

# **OROGENIC GOLD MINERAL SYSTEM**

**Greg Hall**

**Golden Phoenix International**

*With acknowledgements to Scott Halley, John Walshe, Bruce Hobbs, Graham Begg, Ned Stolz, Janet Tunjicja, Karen Connors, Vic Wall, Chris Heinrich and many others including Goldfields, Barrick Gold Corporation, Centamin, Nyota, Chalice Gold Mines*

# Giant Gold Deposit Database

**Deposits greater than 150t contained gold**

CLASS	Number	Gold t	%
Witwatersrand	7	49,546	52.2
Orogenic	55	25,643	28.0
Porphyry / Epithermal	38	14,241	15.6
Carlin	5	1,525	1.7
Alluvial	1	471	0.5
TOTAL	106	91,435	100.0

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*Source: Placer Dome Exploration Database*

# Giant Gold Deposit Database

**Deposits greater than 150t contained gold**

	CLASS	Number	Gold t	%
<b>OROGENIC</b>	Archaean	21	9,880	10.8
	Sediment Hosted	19	8,530	9.3
	Intrusive Related	15	7,233	7.9
	<b>TOTAL</b>	<b>55</b>	<b>25,643</b>	<b>28</b>
<b>PORPHYRY</b>		15	7,233	7.9
<b>EPITHERMAL</b>		23	7,008	7.7
	<b>TOTAL</b>	<b>38</b>	<b>14,241</b>	<b>15.16</b>

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*Source: Placer Dome Exploration Database*

# **THE OROGENIC GOLD MINERALISING SYSTEM**

GEODYNAMICS

ARCHITECTURE

FLUID SOURCES

FLUID PATHWAYS AND DRIVERS

DEPOSITION MECHANISMS

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# Au & Cu-Au Deposit Genesis

## MAIN SETTINGS

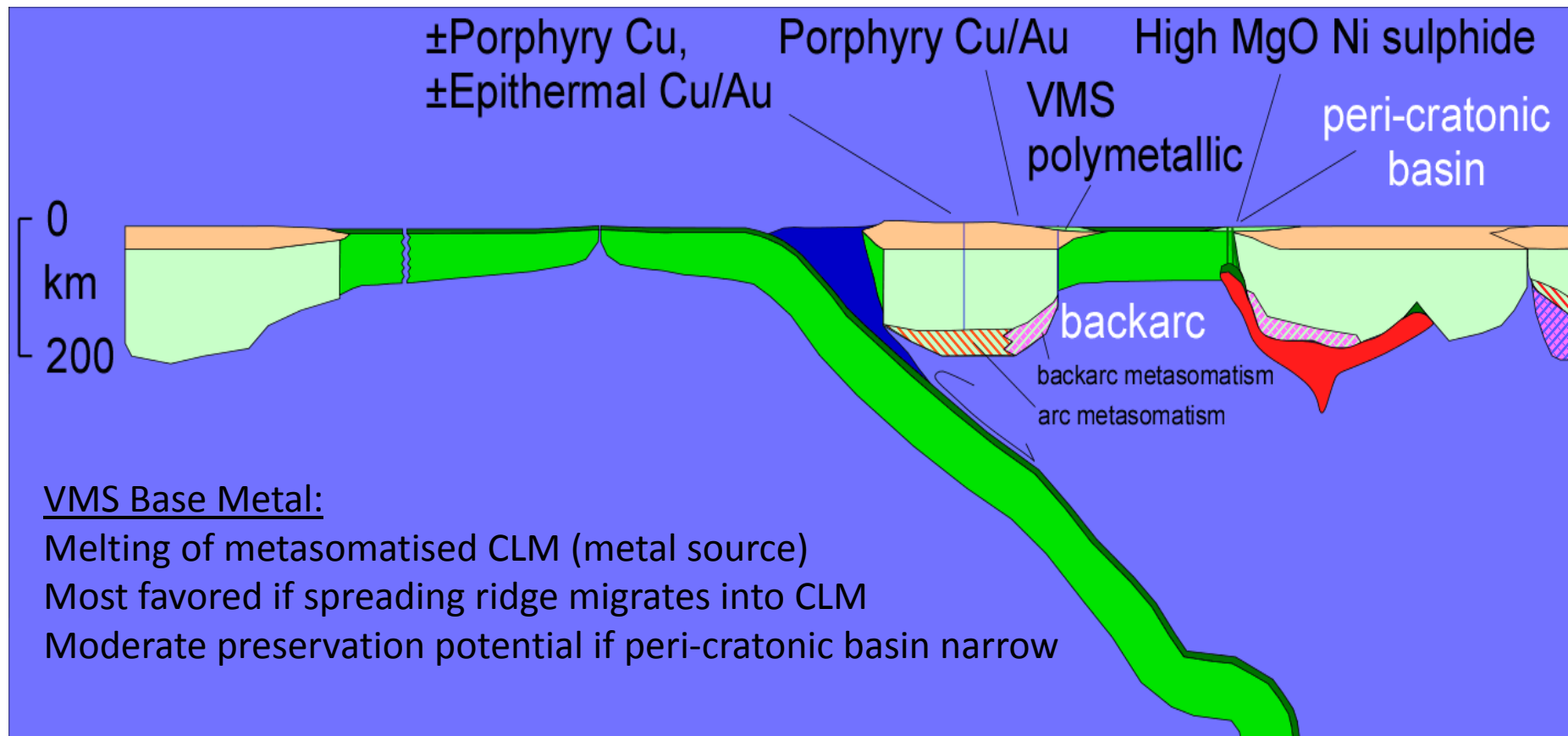
- Inverted Peri-cratonic ( $\pm$  backarc) Basins
  - West Lachlan, Yilgarn, Abitibi, Tintina Belt, Birrimian, Arabian Nubian Shield, Lake Victoria, Tianshan
- Magmatic Arcs with history of disrupted subduction (e.g. collision & polarity flip; flat slabs)
  - SW Pacific Cu-Au porphyries and epithermal Au; East China
- Combination of the above
  - Great Basin/Carlin Trend

# Metasomatized (Ancient?) Mantle

- Common to most of these settings is the presence of continental lithospheric mantle (SCLM), either as the substrate to pericratonic margins or as microcontinental blocks
- Alkaline mantle-derived melts are an important ingredient in gold-rich magmatic systems (Loucks & Ballard, 2003) and possibly also in Orogenic Au systems
- Metasomatism of lithospheric mantle by subduction-related magmas/fluids creates the source region for these melts

Ancient lithospheric mantle domains accumulate this metasomatism throughout their history – a metal source region waiting to be tapped!

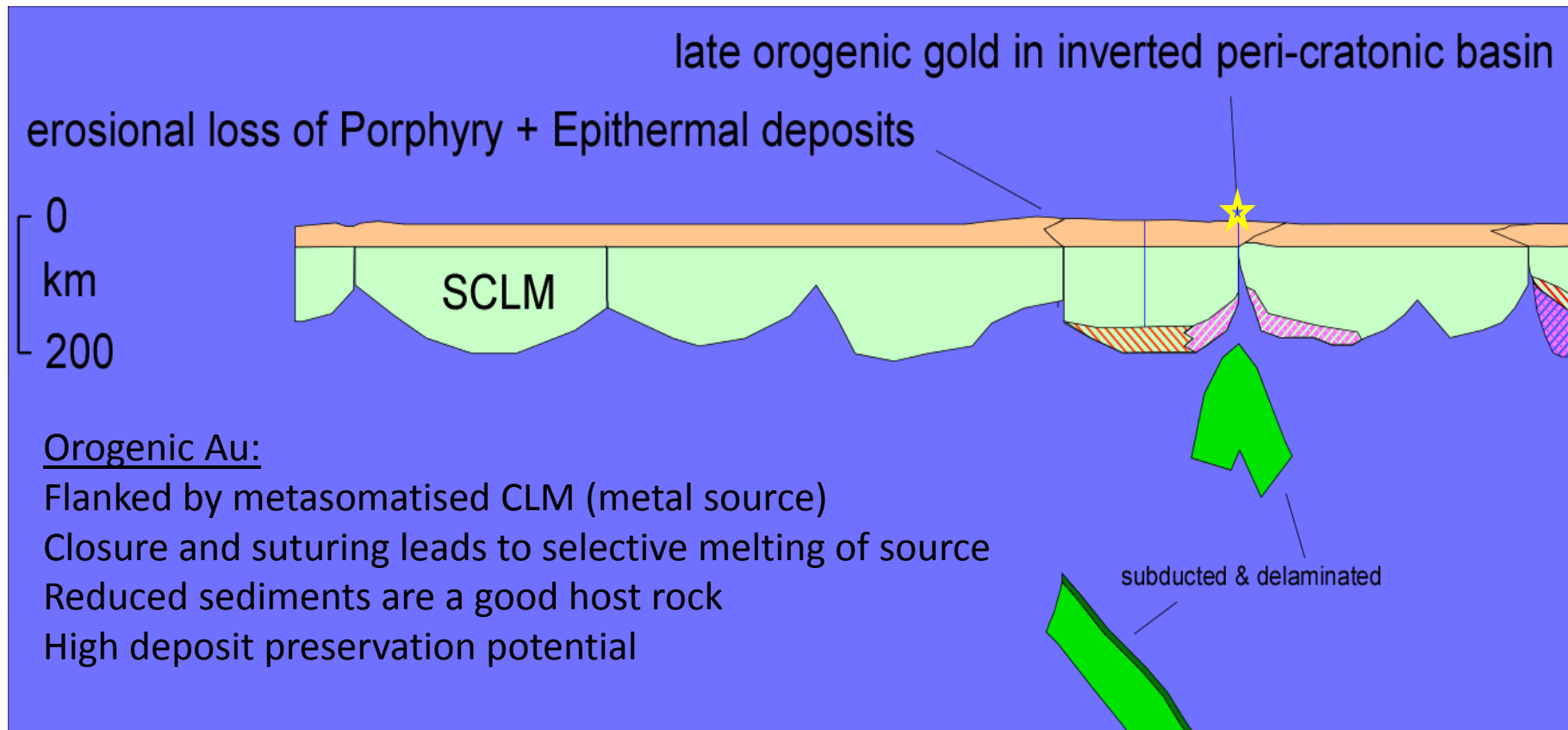
# Backarc/Peri-cratonic: VMS & CD base metal, Ni sulphide



