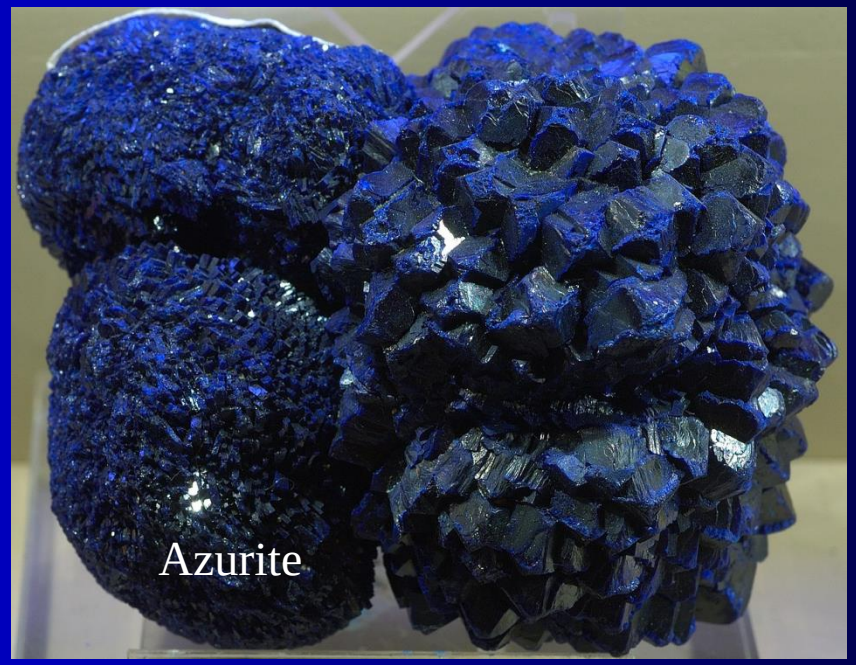
Economic Minerals



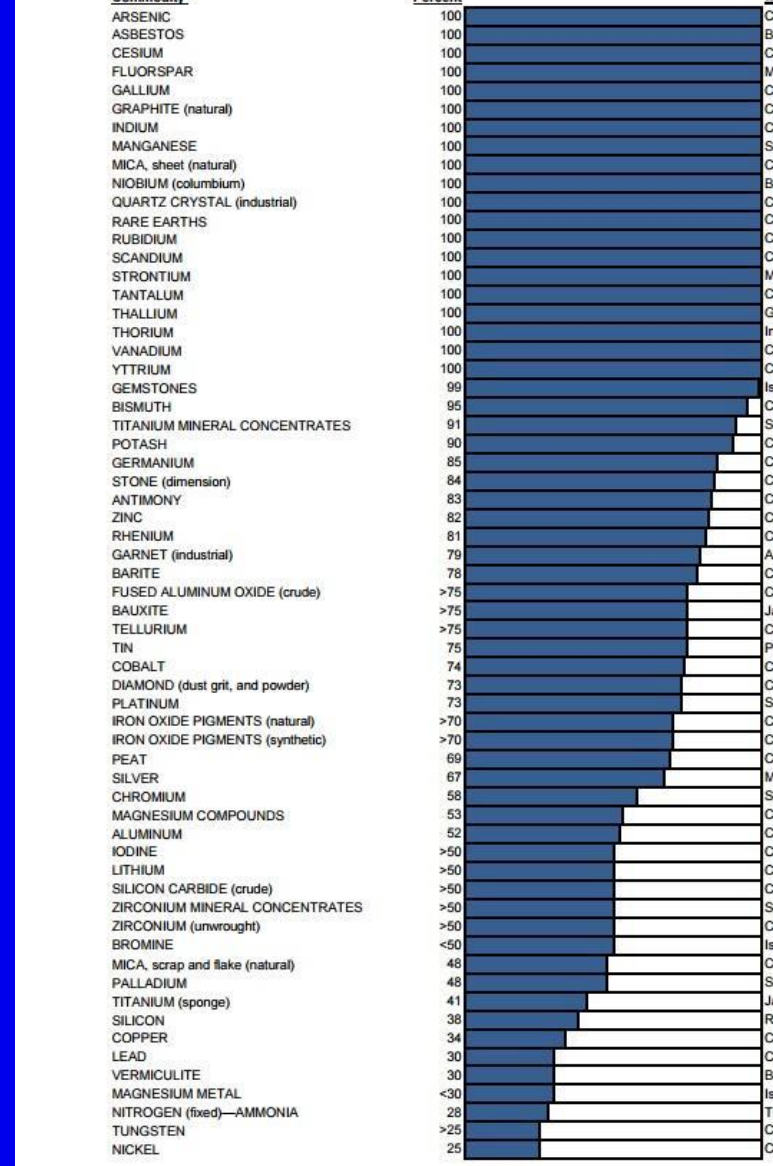
- Metallic minerals are mined specifically for the metals that can be extracted by smelting
  - Examples: Sphalerite (zinc), galena (lead)
- Nonmetallic minerals are mined for their chemical or physical properties they have, not the metals they contain
  - Examples: Clay, gravel, salt, gems

TABLE 18.1 Mineral Resources and Their Uses

Metals	
Abundant metals	iron, aluminum, magnesium, manganese, titanium, silicon
Scarce and rare metals	copper, lead, zinc, nickel, chromium, gold, silver, tin, tungsten, mercury molybdenum, uranium, platinum, and many others
Nonmetals	
Used for chemicals	sodium chloride (halite), sodium carbonate, borax, calcium fluoride (fluorite)
Used for fertilizers	calcium phosphate (apatite), potassium chloride, sulfur, calcium carbonate (limestone), sodium nitrate
Used for building	gypsum (for plaster), limestone (for cement), clay (for brick and tile), asbestos, sand, gravel, crushed rock, shale (for brickmaking), decorative stone
Used for jewelry	diamond, corundum (ruby and sapphire), garnet, amethyst, beryl (emerald), and many others
Used for glass and ceramics	clays, feldspar, quartz (silica sand)
Used for abrasives	diamond, garnet, corundum, pumice, quartz

2016 U.S. NET IMPORT RELIANCE

Commodity	Percent	Major import sources (2012–15)
ARSENIC	100	China, Japan
ASBESTOS	100	Brazil
CESIUM	100	Canada
FLUORSPAR	100	Mexico, China, South Africa, Mongolia
GALLIUM	100	China, Germany, United Kingdom, Ukraine
GRAPHITE (natural)	100	China, Mexico, Canada, Brazil
INDIUM	100	Canada, China, France, Belgium
MANGANESE	100	South Africa, Gabon, Australia, Georgia
MICA, sheet (natural)	100	China, Brazil, Belgium, Austria
NIOBIUM (columbium)	100	Brazil, Canada
QUARTZ CRYSTAL (industrial)	100	China, Japan, Romania, United Kingdom
RARE EARTHS	100	China, Estonia, France, Japan
RUBIDIUM	100	Canada
SCANDIUM	100	China
STRONTIUM	100	Mexico, Germany, China
TANTALUM	100	China, Kazakhstan, Germany, Thailand
THALLIUM	100	Germany, Russia
THORIUM	100	India, France, United Kingdom
VANADIUM	100	Czech Republic, Canada, Republic of Korea, Austria
YTTRIUM	100	China, Estonia, Japan, Germany
GEMSTONES	99	Israel, India, Belgium, South Africa
BISMUTH	95	China, Belgium, Peru, United Kingdom
TITANIUM MINERAL CONCENTRATES	91	South Africa, Australia, Canada, Mozambique
POTASH	90	Canada, Russia, Chile, Israel
GERMANIUM	85	China, Belgium, Russia, Canada
STONE (dimension)	84	China, Brazil, Italy, Turkey
ANTIMONY	83	China, Thailand, Bolivia, Belgium
ZINC	82	Canada, Mexico, Peru, Australia
RHENIUM	81	Chile, Poland, Germany
GARNET (industrial)	79	Australia, India, South Africa, China
BARITE	78	China, India, Morocco, Mexico
FUSED ALUMINUM OXIDE (crude)	>75	China, Canada, Venezuela
BAUXITE	>75	Jamaica, Brazil, Guinea, Guyana
TELLURIUM	>75	Canada, China, Belgium, Philippines
TIN	75	Peru, Indonesia, Malaysia, Bolivia
COBALT	74	China, Norway, Finland, Japan
DIAMOND (dust grit, and powder)	73	China, Ireland, Romania, Russia
PLATINUM	73	South Africa, Germany, United Kingdom, Italy
IRON OXIDE PIGMENTS (natural)	>70	Cyprus, France, Austria, Spain
IRON OXIDE PIGMENTS (synthetic)	>70	China, Germany, Canada, Brazil
PEAT	69	Canada
SILVER	67	Mexico, Canada, Peru, Poland
CHROMIUM	58	South Africa, Kazakhstan, Russia
MAGNESIUM COMPOUNDS	53	China, Brazil, Canada, Australia
ALUMINUM	52	Canada, Russia, United Arab Emirates, China
IODINE	>50	Chile, Japan
LITHIUM	>50	Chile, Argentina, China
SILICON CARBIDE (crude)	>50	China, South Africa, Netherlands, Romania
ZIRCONIUM MINERAL CONCENTRATES	>50	South Africa, Australia, Senegal
ZIRCONIUM (unwrought)	>50	China, Japan, Germany
BROMINE	<50	Israel, China, Jordan
MICA, scrap and flake (natural)	48	Canada, China, India, Finland
PALLADIUM	48	South Africa, Russia, Italy, United Kingdom
TITANIUM (sponge)	41	Japan, Kazakhstan, China
SILICON	38	Russia, China, Canada, Brazil, South Africa
COPPER	34	Chile, Canada, Mexico
LEAD	30	Canada, Mexico, Republic of Korea, Peru
VERMICULITE	30	Brazil, South Africa, China, Zimbabwe
MAGNESIUM METAL	<30	Israel, Canada, China, Mexico
NITROGEN (fixed)—AMMONIA	28	Trinidad and Tobago, Canada, Russia, Ukraine
TUNGSTEN	>25	China, Canada, Bolivia, Germany
NICKEL	25	Canada, Australia, Norway, Russia



ORE GRADE for SELECTED ELEMENTS

Clarke: the average abundance of an element in the earth's crust

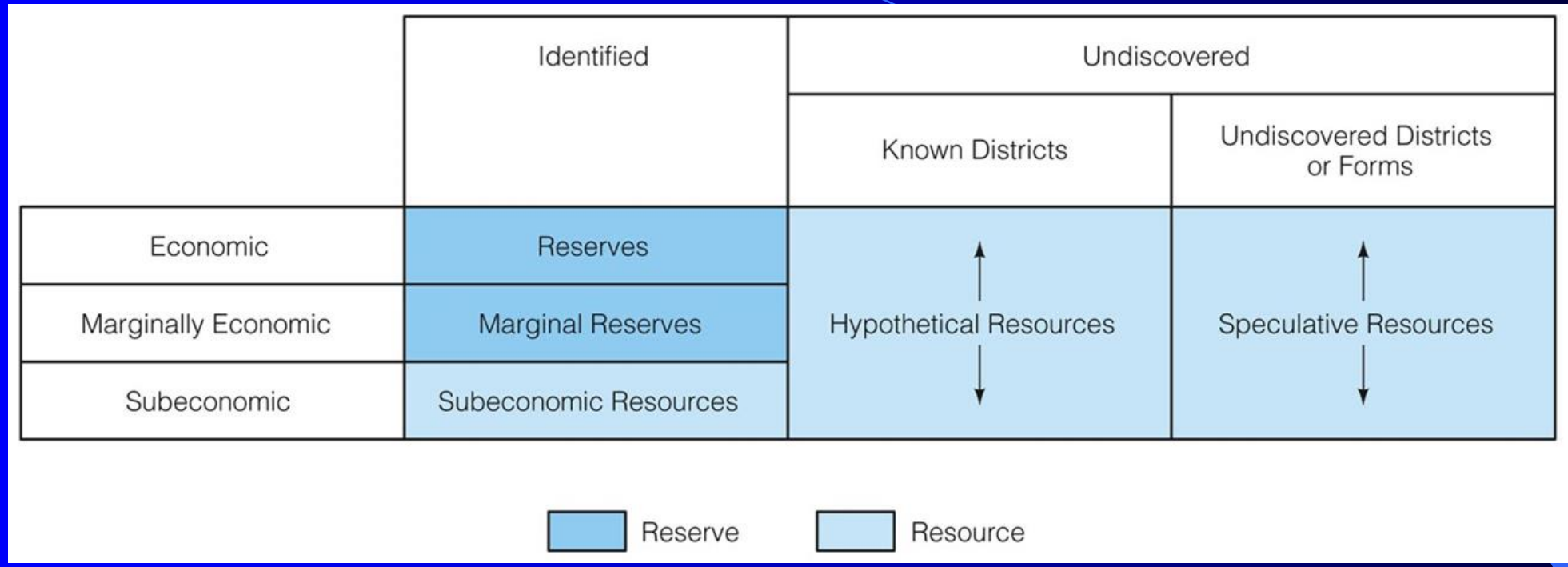
Clarke of Concentration: the concentration of an element in a rock compared with its average concentration in the earth's crust.

