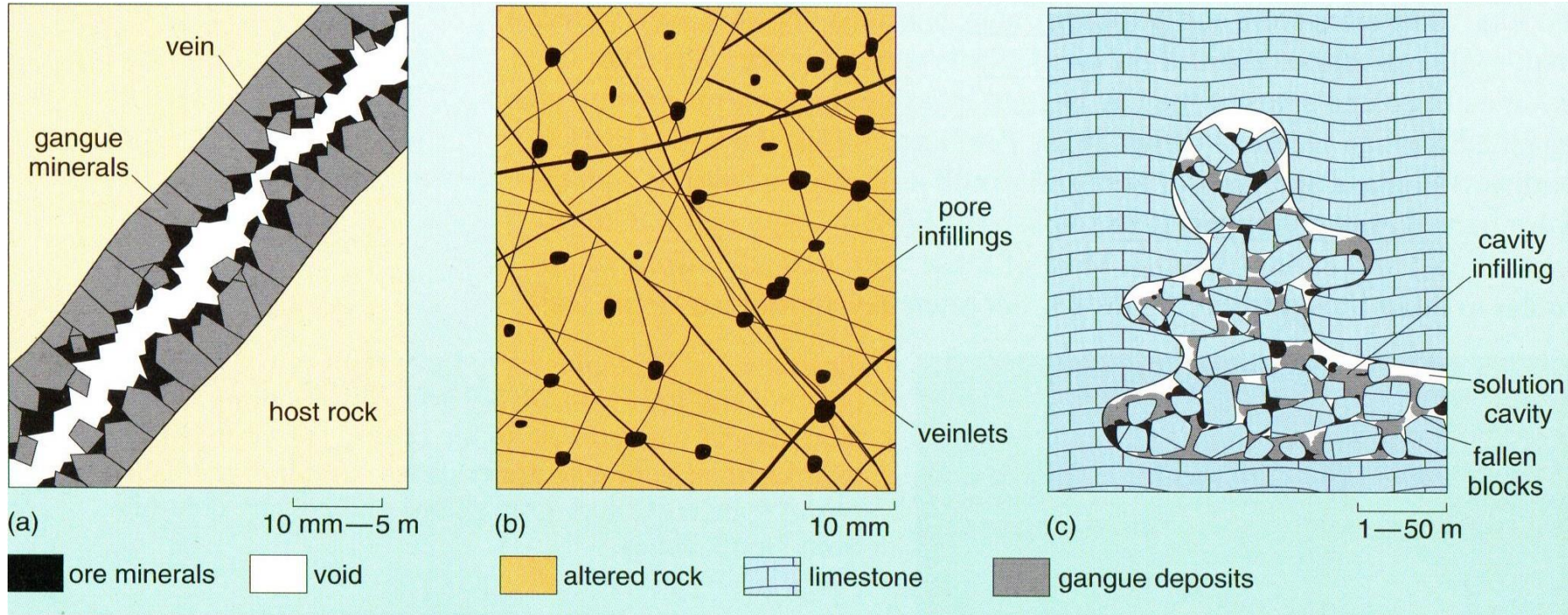


Figure 3.8 (a) The location of bauxite deposits on the island of Jamaica. (b) A cross-section A-B through a bauxite field in the middle of the island, showing the occurrence of bauxite in pockets. (c) Exposure of bauxite (red-brown) in Jamaica showing the deeply pitted surface of the underlying limestone (creamy white).

