

EARTH 471

Mineral Deposits

Sedimentary ore deposits

Ore deposits form in sedimentary environments through two geological mechanisms:

1) Chemical Precipitation

Ores are derived from chemical precipitation of minerals out of solution (sea or lake waters)

2) Physical accumulation

Minerals trapped during the processes of sediment entrainment, transport and deposition

Chemical Precipitation

Chemical precipitation – general concept

Chemical sediments form in marine or marginal marine environments

Chemical processes by which ore concentrates are complex and controlled by:

- Redox (oxidizing v. reducing conditions)
- pH
- Climate
- Paleolatitude
- Biological activity
- Atmospheric evolution

Chemical precipitation deposits

1) Iron deposits

- Bog iron ores: lakes and swamps in tundra regions of the northern hemisphere
- Ironstone: Phanerozoic, widespread, important in the eastern USA
- **Banded iron formations** (BIFs): most important source of iron ore worldwide

2) Manganese deposits

- Bedded Mn deposits: similar to BIFs
- Mn nodules: occur on the sea floor, polymetallic

3) Phosphorites

4) Evaporites

5) Black shales

Banded Iron formations (BIFs) – fun facts

- Bedded, iron-rich (>15% Fe) chemically precipitated sedimentary rocks
- Layered (> ~3 cm), banded (0.5–3 cm), and/or laminated (<1 mm)
- Restricted to particular times (3.5–3.0 Ga, 2.5–2.0 Ga, and 1.0–0.5 Ga)
- Range in thickness from a few metres to 100s of meters
- Vary from 100s of metres to 100s of kilometres in length
- Associated with chert (microcrystalline quartz)
- Provide 50% of iron ore worldwide
- Also known as: ‘banded jaspilites’, ‘itabirites’, ‘banded hematite quartzite’, ‘taconite’ and ‘ironstone’

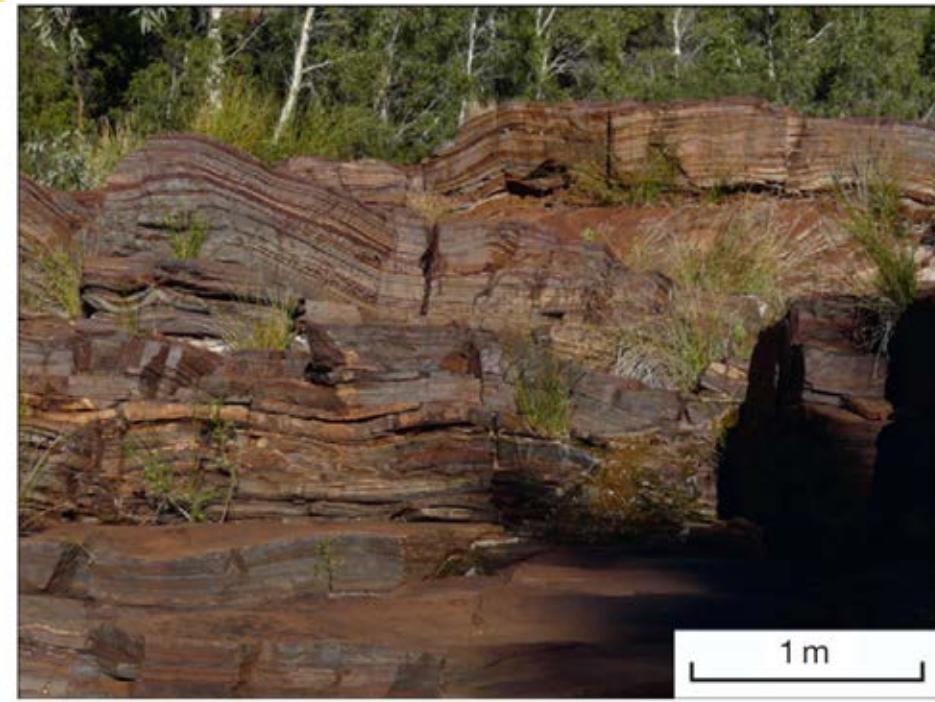


Figure 5 West Australian banded iron-formation from the Fortescue Falls.

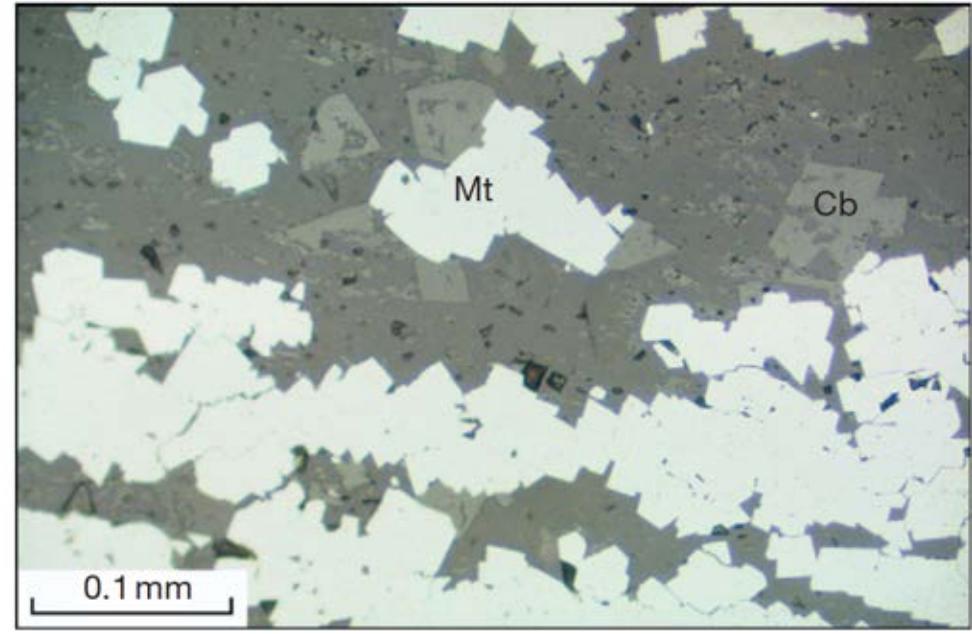


Figure 10 Microphotograph of BIF with raftS of magnetite (Mt), with chert (or microquartz) and carbonate (Cb) (reflected light).

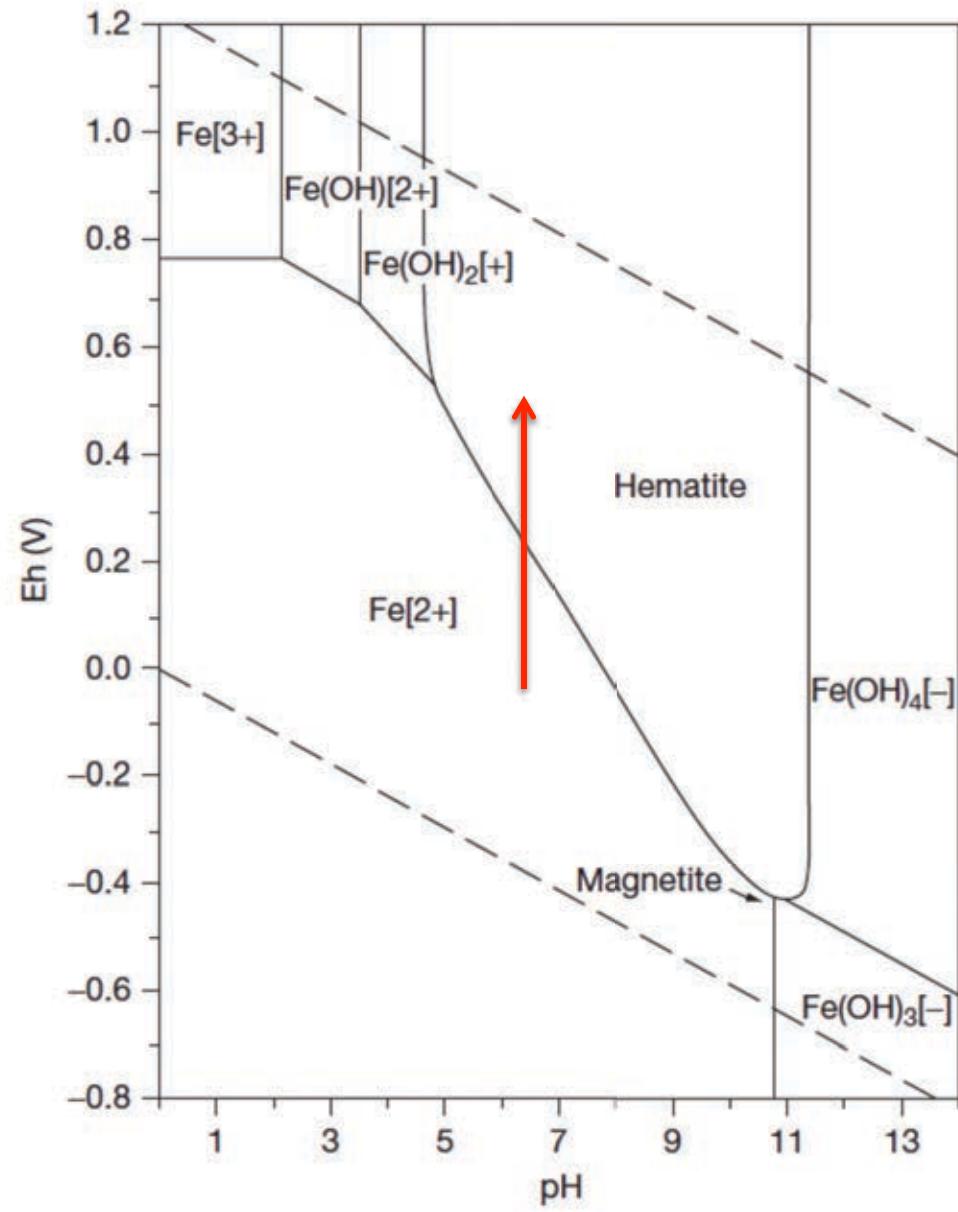
Ramanaidou & Wells (2014)

Iron geochemistry:

Four valence states, but
Fe²⁺ (reduced, ferrous) and
Fe³⁺ (ferric, oxidized) are
most common

Under reducing conditions,
Fe²⁺ is soluble in water

Under oxidizing conditions,
Fe³⁺ and ferric oxides (e.g.
hematite) are insoluble



Ramanaidou & Wells (2014)

**Table 3** Mineralogy of iron-formation and iron ore

Name	Formulae	Origin
Magnetite	FeO Fe ₂ O ₃	Named in 1845, magnetite is derived from the name of a Greek shepherd, Magnes, on Mt Ida after noting that iron nails in his shoe and the iron ferrule of his staff were attracted to a rock (Gaines et al., 1997)
Maghemite	γ -Fe ₂ O ₃	Named in 1927 from the first syllables of MAGnetite and HEMatite, in reference to the magnetism of the former and the composition of the latter (Gaines et al., 1997)
Kenomagnetite	Fe ²⁺ _{1-y} (Fe ²⁺ Fe ³⁺ _{1+2y/3}) _{y/3} O ₄	Intermediate phase that forms during the topotactic oxidation of magnetite to maghemite, with the term kenomagnetite applied to transitional phases of the magnetite-maghemite series (Greenwood and Gibb, 1971; Kullerud et al., 1969)
Hematite	α -Fe ₂ O ₃	Named in antiquity from the Greek, 'haimatitis,' in reference to the 'blood-like color' of the powder <i>Martite</i> : Term used to describe hematite pseudomorphs after magnetite <i>Platy and microplaty hematite</i> : Terms introduced by Morris (1980, 1985) to describe fine platy hematite crystals around 50–100 μ m in size found in iron ore
Goethite	α -FeOOH	Named in 1806 after German poet, philosopher and naturalist Johann Wolfgang von Goethe (1749–1832) (Gaines et al., 1997). In the past, the term 'limonite' has been synonymous with goethite (Nickel and Nichols, 1991) Many types of goethites are found in iron ore; they include: (1) the goethite pseudomorphs after gangue minerals such as chert, carbonate, and silicates (Morris, 1980, 1985); (2) ochreous goethite or 'limonite' – soft to medium hard, with micropores, yellow in color with a chalky appearance, and; (3) vitreous goethite – black to dark brown in color, hard, and glassy with a conchoidal fracture
Pyrite	FeS	Known since antiquity, the name is derived from the Greek, 'pyr,' for fire as sparks can be produced when crystals are struck (Gaines et al., 1997)
Siderite	FeCO ₃	Name derived from the Greek word sideros, 'iron.' It is a valuable iron mineral, since it is 48% iron and contains no sulfur or phosphorus. Both magnesium and manganese commonly substitute for the iron
Chamosite	(Fe ²⁺ ,Mg) ₅ Al(AlSi ₃ O ₁₀)(OH)	Named after the municipality of Chamoson, in Switzerland. Chamosite is the Fe ²⁺ end member of the chlorite group. A hydrous aluminium silicate of iron, which is produced in an environment of low to moderate grade of metamorphosed iron deposits, as gray or black crystals in Oodial iron stones
Berthierine	(Fe ²⁺ ,Fe ³⁺ ,Al,Mg,Mn) ₂ (Si,Al) ₂ O ₅ (OH) ₄	Berthierine is used as the term to describe Fe-rich 1:1 trioctahedral (serpentine group) silicates of general formula with a 0.7 nm basal spacing (Taylor, 2005; Young, 1989)

Source: Ramanaidou ER, Wells M, Belton D, Verral M, and Ryan C (2008) Mineralogical and microchemical methods for the characterization of high-grade BIF derived iron ore. *Reviews in Economic Geology* 15: 129–156.

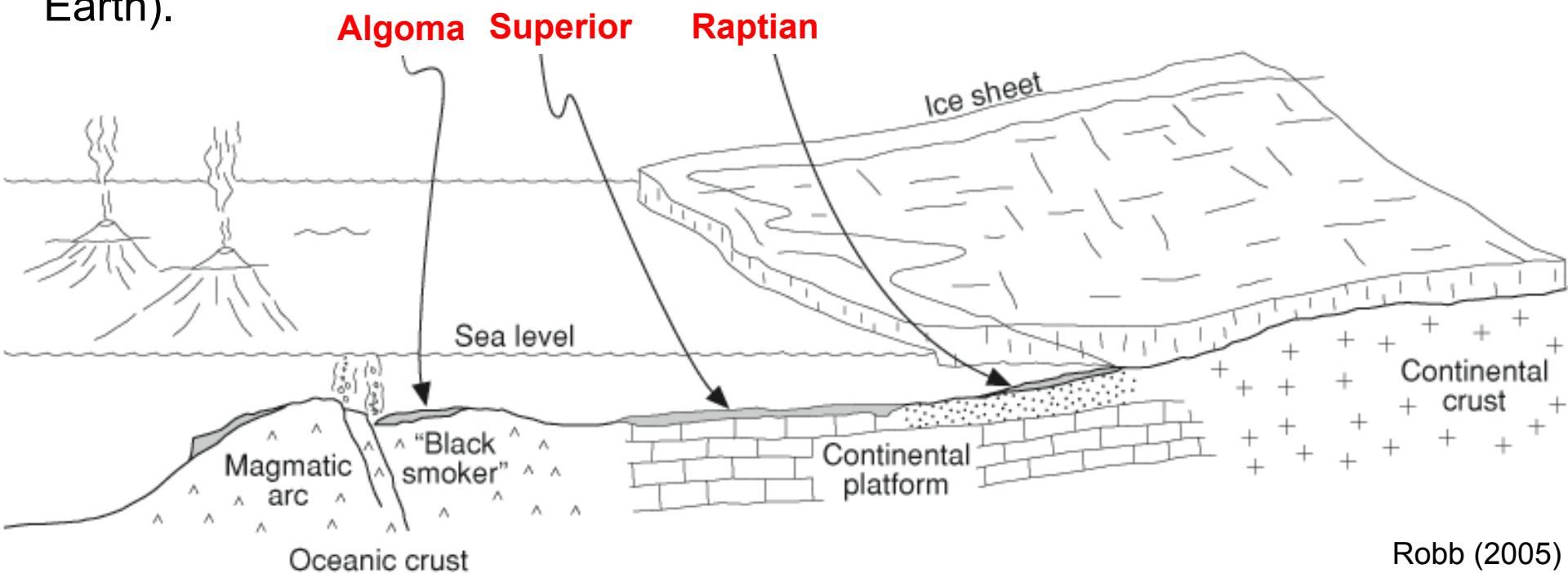
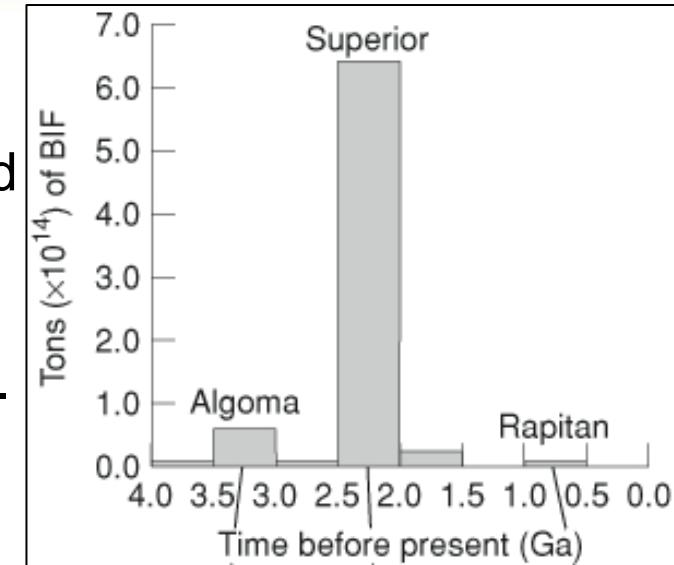
Ramanaidou & Wells (2014)

Three BIF types:

Lake Superior Type: sedimentary in origin. Formed on stable continental platforms.

Algoma type: associated with volcanic rocks and considered to be of hydrothermal hot spring origin. Commonly found in greenstone belts.