Ore Grade, or the **Clarke of Concentration changes over time and is affected by:**

1. The availability of minerals with high concentrations if the element (e.g. Cu_2S, PbS, etc. REEs, for example, lack such minerals)
2. The difficulty and expense of recovering the metal from its ore (e.g. Aluminum, Titanium)
3. Advances in mining and refining technology
4. Changes in the value that society places upon the metal (e.g. Gold, REE, Lead, Tin).

Metal	Clarke (in percent)	Ore Grade (in percent)	Clarke of Concentration for Ore Grade
Aluminum	5.13	30	4
Iron - Fe	5.00	60	12
Titanium	**0.66**	**15**	**23**
Copper	0.0055	0.25	45
Rare Earths	**0.019**	**1.6**	**84**
Nickel	0.0075	1.5	200
Gold - Au	0.0000005	0.00023	460
Manganese	0.10	35	350
Uranium	0.0002	0.1	500
Zinc	0.007	4.0	600
Lead – Pb	0.0013	4.0	3000
Chromium	0.01	30	3000
Tin – Sn	0.0002	1.0	5000
Silver – Ag	0.00001	0.05	5000

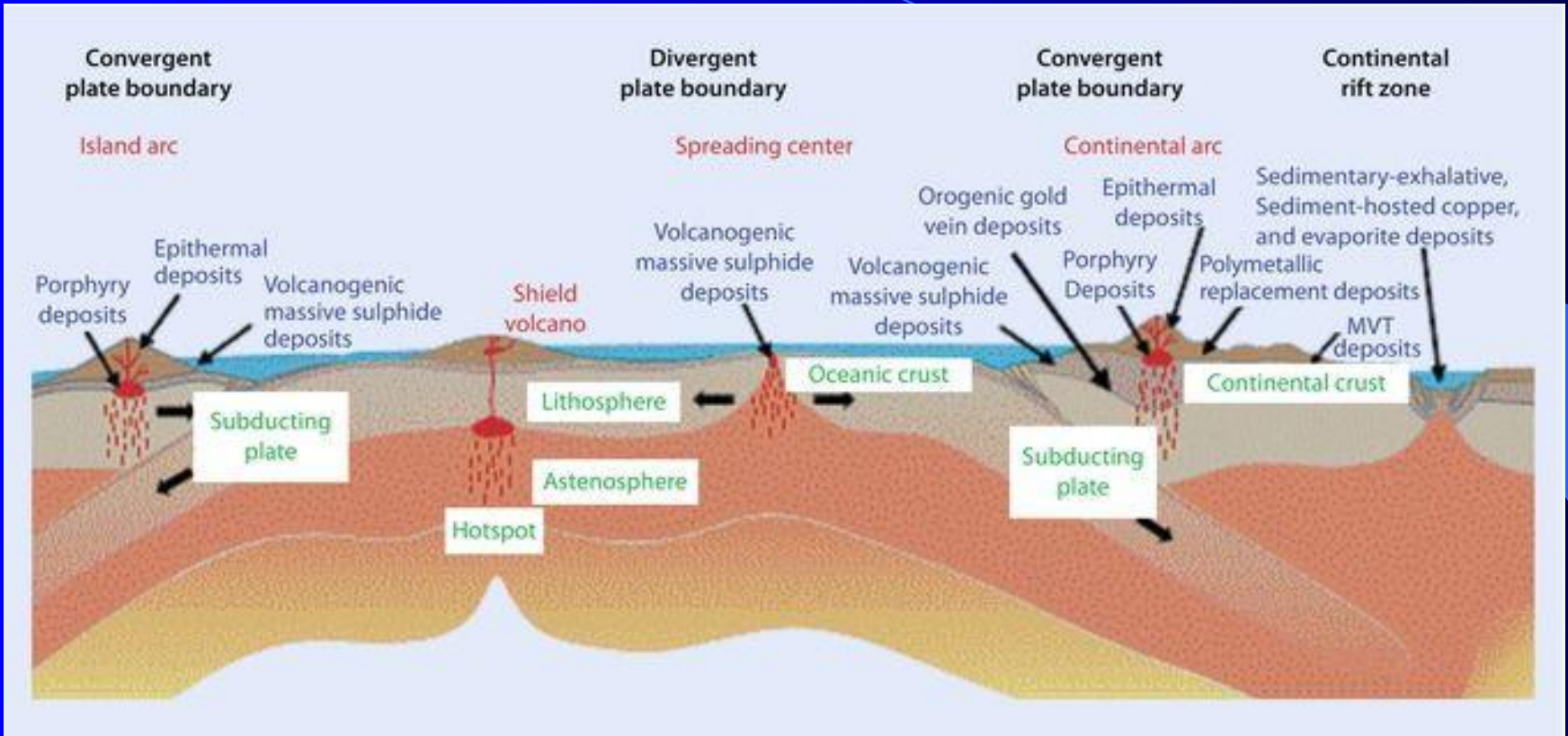
In general, the larger the Clarke of Concentration, the smaller the typical orebody becomes


Identified
Undiscovered
Known Districts
Undiscovered Districts or Forms
Economic
Reserves
Marginally Economic
Marginal Reserves
Subeconomic
Subeconomic Resources
Hypothetical Resources
Speculative Resources
Reserve
Resource

A geologic process or combination of processes must produce a localized enrichment of minerals for a mineral deposit to form. Mineral deposits are “accidents of nature”.

1. Hydrothermal solutions
2. Metamorphic or magmatic processes
3. Chemical sedimentary processes
4. Action of waves or currents
5. Weathering

Ore Deposits and Tectonic Settings

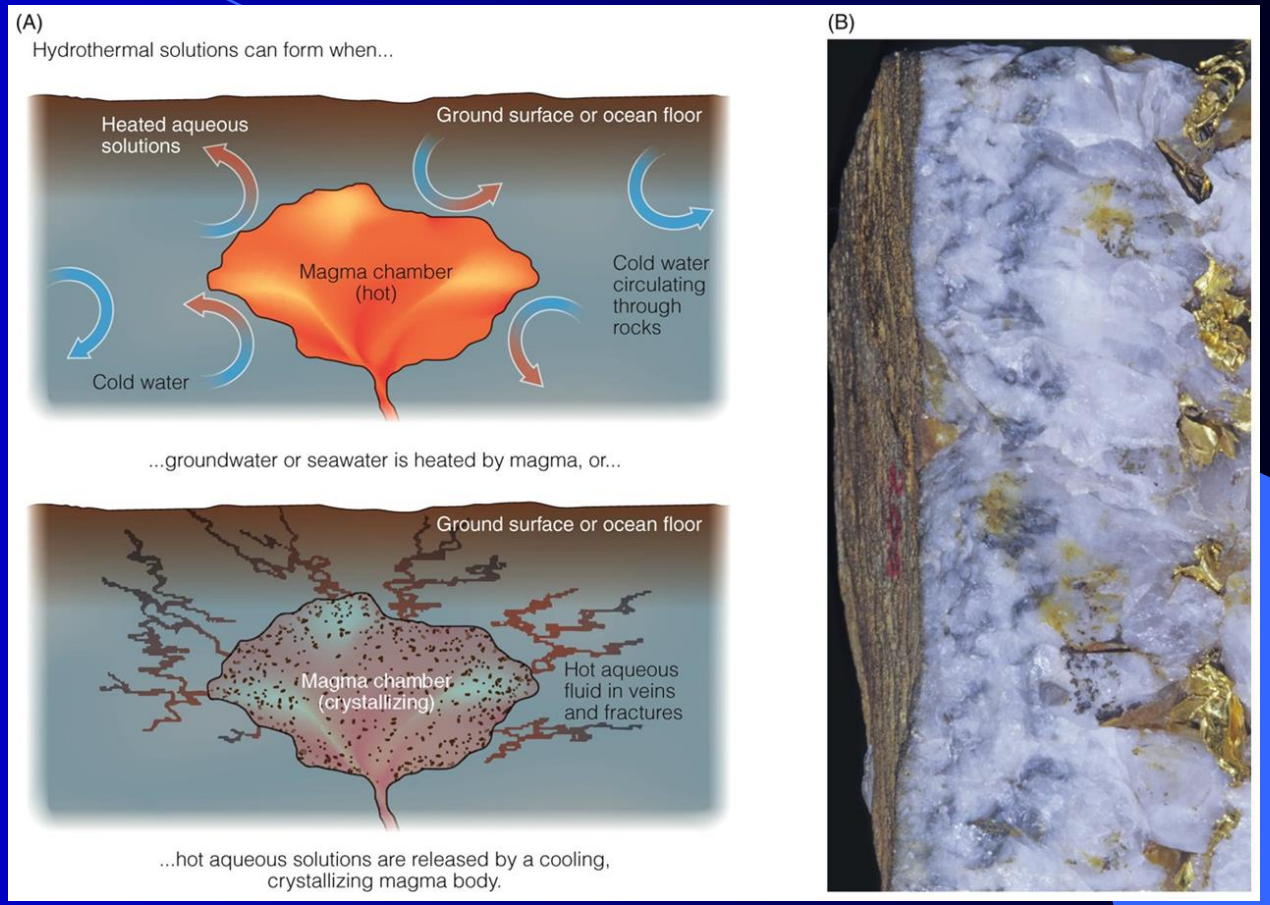


Hydrothermal ore deposits

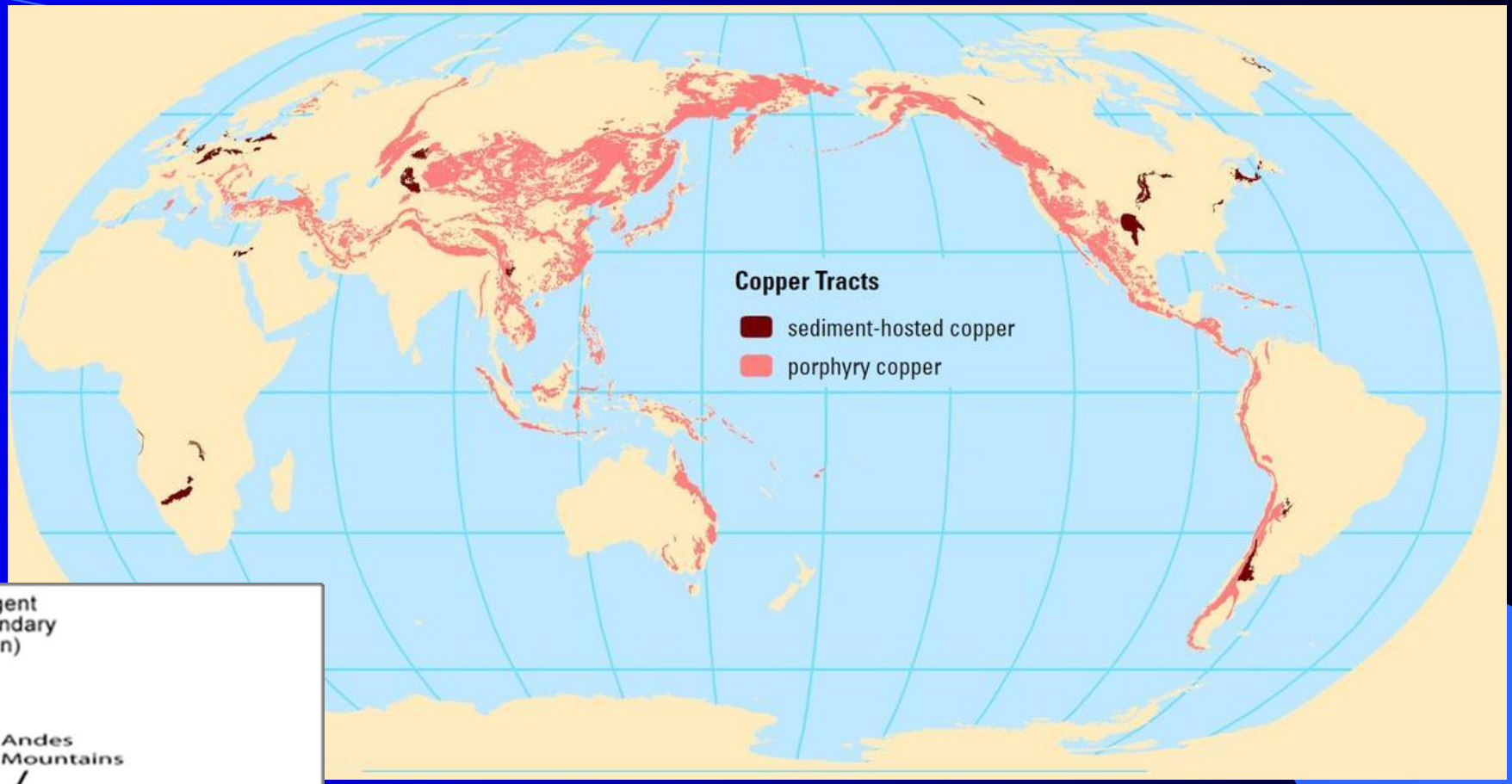
- Hot, aqueous, metal-saturated fluids that react chemically with crustal rock
- Most mineral deposits
- Primary sources of metals
- Veins
- Stratabound mineral deposits

