



GIFT WORKSHOP – 2015



MINERAL DEPOSITS WHERE DO THEY COME FROM AND HOW DID THEY GET THERE?

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THE UNDERSTANDING OF ORE FORMING PROCESSES
IS VITAL FOR THE PROPER AND SUSTAINABLE
MANAGEMENT OF GLOBAL METAL RESOURCES...

...it is also key to the environmental remediation
that must accompany all mining activity



UNDERSTANDING **ORE FORMING** PROCESSES
PROVIDES GEOLOGISTS WITH FASCINATING
INSIGHTS INTO THE WORKINGS OF THE EARTH
....BOTH AT AND BELOW ITS SURFACE

Different geological processes (igneous,
hydrothermal, sedimentary) give rise to very
different types of ore deposits....

The various stages of earth history also gave
rise to differing styles of ore formation.....

THIS LECTURE WILL ATTEMPT TO COVER 4 MAJOR PROCESSES.....

1. Circulation of sea water through the oceanic crust
[‘black smokers’ and Cu-Zn-Pb massive sulphide deposits]
2. Concentration of metals in sediments linked to the ‘Snowball Earth’ events
[Cu-Co ores of the Central African Copperbelt]
3. Granites and fluids along subducting plate margins
[the ‘porphyry copper’ giants of the Andes]
4. Basalt magmatism and fractional crystallization
[the Cu-Ni-PGE deposits of the Bushveld Complex]

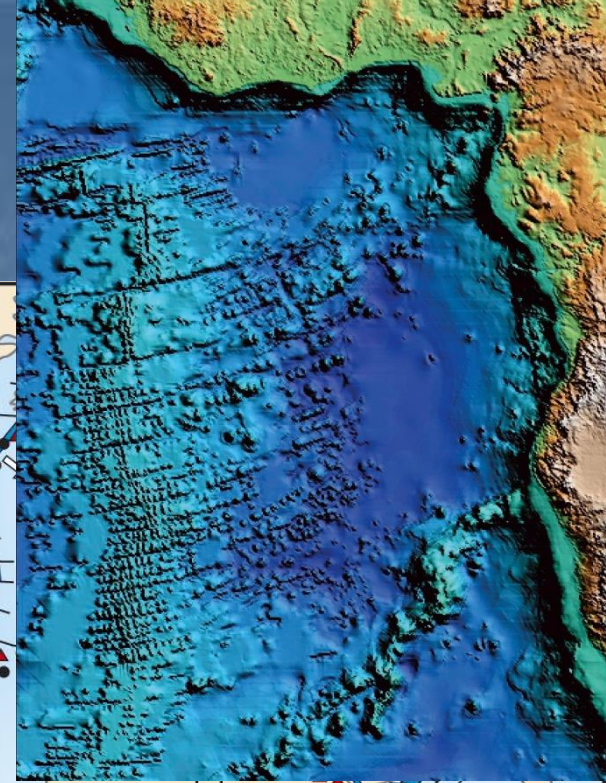
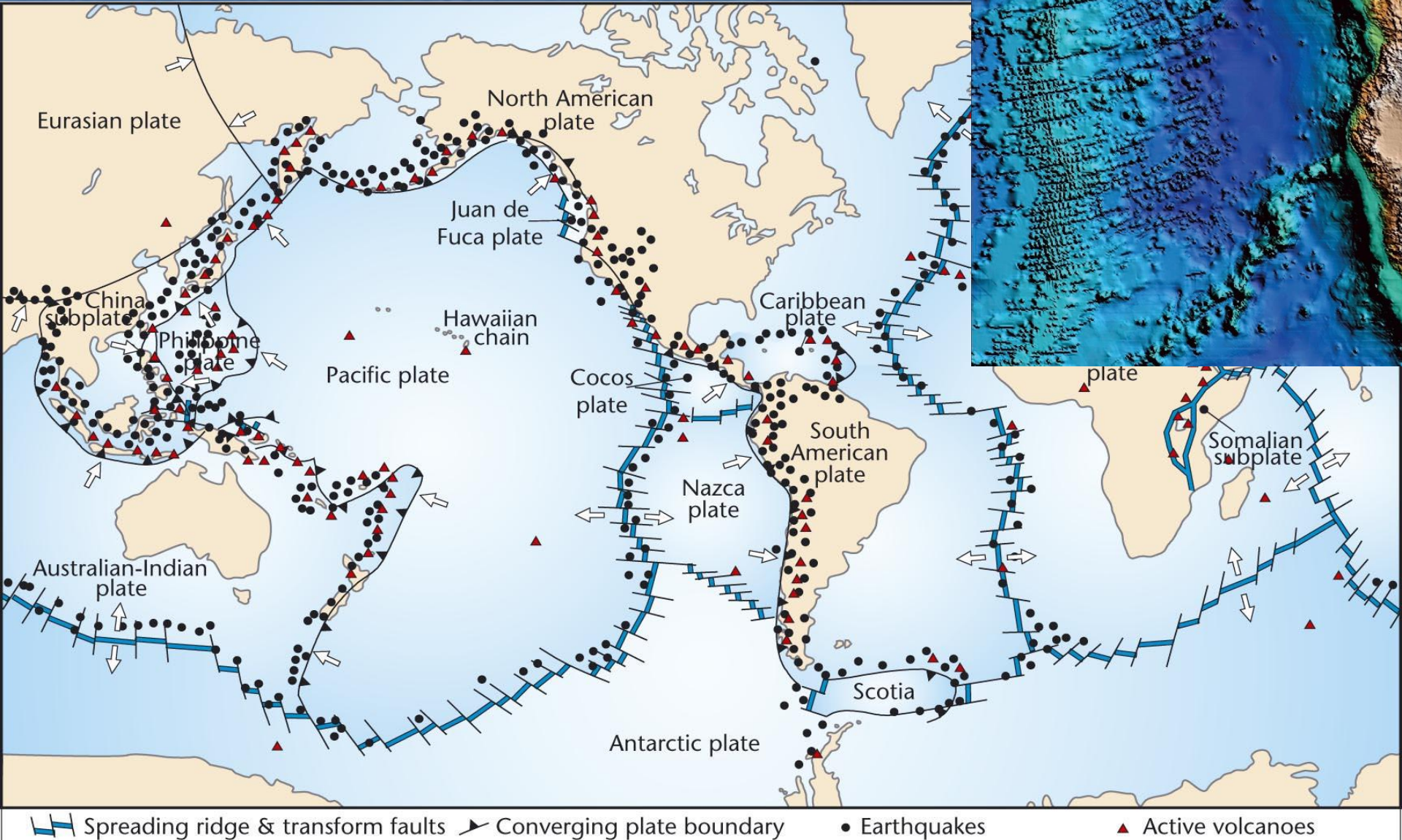
1. OCEAN FLOOR HYDROTHERMAL PROCESSES



Alvin

**exhalative vent
or 'black smoker'.....first
observed 1977**

BLACK SMOKERS HAVE BEEN LOCATED AT 'SPREADING CENTRES' THROUGHOUT THE PACIFIC AND INDIAN OCEANS.....some 370 trillion gallons of sea water pass through vents each year



VOLCANOGENIC MASSIVE SULPHIDE (VMS)mainly Cu and Zn

SEDIMENTARY EXHALATIVE (SedEx)mainly Pb-Zn

Cyprus (Troodos), Kidd Creek (Canada), Kuroko (Japan)

**Broken Hill, Mt Isa (Australia), Sullivan (BC),
Red Dog (Alaska), Navan (Ireland)**



This black smoker, from the East Pacific Rise, consists of a sulfide mound with several actively venting chimneys. (© Woods Hole Oceanographic Institution)