HP Hydrothermal Processes

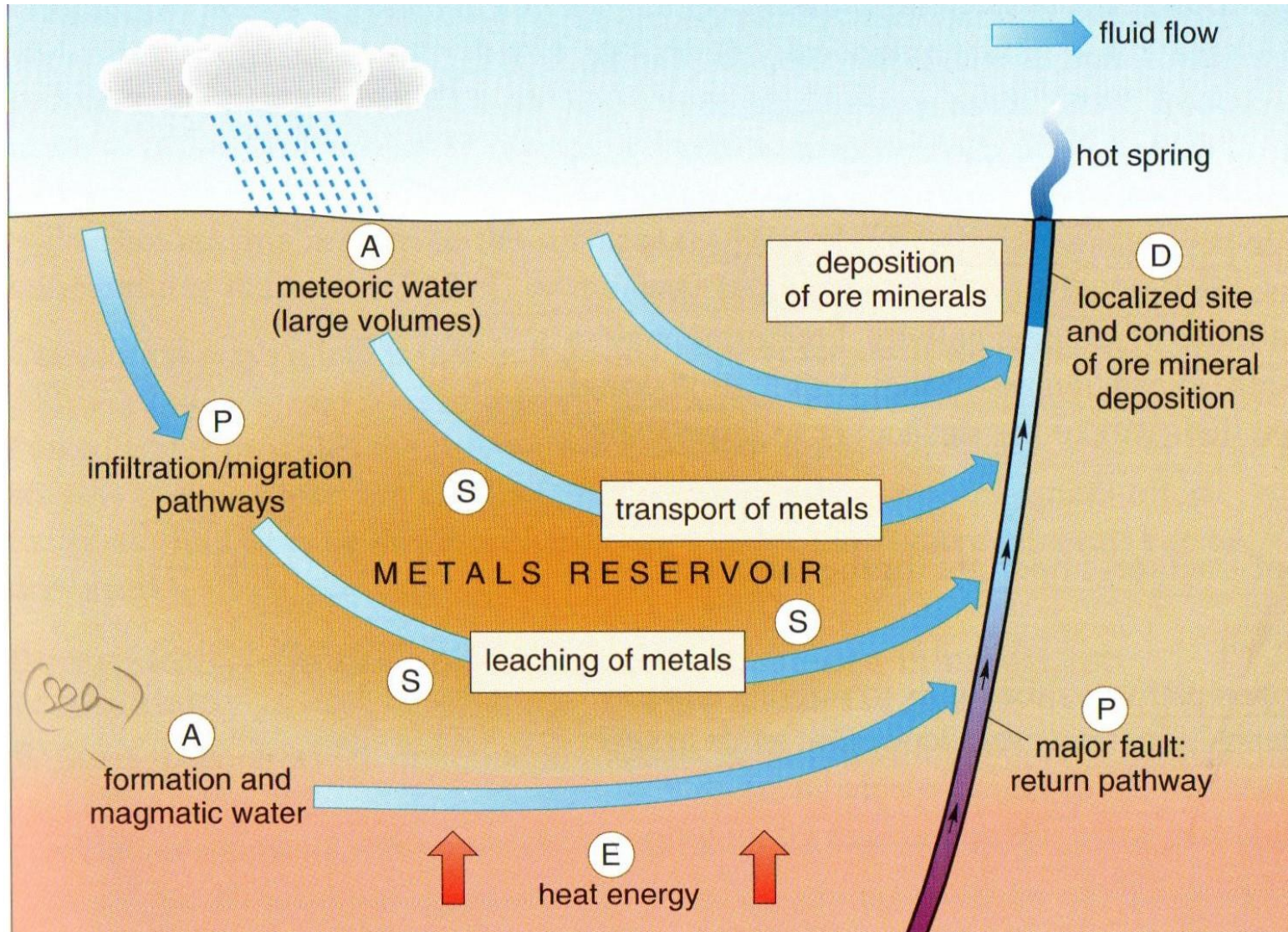
- The most diverse of all ore deposits.
- Ores deposited by hot watery fluids in voids and fissures in the Earth's crust.
- Ores confined and well suited to small scale extraction.
- Hydrothermal fluids may originate from rainfall, the sea, or from magmatic water.
- The more dissolved salts they contain, the more corrosive these fluids are and effective in shifting metals.