Graham Begg, 2011

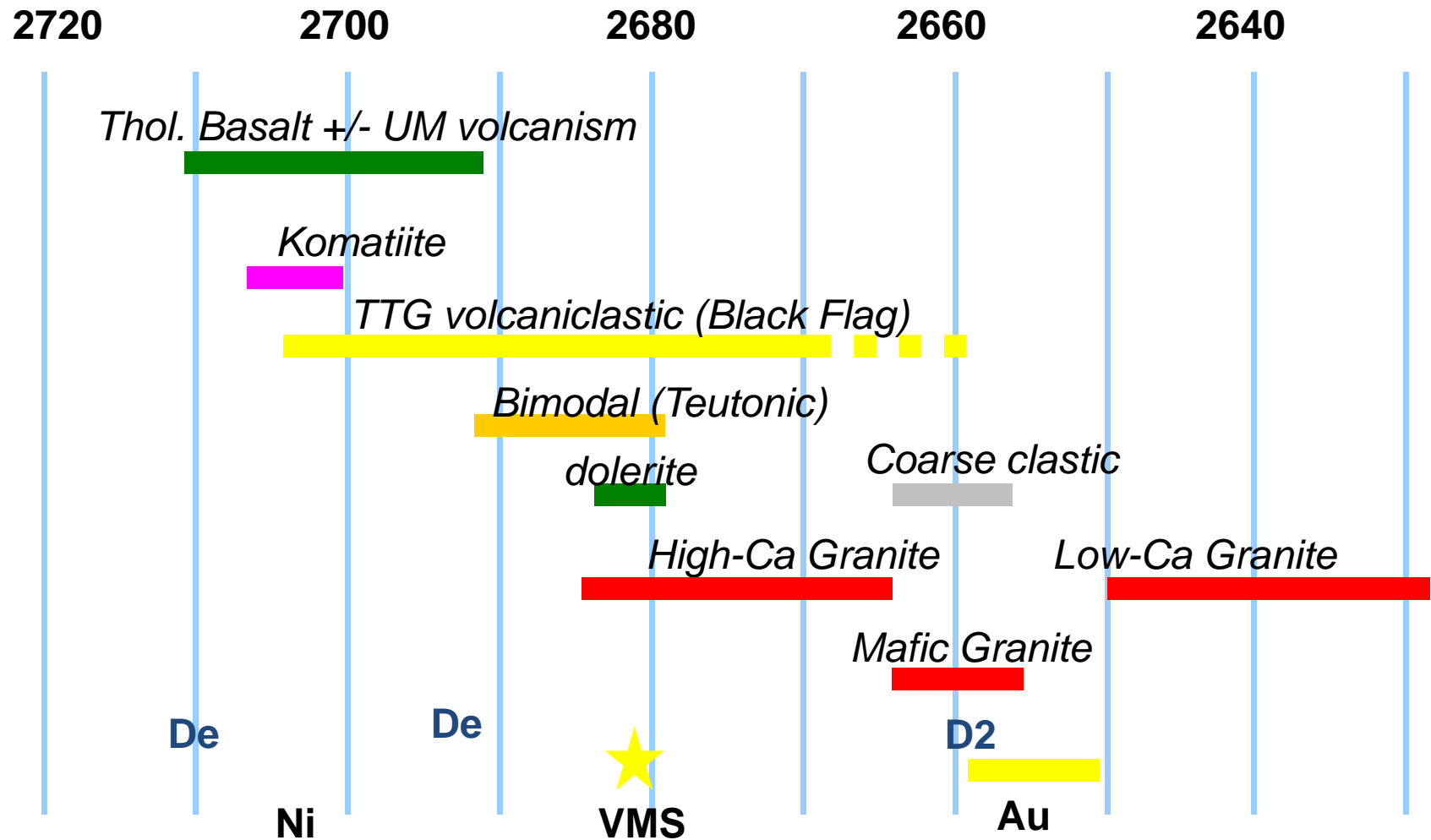


# Backarc/Peri-cratonic : Orogenic Au

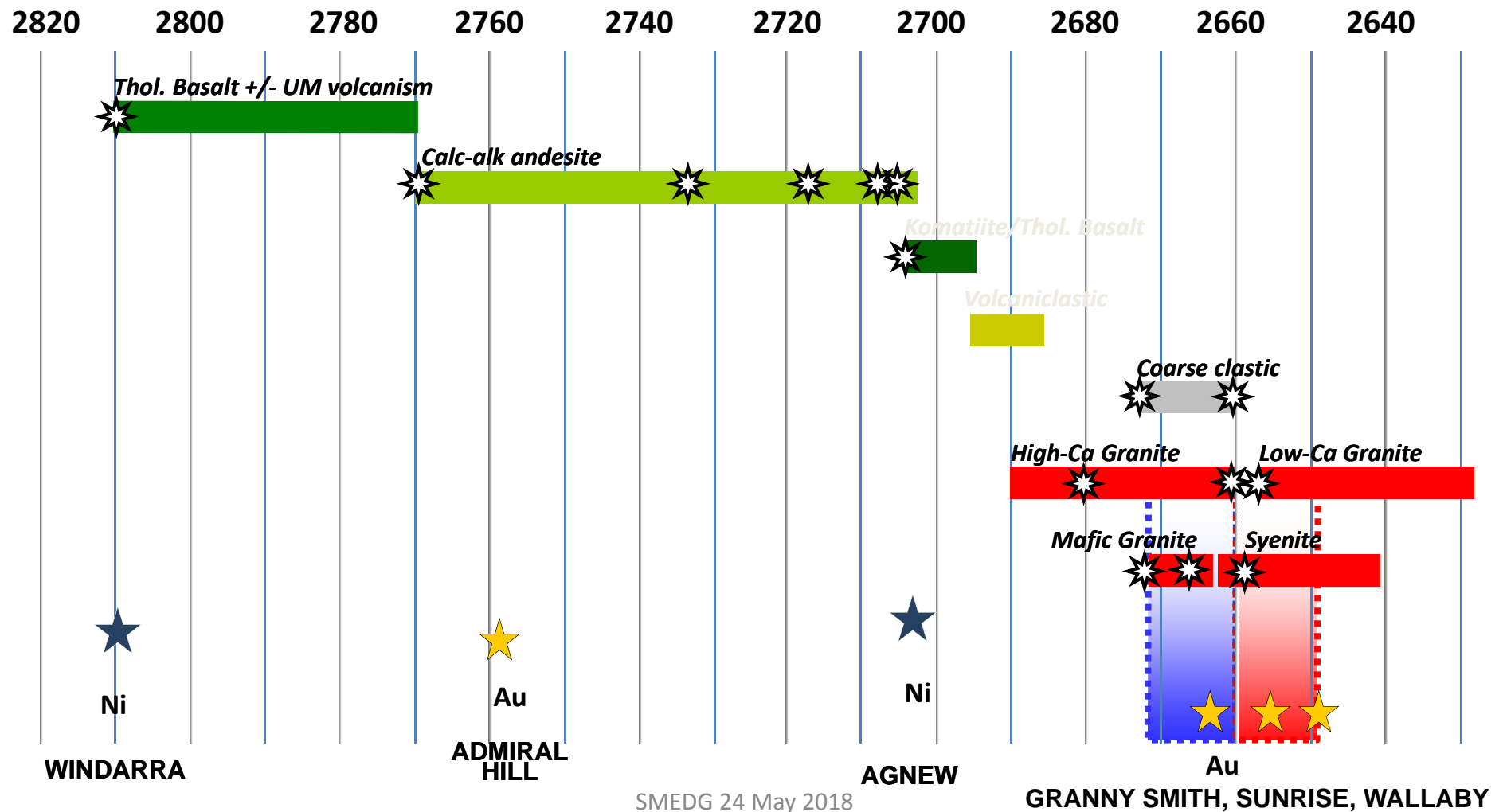


Graham Begg, 2011

# Kalgoorlie Geochronology



# Laverton Geochronology



## OROGENIC GOLD Geodynamics

- Gold is always immediately post-metamorphic peak for large deposits or later for smaller deposits
- Gold is always after collision and deformation
- Regional magmatism shows evidence of mantle contamination
- Giant gold deposits are located above collision boundaries
- Gold deposits formed at depth are never refractory. Gold deposits formed at shallower depths often are refractory (not enough heat in the wall rocks to anneal sulphides or recrystallise “preg-robbing” hydrothermal carbon after formation)

## OROGENIC GOLD Geodynamics

- Arabian Nubian Shield is a composite terrain of largely oceanic crust micro-continents that amalgamate in the Pan African Orogeny
- There is no pre-existing continental basement only new crust hence VMS deposits can form
- The formation of this mafic crust created depleted sub-continental lithospheric mantle
- The coalition of these fragments is driven by oceanic plate subduction which metasomatises the depleted sub-continental lithospheric mantle
- The Arabian Nubian Shield is highly prospective for large VMS, Nickel and Gold deposits

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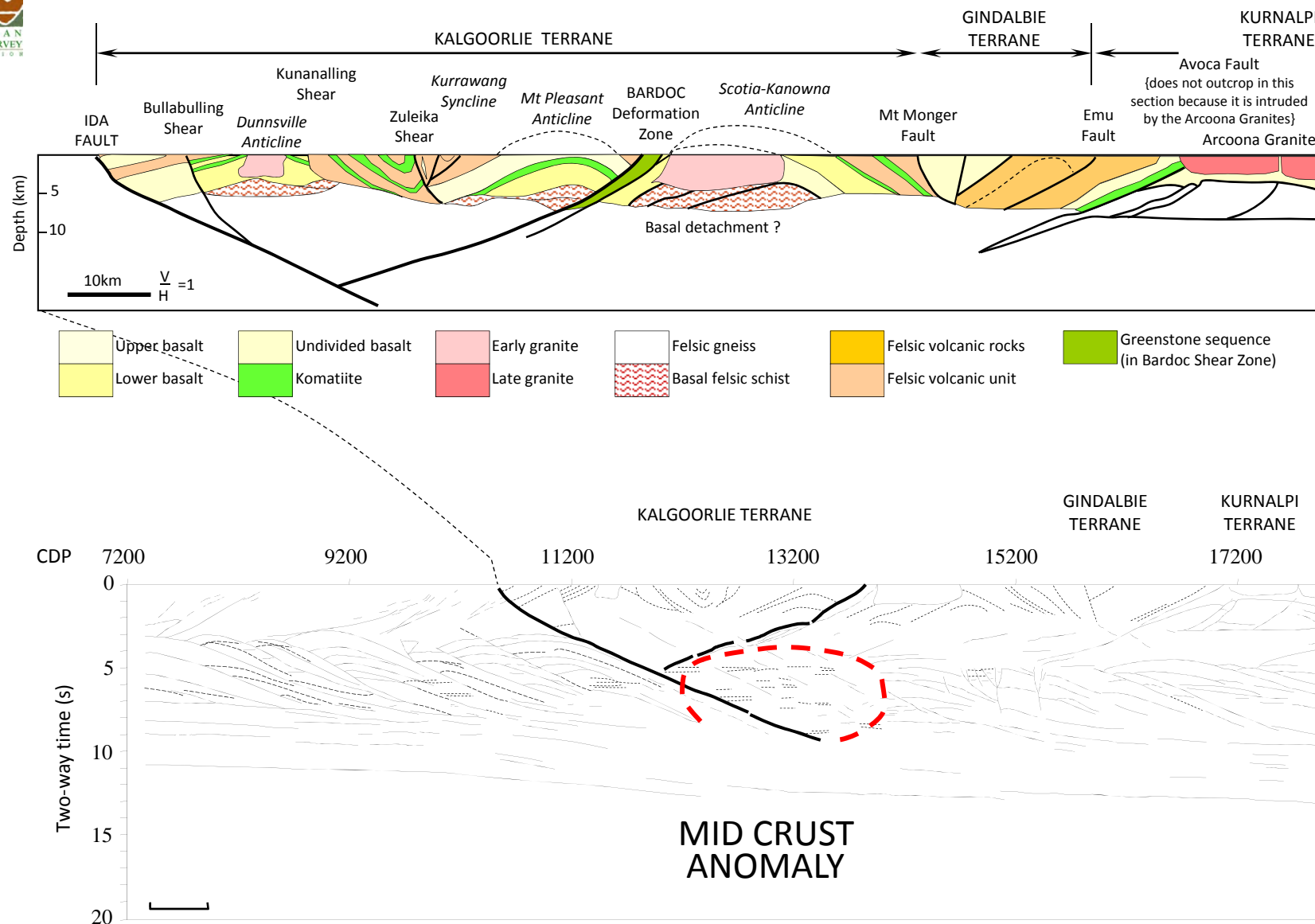
DEPOSITION MECHANISMS

