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# Economic Geology

## Precious and rare metals and their ore deposit types

Module 5

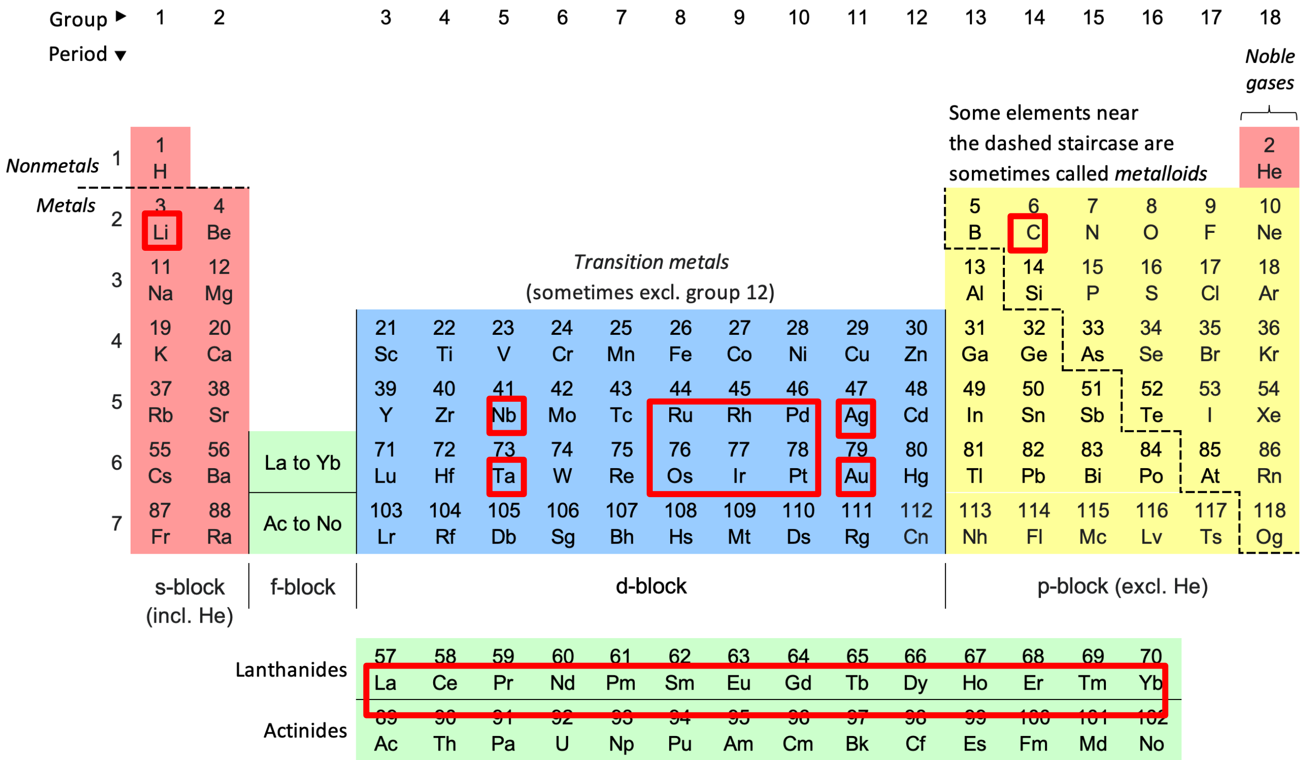
Thomas Ulrich
Institute for Disposal Research

# Content and structure

- Module 1: Intro, element abundance, plate tectonics, economics
- Module 2: Minerals, Rock types
- Module 3: Ore forming processes
- Module 4: Base metals and their ore deposit types
- **Module 5: Precious and rare metals and their ore deposit types**
- Module 6: Sustainability
- Module 7: Summary

# Structure of this part

- In the following, different precious and rare metals will be discussed in relation to their uses and in which type of ore deposit they can be found.



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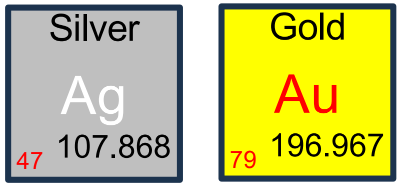
# Precious and rare metals

- Gold and silver (Au-Ag)
- Carbon (diamonds)
- Platinum group elements (PGE)
- Rare earth elements (REE)
- Lithium (Li)
- Tantalum and niobium (Ta-Nb)

# Deposit types for precious and rare metals

- Magmatic sulphide deposits
- Magmatic deposits (granites, carbonatites)
- Hydrothermal deposits
- Placer deposits
- Brine deposits
- Supergene enrichment

# Au-Ag




- Gold and silver
- Uses of gold
- Gold and silver deposits
  - Orogenic Au deposits
  - Epithermal deposits
  - Placer deposits

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# Gold

Gold
Au
79 196.967

- Corrosion resistant, soft metal
- Ore mineral(s): native gold (Au), electrum (AuAg), pyrite
- Top suppliers: China, Australia, Canada, South Africa, Russia
- Reserves: 52‘000 t
- Resources: 33‘000 t

USGS 2022

# Gold uses

Gold
Au
79 196.967

- Jewellery
- Bars
- Coins
- Wires
- Nanoparticles

# Silver

Silver
Ag
47 107.868

- Soft metal, tarnishes slowly
- Ore mineral(s): native silver (Ag), argentite, galena
- Top supplier: Mexico, Peru, China
- Reserves: 550‘000 t
- Production: 26‘000 t

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# Silver uses

Silver
Ag
47 107.868

- Jewellery
- Solder
- Tableware, mirrors
- Nanoparticles

# Au-Ag-deposits

- Orogenic deposits
- Epithermal deposits
- Placer deposits (Au)

# Orogenic Au deposits

- Metamorphic-hydrothermal deposits.
- Fluids are generated due to release of $H_2O$ and $CO_2$ from metamorphic reactions.
- Mineralization occurs mainly in veins (cm to m wide) related to large shear zones.
- High-grade, low tonnage.
- Ore body elongated, irregular

# Orogenic Au deposits: geological setting

- Archaean and Early Protoerozoic greenstone belts (deformed volcanic-sedimentary sequences and later intrusions). In Canada, W-Australia, Africa
- Slate belts (deformed turbidite sequences). S-Australia
- Cordilleran type belts (batholite intrusions)

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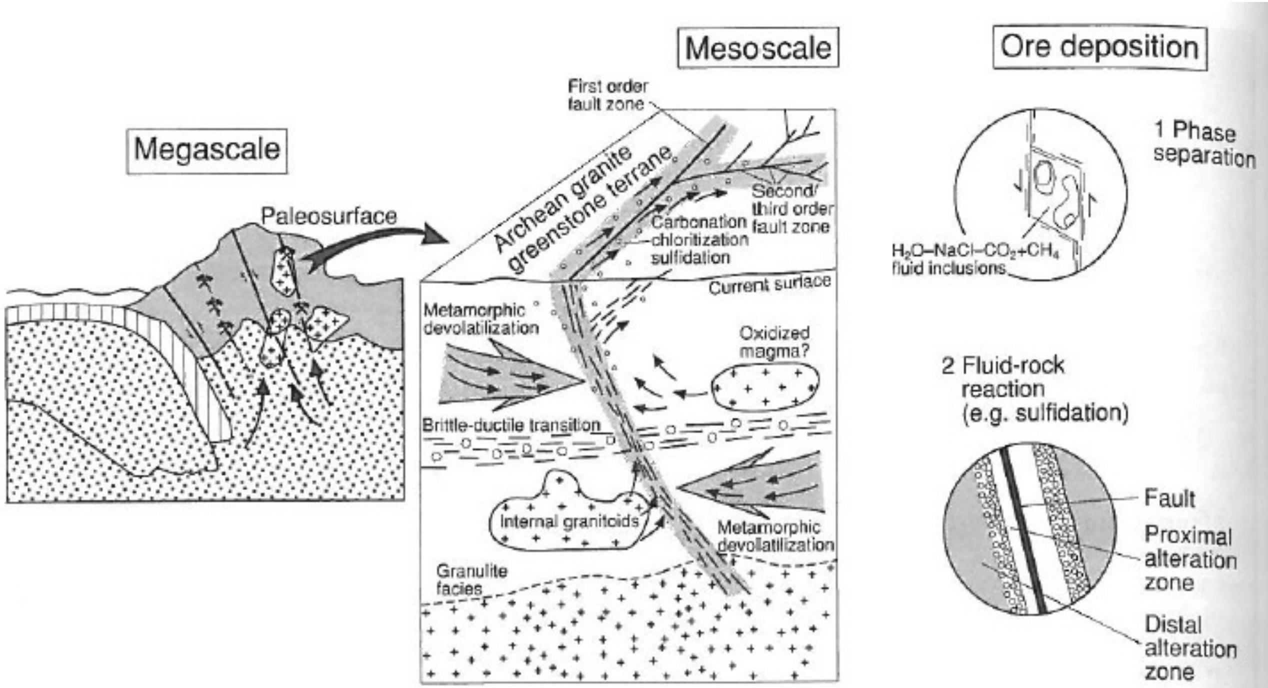
# Orogenic Au deposits

- Metamorphic $H_2O$-$CO_2$ fluids associated to regional metamorphism at convergent plate margins. Fluid flow driven by pressure fluctuation during seismic events.
- Older terms are mesothermal or lode-gold deposits.
- Characterized by qtz veins and fracture-related textures.
- Associated with deep shear zones and greenstone stone belts (Archean)

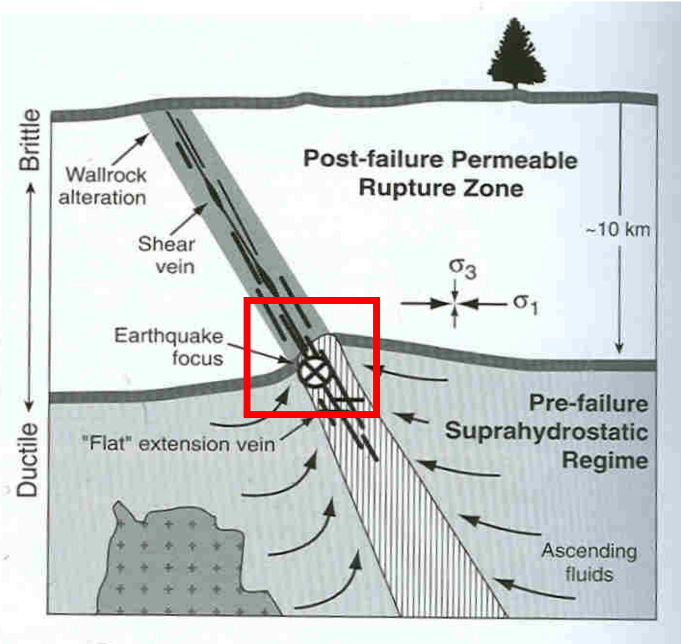


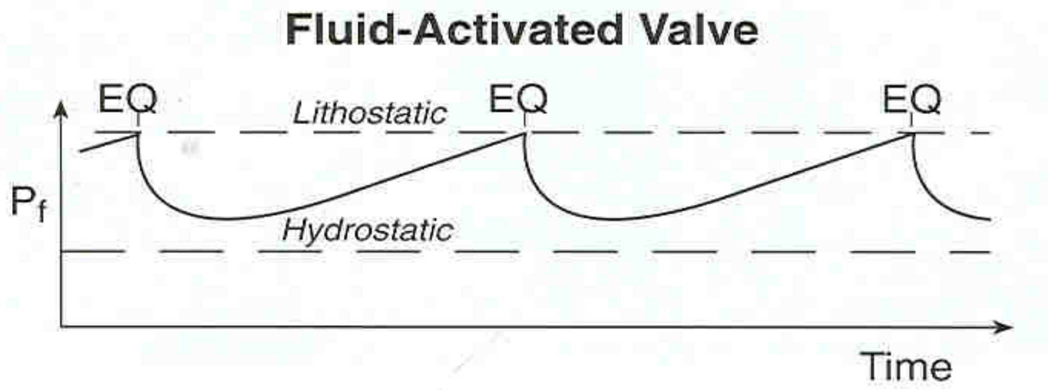

Hagemann and Cassidy 2000

# Orogenic Au deposits

Fault valve model for vein formation
(Sibson et al., 1988, Geology):

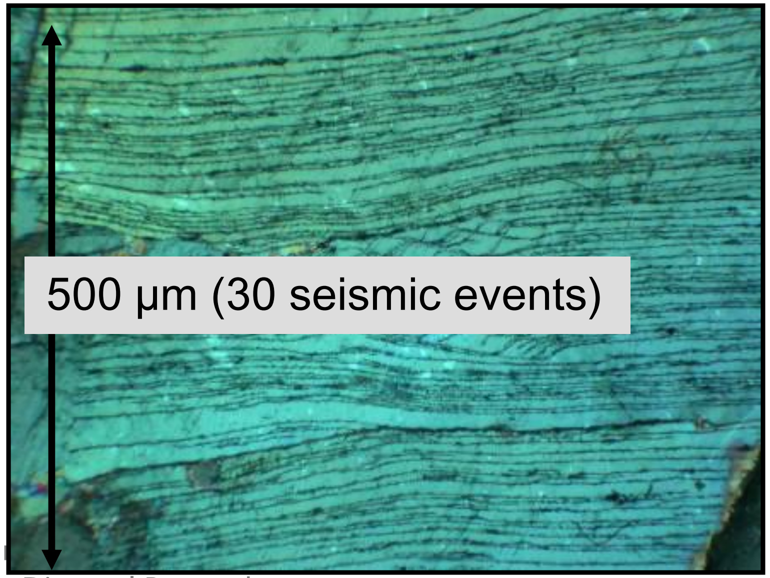
▪ Fluid overpressures are predicted by this model for vein emplacement. In this model, rupture (EQ) and vein formation is the result of:
P(H) > P(L) + T(rock).
This is cyclic and pulses, hence, many vein events occur.