....blind crabs



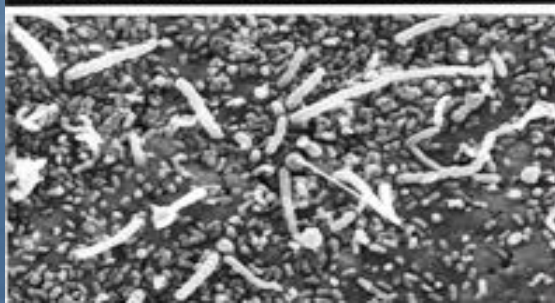
.....tube worms



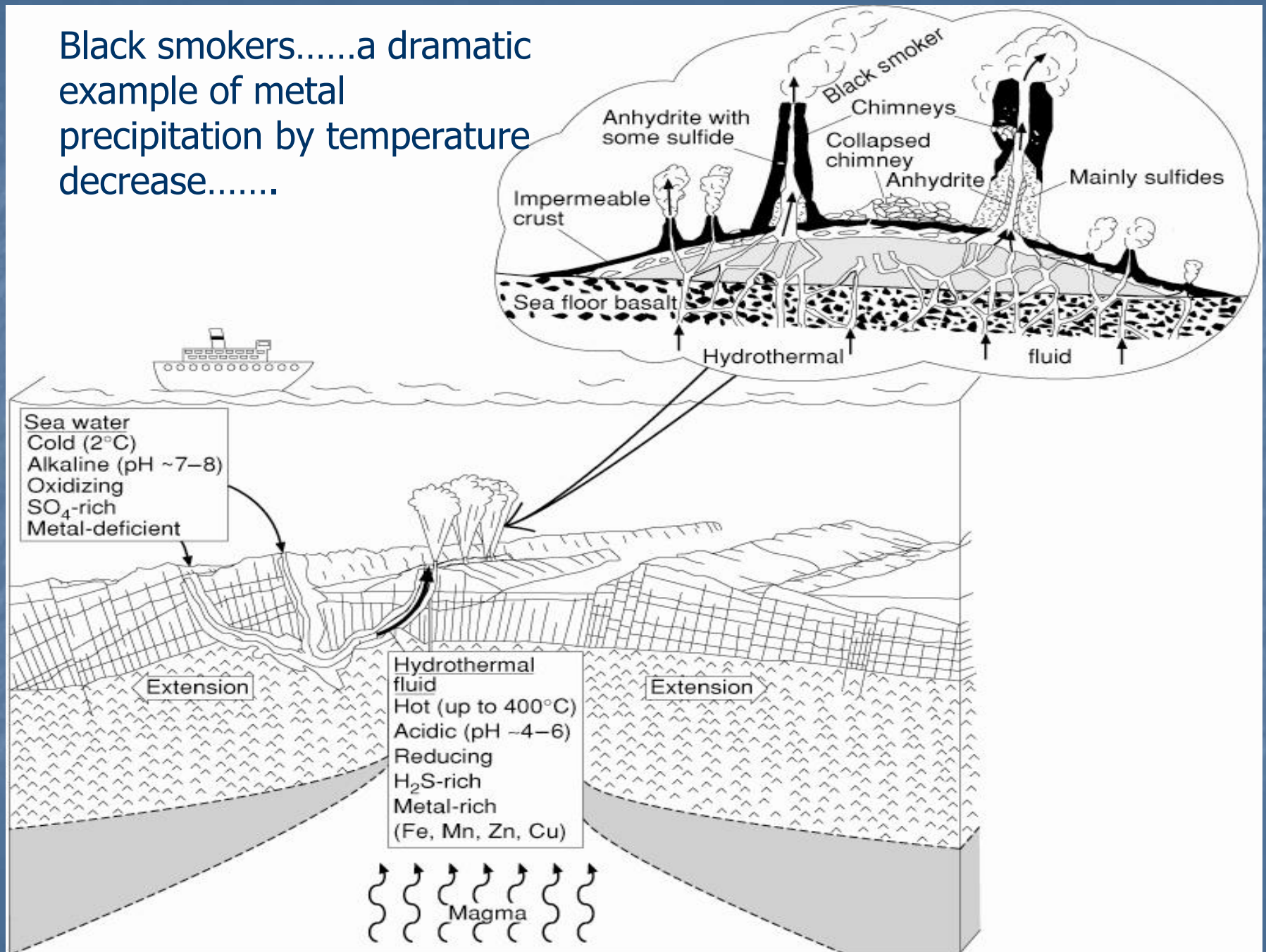
....chemosynthetic
bacteria



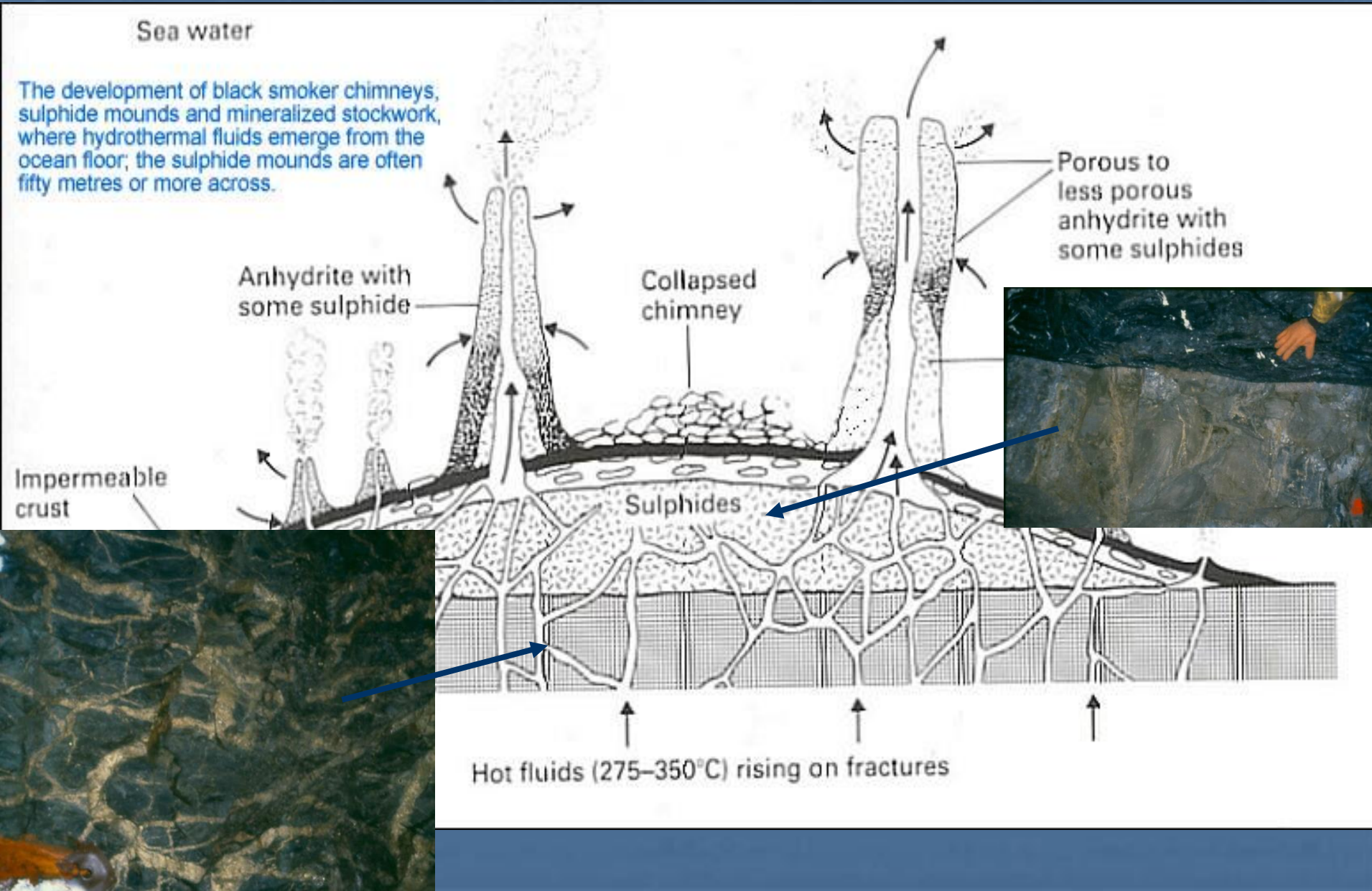
0006 15KV X1,800 10µm WD29

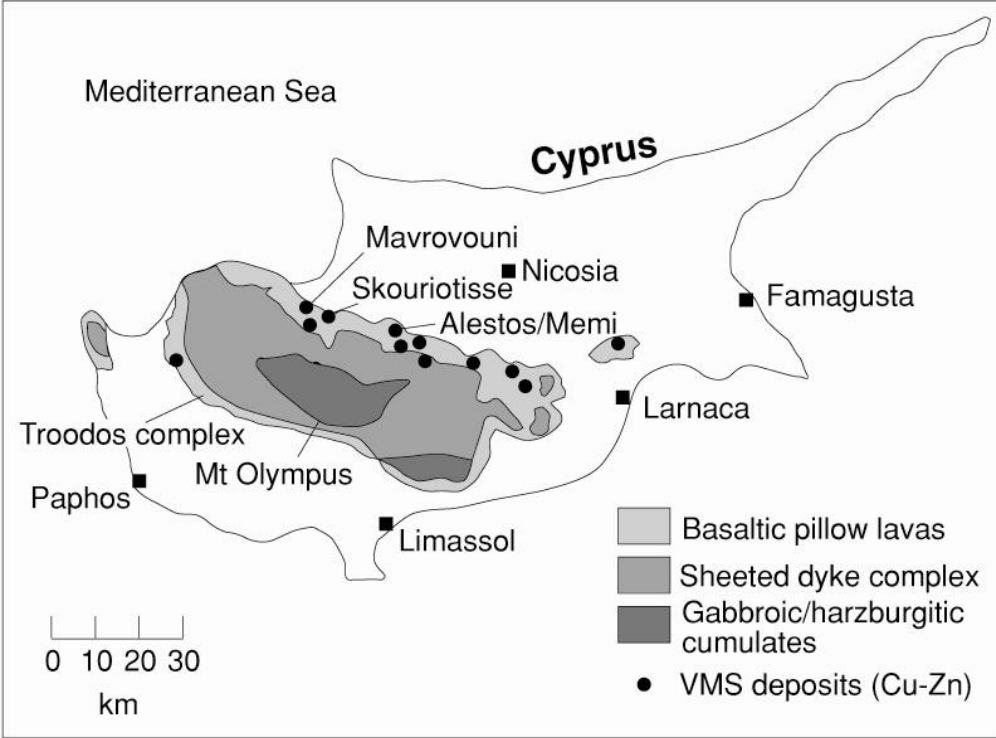


Black smokers.....a dramatic example of metal precipitation by temperature decrease.....



....the classic 'massive sulphide' mound model....







**IN THE TROODOS MOUNTAINS
OF CYPRUS ONE CAN.....**

**...see the pillowed ocean floor
basalts.....**



**....and the sheeted dykes that feed magma
into the spreading centre....**

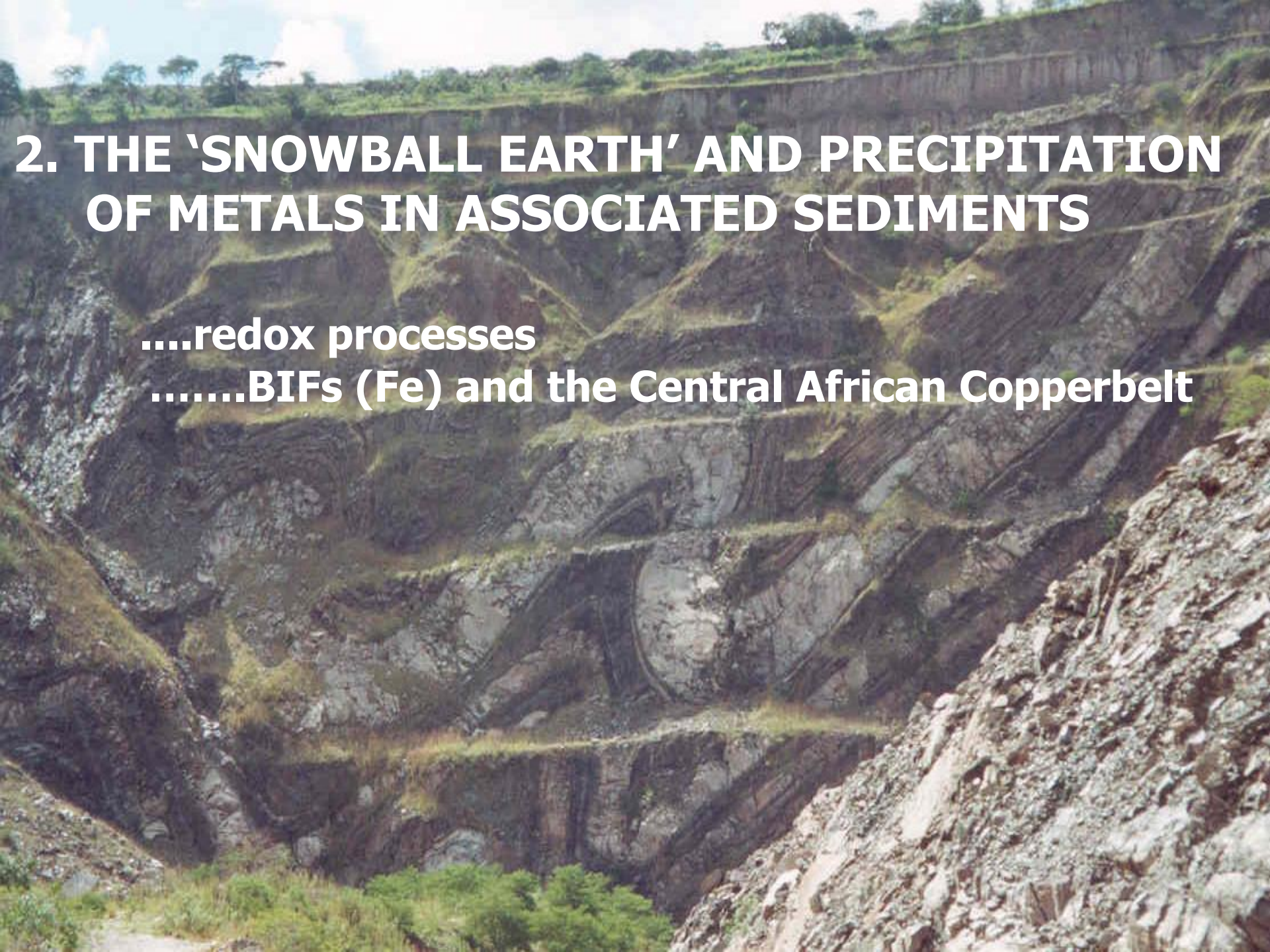
**....as well as the remnants of mined out Cu-Zn
VMS deposits**



