WEST AFRICAN OROGENIC GOLD DEPOSITS: DO THEY FIT THE GLOBAL PARADIGM?

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RANDGOLD RESOURCES

INCORPORATED IN JERSEY, CHANNEL ISLANDS

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SUERC

Scottish Universities Environmental Research Centre

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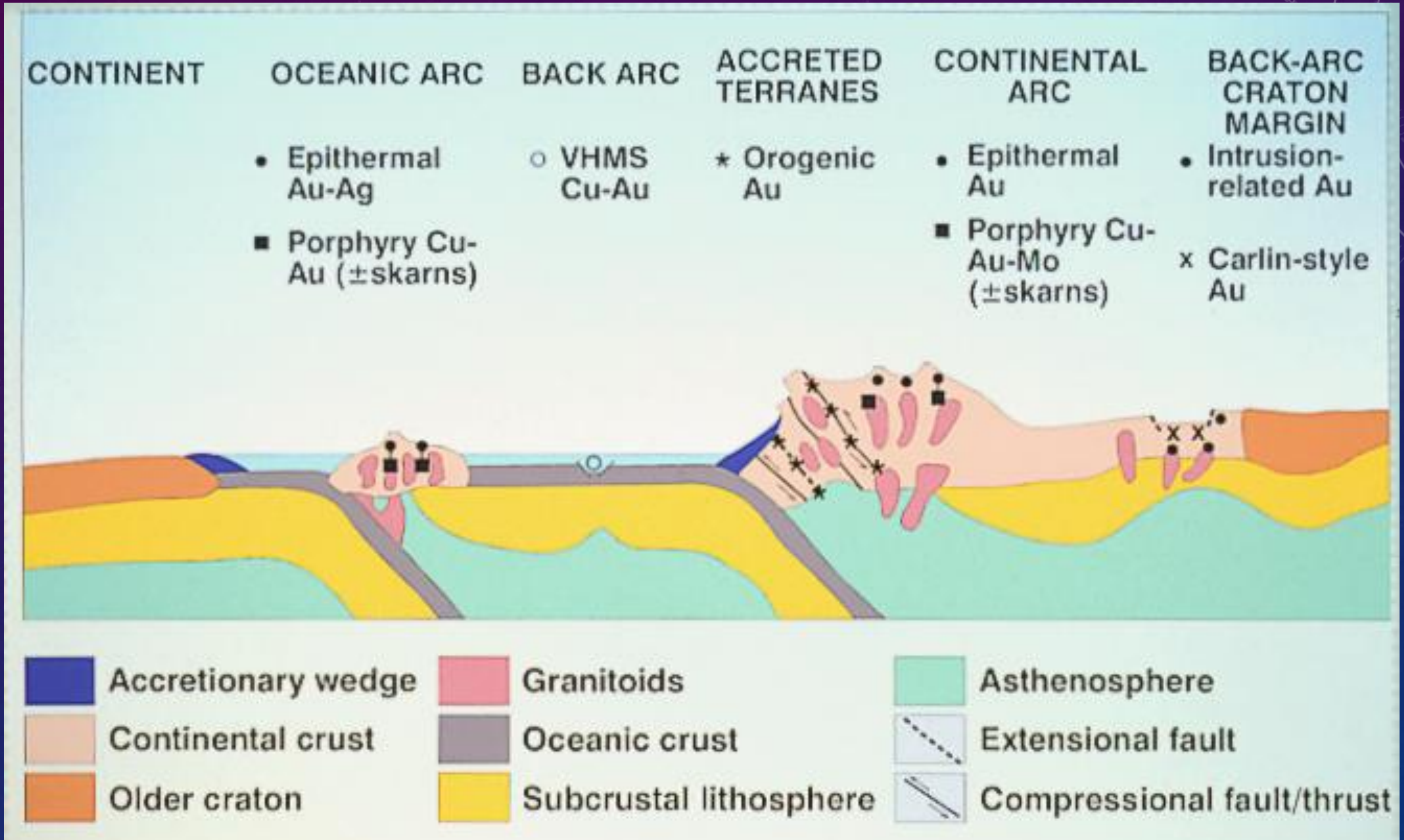
POTSDAM

WHAT ARE OROGENIC GOLD DEPOSITS?

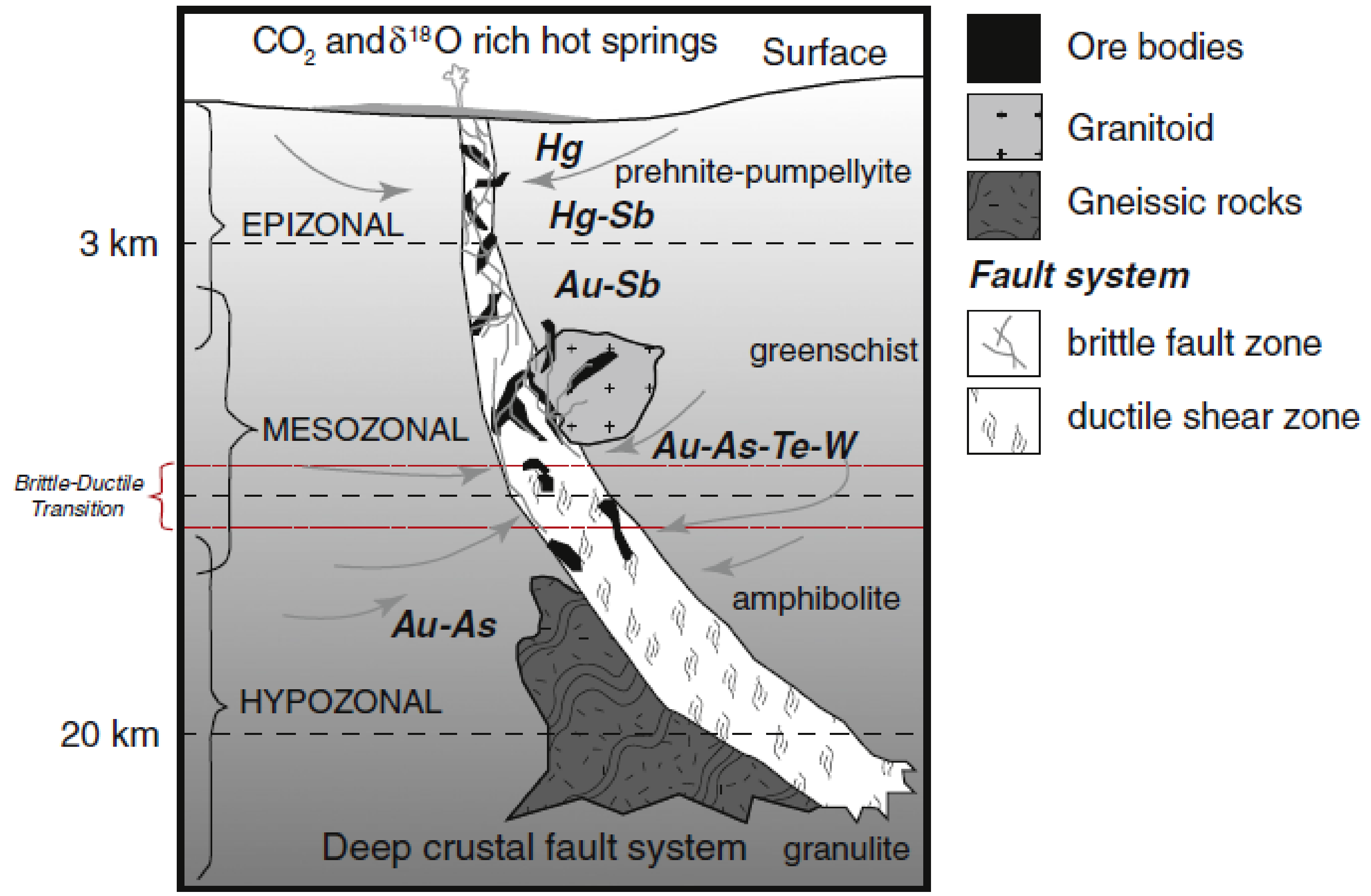
- The most abundant producer of gold on Earth
- Mesothermal rather then epithermal epigenetic ore deposits
- Temporally linked to periods of crustal growth in accretionary or collisional orogens
- Struturally controlled, steeply dipping ore lodes commonly located in allochthonous terranes characterised by strike slip faults
- Regional first order strike-slip structures provide the main control of deposit distribution with greatest ore fluxes in higher order shears, faults, and folds
- Generated in metamorphic terrains and hosted in greenschist facies mafic rocks, volcanic or intrusive, or clastic sediments
- The standard model suggests that they form from deep seated low salinity H_2O - $CO_2 \pm CH_4 \pm N_2$ metamorphic fluids that carry Au-Ag $\pm$ As $\pm$ B $\pm$ Bi $\pm$ Sb $\pm$ Te $\pm$ W (low base metal)

Tectonic Settings of Epigenetic Gold Deposits

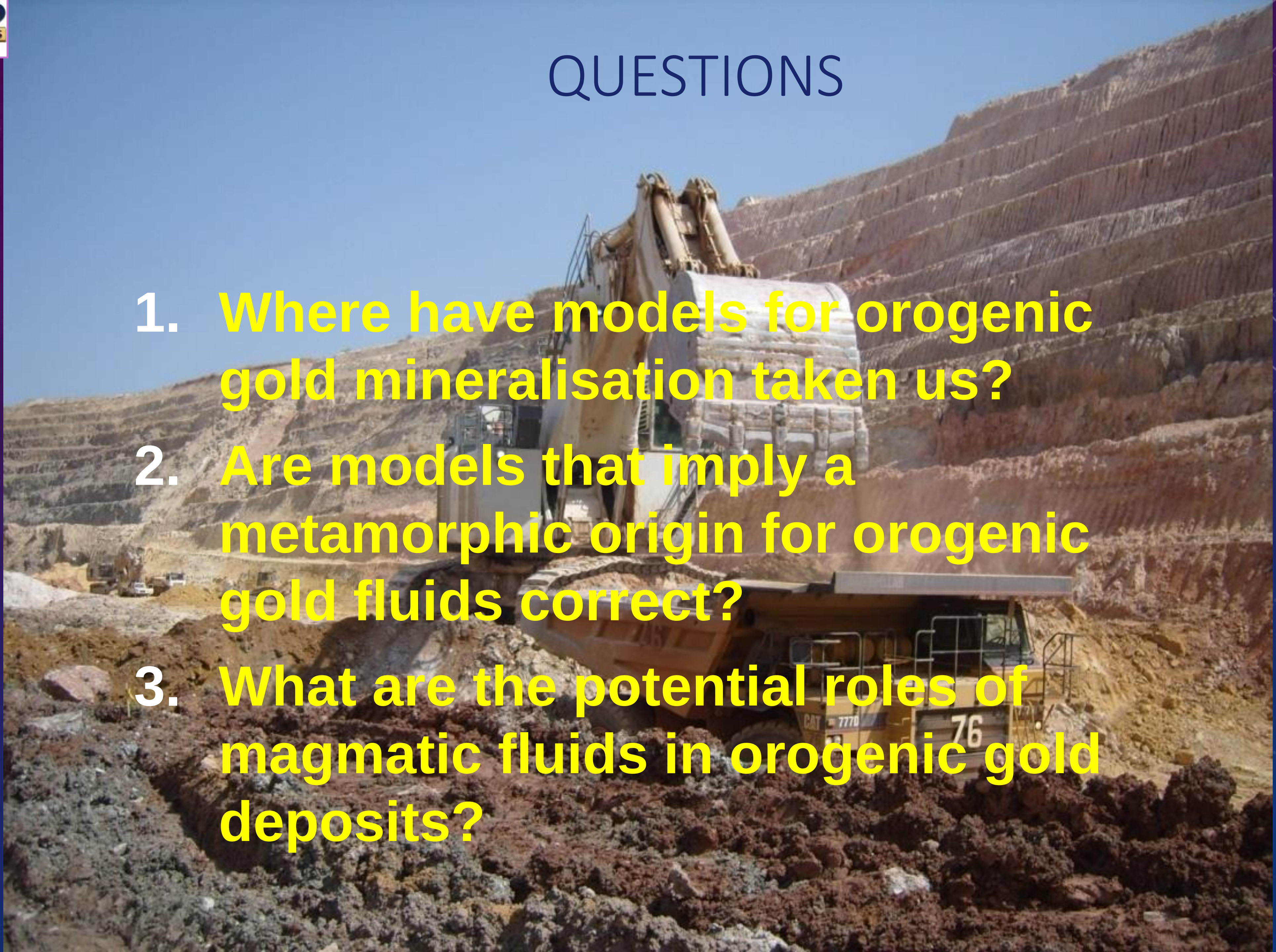


Herrington after Groves et al. (2003. Econ Geol)

GROVES & GOLDFARB 2015

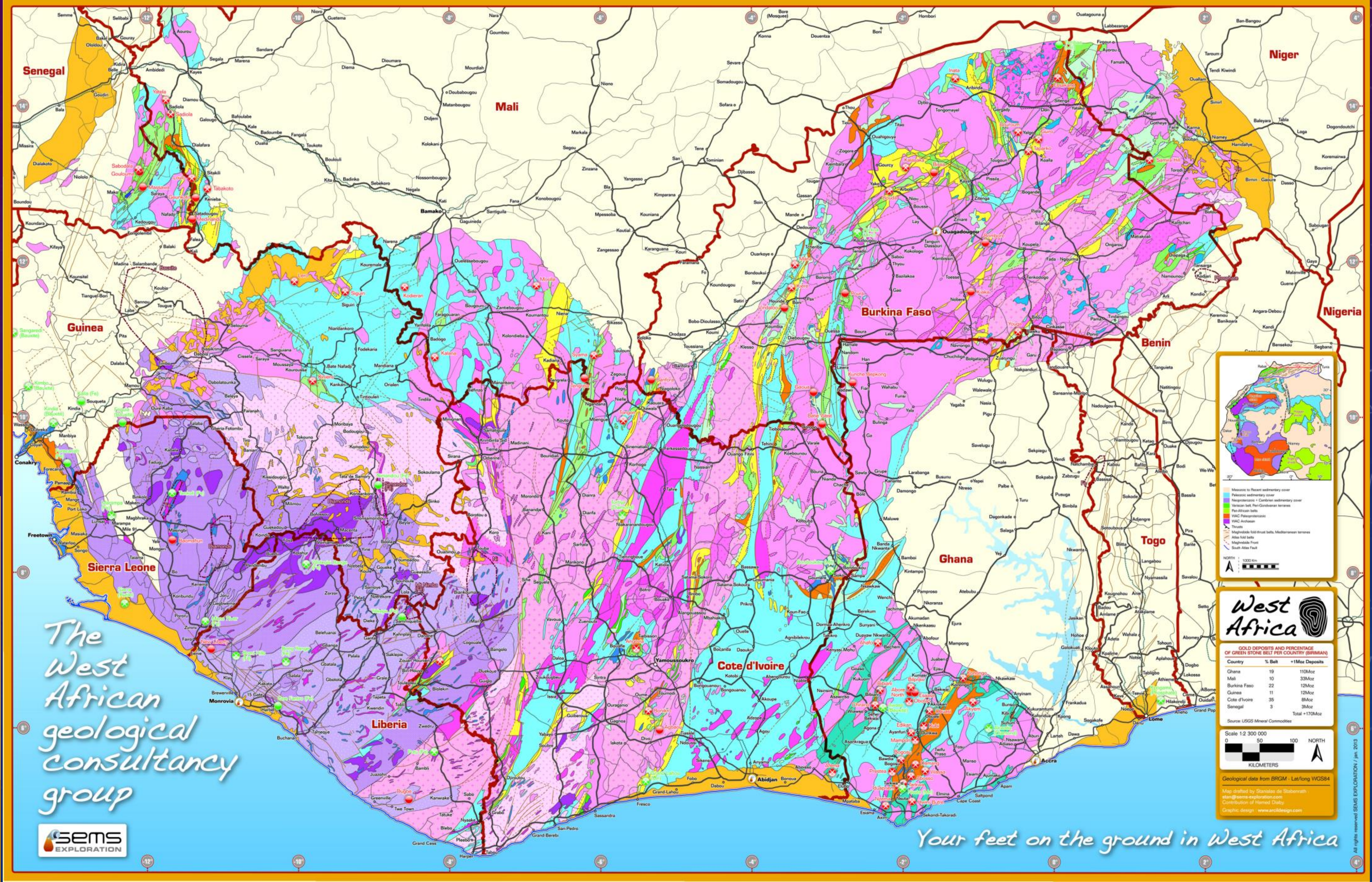


QUESTIONS



1. **Where have models for orogenic gold mineralisation taken us?**
2. **Are models that imply a metamorphic origin for orogenic gold fluids correct?**
3. **What are the potential roles of magmatic fluids in orogenic gold deposits?**