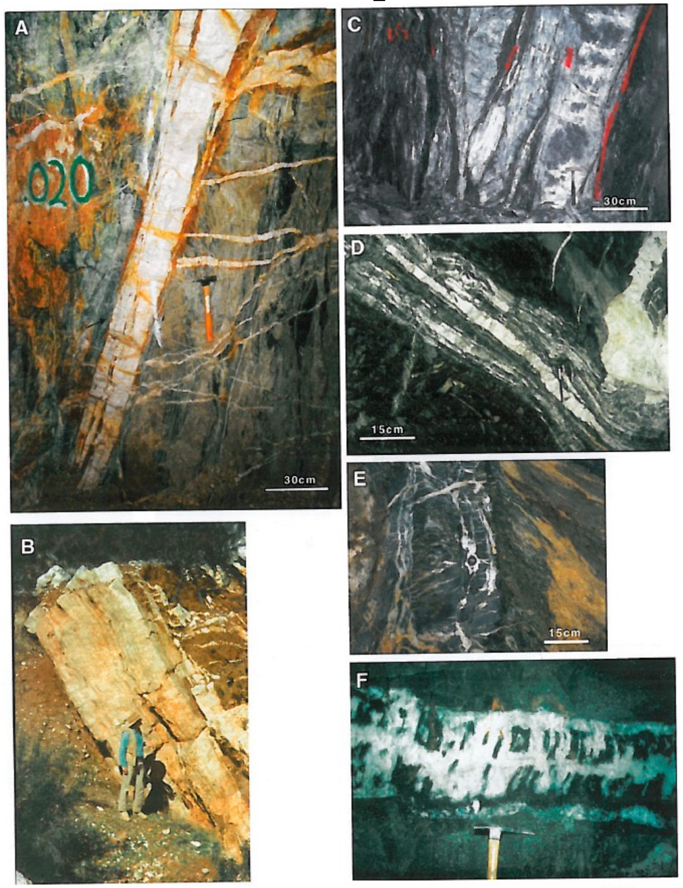



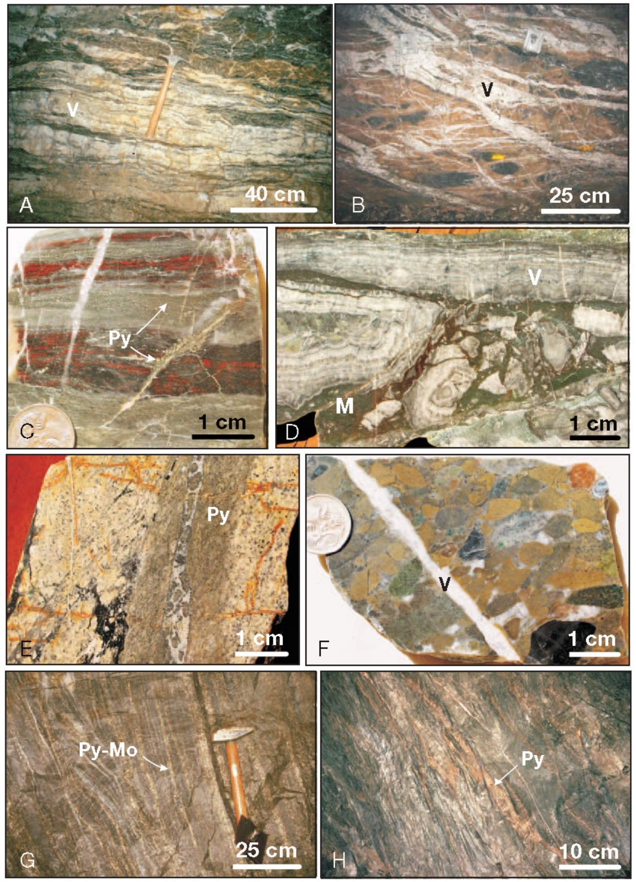
# Orogenic Au deposits

Repeated opening and closing of vein structures




# Orogenic Au deposits



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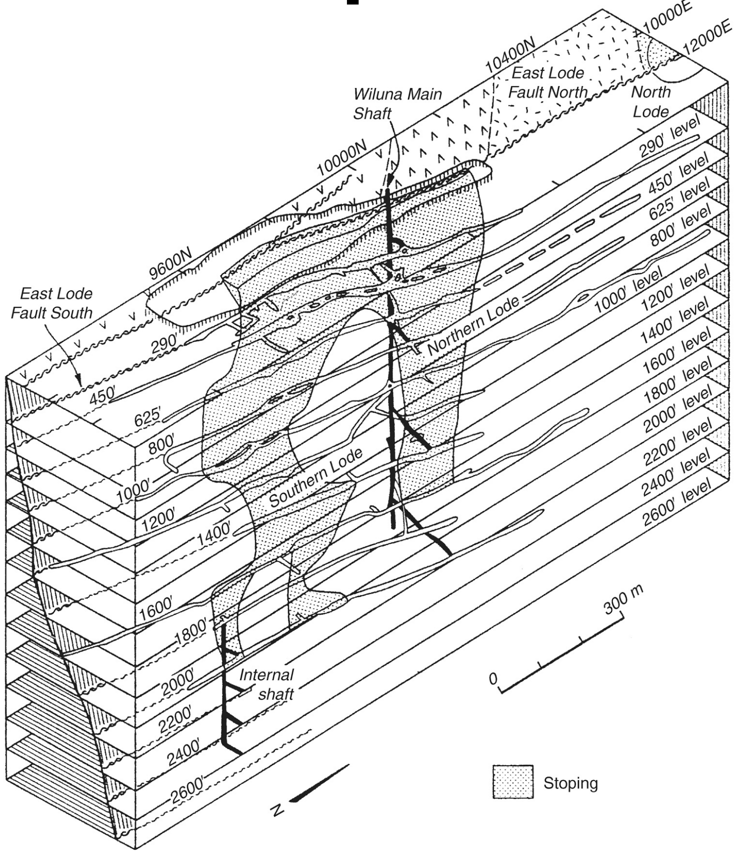
# Orogenic Au deposits




Wiluna W. Australia

- Ore grade is vertically continuous in a vein
- Underground mining techniques are applied, following the structures of the mineralization

# Orogenic Au deposits

- **Sulfide mineralogy:** pyrite (in mafic rocks), arsenopyrite (in metasediments), ±stibnite, pyrrhotite

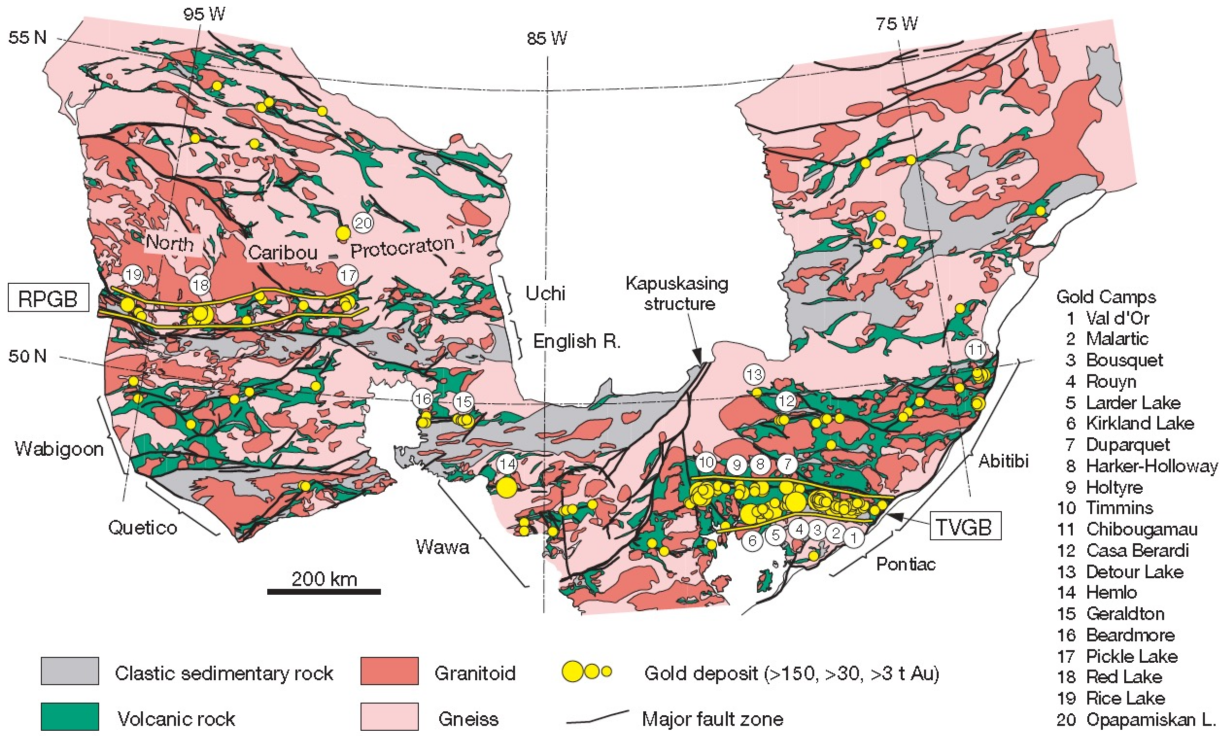
- **Alteration** styles include carbonatization and chloritization ±tourmaline, muscovite, biotite, K-fsp, albite

- **Hydrothermal fluid:** generally <400°C, $CO_2$-rich and $d^{18}O$-rich, depth between 2-20km, low to moderate salinity (3-12wt% NaCl eq.), pH neutral, slightly reduced, dominated by sulfide complexes

- **Au deposition** is related to fluid-rock interaction (e.g. desulfidation of fluid in Fe-rich rocks), and $H_2O$-$CO_2$ phase separation that coincides with the ductile-brittle transition. Au often related to qtz-cc veins.

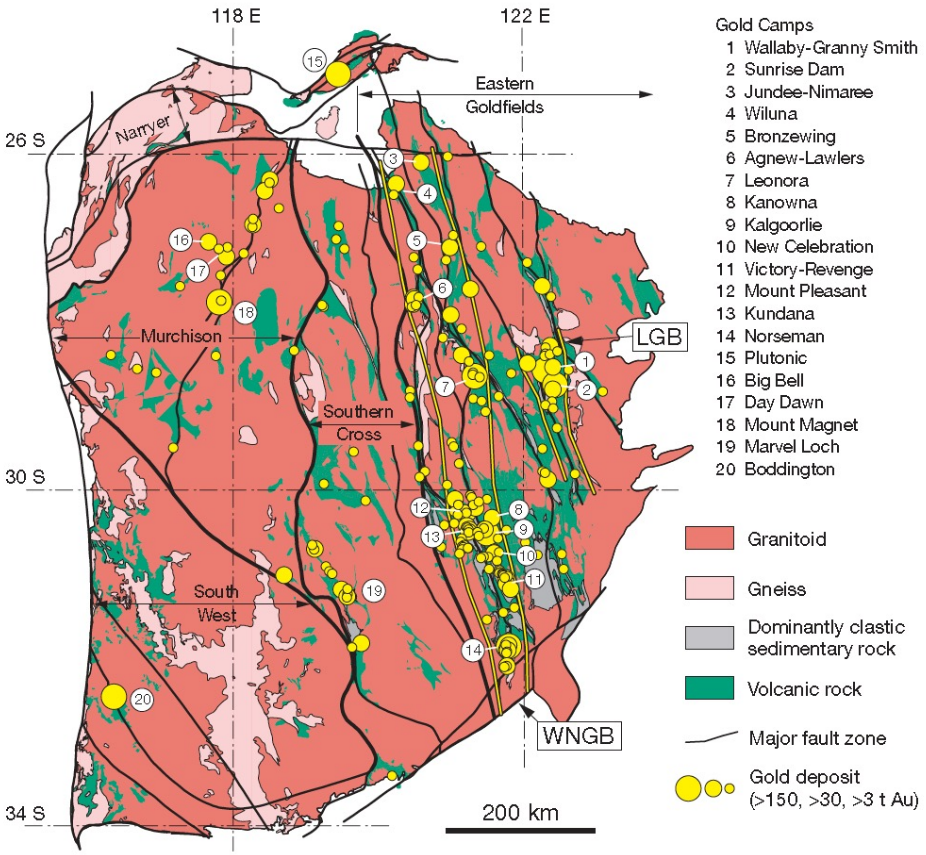
# Orogenic Au deposits

## Gold camps of the Superior Province, Canada



# Orogenic Au deposits

## Gold camps of the Yilgarn Craton, Australia



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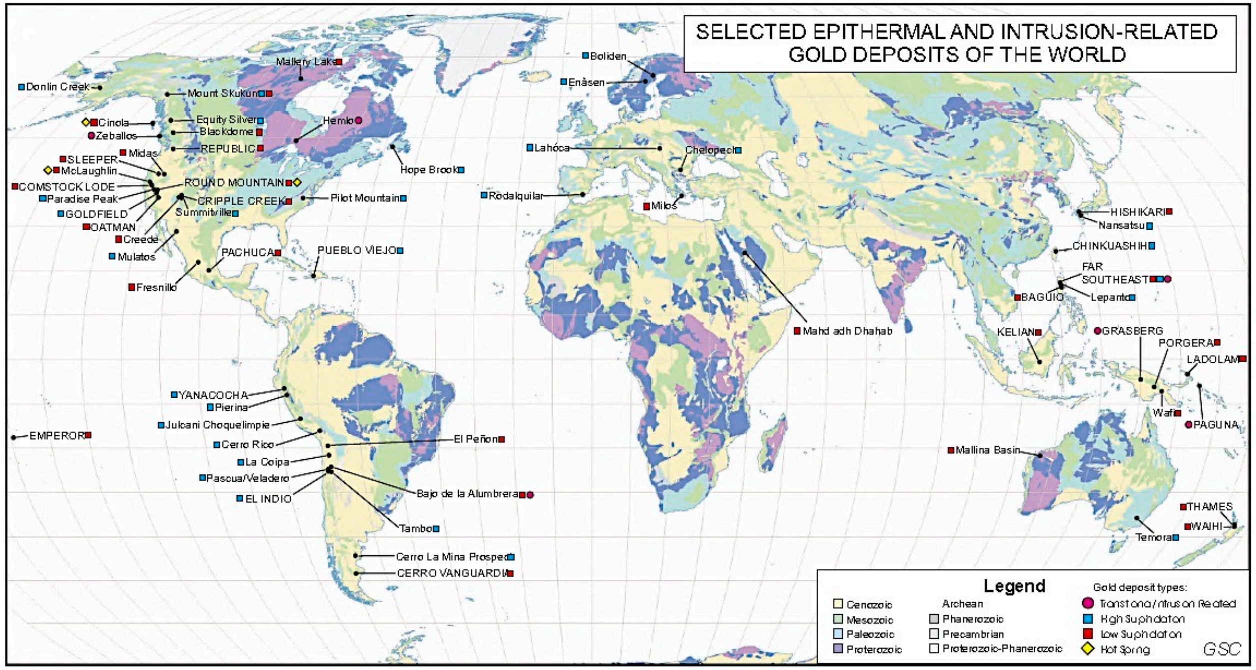
# Epithermal Au-Ag deposits

- (Magmatic)-hydrothermal deposits
- Fluids are magmatic and mixed with meteoric water
- High and low sulfidation types
- Often related to underlying porphyry systems
- Mineralization in veins and disseminated.
- Medium to high-grade, high tonnage.
- Ore body elongated


Alteration, Famatina, Argentina; Pudack et al, 2009)

# Epithermal Au-Ag deposits




Tectonic setting is similar to porphyries and often related to them. Shallow crustal deposits.
High-grade moderate to low tonnage type deposits.

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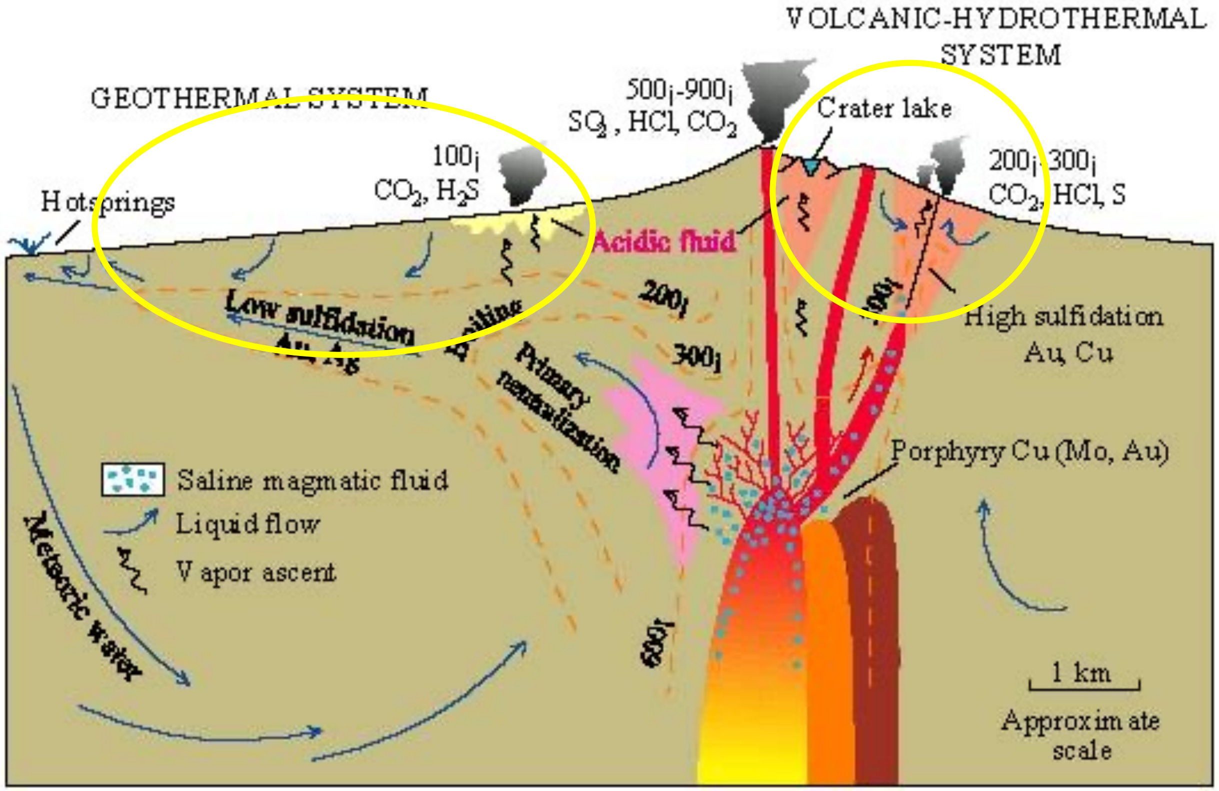
# Epithermal Au-Ag deposits