HP Mineralisation



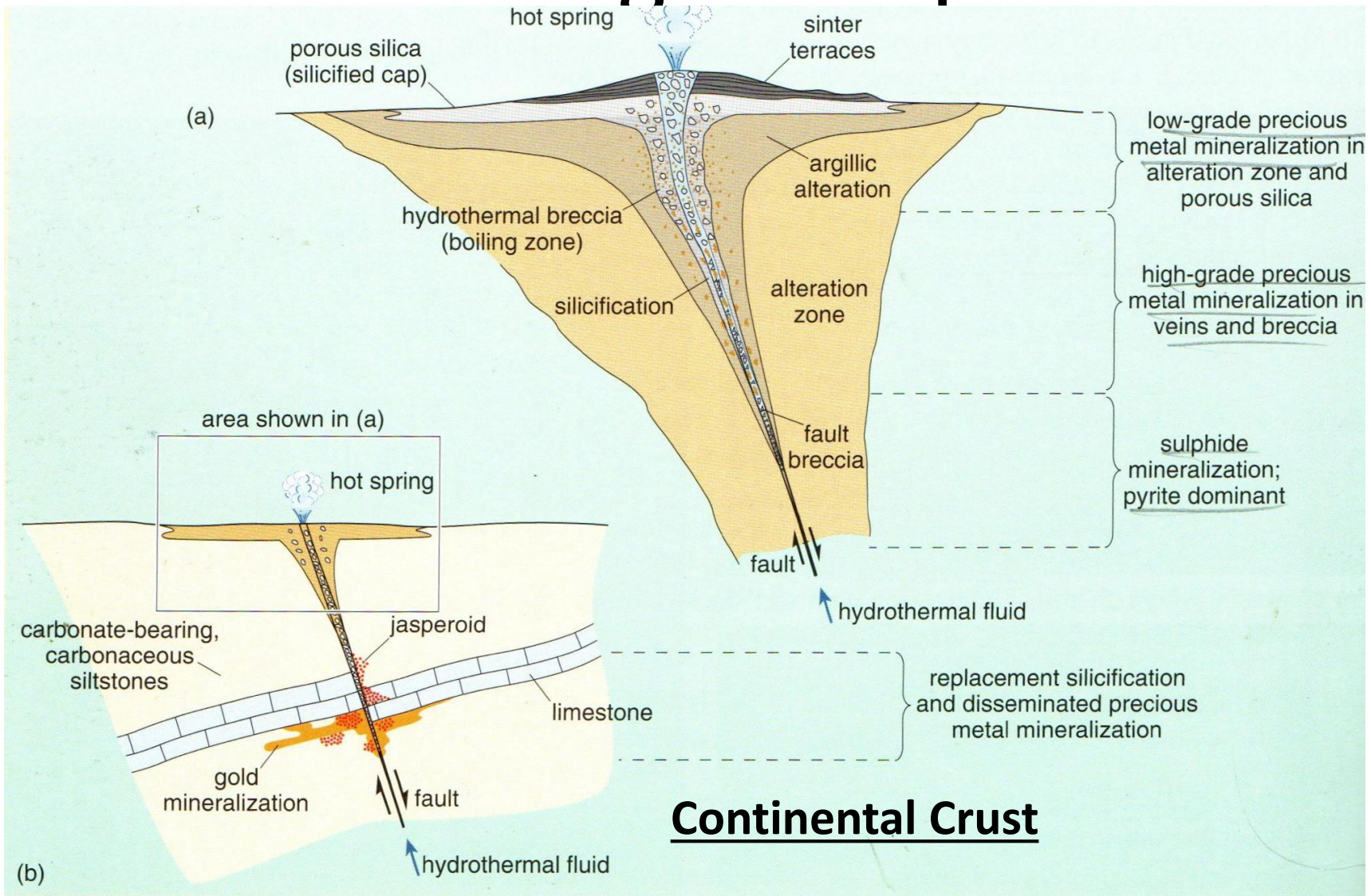
Tends to close fractures and voids, so repeated activation increases formation of deposits in veins and fractured strata (stockwork). In limestone, solution cavities can form deposition sites.