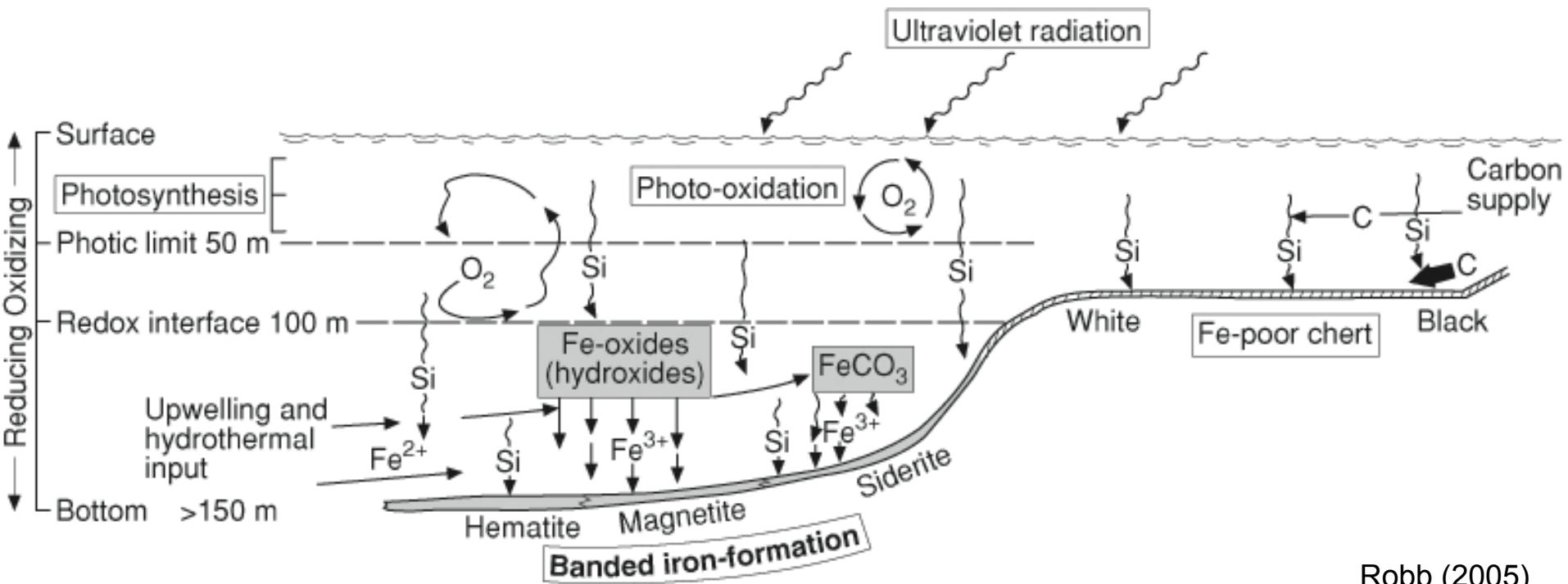
Rapitan type: Associated with glacial sediments formed during the Neoproterozoic (snowball Earth).



Superior BIF genesis:

Source of Fe: most likely ocean water (suggested by the lack of aluminous silicate minerals in BIFs)

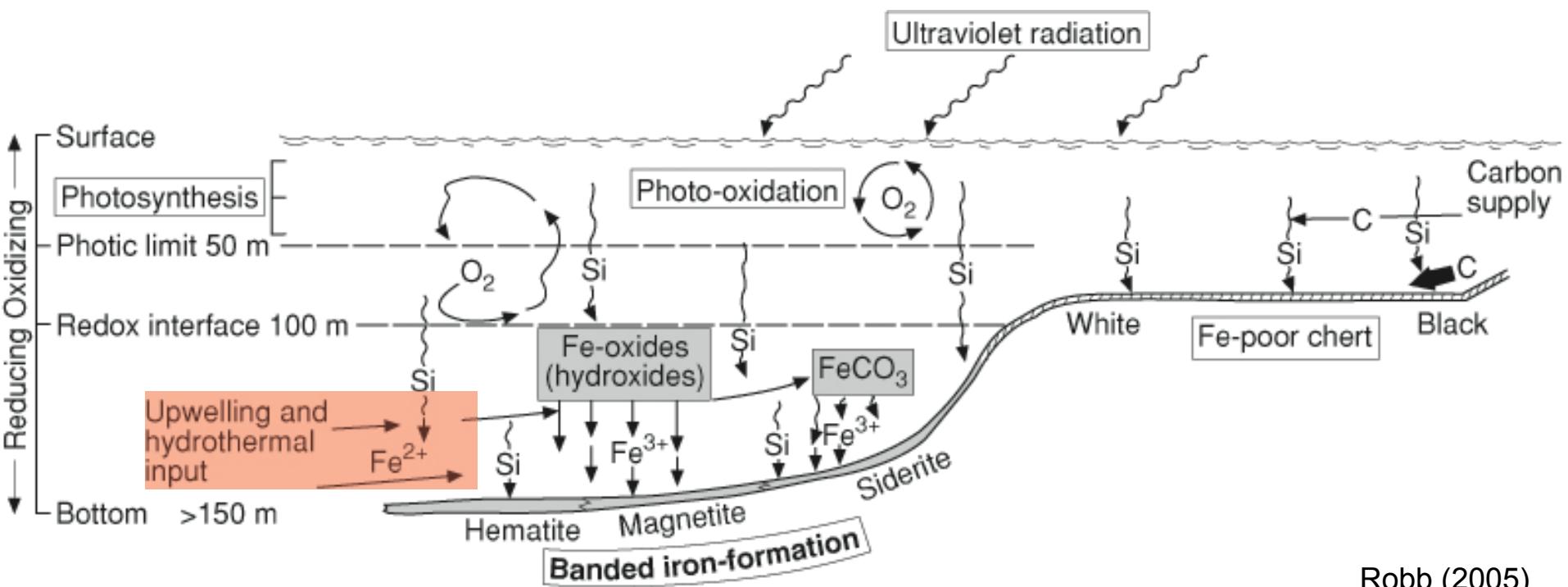
Genetic models are still controversial!!



Robb (2005)

Superior BIF genesis ?:

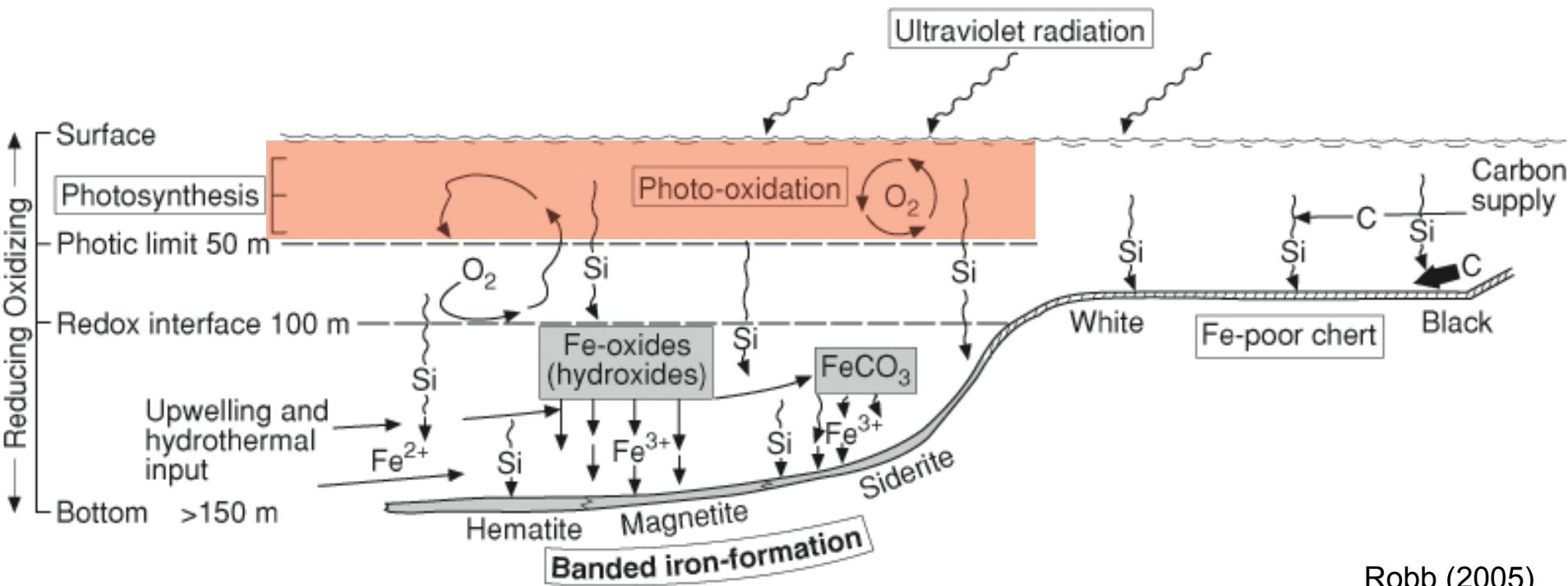
1) Fe^{2+} in reduced deep ocean water is introduced to a shallower shelf environment by upwelling currents



Robb (2005)

Superior BIF genesis ?:

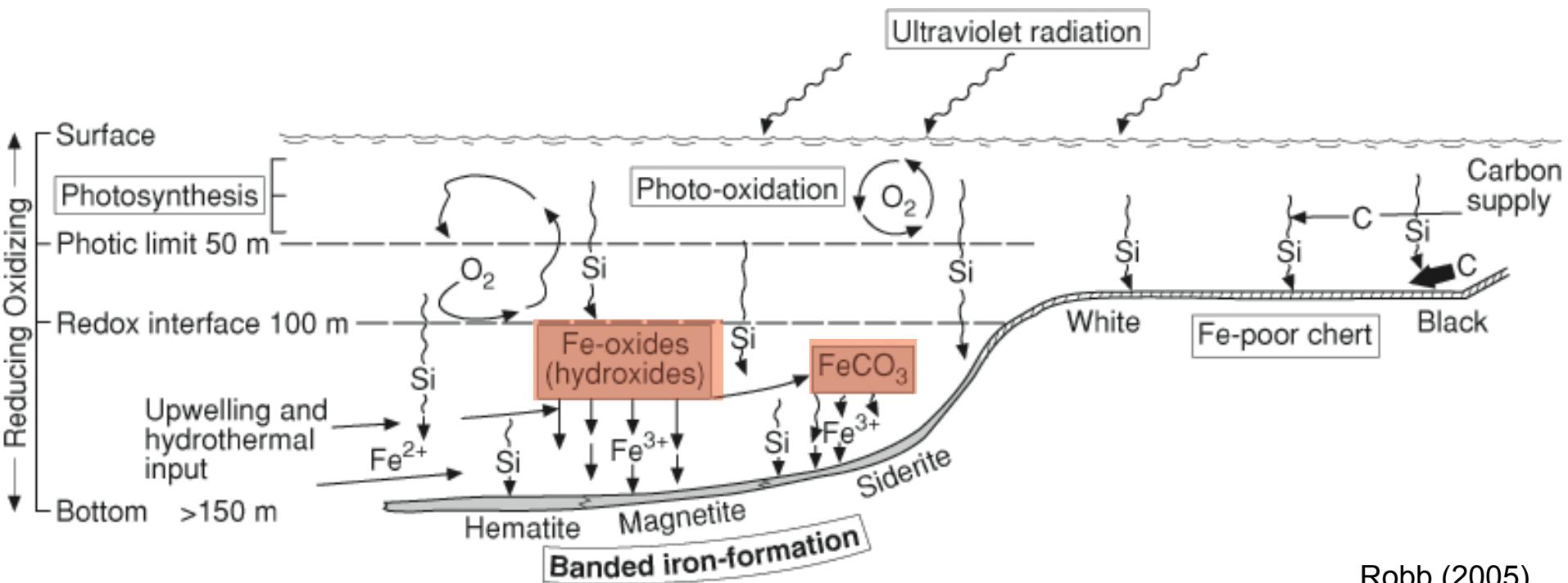
2) Oxidation of Fe ($\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$) takes place at shallow water levels where sunlight can penetrate to produce oxygen by: (1) photosynthesizing organisms produce O in the photic zone, and/or (2) photo-oxidation of iron by photons of ultraviolet to blue light, or (3) metabolic ferrous iron oxidation by “iron bacteria”



Robb (2005)

Superior BIF genesis ?:

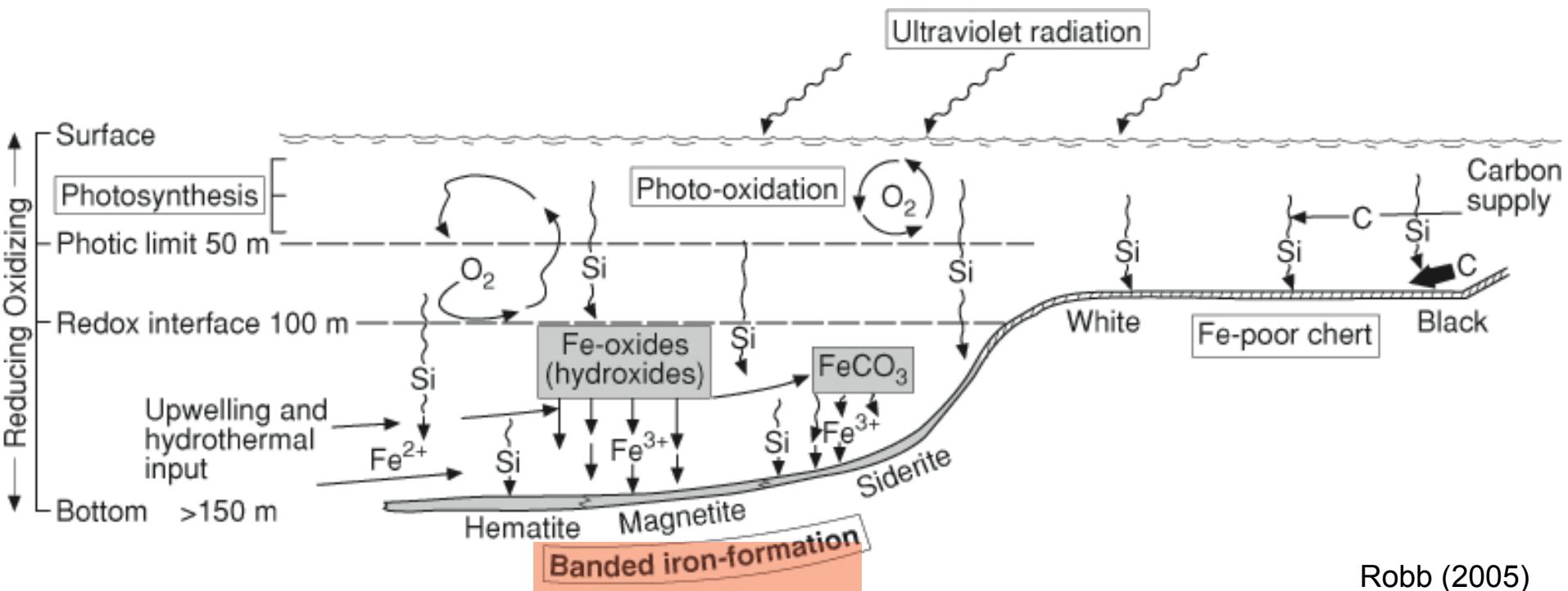
3) Fe^{3+} makes ferric hydroxide (Fe(OH)_3), which precipitates from the water column (or precipitates as FeCO_3 if there is abundant carbonate)



Robb (2005)

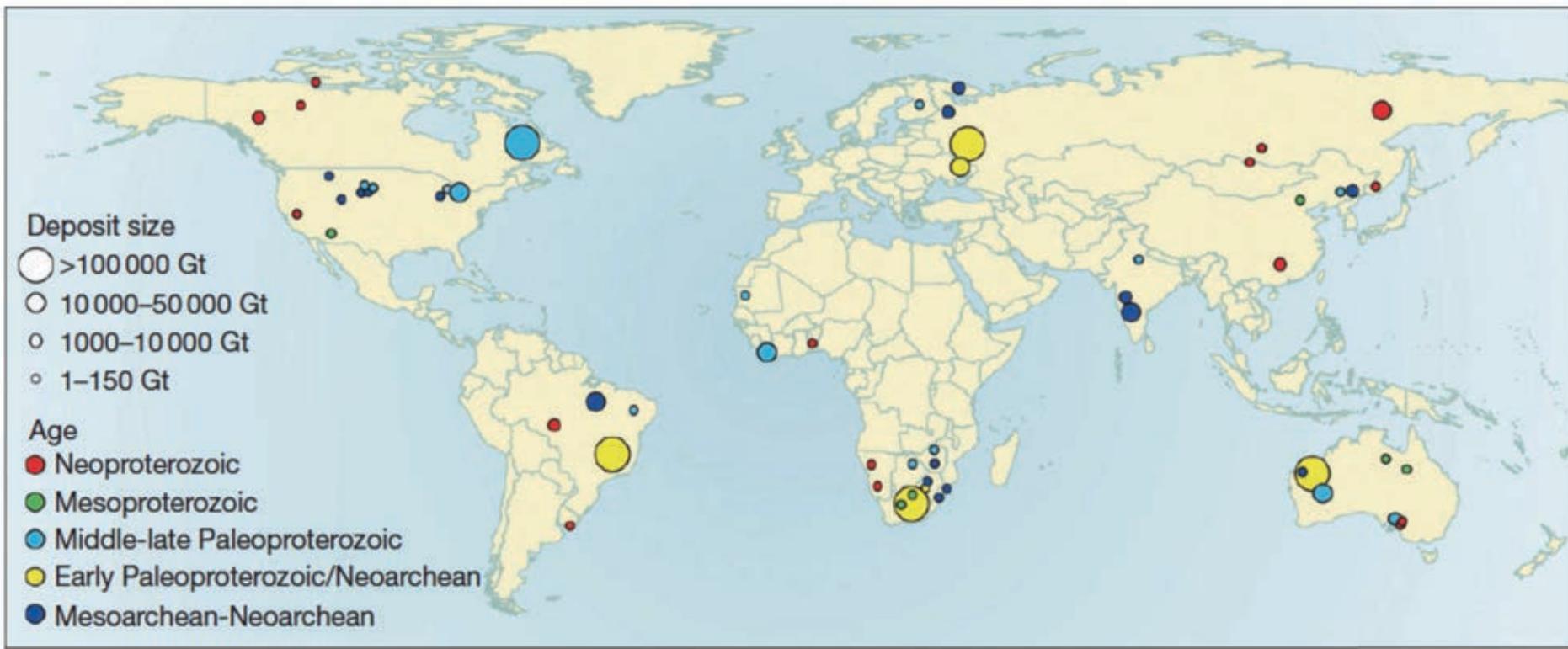
Superior BIF genesis ?:

4) Diagenesis and recrystallization during low-grade metamorphism causes new mineral growth (e.g. magnetite, hematite)



Robb (2005)

BIF deposits worldwide



Ramanaidou & Wells (2014)