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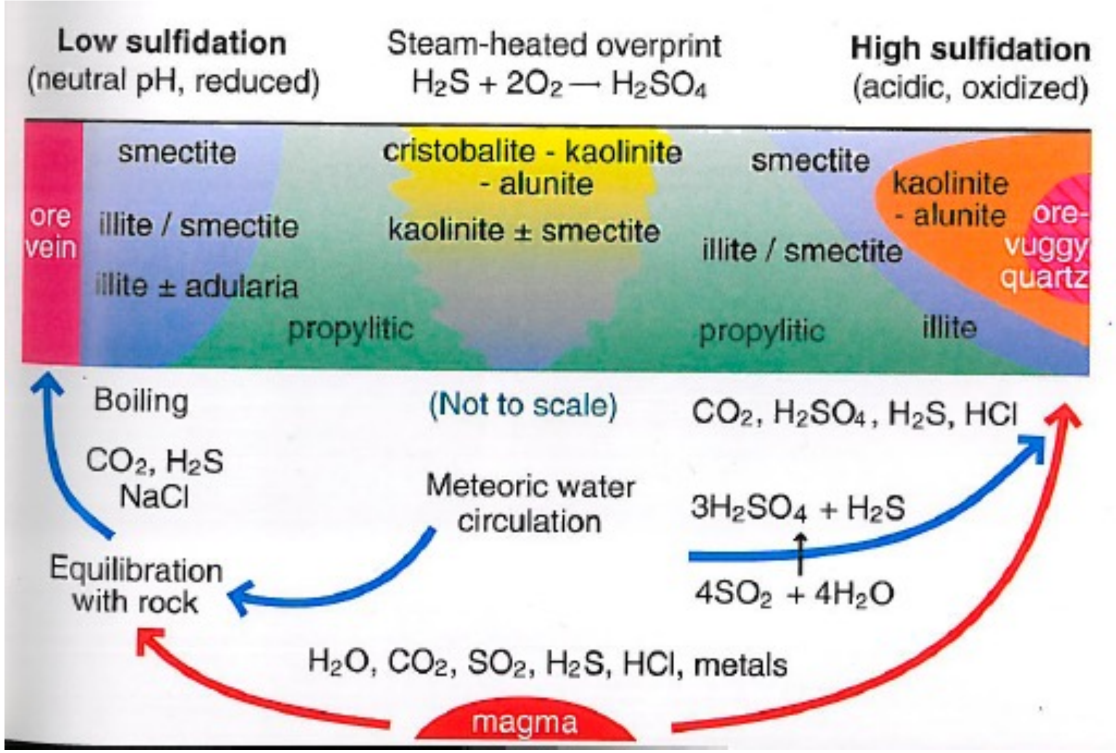
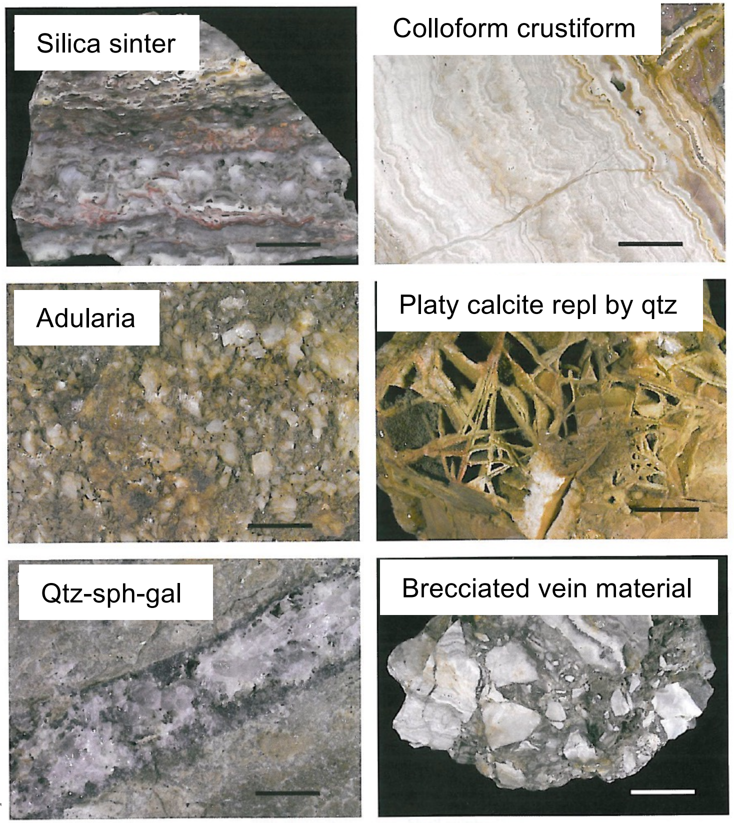
# Epithermal Au-Ag deposits

High and low sulfidation differ in terms of mineralogy, and fluids involved in the ore formation



# Epithermal Au-Ag deposits

## Low-sulfidation rock textures



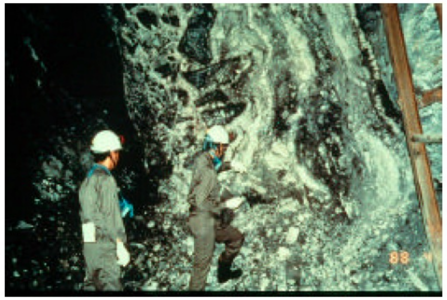



**Photo 19.** Banded adularia-sericite epithermal gold-silver fissure vein showing marginal floating clast breccias, Hishikari

**Photo 20.** Banded adularia-sericite epithermal gold-silver mineralization showing well developed banded quartz and ginguro ore from Golden Cross.

**Photo 21.** Adularia-sericite epithermal gold-silver mineralization showing well developed quartz pseudomorphing platy calcite from Vera Nancy.

**Photo 22.** Banded banded vein with chalcedony, ginguro band and pink adularia, Cracow.

# High-sulfidation rock textures

**Photo 31.** Diatreme breccia showing silicification of the within the finely comminuted breccia matrix and vughy silica alteration of porphyritic, interpreted intrusion, fragments, Veladero.

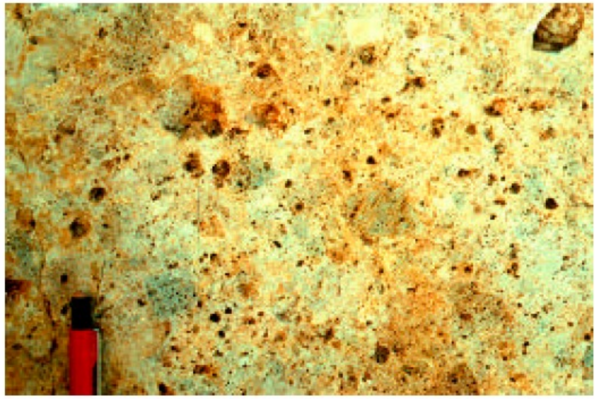


**Photo 32.** Vughy silica alteration of a lapilli tuff, Del Carmen.

Vuggy qtz

**Photo 33.** Vughy silica alteration of porphyry intrusion, El Indio district.

# Placer Au deposits

- Sedimentary deposits (see also base metal deposits (Sn-W)).
- Gold grains are transported in a river and deposited due to physical properties (density, fluid flow, grain size/shape).
- Medium to high grade, high tonnage
- Ore body lateral extensive, but relatively thin
- Most famous is the Witwatersrand deposit in South Africa

# Placer Au deposits

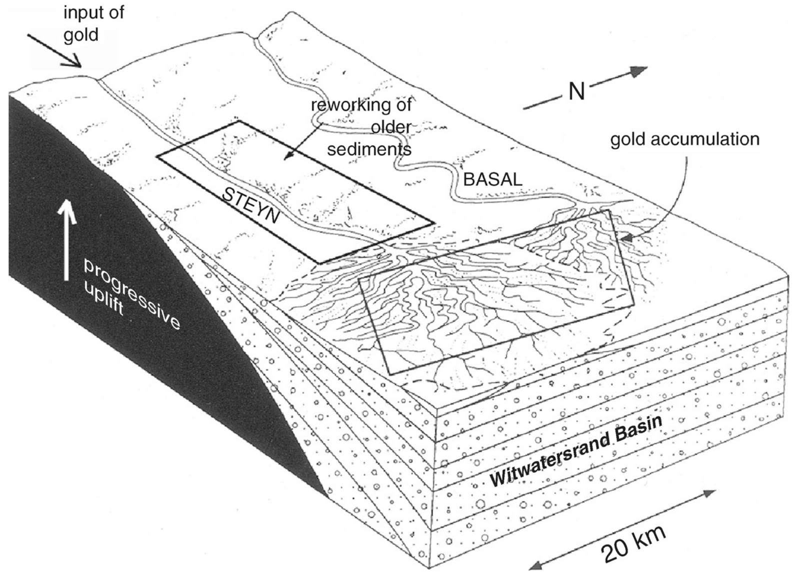
Used to be one of the largest gold producer, over 50 000t, 35% global Au production

7 km of terrestrial clastic sedimentation over 300 Mio years (3-2.7Ga)

Arenites, minor shales and sandstone, but Au is hosted in qtz conglomerate

Uraninite is an important by-product

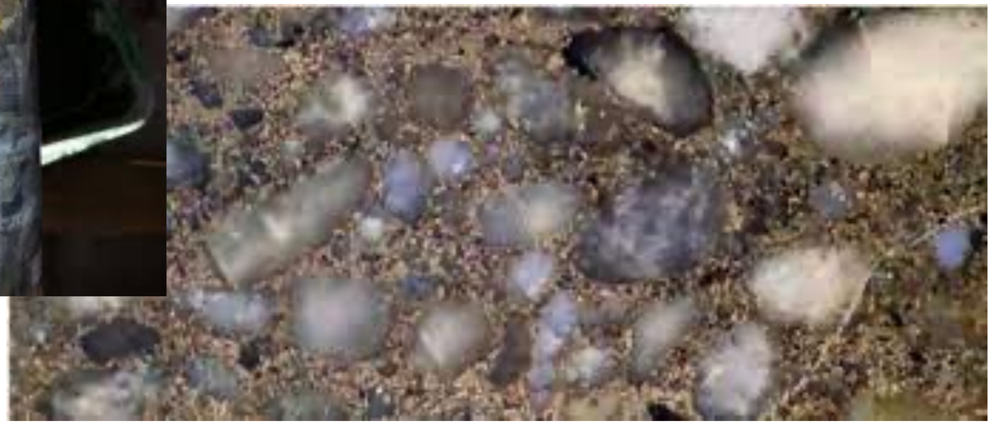
## Witwatersrand Au deposit




Braided river system and repeated re-working is an important process to enrich ore

# Placer Au deposits

## Witwatersrand Au placer deposit

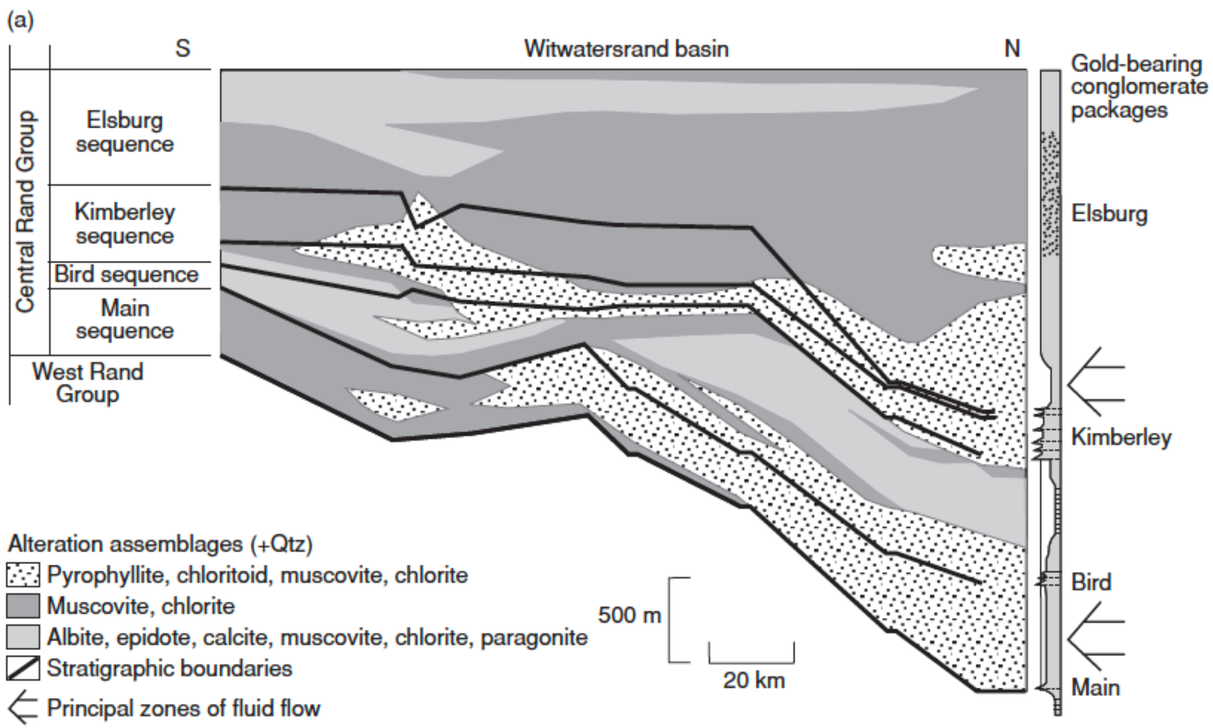



Quartz-pyrite conglomerate with gold grains entrianed.

# Placer Au deposits

- Modified placer deposit:
- Hydrothermally overprinted.
- Remobilization and precipitation of gold.

## Witwatersrand Au deposit, alteration



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# C

Carbon
C
6 12.011

- Carbon
- Uses of carbon (diamond, graphite and fossil fuels)
- Diamond deposits
  - Kimberlites
  - Placer deposits

# Carbon

Carbon
C
6 12.011

- Occurs as the hardest and one of the softest minerals
- Ore mineral(s): diamond, graphite (C),
- Top suppliers (diamond): South Africa, Russia, Congo
- Reserves (diamond): 1,3Mrd carat
- Production: 46Mio carat

USGS 2022

# Carbon

Carbon
C
6 12.011

- Occurs as the hardest and one of the softest minerals
- Ore mineral(s): diamond, graphite (C),
- Top suppliers (graphite): China, Brazil, Norway
- Reserves (graphite): 330Mio t
- Resources: 800 Mio t

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Carbon
C
6 12.011

## Diamond uses

- Jewellery
- Industrial (cutting, grinding, drilling)

## Graphite uses

- Electric motors, batteries, lubricants
- Alloys (steel)
- Carbon fibers
- Pencils

# Diamond deposits

- Kimberlites
  - Low grade- high tonnage
  - Ore body restricted laterally, but vertical extensive
- Placer deposits (see also base metal deposits (Sn-W) and Au deposits).
  - Medium-high grade, large tonnage
  - Ore body laterally extensive, but often only thin layers

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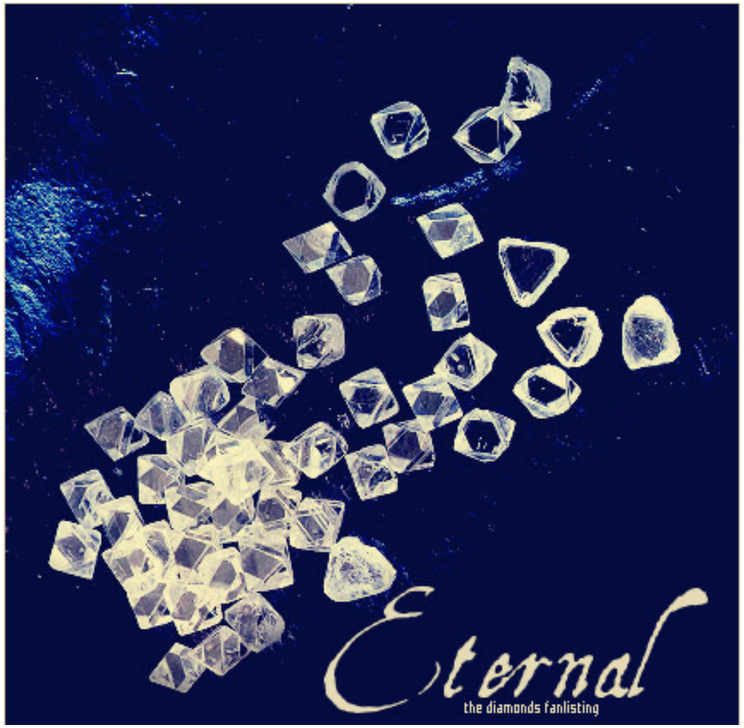
# Diamond deposits




- **One carat = 0.2 grams**
- Until recently industry dominated by a few producers (e.g., DeBeers) – was an **artificial Cartel**.
- **Conflict diamonds** – an important issue in recent years (e.g. Blood Diamonds movie) with premium on non-conflict sources (e.g., Canada).