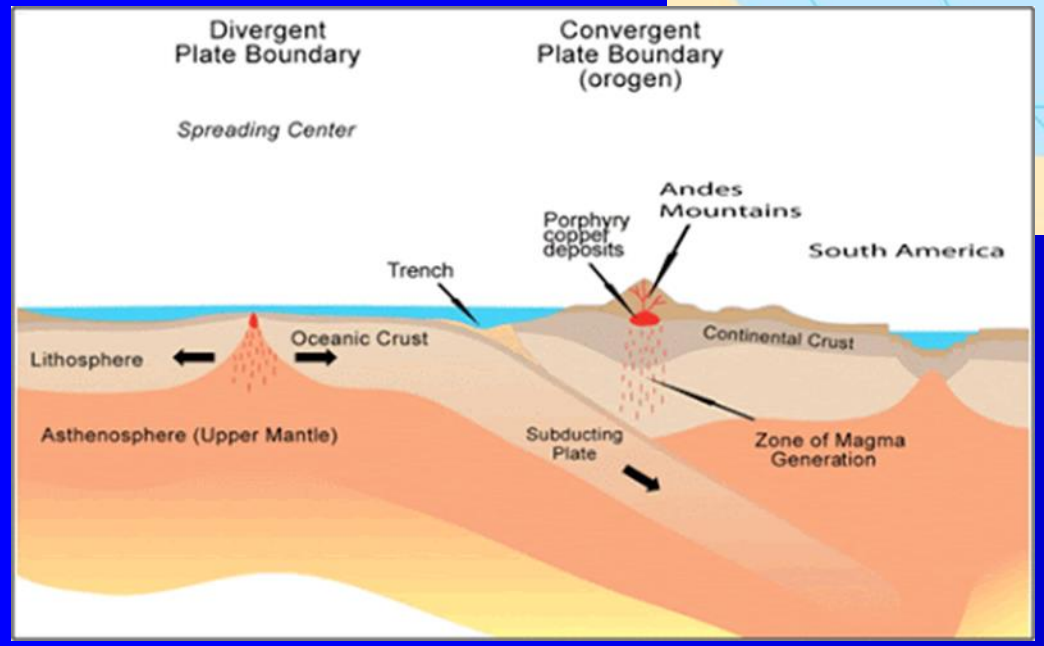
Hydrothermal deposits

Kind of deposit	Mode of formation	Chief ores formed
Hypothermal	These are formed at great depth at high temperature and pressure.	Gold-quartz veins copper-tourmaline lead-tourmaline molybdenite.
Mesothermal	These are formed at intermediate depths at high temperature and pressure.	Pyrite, Chalcopyrite Galena. Arsenopyrite Native gold.
Epithermal	These are formed at low depth under moderate temperature and pressure.	Native gold, Marcasite pyrite. Cinnabar, stibnite.



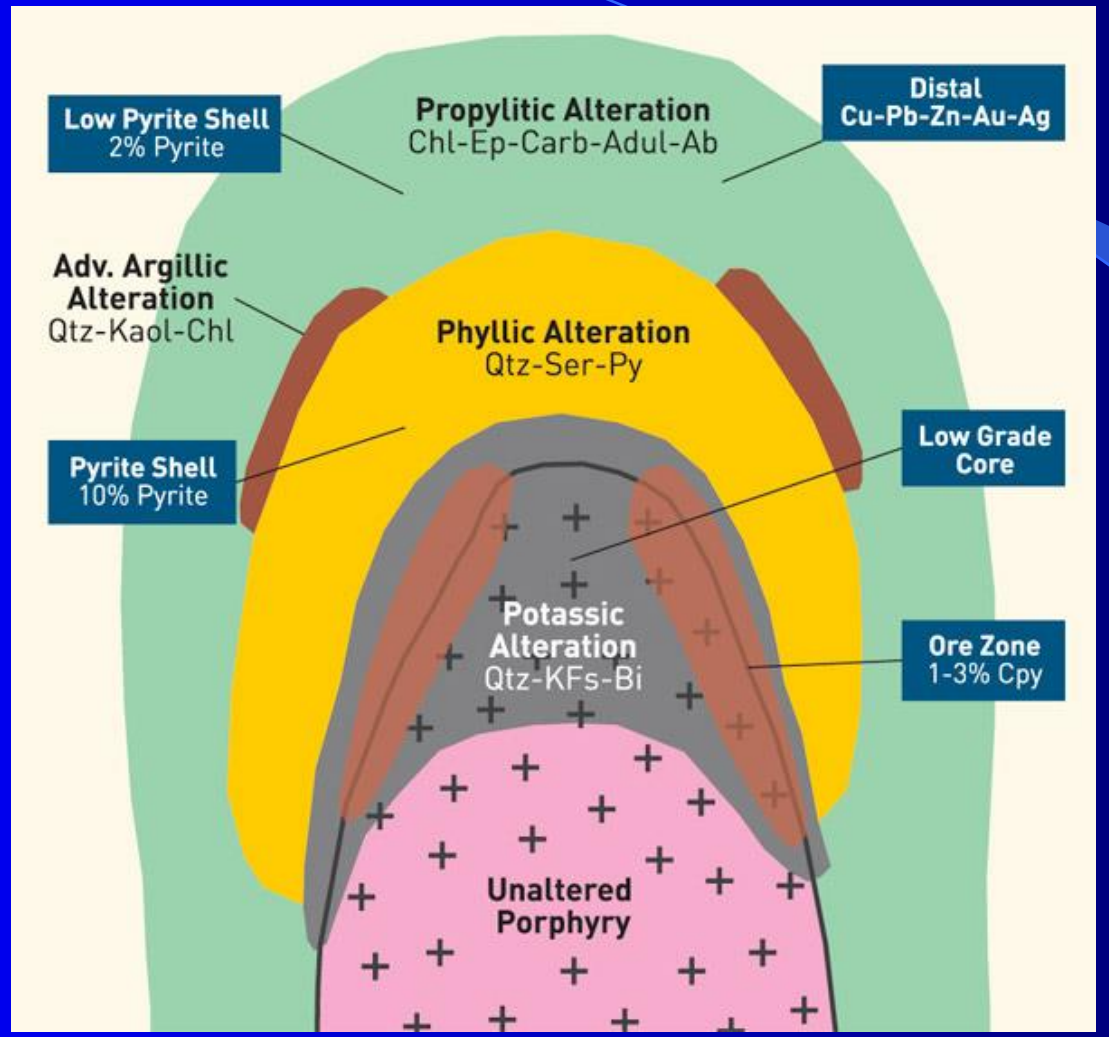
Sediment-hosted and porphyry copper deposits

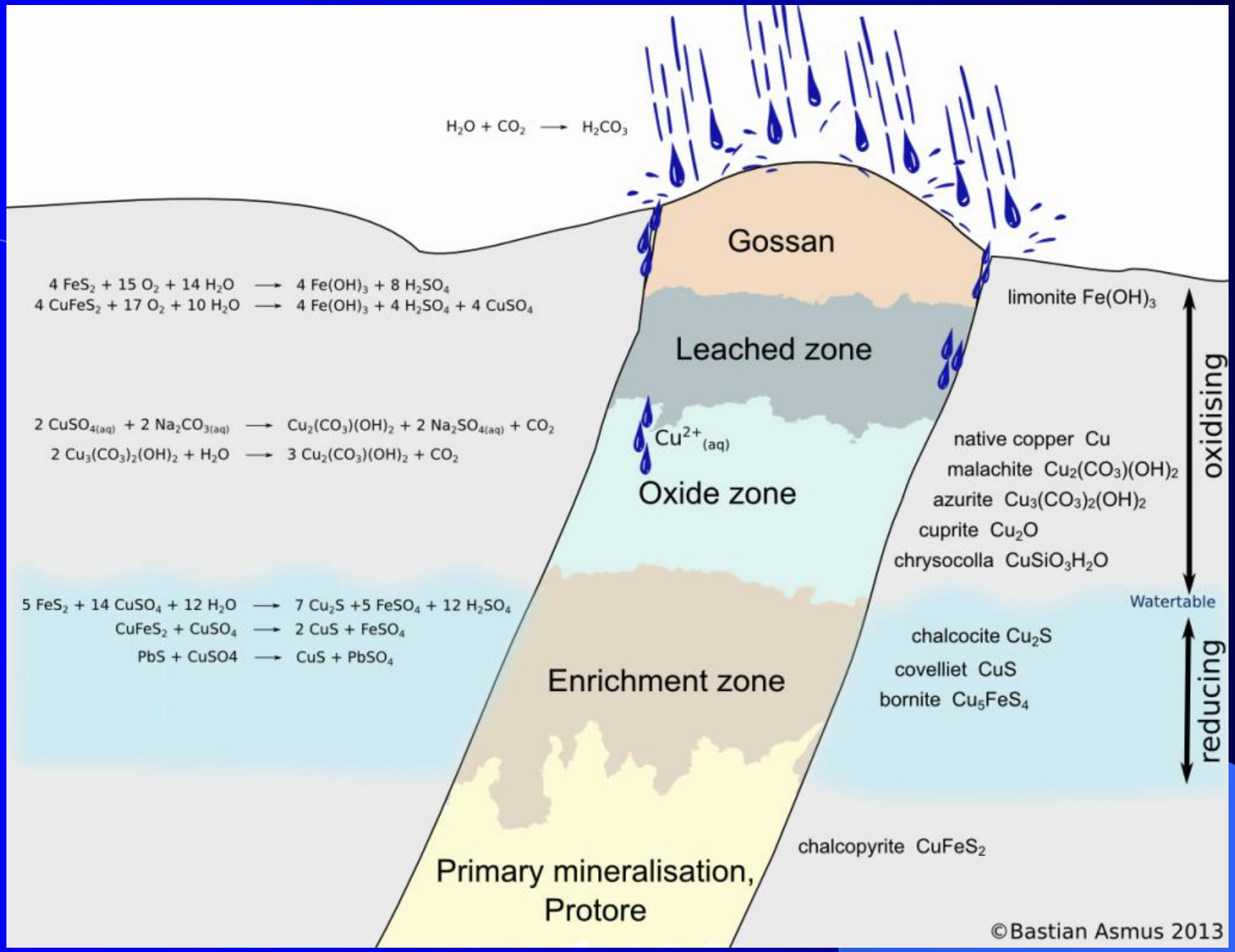




Porphyry copper deposits are associated with current or paleo subduction zones.