Iron ore in Canada

- Smelting and casting of Fe ore was Canada's first industry
- Samuel de Champlain reported iron ore in 1604
- Used for cast iron stoves, pots, kettles, bullets and canons
- Canada accounts for 71% of iron ore imports in the USA
- World-class deposits in the Labrador Trough (mined since 1954)
- Most mines are open pit

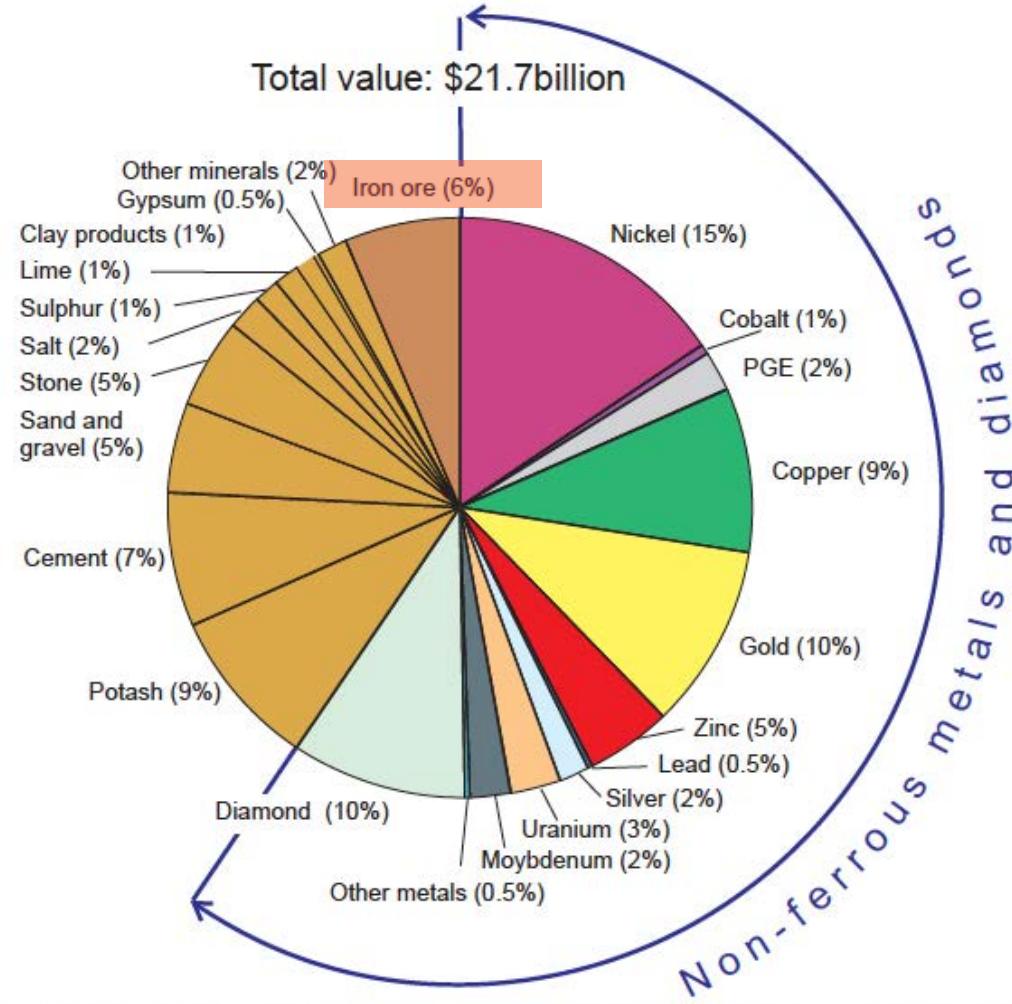


FIGURE 1. Canadian production of non-fuel mineral resources during 2004 by commodity. Only non-ferrous metals and diamonds are discussed in this article. Data from McMullen and Birchfield (2005).

Goodfellow (2007)

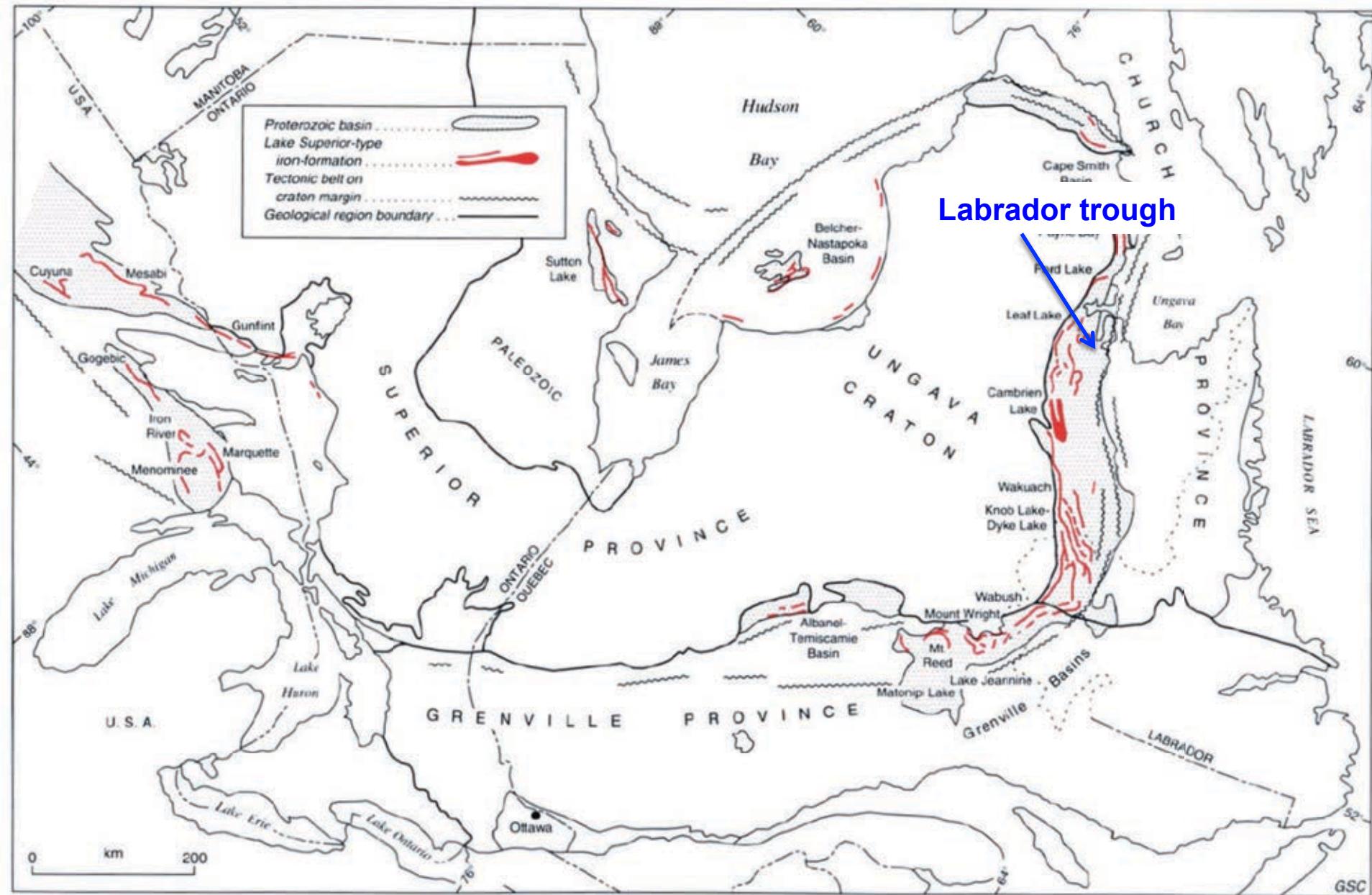


Figure 3-3. Distribution of Lake Superior-type iron-formation in sedimentary-tectonic basins marginal to the Paleozoic Province.

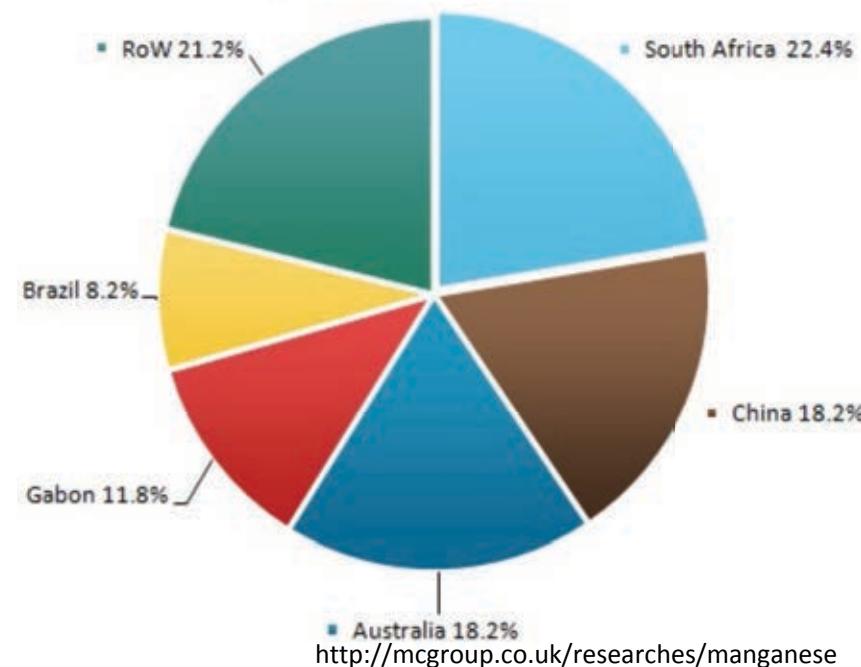
Gross (1996)

Manganese

- Stone age: MnO_2 used as a pigment
- Spartans used MnO_2 in iron ore to make steel that was stronger than their opponents
- Recognized as an element by Scheele in 1771
- Isolated by Swedish chemist Johan Gahn in 1774
- >90% used in steel manufacturing: increases hardness without reducing malleability

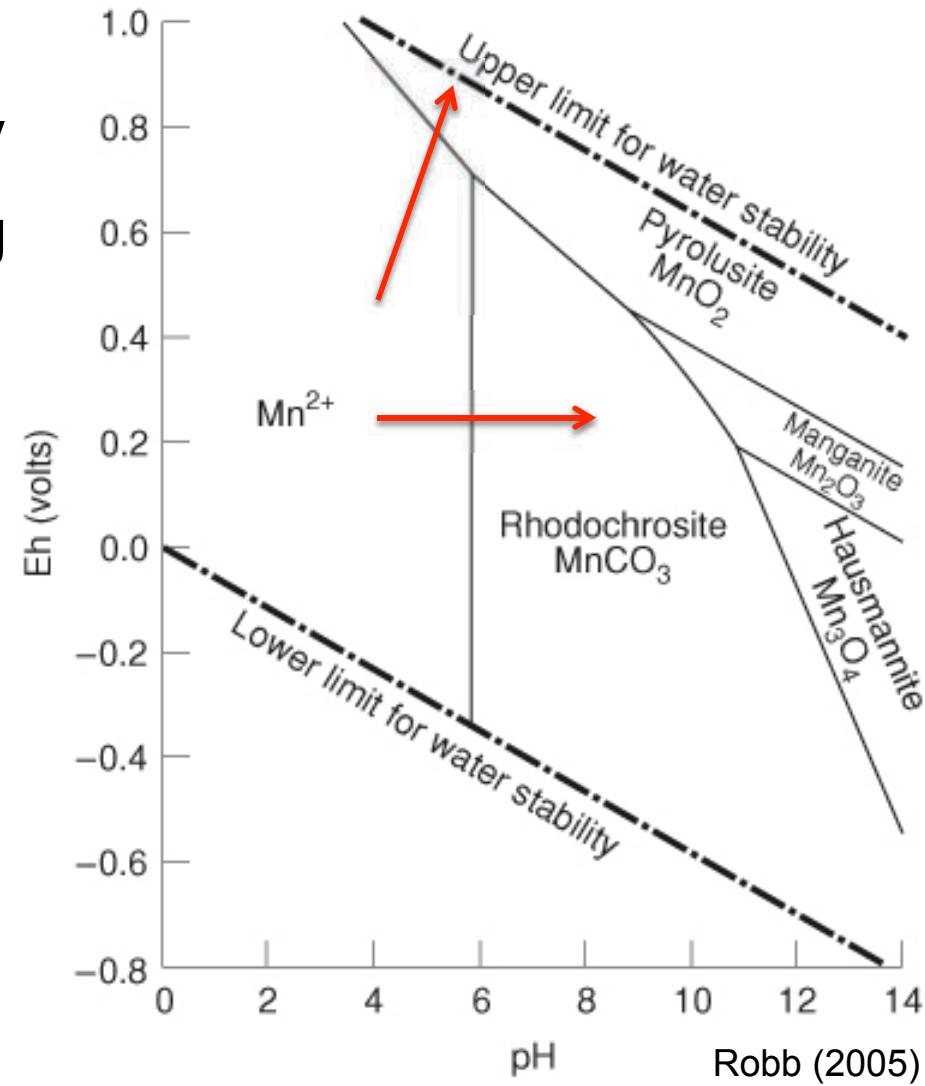


Global Manganese Mine Production in 2013



Manganese geochemistry

- Mn^{2+} (soluble under reducing and acidic conditions)
- Mn^{3+} and Mn^{4+} less soluble and stabilize as Mn-oxides under oxidizing and alkaline conditions
- Pyrolusite (MnO_2) and rhodochrosite (MnCO_3) are the dominant ore minerals



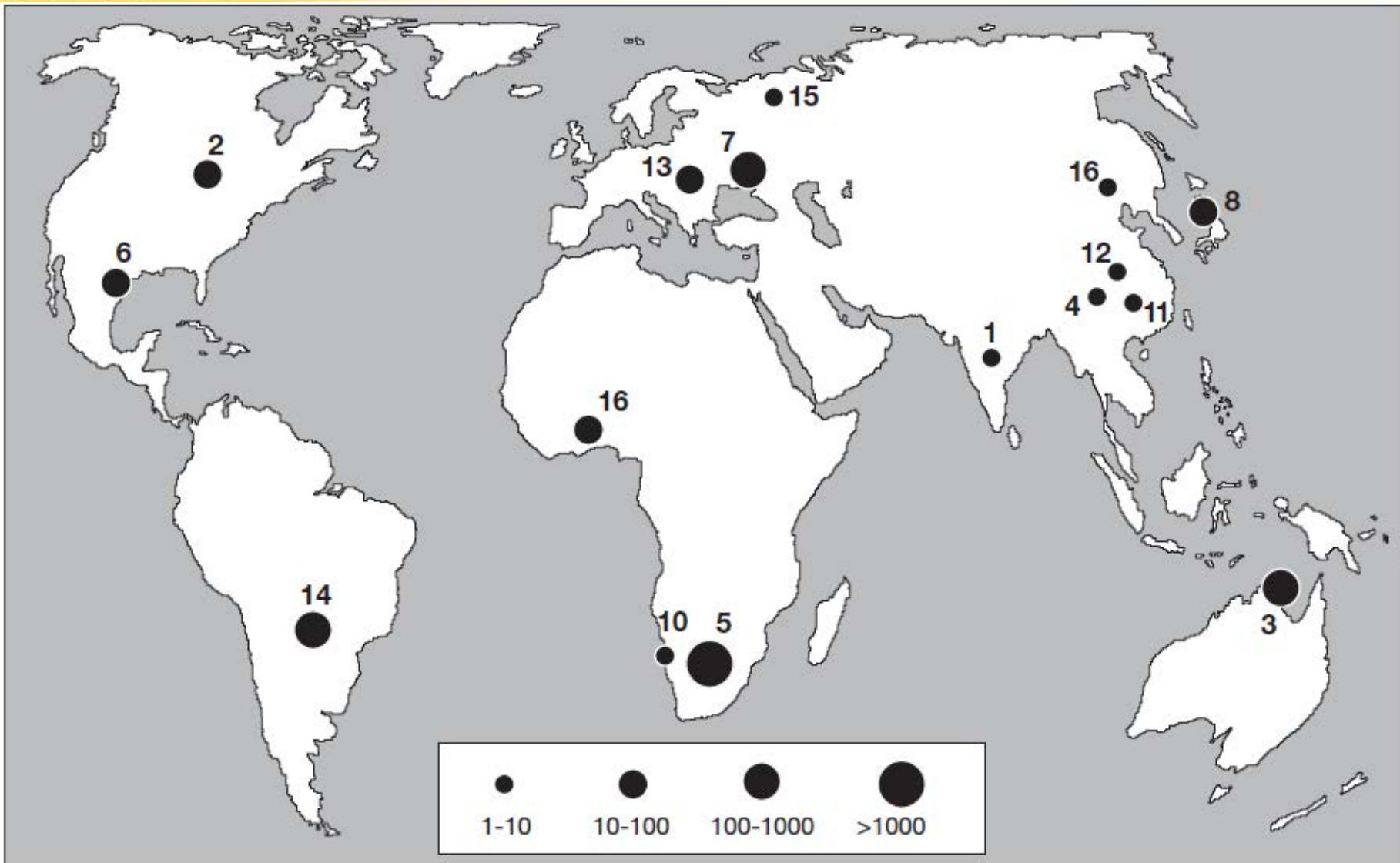
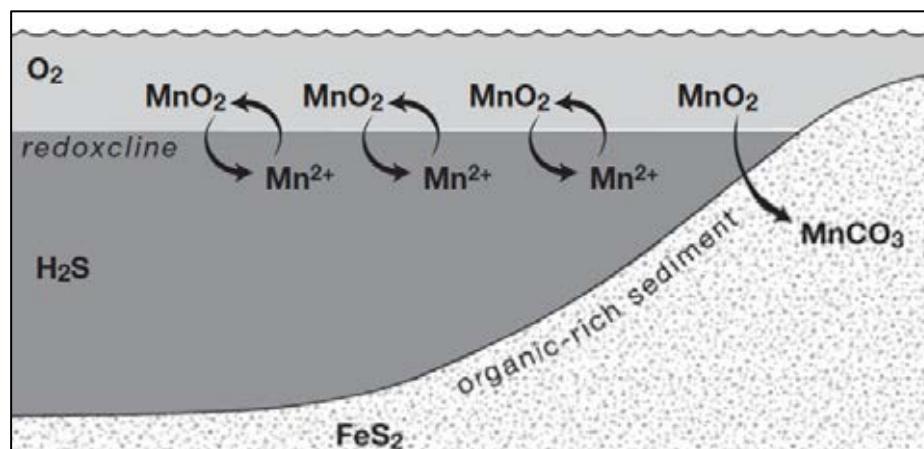


FIG. 1. Deposits mentioned in text: (1) Adilabad, (2) Cuyuna IF, (3) Groote Eylandt, (4) Jiaodingshan, (5) Kalahari, (6) Molango, (7) Nikopol', (8) Noda-Tamagawa, (9) Nsuta, (10) Otjosondu, (11) Taojiang, Tanganshan, (12) Tiantaishan, (13) Urkút, (14) Urucum, (15) Usa, (16) Wafangzi. Size of the circle is proportional to reserves of Mn metal in millions of metric tonnes.