LEGENDE


The West African geological consultancy group
SEMS EXPLORATION
Senegal
Mali
Niger
Guinea
Burkina Faso
Nigeria
Benin
Sierra Leone
Togo
Ghana
Liberia
Cote d'Ivoire
West Africa
GOLD DEPOSITS AND PERCENTAGE OF GREEN STONE BELT PER COUNTRY (BIRIMIAN)
Country | % Belt | +1Moz Deposits
Ghana 19 110Moz
Mali 10 33Moz
Burkina Faso 22 12Moz
Guinea 11 12Moz
Cote d'Ivoire 35 8Moz
Senegal 3 3Moz
Total +170Moz
Source: USGS Mineral Commodities
Scale 1:2 300 000
0 50 100
KILOMETERS
NORTH
Geological data from BRGM - Lat/long WGS84
Map drafted by Stanislas de Stabenrath
stan@sems-exploration.com
Contribution of Hamed Diaby
Graphic design : www.arclidesign.com
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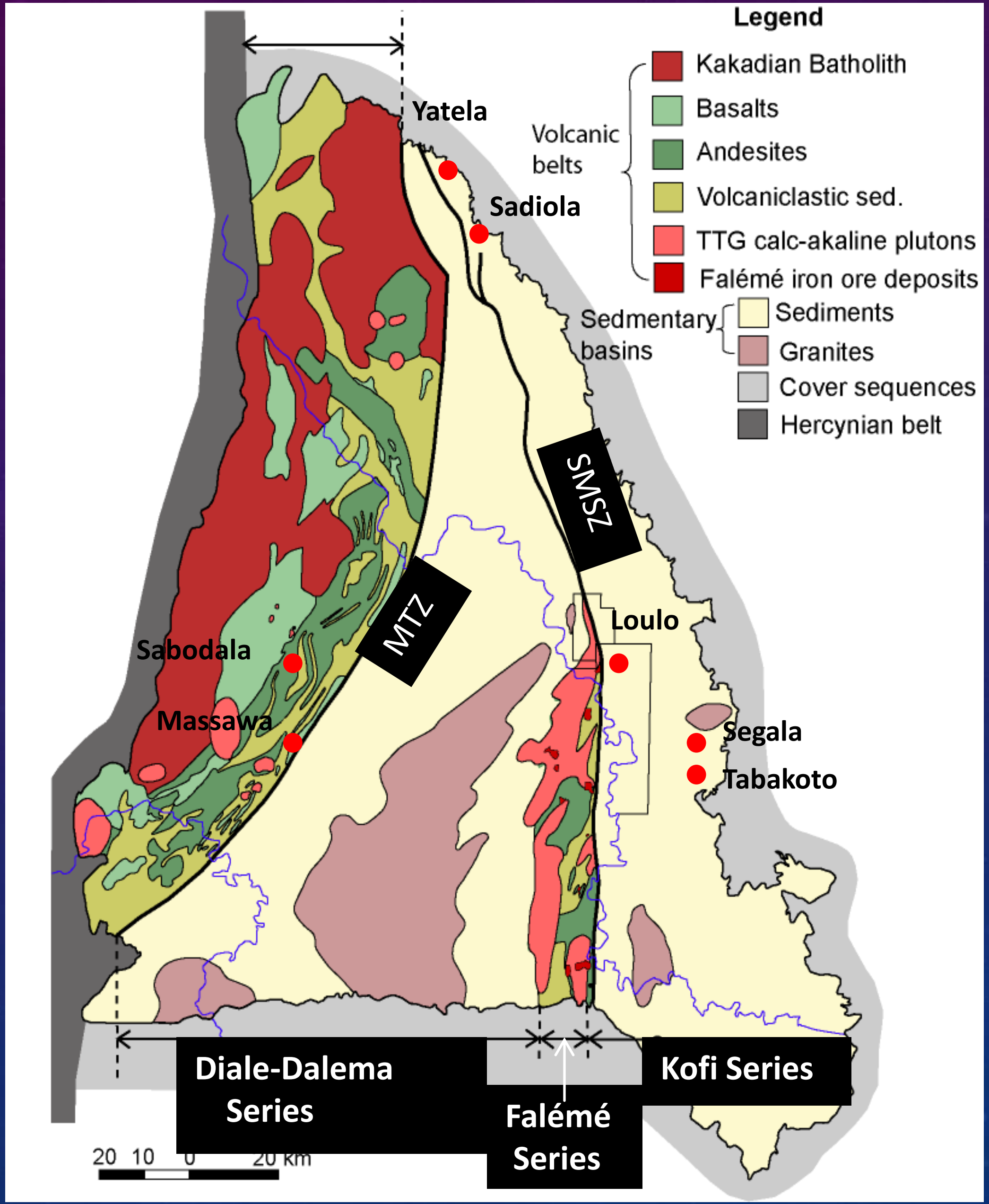
Your feet on the ground in West Africa

Regional geology of the KKI



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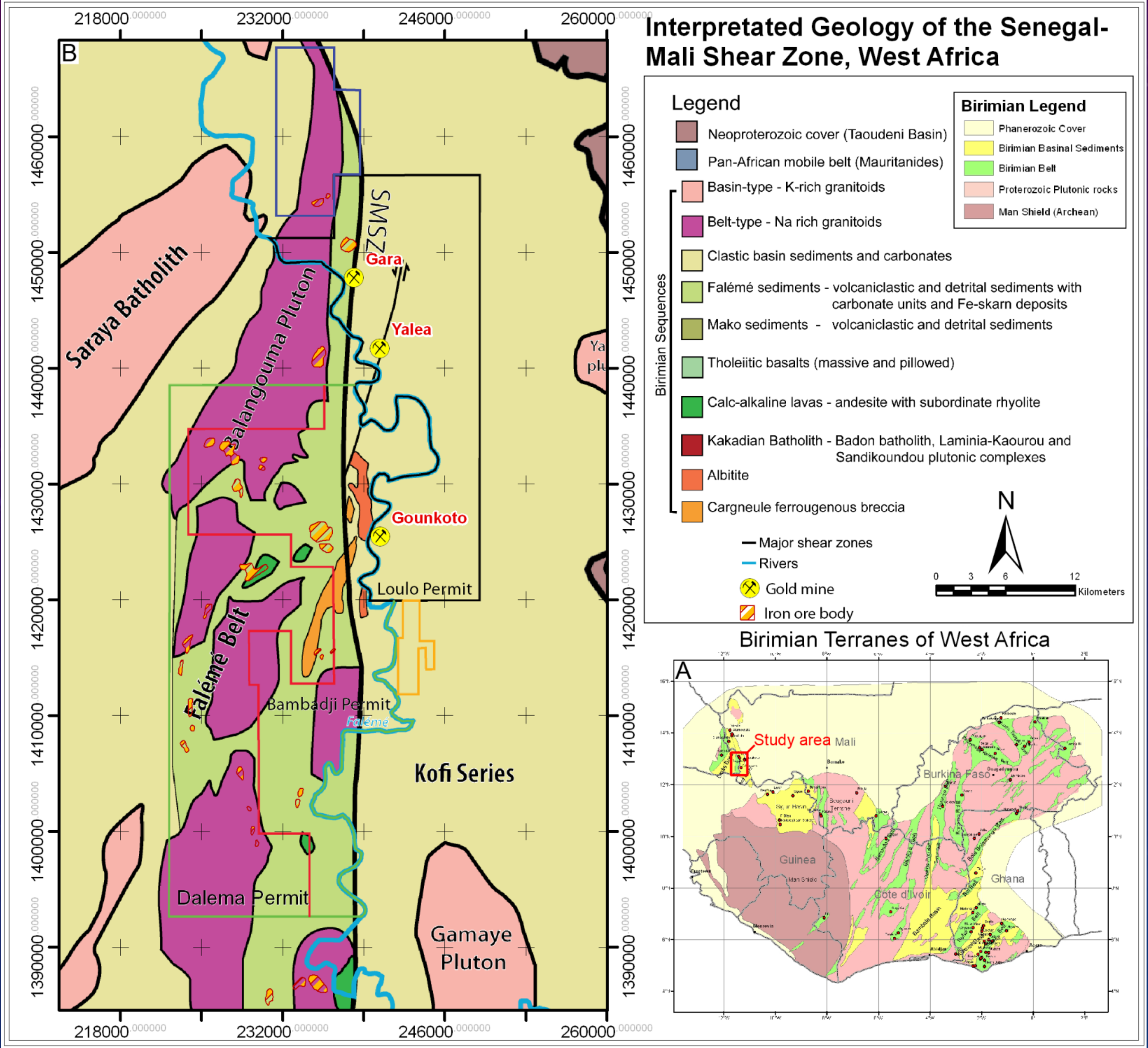


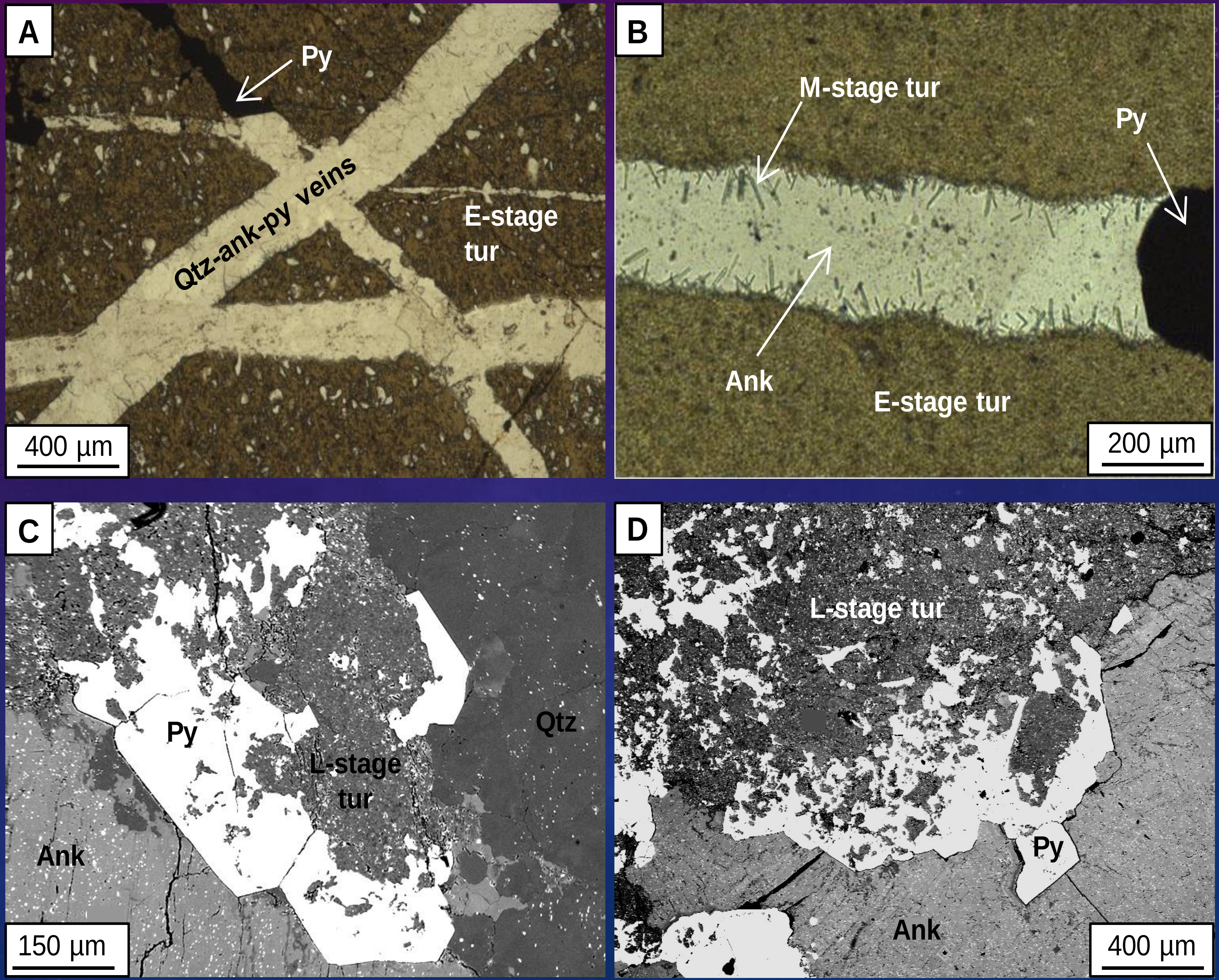
Yalea Open Pit 2010

Gounkoto Open Pit - 2014

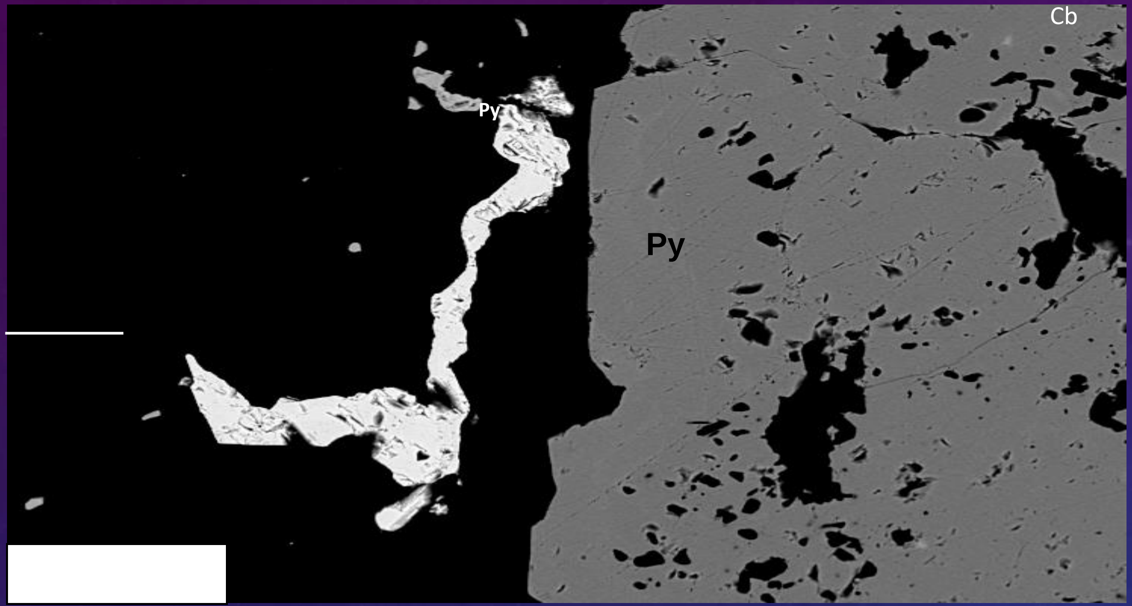
GARA - ORE MINERALOGY

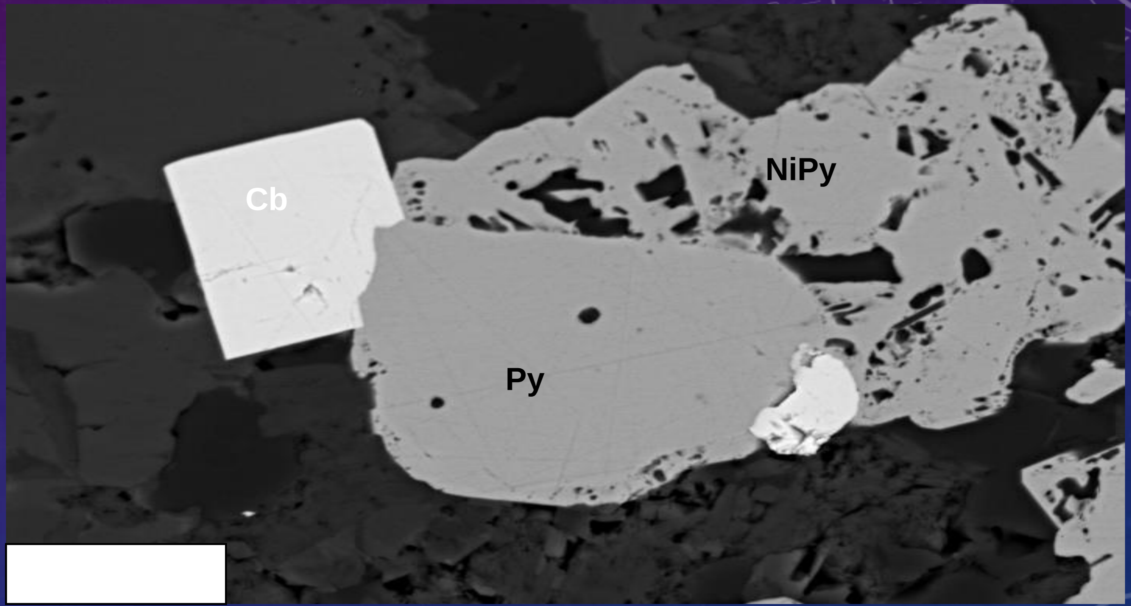
Loulo, West Mali: Gara stockwork in quartz-tourmaline rock
Quartz and carbonate veins with pyrite