2. THE 'SNOWBALL EARTH' AND PRECIPITATION OF METALS IN ASSOCIATED SEDIMENTS

....redox processes

.....BIFs (Fe) and the Central African Copperbelt

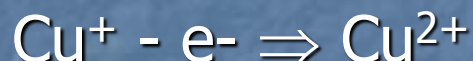


REDOX REACTIONS.....how do they work?

➤ OIL RIG....OXIDATION IS LOSS

REDUCTION IS GAIN.....of e⁻

➤ Oxidation..... $\text{U}^{4+} - 2\text{e}^- \Rightarrow \text{U}^{6+}$



(increases uranium/copper solubility....

∴ reduction precipitates uranium/copper)

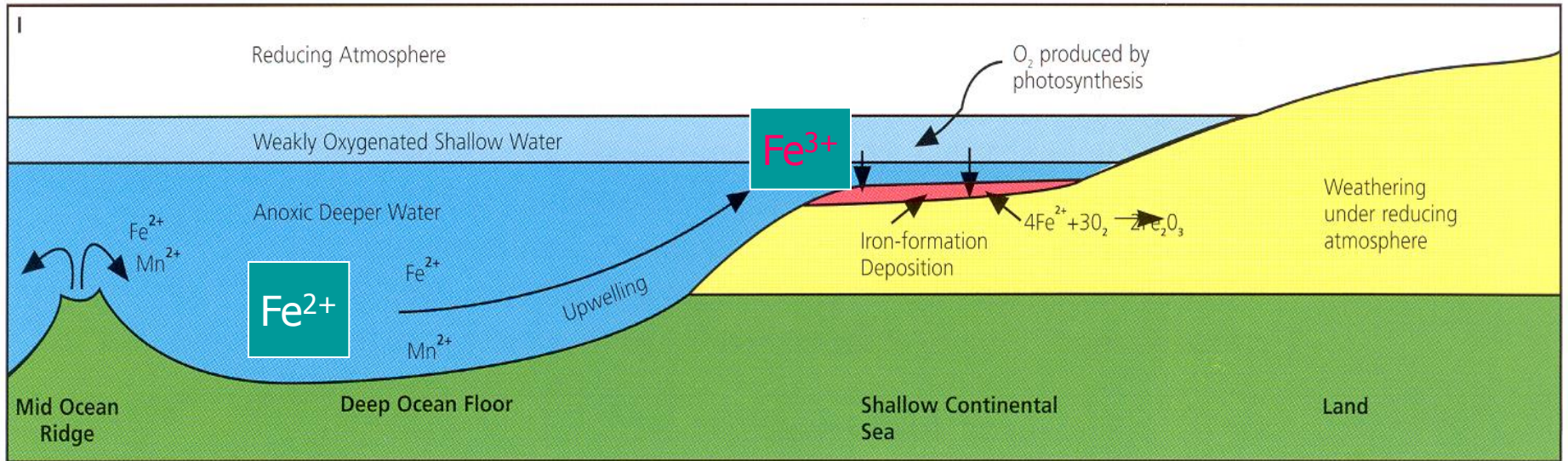
➤ Reduction..... $\text{Fe}^{3+} + \text{e}^- \Rightarrow \text{Fe}^{2+}$

(increases iron solubility.....

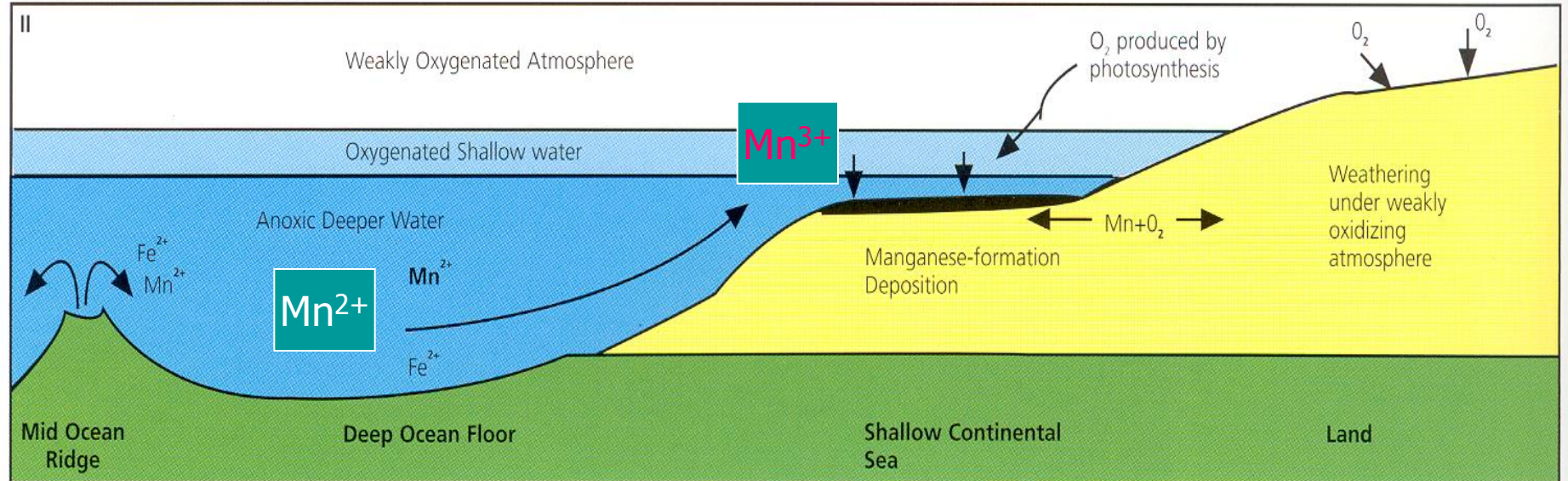
∴ oxidation precipitates iron)

....the upwelling hypothesis

Before 2300 million years ago



Period 2200-2300 million years ago





**BANDED IRON FORMATION (BIF)....
.....the main ore of iron world-wide**



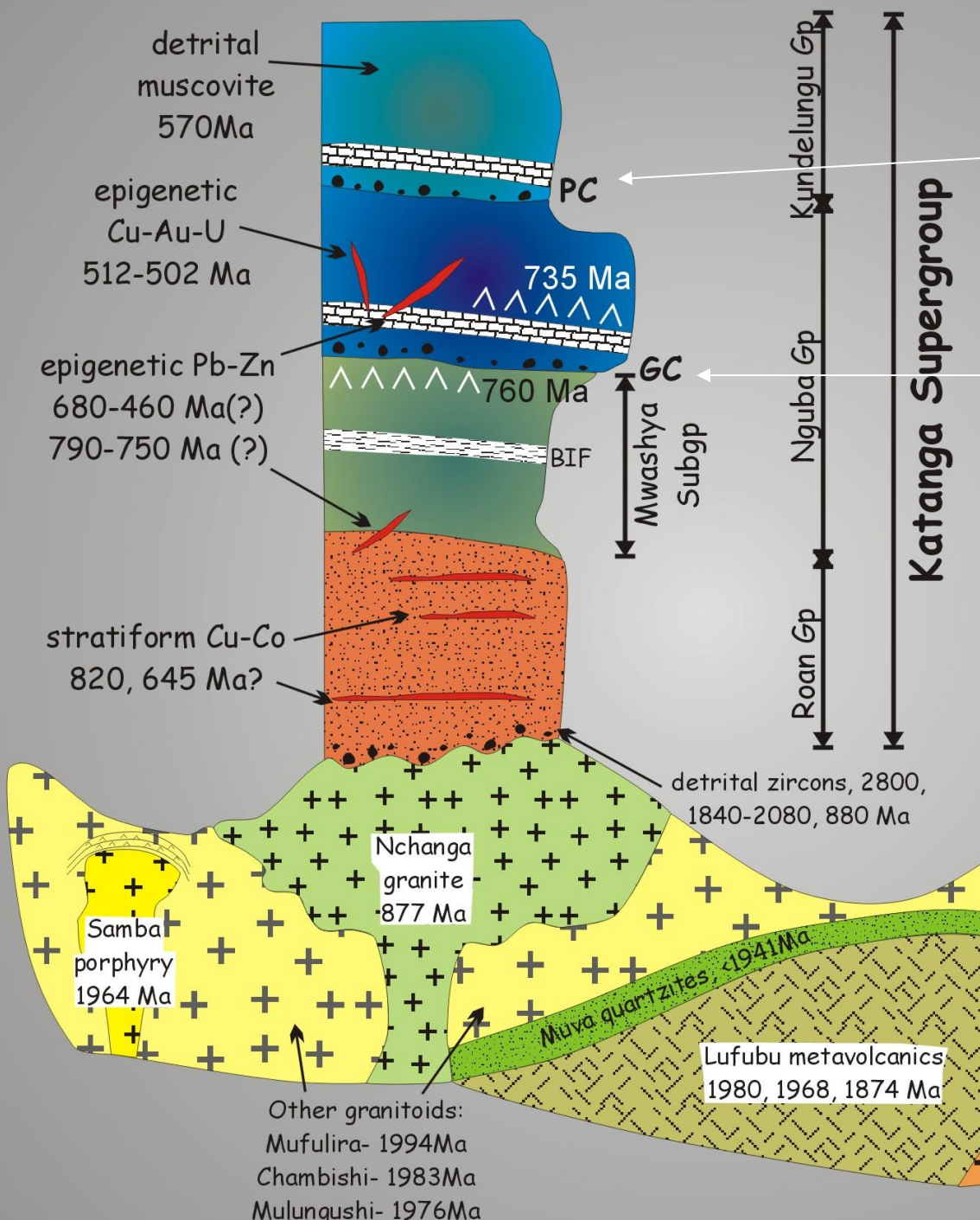
Also stratiform Cu-Co
mineralization in the
Central African
Copperbelt.....