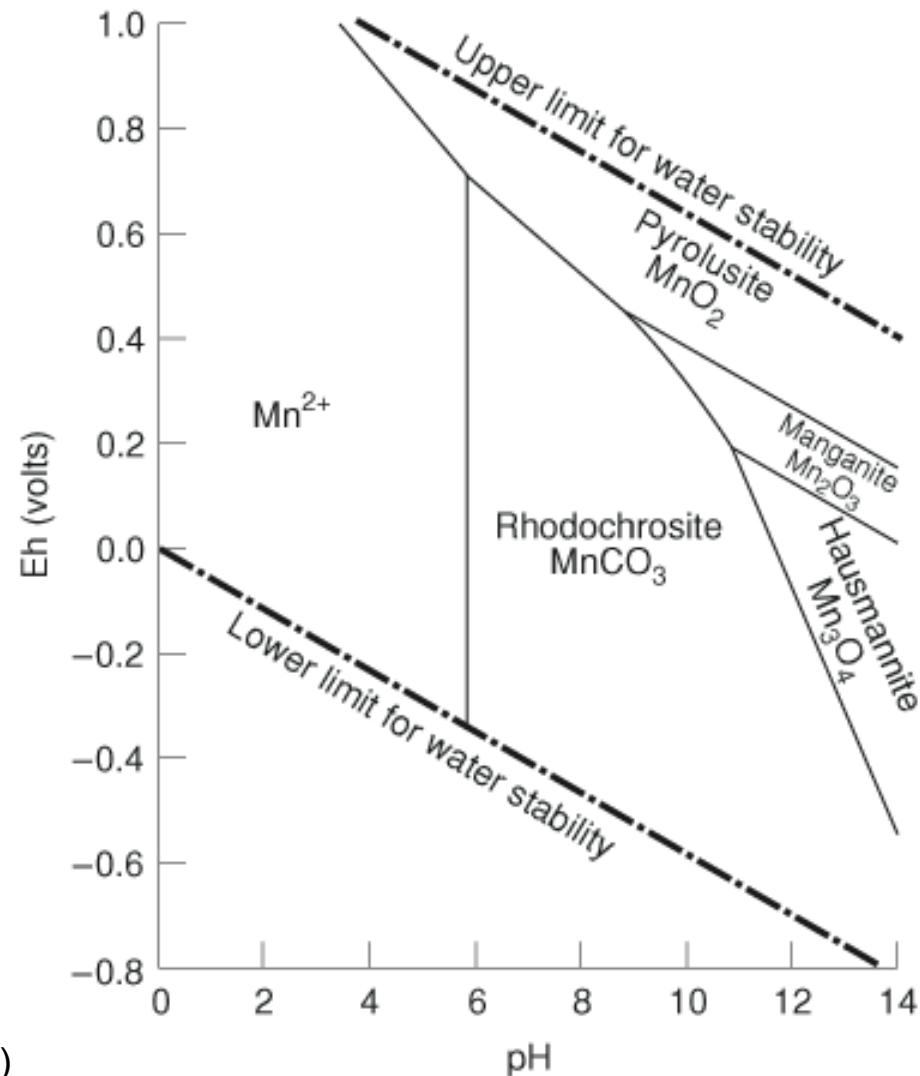
Maynard (2010)

Euxinic basin model

- Reducing conditions to the bottom of the basin
- Mn-oxide forming reaction occurs at the 'redoxcline'

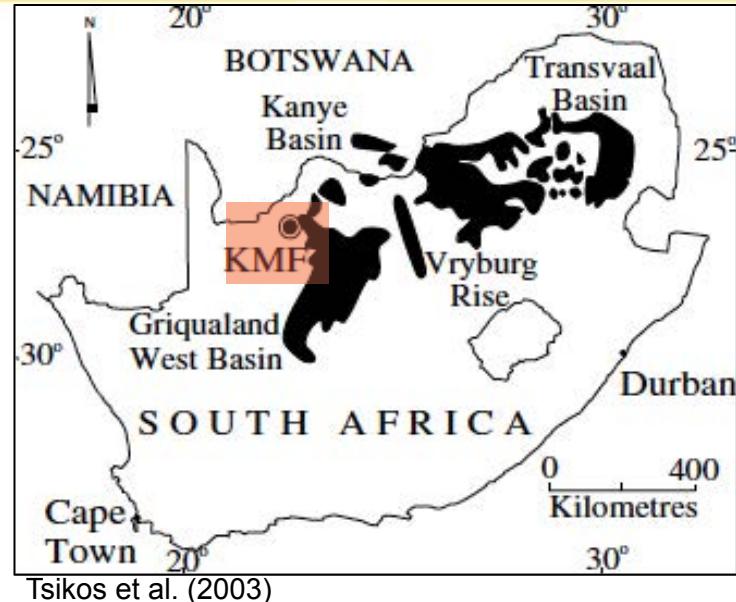


Maynard (2010)



Kalahari Mn fields

- South Africa
- Described in 1907
- Mining started in 1940
- Contain 50% of the world's Mn resources
- Stratiform Mn deposits interlayered with Superior type BIFs
- 8 Gt at 20–48% Mn
- 15–45m thick layers are currently being mined
- Many weird Mn-bearing minerals (braunite, hausmannite, todorokite...)



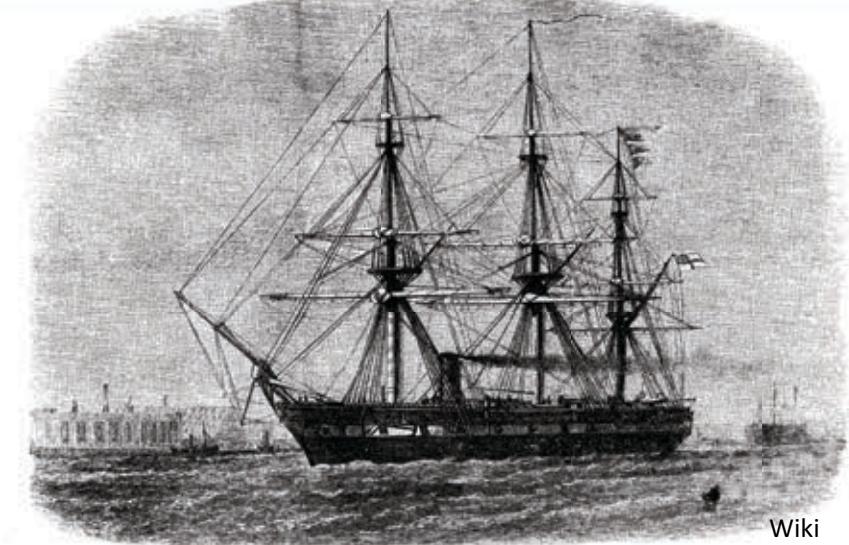
http://umk.co.za/gallery_umk_the_mine.html

Manganese nodules on the seafloor

- Discovered during the HMS Challenger 1872–6 expedition
- Vast resource of Mn, Fe, Cu and Ni
- Occur in areas where accumulation rates are low, little sedimentation and high biological productivity
- Some Pacific Ocean nodules have up to 2 wt% Ni + Cu

Lots of proposed genetic mechanisms:

1. Precipitation of metals from solution onto nuclei
2. Bacterial activity and oxidation
3. Upward diffusion of metals in ocean bottom sediment pore waters
4. And others as well...

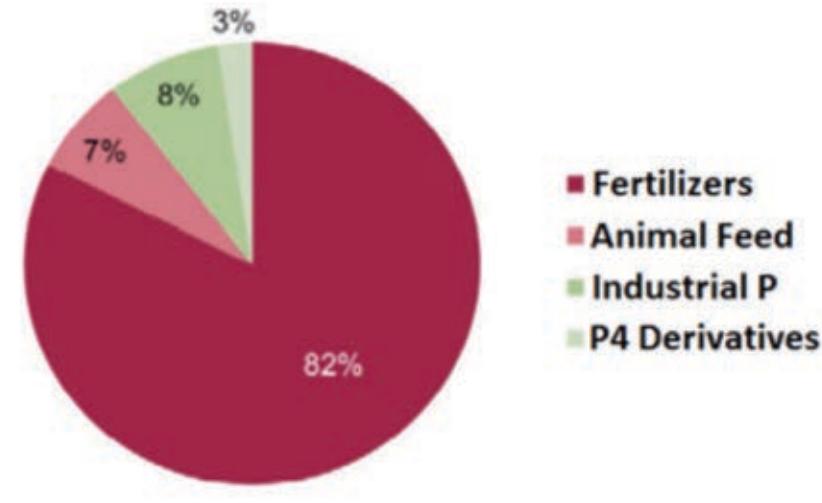


Wiki

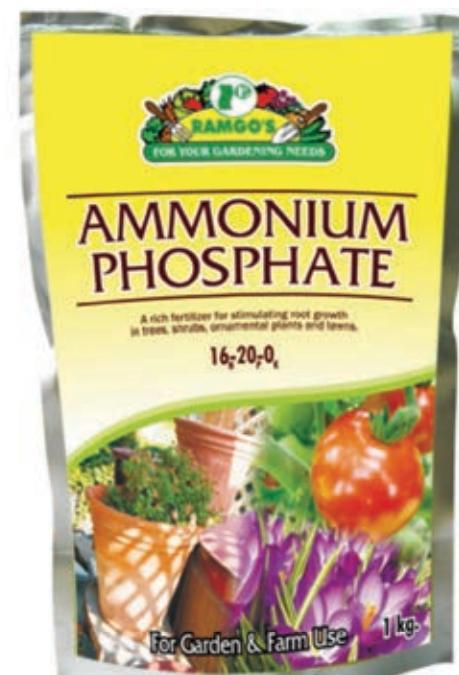


Phosphorous

- Discovered in 1669 by Hennig Brandt in Germany
- Essential element for the growth and development of most organisms (DNA, RNA, ATP)
- Building block for bones and teeth of vertebrates and shell/exoskeletons on invertebrates
- Phosphate used as a fertilizer (ammonium phosphate $(\text{NH}_4)_3\text{PO}_4$)
- 150 Mt phosphate a year used for artificial fertilizers
- Main source are phosphorites (sediments with 15–20% P_2O_5)



<http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/phosphorus.html>



<http://ramgoseeds.com/>

Guano was historically a major source of phosphorous and nitrogen

Peru and Chile were a major source of fertilizer in the nineteenth century



ON THE COMPOSITION AND VALUE OF BAT GUANO

By C. F. MILLER

Received April 20, 1914

At various points in this country, especially in the warmer regions, caves exist which are frequented by bats in such numbers that their excrement or "bat guano" has accumulated in amounts sufficient to give it some commercial importance as a fertilizer.

Generally, the amount of guano is rather limited in any one deposit and in the aggregate, the entire quantity now in sight, or probably to be discovered in this country, is not sufficient to appreciably affect the fertilizer industry. On the other hand, such a deposit may represent a considerable fortune to the individual owner or owner, and the frequency with which small deposits occur, justifies a short discussion of composition and value.

Following table containing the results of analyses of guano samples sent to this Bureau from time to time shows their composition as well as the locality from which they were taken.

BAT GUANO ANALYSES

Results in percentages, based on air-dry sample

LOCATION	N(a)	P ₂ O ₅	K ₂ O	VOLATILE	ANALYST
Island, N. M.....	4.24	2.31	1.28	..	J. A. Cullen
Mts., N. M.....	1.77	2.68	0.41	40.0	C. F. Miller
M.....	10.82	1.08	1.01	..	W. H. Wagggaman
Mo.....	8.10	2.06	0.58	..	B. E. Brown
Porto Rico(b).....	1.00	3.40	0.21	..	W. H. Wagggaman
Porto Rico(b).....	0.50	2.40	0.29	..	W. H. Wagggaman
Santo Domingo.....	11.84	4.80	1.61	90.0	C. F. Miller
Estimated by Mr. T. C. Trescott, of the Bureau of Chemistry. None of these samples contained considerable calcium carbonate.					

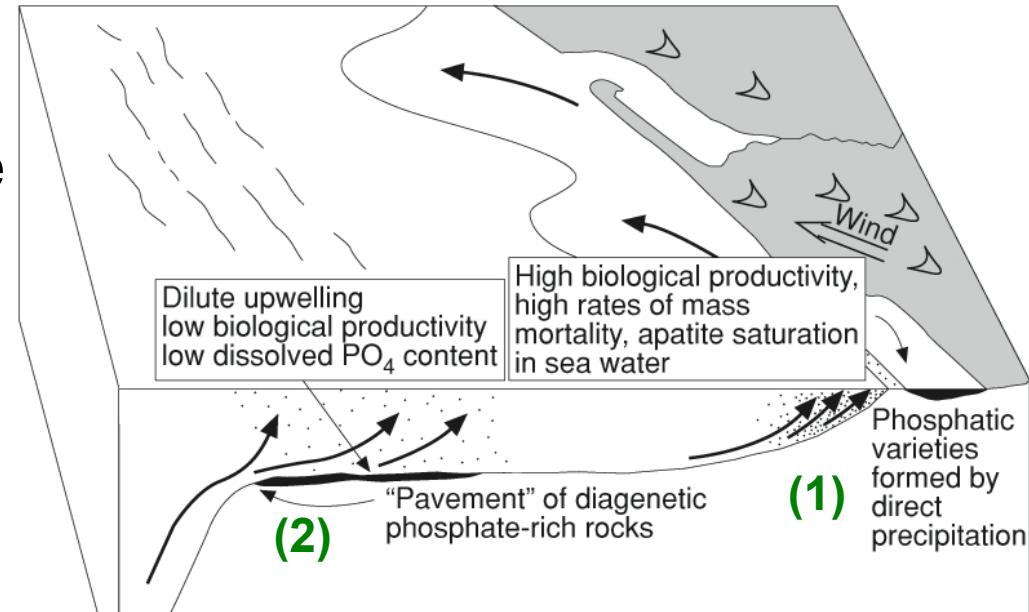
**Fertilizer and Chemical Minerals:
Phosphate, Nitrate, and Sulfur Deposits**


Kesler (1994)

Phosphorite deposits

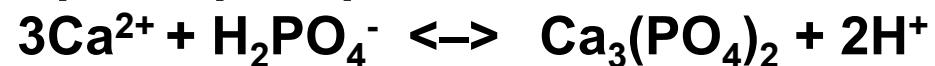
Upwelling of cold (P rich) seawaters in shallow marine environments. Apatite precipitation can occur by two (?) mechanisms:

- (1) Organisms produce shells/bones/teeth that accumulate in shallow restricted marine basins
- (2) Phosphatic replacement of fossiliferous limestone (diagenesis) outer shelf



Robb (2005)

Apatite precipitation:



Evaporite deposits

World's most important source of rock salt (Halite: NaCl), potash, borates and nitrates.

Product of chemical precipitation due to the evaporation of brines



Salt fun facts!

Salt (NaCl or halite) is an essential part of human and most animal diets

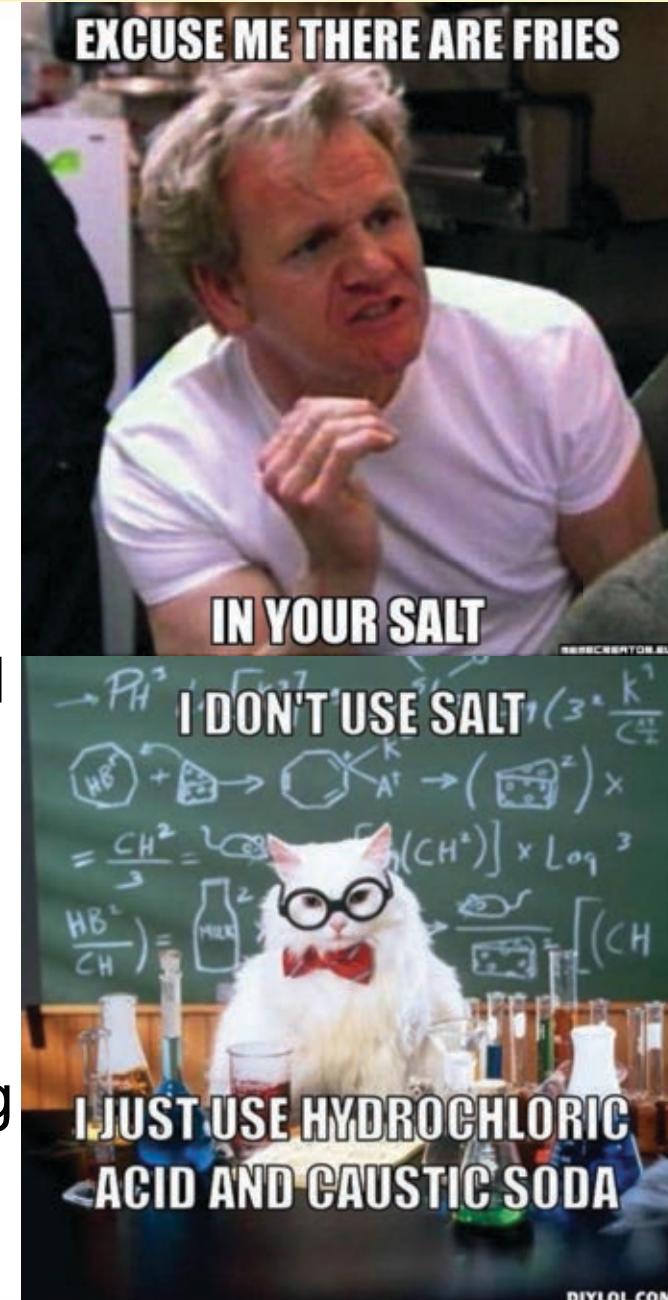
- 1 g/kg human body weight is fatal in humans
- 4 g per day is recommended intake

Primarily used in the chemical industry to produce: chlorine, soda ash (Na_2CO_3) and sodium hydroxide (NaOH , caustic soda)

- These are the basic chemicals for glass, paper, PVC and aluminum metal manufacturing

~40% of salt in USA used for road de-icing

Halite is widely distributed and cheap



Potassium, magnesium, calcium and boron also form useful salts!