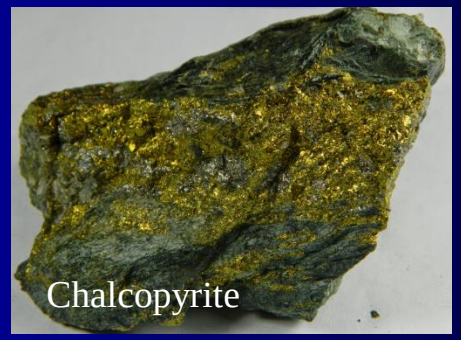
Porphyry Copper Deposit
Bingham Canyon



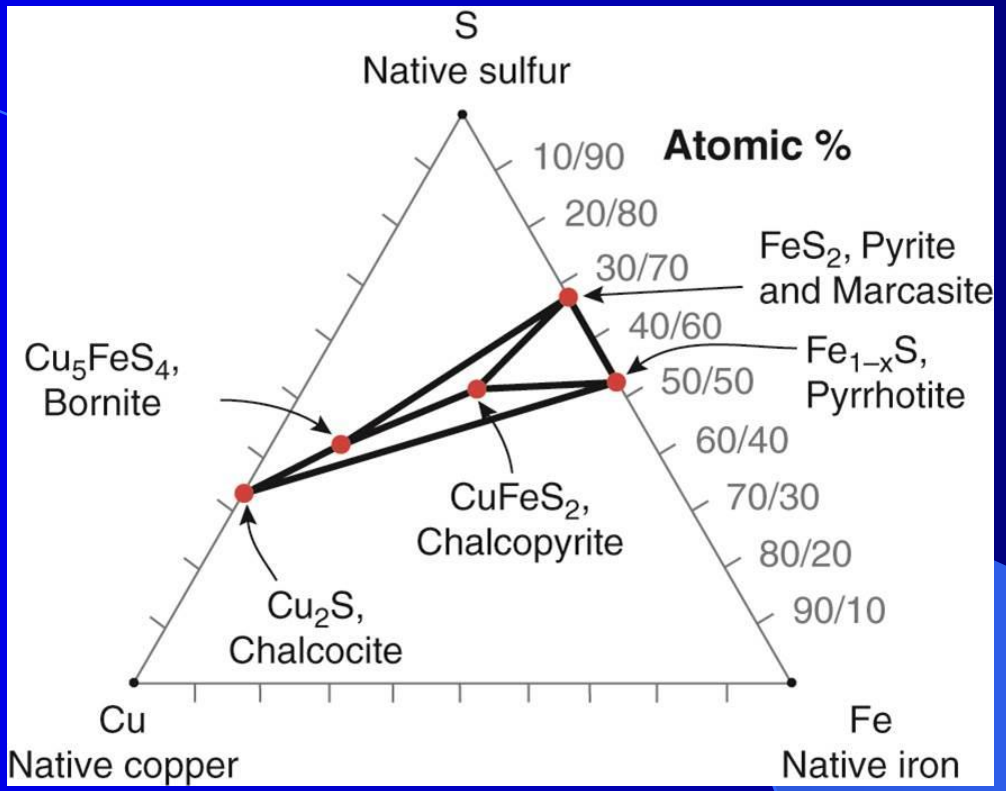

$H_2O + CO_2 \rightarrow H_2CO_3$
Gossan
$4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3 + 8\ H_2SO_4$
$4\ CuFeS_2 + 17\ O_2 + 10\ H_2O \rightarrow 4\ Fe(OH)_3 + 4\ H_2SO_4 + 4\ CuSO_4$
limonite $Fe(OH)_3$
Leached zone
$2\ CuSO_{4(aq)} + 2\ Na_2CO_{3(aq)} \rightarrow Cu_2(CO_3)(OH)_2 + 2\ Na_2SO_{4(aq)} + CO_2$
$2\ Cu_3(CO_3)_2(OH)_2 + H_2O \rightarrow 3\ Cu_2(CO_3)(OH)_2 + CO_2$
$Cu^{2+}_{(aq)}$
Oxide zone
native copper Cu
malachite $Cu_2(CO_3)(OH)_2$
azurite $Cu_3(CO_3)_2(OH)_2$
cuprite Cu_2O
chrysocolla $CuSiO_3H_2O$
oxidising
Watertable
$5\ FeS_2 + 14\ CuSO_4 + 12\ H_2O \rightarrow 7\ Cu_2S + 5\ FeSO_4 + 12\ H_2SO_4$
$CuFeS_2 + CuSO_4 \rightarrow 2\ CuS + FeSO_4$
$PbS + CuSO4 \rightarrow CuS + PbSO_4$
Enrichment zone
chalcocite Cu_2S
covelliet CuS
bornite Cu_5FeS_4
reducing
chalcopyrite $CuFeS_2$
Primary mineralisation,
Protore
©Bastian Asmus 2013


Bornite


Native sulfur


Chalcopyrite


Chalcocite



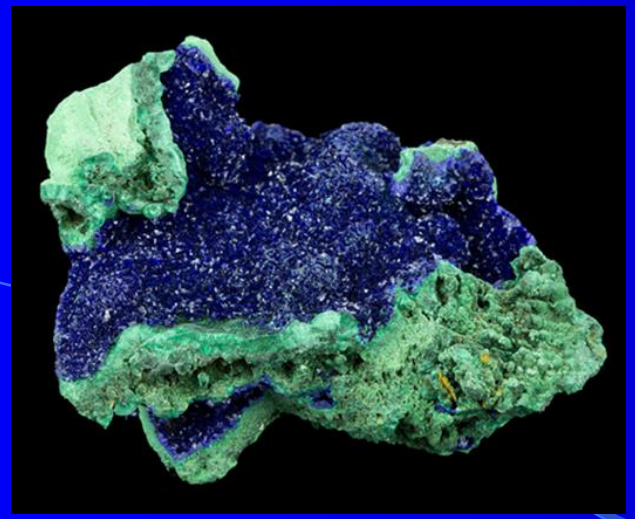

Pyrite


Native copper


Pyrrhotite

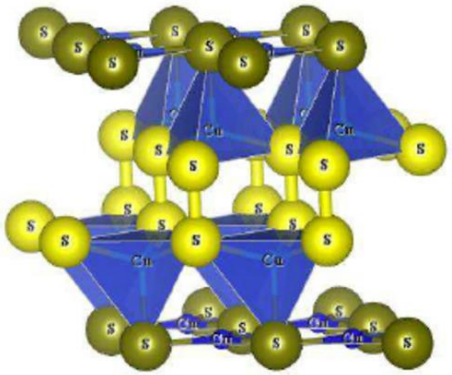
Native iron in basalt

Azurite - $Cu_3(CO_3)_2(OH)_2$ - monoclinic



Malachite - $Cu_2CO_3(OH)_2$ - monoclinic

Malachite room, Hermitage, St. Petersburg

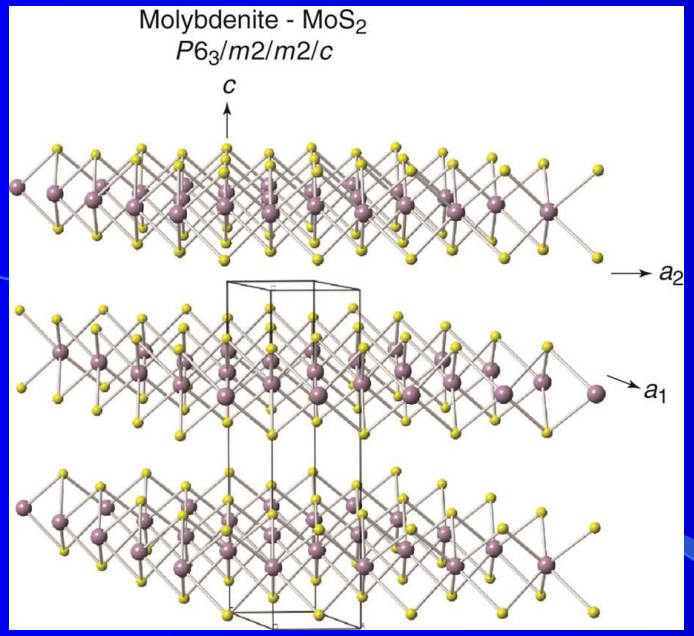


Covellite (CuS) – Hexagonal - supergene mineral

Chrysocolla [$Cu_{2-x}Al_x(H_{2-x}Si_2O_5)$]

Phyllosilicate

Formed in oxidized zones of copper ore deposits

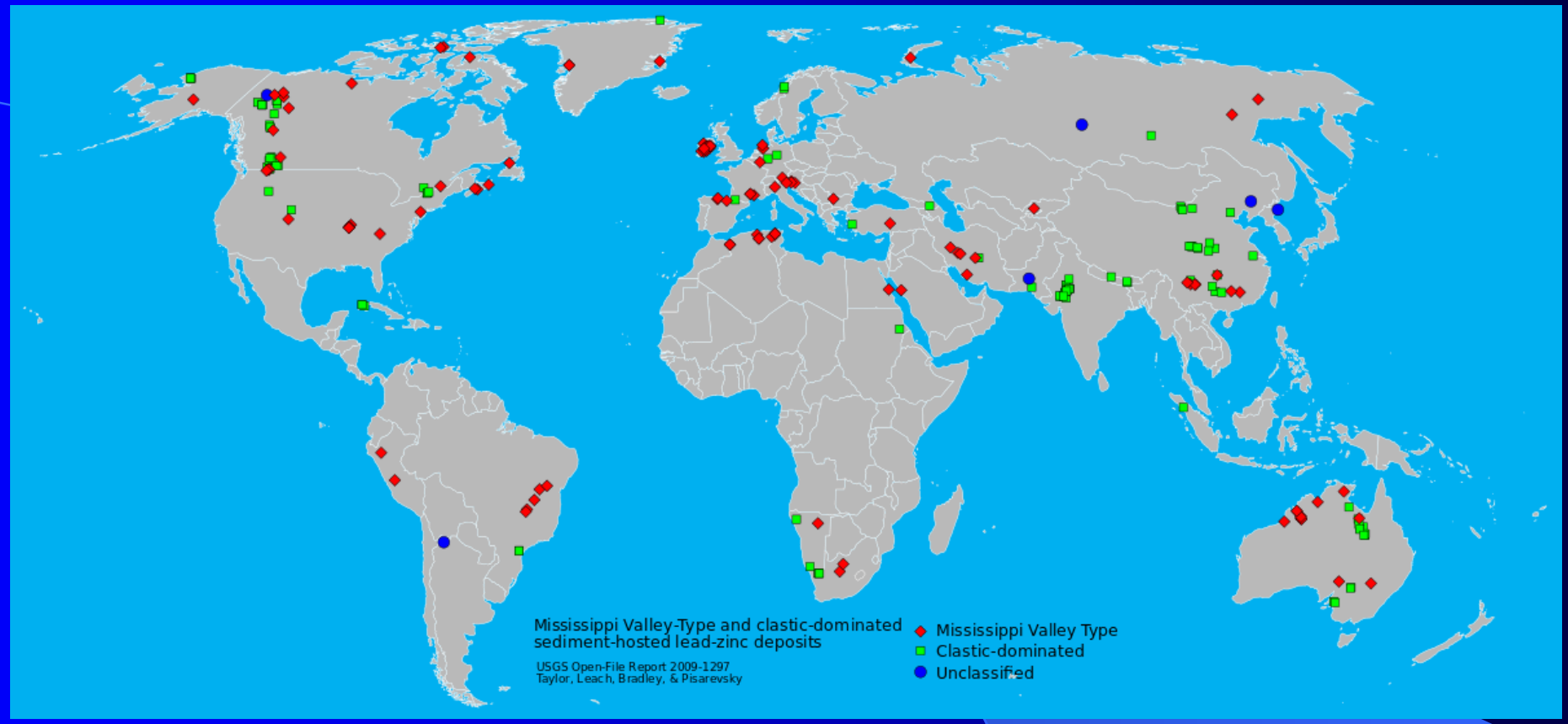


Molybdenite (MoS_2) is a hexagonal mineral.

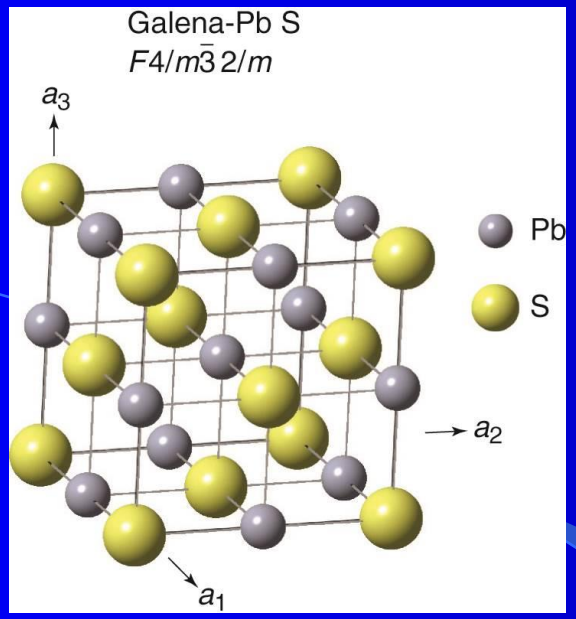
Layers are held together by weak van der Waals bonds (think graphite).

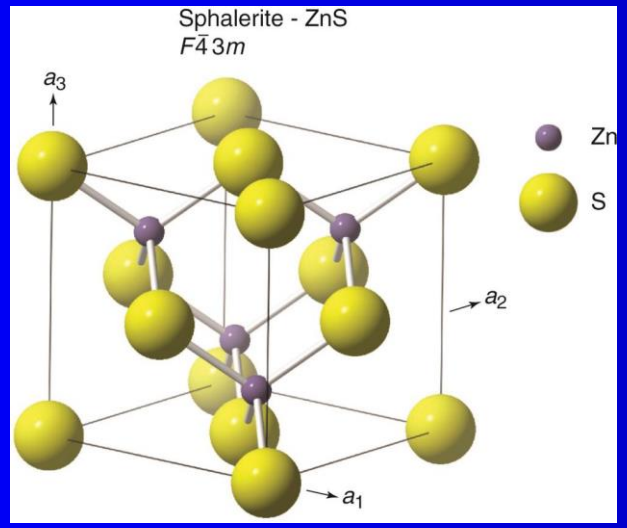
Molybdenite occurs in porphyry-type deposits.