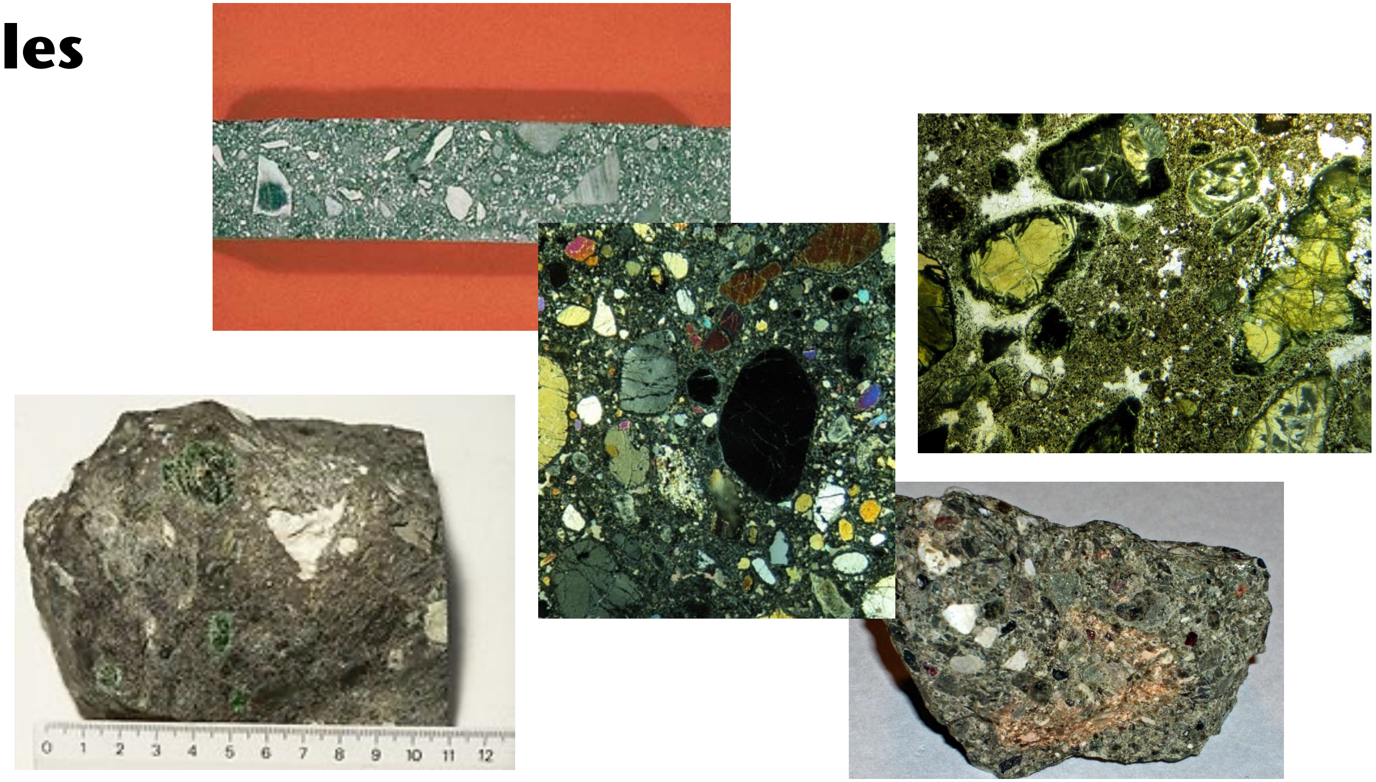
# Diamond deposits

- At 6.04 carats, an extremely rare fancy vivid blue diamond ring shown from a Sotheby's preview in Hong Kong October 3, 2007. One of the rarest gems in the world, this flawless blue diamond sold for **US $7.98 million** ($1.32 million per carat), making it **the most expensive gemstone in the world, per carat.**
- Annenberg diamond (32 carats) - sold for $7.7 million, Oct. 2009.
- **These diamonds illustrate the important features of evaluating diamonds – size, clarity, color, crystal which dictates $$$.**

# Diamond deposits

## Kimberlite samples

Potassic ultrabasic rock with olivine, pyroxene, garnet, Cr-diopside, phlogopite, ilmenite, calcite… Xenocrysts and xenolithic material abundant .



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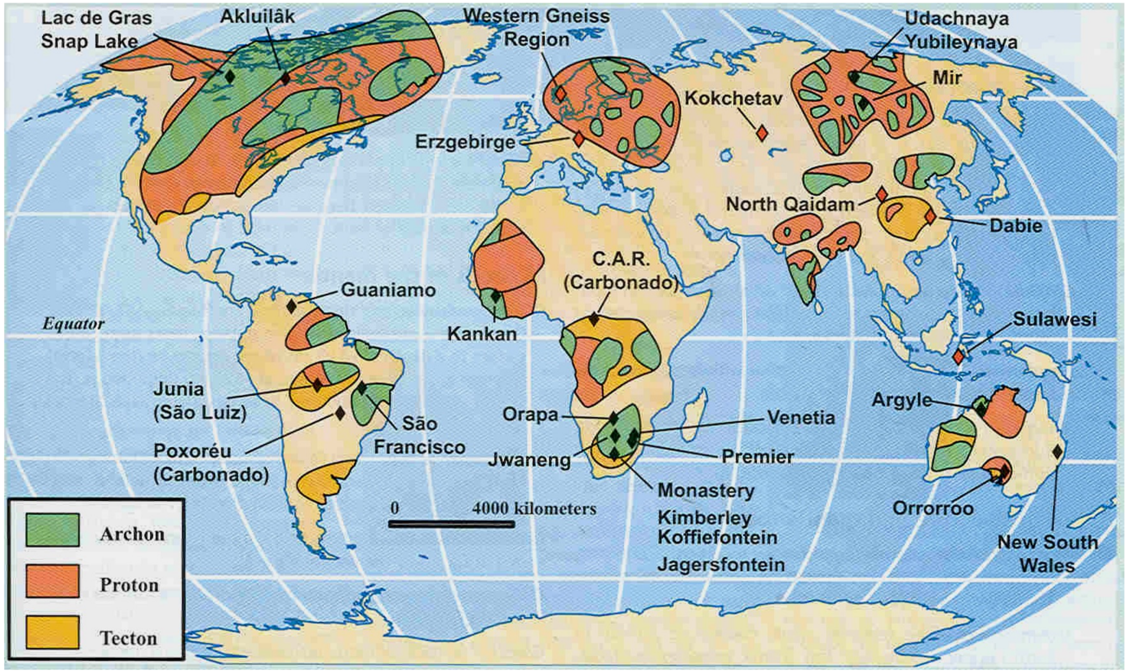
# Diamond deposits

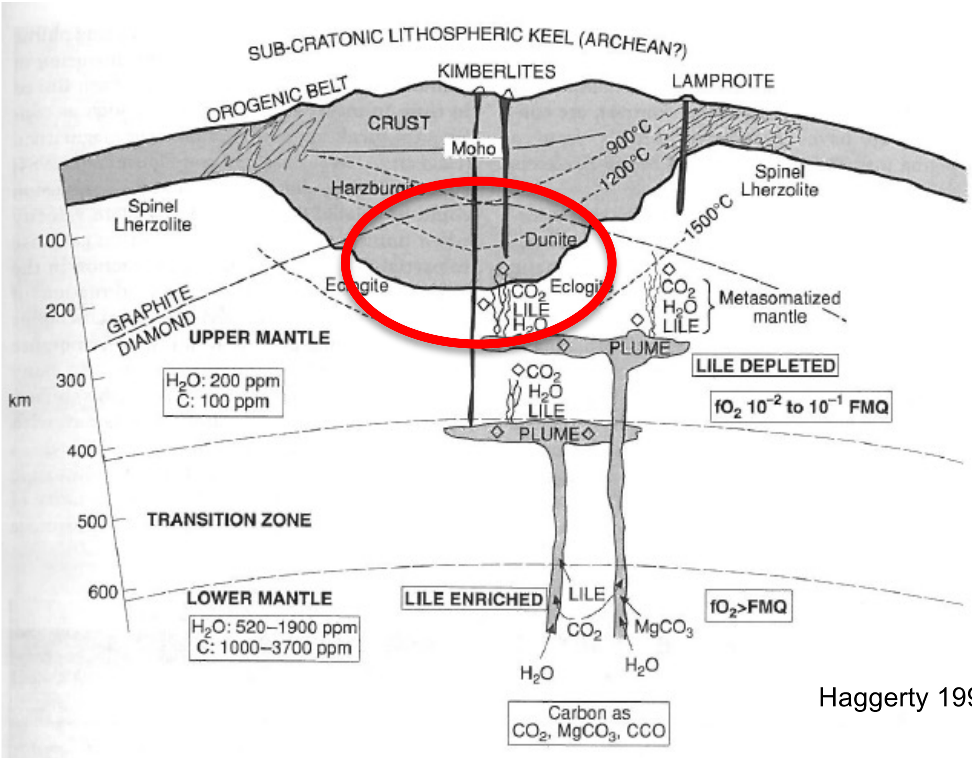
## Kimberlite Distribution

- Found in cratons globally
- Pulses of kimberlite from Archean to present, but only certain ages are diamondiferous (none older than 1200 Ma)



# Diamond deposits

**Diamond formation** conditions:
100-300km
900-1300C,
reduced



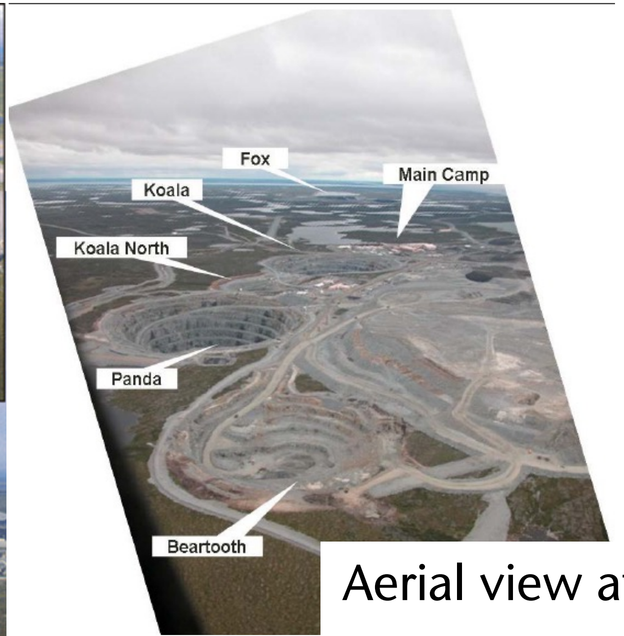

Haggerty 1999

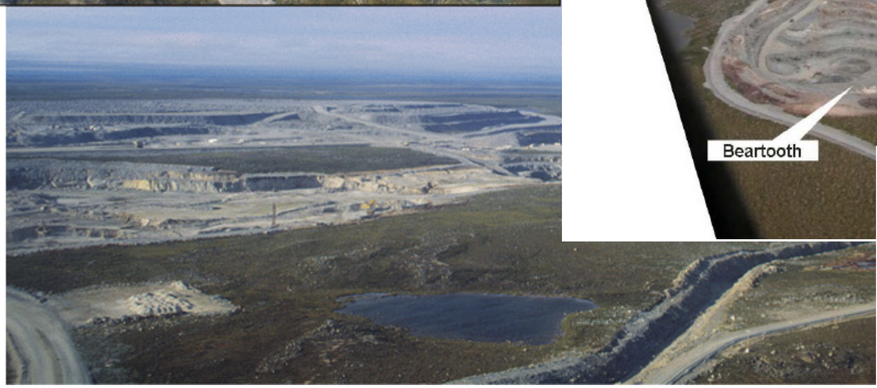
Critical where the kimberlite magma was generated whether it can sample the ‘diamond window’.

Most diamonds are lithospheric

Source of C from lower mantle, ‘oxidized’

# Diamond deposits



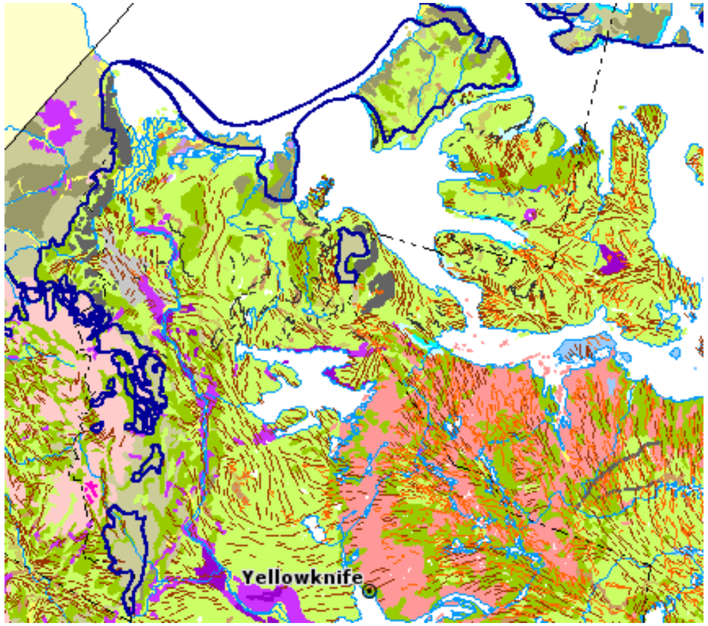



Aerial view at EKATI pipes, NWT:

- Diamondiferous pipes occur in clusters.
- Many pipes are mined in a deposit area.
- Pipes may coexist at time of emplacement.

# Diamond deposits

- Kimberlites are soft (carbonate rich)…thus, easily eroded.
- If prospective areas are glaciated then get dispersal trains.
- Erosion leads to depressions (now lakes, glacial till).
- Rocks are magnetic….airborne surveys…circular features, beneath lakes, tills.

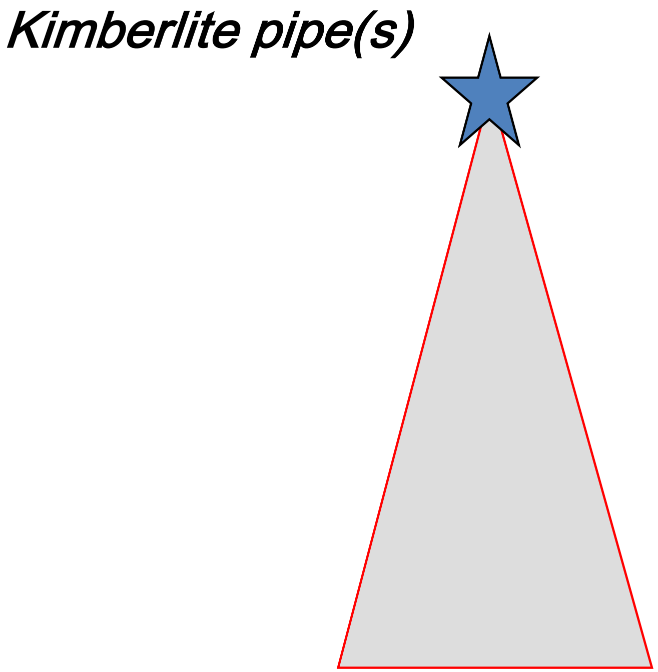



• NWT glacial map - ice flow, till sheets (in greens)… this is a large area to explore!