# OROGENIC GOLD Architecture

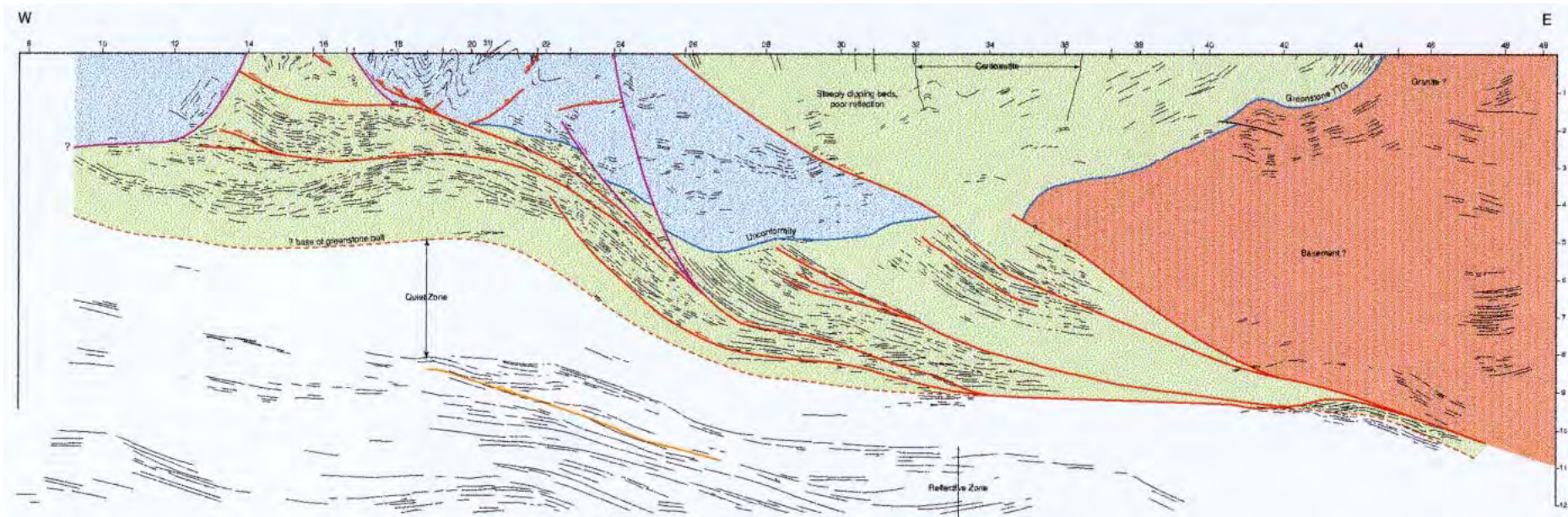
- Major gold deposits are located in giant antiforms in the hangingwall of suture zones of cratonic fragments
- The suture zone extends to the crust mantle boundary
- Major gold deposits are located above this suture zone where that zone is intersected by a major deep fault at high angle to the suture zone
- Major gold deposits are located immediately within or adjacent to a late sedimentary basin or cover sequence

# SEISMIC CROSS SECTION KALGOORLIE 100moz

REGIONAL





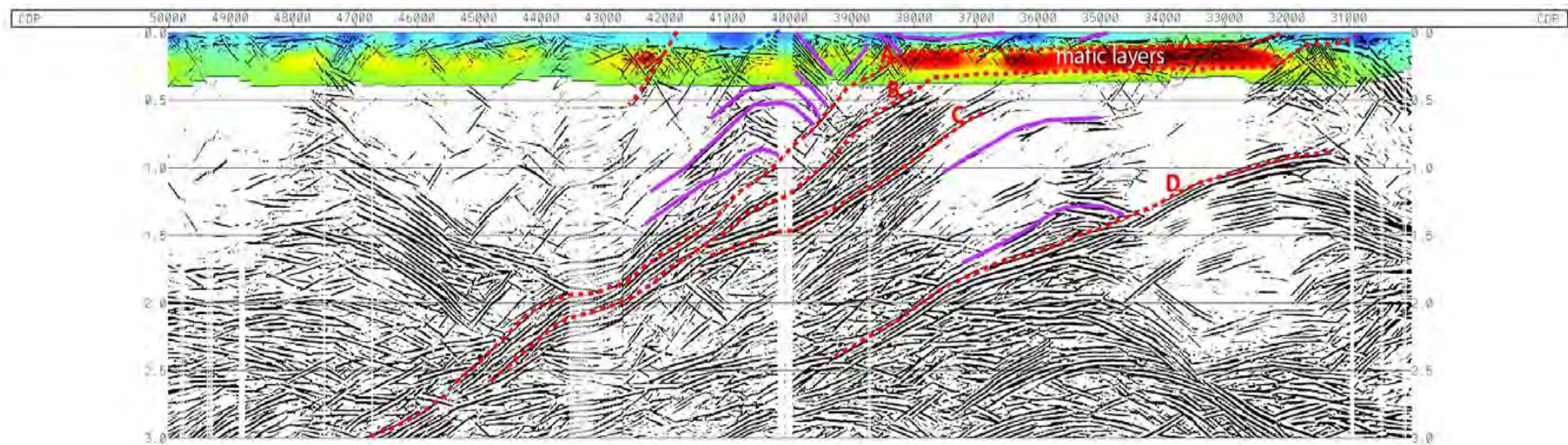


## Seismic Line NY2 at LAVERTON Yilgarn Province

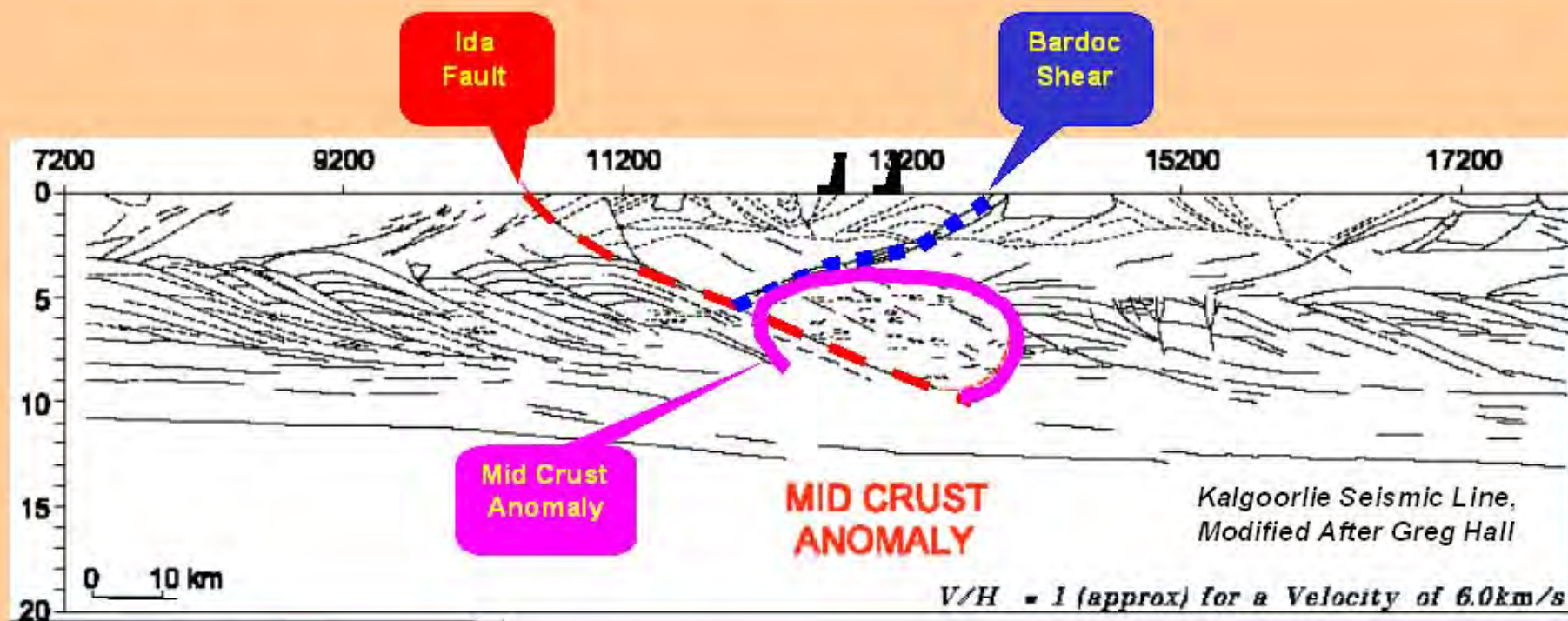
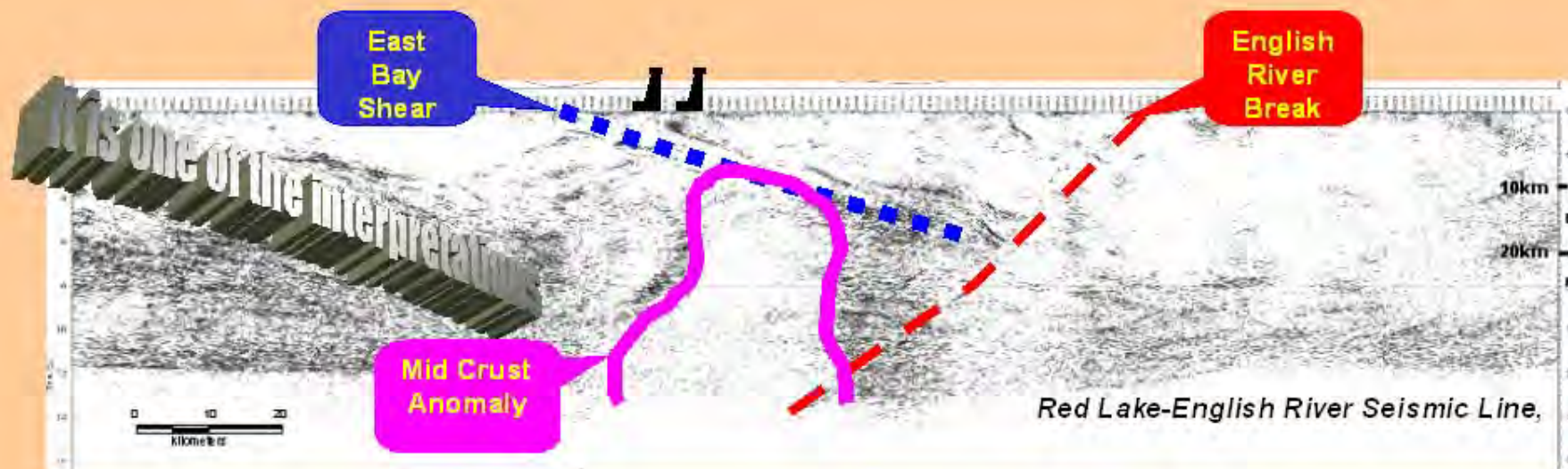
- Greenstone Belt extends to between 5 and 13km
- Quiet Zone probably comprises homogeneous and weakly foliated granites
- Thick zone of probably basement gneiss. Cuts are interpreted as faults and shears, mainly as thrusts
- Master fault extends to the mantle
- Host 7mozs on section