HP Anatomy of the system



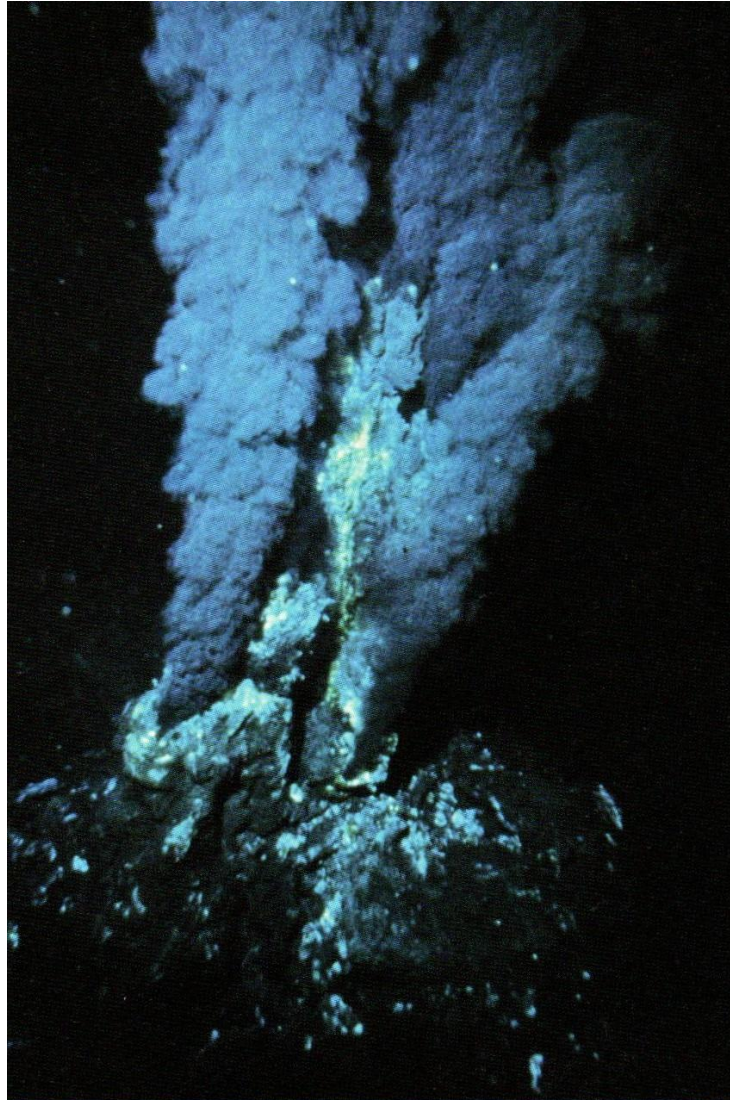
HP Terrestrial Exhalative system

Nevada gold deposits

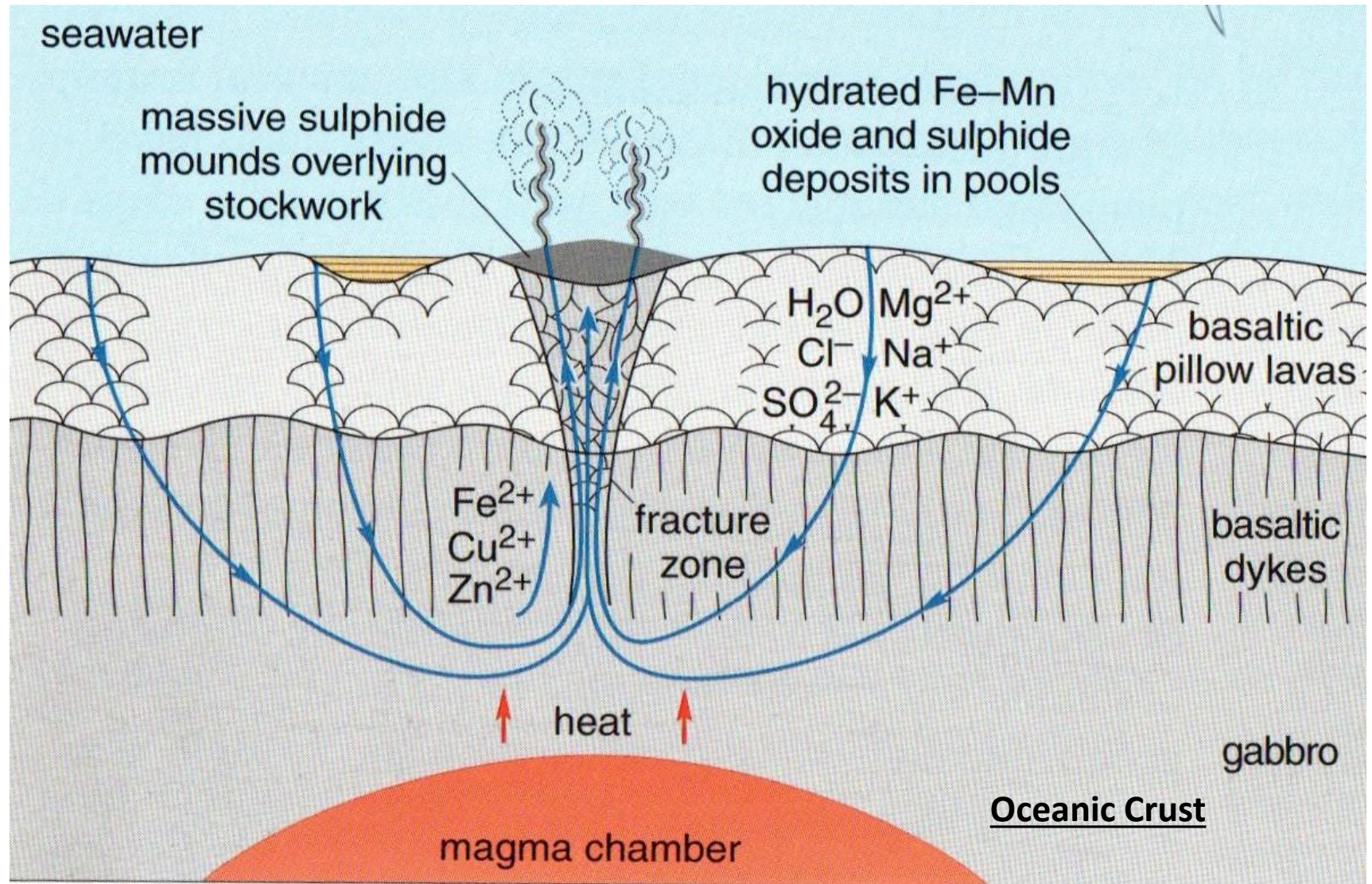


HP Submarine Exhalative deposits