Mississippi Valley Type Ore Deposits



Galena and Sphalerite – both minerals are isometric

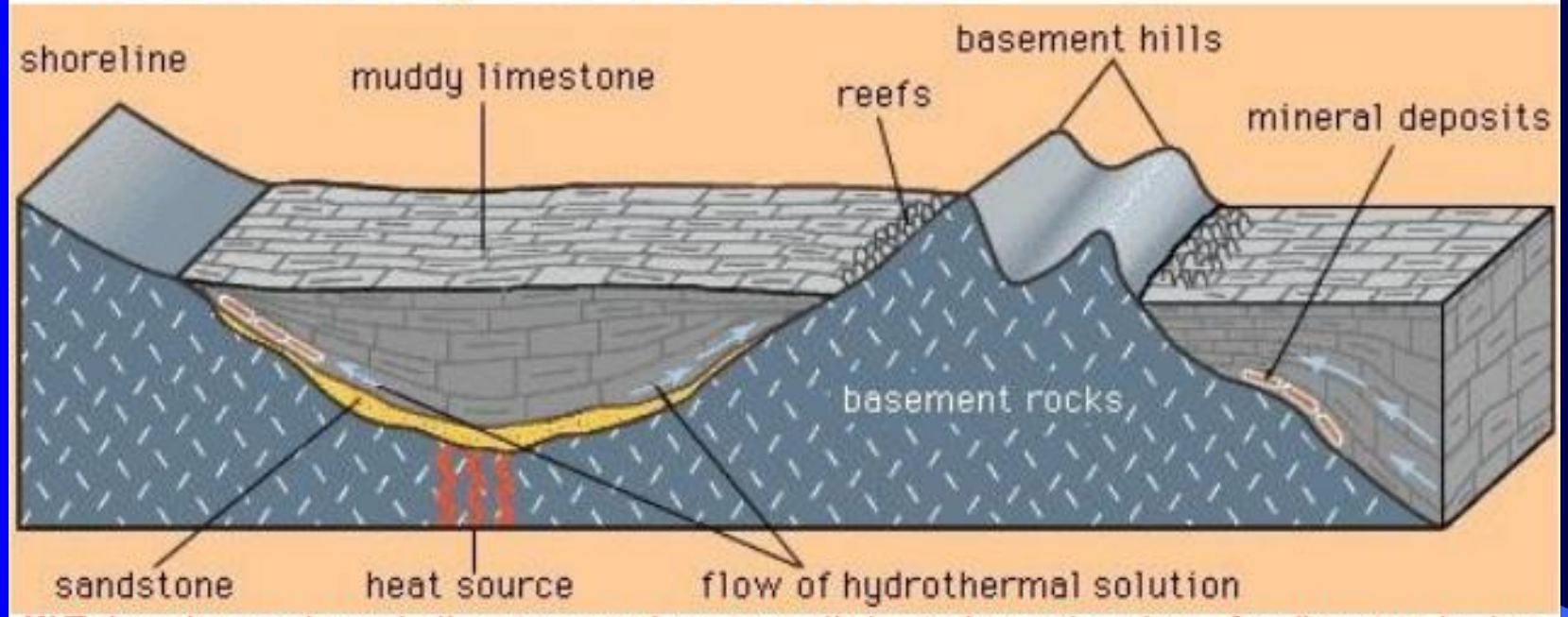




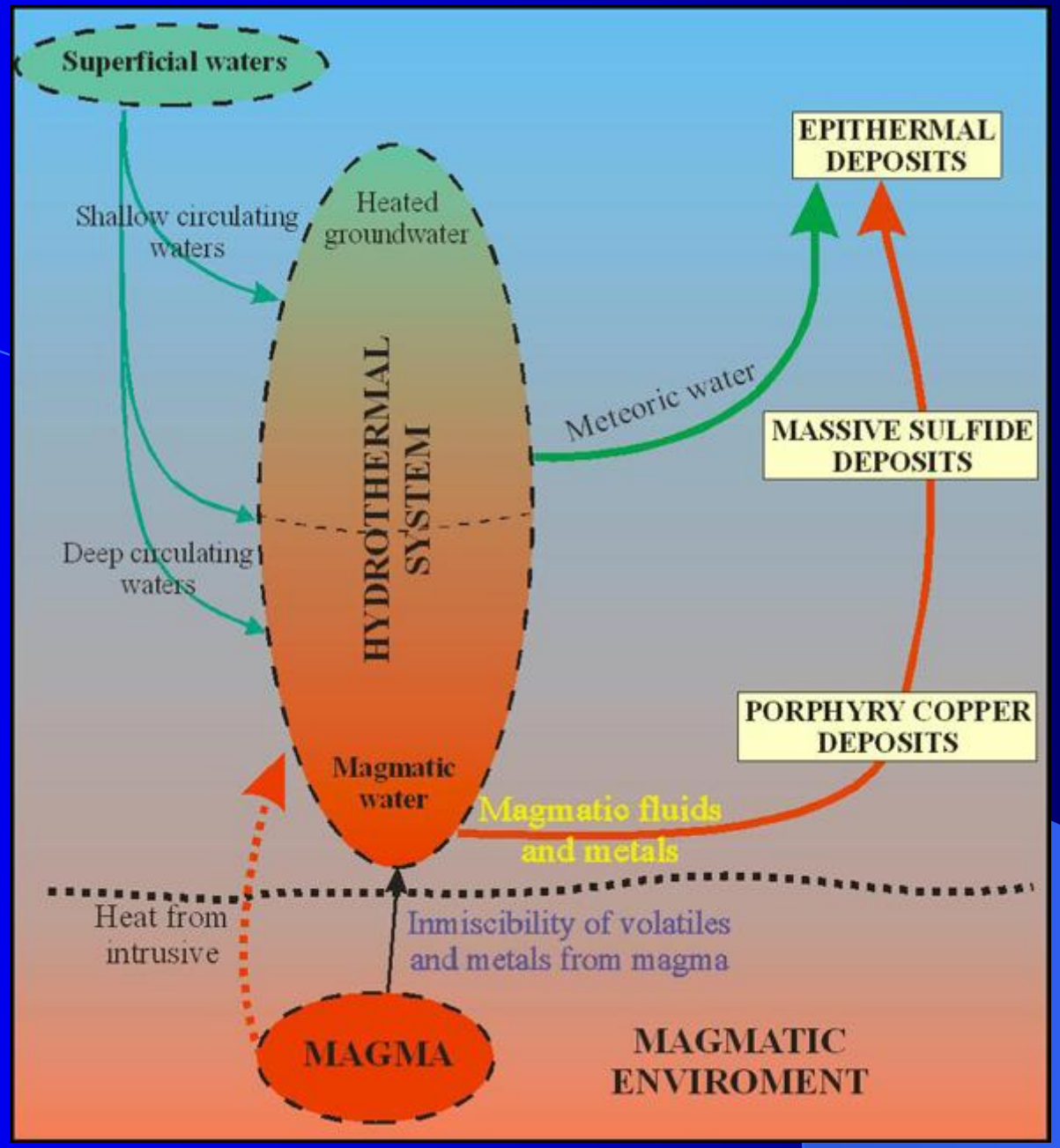
MVT Ores

Sphalerite and Galena in brecciated, dolomitized limestone

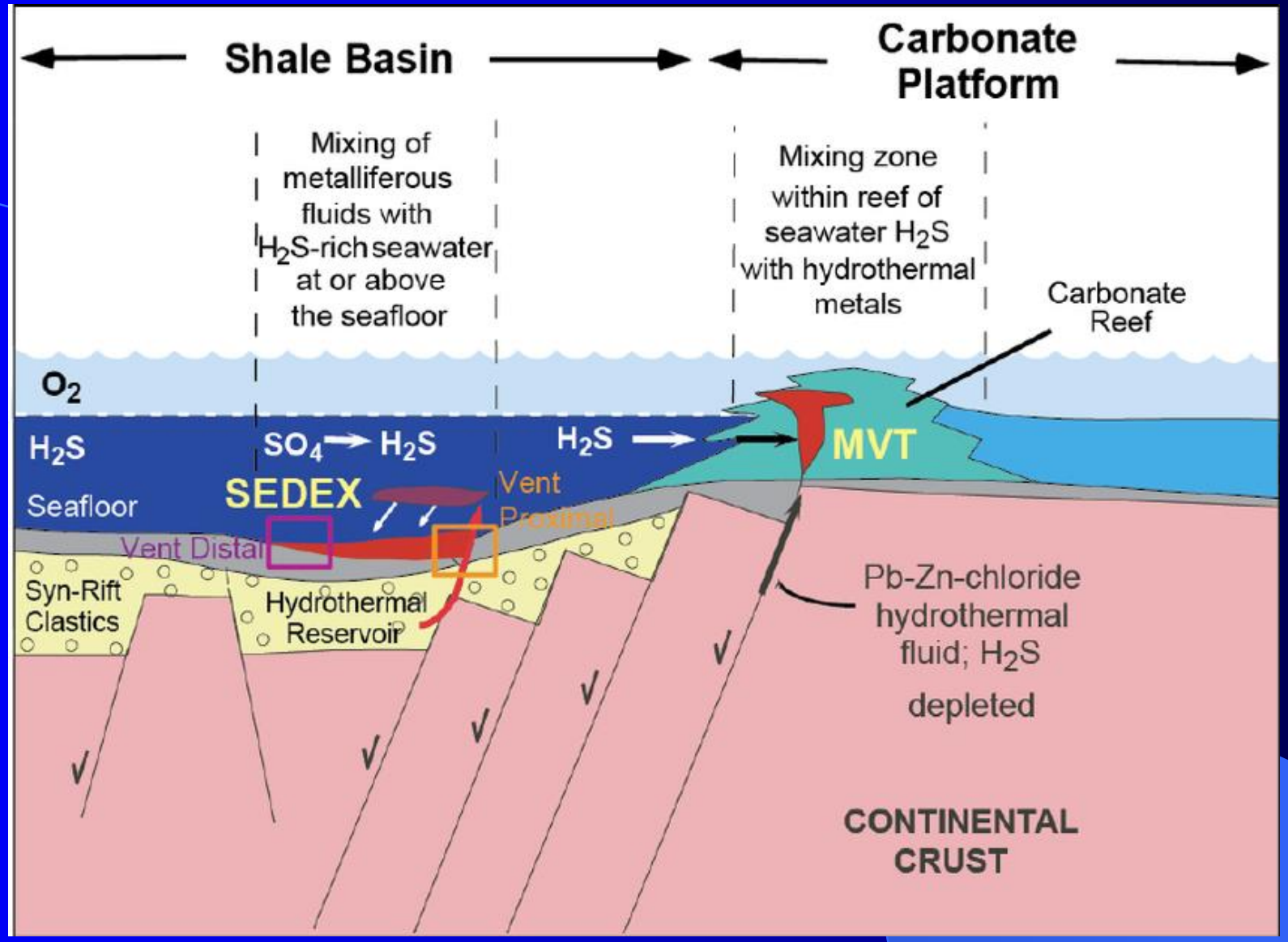
Pb-Zn originate diagenetically by mixing hydrothermal diagenetic water with near surface waters that contained reduced sulphur during diagenesis. The diagenetic process was encouraged by bacterial sulphate reduction and consumption of organic matter of the carbonate rocks. Diagenetic ore fluids were derived mainly from evaporated seawater and were driven within platform carbonates by large-scale tectonic events. In addition, magmatic fluids rich in fluorine were mixed into the diagenetic fluids. Diagenetic-hydrothermal carbonate hosted Pb-Zn mineralization is closely related to basinal evolution.