# Seismic Section at Red Lake Canada

## Host to 40 mozs

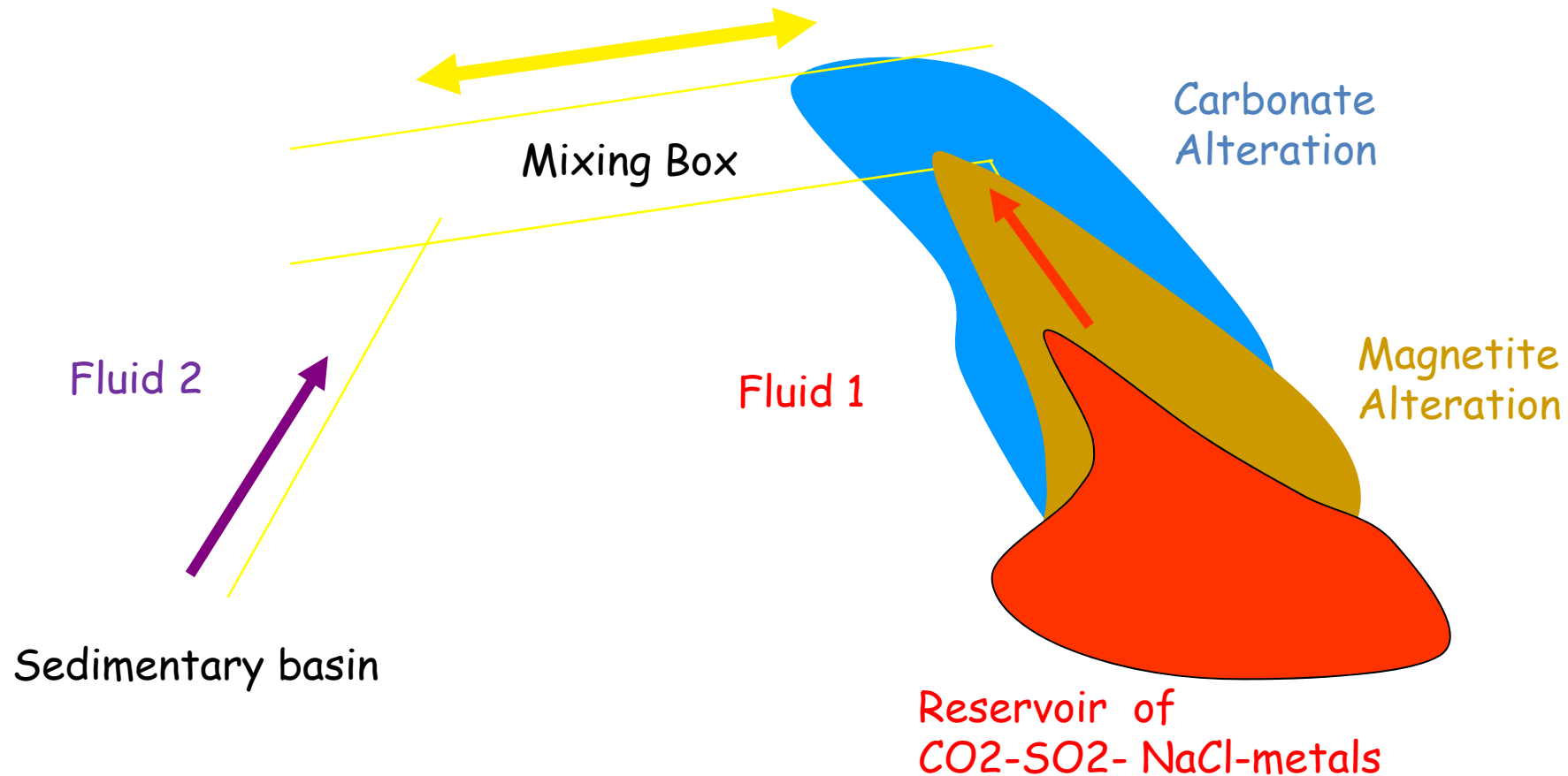






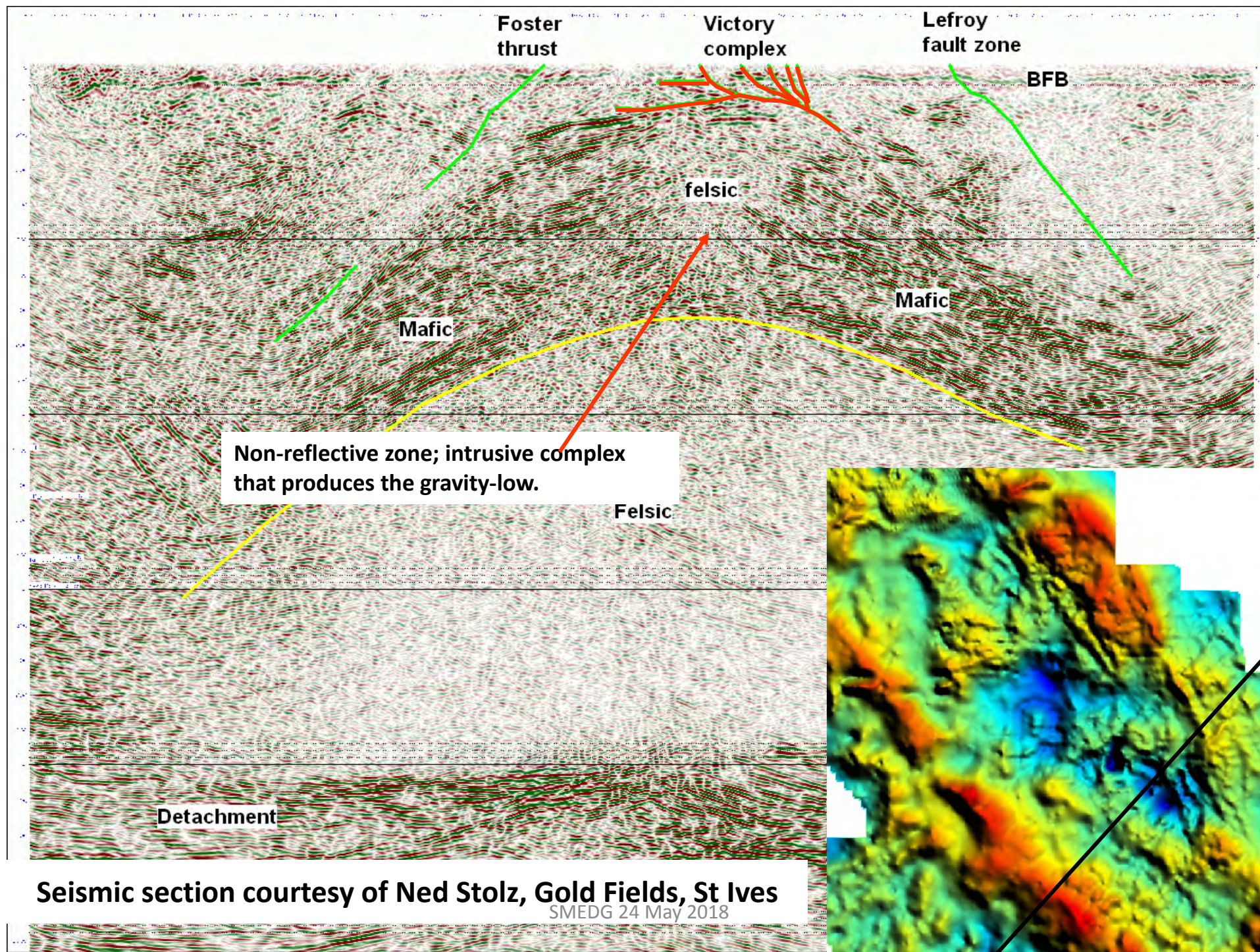
# Hangingwall architecture

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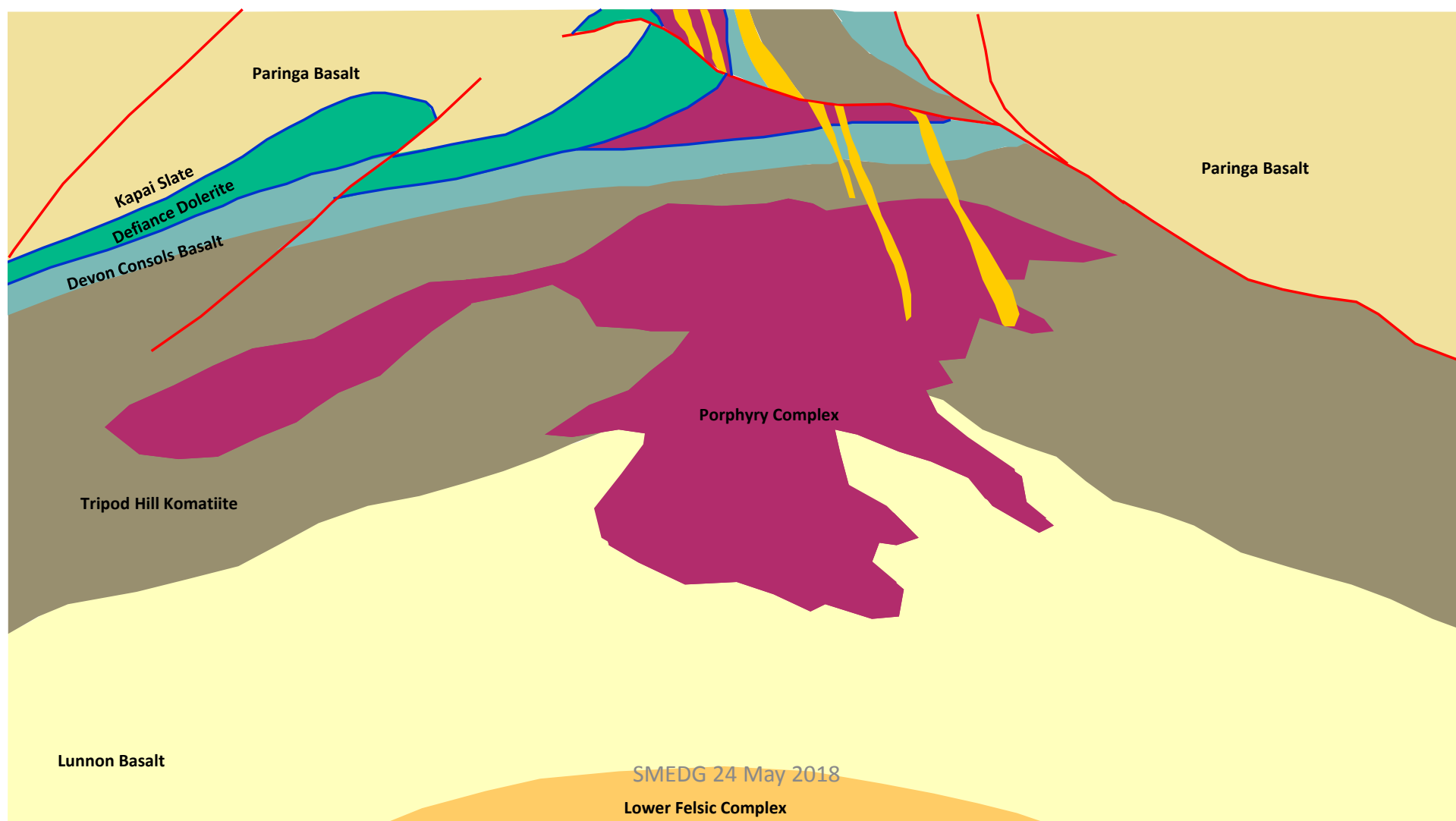
“Observe” the magma chamber in the geophysical image