STRATIFORM Cu-Co
MINERALIZATION SEEMS
TO OCCUR IN STRATA
CHARACTERIZED BY A
REDOX CHANGE.....





MARINOAN
ca. 630 Ma

STURTIAN
ca. 730 Ma

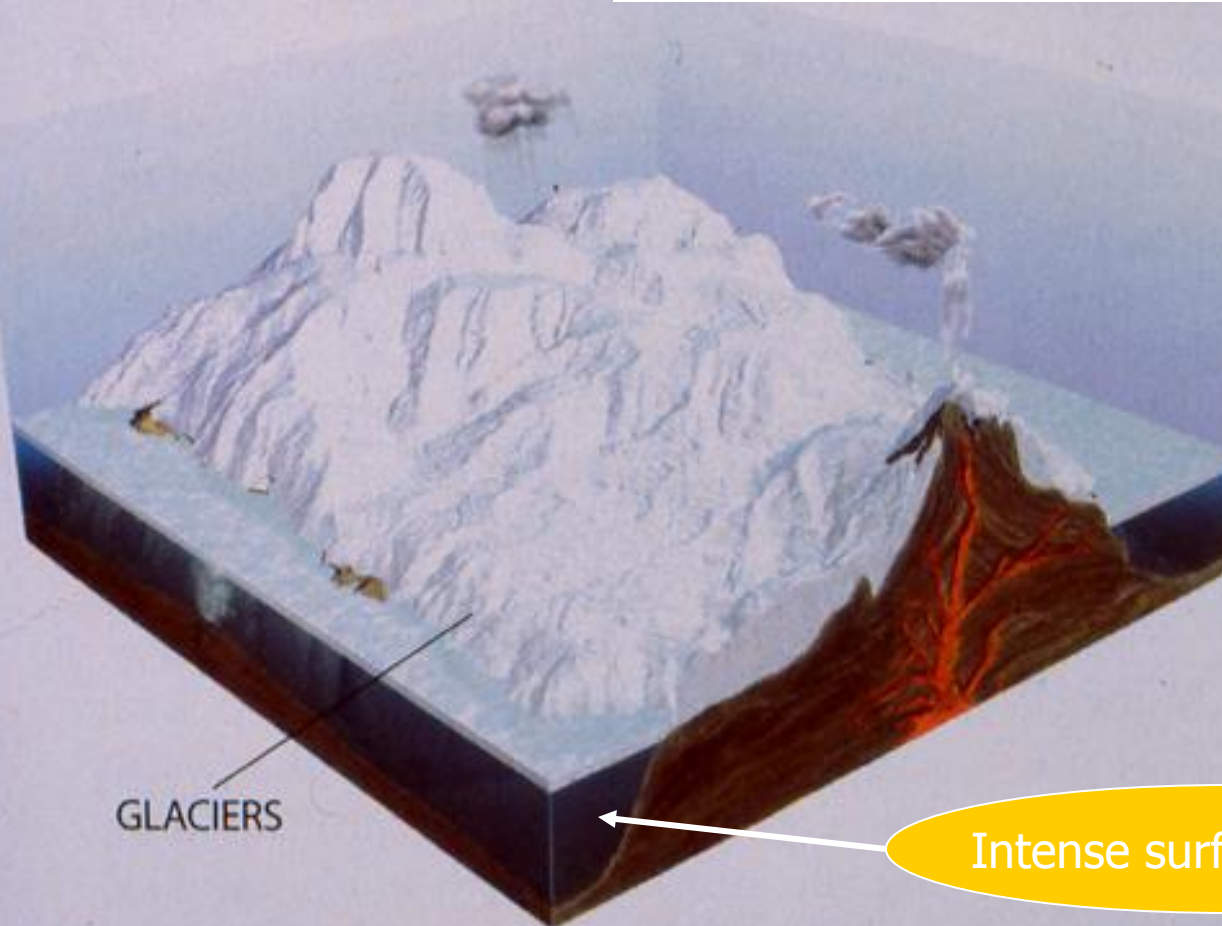
2 Snowball Earth events
in the Katangan?



The Snowball Earth

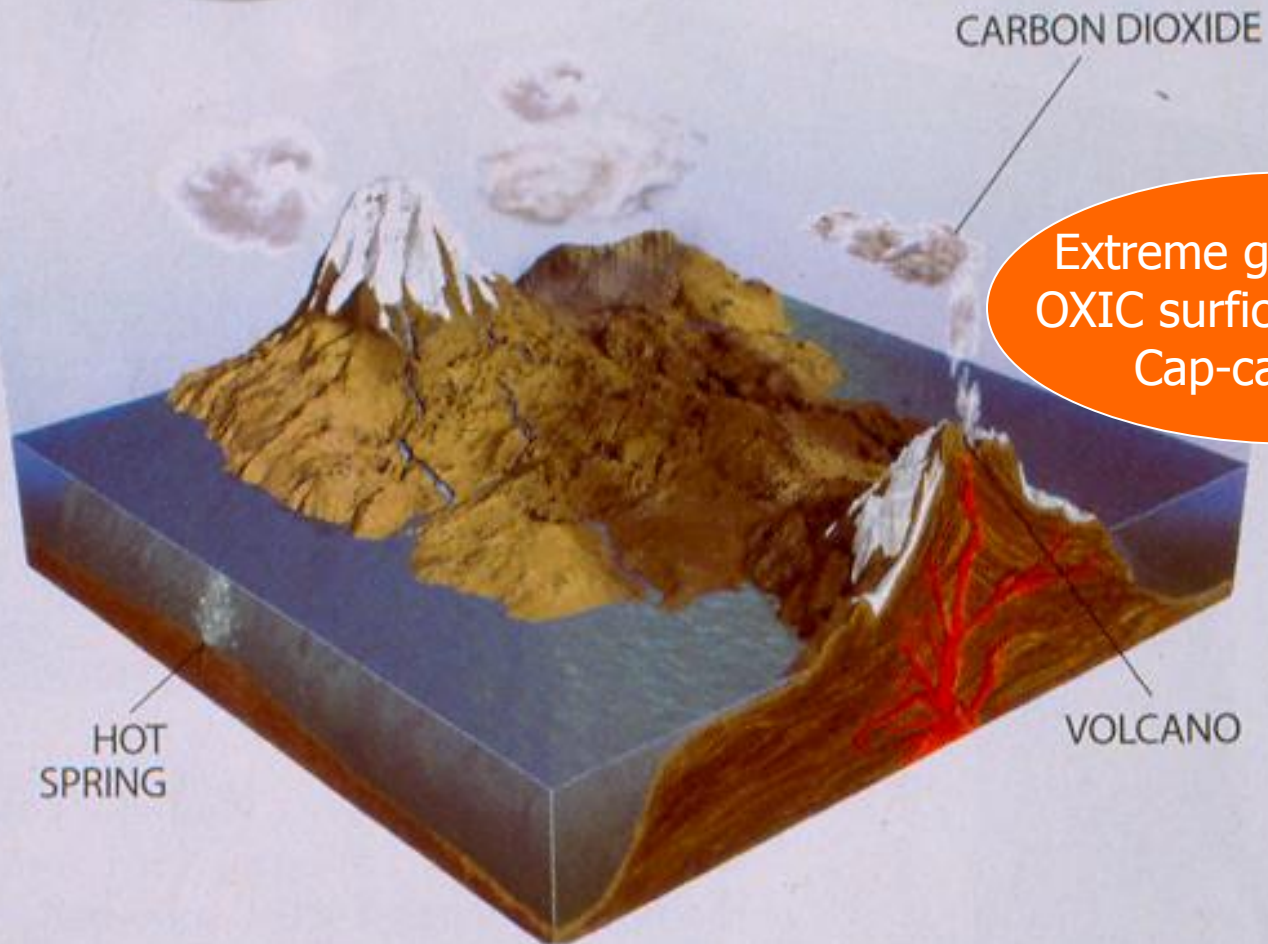
Palaeoproterozoic (2400 Ma)

Neoproterozoic (580 Ma - Varangian
620 Ma – Marinoan PC?
750 Ma – Sturtian GC?)