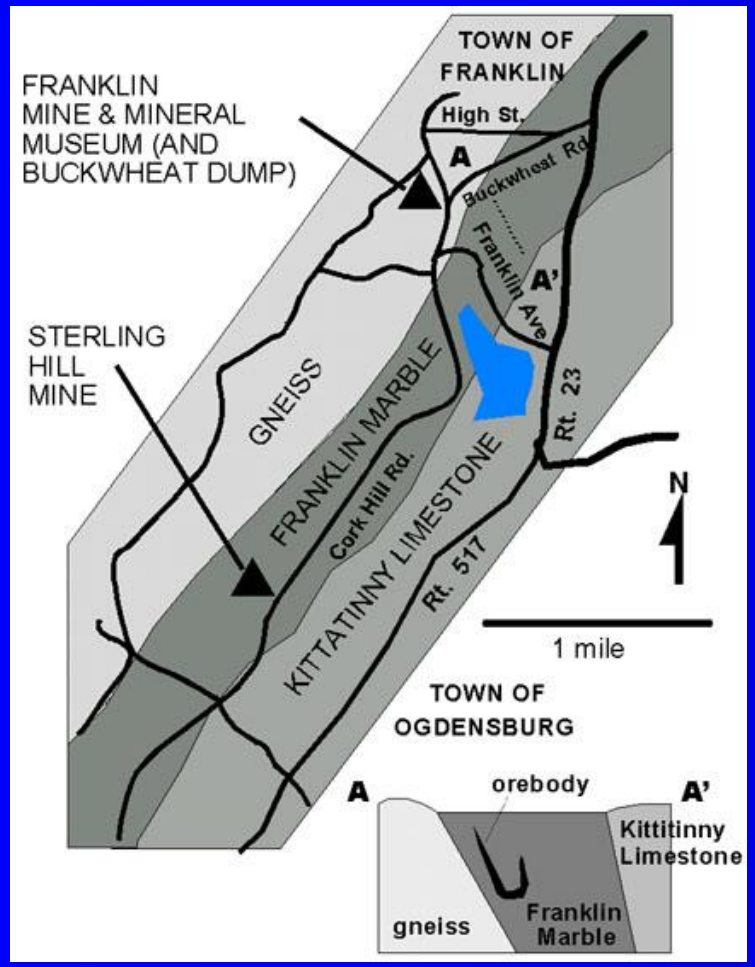
MVT deposits are always in limestones and are generally located near the edges of sedimentary basins. The hydrothermal solutions that introduced the ore minerals (principally the lead mineral galena and the zinc mineral sphalerite) apparently flowed through the sandstones and conglomerates that commonly underlie the limestones. Where they met a barrier to flow, such as a basement high or a basin edge, the solutions moved and reacted with the limestone, depositing ore minerals.

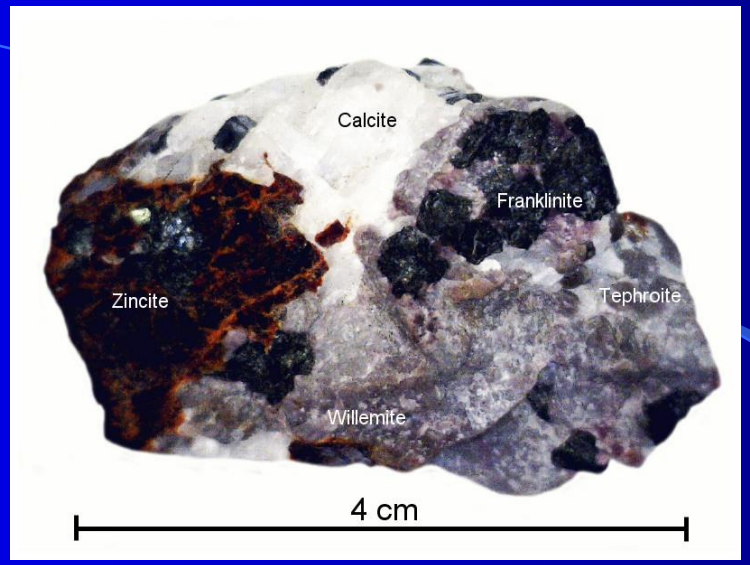

Superficial waters
Shallow circulating waters
Heated groundwater
HYDROTHERMAL SYSTEM
Deep circulating waters
Meteoric water
EPITHERMAL DEPOSITS
MASSIVE SULFIDE DEPOSITS
PORPHYRY COPPER DEPOSITS
Magmatic water
Magmatic fluids and metals
Heat from intrusive
Inmiscibility of volatiles and metals from magma
MAGMA
MAGMATIC ENVIROMENT

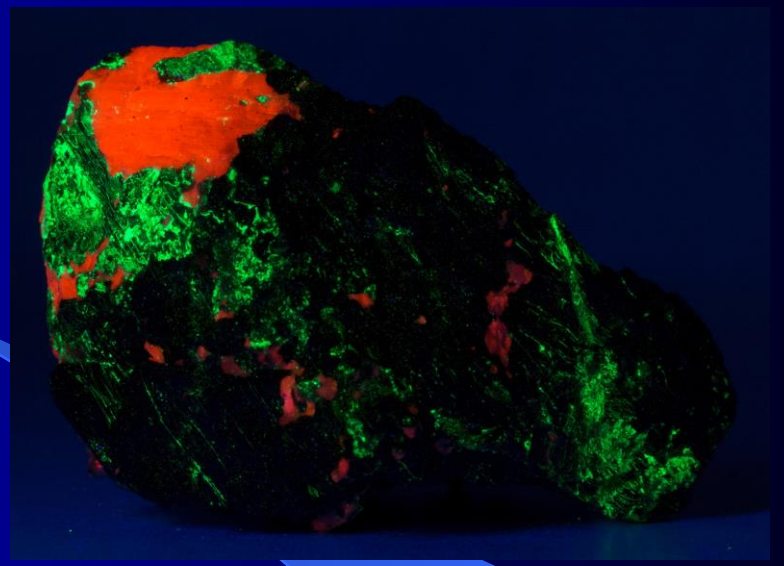
SEDEX – Sedimentary Exhalative deposits

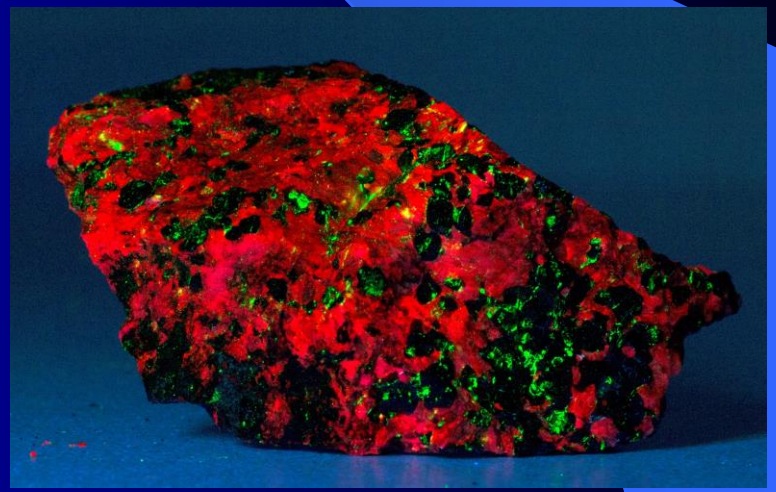


Franklin Furnace – Sterling Hill New Jersey Ore deposits.

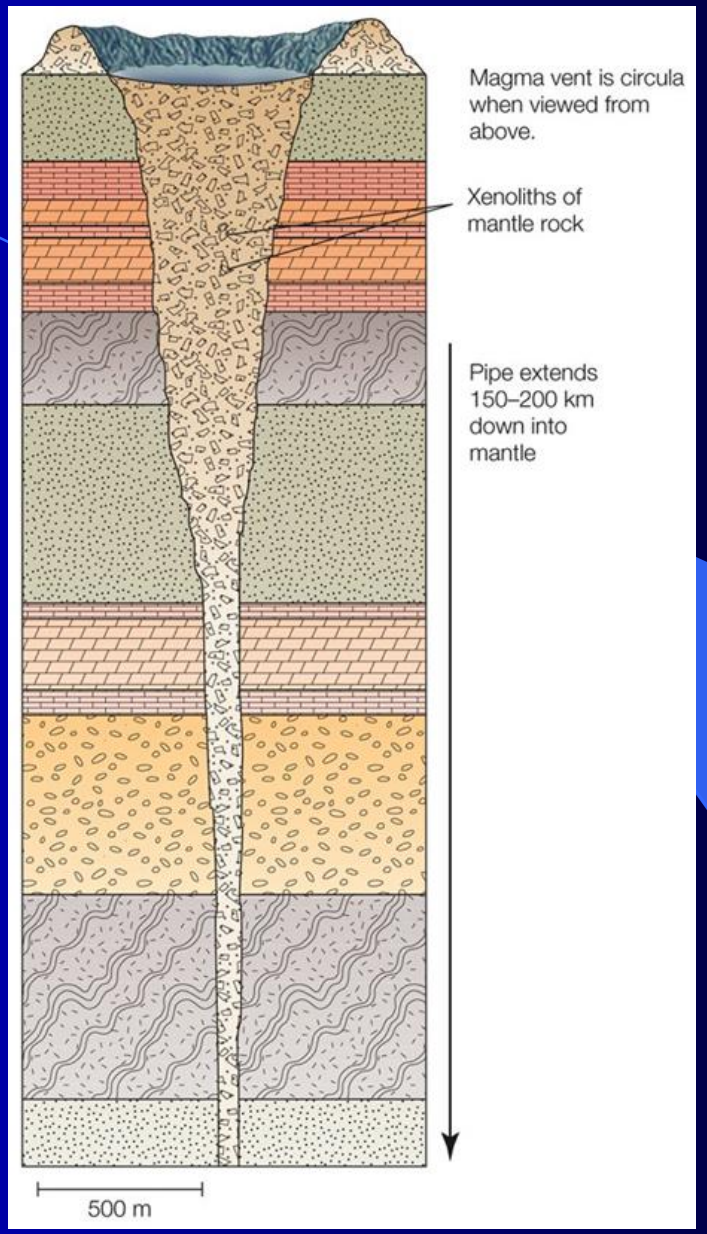


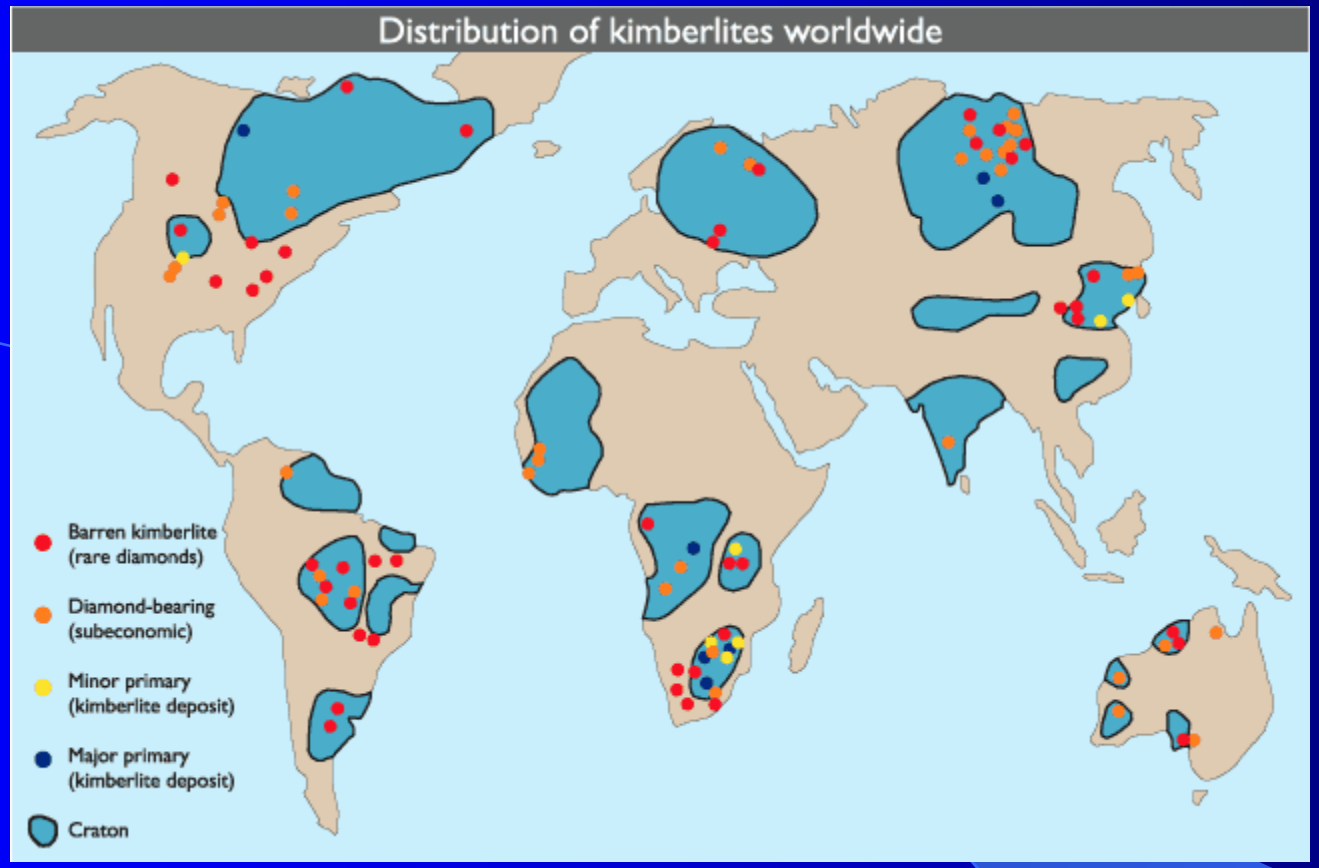


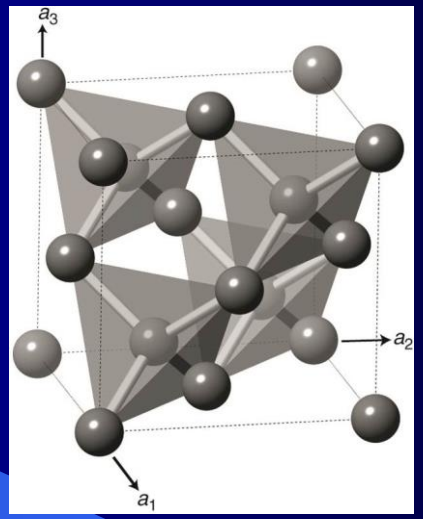




- Metamorphic ore deposits
  - Alteration and recrystallization
- Magmatic ore deposits
  - Fractional crystallization
  - Pegmatites
  - Kimberlite pipes