Seismic section courtesy of Ned Stolz, Gold Fields, St Ives  
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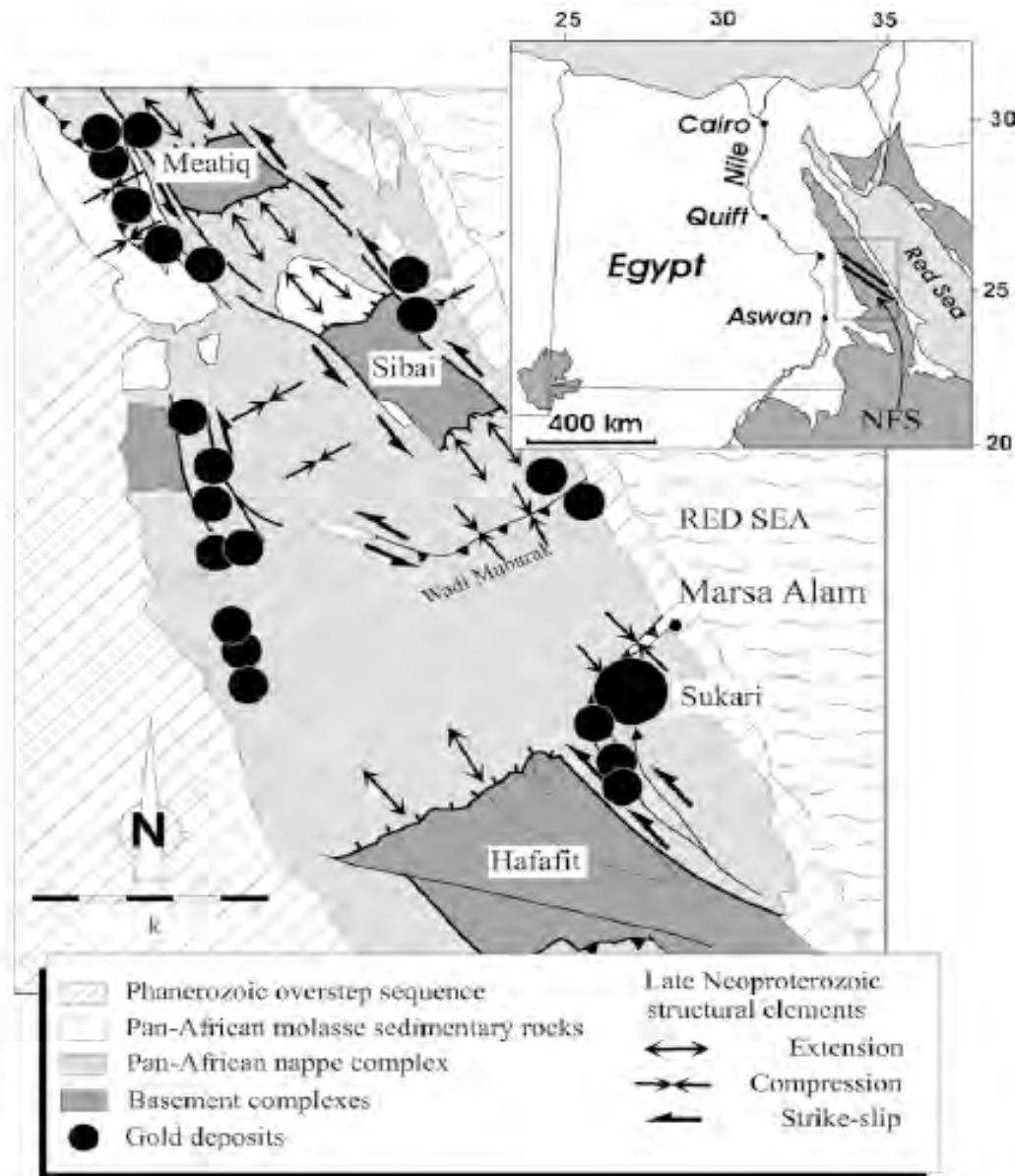


## OROGENIC GOLD Architecture

- Arabian Nubian Shield is comprised of numerous terrains whose boundaries strike largely north south
- The northern ANS (Egypt) shows metamorphic core complexes and late sedimentary basins (molasse)
- The southern ANS (Ethiopia, Eritrea) shows deeper levels of erosion with larger plutons and lacks late sedimentary basins
- Sukari (14mozs) is located on a crustal suture at intersection of Najd Fault System and is adjacent to a molasse basin located in the footwall of a suture zone

# OROGENIC GOLD Architecture

**Fig. 1** General geology and location of gold deposits of the central Eastern Desert. Note concentration of metal occurrences close to major faults. Location of the Najd Fault System (NFS) is marked in the *inset*





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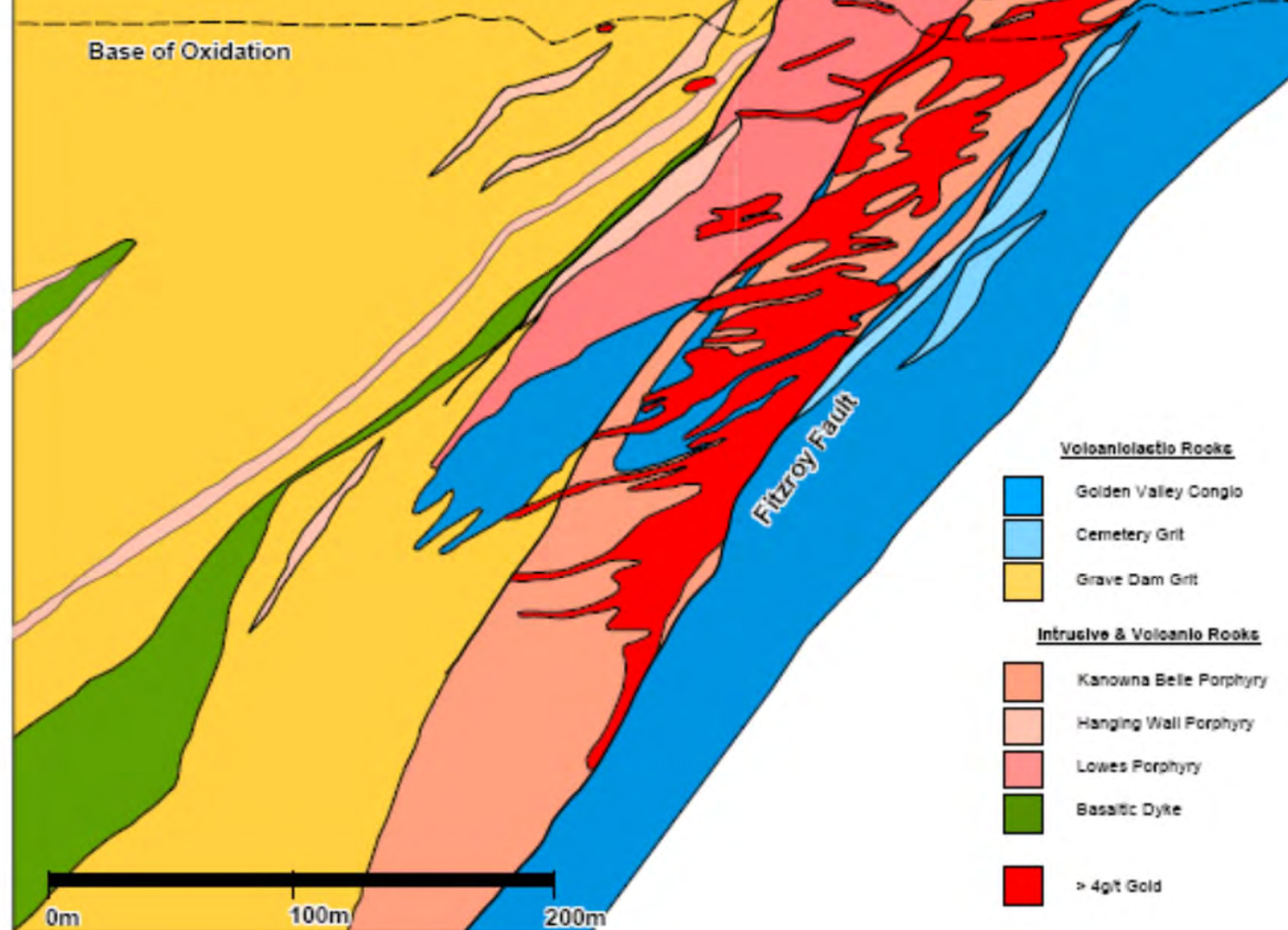
## OROGENIC GOLD Fluid Sources

- Ultimate source of gold and much of the sulphur is depleted sub-continental lithospheric mantle (SCLM)
- Fractionated deep source crustal magmas (syenites to I type granite) act as fluid carriers. Intrusive porphyries and lamprophyres often occur at the site of gold deposits. Seismic reflection and gravity data show magma bodies at depth.
- Fluids are oxidised and precipitate anhydrite
- Locally mantle fluid arrives direct at the deposition site and creates very high grade veins. Fluid inclusions in these gold veins are CO<sub>2</sub>-SO<sub>2</sub> mixtures devoid of water. Celestite (Sr carbonate) in these veins shows a pure mantle isotopic signature.
- Gold is carried as a thio-sulphate complex