Intense surficial ANOXIA

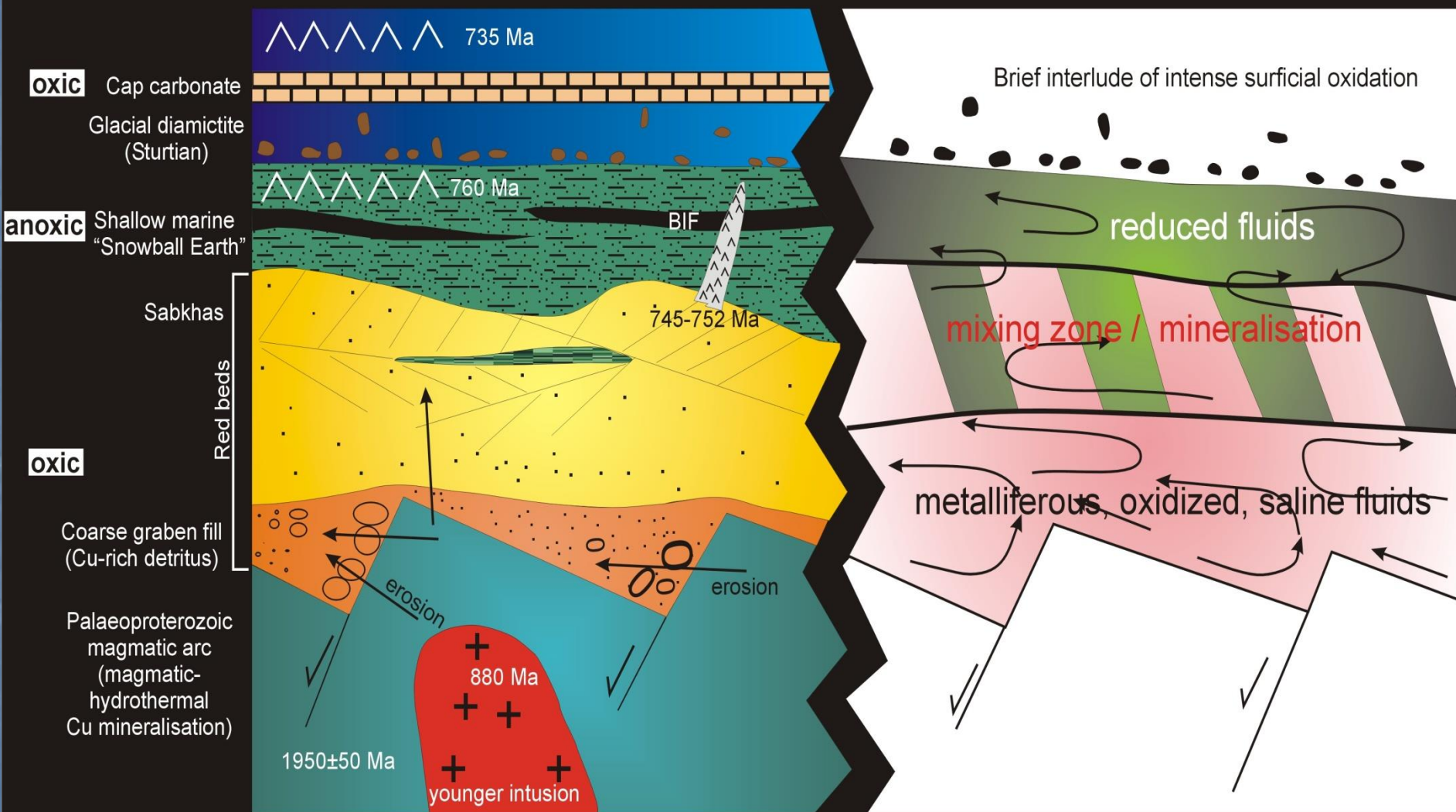
The Snowball aftermath



Extreme greenhouse....
OXIC surficial conditions,
Cap-carbonates

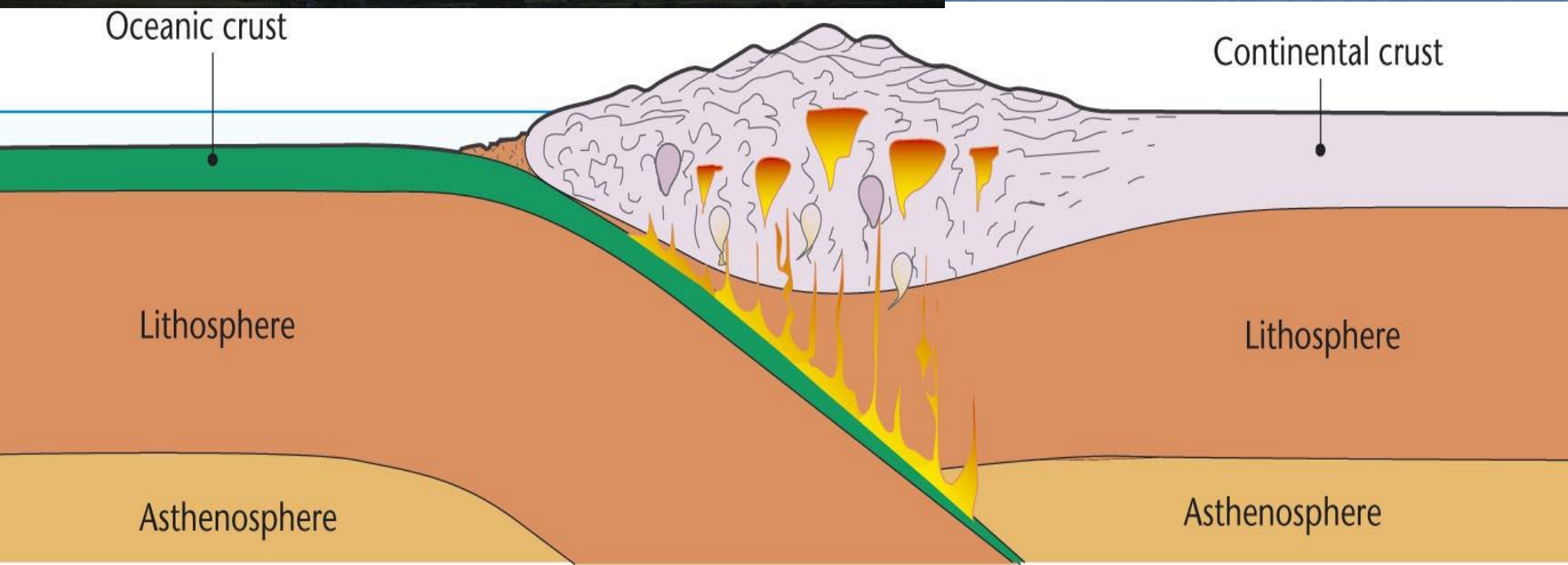
ENVIRONMENT

FLUID REGIME

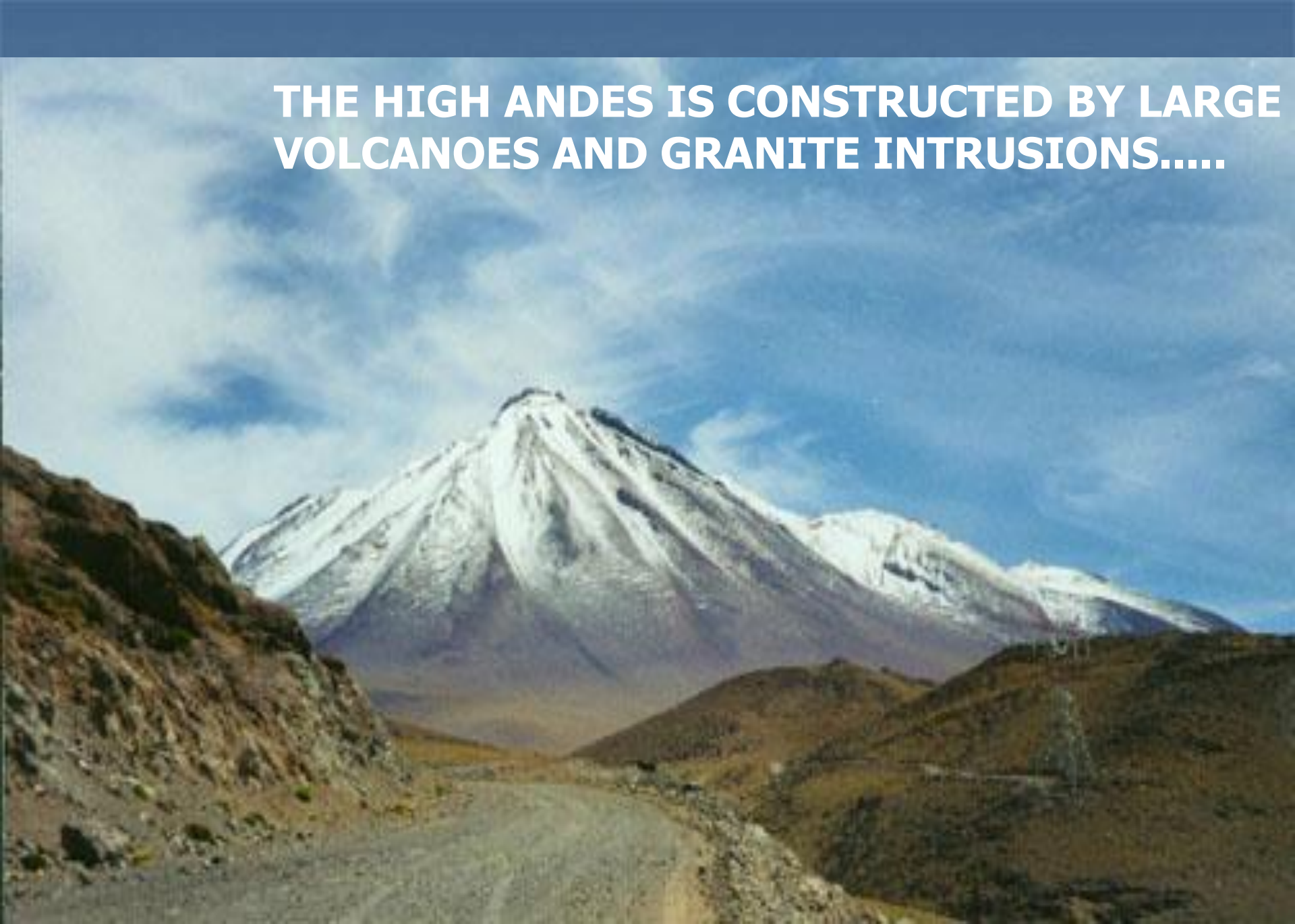


3. SUBDUCTION RELATED GRANITE MAGMATISM AND VOLCANIC FLUIDS....

.....THE 'PORPHYRY' Cu-Mo GIANTS OF THE CHILEAN ANDES



THE HIGH ANDES IS CONSTRUCTED BY LARGE VOLCANOES AND GRANITE INTRUSIONS.....



....and on top of them
sit some of the
great porphyry copper
deposits of the world.....