• Can we make it easier for exploration? **Yes, use indicator minerals.**

# Diamond deposits

## Exploration for Diamonds:




- Kimberlites offer a small target (<1-2 km$^2$) area for exploration.
- Use the dispersal of kimberlite material due to glaciation to an advantage.
- Regional programs start down ice from the target area and zero in on the small source area up ice.
- Minerals in kimberlites of high P-T origin.
- Size, shapes of minerals – these relate to source and distance of transport (from kimberlite).

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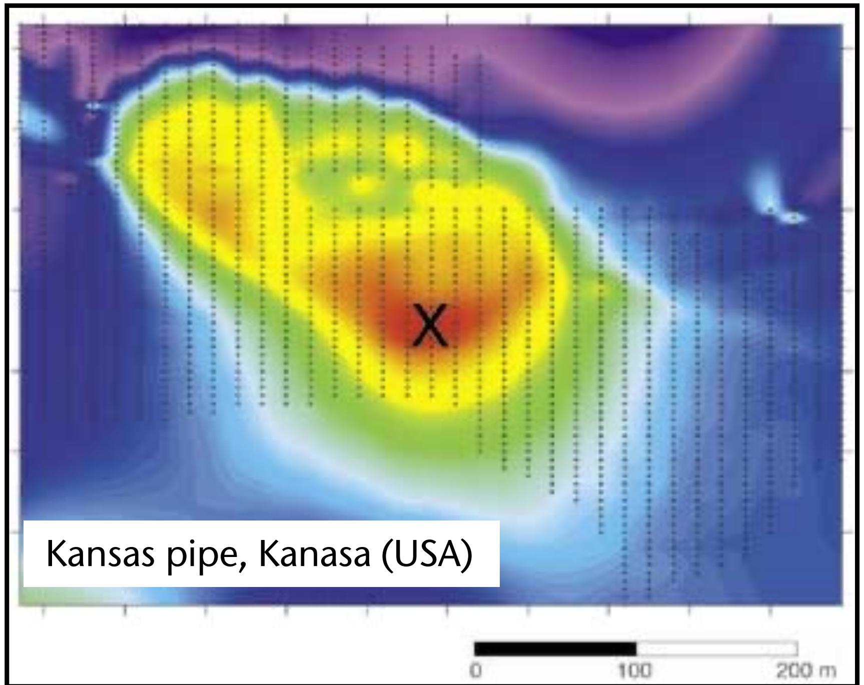
# Diamond deposits




Kimberlite pipes… note the scale! X marks location of diamond drill hole that hit the pipe

Exploration for Diamonds:

- Kimberlites are magnetic, thus have good signatures, but are small (<few 100 m) for regional surveys.
- Use detailed grids to locate pipes after finding high-potential area.
- Select target areas after this for drilling.

# Diamond deposits

Kimberlites are the transport medium to bring diamonds to the surface and their economic value depends not so much on tonnage than on gem-quality diamonds that can be found.
For example: the Kimberly mine in South Africa resulted in ‘only’ 3t of diamonds out of 24Mt of kimberlite (1:8’000’000)

Important deposits of diamonds do not only include the kimberlite bedrock, but **placer deposits** and beaches, including submarine shelf deposits.

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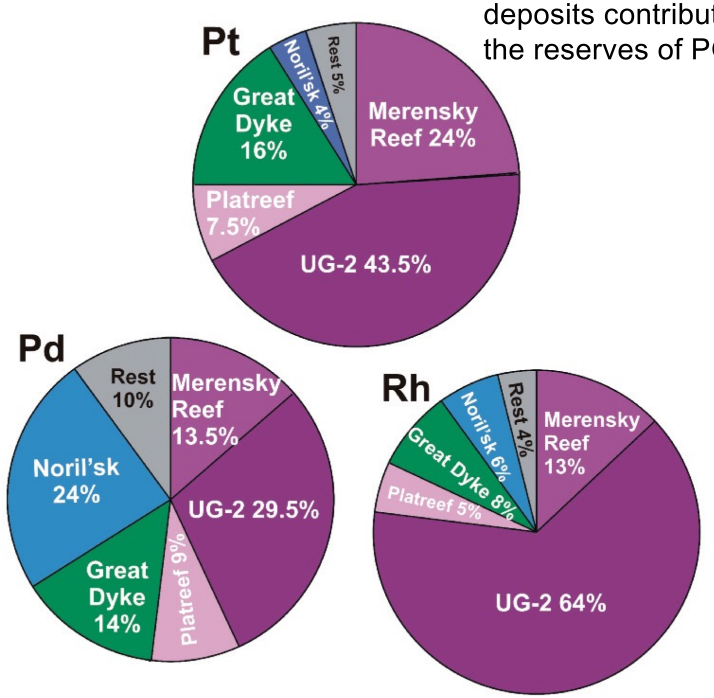
# Platinum group elements (PGE)

| | | |
|---|---|---|
| 44 Ru | 45 Rh | 46 Pd |
| 76 Os | 77 Ir | 78 Pt |

- Among the rarest metals on earth
- Typically tiny minerals (10s-100s µm)
- Magmatic ore deposits with grades of 5-15ppm (mainly Pd, Pt)
- South Africa and Russia
- Used in catalytic converters, jewellery, alloys

The different ore deposits contributing to the reserves of PGE




Mungal and Naldrett 2008
Economic Geology

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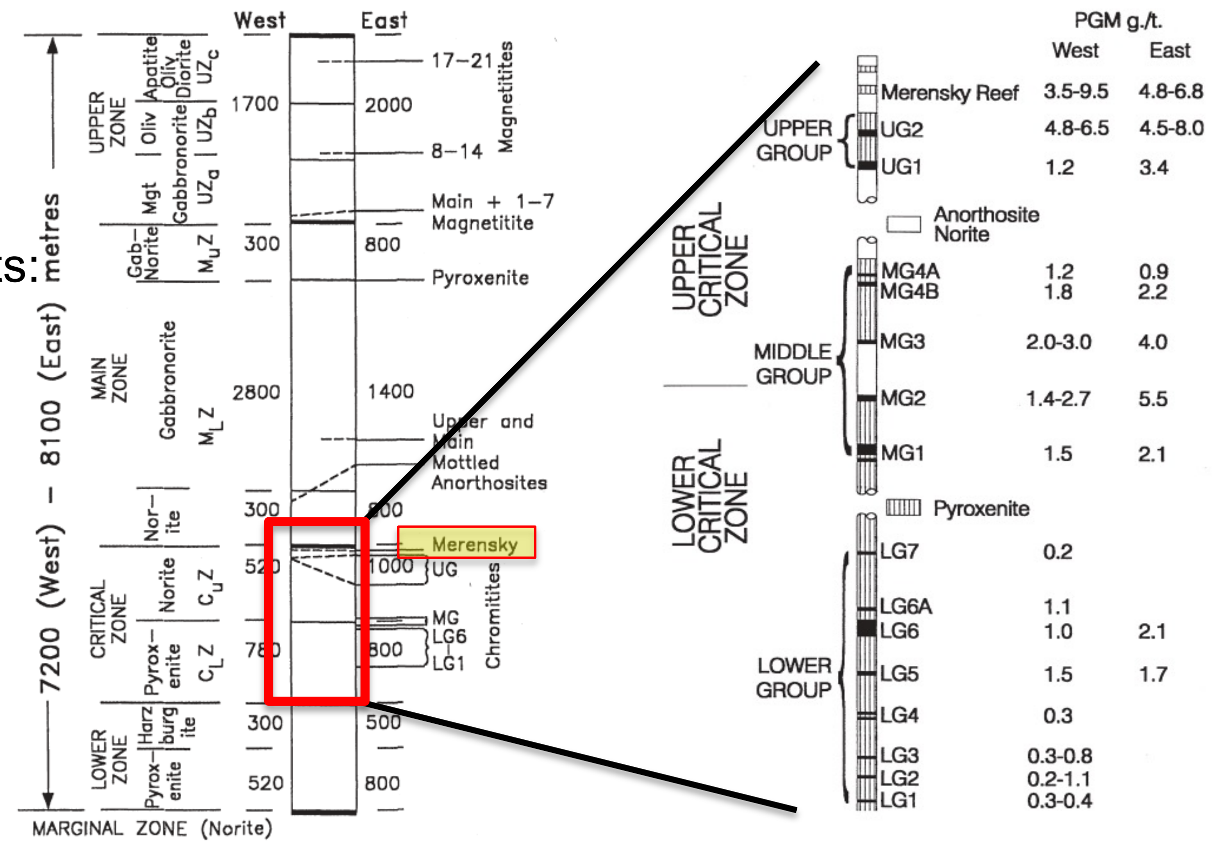
# PGE deposits

- PGE minerals form in mafic magmatic intrusions (see module on base metals, magmatic massive sulphide deposits with Ni and Cr, Cu, Co).
- Sulphide melt immiscibility and the high partitioning coefficient for PGE enriches them in the sulphide melt.
- Arsenides, tellurides, selenides
- Low grade, high tonnage
- Ore body laterally extensive, but restricted to thin layer

# PGE deposits

Bushveld stratigraphy

Chromite layers with PGM content



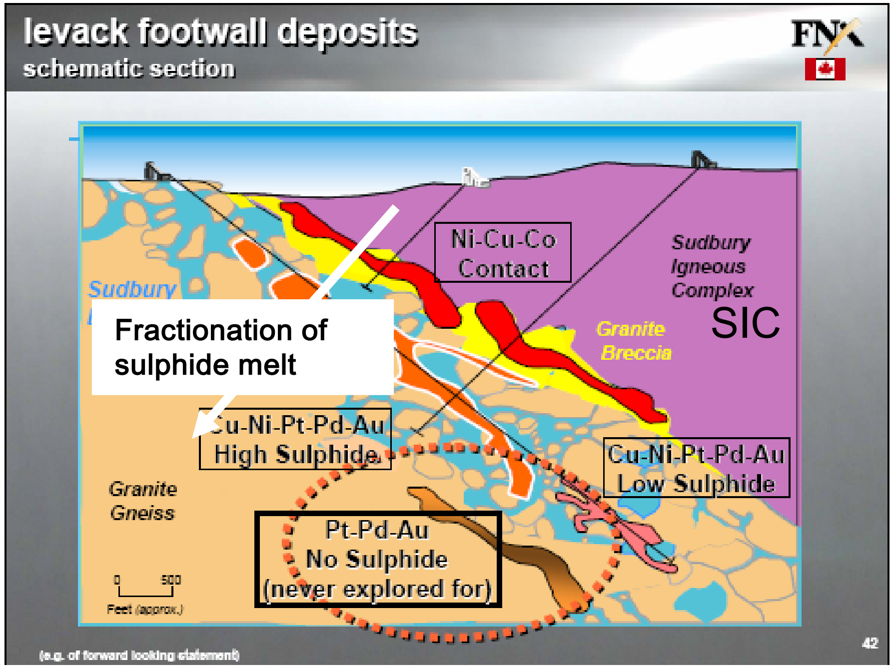

From Cawthorn 1999

Other important PGE deposits:

- Sudbury, Canada
- Talnak, Norilsk, Russia

# PGE deposits

Proposed Exploration Model for Ni-Cu-PGE Sulphide Deposits at Levack, Sudbury Igneous Complex




(FNX website)

- Note the depletion or enrichment trends in the Ni-Cu-PGE ores from top to bottom.
- There is a T gradient from the Ni-rich to the Pt-Pd-Au -rich and sulphide-poor residuum of the fractionated melt.

**- Ni rich at the base of SIC/contact**
**- Cu rich into the footwall**
**- Cu-PGE further into footwall**
**- Note low sulphide ore furthest away**

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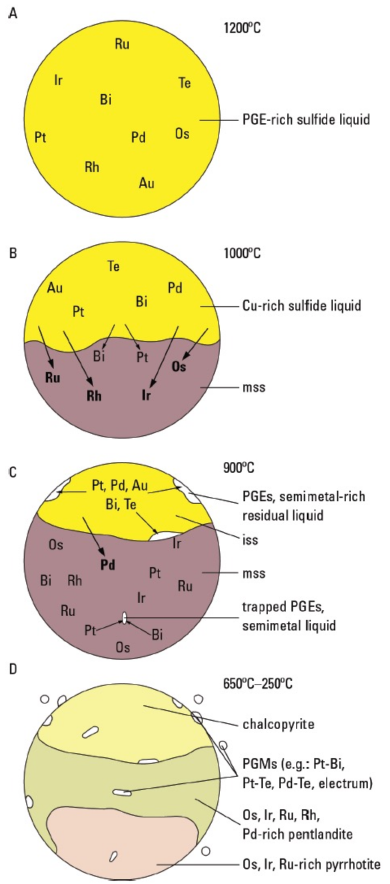
# PGE deposits




Temperature decrease

## PGE partitioning in a fractionating sulfide melt

mss: monosulfide solid solution

iss: intermediate solid solution

The Ni-Cu sulphide ore seen today was originally a high T (>1200°C), immiscible sulphide melt in a silicate melt. Thus, we must understand how this melt became metal rich and also understand the process by which it formed, before we can understand the deposits.

Holwell and McDonald 2010

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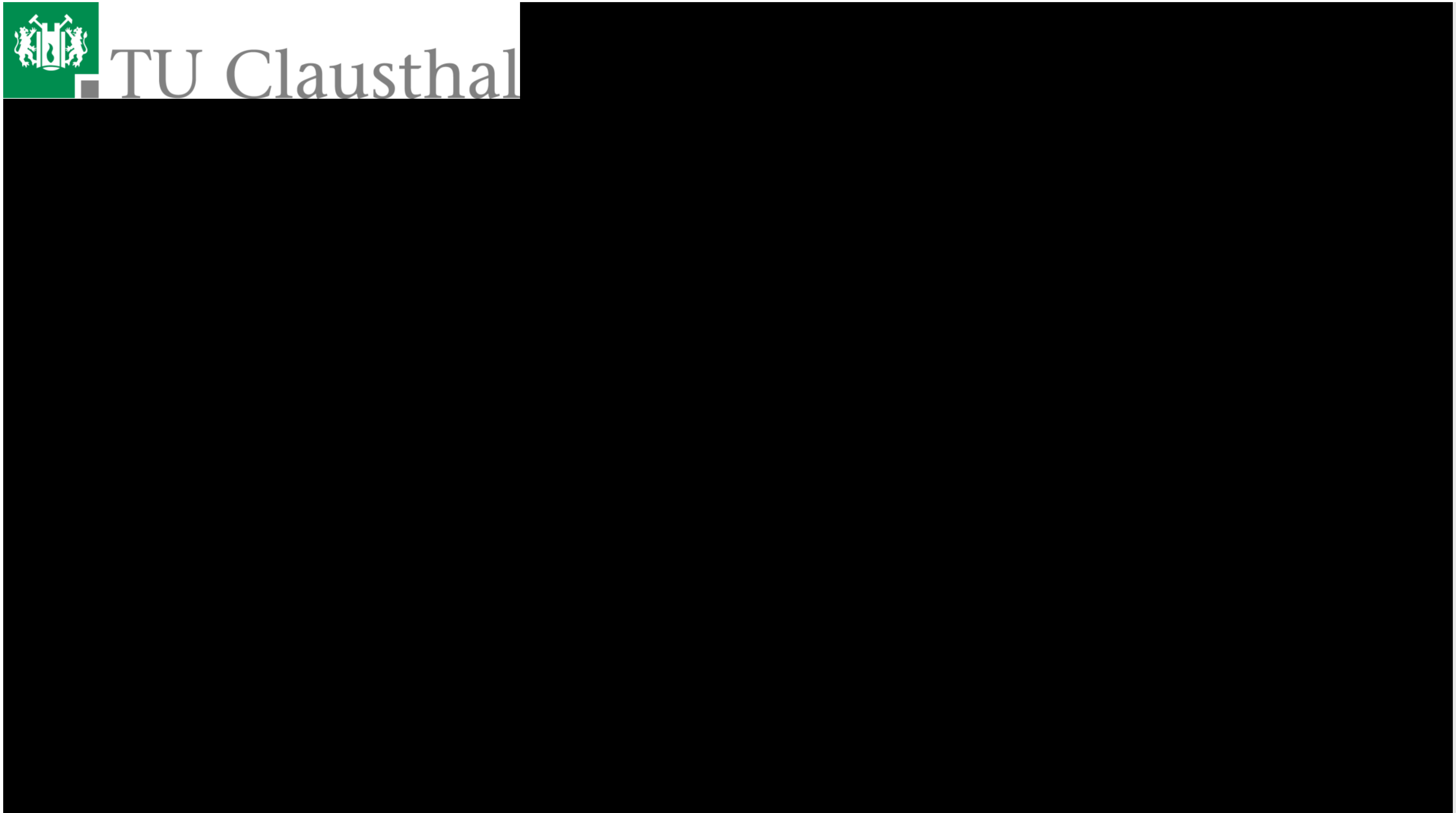