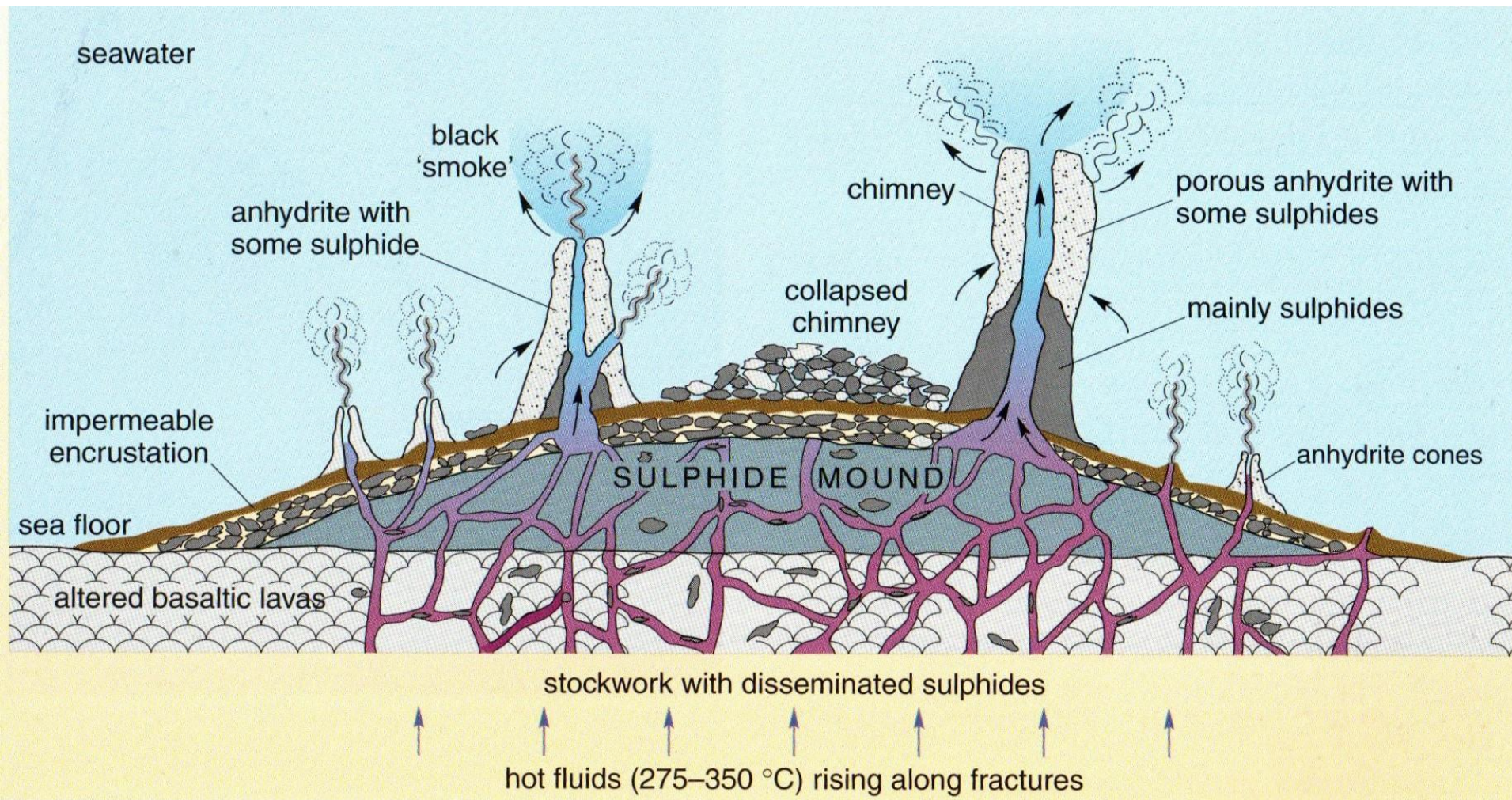
Black Smokers



HP Mechanism of a Black Smoker



HP Development of Smoker Chimneys

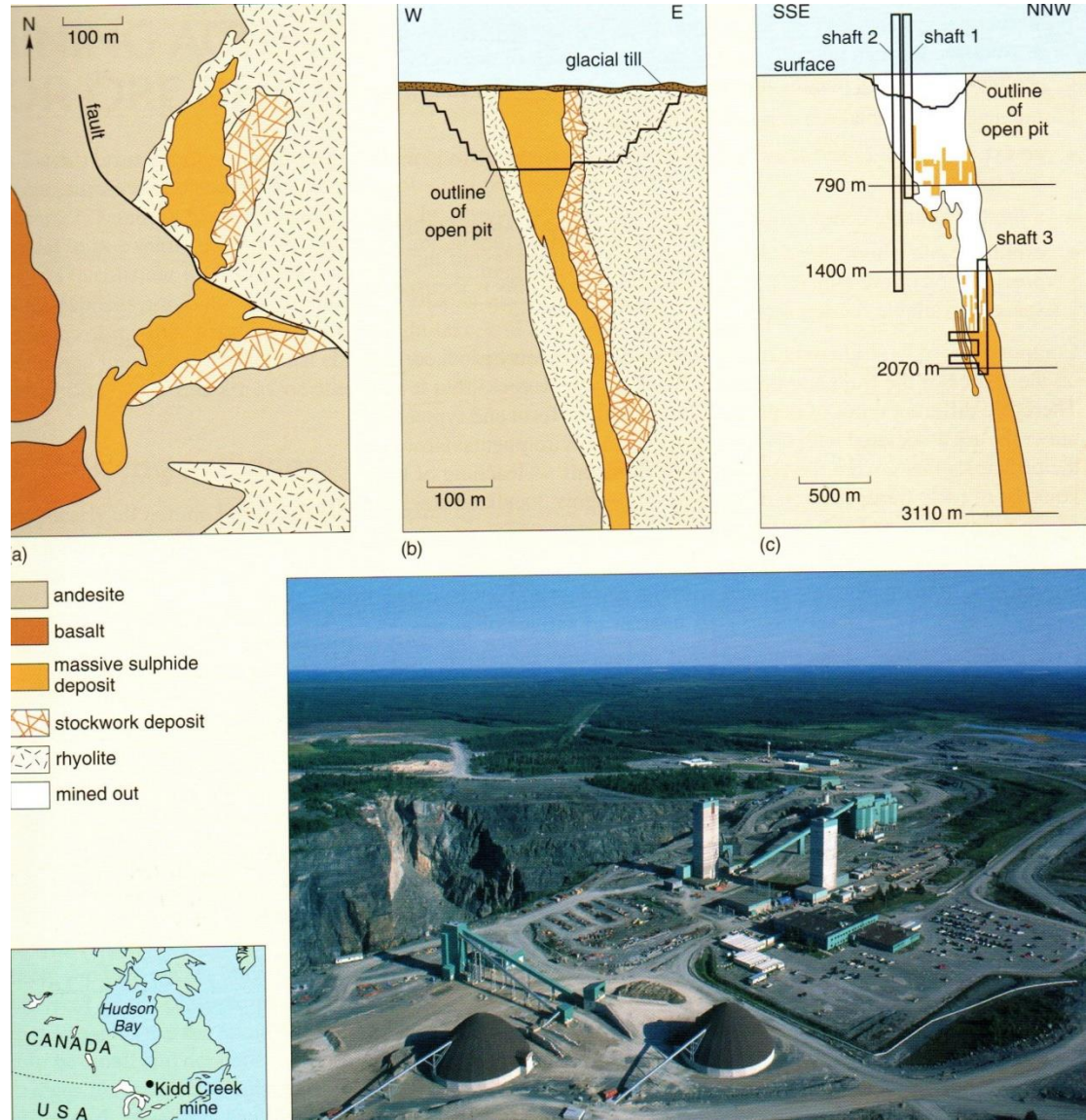


HP Kidd Creek Ontario