MULTI-STAGE TOURMALINE GENERATION AT GARA



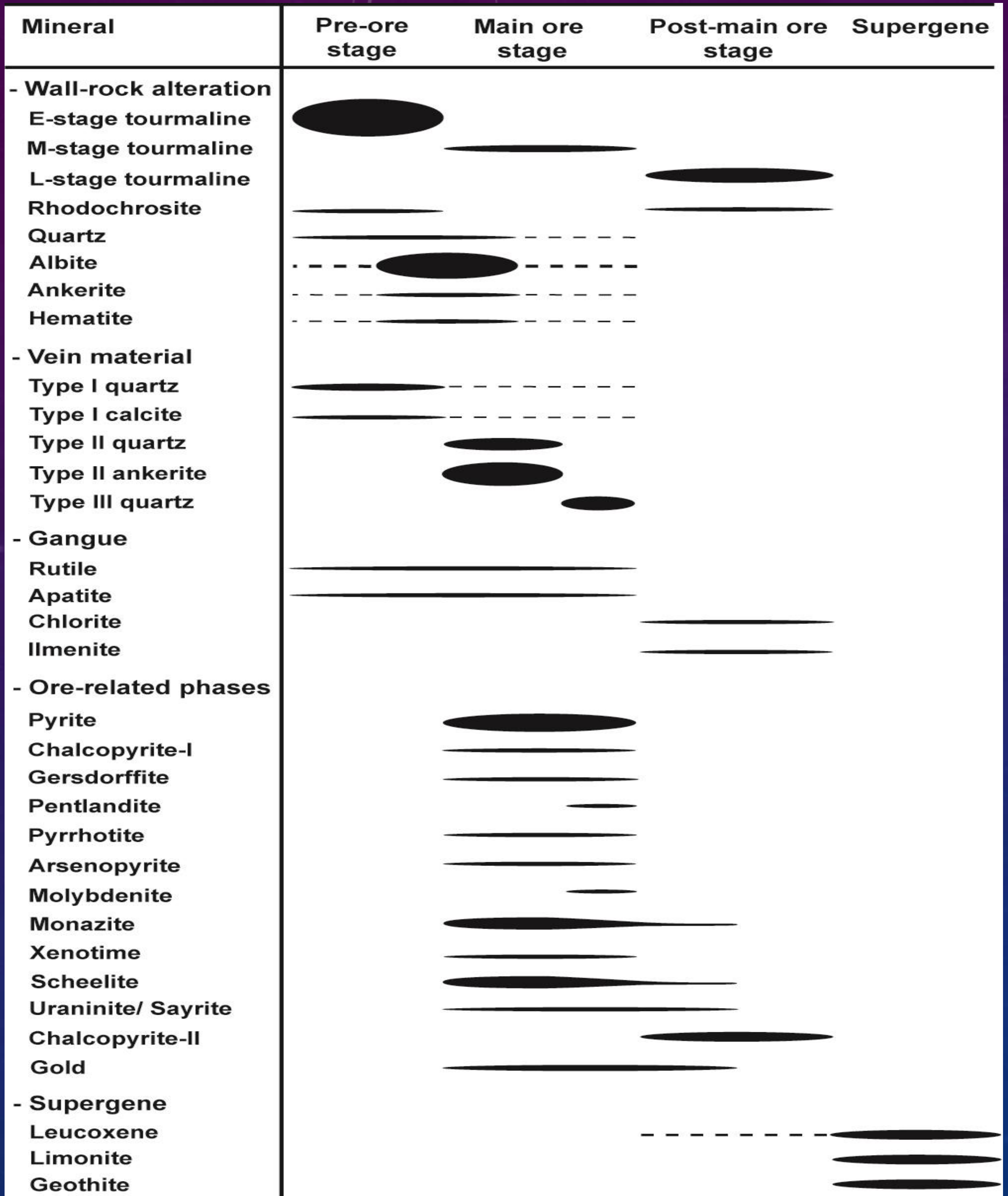
MINERAL PARAGENESIS





Ni-Co sulphides at Yalea North

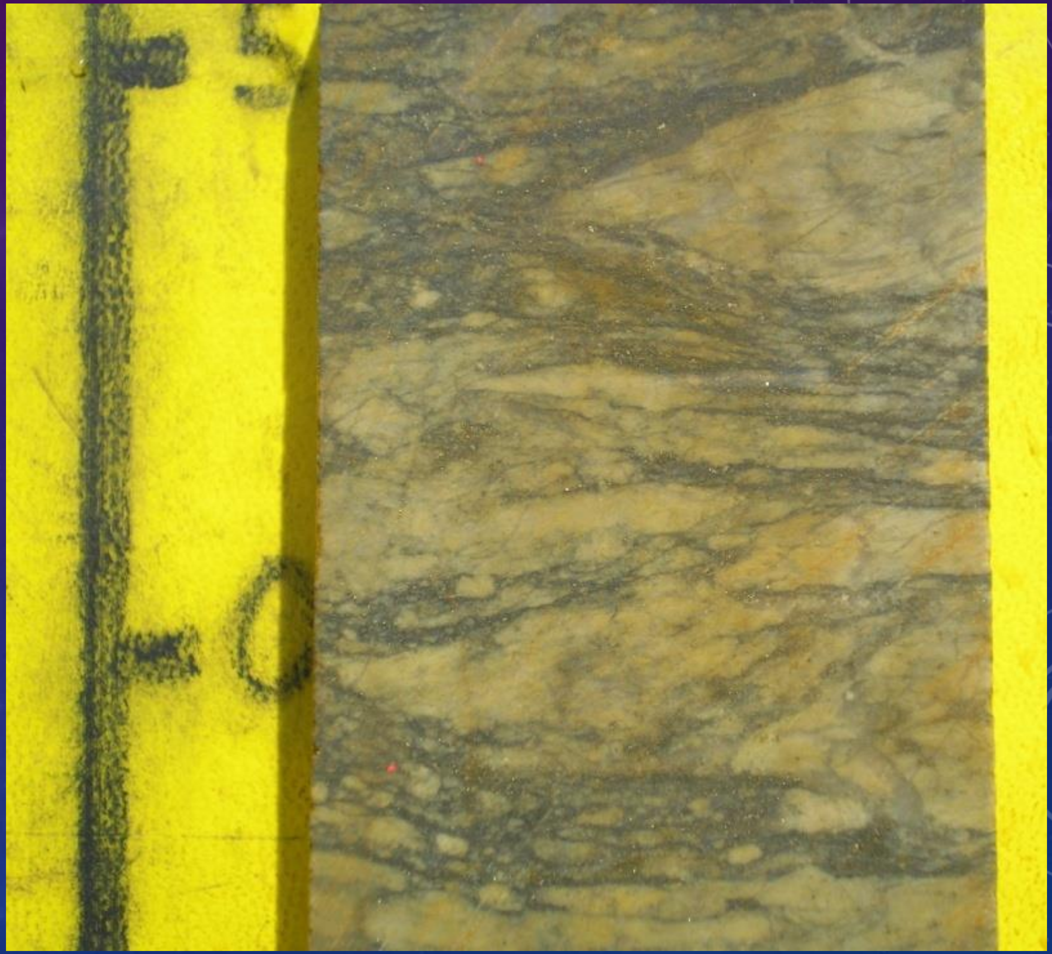
Mineral Paragenesis at Gara




cm
5
10
15

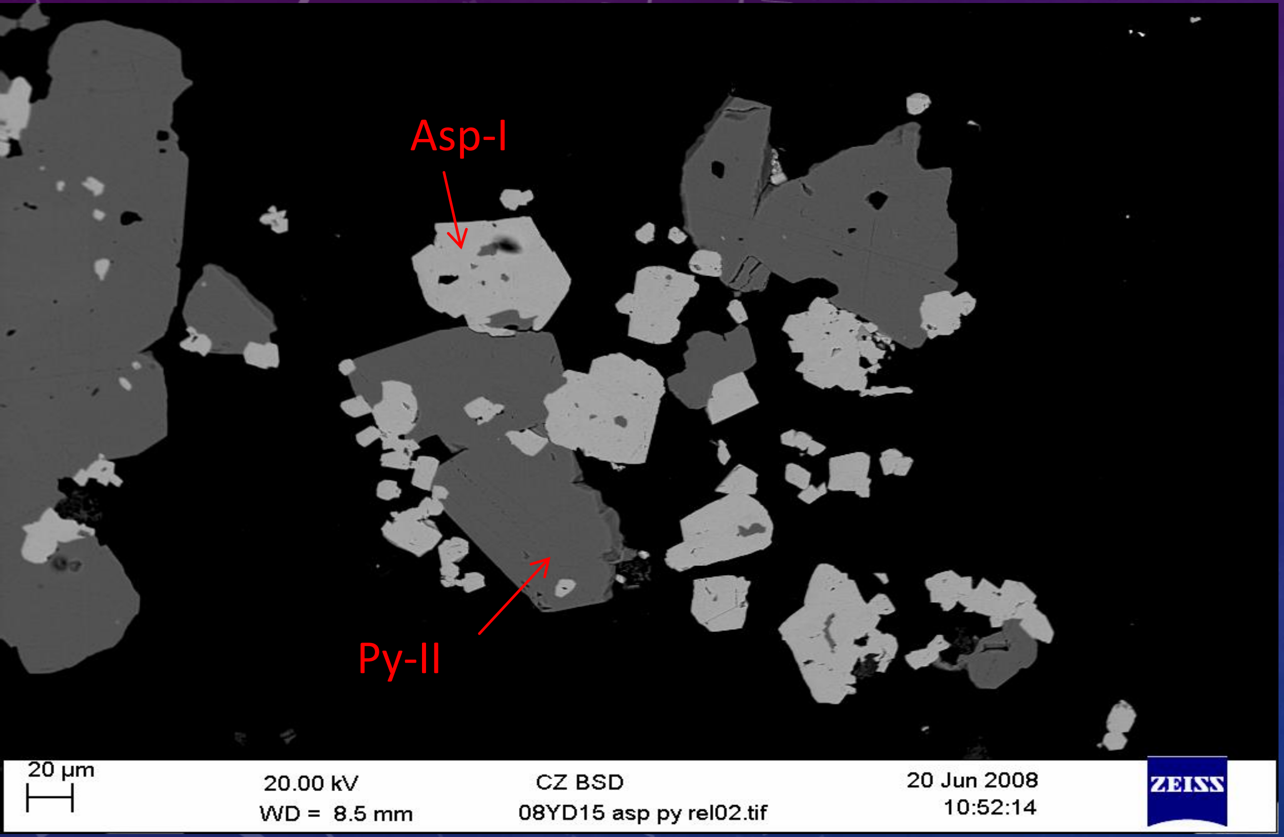
YALEA MINERAL PARAGENESIS

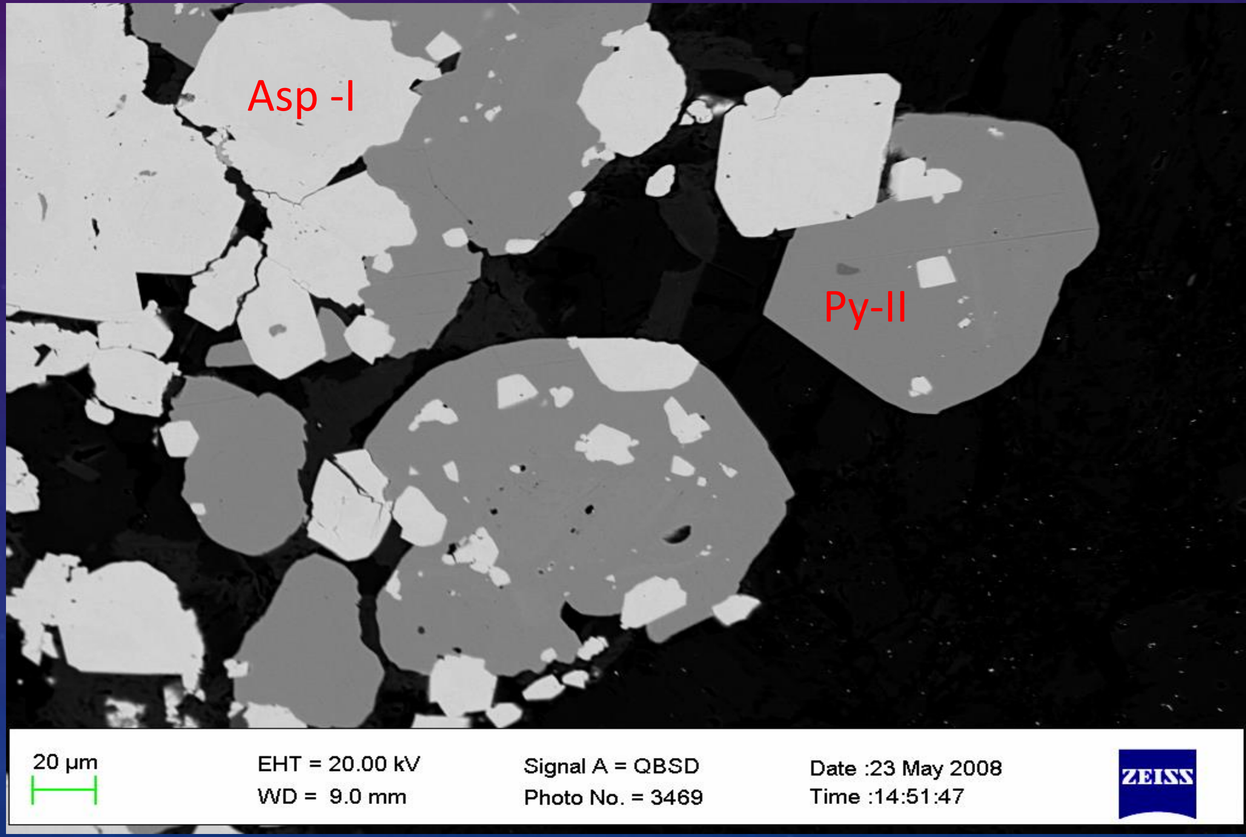
Albitic QR alteration



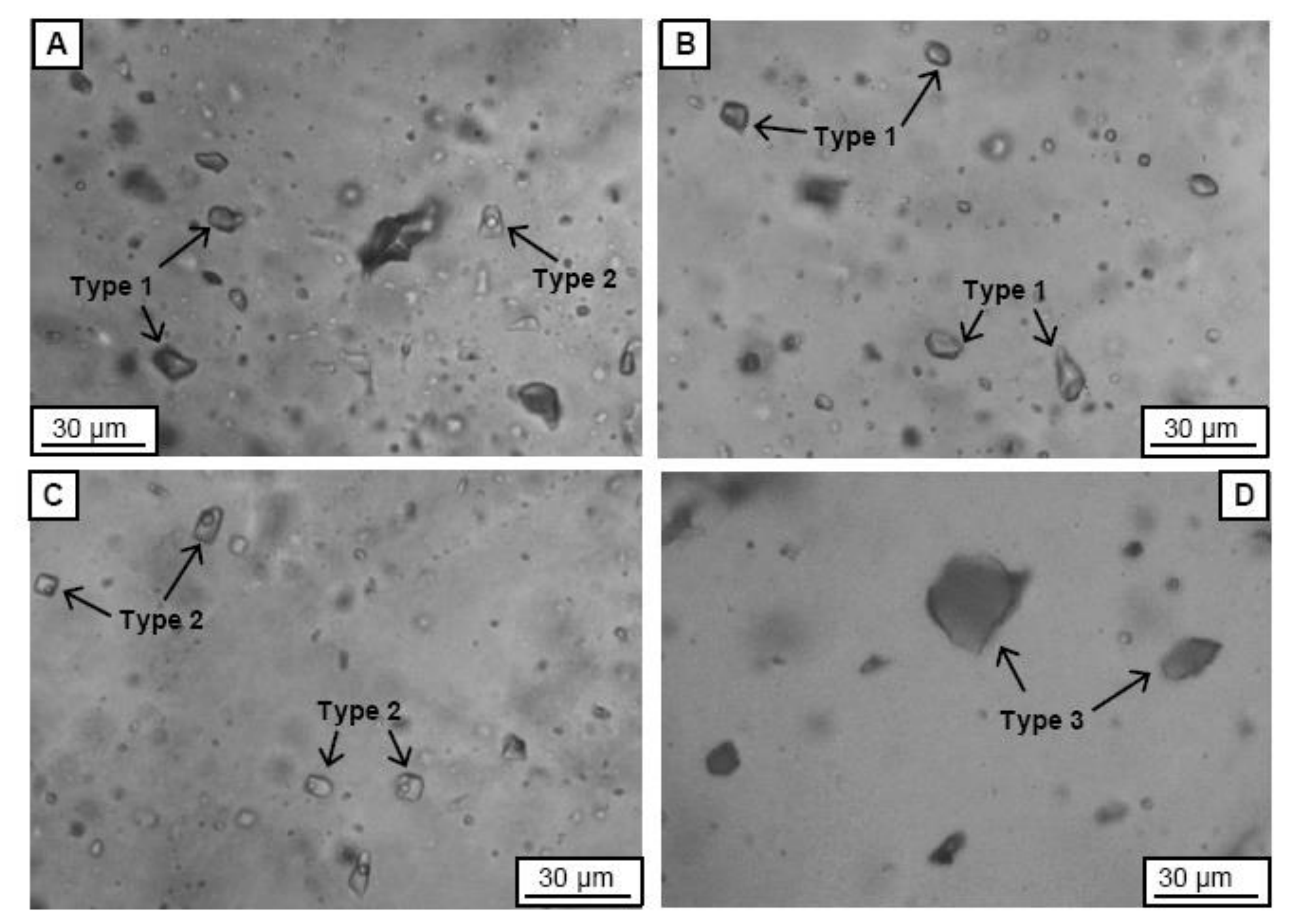
Ductile textures (rich in carbonate)