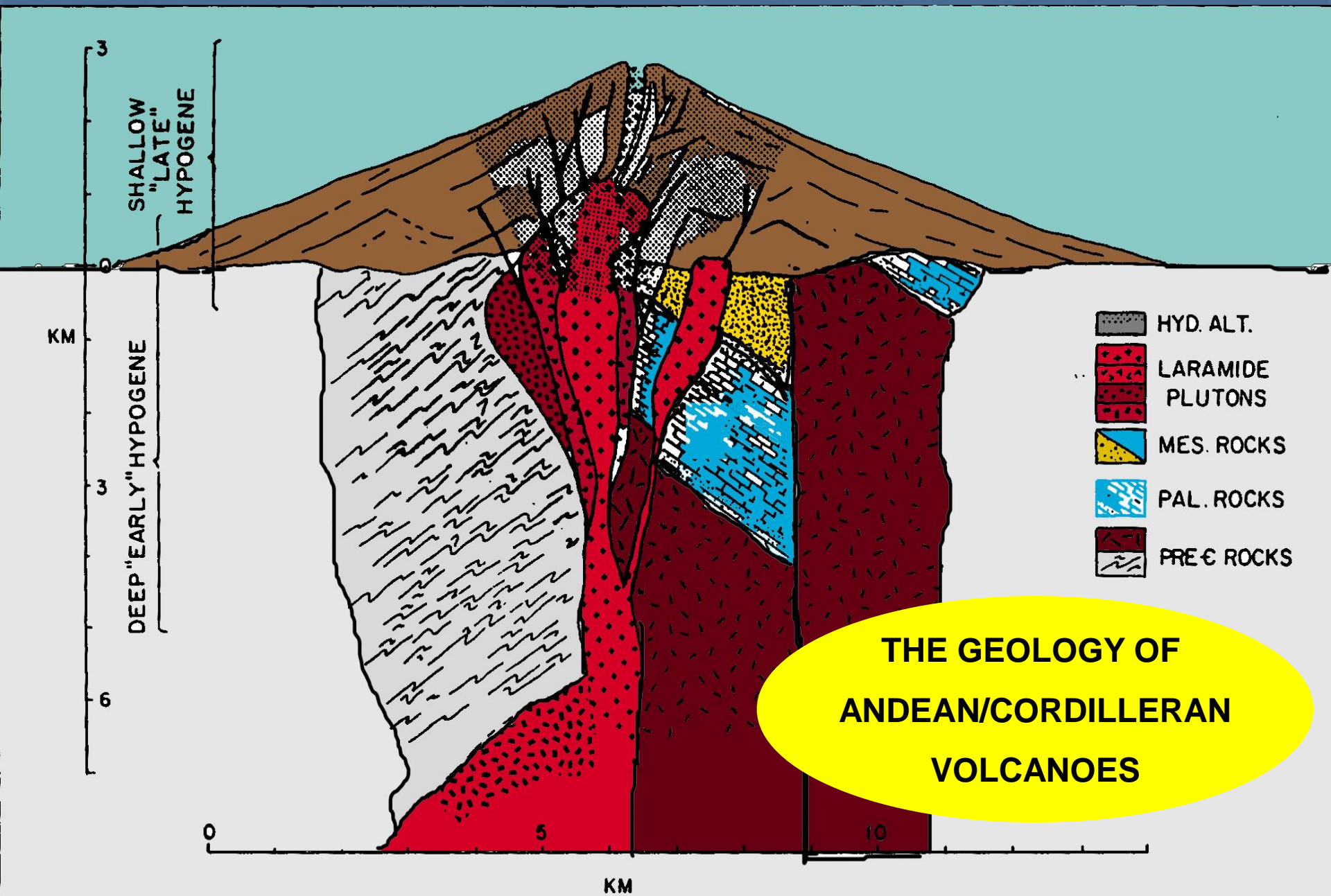


ASTER/VNIR, RGB-321 (2000/04/07) METI/ERSDAC

0 1 2 3 4 5 km



El Teniente, Chile



THE GEOLOGY OF ANDEAN/CORDILLERAN VOLCANOES



MAGMAS CONTAIN VARIABLE AMOUNTS OF VOLATILES (H_2O , CO_2 , H_2S etc) THAT EXSOLVE AT HIGH CRUSTAL LEVELS DUE TO PRESSURE DECREASE.....

Magmatic-hydrothermal fluid....