South East

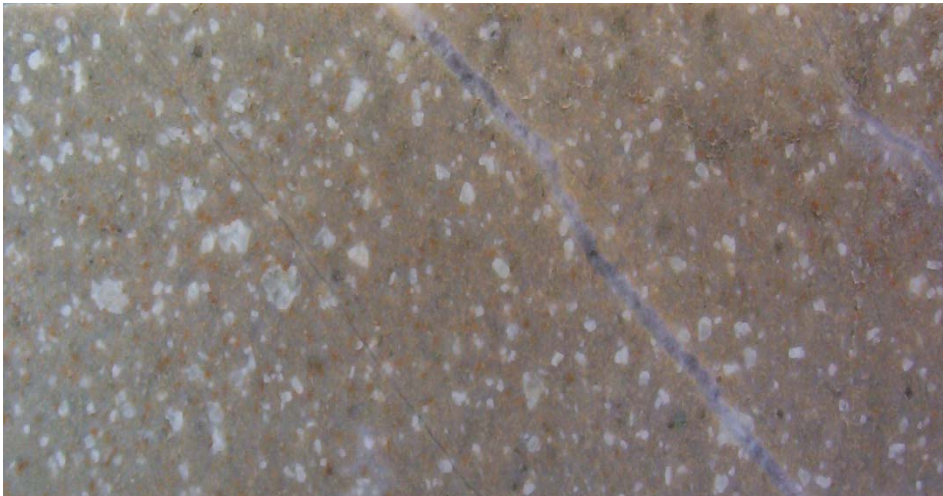
North West

**Kanowna Belle  
Schematic Section 20000mE  
Looking South**

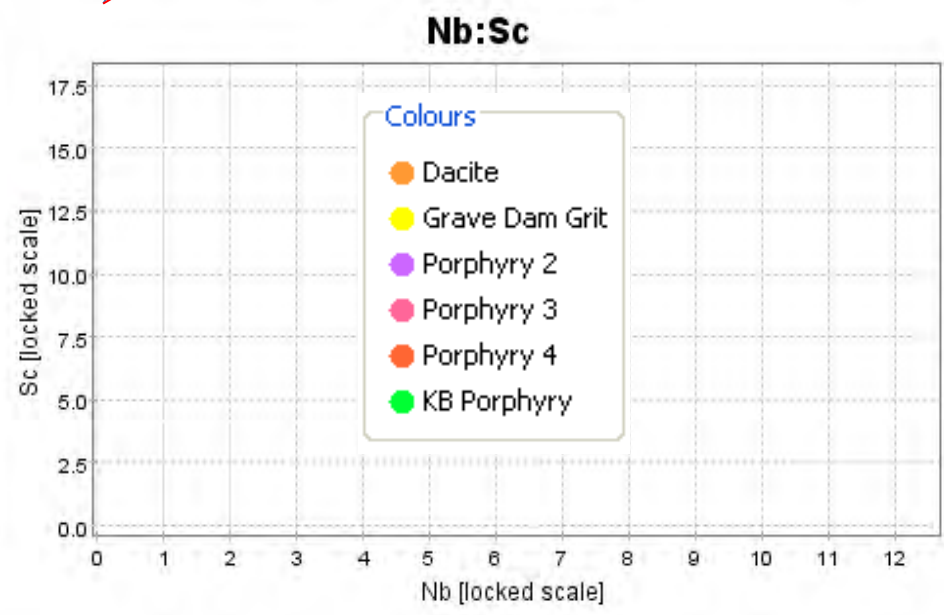
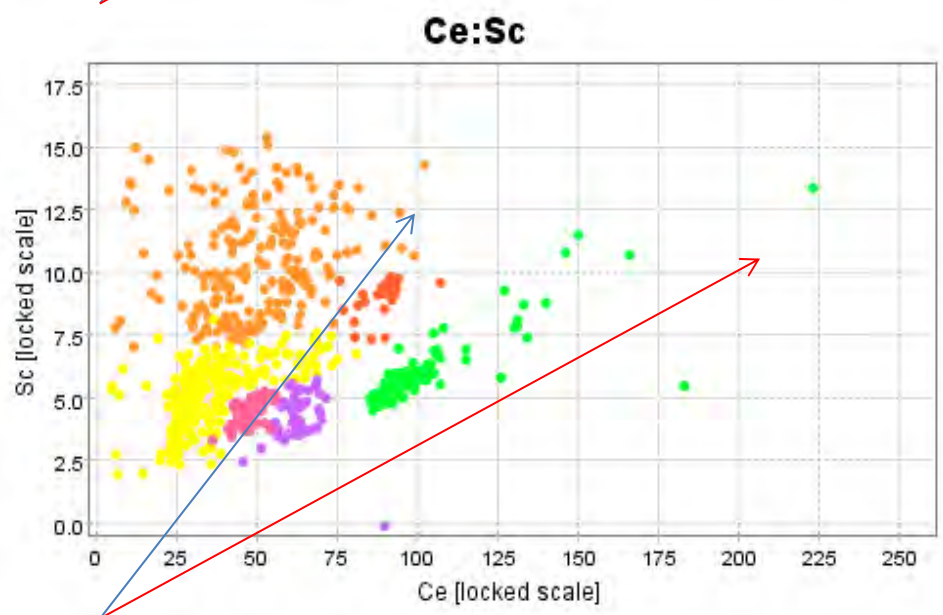
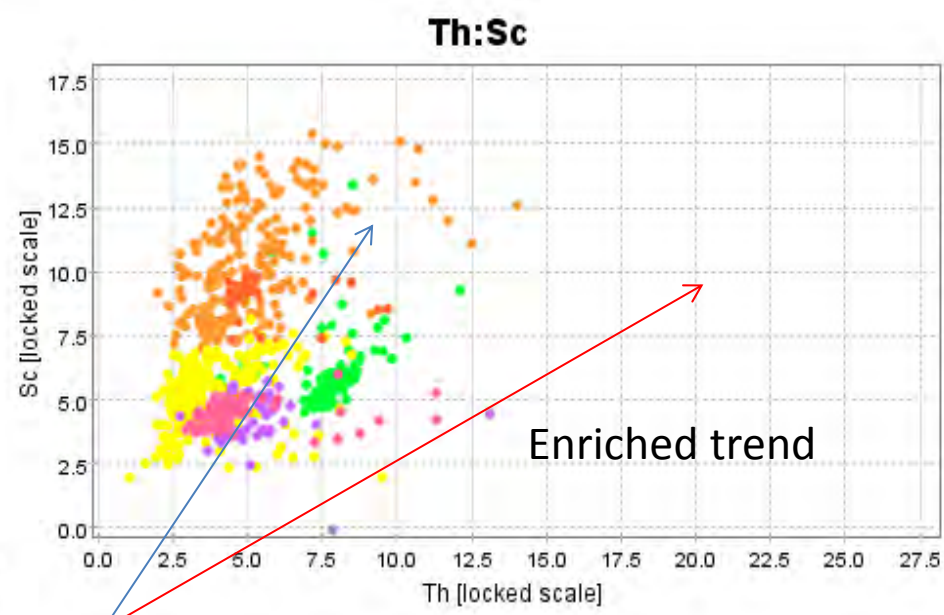
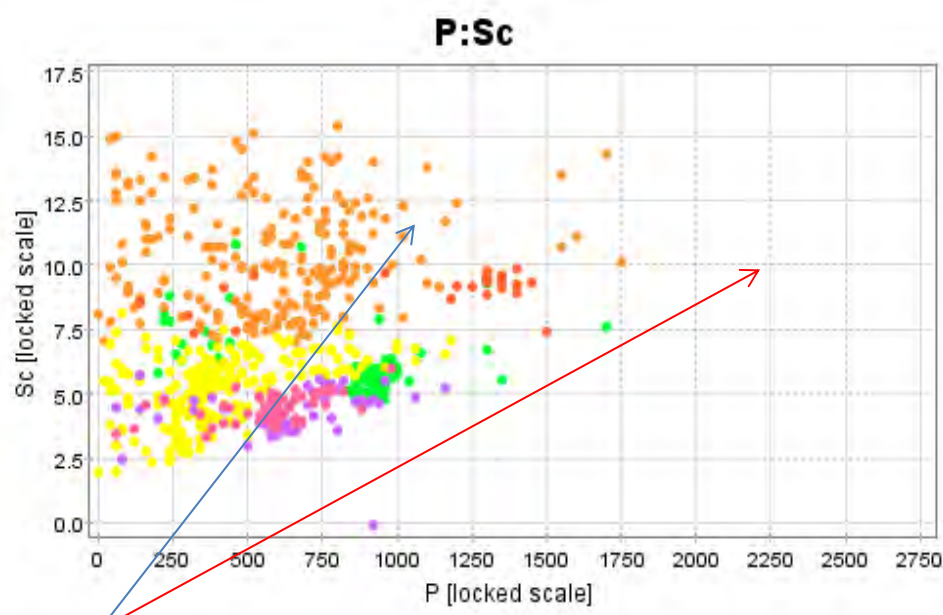


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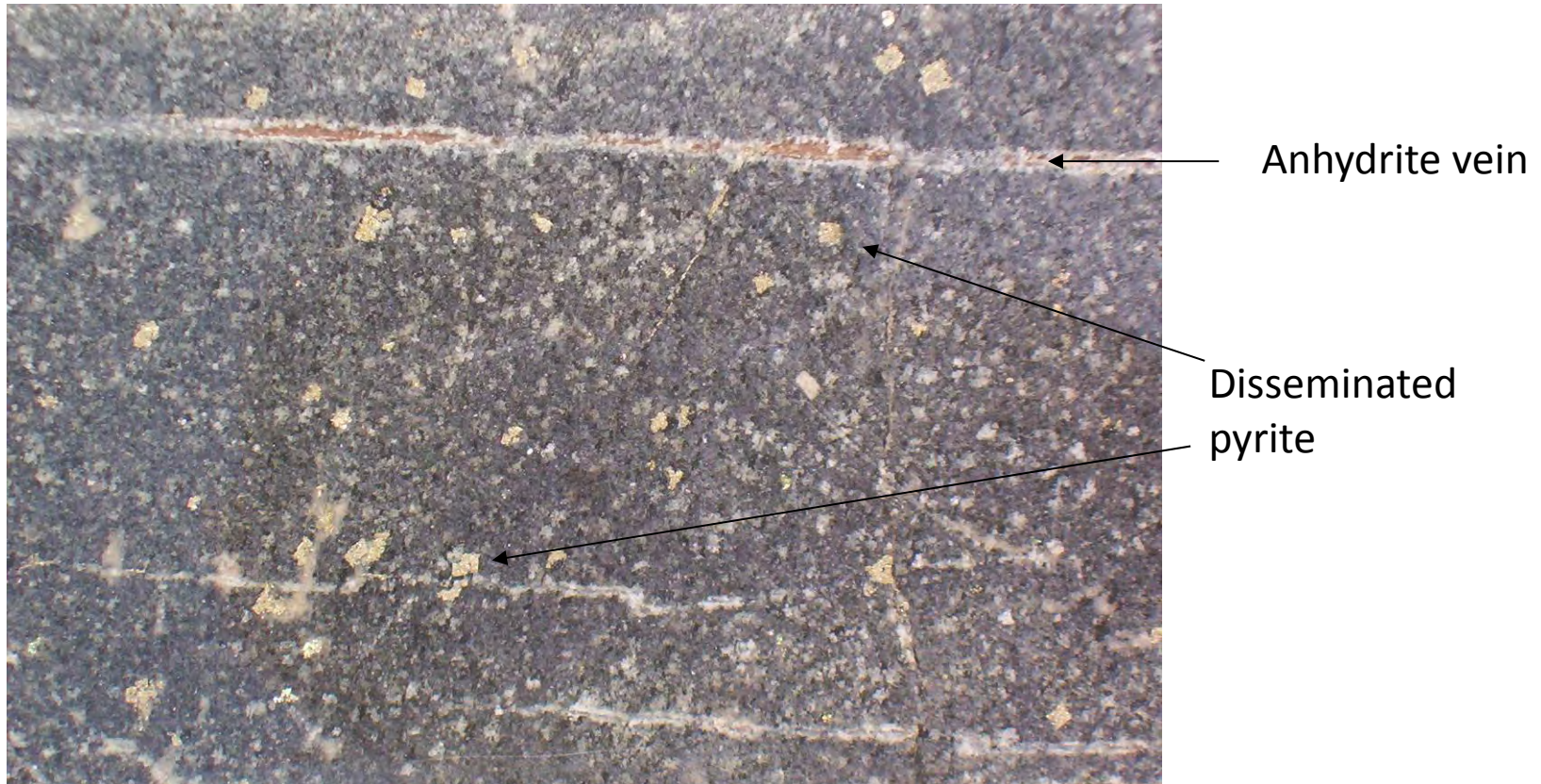








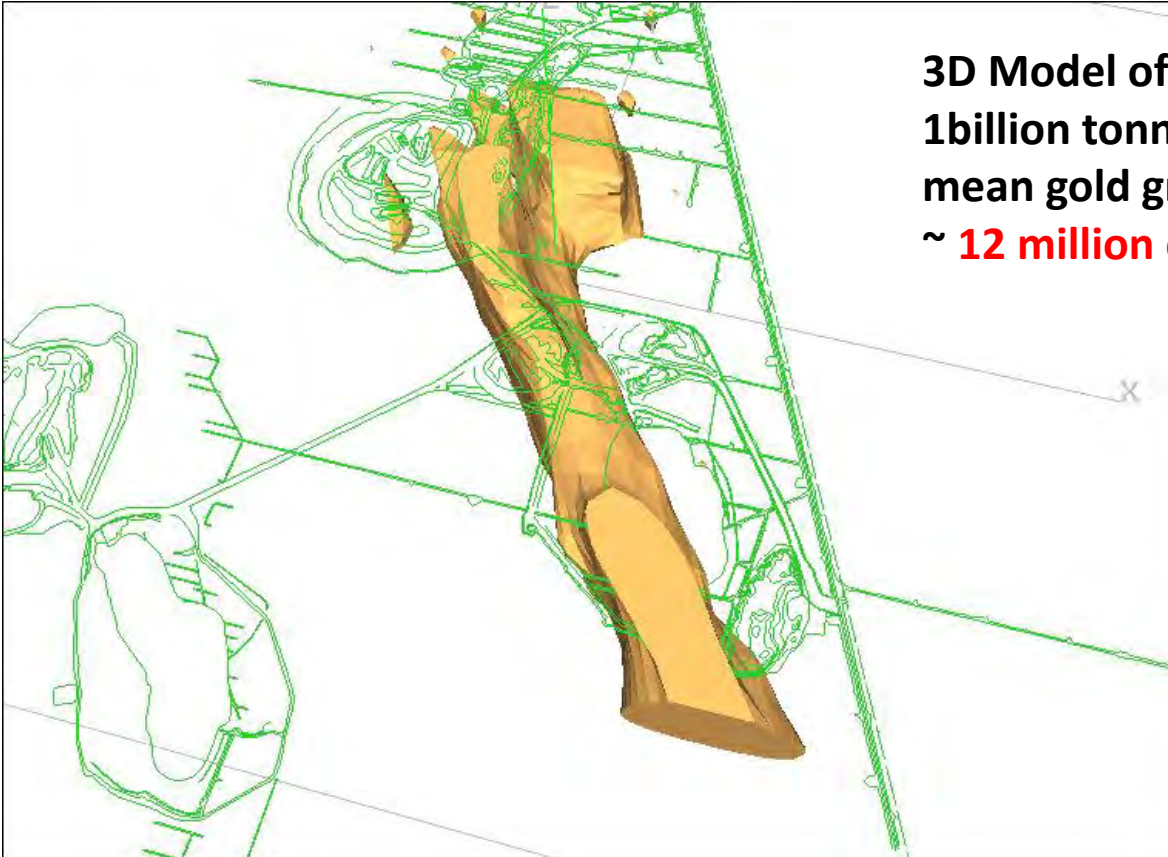
KD3011 607m, 1.23g/t



Significant Au and pyrite content in porphyries that are not notably altered;  
=> Fluid is in equilibrium with the porphyry.