Table 4.1 Important potassium salt minerals

		g/cm ³	% K ₂ O
Sylvite	KCl	1.99	63.1
Carnallite	KCl·MgCl ₂ ·6H ₂ O	1.6	17.0
Kainite	KCl·MgSO ₄ ·3H ₂ O	2.15	18.9
Langbeinite	K ₂ SO ₄ ·2MgSO ₄	2.82	22.6
Polyhalite	K ₂ SO ₄ ·MgSO ₄ ·2CaSO ₄ ·2H ₂ O	2.77	15.5

Table 4.2 Important salt minerals of magnesium, sodium, calcium and boron

		g/cm ³
Bischofite	MgCl ₂ ·6H ₂ O	1.59
Blödite	Na ₂ SO ₄ ·MgSO ₄ ·4H ₂ O	2.23
Boracite	MgCl ₂ ·5MgO·7B ₂ O ₃	2.90
Epsomite	MgSO ₄ ·7H ₂ O	1.67
Glauberite	Na ₂ SO ₄ ·CaSO ₄	2.8
Gaylussite	CaNa ₂ (CO ₃) ₂ ·5H ₂ O	1.99
Halite (rock salt)	NaCl	2.16
Kieserite	MgSO ₄ ·H ₂ O	2.57
Mirabilite	Na ₂ SO ₄ ·10H ₂ O	1.49
Natron	Na ₂ CO ₃ ·10H ₂ O	1.45
Tachhydrite	2MgCl ₂ ·CaCl ₂ ·12H ₂ O	1.66
Thenardite	Na ₂ SO ₄	2.66
Trona	Na ₃ H(CO ₃) ₂ ·2H ₂ O	2.14

Pohl (2011)

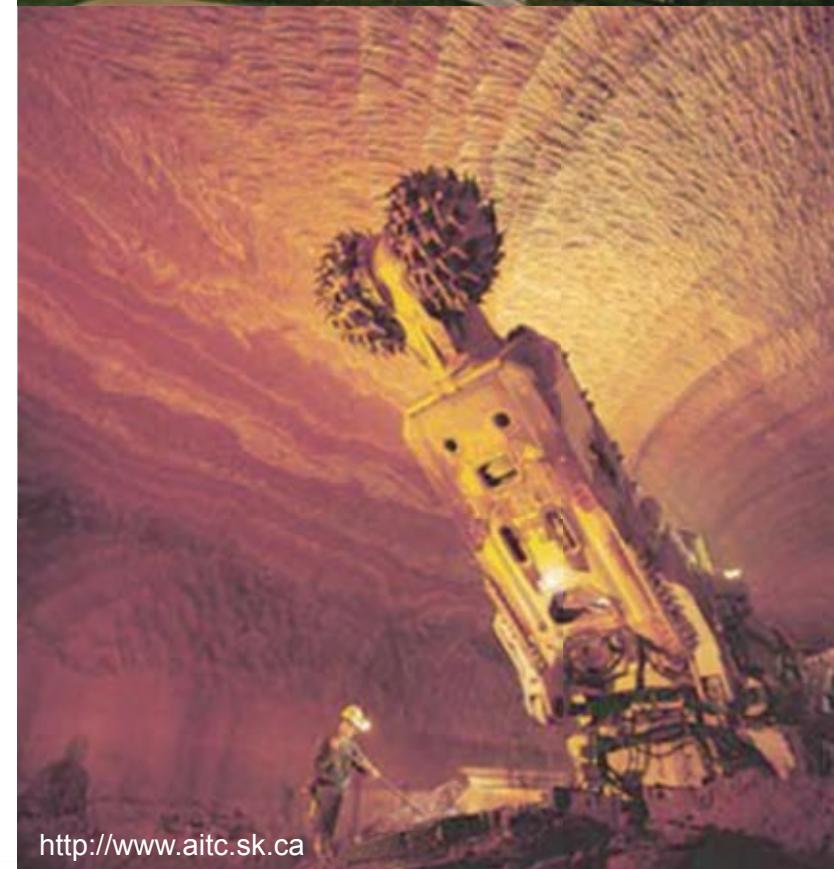


But, potassium salts are not common

- 12 countries produce K salts
- Biggest producer: CANADA!
- Saskatchewan is the largest potash producer in the world
- K is the 5th most important element in terrestrial biomass (C, O, H, N, P)
- Agriculture consumes 95% of K salts
- Minimum grade for K salt deposits is ~10% K₂O



<http://www.aitc.sk.ca>



<http://www.aitc.sk.ca>



SODIUM SULPHATE

- 29 Metisko Lake
30 Chaplin Lake
31 Ingebright Lake

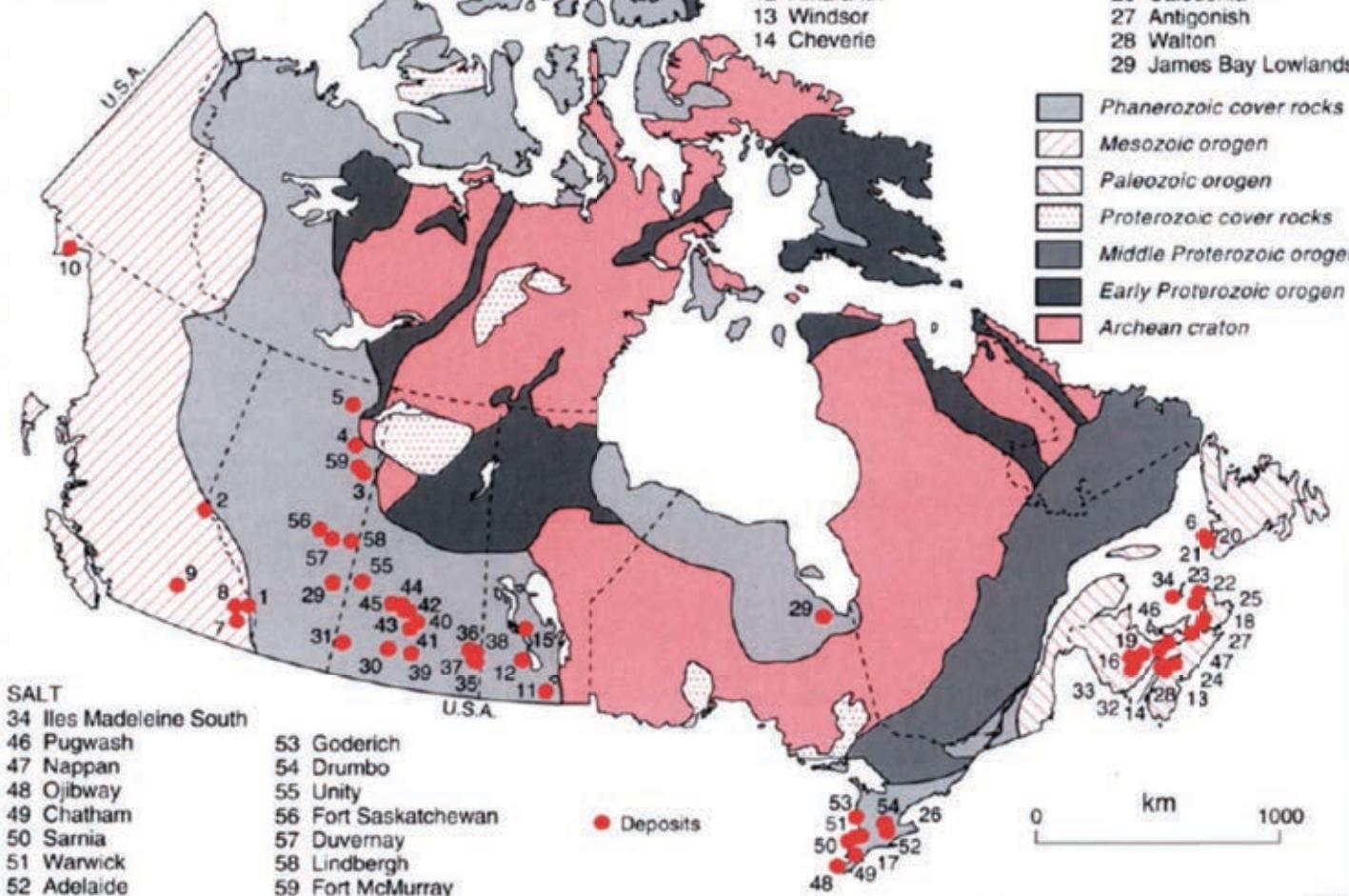
POTASH
32 Salt Springs
33 Plumwaseep-Millstream
35 Rocanville
36 Esterhazy
37 St. Lazare
38 Canamax

39 Kalium-Belle Plaine
40 Porcupine Prime
41 Watrous
42 Lanigan
43 Allan-Colonsay
44 Saskatoon
45 Vanscoy-Cory

GYPSUM

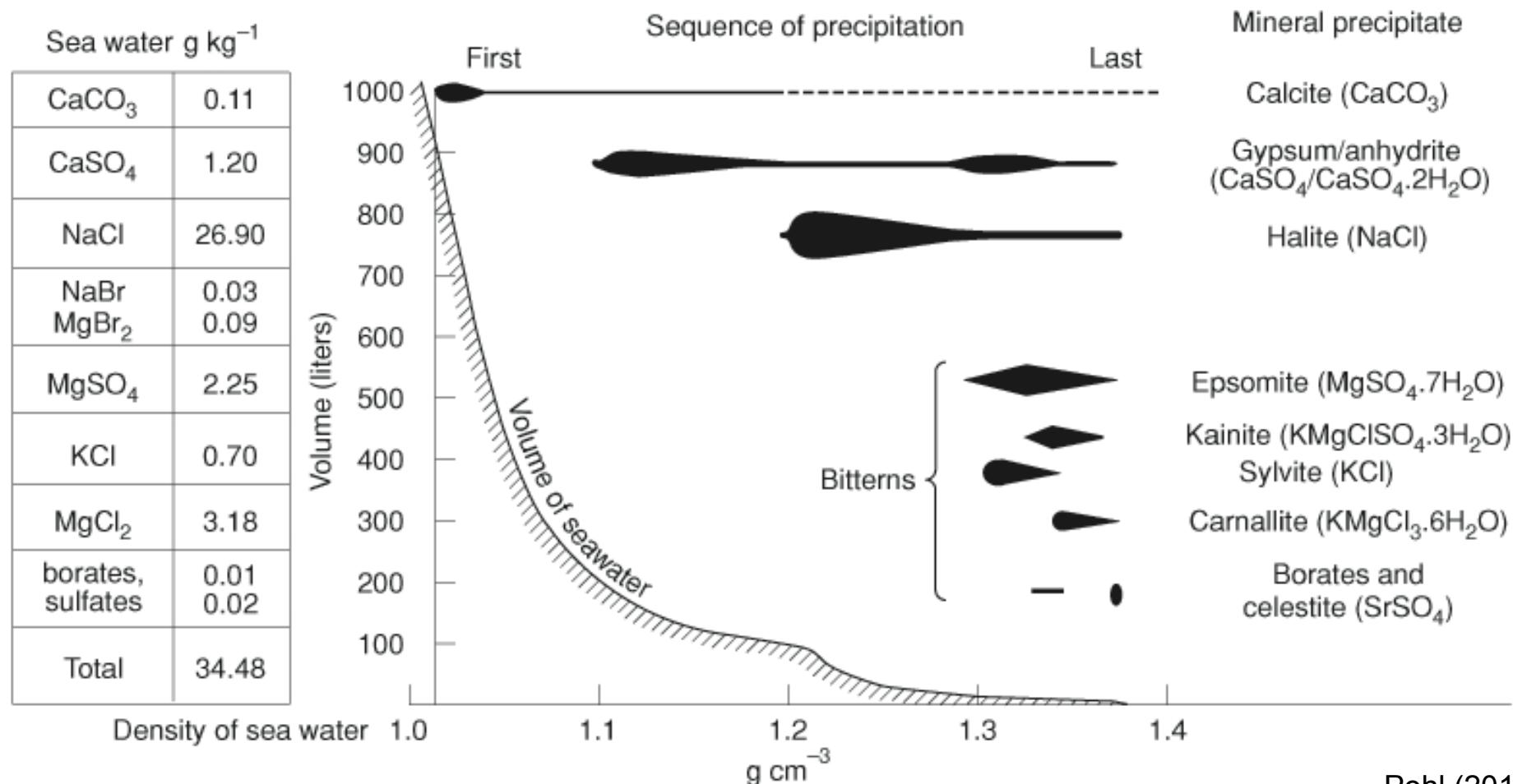
- 1 Kananaskis
2 Fetherstonehaugh
3 Clearwater
4 Athabasca
5 Peace Point
6 Romaines Brook
7 Lussier River
8 Windermere (Western Gypsum)
9 Falkland
10 O'Connor
11 Silver Plains
12 Amaranth
13 Windsor
14 Cheverie

15 Gypsumville
16 Havelock
17 Hagersville
18 River Denys
19 Hillsborough
20 Flat Bay
21 Fischell's Brook
22 Cheticamp
23 Dingwall
24 Milford
25 Little Narrows
26 Caledonia
27 Antigonish
28 Walton
29 James Bay Lowlands



Bell (1996)

Genesis: Water vapor is removed into the atmosphere by evaporation and the total content of dissolved salts increases. Salts precipitate when their solubility limits are reached.



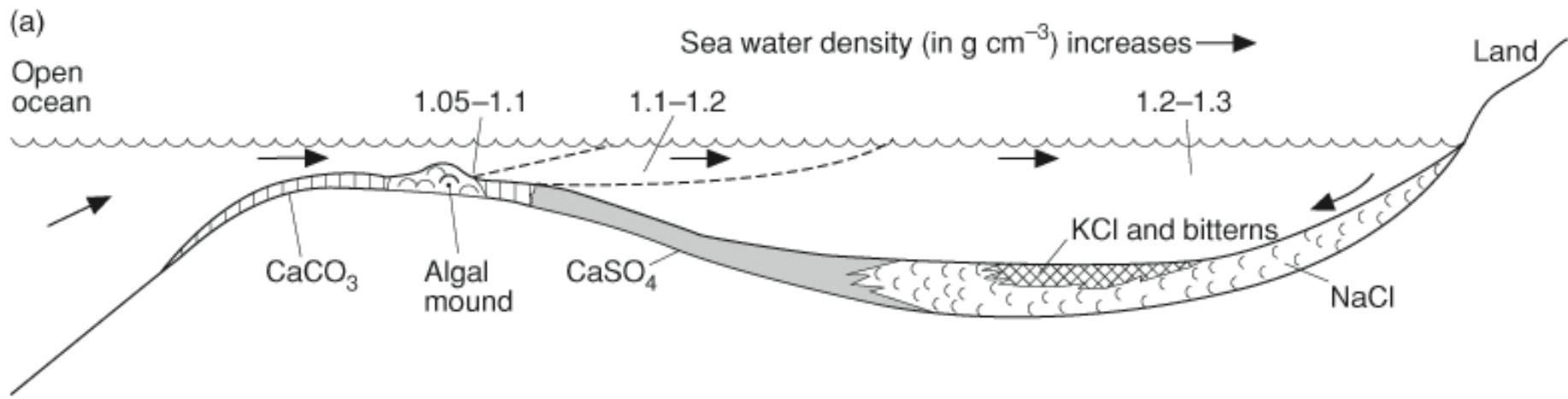
Evaporites – two important settings:

Marginal marine represented by lagoons or restricted embayments into which periodic or continual sea water recharge occurs. Laterally extensive and thick, but limited range of precipitants

Intracontinental or lacustrine: Smaller and thinner, but with a more diverse range of precipitants since continental fluvial input can be more variable

Shallow marine setting

- Evaporation results in a stratified water column with salt-rich brines at the bottom (denser) and fresher water at the top (less dense).
- In a restricted basin, the brine becomes isolated from the ocean and concentrates at the bottom of the basin
- Seawater recharge replenishes the solution, more evaporation....more replenishment...etc.



Robb (2005)

Continental setting

- Important sources of B, I, Li, Mg, K and Na
- Usually associated with ephemeral lakes: lakes that are usually dry, but become periodically flooded during and after rainfalls
- Lakes were originally large freshwater, but are now salt lakes (e.g. Great Salt Lake of Utah)

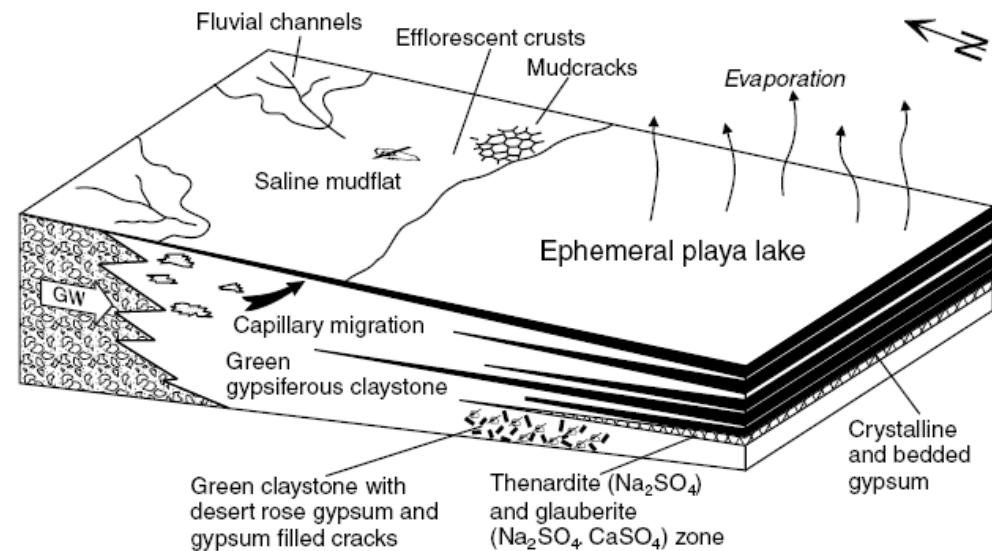


Figure 4.11 Schematic block diagram showing environmental elements of sedimentation in Late Miocene playa lakes of the Beypazari Basin, Central Anatolia (Yagmurlu & Helvaci 1994). This basin contains important deposits of trona, gypsum, oil shale and lignite. GW – groundwater inflow from alluvial fans.