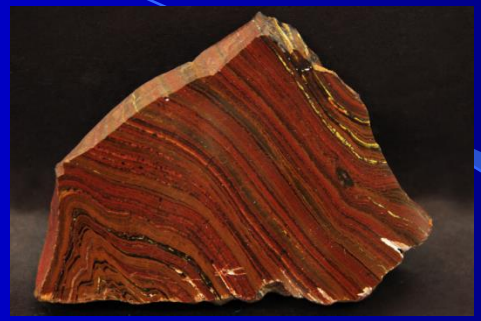



Distribution of kimberlites worldwide
Barren kimberlite (rare diamonds)
Diamond-bearing (subeconomic)
Minor primary (kimberlite deposit)
Major primary (kimberlite deposit)
Craton

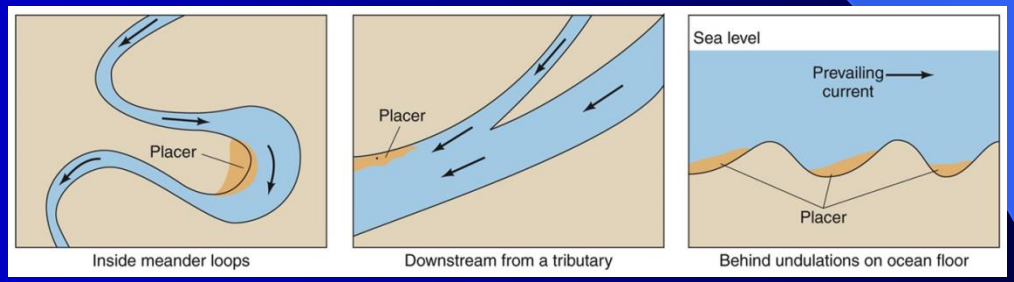

a_3
a_2
a_1

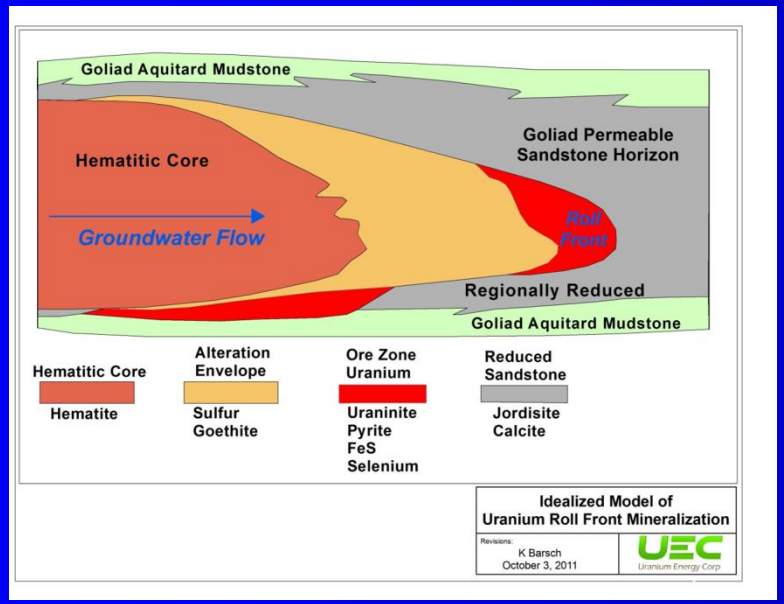

0 1 2 3 4 5 6 7 8 9 10 11 12

- Sedimentary ore deposits
  - Concentration by sedimentation
    - Precipitation by seawater or lake water
  - Evaporation
    - Evaporite deposits
  - Biochemical reactions
    - Banded iron formations

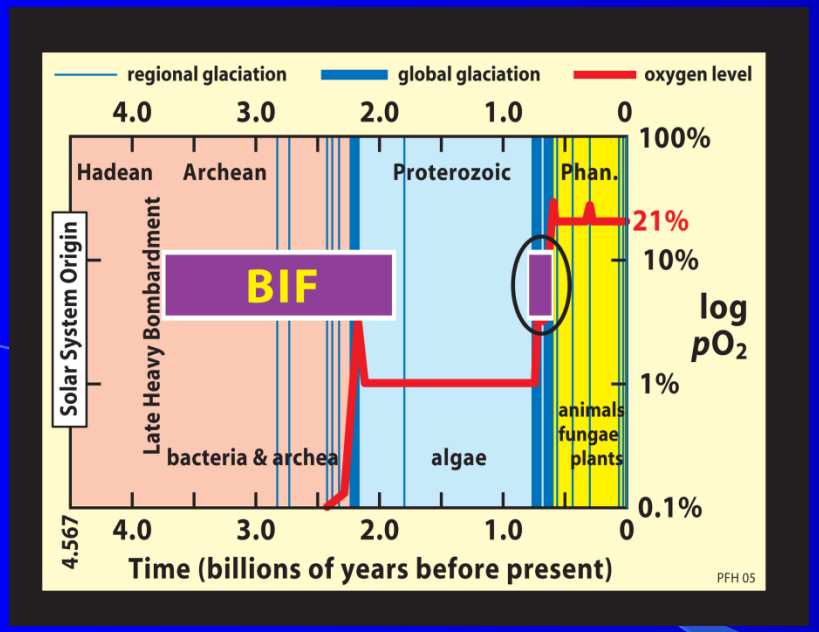


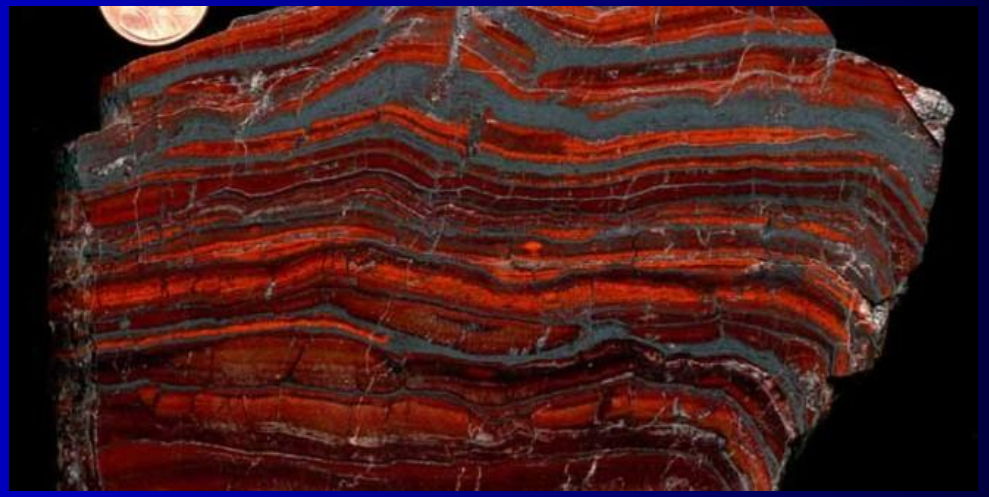
- Placer ore deposits
  - Heavy mineral grains concentrated by sifting or winnowing by flowing water

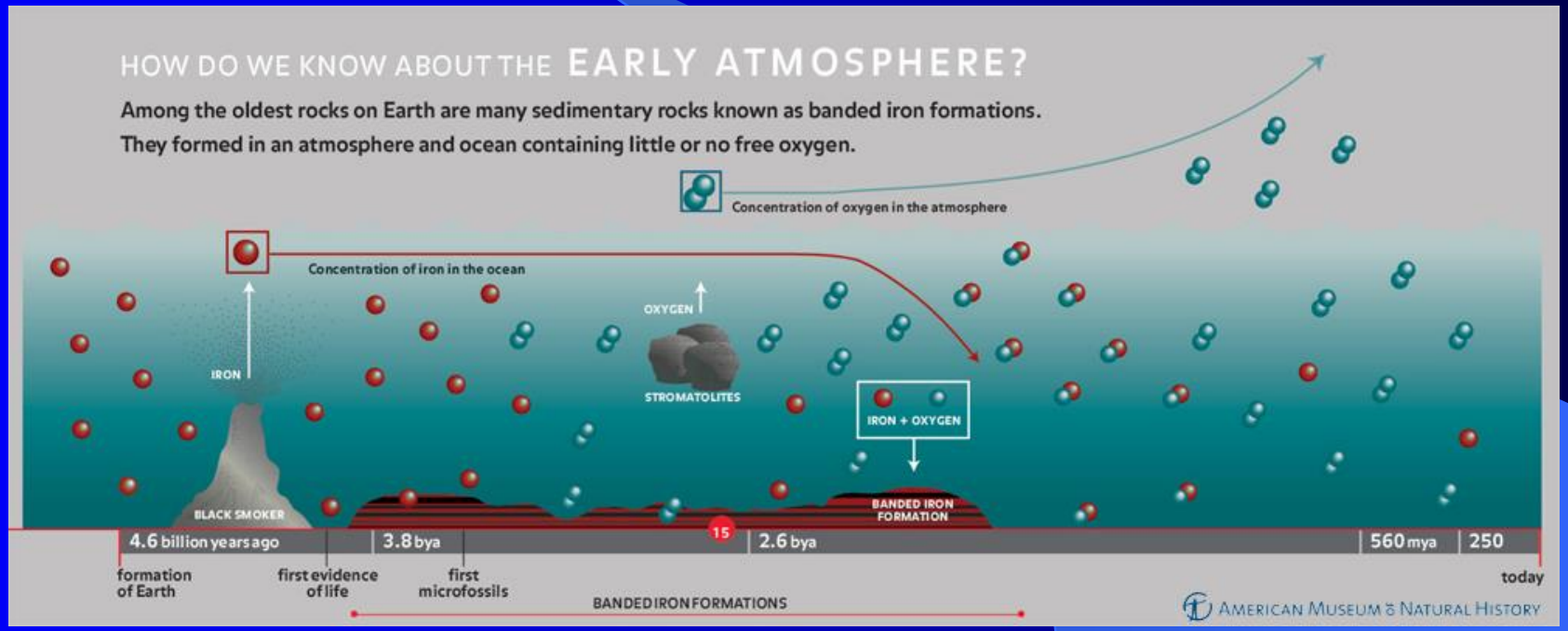




Banded Iron Formation (BIF)

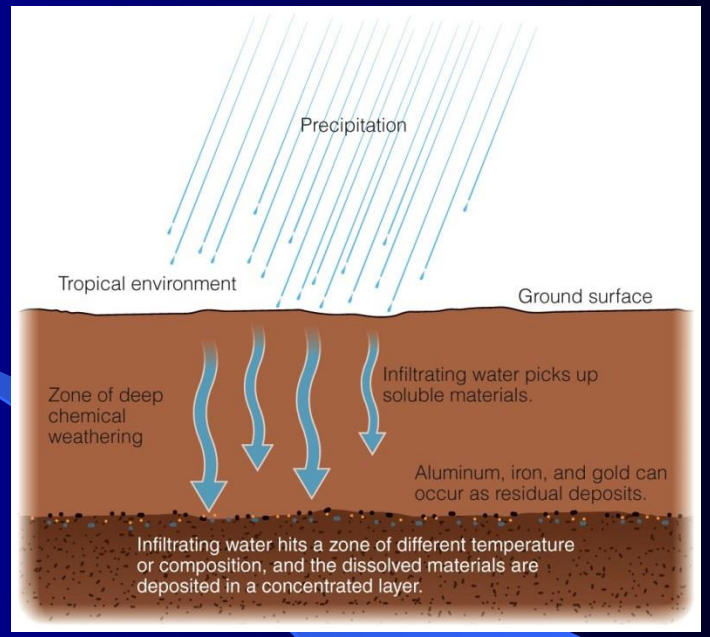






Placer gold mining

- Residual ore deposits
  - Chemical weathering
  - Removes soluble materials first, leaving a concentrated layer of insoluble minerals behind
  - Dissolved materials carried by water may be deposited in one concentrated layer
  - Laterites