A recently discovered 2700Ma old massive sulphide deposit, first mined as a pit, but now by shaft methods.

Over three times as much Cu as all the mines in Cyprus.

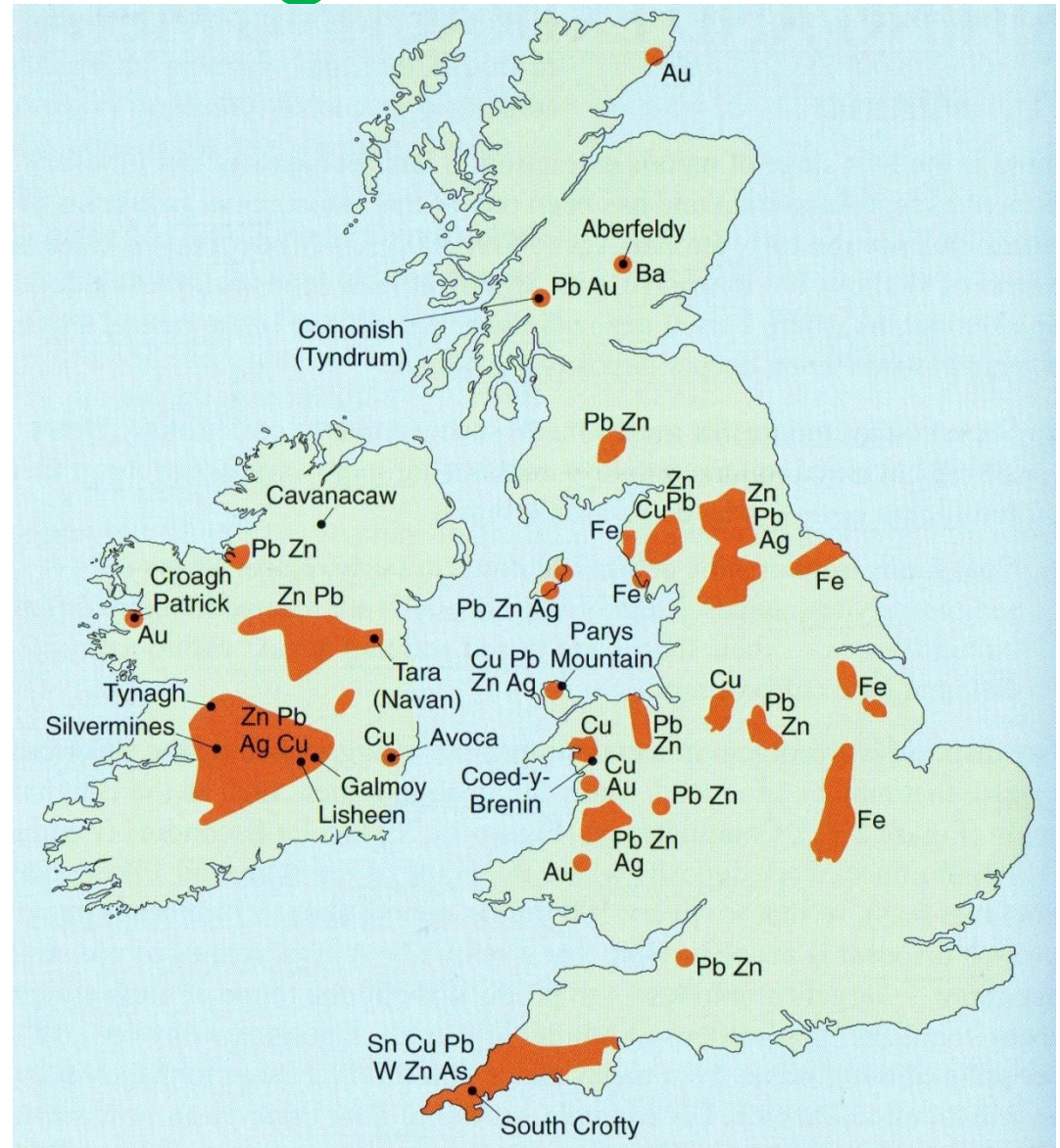
Also rich in Zn, Pb and Ag.