# REE (La-Lu)


- Rare earth Elements (REE)
- Uses of REE
- REE deposits
  - Magmatic (carbonatite, alkaline intrusions) deposits
  - Supergene deposits

# REE


- Group of 15 elements with similar properties
- Ore mineral(s): bastnäsite (La, Ce, Y)$CO_3$F), monazite,
- Top suppliers: China, Australia, Brazil, Russia
- Reserves: 130Mio t
- Resources: larger than 20Mio t

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# REE uses

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 57 La Lanthanum 138.905 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.243 | 61 Pm Promethium 144.913 | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 |
| 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.925 | 66 Dy Dysprosium 162.500 | 67 Ho Holmium 164.930 | 68 Er Erbium 167.259 | 69 Tm Thulium 168.934 | 70 Yb Ytterbium 173.055 | 71 Lu Lutetium 174.967 |

- Batteries
- Magnets
- Electrical motors
- LED screens

# Rare Earth Elements (REE) deposits

- Magmatic (carbonatite, alkaline intrusions)
- Supergene enrichment

# Carbonatite deposits

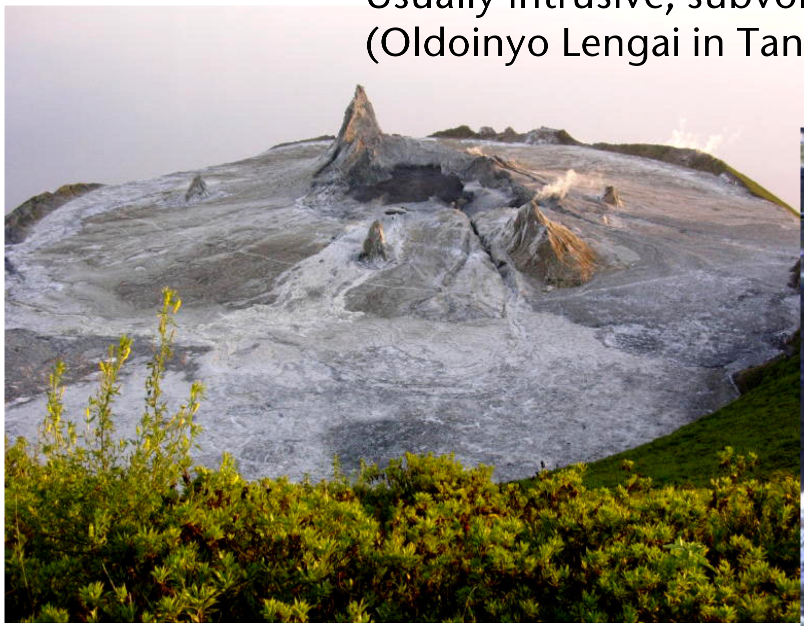
- Carbonate-rich melt
- 3 different potential formation processes:
  - Direct, low-degree partial mantle melts (3%) and fractional crystallization
  - Extreme crystal fractionation
  - Liquid immiscibility between silicate and carbonate melt

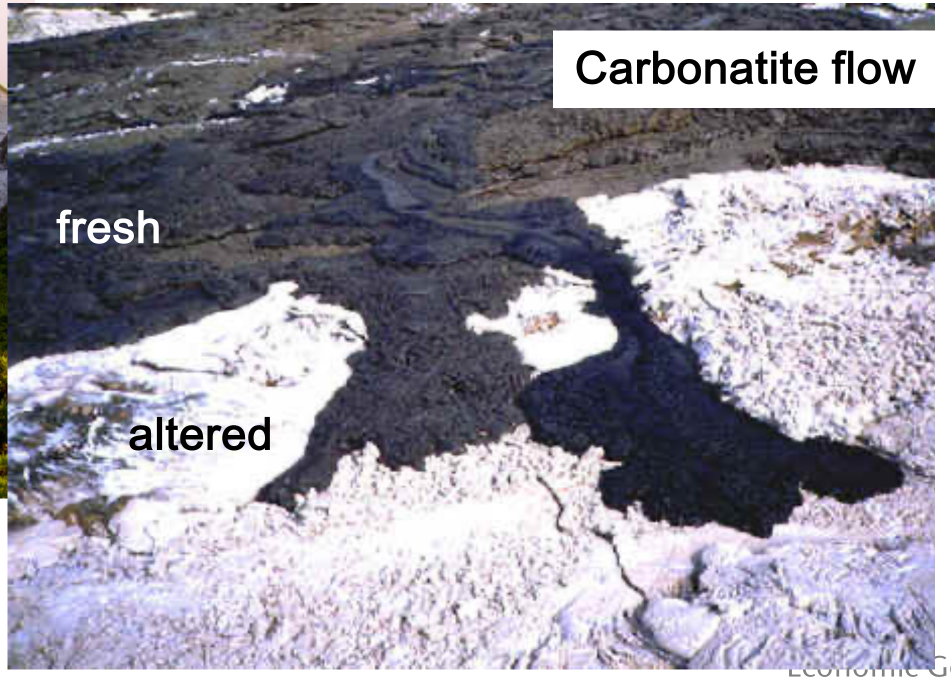
# Carbonatite deposits

- Continental rift settings
- Fenitization: (type locality is Fen in Norway) potassium/sodium metasomatism/alteration with arfvedsonite and glaucophane, phosphates, biotite, K-fsp, hematite and other Fe and Ti oxides.
- Low grade, high tonnage
- Ore body 'concentric'

# Carbonatite deposits

Usually intrusive, subvolcanic, but only one active carbonatite volcano (Oldoinyo Lengai in Tanzania). Has lowest lava eruption T of 500-600°C.





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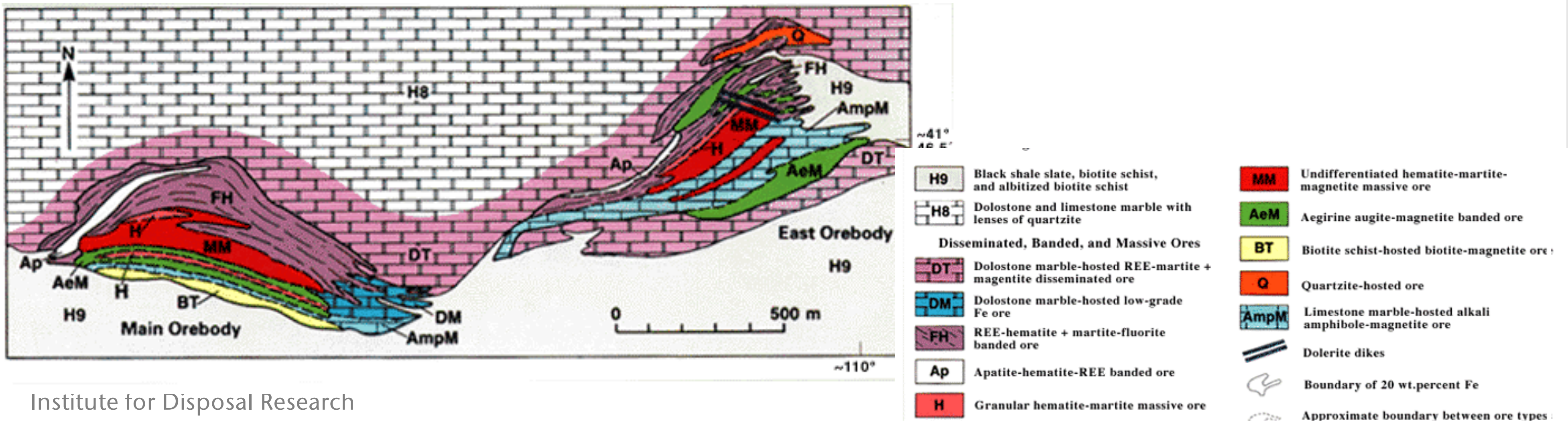
# Carbonatite deposits

- Freshly erupted carbonatite lava in one the craters of Oldoinyo Lengai, Tanzania (pic from T. Dockx).
- This is the ONLY known carbonatite lava in the world.

# **Carbonatite deposits:** Bayan Obo, Inner Mongolia

- Polymetallic REE-Fe-Nb deposit (127 minerals known, 12 type localities!)
- Originally Fe deposit (1927), but REEs discovered in 1936 and Nb ores in the 1950s.
- Reserves of >48 Mt of 6% REE (70% of world's REE reserves), 1 Mt of $Nb_2O_5$ (0.13%) and 1500 Mt of Fe (35%).
- Also the world's largest F deposit - 130 Mt. and second largest Nb resource



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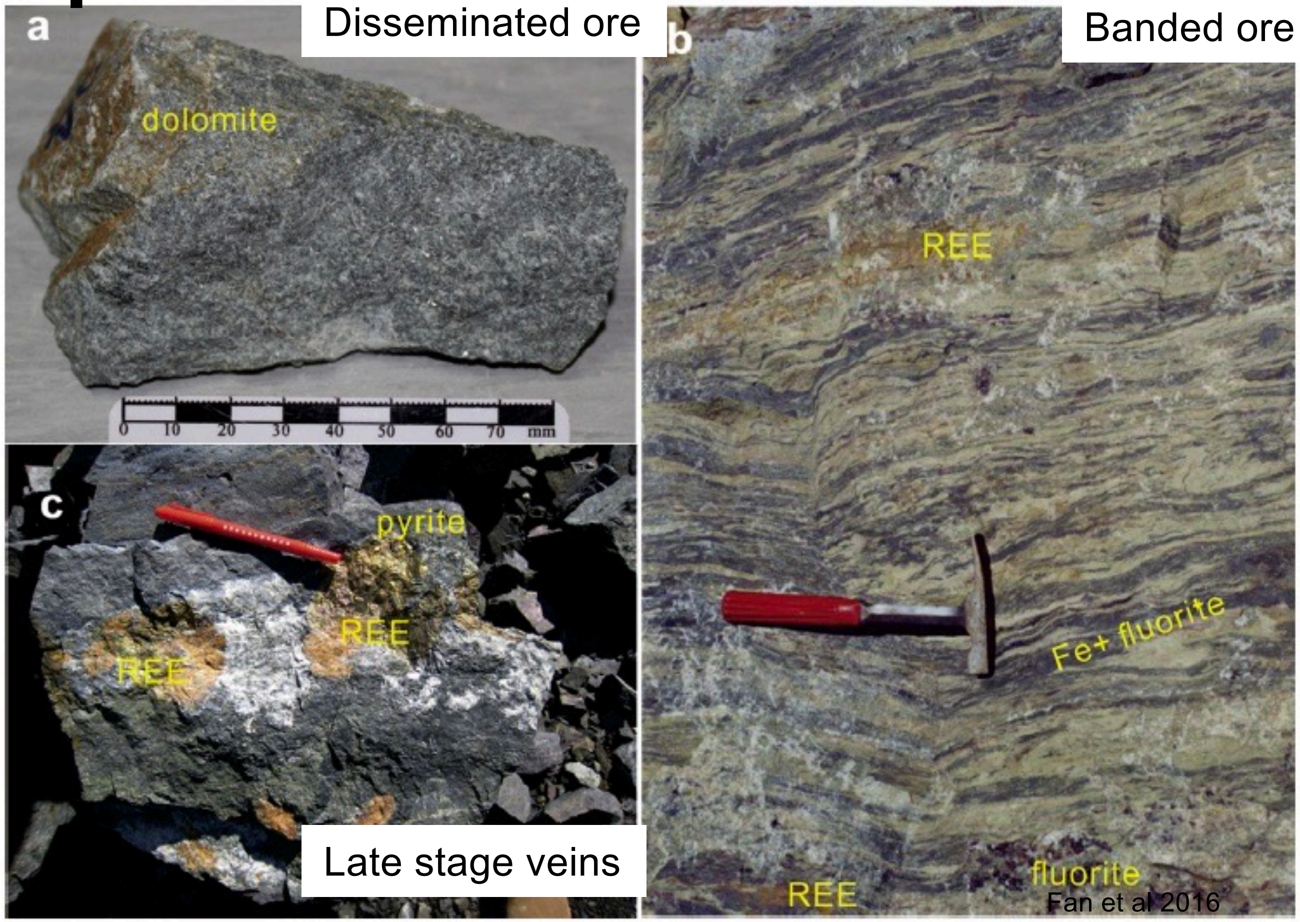
# Carbonatite deposits

Rocks from Bayan Obo



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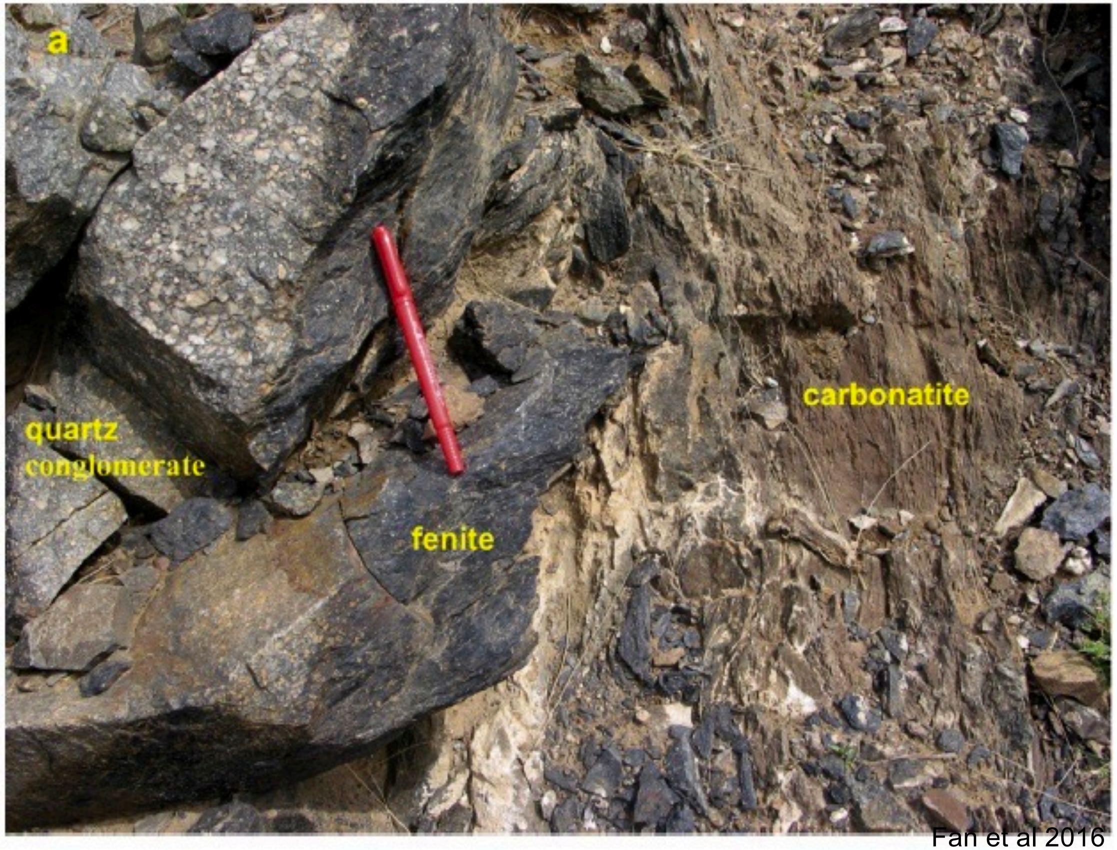
# Carbonatite deposits

Rocks from Bayan Obo

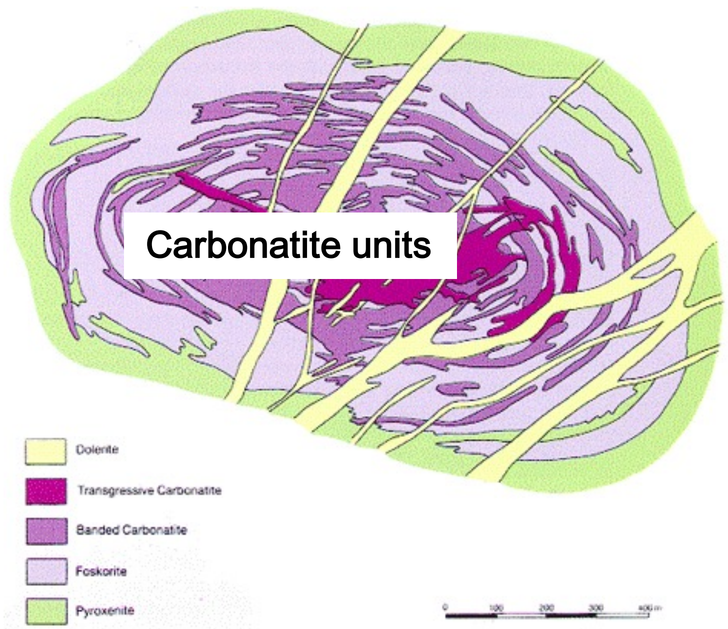
Contact of carbonatite to wall rock quartz conglomerate and fenite alteration.