YALEA – KEY ORE MINERALOGY





LOULO, LOW SALINITY FLUID INCLUSIONS



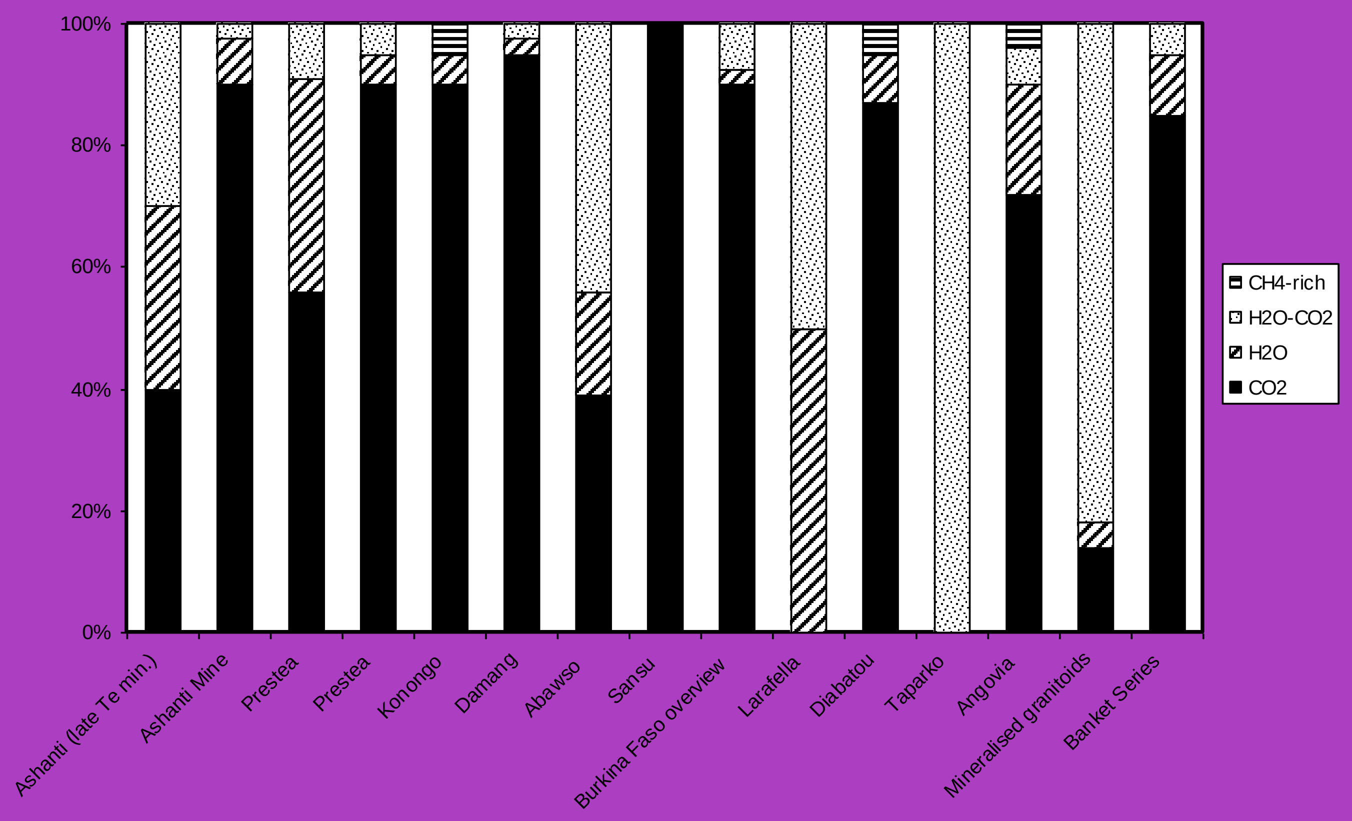
Type 1
mono- or bi-phase CO_2 inclusions (60-90%)

Type 2
rare l+v H_2O inclusions (<5%)

Type 3
mixed CO_2-H_2O inclusions (5-12%)

LOW SALINITY FLUIDS

- This range of fluids is seen elsewhere in the Birimian
- Fluid immiscibility (Coulibaly et al., 2008) +/or post-entrapment modifications (e.g. Klemd et al., 1997)
- Low salinity H_2O-CO_2 fluids common for orogenic Au deposits and generally suggested to represent a metamorphic fluid source???



Summary of FI work from Ghana, Burkina Faso & Cote d'Ivoire

GARA HYPERSALINE FLUID INCLUSIONS (LAWRENCE ET AL. 2013

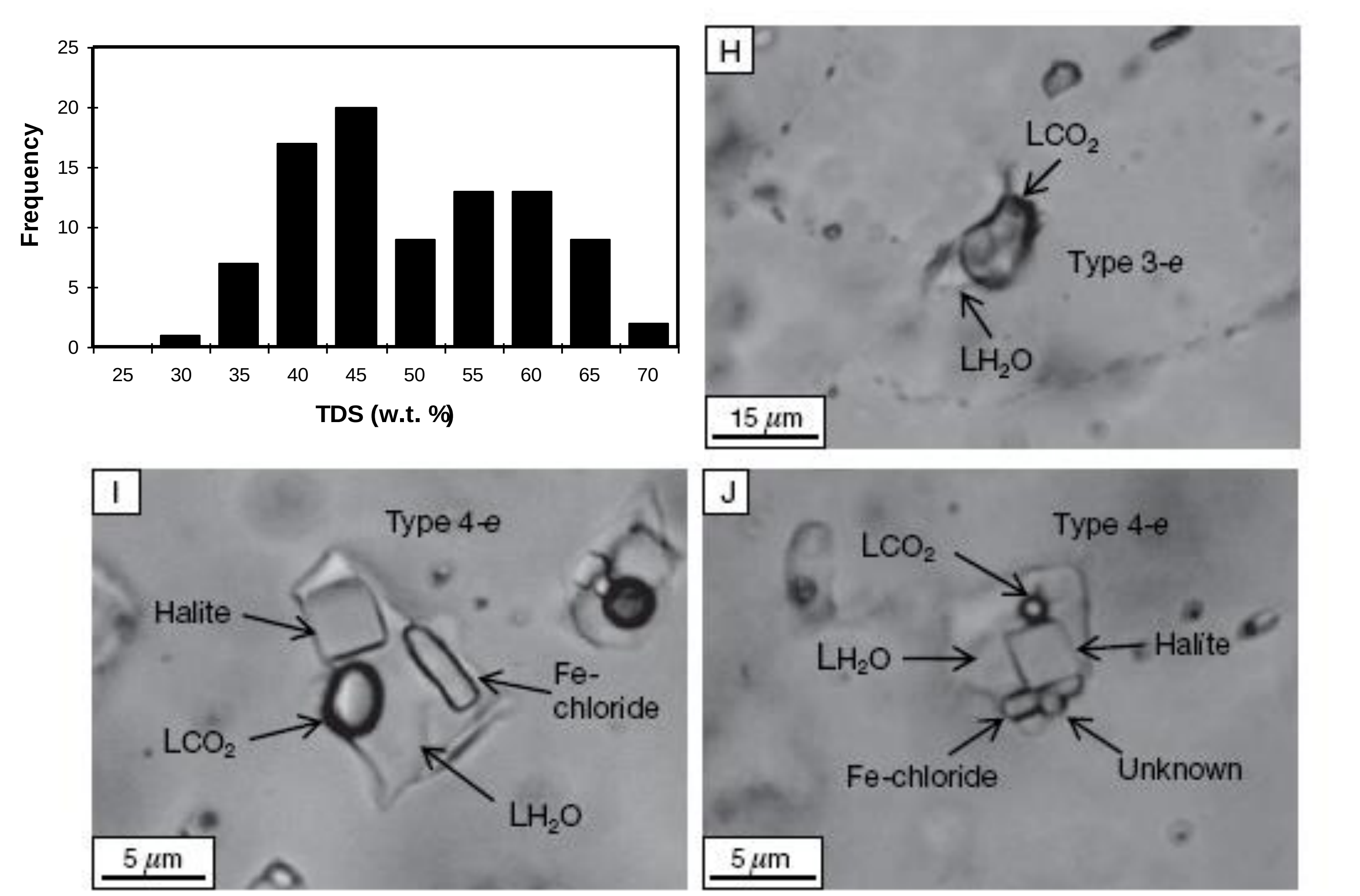
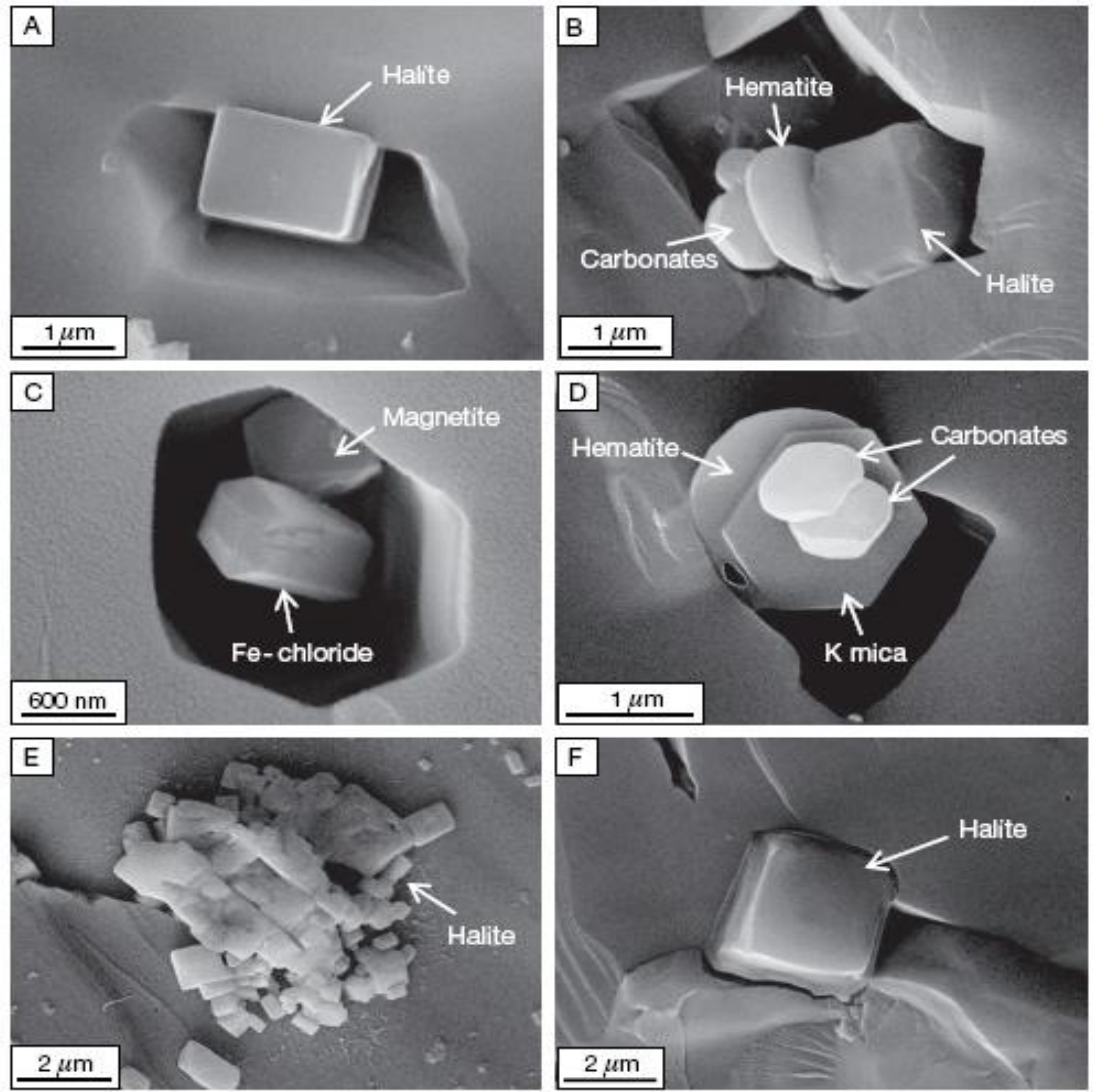


FIG. 3. (*Cont.*)



GARA

CRACKED HYPSERSALINE FLUID INCLUSIONS

GARA VS YALEA

Gara

- Tourmaline rich
- Fe-REE-As-Ni-Co-Au±Cu±W
- Pyrite dominant sulfide
- Aspy, cpy, gersdorffite, pentlandite, pyrrotite, cobaltite, monazite, xenotime, scheelite
- Qtz-cc veins
- Abundant High salinity fluid inclusions

Yalea

- Tourmaline poor
- Fe-As-Cu-W-Pb-Sb-Au-Ag
- Pyrite-arsenopyrite rich
- Asp + py + scheelite + late Cu minerals + Pb minerals (absence of tourmaline, REE and Ni-Co sulphides)
- Carb – phyllic alteration
- No high salinity fluid inclusions

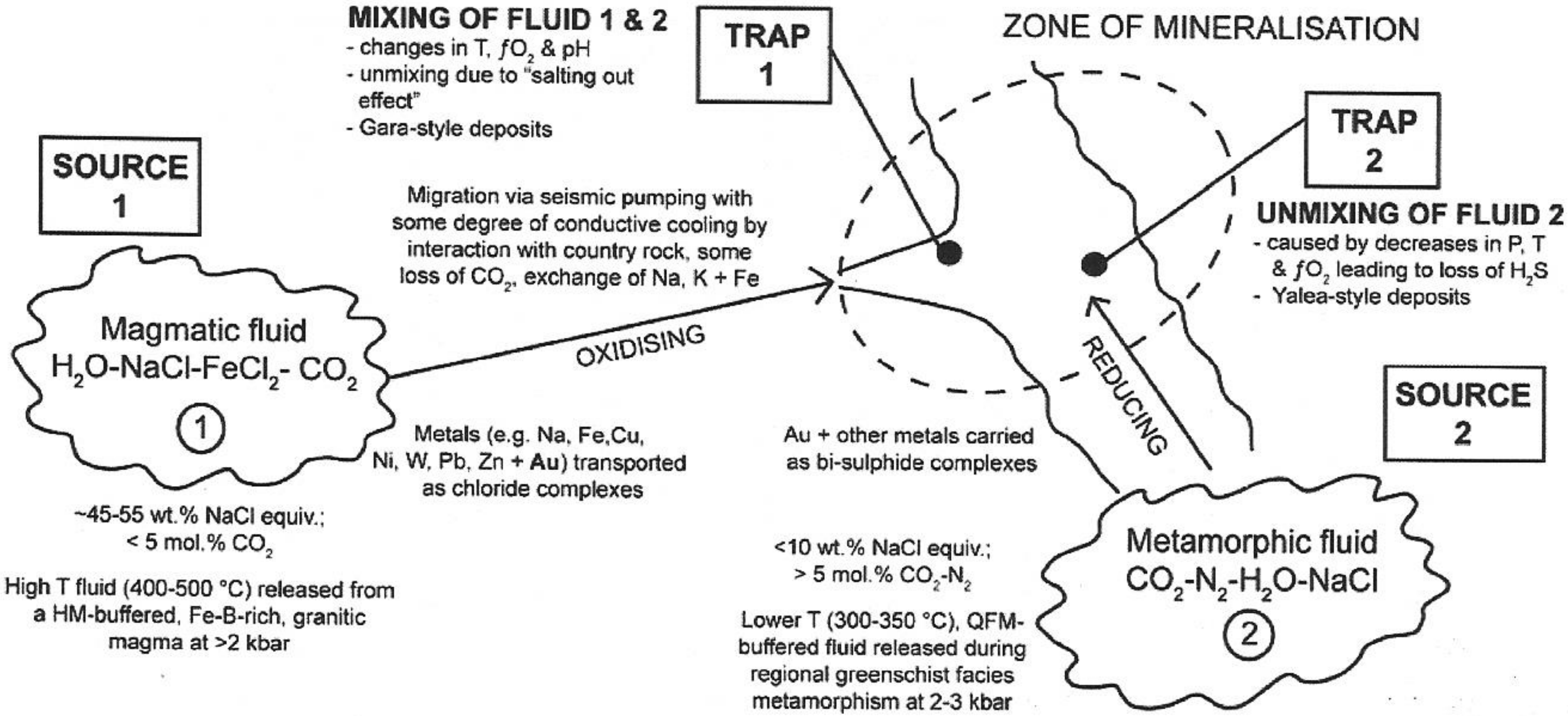

MIXING OF FLUID 1 & 2
- changes in T, fO_2 & pH
- unmixing due to "salting out effect"
- Gara-style deposits
TRAP 1
ZONE OF MINERALISATION
TRAP 2
SOURCE 1
Migration via seismic pumping with some degree of conductive cooling by interaction with country rock, some loss of CO_2, exchange of Na, K + Fe
UNMIXING OF FLUID 2
- caused by decreases in P, T & fO_2 leading to loss of H_2S
- Yalea-style deposits
Magmatic fluid
H_2O-NaCl-$FeCl_2$- CO_2
1
OXIDISING
REDUCING
SOURCE 2
Metals (e.g. Na, Fe,Cu, Ni, W, Pb, Zn + Au) transported as chloride complexes
Au + other metals carried as bi-sulphide complexes
~45-55 wt.% NaCl equiv.; < 5 mol.% CO_2
High T fluid (400-500 °C) released from a HM-buffered, Fe-B-rich, granitic magma at >2 kbar
Metamorphic fluid
CO_2-N_2-H_2O-NaCl
2
<10 wt.% NaCl equiv.; > 5 mol.% CO_2-N_2
Lower T (300-350 °C), QFM-buffered fluid released during regional greenschist facies metamorphism at 2-3 kbar