90°C, pH=2



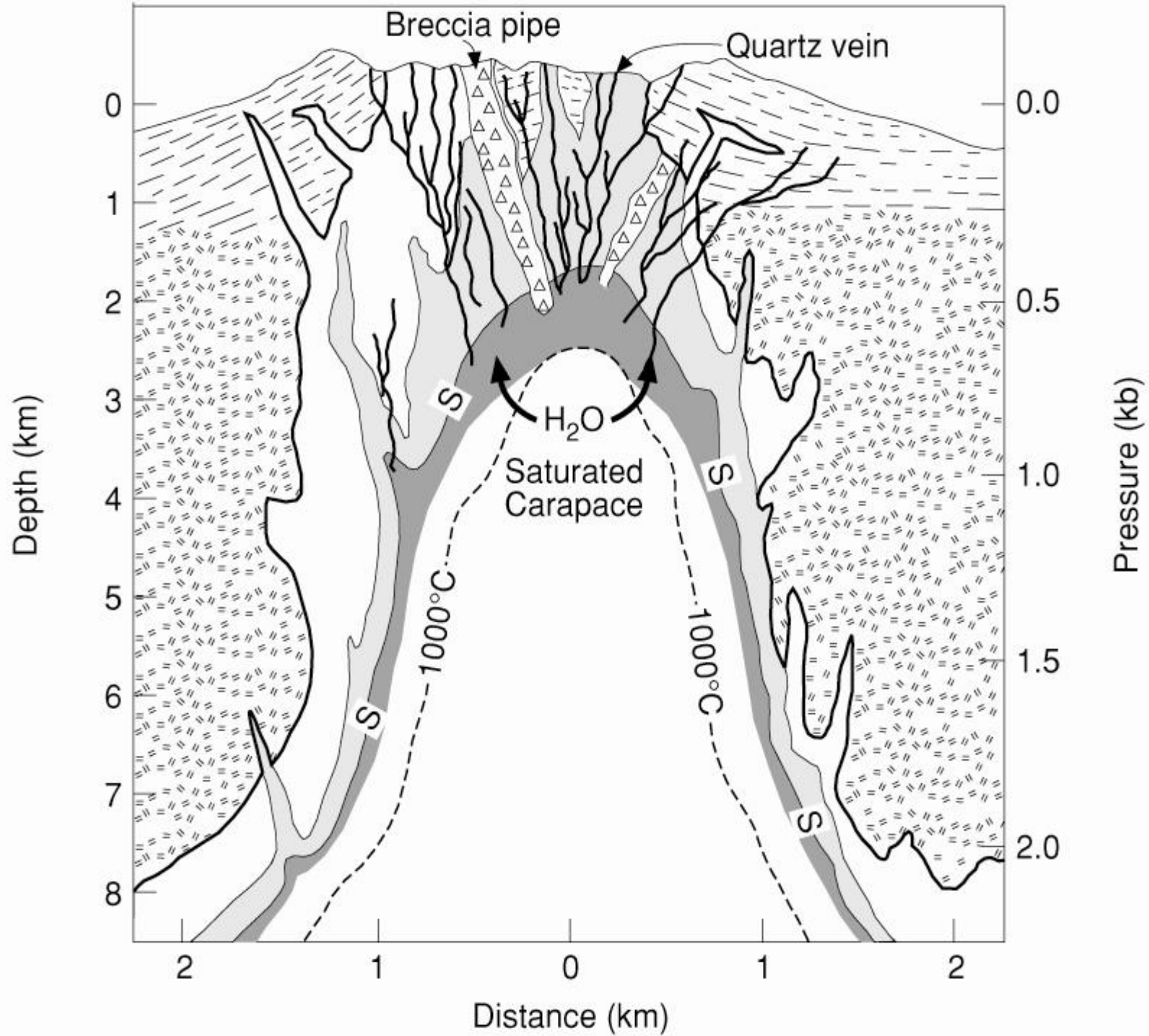


KASUGA GOLD MINE
Kyushu, Japan



Weairakei, North Island,
New Zealand







Fresh rock

Altered rock



Morenci Cu-Mo mine, Arizona

**PRECIPITATION OF
PYRITE (FeS_2) AND
CHALCOPYRITE
(CuFeS_2)**

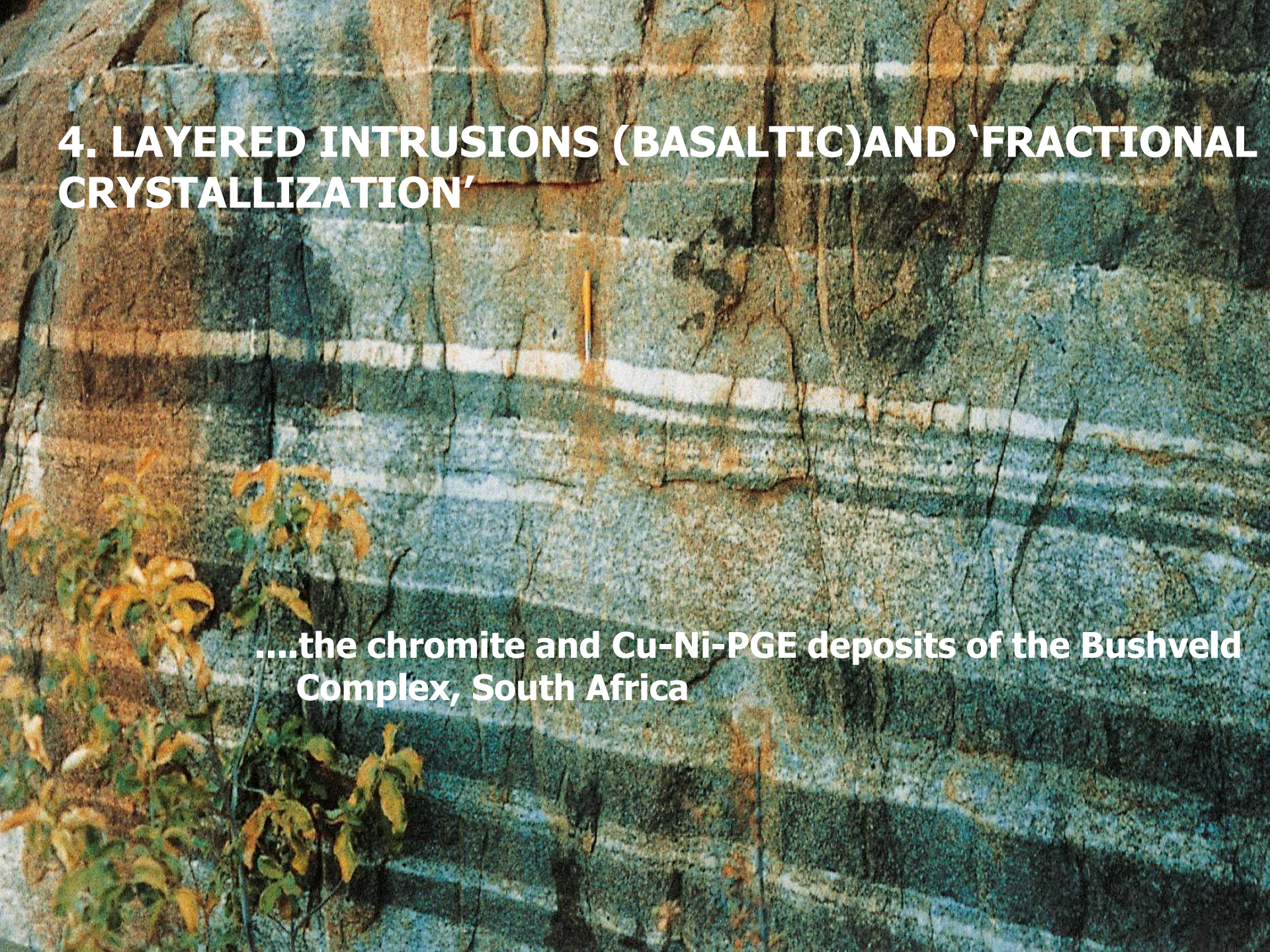


**Vein stockwork in
granite porphyry**



4. LAYERED INTRUSIONS (BASALTIC) AND 'FRACTIONAL CRYSTALLIZATION'

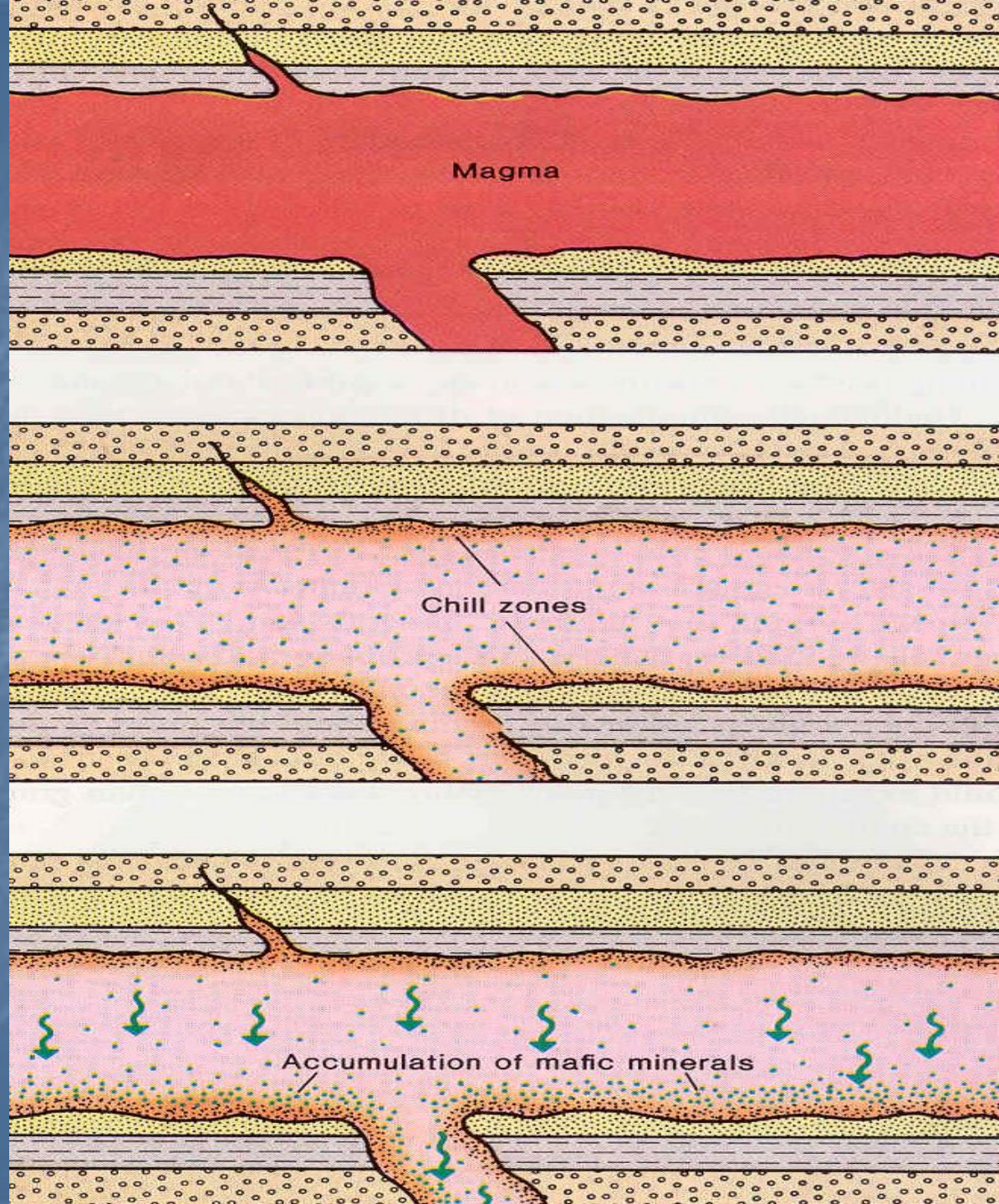
....the chromite and Cu-Ni-PGE deposits of the Bushveld Complex, South Africa



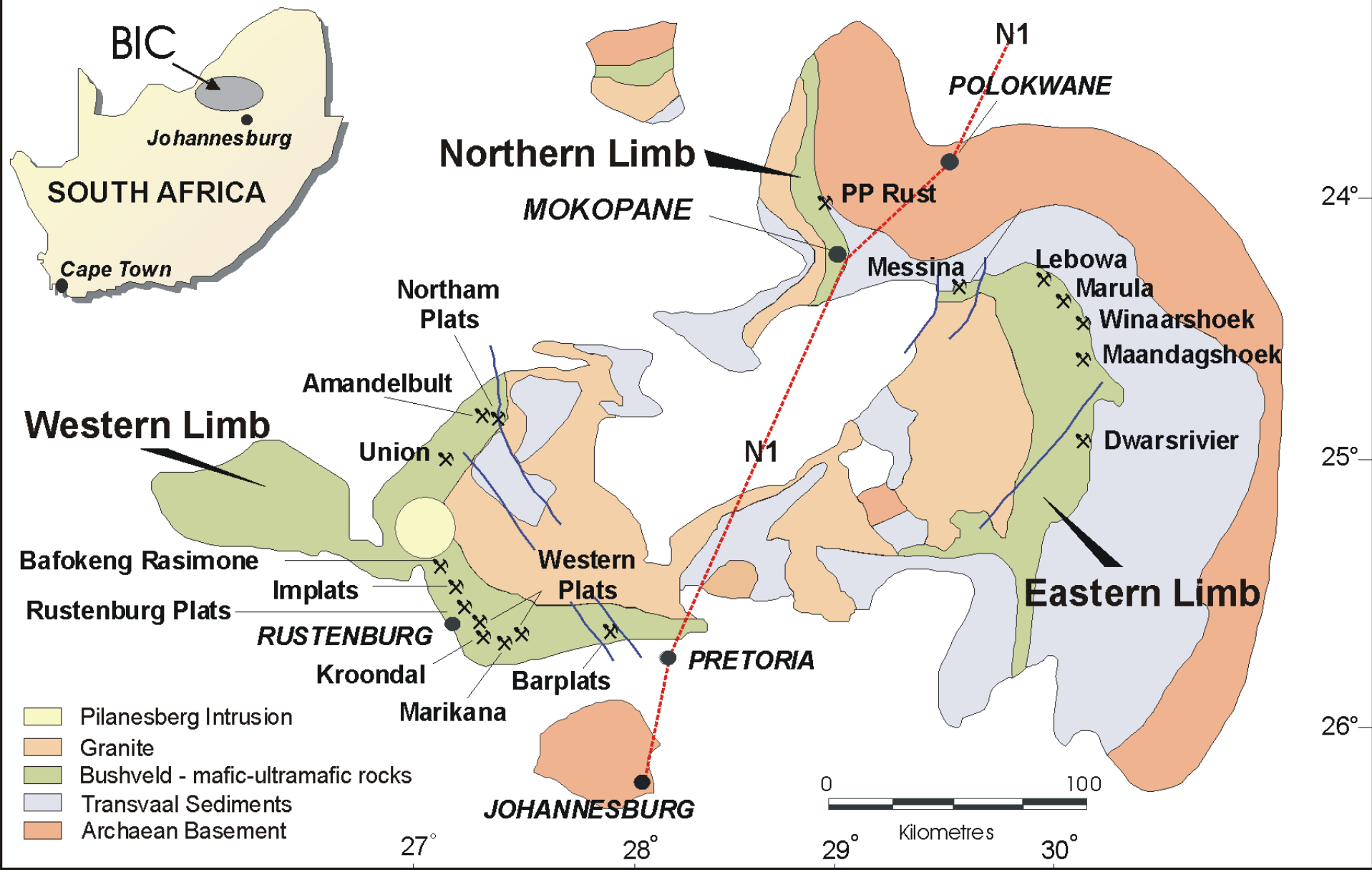
WHAT IS CRYSTAL FRACTIONATION?

...as early crystals form and settle to the floor of the magma chamber, the residual magma changes composition....

...so later crystals also change composition, ultimately forming a 'layered intrusion'



The Bushveld Complex



THE BUSHVELD COMPLEX
CONTAINS >80% OF THE
WORLD'S PGE RESERVES AND A
SUBSTANTIAL PORTION OF ITS
CHROMIUM RESERVES....