Fan et al 2016

# Carbonatite deposits

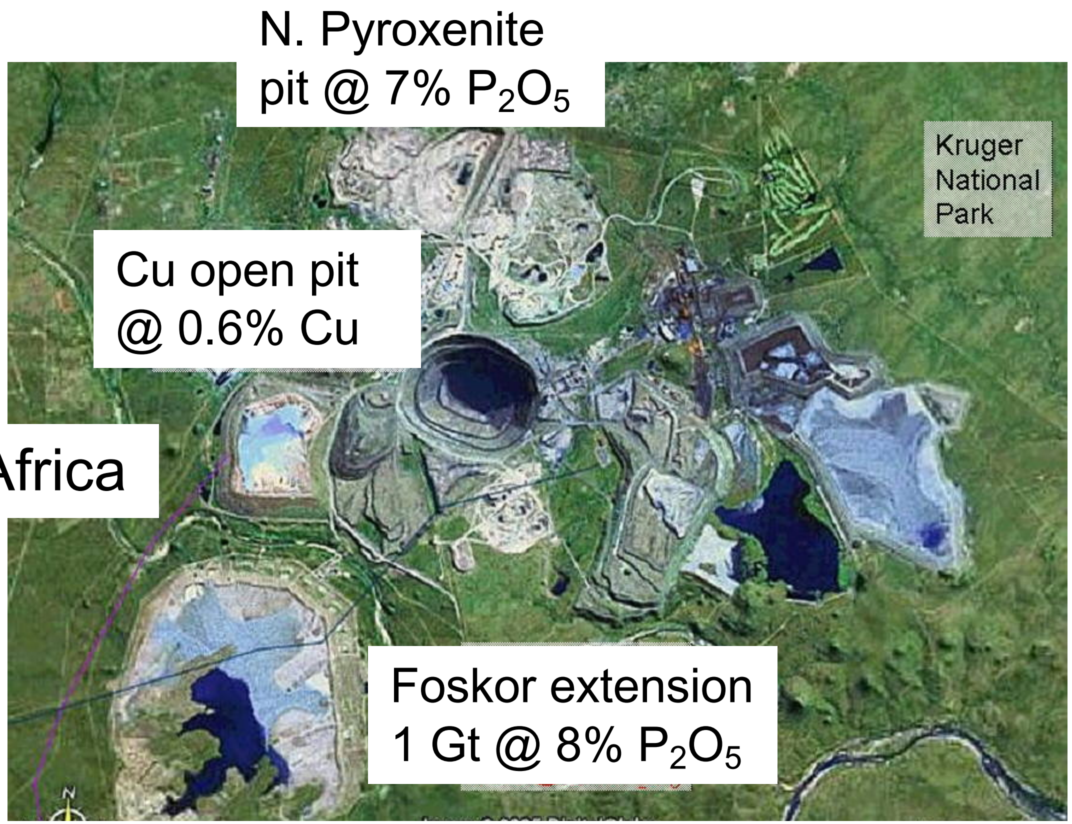
## Phalaborwa Complex, S. Africa




- 2 Ga eroded carbonatite complex; volcanic neck remains (see rings).
- Dunite-pyroxenite margin to carbonatite-phoscorite core.
- Locally coarse mica-peridotite pegmatites.
- Alteration of UM to serpentinite and vermiculite occurs.
- Large (original) reserve (1-2 Bt) of Cu, Zr, phosphate, magnetite; minor PGE, Au, U also recovered.

# Carbonatite deposits

Aerial Shot of Phalaborwa, S. Africa



# Carbonatite deposits

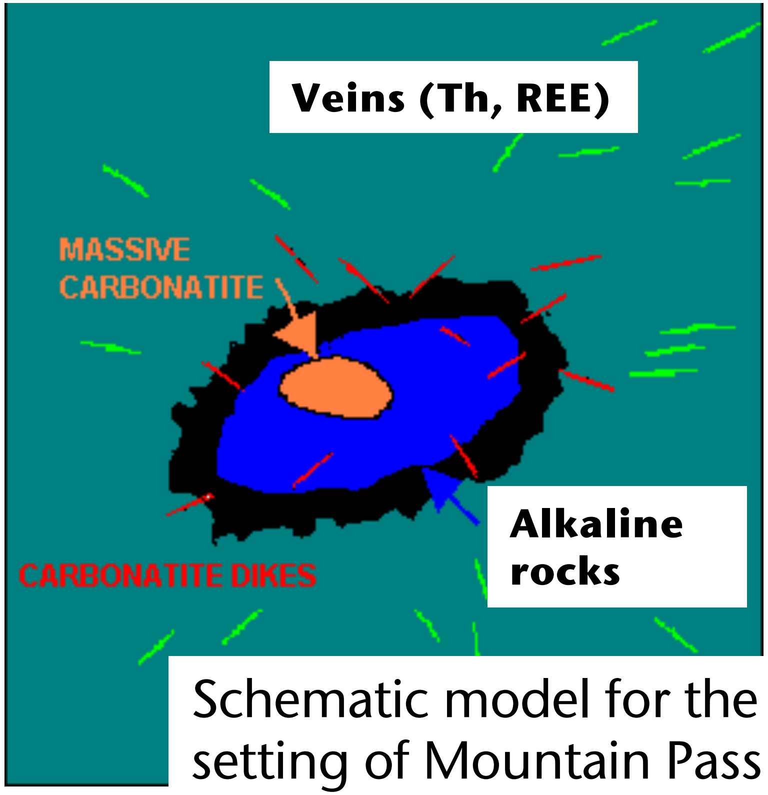
Phalaborwa Mine Open Pit (2 km, 0.8 km deep)

Carbonate-phlogopite-magnetite

Carbonate-baddeleyite ($ZrO_2$)

# Carbonatite deposits

## Mountain Pass, California




Schematic model for the setting of Mountain Pass

- Mt. Pass is the largest REE mine in western hemisphere and **formerly largest global producer**.
- Syenite intrusions with associated carbonatite.
- **Fenitization of country rocks.**
- Thorium-REE occur as carbonate phases (bastnesite) in veins.
- Veins are Qtz-K-feldspar-Mt-Apatite and Carbonate (calcite-ankerite-siderite) types.
- Veins are abundant and large (to 1-2 km, <1-10 m width).

(see Castor, 2008, Can. Mineral.)

# Carbonatite deposits

Bastnäsite sample from Mountain Pass

# Alkaline intrusion deposits

- The main rocks are syenites. Some are $SiO_2$ undersaturated or close to $SiO_2$ saturation.
- Form from fractional crystallization of metasomatized mantle rocks (alkaline basalts).
- Can have an uncommon mineral assemblage.
- Occur also in rift settings

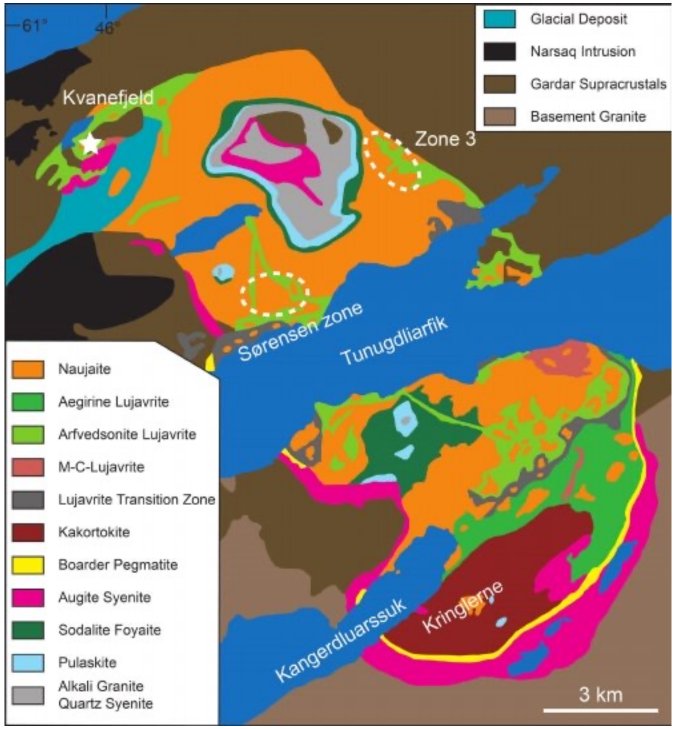
# Alkaline intrusion deposits

## Ilimaussaq intrusion, S. Greenland

- Mineralogical paradise (> 200 minerals, some only in this location)
- 2 potential deposits

Kvanefjeld and Kringlerne

- REE, U, Zr, Nb, Ta



# Alkaline intrusion deposits

## Ilimaussaq intrusion, S. Greenland

- The main rocks are nepheline syenites (with very special names: kakortokite, lujavrite, naujaite etc.)
- Their mineralogy is: K-feldspar, amphibole (arfvedsonite), nepheline, pyroxene (aegirine).
- Ore minerals include: eudialyte (Kringlerne) and steenstrupine (Kvanefjeld)

# Alkaline intrusion deposits

- Other important alkaline intrusions with REE (and Ta, Nb) mineralization are in Russia (Lovozero) and in Canada (Mount St. Hilaire, Nechalacho)

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# Li

Lithium
Li
3 6.94

- Lithium
- Uses of lithium
- Lithium deposits
  - Magmatic-hydrothermal deposits (pegmatites)
  - Brine deposits

# Lithium

Lithium
Li
3 6.94

- Low density, silvery, soft metal
- Ore mineral(s): spodumene (Li-pyroxene), Li-carbonate in brine, petalite, lepodolite
- Top suppliers: Chile, Australia, China
- Reserves: 26Mio t
- Resources: 98Mio t

USGS 2022

# Lithium uses

Lithium
Li
3 6.94

- Rechargeble Li-ion Batteries
- Aluminium-lithium alloys
- Speciality glasses
- Medicine

Thomas Ulrich
Institute for Disposal Research

# Lithium ore deposits

- Pegmatites
- Brines

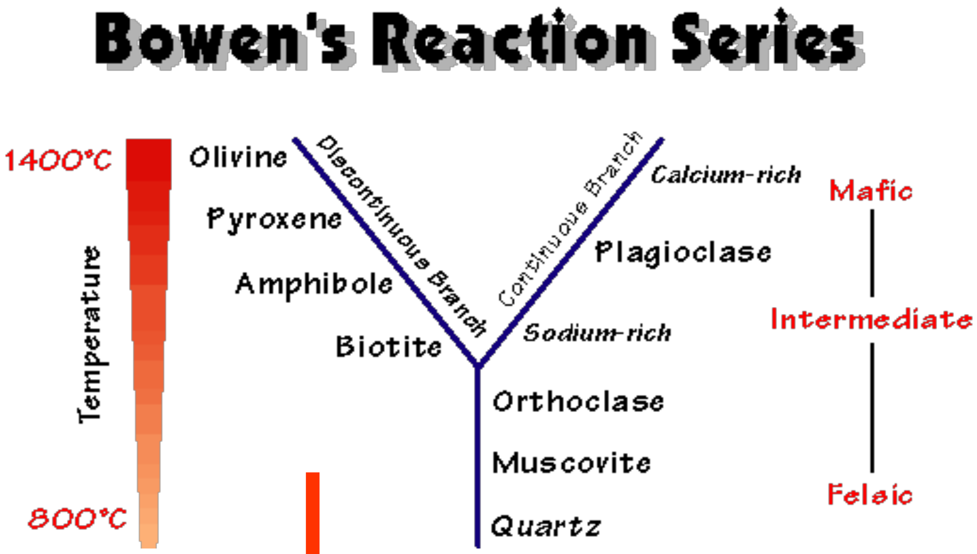
# Pegmatites

- Magmatic (hydrothermal) rock characterized by large crystals.
- Contains rare metals due to their incompatibility during melt crystallization/ fractionation.
- Can also contain gemstones.
- High grade, medium tonnage
- Ore body elongated to concentric

# Pegmatites

- **Textural term** to describe coarse-grained rocks (to metre-scale crystals) dominated by feldspars, quartz, mica. Thus, generally felsic in nature.
- Occur in a variety of geological settings.
- Granitic/felsic in composition, but also in basic rocks (e.g., Bushveld Complex).
- Enriched in volatiles (e.g., F, B, $H_2O$, Li).
- Felsic pegmatites solidify down to ca. 350-400°C (due volatiles as we will see later).

# Pegmatites




**To <500°C with $H_2O$, F, Li, B,**

**Fractionation**

**Mafic Complexes (Ni, Cu, Cr, Ti, PGE's)**

**Granites-Pegmatites (Sn, W, Rb, Li, Cs, Ta, Nb, Be)**

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# Pegmatites

- Two main families:
- - Nb-Y-F (sub-alkaline (I-type))
- - Cs-Li-Ta (peraluminous (S-type))

- The presence of B, P, F decrease the solidus, but also increase the $H_2O$ solubility, leading to a hydrous melt.

- Extreme fractionation (up to 99%) leads to the enrichment of incompatible elements reaching ore grade.

Tourmaline, Minas Gerais, Brazil

Also economically important source for feldspar, quartz, micas, and some Nb-Ta-REE-bearing minerals.

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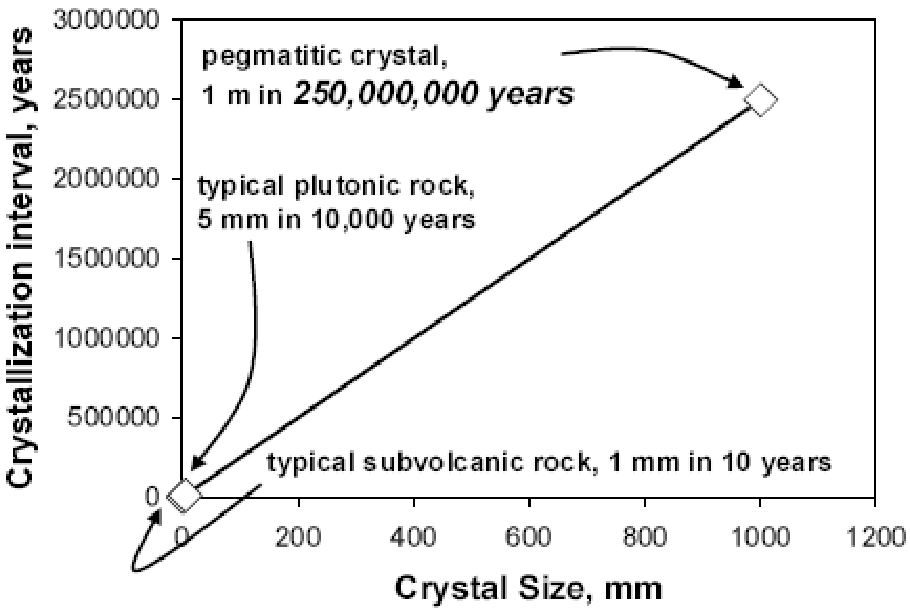
# Pegmatites

## Coarse Textures in Pegmatites:

- Growth rates of crystals do NOT mimic that in igneous systems – otherwise take very long time (10s-100s millions yrs) to grow to their size.