Figure 14

RANDGOLD RESOURCES
INCORPORATED IN JERSEY, CHANNEL ISLANDS

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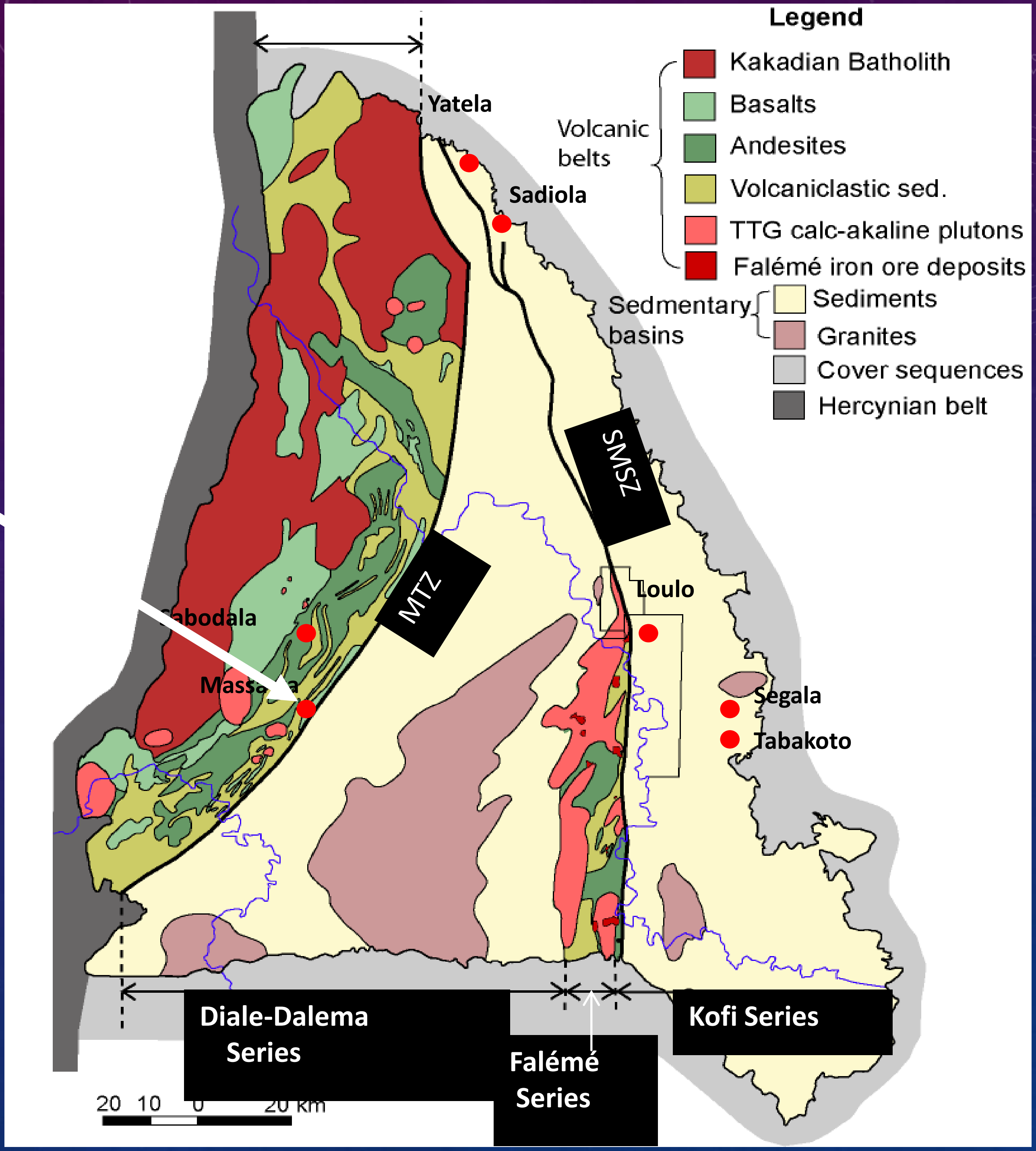
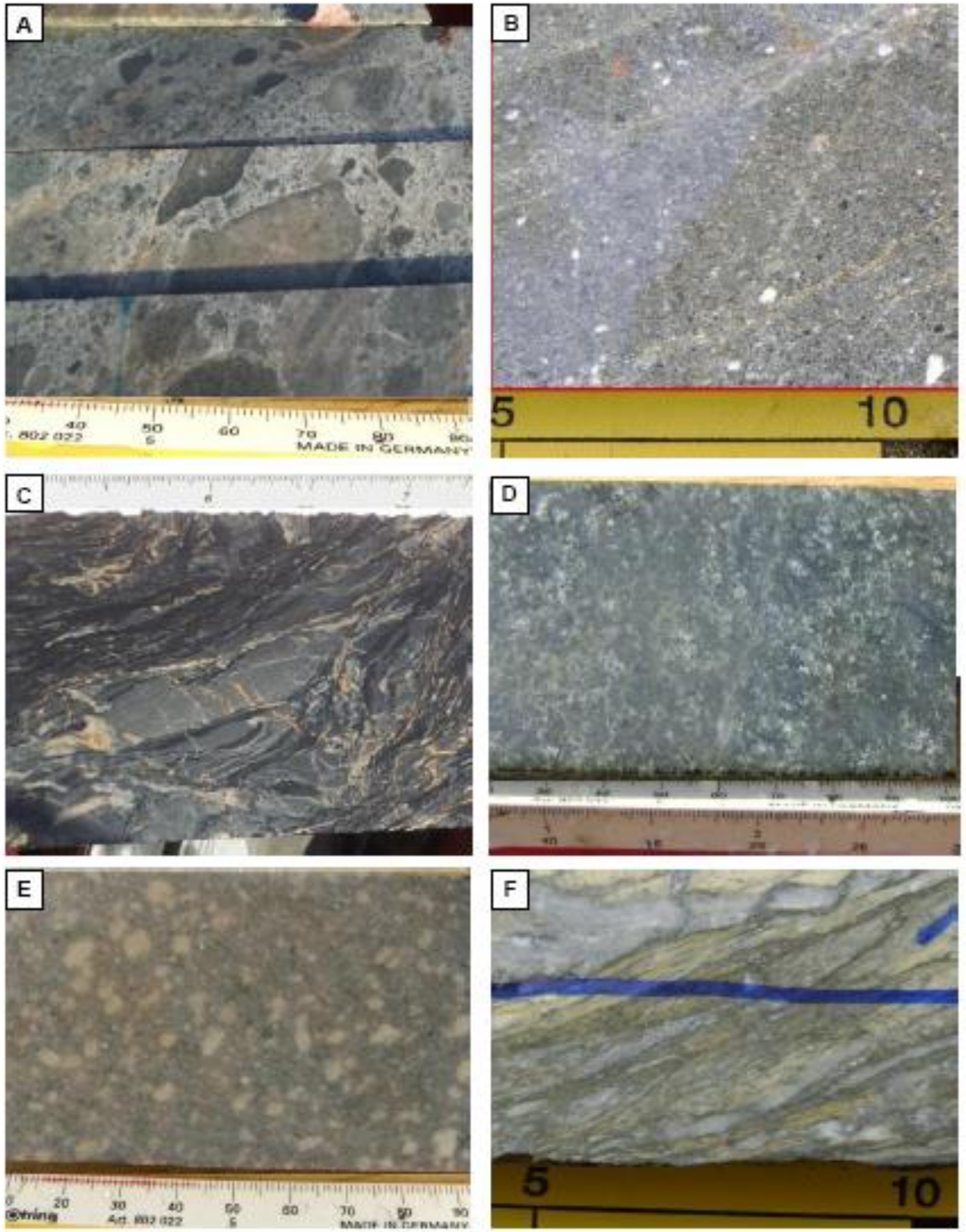
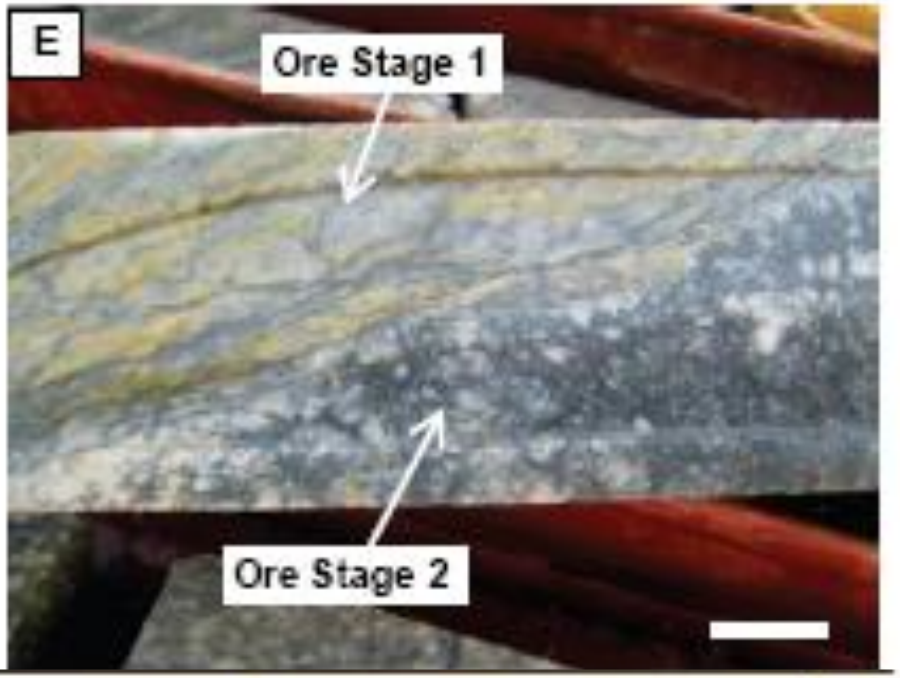
Massawa

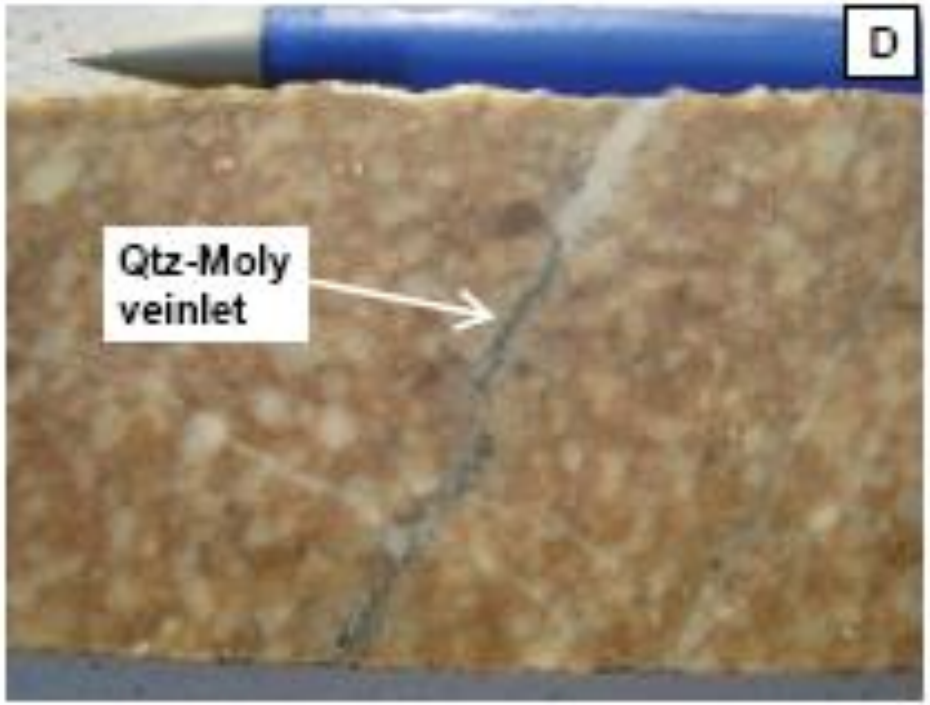




Massawa deposit is hosted in:

A. Volcaniclastic agglomerate
B. Greywackes
C. Graphitic schists
D. Gabbro
E. Feldspar Porphyrys some mineralised and some not
F. Ductile, carbonate-sericite-quartz alteration zone





Three mineralising events

1. Ore stage 1 (replacive qtz, ser, ank, pyr, aspyr, Au
2. Barren qz- molybdenite veins
3. Ore stage 2 (quartz-stibnite-Au)