HP Metal Mining in Britain

Apart from the iron deposits, these are all of hydrothermal origin.

Those named are of recent interest.



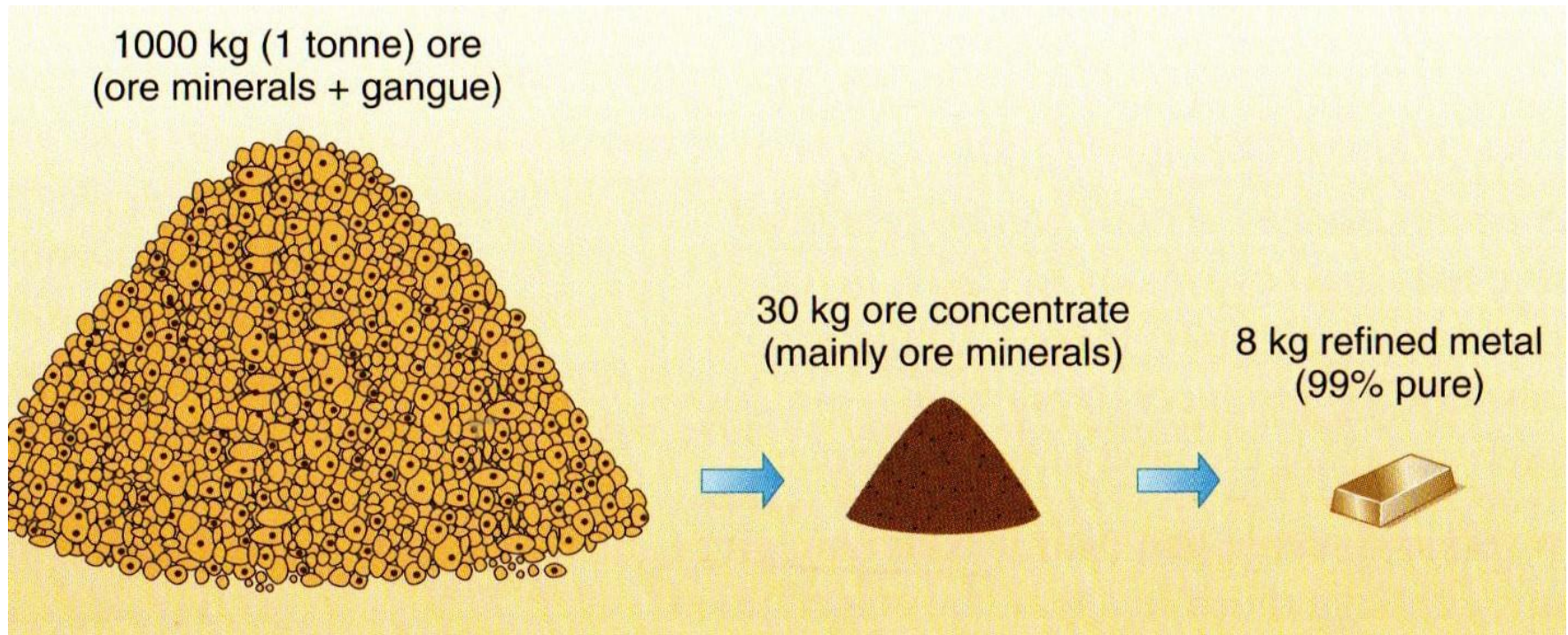
HP A Sample from Parys Mountain



Figure 4.14 Pyrite mineralization in dark, metalliferous sediment — from the sulphide deposit at Parys Mountain, Anglesey. Field of view 18 cm across.