Salt mining

Solution mining

- Vertical holes are drilled into salt body
- Fresh water injected and brine pumped out
- Can result in large collapse craters
- Evaporation may be in large evaporation pans at the surface



Hard Rock mining

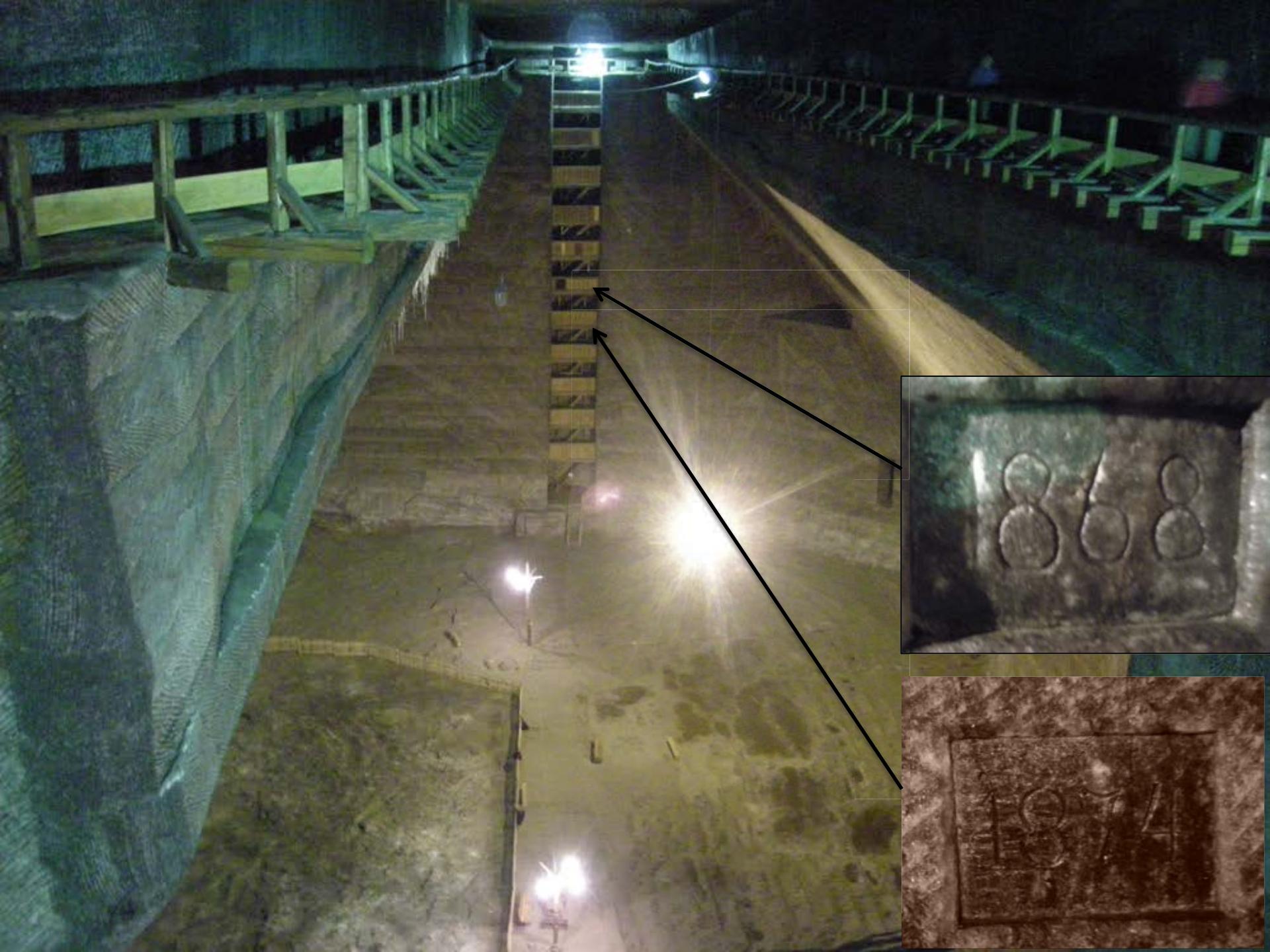
- Excavation of rock salt underground separate, leaving rock pillars as support for the roof
- KCl and NaCl are mechanically very different, which can be a challenge for mine design

Salina Turda – Romanian Salt Mine

- Mined from 1075 to 1932
- Open to the public in 1992
- Also used as a spa for halotherapy!

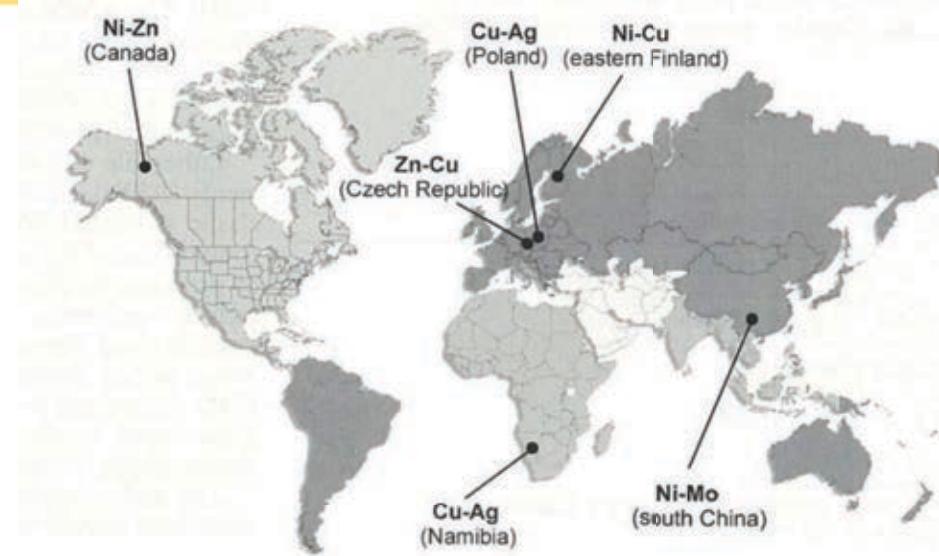






Black shales

- Rich in organic matter (carbon) and some metals (V, Cr, Co, Ni, Tu, Cu, Pb, Zn, Mo, U, Ag, Sb, Ti, Se and Cd)
- Some are mined directly, but also represent an important source of metals for hydrothermal ore deposits or traps
- Deposition is commonly linked to Ocean Anoxic events
- Stratiform or stratabound ores
- Generally low grade, but may be laterally extensive
- Only production has taken place in China



From Ross Large



http://www.nwtgeoscience.ca/petroleum/Peel/peel650/pic_1.jpg

Black shales

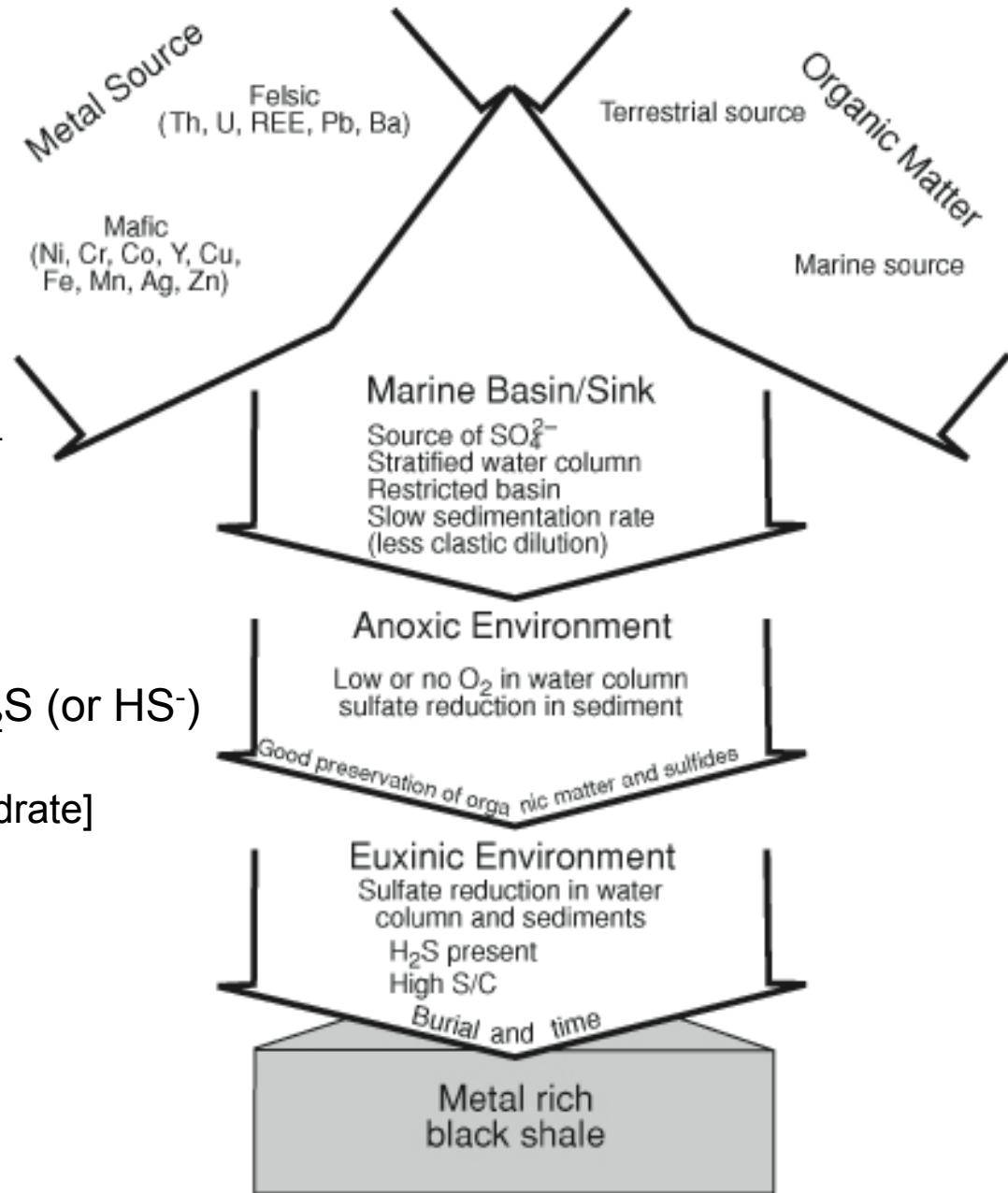
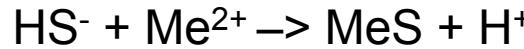
Deposited in anoxic and euxinic (reduced sulfur species stable) environments

Sulfate-reducing bacteria produce HS⁻ or H₂S (depending on pH) from SO₄²⁻



[R is some complex organic carbohydrate]

Which leads to...





Nick Deposit Yukon

- Discovered 1981
- Hosted in Devonian black shales of the Selwyn basin
- 400 km strike length
- Layers are 10–40 cm thick
- 5% Ni, 0.7% Zn, 3000 ppm V
- Minor amounts of Au, PGE, Se, As, Mo, Re
- Not currently economic ☹
- Some exploration in similar rocks in B.C. by Canada zinc metals Corp.



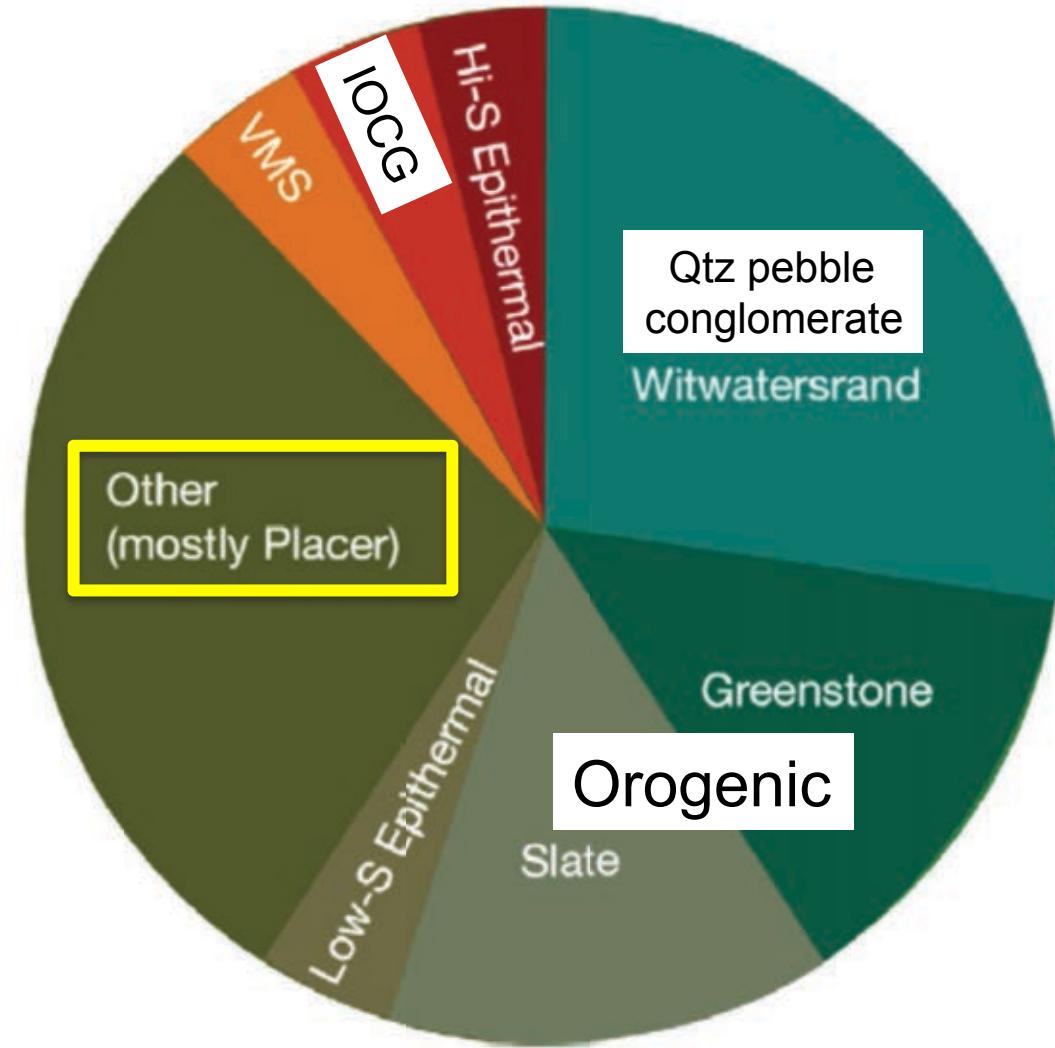
Physical accumulation

Physical accumulation:

Placer: Deposits formed by sedimentary sorting in a present-day sedimentary environment

Paleoplacer: Deposits that formed in a sedimentary unit that has been buried and in some cases deformed and metamorphosed

Gold deposits



Phillips & Powell (2013)

Minerals have specific properties in a clastic sedimentary environment that allow them to be preserved and accumulate:

Greater density than the dominant sedimentary component (usually quartz and feldspar: $p = \sim 2.7 \text{ g/cm}^3$)

Physically stable

- **Hardness** controls physical stability
- **Malleability** can also control physical stability

Chemically stable or unreactive

- Some minerals readily dissolve in surface waters (e.g. calcite)
- Some minerals decompose in the current atmosphere (e.g. pyrite, uraninite)

Minerals that readily decompose at the surface (e.g. sulfides) are rarely concentrated.

Table 5.1 Minerals mined from placer and palaeoplacer deposits, their physical properties, common placer settings of ores, and the types of rocks that provide primary sources of the minerals.

Mineral	Chemical formula	Density (g cm ⁻³)	Hardness (Moh's scale)	Setting of deposits	Major hard-rock source of mineral
Rutile	TiO ₂	< 5.5	6–6.5	Strandline	Widespread
Ilmenite	FeTiO ₃	4.75	5–6	Strandline	Beach/ shoreline
Zircon	ZrSiO ₄	4.6	7.5	Strandline	Felsic igneous rocks
Monazite	(REE)PO ₄	5.1	5	Strandline	Felsic igneous rocks
Garnet	X ₂ Y ₃ Si ₃ O ₁₂ *	3.35–4.3	6–7.5	Strandline and fluvial	Garnet-rich gneisses and skarns
Chromite	FeCr ₂ O ₄	5.1	7.5–8	Fluvial	Ores
Gold	Au	19.3	2.5–3	Fluvial	Ores
Cassiterite	SnO ₂	7.0	6–7	Fluvial	Rivers
Uraninite	UO ₂	8.7–10.9	5–6	Fluvial	Granites
PGMs	(various)	6.7–22.9	3–7	Fluvial	Ores
Diamond	C	3.5	10	Fluvial and strandline	Ores

*X and Y in the chemical formula for garnet refer to crystal sites that hold dominantly 2+ and 3+ cations respectively.

Ridley (2013)

Physical processes involved

- Flowing water (most important)
- Glacial processes
- Aeolian processes

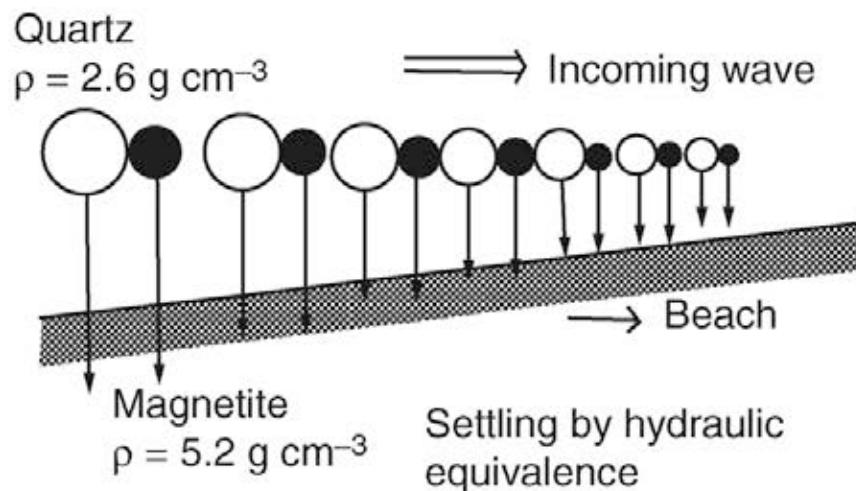
Differences in particle hydraulics: rate of settling of particles from laminar or turbulent flow is related to mineral size, density and shape.

Differential particle entrainment: flow resistance and boundary shear stresses imposed from the bed below the fluid. Small particles may also be trapped between larger ones.