*1569

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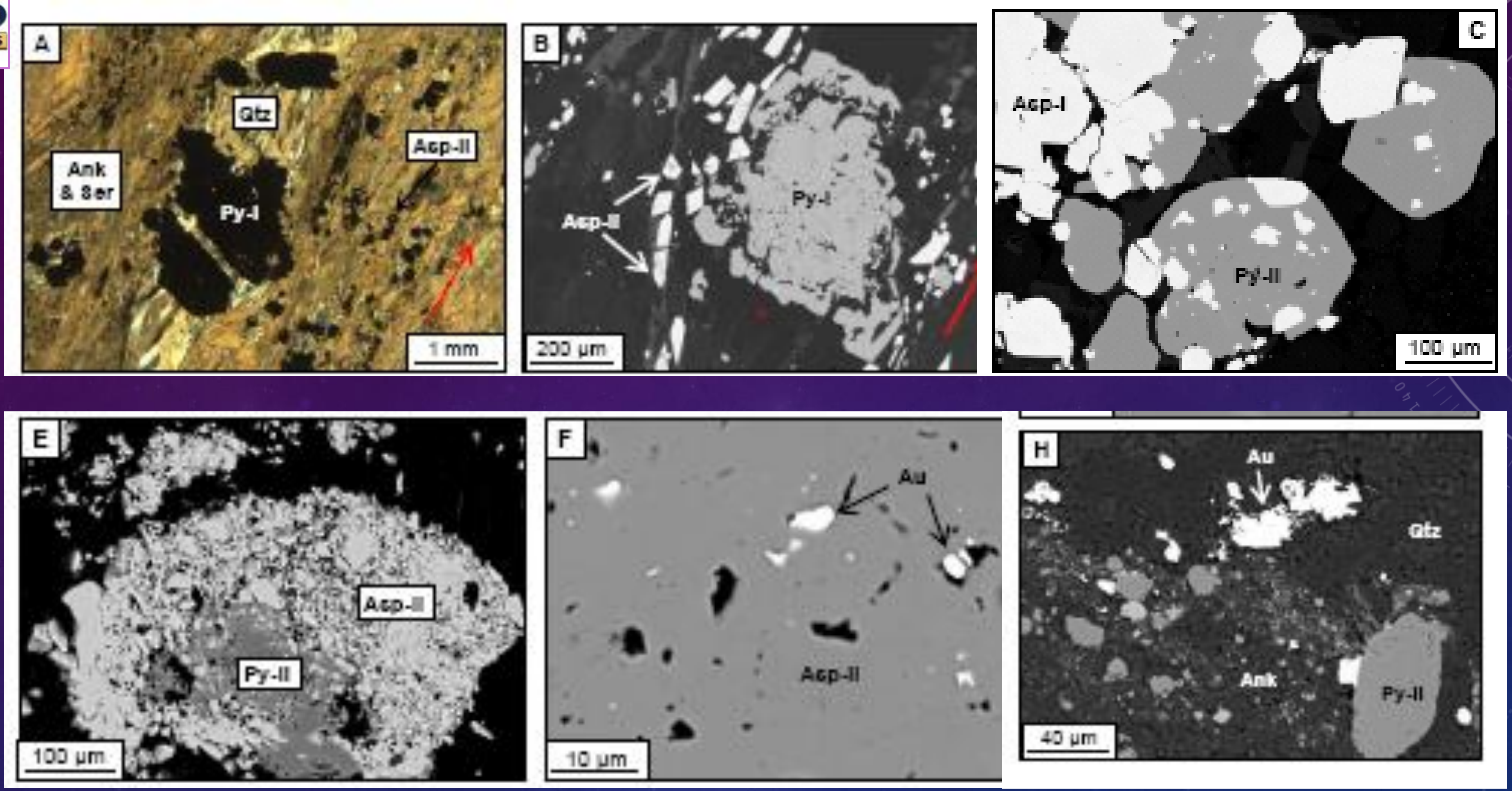
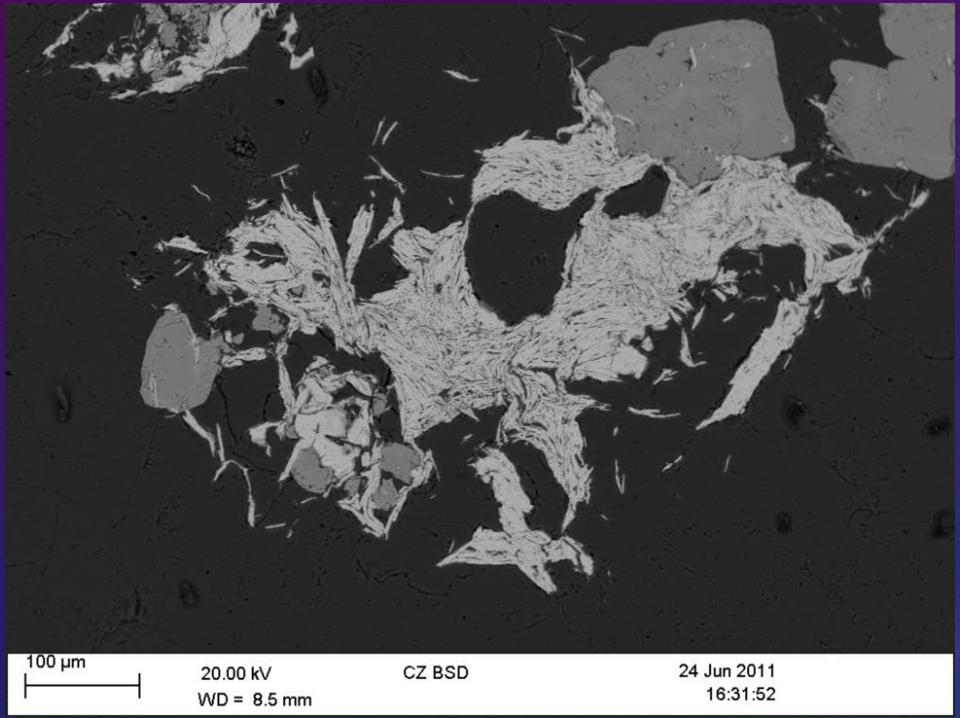
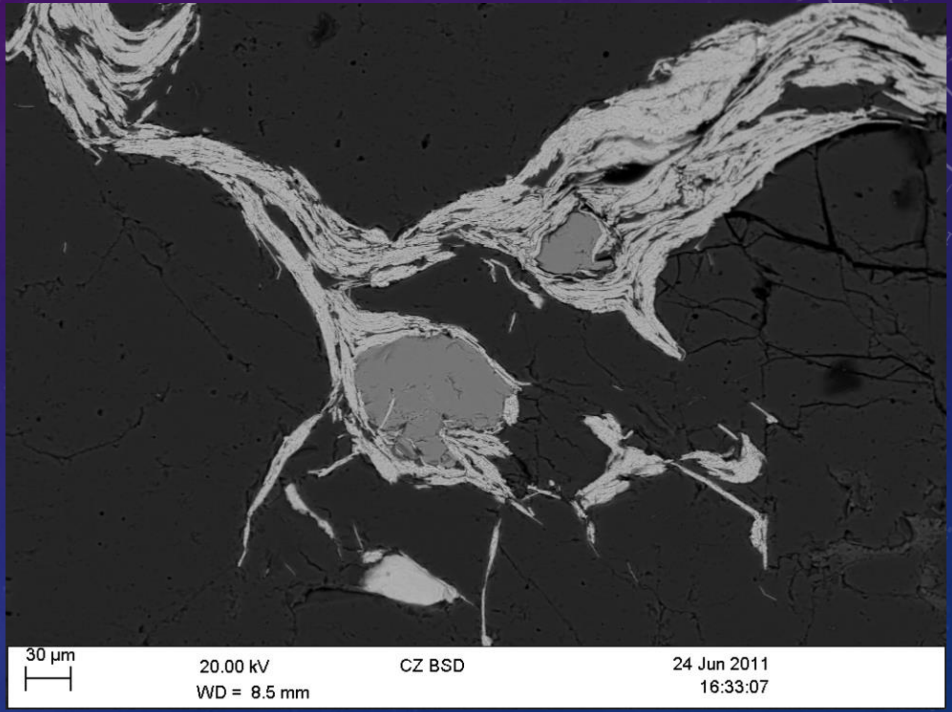


Main Ore Phase Stage 1:

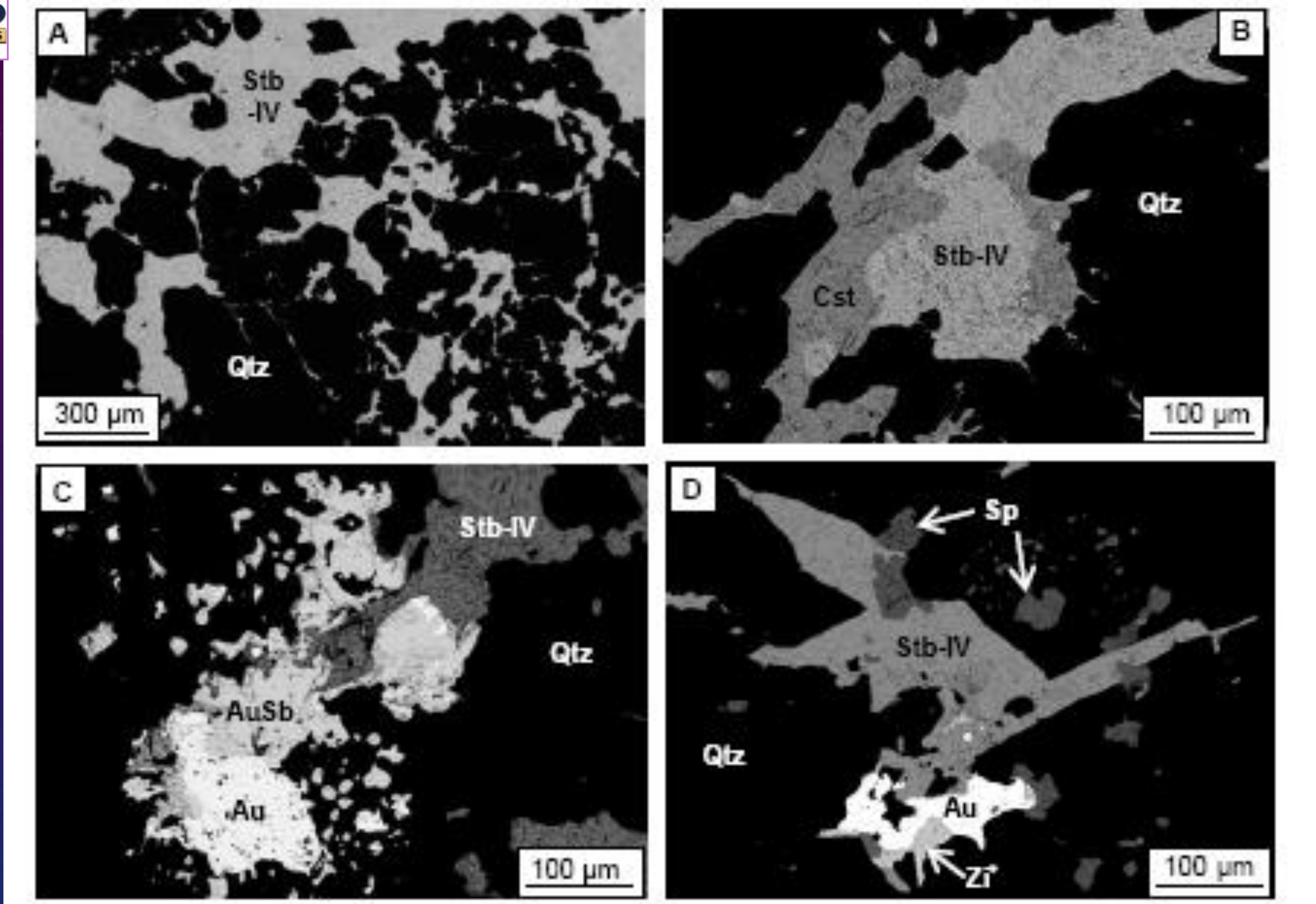
A: Ankerite-sericite-quarz alteration; B: Asp after Pyr;
C: Pyr after Asp; E: Asp after Pyr; F: Au in Asp; H: Au in qtz.

MINERAL PARAGENESIS

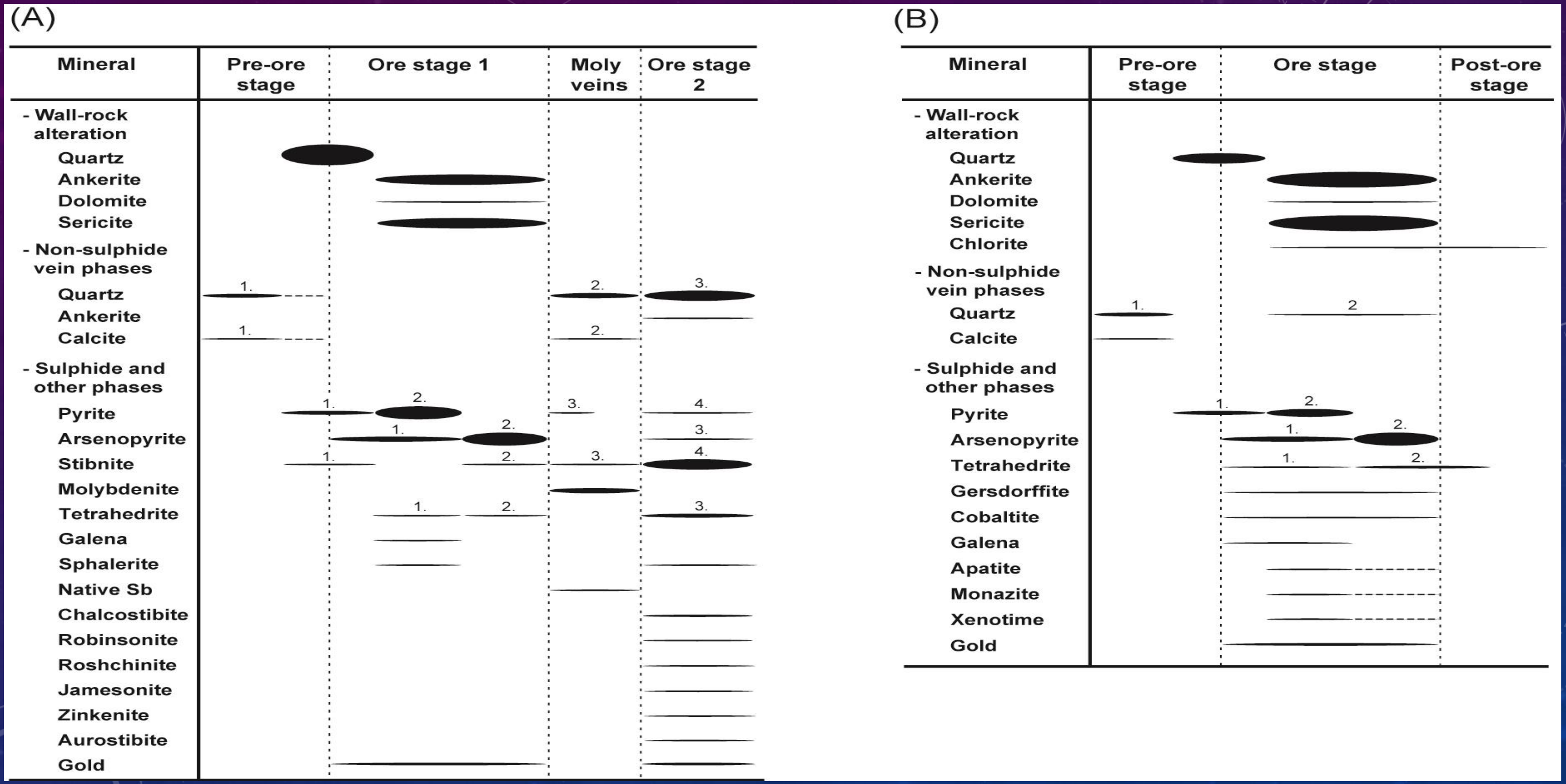


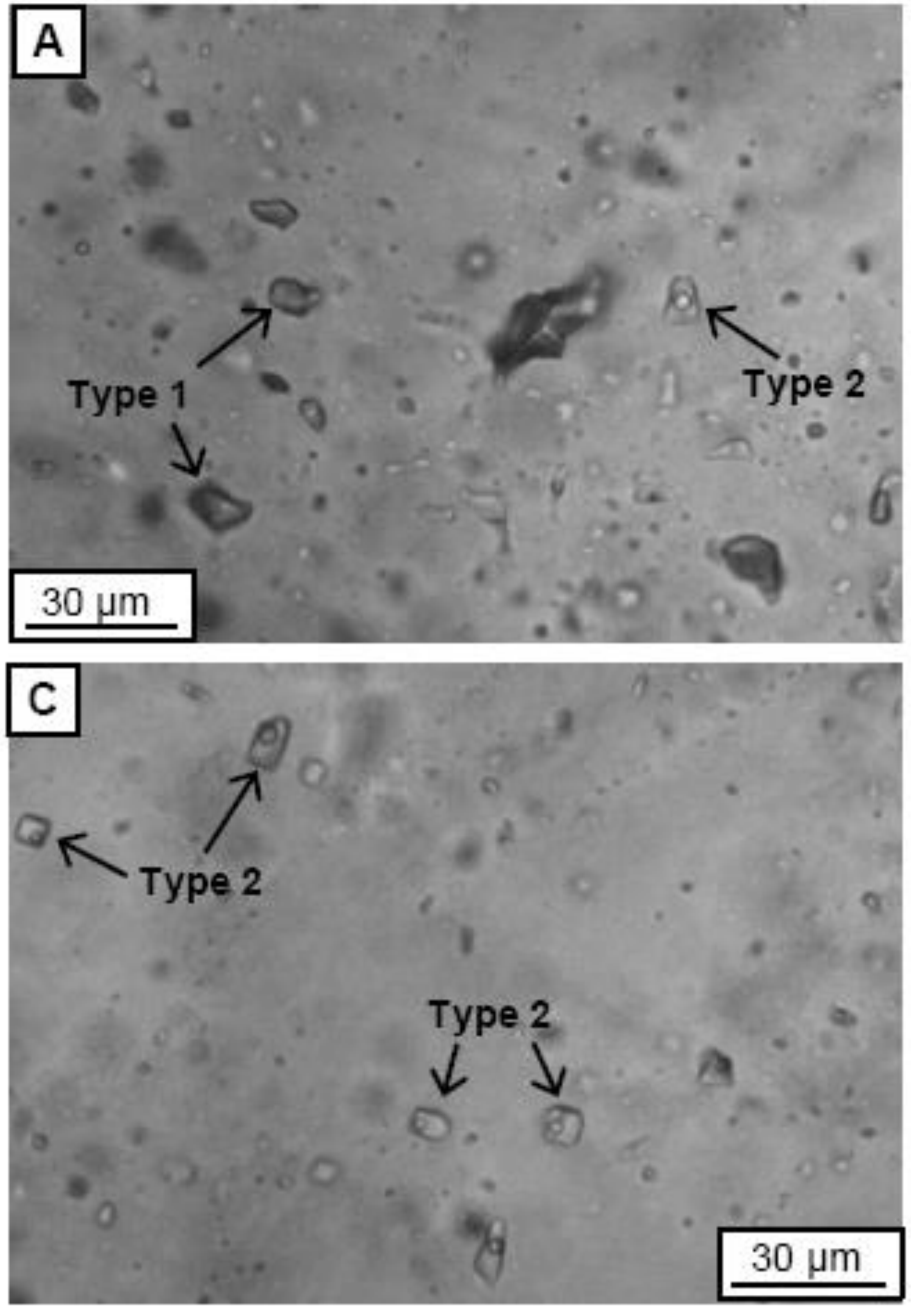


Qtz-Molybenite veining at Massawa: Stage 2



A: Qtz intergrown with stibnite; B: stibnite-chalcostibite-quartz; C: stibnite associated with aurostibite and native gold; D: Stibnite intergrown with sphalerite, gold and zinkerite


(A)
Mineral
Pre-ore stage
Ore stage 1
Moly veins
Ore stage 2
- Wall-rock alteration
Quartz
Ankerite
Dolomite
Sericite
- Non-sulphide vein phases
Quartz
Ankerite
Calcite
- Sulphide and other phases
Pyrite
Arsenopyrite
Stibnite
Molybdenite
Tetrahedrite
Galena
Sphalerite
Native Sb
Chalcostibite
Robinsonite
Roshchinite
Jamesonite
Zinkenite
Aurostibite
Gold
(B)
Mineral
Pre-ore stage
Ore stage
Post-ore stage
- Wall-rock alteration
Quartz
Ankerite
Dolomite
Sericite
Chlorite
- Non-sulphide vein phases
Quartz
Calcite
- Sulphide and other phases
Pyrite
Arsenopyrite
Tetrahedrite
Gersdorffite
Cobaltite
Galena
Apatite
Monazite
Xenotime
Gold