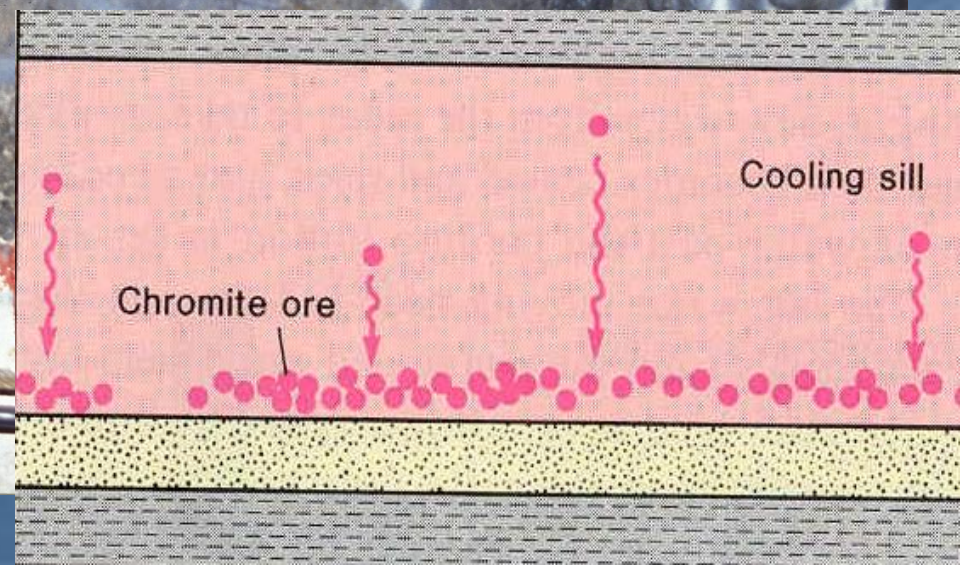
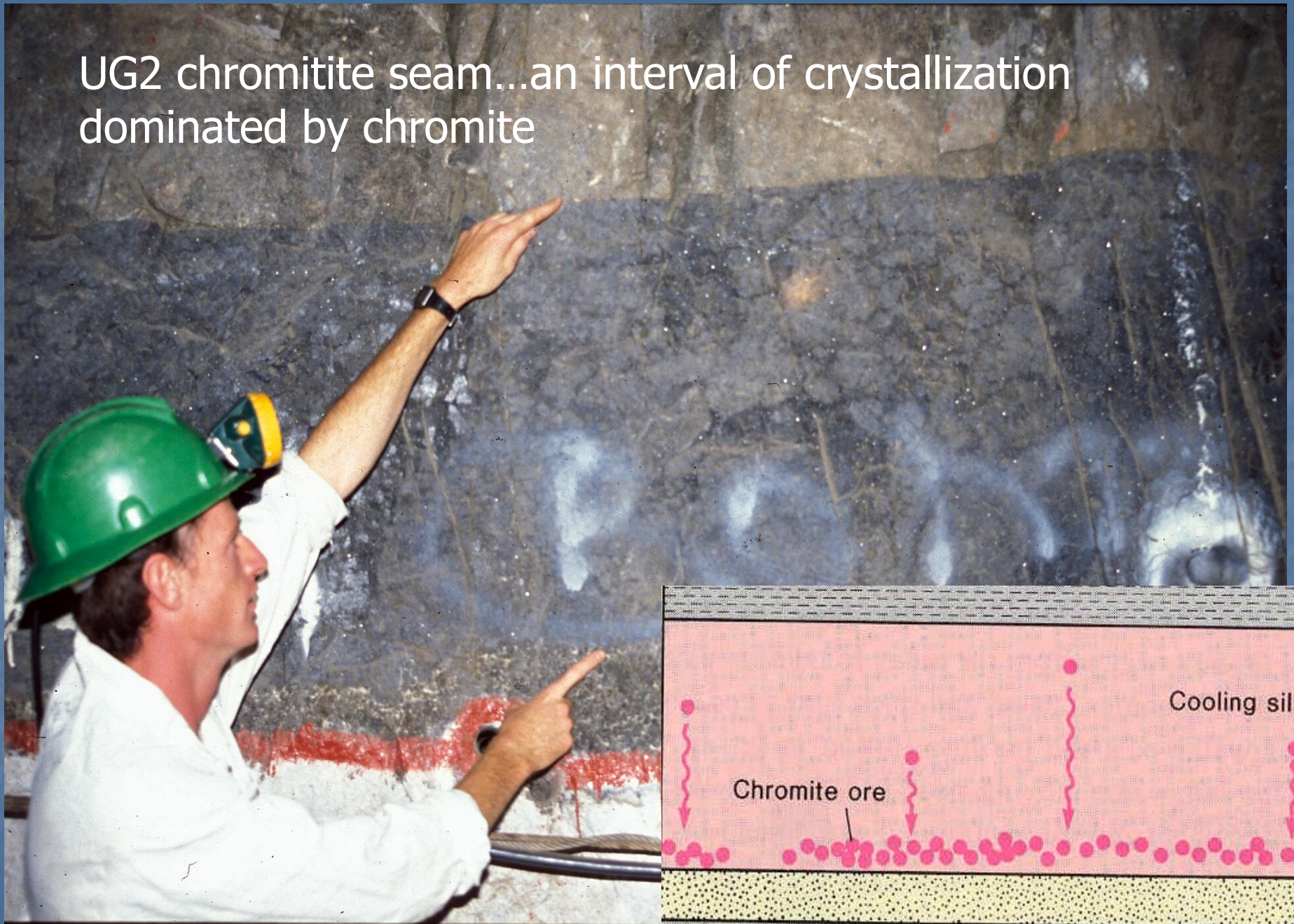


Merensky Reef

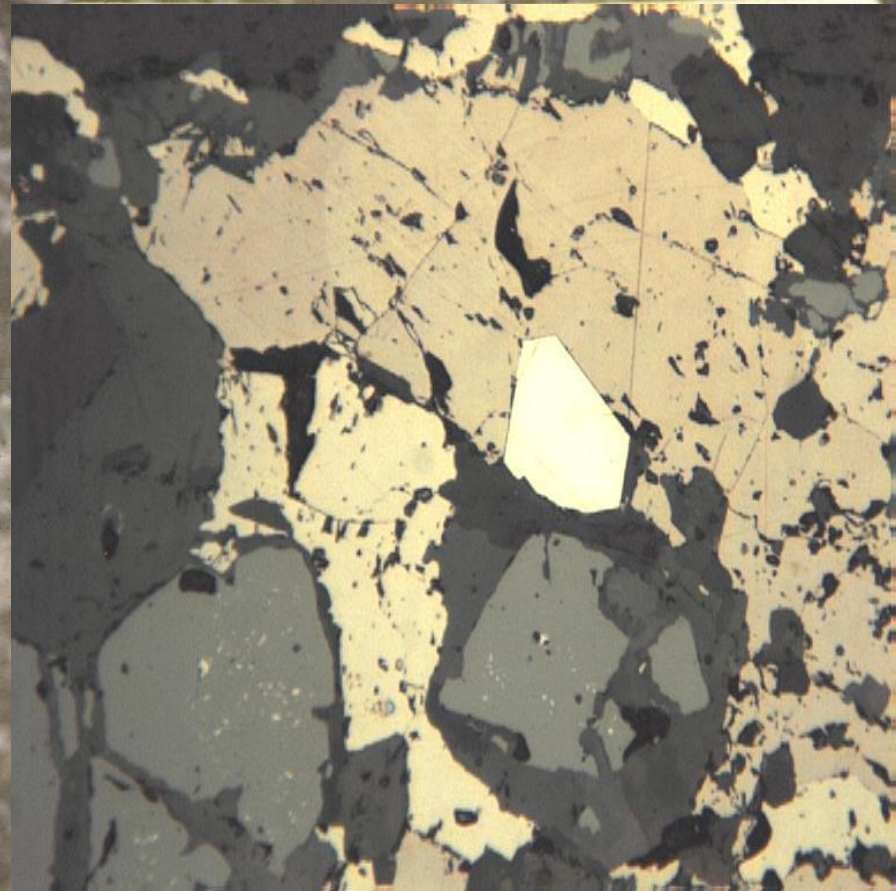


UG1 chromitite seams

UG2 chromitite seam...an interval of crystallization dominated by chromite



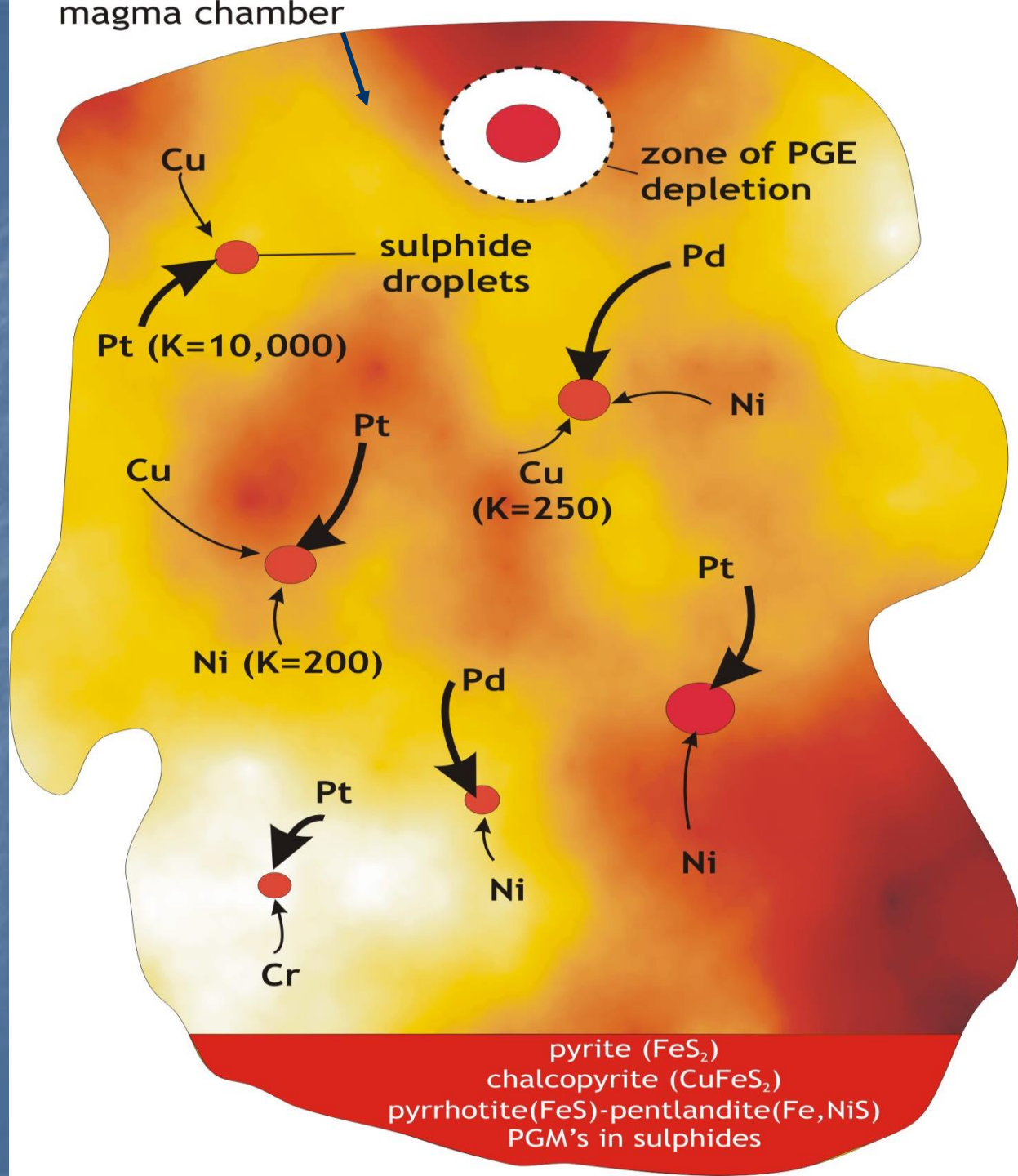
MERENSKY REEF.....pyroxene and plagioclase, with interstitial
Cu-Ni sulphide minerals



...sulphide immiscibility and partitioning of siderophilic metals (Cu, Ni, PGE) into the sulphide globules which tend to coalesce at the base of the magma chamber.....

...a potentially very important ore-forming process...

eg. Merensky reef (PGE)
Sudbury (Ni-Cu)
Kambalda (Ni-Cu)
Norilsk (Ni-Cu)





METAL DEPOSITS FORM IN RESPONSE
TO SEVERAL DIFFERENT PROCESSES AND
OCCUR THROUGHOUT GEOLOGICAL TIME...

...tectonics, granite and basaltic magmatism,
hydrothermal fluid flow, redox controls,
crystal fractionation, etc