**Some of the St Ives porphyries are inherently enriched in Au and S**



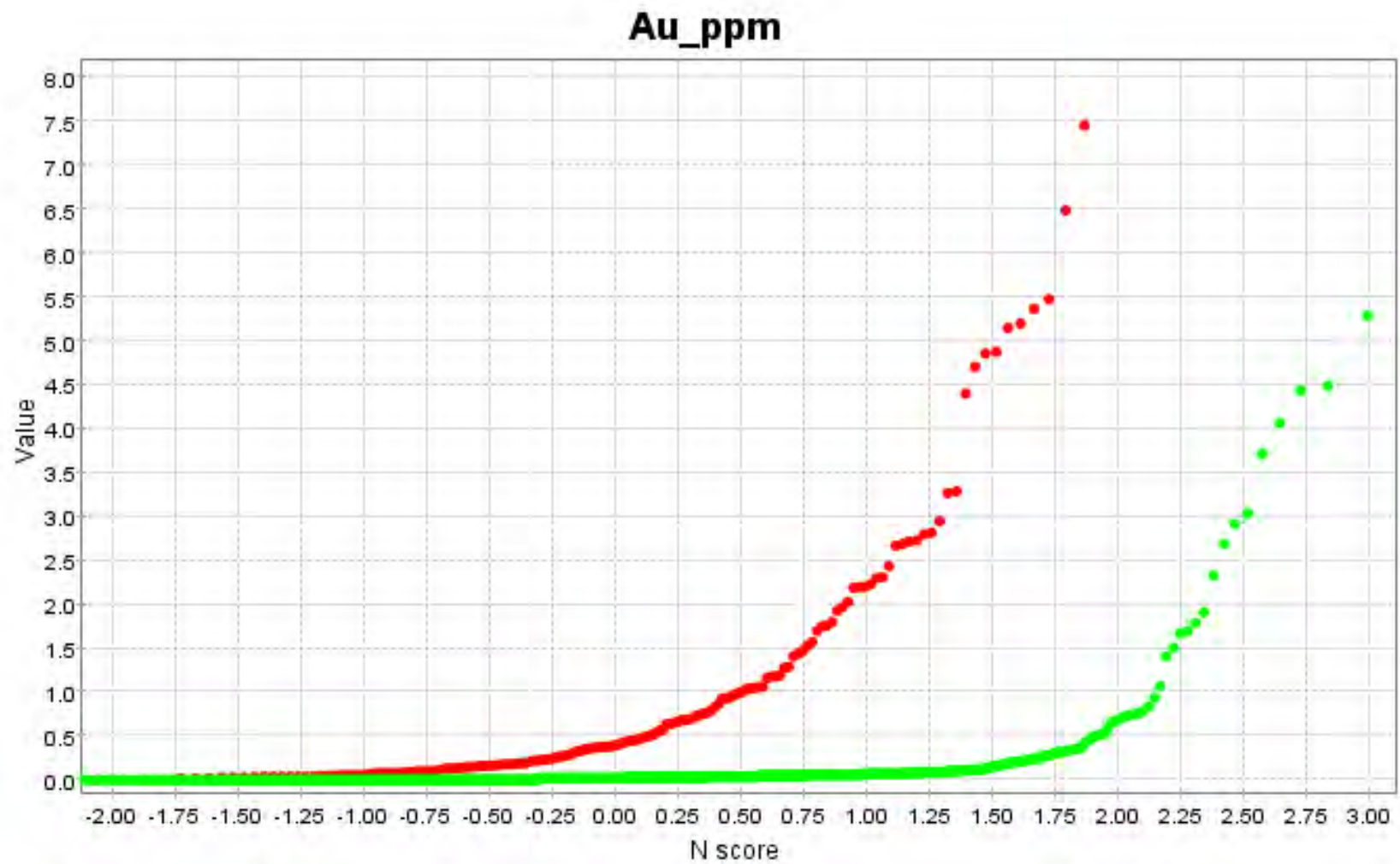


**3D Model of the Beta Porphyry**  
**1billion tonnes**  
**mean gold grade = 0.37g/t**  
**~ 12 million ounces**

**Footwall porphyries commonly have 100mt to 1,000mt of porphyry @ 0.05 to 0.5 g/t Au, e.g. Victory, Revenge, New Celebration, Binduli, Mt Pleasant, Kundana, Granny Smith, Lancefield, Mt Morgans, Agnew, etc**

**All gold-rich porphyries have the same enriched trace element signature!!!**

Compare Beta Porphyry + Santa Anna T with all mafics.





## FI 7, Beta Porphyry





## Santa Anna Trondjhemite



## OROGENIC GOLD Fluid Sources

- Late basins hold water and black shale. Methane is generated during gold deposit formation
- This reduced fluid is convected into the orogenic gold system during gold deposit formation
- The mixing of these two fluids causes precipitation of gold from thio-sulphate complexes by reduction of sulphate to sulphide
- Locally this fluid mixing precipitates hydrothermal carbon by the reaction



## OROGENIC GOLD Fluid Sources

- Arabian Nubian Shield is host to late fractionated acid intrusive rocks that stitch along crustal sutures
- Sukari (14mozs) is hosted by a highly fractionated intrusive rock
- Zara (1mozs) is hosted by a fractionated intrusive rock
- Host rock at Sukari contains black shales
- Late sedimentary basins near Sukari occur in the footwall of the suture fault. This basin was far more extensive than the currently preserved remnants

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## OROGENIC GOLD Fluid Pathways and Drivers

- The architecture of the system above the mantle tapping fault promotes fluid mixing
- The architecture involves antiforms existing beneath seals (usually regressive sedimentary sequences or sometimes thrusts)
- Gold deposits occur in areas of intersecting faults that were active during sedimentation of the host sequence and act as valves (not pumps)
- These faults access reservoirs of fluids with different redox potential
- Intersecting faults beneath a seal define an ore system

# St Ives Goldfield

## Keys to size and grade??

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- Fluid mixing
- An architecture promotes fluid mixing

# “Observe” redox gradient in mineral zonations

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- Oxidized
  - Hematite
  - Magnetite\*
  - Pyrite
  - Arsenopyrite
  - Pyrrhotite\*
  - Loellingite