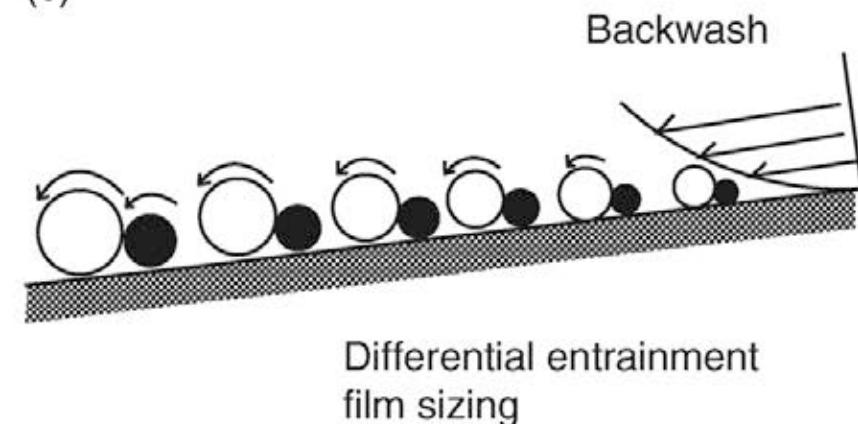


Beach sands can concentrate heavy minerals

(a)



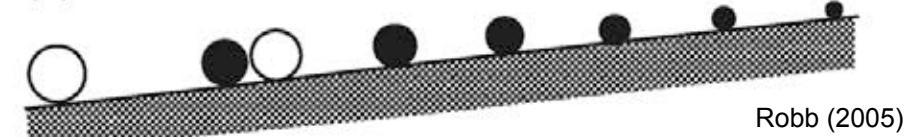
(c)



(b)



(d)



<http://dmme.virginia.gov/DGMR/ocssands.shtml>

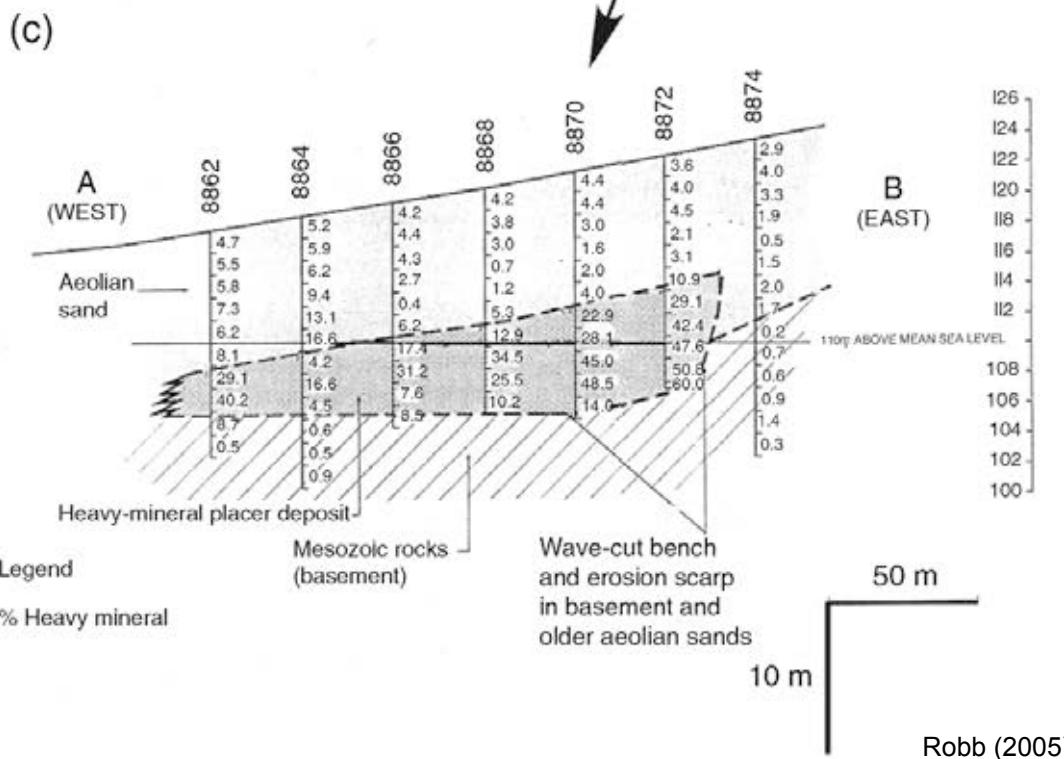
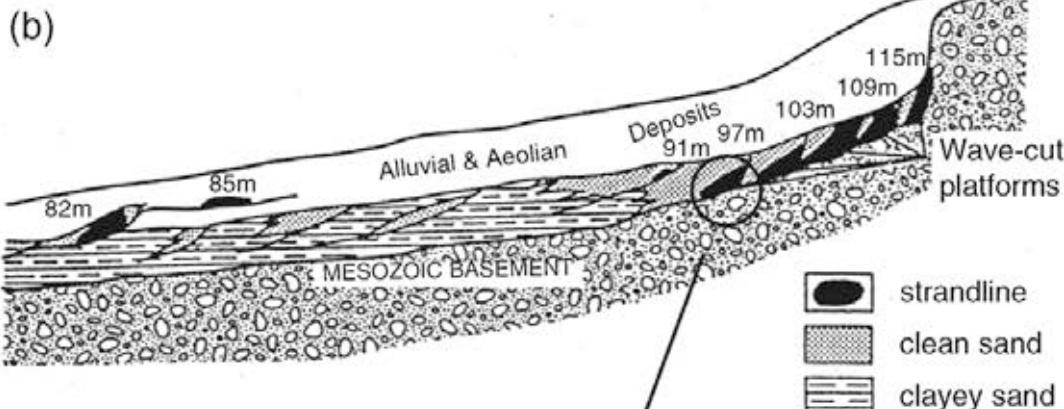
Pliocene heavy-mineral sands in Western Australia →

Multiple paleoshorelines

Each deposit forms a lenticular cross section

Shorelines and paleoshorelines a major source of:

- Rutile, ilmenite
- Zircon
- REE-bearing minerals



Monazite (REE-phosphate) sands



River placer deposits

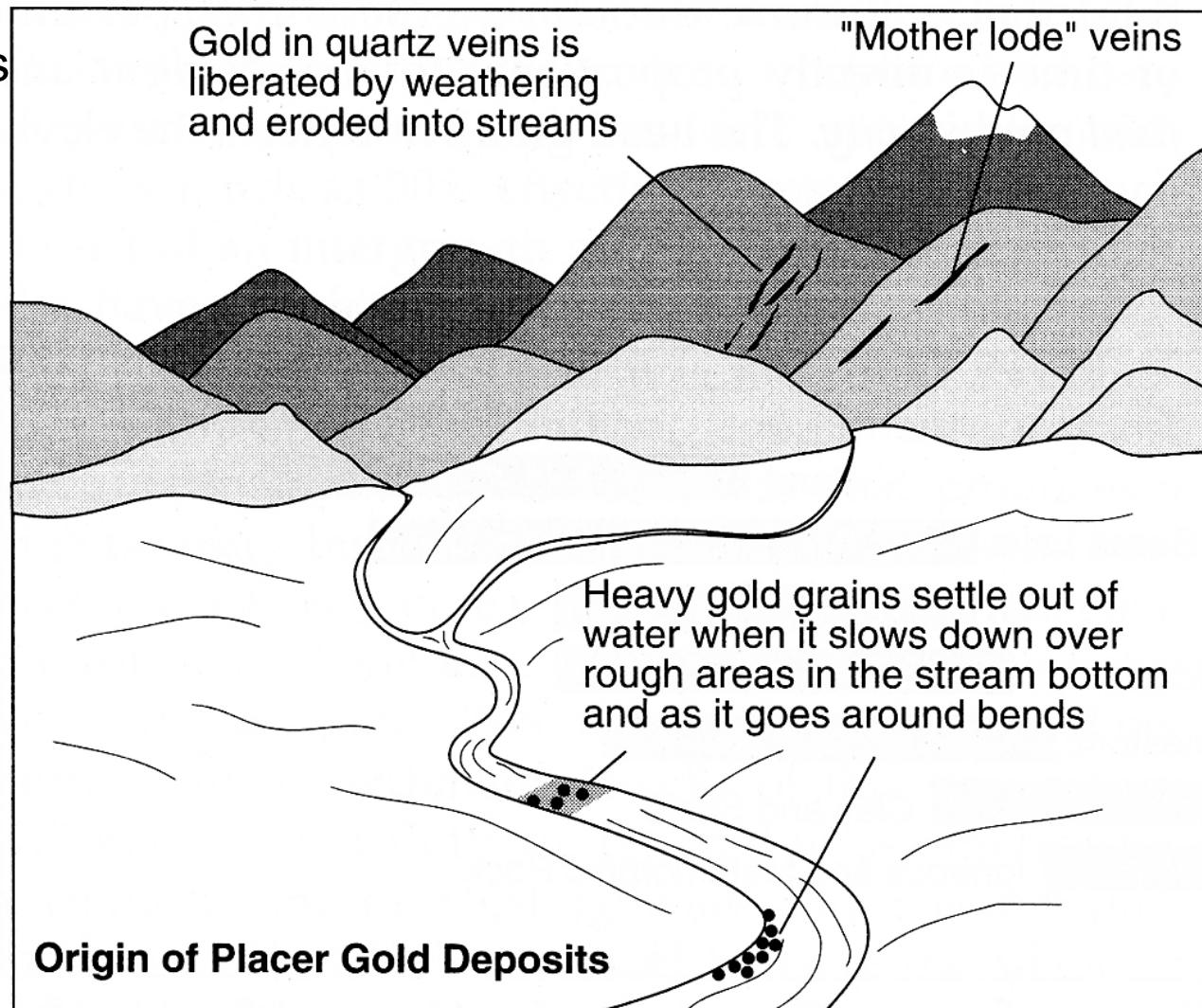
Mother lode: primary source of placer minerals (usually proximal to the placer deposit)

In many cases, the source is uneconomic... but the placer deposit may be economic!

Nature removes the gangue!

Important source of:

- Gold
- Diamonds
- Uraninite
- Platinum



Kessler (1994)

Residual placers accumulate immediately above a bedrock source

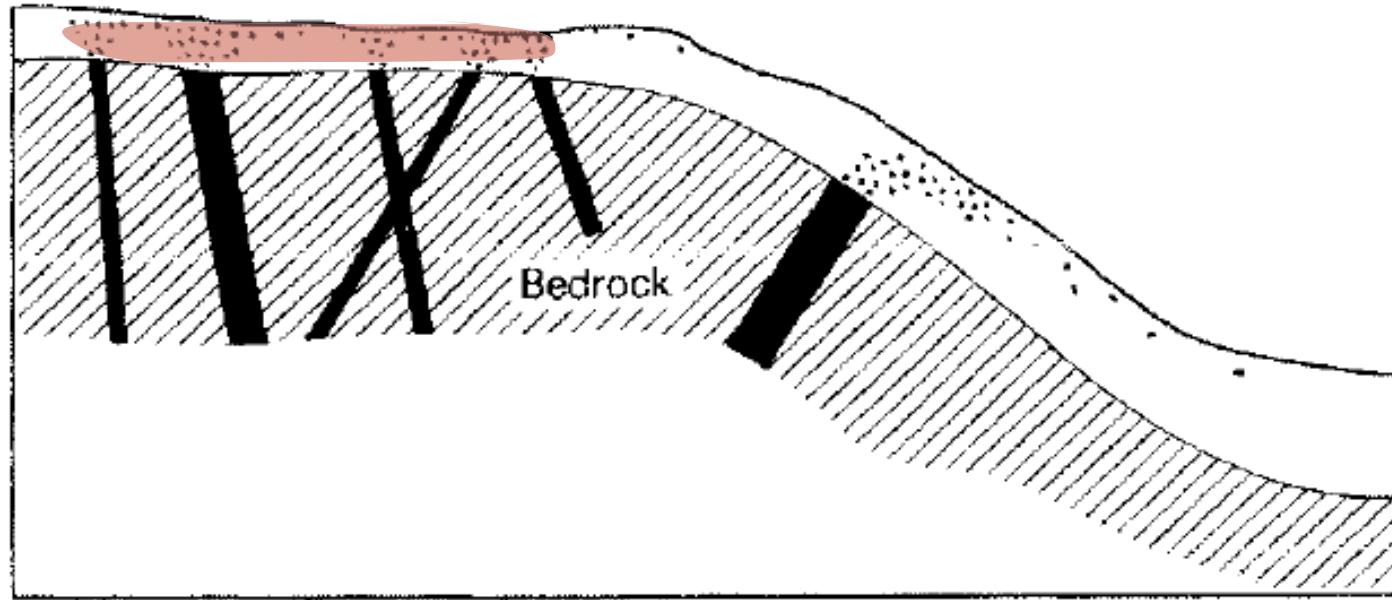


Fig. 18.1 The formation of residual (left) and eluvial (right) placer deposits by the weathering of cassiterite veins.

Evans (1993)



Stream placers

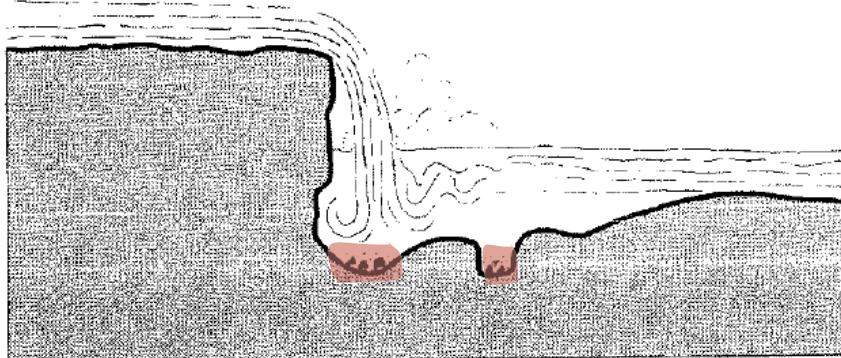


Fig. 18.3 Plunge pools at the foot of waterfalls and potholes can be sites of heavy mineral accumulations.

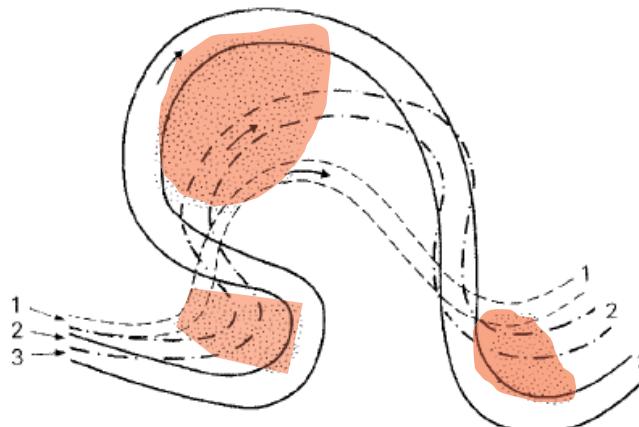


Fig. 18.5 Formation of pay streaks (dotted) in a rapidly flowing meandering stream with migrating meanders.
1 = original position of stream; 2 = intermediate position; 3 = present position. Note that pay streaks are extended laterally and downstream. Arrows indicate direction of water flow.

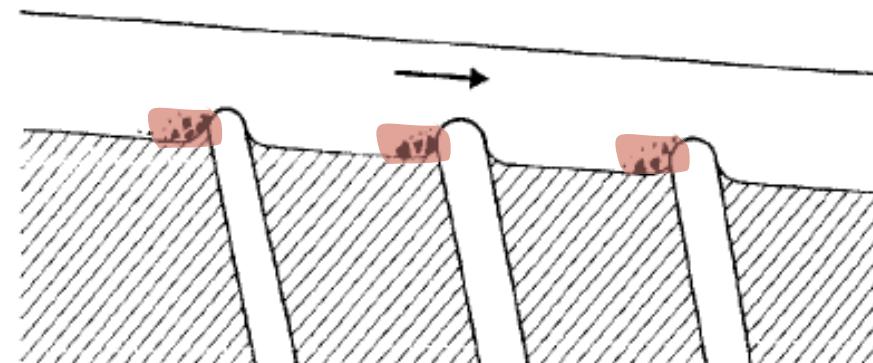


Fig. 18.2 Quartzite ribs interbedded with slate serving as natural riffles for the collection of placer gold.