Dominant fluid inclusions in both qtz-stibnite veins (A and C) and quartz associated with stage one ore (B) are:

Type 1 CO_2-CH_4 and

Type 2 H_2O-NaCl

RANDGOLD RESOURCES INCORPORATED IN JERSEY, CHANNEL ISLANDS

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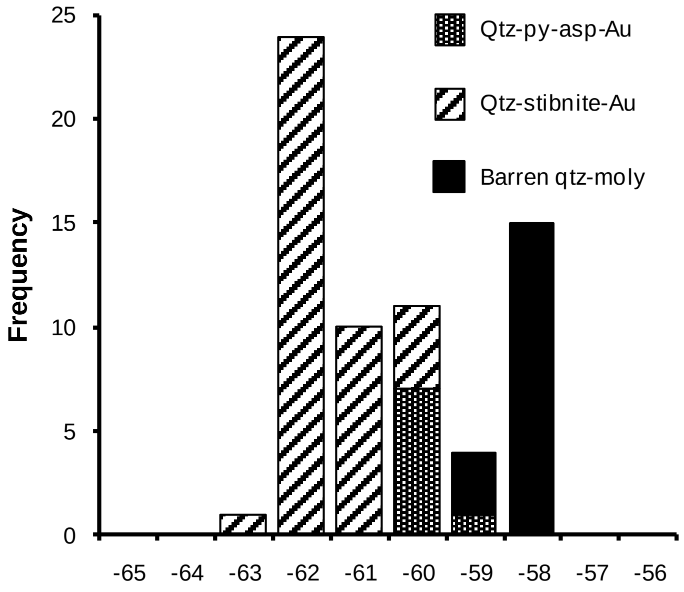
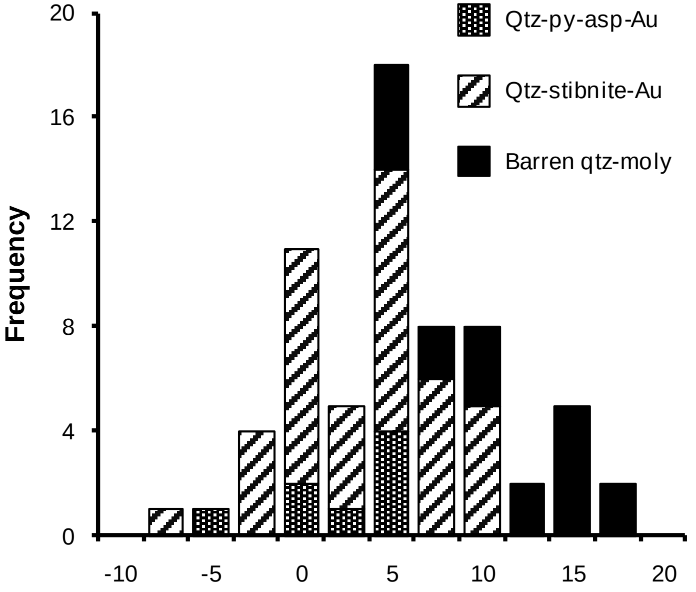
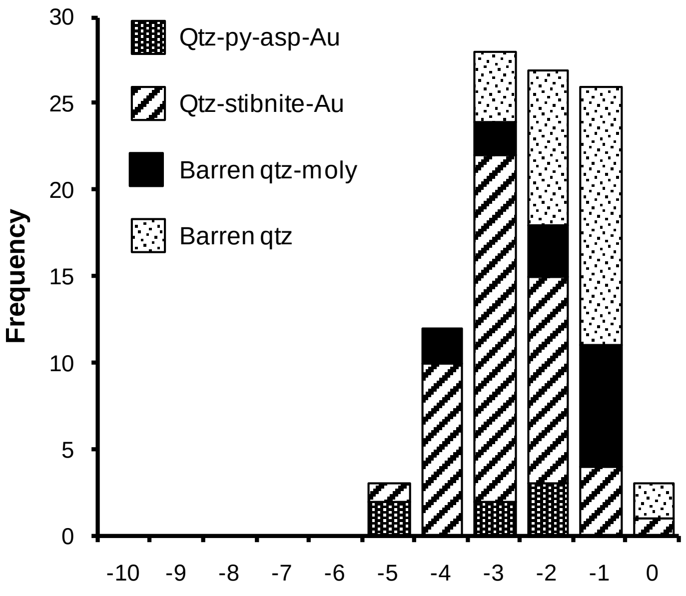


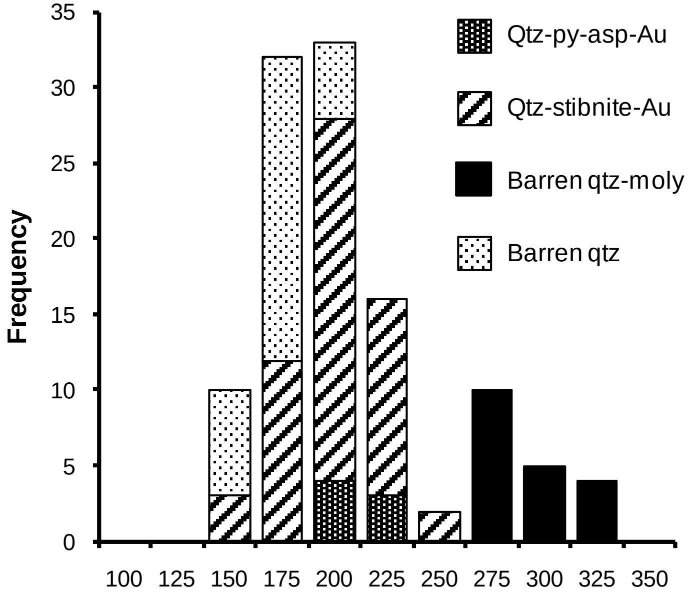
Type 1. $T_{m(CO2)}$



Type 1. $T_{h(CO2)(L)}$



Type 2. $T_{m(ice)}$



Type 2. $T_{h(L)}$

NB

Typical Metamorphic Fluids

Type 1.

Ore stage 1

15 – 33% Mol% CH_4

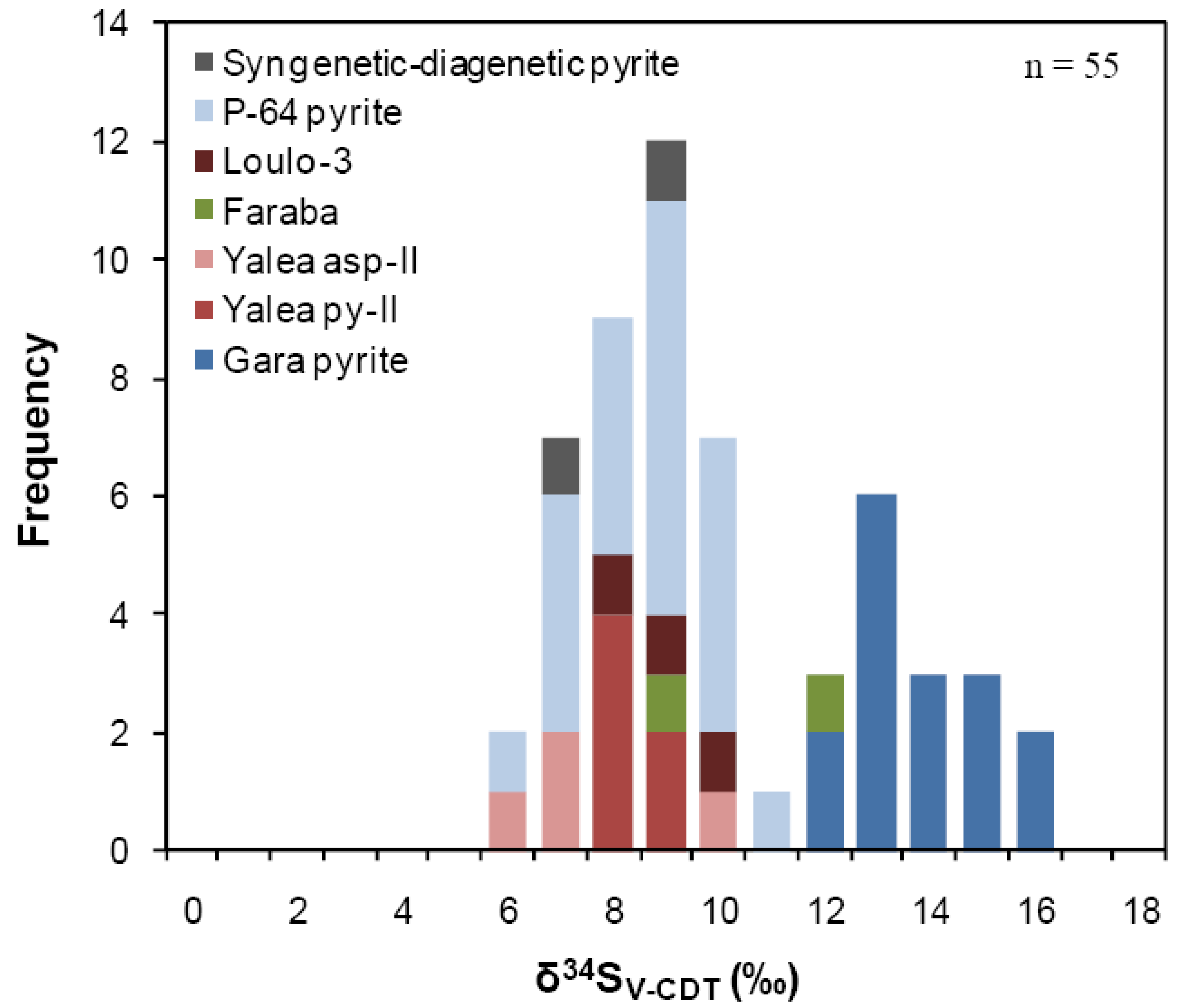
Ore Stage 2

10 – 15% Mol% CH_4

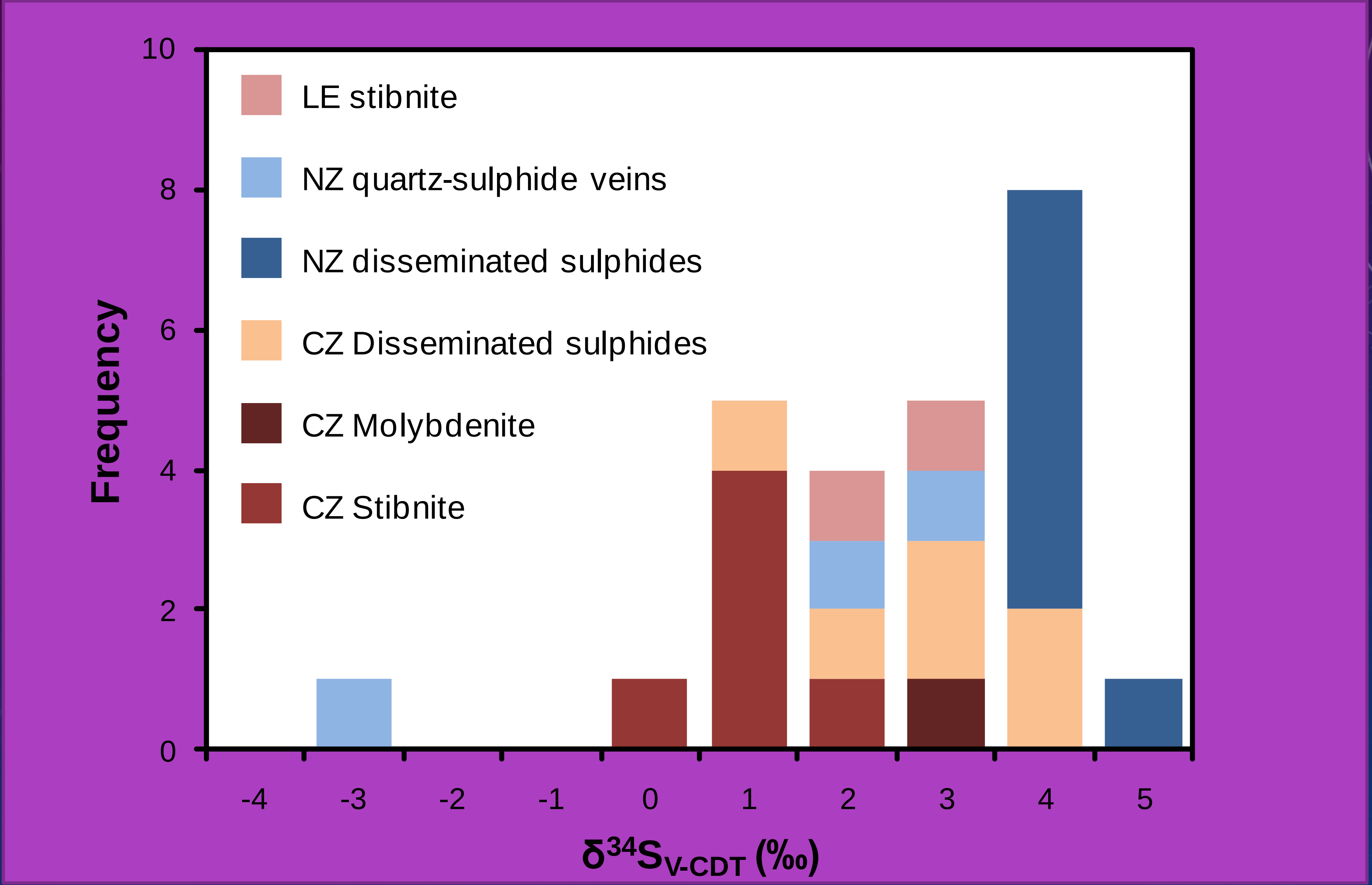
Type 2

2 – 8% NaCl

LOULO STABLE ISOTOPES: LAWRENCE ET AL 2013



MASSAWA SULPHUR ISOTOPE DATA



Sulphur Isotope data overlap for all stages.
(NB diagenetic sulfides in the KKI have $\delta^{34}S$ values of 6 – 15 ‰)