Treatment of Ores – Mineral Dressing

- Geological processes have helped us produce the 1te of ore above the minimum exploitable grade: mineral dressing will produce the 30kg of concentrate.

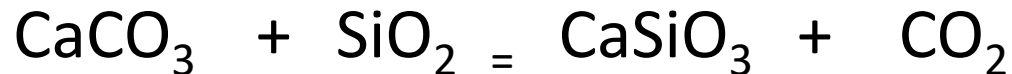


Mineral Dressing

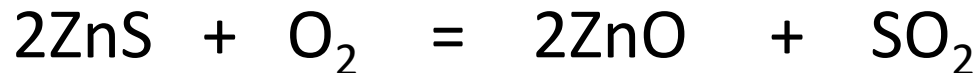
- Four general types of unit operation:
 - 1 Comminution (particle size reduction)
 - 2 Separation by screening
 - 3 Concentration using physical or surface chemical properties, e.g gravity, electrostatic separation, magnetic separation, automated sorting using optical sensors at all wavelengths, froth flotation, leaching
 - 4 Dewatering

Metal Extraction

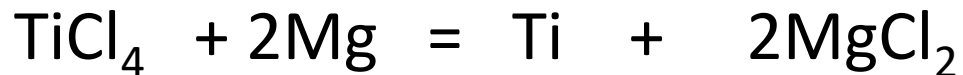
- Smelting traditionally involves roasting oxide ores with carbon to reduce them, with a flux (limestone) to form a liquid slag from residual silicates:



- Sulphide ores would be roasted in air first:



Other metals are extracted by electrolysis of fused salts (Al, Na, Mg) or by reacting their salts with a more highly reactive metal:



Metal Extraction Summary

Iron	Redn of oxide by C,CO in blast furnace
Aluminium	Electrolysis of alumina dissolved in fused cryolite
Copper	Simple collection of native Cu or staged reductionn of sulphide ores with C
Zinc	Redn of oxide by C,CO in blast furnace, following roasting of sulphide
Manganese	Reductionn of oxide or carbonate ores with C
Lead	Reduction of oxide by C,CO in blast furnace, following roasting of sulphide
Nickel	Usually by electrolysis, purified via carbonyl Ni(CO)_4
Magnesium	Redn of oxide by Si in the form of a ferrosilicon alloy
Tin	Redn of oxide by C in various types of furnace
Titanium	Redn of TiCl_4 by Mg
Tungsten	Redn of WO_3 by C or H_2
Silver	Solvent extraction from argentiferous lead with molten zinc
Gold	Simple collection of native Au, or amalgamation with Hg, or cyanide leaching
Mercury	Simple roasting of sulphide

The End

A bit of history

	advances and discoveries	date	items produced
		2000	platinum in catalytic converters lithium batteries gold in electronic components lead tetraethyl in petrol
	bacterial leaching for extraction of metals titanium metal manufactured stainless steel and duralumin developed froth flotation for separating ore minerals	1900	tungsten in light bulbs molybdenum steel for armour plating copper electricals
	electrolytic extraction of aluminium cyanide extraction of gold steel production by Bessemer process galvanizing of steel	1800	tin cans
	magnesium produced by electrolysis		
	concentration of ores by mechanized dressing		
	steam engines used for drainage, haulage and mechanical ore processing	1700	gold standard introduced brass clocks and instruments
	tunnelling with explosives	1600	
	<i>De Re Metallica</i> – accounts of mining, ore processing and metal refining	1500	bronze cannon
	copper precipitated from solution onto iron scrap by Moors in Spain	1400	copper engraving plates cast-iron cannon balls
	zinc smelted in India	1200	
	extraction of gold by amalgamation with mercury	1000	
		AD	lead plumbing, containers and liners bronze weapons, armour, knives and musical instruments
Iron Age	iron tools for mining, waterwheels for mine drainage, Rio Tinto, Spain Chinese produce cast iron ventilated underground galleries, Timna	1000	iron weapons gold leaf used in Egypt lead currency – animal heads, Assyria
	smelting of iron by Hittites		
Bronze Age	mining with metal tools	2000	bronze tools and weapons
	tin mining, Taurus Mountains, Anatolia	3000	worked (meteoritic) iron objects in tombs
Copper Age	mining underground firesetting to break rock	4000	copper tools, weapons, jewellery
	mining with stone tools		
	smelting of copper, Balkans	5000	lead bracelet, Yarim Tepe
	lead smelting, Mesopotamia		
	gold sheet and castings in burials, Bulgaria	6000	copper awl, N. Mesopotamia
		7000	
	copper working, N. Iraq	8000	copper beads, N. Iraq