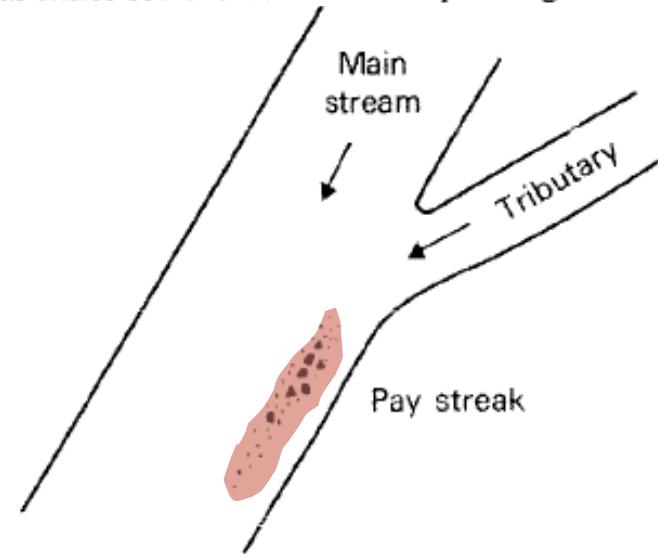
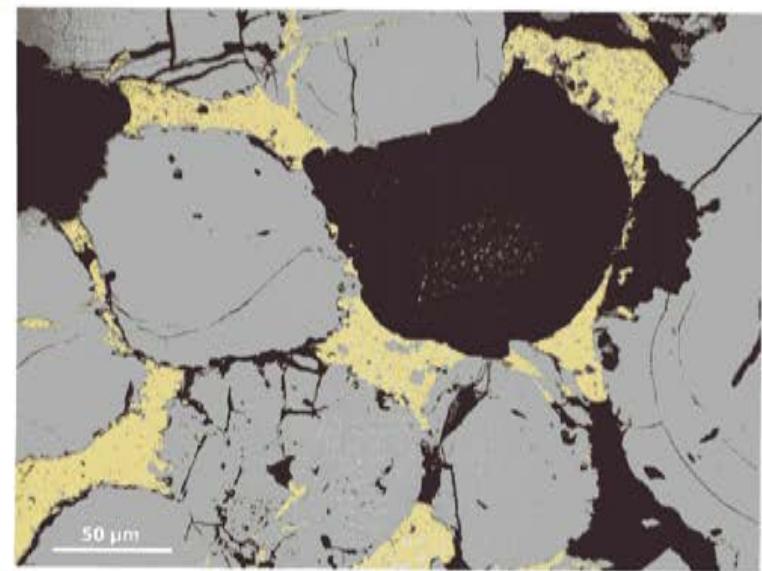
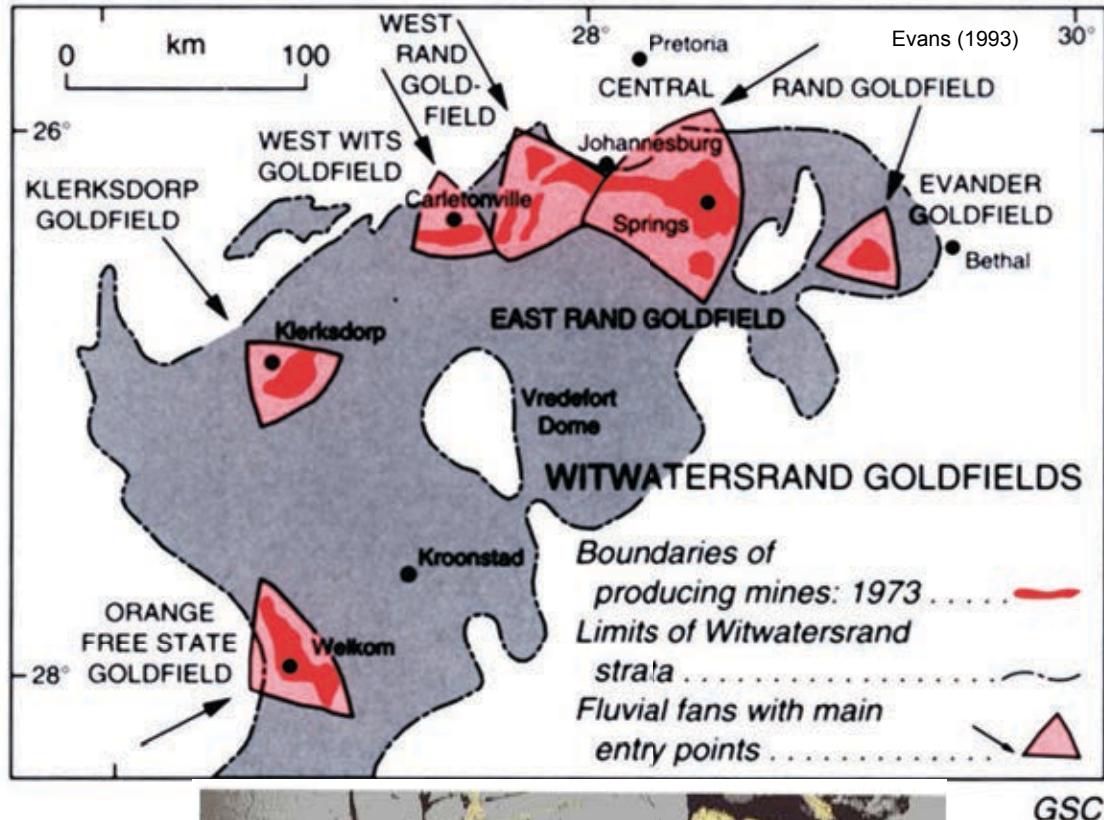


Fig. 18.4 A pay streak may be formed where a fast-flowing tributary enters a master stream.

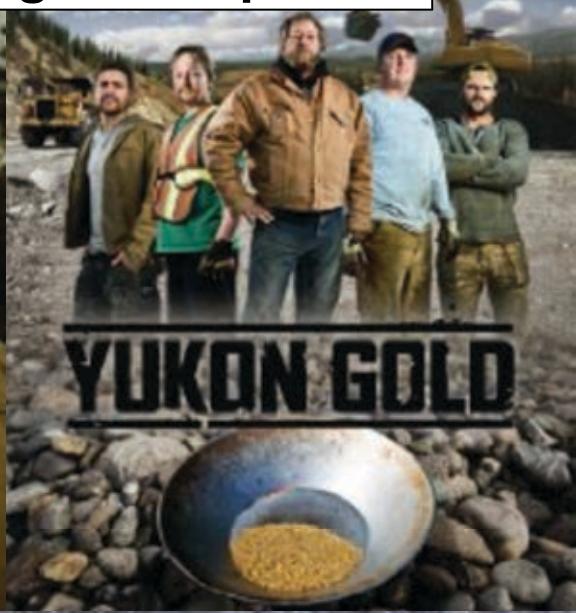
Evans (1993)

Witwatersrand Au

- Small scale gold prospecting in the 1850s
- Two prospectors found gold-rich conglomerate on a old farm and sold their claims for a few dollars – today their gold fields are worth billions
- Gold rush in 1886, which led to the establishment of Johannesburg
- >50% of all gold mined in human history comes from here
- 2% of world's U resources



For more information on placer mining techniques...

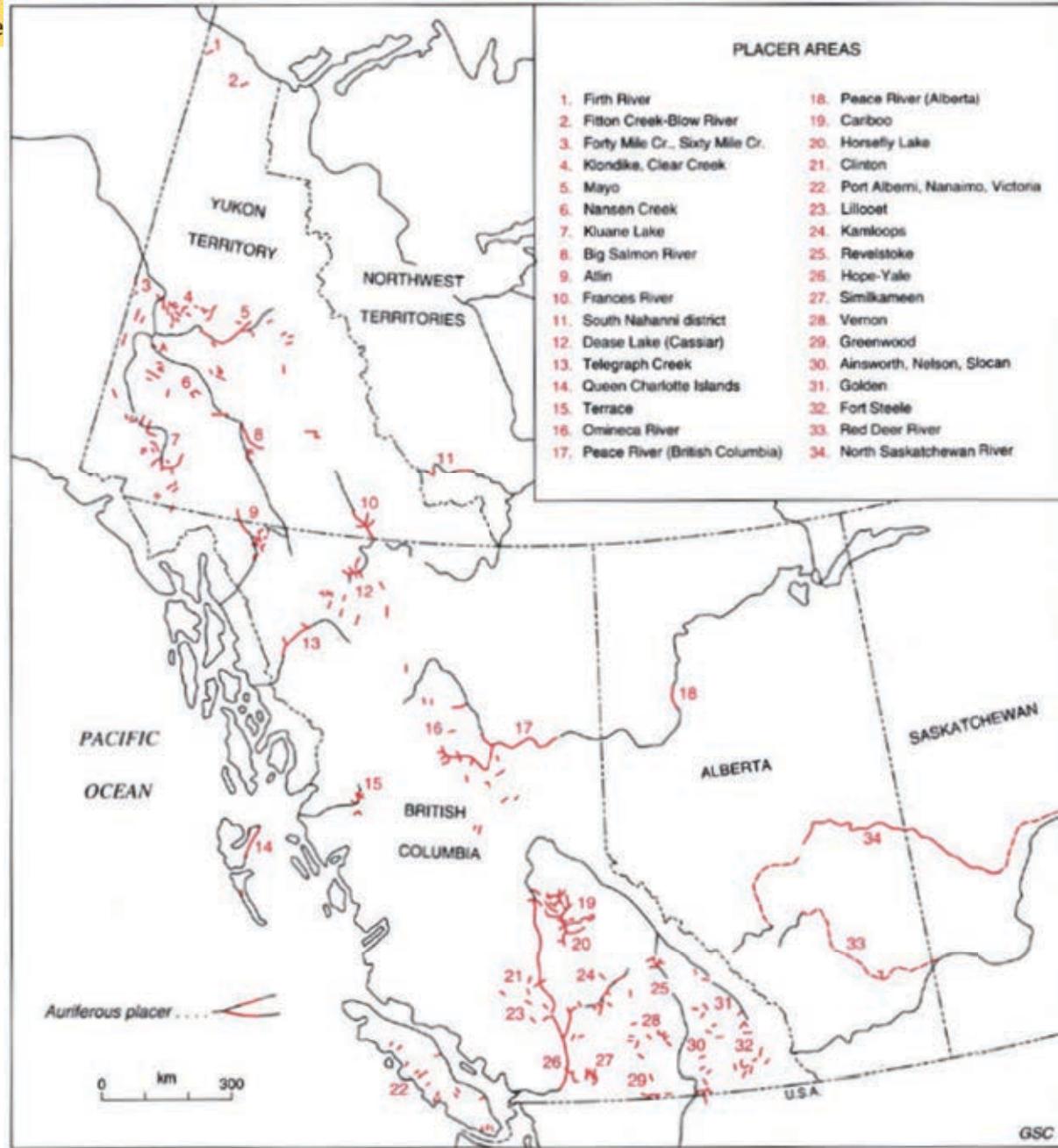


Placer diamond mining



Placer Au and Pt in Canada

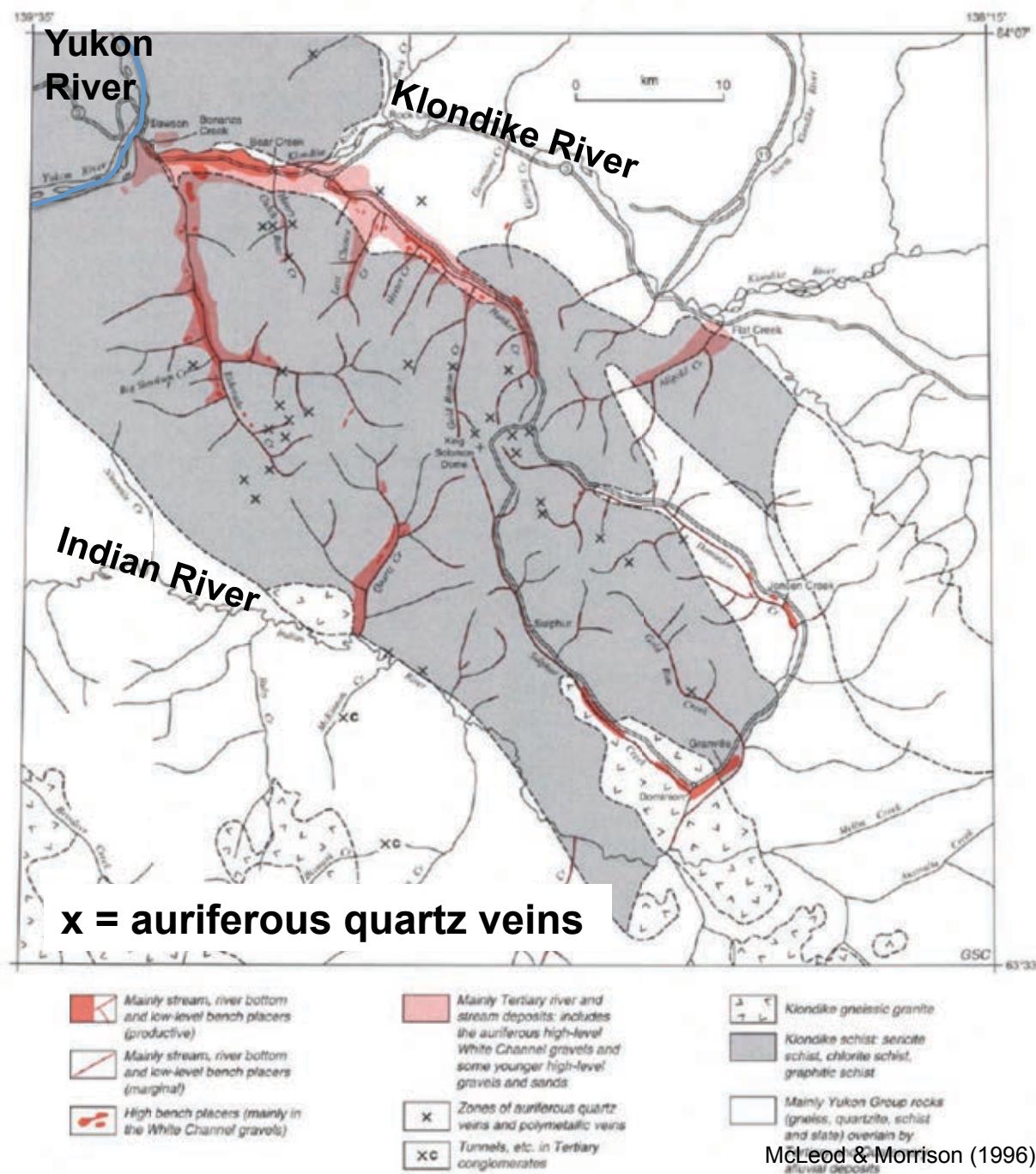
- 1900: placer gold accounted for 85% of Canadian gold
- Placer deposits have contributed to 7% of total Canadian Au production (as of 1996)
- Range from small scale operations (prospectors) to large scale (mines)
- Deeply weathered terrains
- Mature drainage systems
- Unglaciated areas are best (more time for streams to concentrate heavy minerals)



McLeod & Morrison (1996)

Klondike Gold fields, Yukon

- World famous!!
- Unglaciated part of west-central Yukon
- Extends from the Klondike river to the Indian River
- ~2,000 km²
- 1894: William Redford finds gold in Quartz Creek
- 1896: gold discovered on Bonanza creek... resulted in Klondike gold rush



BEDROCK
GOLD IN VEINS

WHITE CHANNEL GRAVEL

(Paleo-Bonanza Creek)

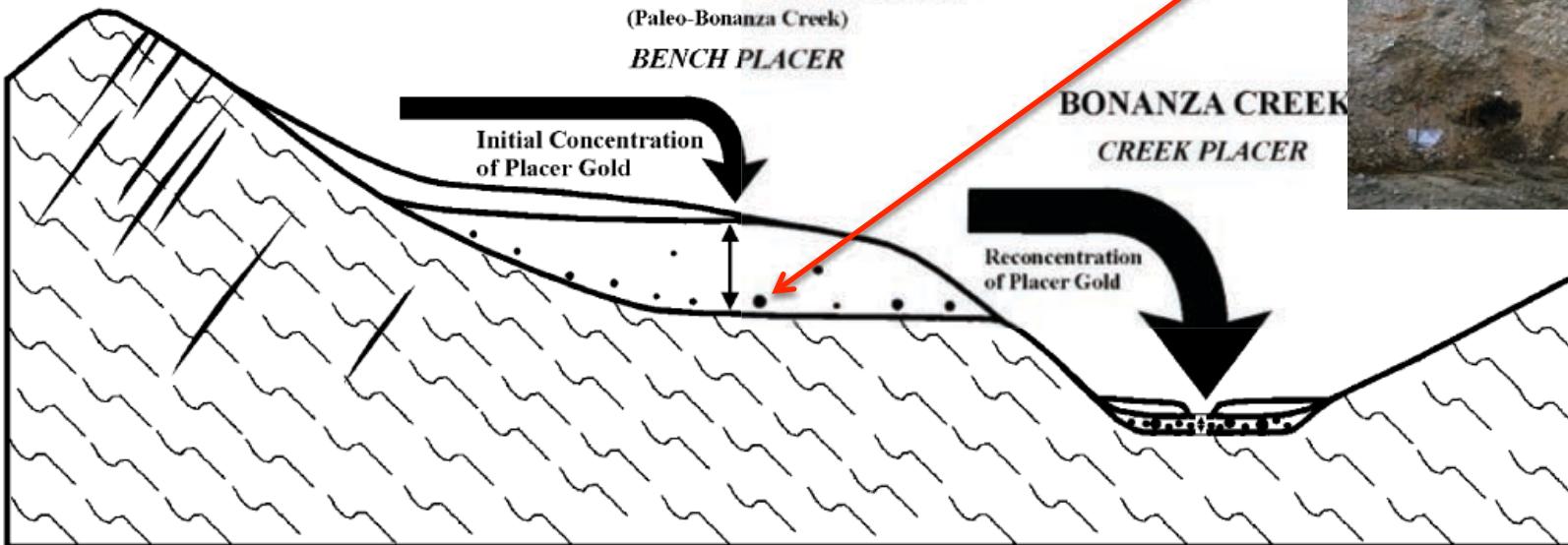
BENCH PLACER

Initial Concentration
of Placer Gold

BONANZA CREEK

CREEK PLACER

Reconcentration
of Placer Gold



~140 Ma: Mesothermal auriferous quartz veins emplaced in bedrock

~5 Ma: Long period of weathering and exhumation of reworked bedrock and produced “White Channel Gravel” deposits. Gold deposited in bedded gravels due to bed roughness.

<5 Ma: Long term exhumation (due to isostatic changes) concentrated gold into low-level gravels

Glaciation (isostatic adjustment) and changes in climate controlled the fluvial systems responsible for concentrating gold

Dawson City (1899)



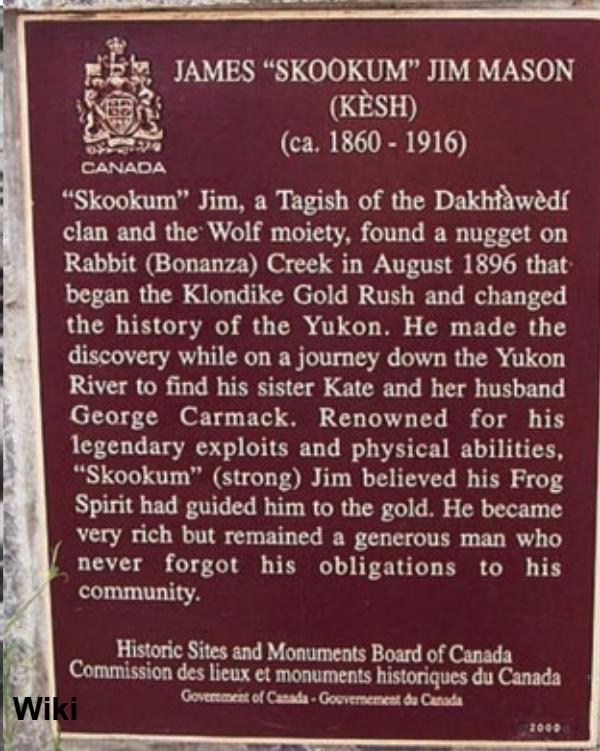
Wiki



Wiki



<http://www.discoveryuk.com>



Wiki



Take home messages:

Chemical precipitation

Deposits: Iron (BIFs), manganese, phosphorites, evaporites, black shales

Precipitation controlled by: redox, pH, climate, paleolatitude, biological activity, atmospheric evolution

Physical accumulation

Sedimentary processes sort minerals at the surface (fluvial, alluvial, eolian, glacial)

Important mineral properties: density, hardness, malleability, chemical stability

Commodities: gold, diamond, uraninite, platinum, oxides