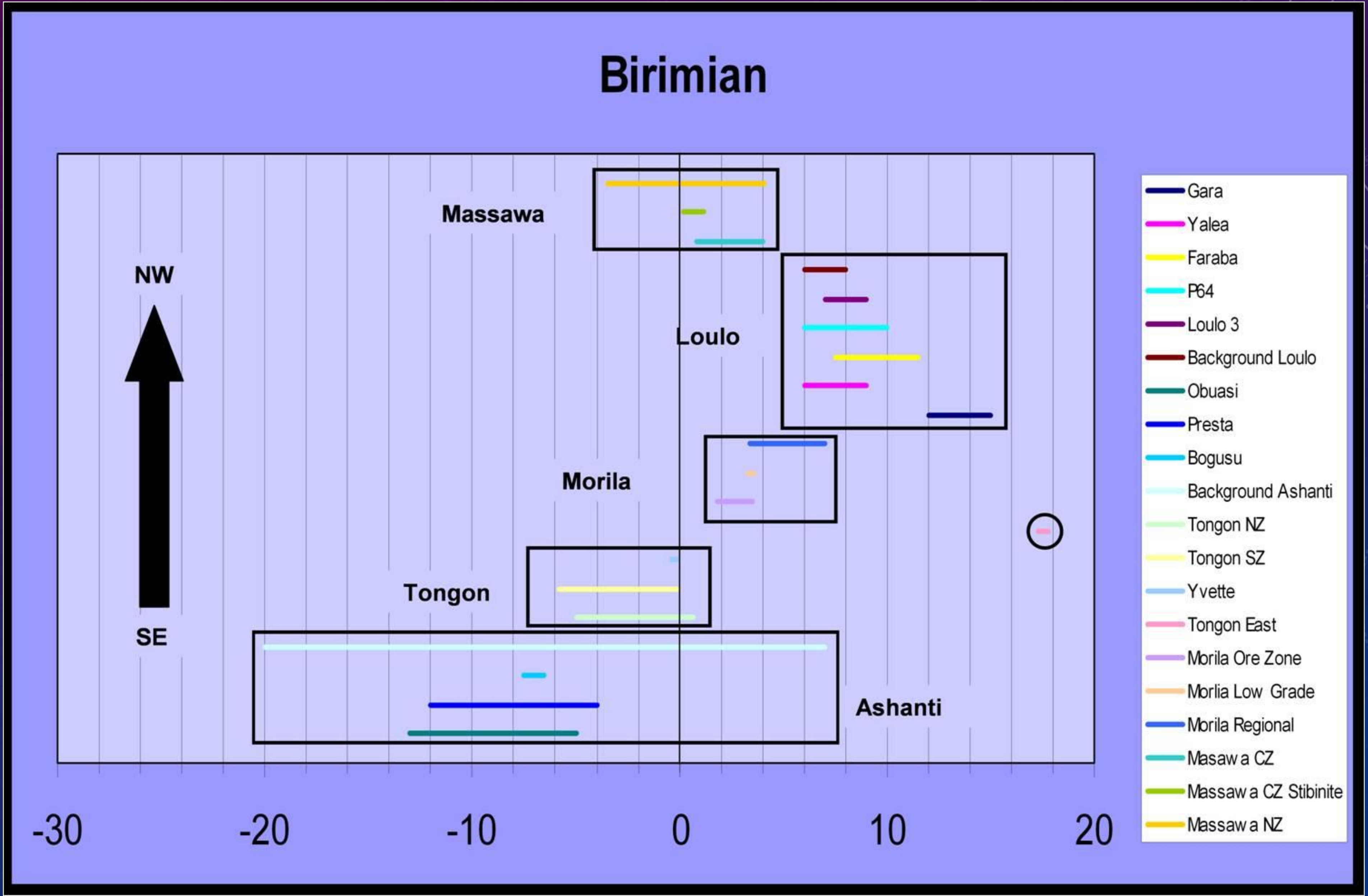
Morila Sulphur Isotope Data

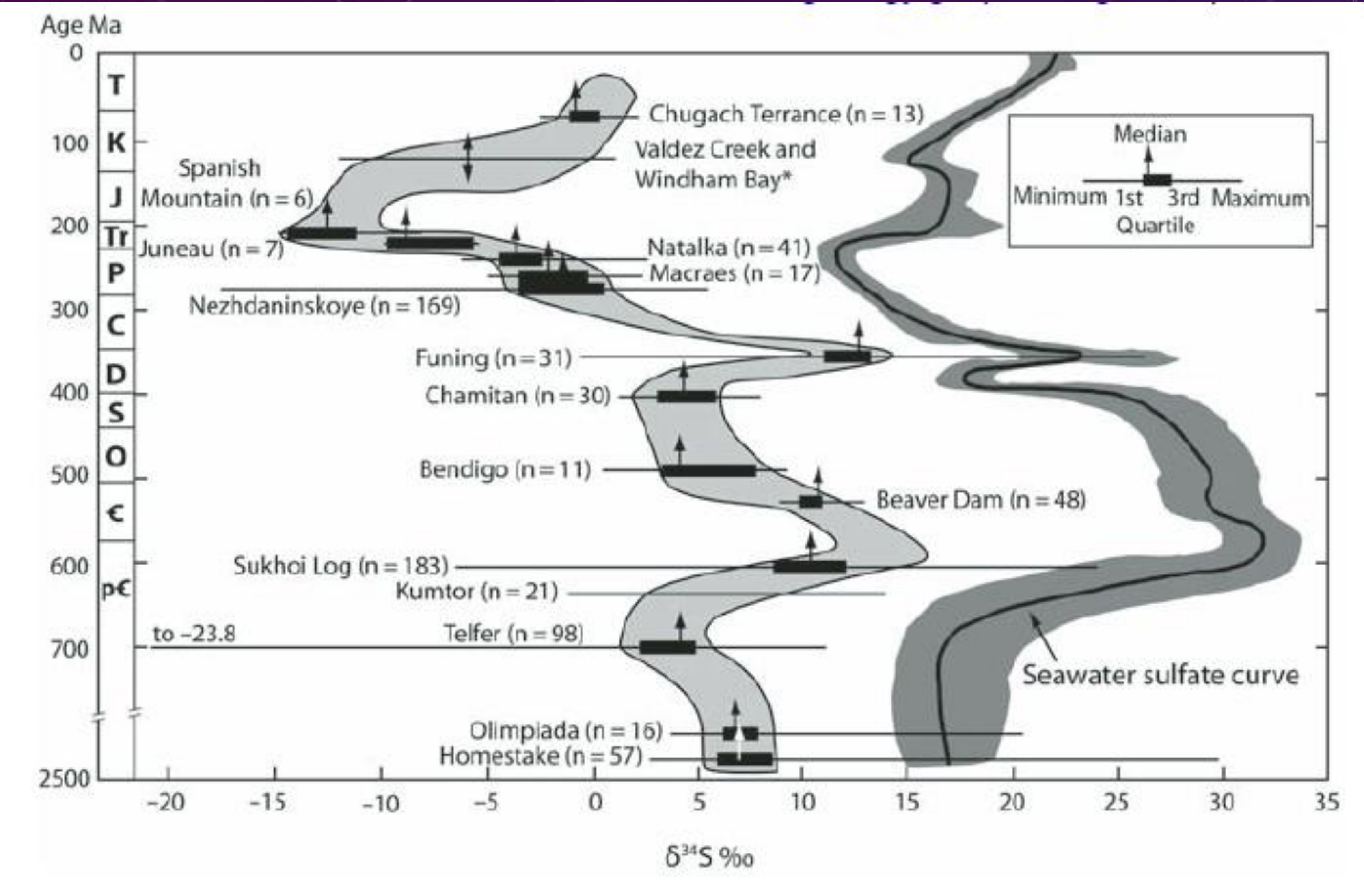
Morila

Interpreted as a Reduced Intrusion Related Gold System (RIRGS)

McFarlane et al. 2011

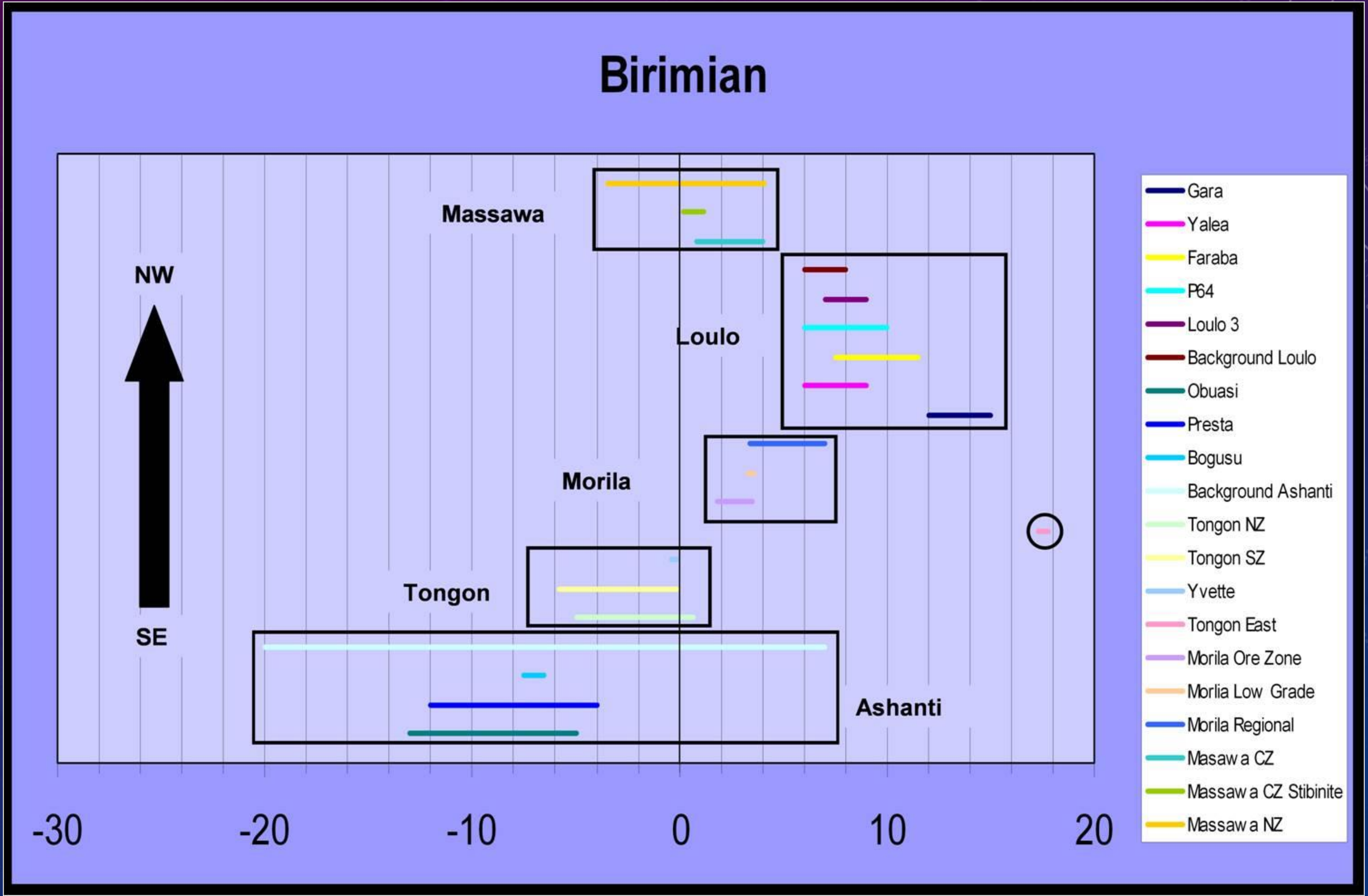
STABLE ISOTOPES





Variation in sulfide S isotope compositions in sediment hosted orogenic gold deposits through time and seawater sulfate curve (Chang, 2008, Geology)

STABLE ISOTOPES



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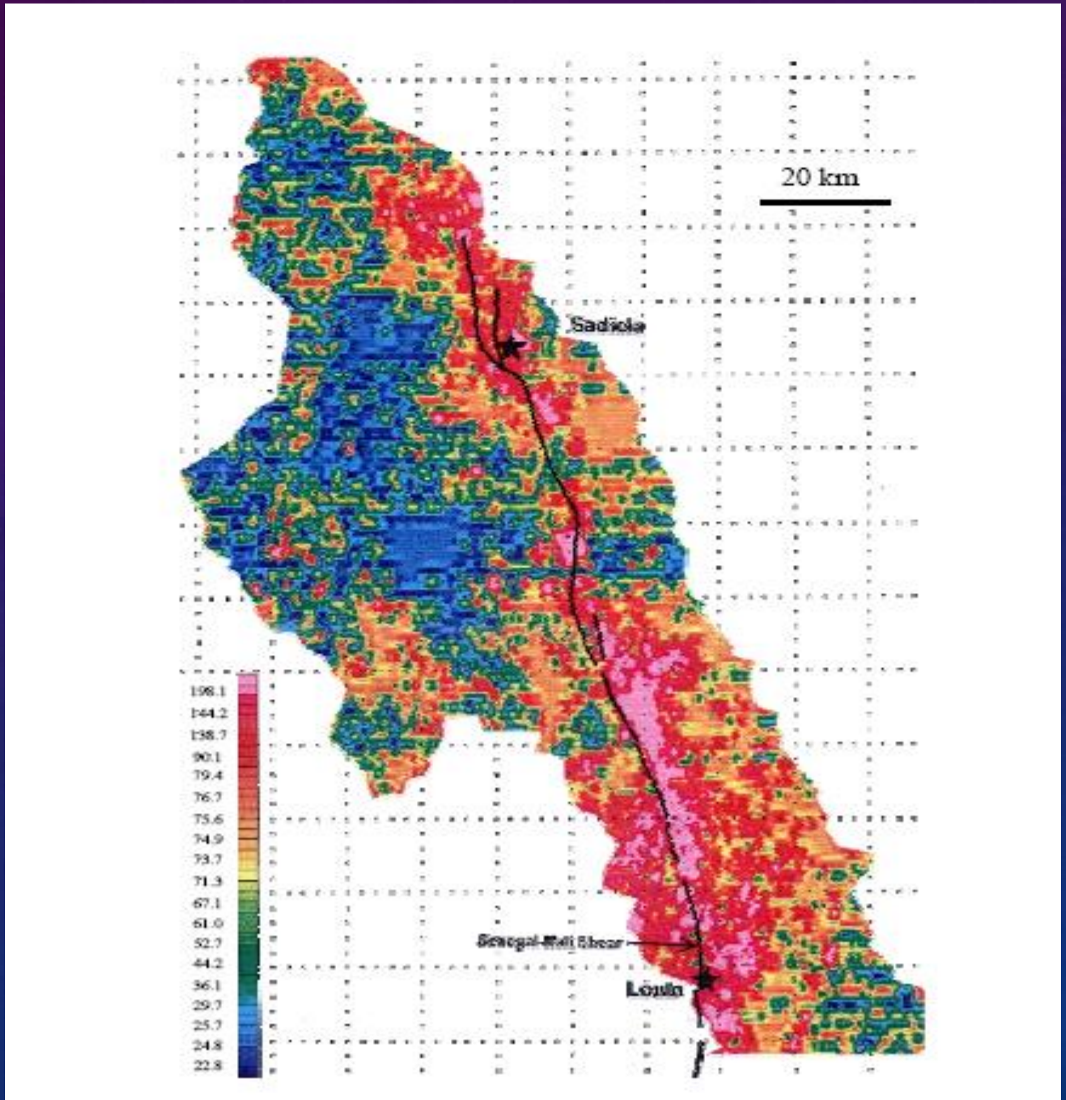
SMSZ - BORON SOIL CHEMISTRY



BORON ISOTOPE DATA – LAMBERT-SMITH 2014

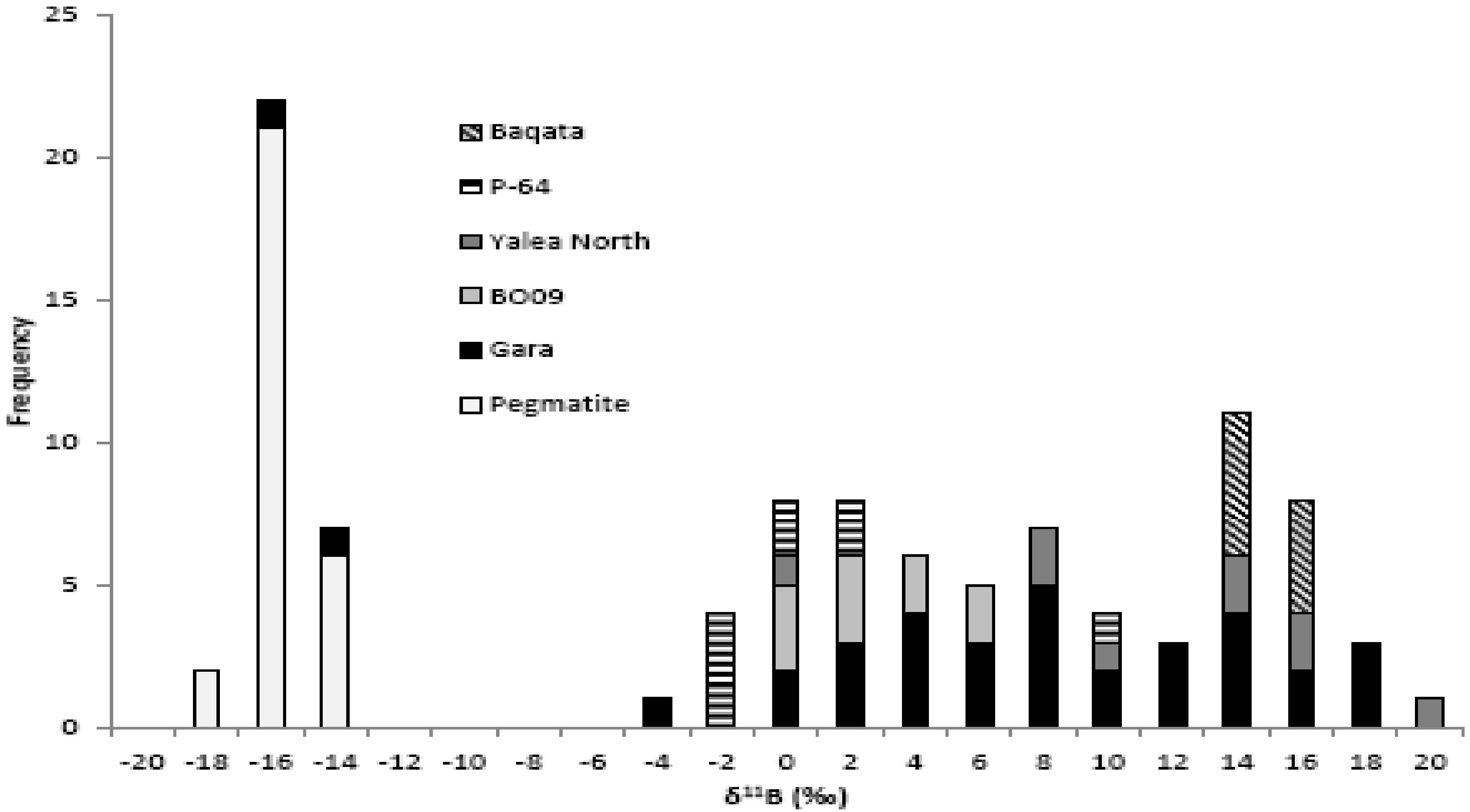


Figure 8.11: Histogram of $\delta^{11}B$ data from hydrothermal and magmatic tourmaline in the Kofi Series and the Falémé Volcanic Belt (n=100).

CONCLUSIONS

- West African Orogenic Gold deposits do not have a one size fits all model – different mineralogies, fluid chemistries and isotope signatures
- Hypersaline fluids can be derived from metamorphic reactions
- Boron does not necessarily mean magmatic
- Not all orogenic gold deposits are sourced from metamorphic fluids
    - The Gara and Yalea deposits at Loulo (bizarrely given the B and Cl levels) are likely sourced from metamorphic fluids
    - S isotope data at Massawa, together with field relations, speak of magmatic fluids
    - Morila is a RIRGS