World Gemstone Map
Created for JewelInfo4u.com
Russia
Alexandrite
Amber
Charoite
Diamond
Emerald
Feldspars
Garnet
Lapis Lazuli
Malachite
Nephrite
Quartz
Rhondonite
Topaz
Tourmaline
Spain
Aventurine
Quartz
Poland
Amber
Venezuela
Diamond
Jasper
Pearls
Canada
Amethyst
Ammolite
Garnet
Labradorite
Sodalite
Egypt
Peridot
Guyana
Diamond
Iran
Turquoise
Afghanistan
Aquamarine, Lapis
Tourmaline, Ruby
Japan
Coral
Jadeite
Pearls
Quartz
Rhodonite
Topaz
Brazil
Agate
Amazonite
Chalcedony
Chrysoberyl
Diamond
Emerald
Garnet
Opal
Beryl
Quartz
Sodalite
Spodumene
Topaz
Tourmaline
Argentina
Rhodochrosite
Pakistan
Aquamarine, Emerald,
Garnet, Ruby, Topaz
Myanmar
Amber
Chrysoberyl
Jadeite
Moonstone
Peridot
Rock Crystal
Ruby
Sapphire
Spinel
Topaz
Tourmaline
Zircon
China
Amber
Amethyst
Aquamarine
Diamond
Nephrite
Pearls
Peridot
Ruby
Sapphire
Turquoise
USA
Aquamarine
Chalcedony
Emerald
Feldspars
Garnet
Nephrite
Peridot
Quartz
Ruby
Sapphire
Spodumene
Topaz
Tourmaline
Turquoise
Chile
Lapis lazuli
Srilanka
Amethyst
Chrysoberyl
Garnet
Moonstone
Ruby
Sapphire
Spinel
Topaz
Tourmaline
Zircon
South Africa
Diamond
Emerald
Garnet
Peridot
Precious beryl
Quartz
Rhodochrosite
Ruby
Tourmaline
Verdite
Madagascar
Agate
Aquamarine
Chrysoberyl
Feldspars
Garnet
Precious Beryl
Quartz
Topaz
Tourmaline
Mexico
Agate
Feldspars
Fire Opal
Quartz
Topaz
Turquoise
Colombia
Emerald
Thailand
Garnet
Ruby
Sapphire
Zircon
Australia
Chrysoprase
Coral
Diamond
Emerald
Jasper
Nephrite
Opal
Pearls
Sapphire
India
Aquamarine
Chalcedony, Chrysoberyl
Diamond, Diopside
Emerald, Garnet
Jasper, Moonstone
Pearls, Quartz
Rhondonite, Ruby
Sapphire
Sodalite
Nigeria
Aquamarine
Sapphire
Spinel
Tourmaline
Zambia
Chrysoberyl
Emerald
Malachite
Zimbabwe
Aquamarine
Chrysberyl
Emerald
Garnet
Topaz
Tourmaline
Vedite
Ghana
Diamond
Angola
Diamond
Congo
Diamond
Botswana
Diamond
Namibia
Aquamarine
Diamond
Topaz
Tourmaline
New Zealand
Nephrite
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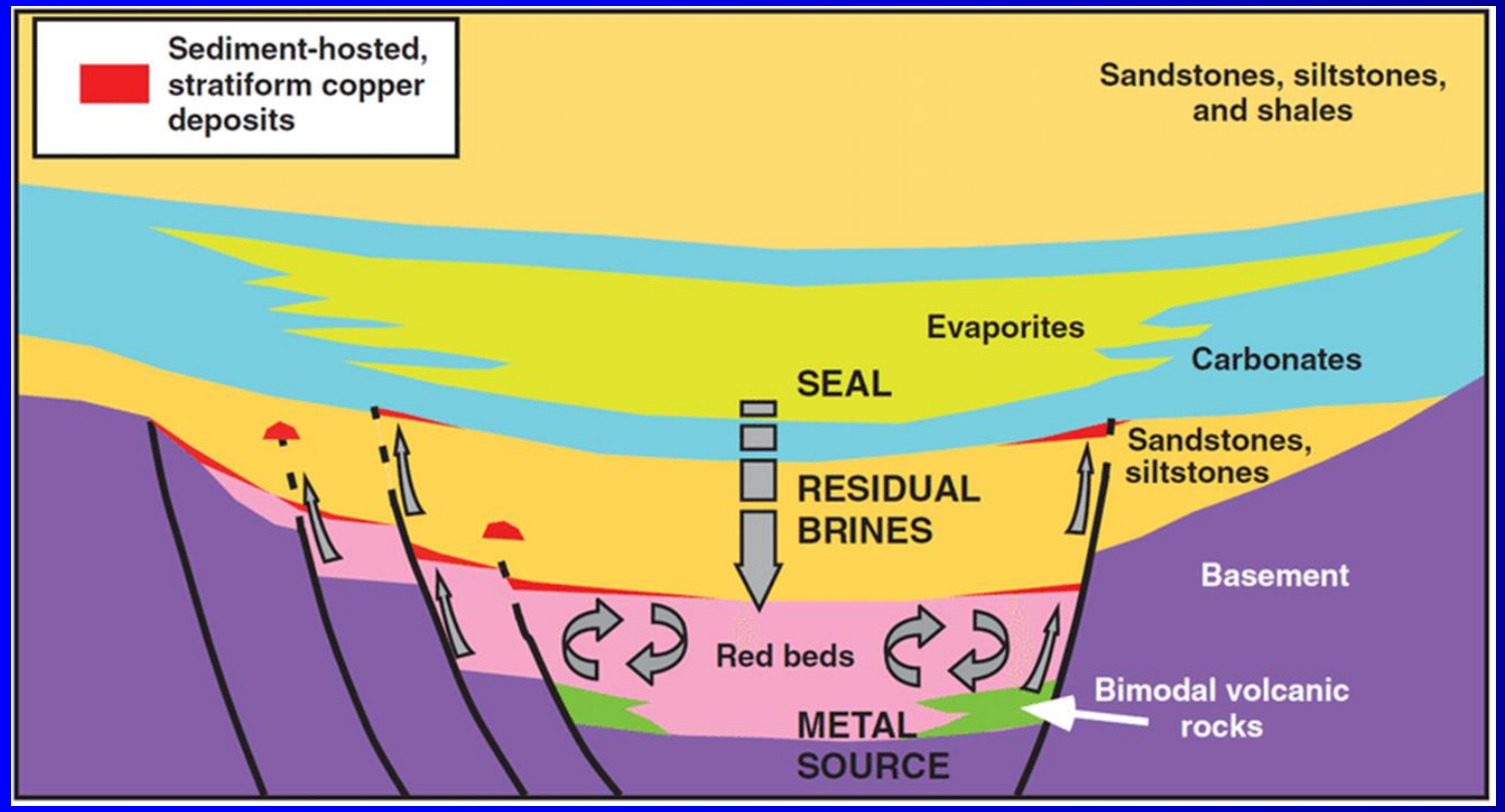
Gemstones
diamond
sapphire
ruby
emerald
garnet
peridot
aquamarine
topaz
amethyst
opal
citrine
zircon

Sediment-hosted Stratiform Copper Deposits




Minerals and Forensic Investigations
Elementary my dear Watson

First Forensic Geology Case

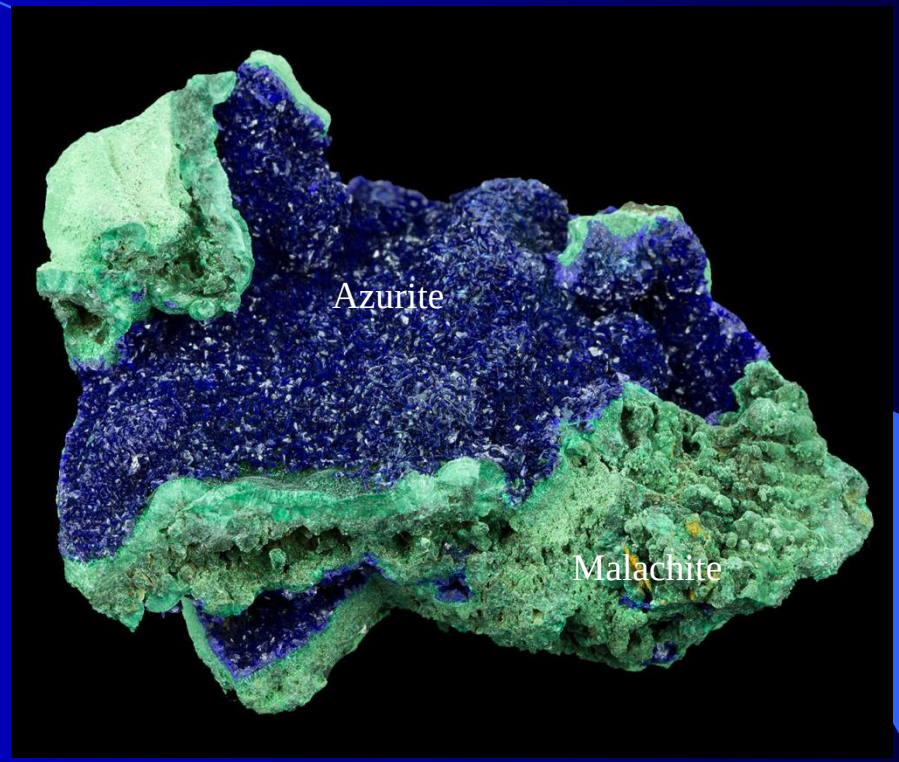
- In October of 1904 the strangled body of Eva Disch was found near Frankfurt, Germany
- When Georg Popp was called in he examined a filthy handkerchief found at the scene that contained bits of hornblende, snuff, and coal
- A suspect, Karl Laubach, used snuff, worked at the coal-burning local gas works, and at a quarry that had hornblende bearing rocks
- The suspect also had mica in the cuffs of his trousers that matched mica at the murder scene

Junger Case

Location: Front Royal, Va.

Crime: Homicide

Evidence: Soil on the Suspect's vehicle compared with soil from the crime scene at a river crossing. Samples contained Malachite and Azurite from an abandoned copper mine just up stream. The soft copper minerals were not found a short distance downstream.
(thanks to Ray Murary)



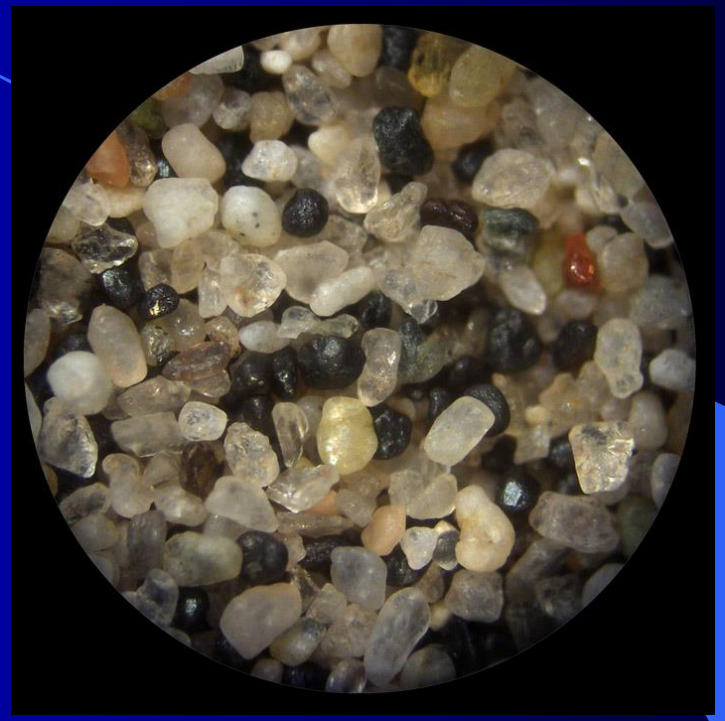
The Reeves Murder Case

In September of 1958 a woman's body was found at the edge of the Anacostia River in Washington, D.C. A peculiar black sand was found on the victim, in a suspect's car, and at the murder scene. Geologic investigation showed that the sand was blast furnace slag that had been spread on a small section of highway to test it for use in the control of snow and ice.

(Block, 1979 p.149-152)

Sand from a Construction Site

In southern Ontario a man was arrested and charged with the beating death of the young girl. The scene of the crime was a construction site adjacent to a newly poured concrete wall. The soil was sand that had been transported to the scene for construction purposes. As such, the sand had received additional mixing during the moving and construction process and was quite distinctive. The glove of the suspect contained sand that was similar to that found at the scene and significantly different in composition and particle size from the area of the suspect's home. This was important because the suspect claimed the soil on the gloves came from his garden. *(Murray and Tedrow, 1992 , p. 16)*



Commercial Foundry Sand

- Sands of heavy minerals, olivine, zircon, etc. are used in foundry work
- In a breaking and entering case at a foundry in Toronto, Canada a suspect's shoes had grains of olivine sand
- Because olivine sand is not found in place in that part of Canada the sand on the shoes indicated that the suspect had been at the foundry. *(Murray and Tedrow, 1992 , p. 79)*