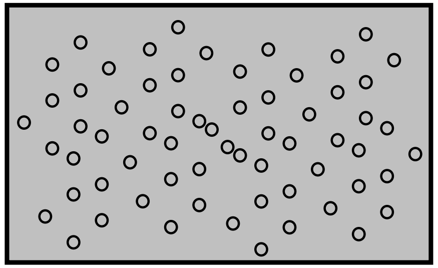
- How do we resolve this dilemma of crystal size, time and growth?

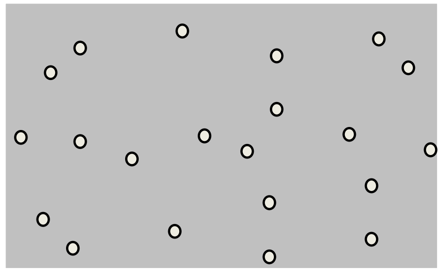


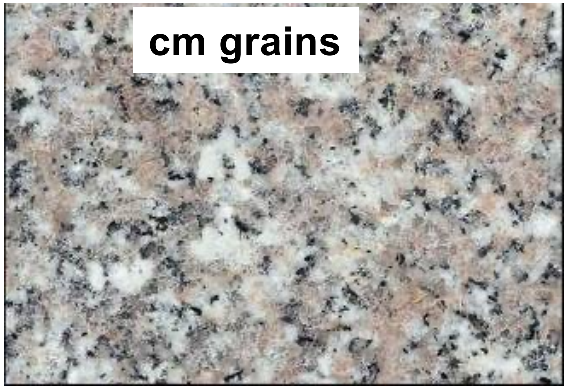
# Pegmatites

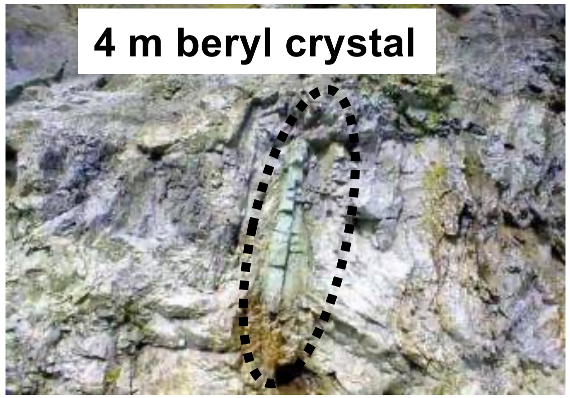
Granite
- **Dense melt**
- **Many nucleation sites**
- **High viscosity**
- **Slow diffusion**

Pegmatite
- **Low density melt/fluid**
- **Few nucleation sites**
- **Low viscosity**
- **Enhanced diffusion**

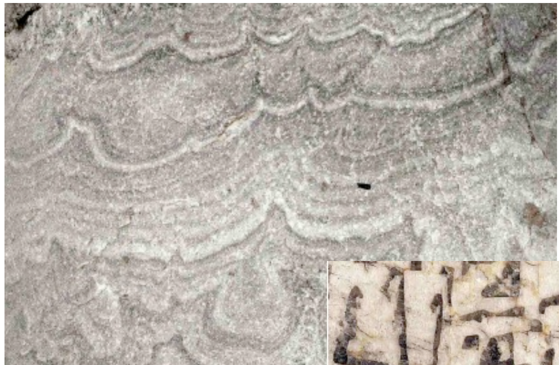


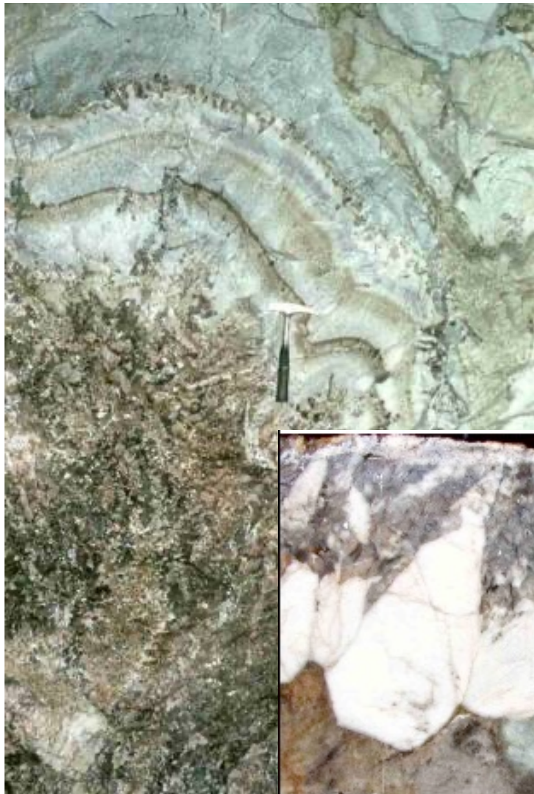




# Pegmatites



Thomas Ulrich
Institute for Disposal Research

# Pegmatites

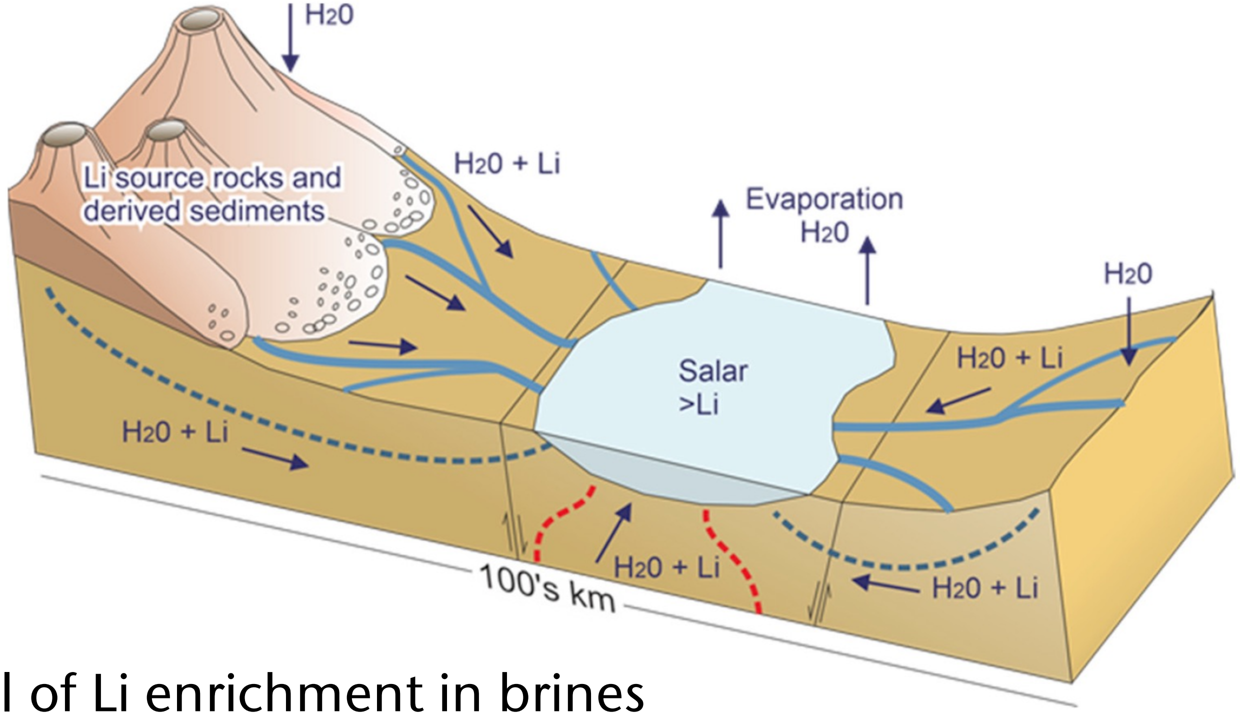
## Some (Li) minerals found in pegmatites…

Quartz, Garnet, Micas,
Rubellite – Li-rich tourmaline (red color)
Cleavelandite – platy form of albite
Blocky K-feldspar – large, coarse grains
Emerald – very green beryl ($Be_3Al_2Si_2O_6$)
Lepidolite – Li-rich mica (purple muscovite)
Spodumene – Li rich pyroxene ($LiAlSi_2O_6$)
Petalite – ($LiAlSi_4O_{10}$)
Holmquistite – Li amphibole
Pollucite – $(Cs,Na)_2Al_2Si_4O_{12} \cdot H_2O$
Apatite – $Ca_5(PO_4)_3(F, H_2O, Cl)$
Tantalite/Columbite – Ta, Nb, Mn, Fe – oxides
Wolframite – $(Fe,Mn)WO_4$
Cassiterite – $SnO_2$

# Li Brine deposits

- Salty solution that contains Li as carbonates or chlorides.
- Weathering of Li-bearing rocks, then evaporation (e.g., salars in the Andes).
- Lithium triangle (Chile, Bolivia, Argentina).

# Li Brine deposits

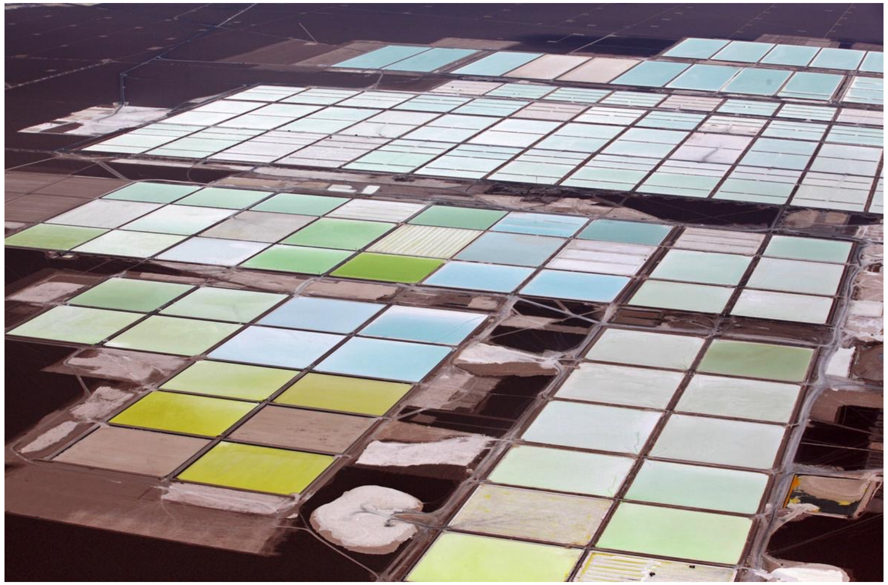



Schematic model of Li enrichment in brines

Rossi et al 2022

# Li Brine deposits

Argentina



Bolivia

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Niobium
Nb
41 92.906

Tantalum
Ta
73 180.948

# Nb and Ta

- Niobium and tantalum
- Uses of niobium and tantalum
- Niobium and tantalum deposits
  - Pegmatites
  - Carbonatites, Alkaline intrusions, Rare element granites
  - Supergene enrichment

# Niobium

Niobium
Nb
41 92.906

- Silvery, corrosion resistant metal
- Ore mineral(s): columbite ($(Fe,Mn)Nb_2O_6$), pyrochlore
- Top suppliers: Brazil, Canada, Congo
- Reserves: more than 17Mio t
- Production: 79‘000 t

USGS 2022

# Tantalum

Tantalum
Ta
73 180.948

- Silvery, corrosion resistant metal
- Ore mineral(s): tantalite ((Fe,Mn)$Ta_2O_6$), columbite (coltan)
- Top suppliers: Australia, Brazil, Canada, China, Congo
- Reserves: more than 300‘000 t
- Production: 2‘000 t

USGS 2022

# Niobium and tantalum uses

Niobium
Nb
41 92.906

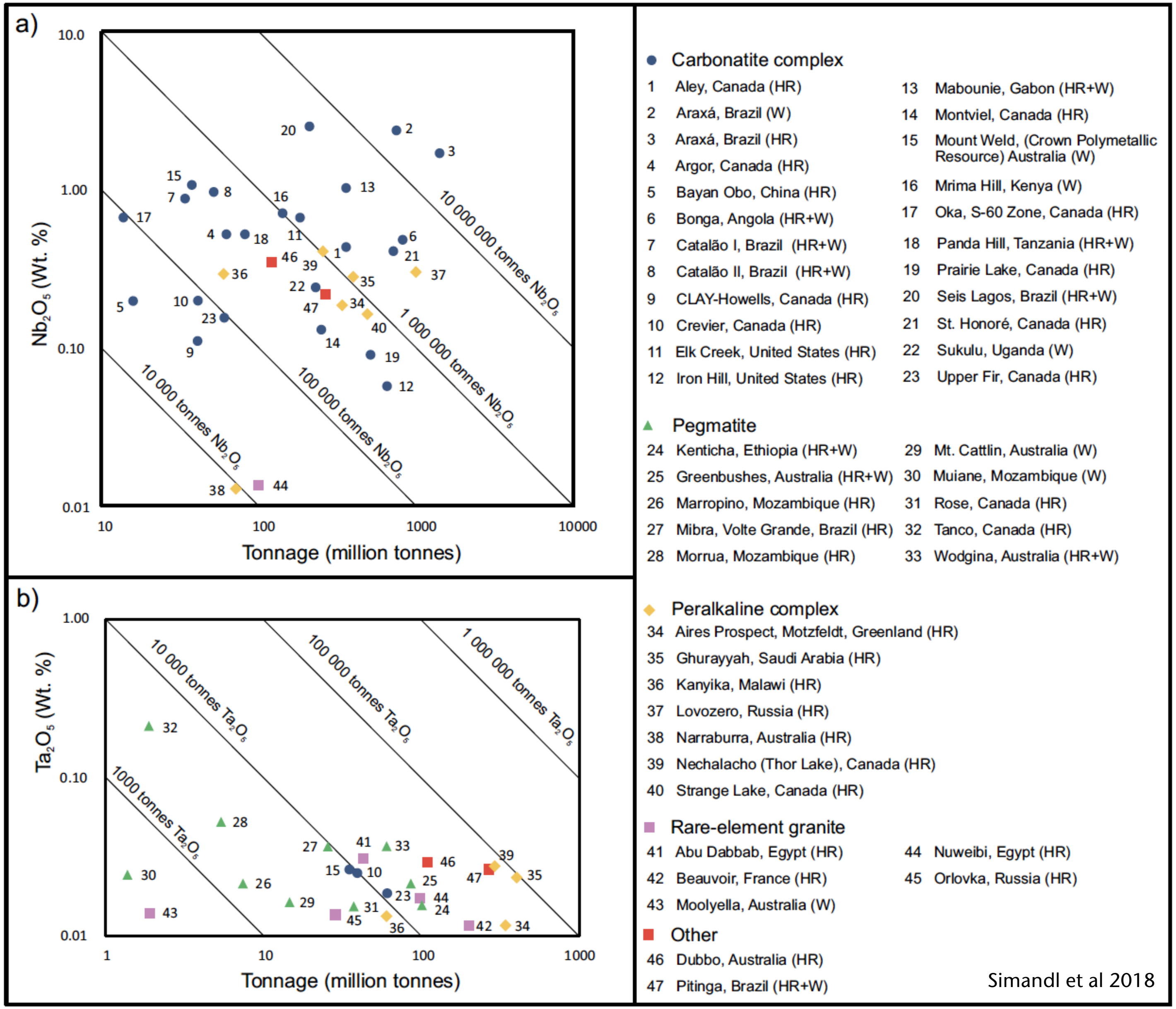
Tantalum
Ta
73 180.948

- Electronic devices, capacitors
- Superconducting magnets
- Alloys

# Nb and Ta ore deposits

- Carbonatites, Alkaline intrusions, Rare element granites
- Pegmatites
- Supergene enrichment

# Niobium and tantalum deposits




Thomas Ulrich
Institute for Disposal Research