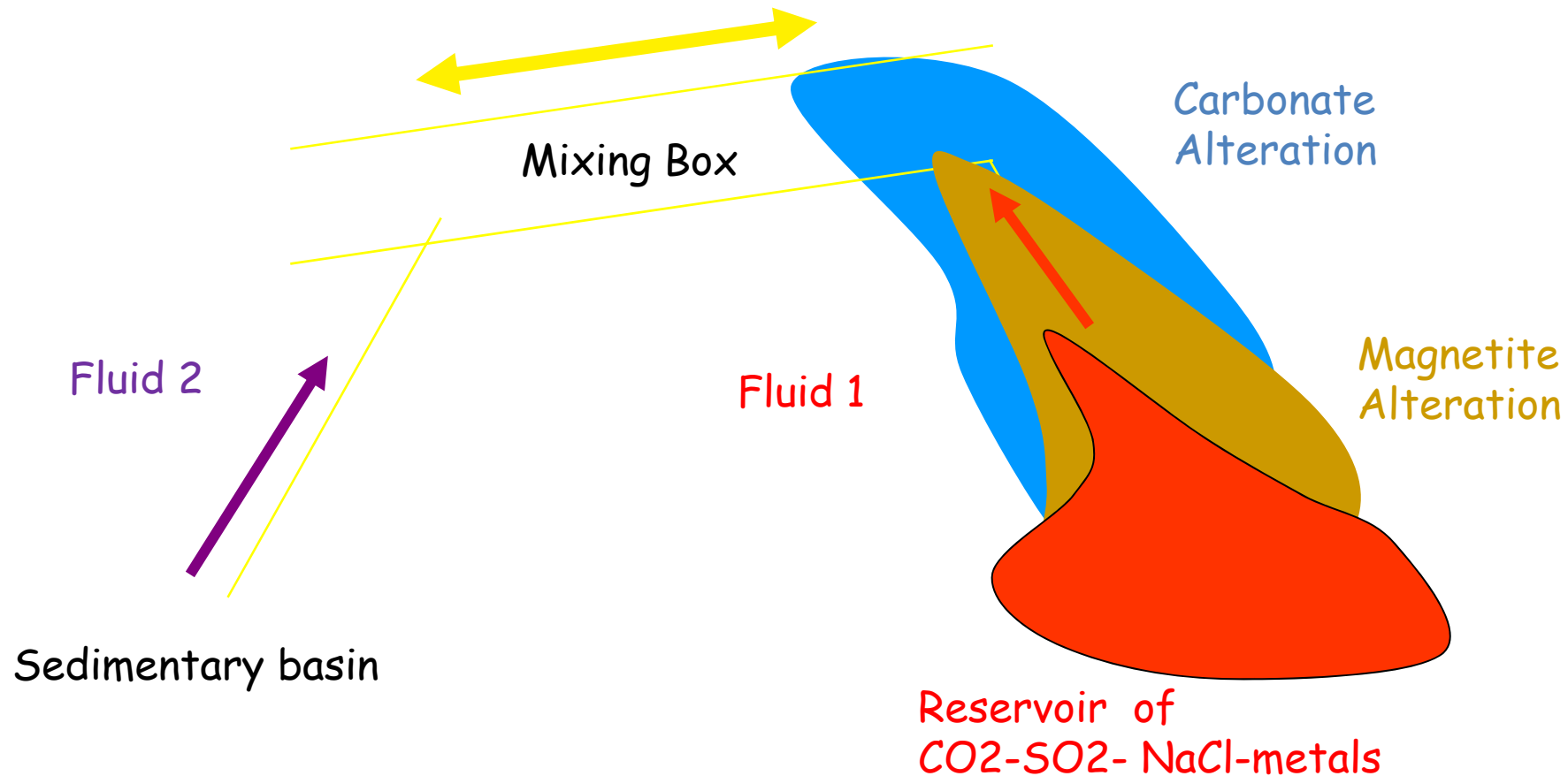
- Reduced

\* Magnetic minerals detected in aeromagnetic surveys



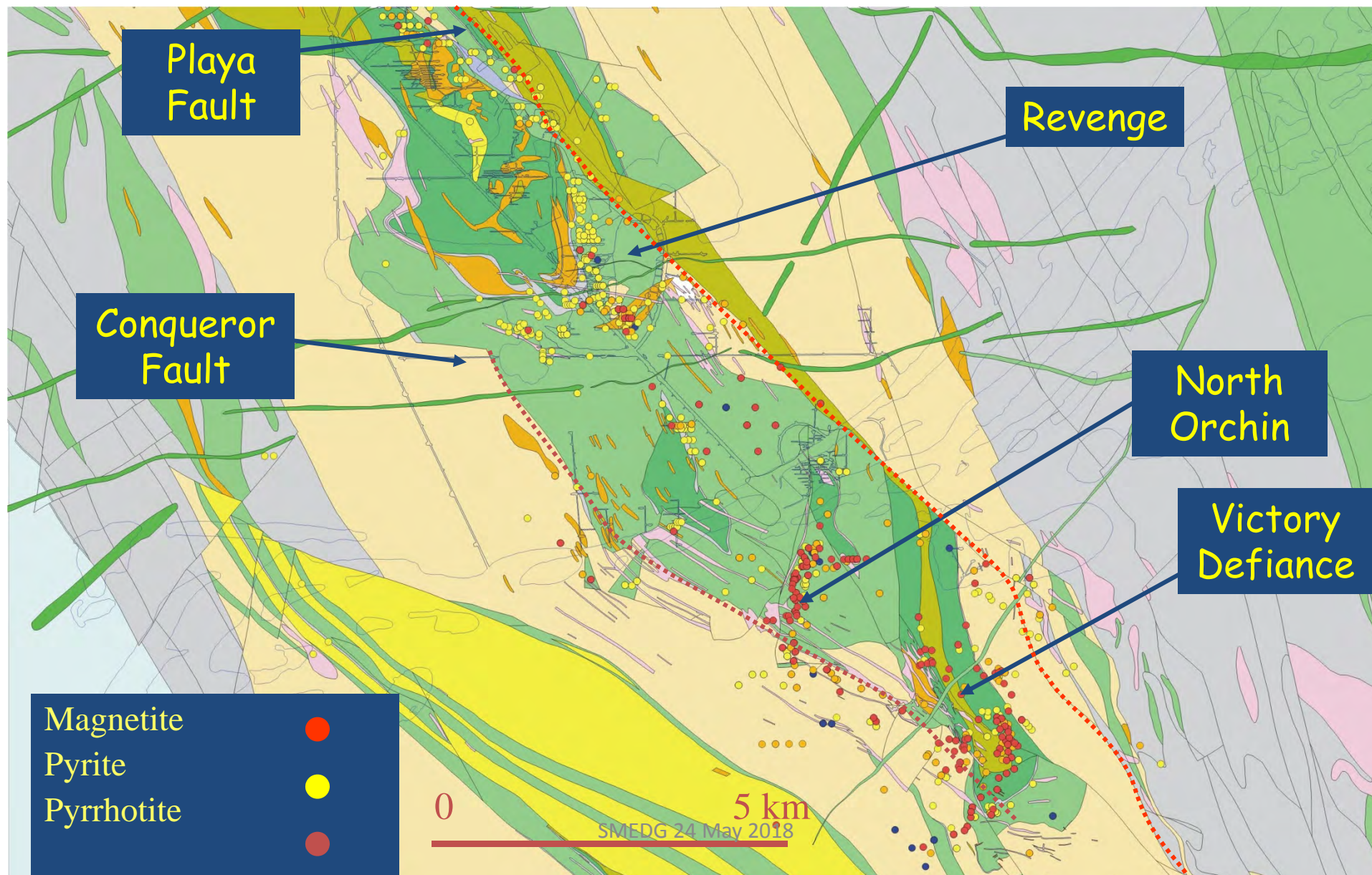
# Commonly two fluids to think about!!

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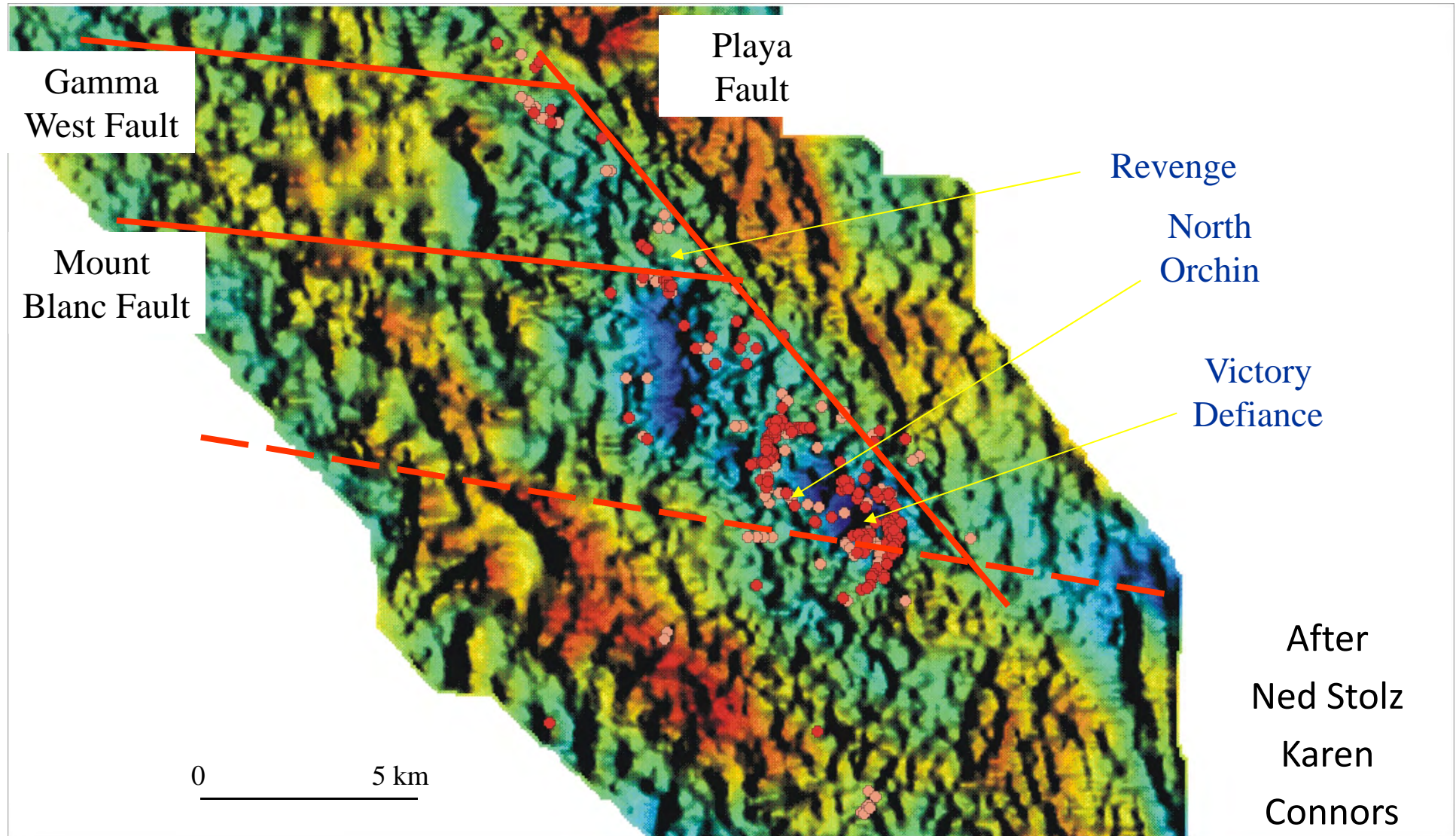
“Observe” the magma chamber in the geophysical image

# St Ives : Alteration in sediments





# Gravity image of the Victory- Defiance Revenge Districts

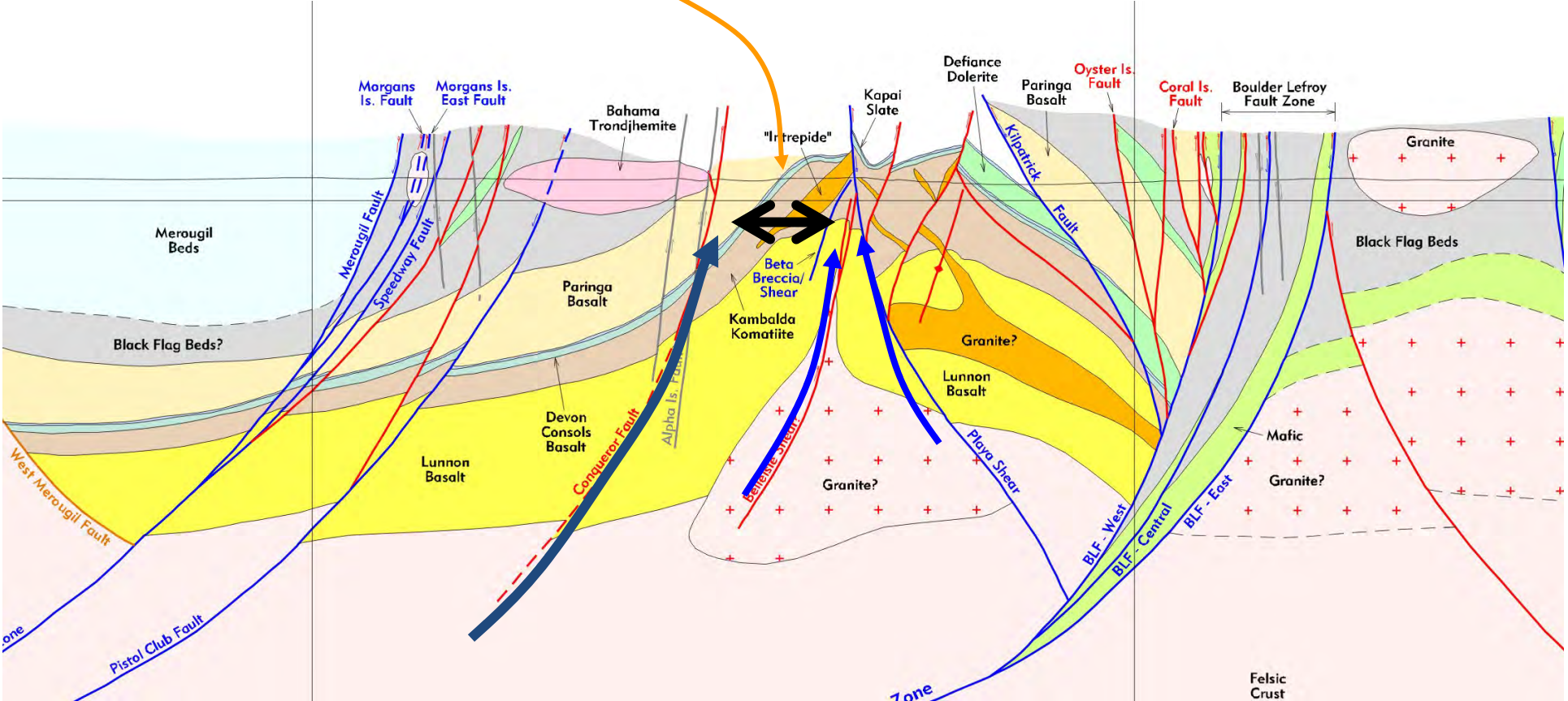


Red – magnetite

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Pink – magnetite/pyrite

# Mixing Box



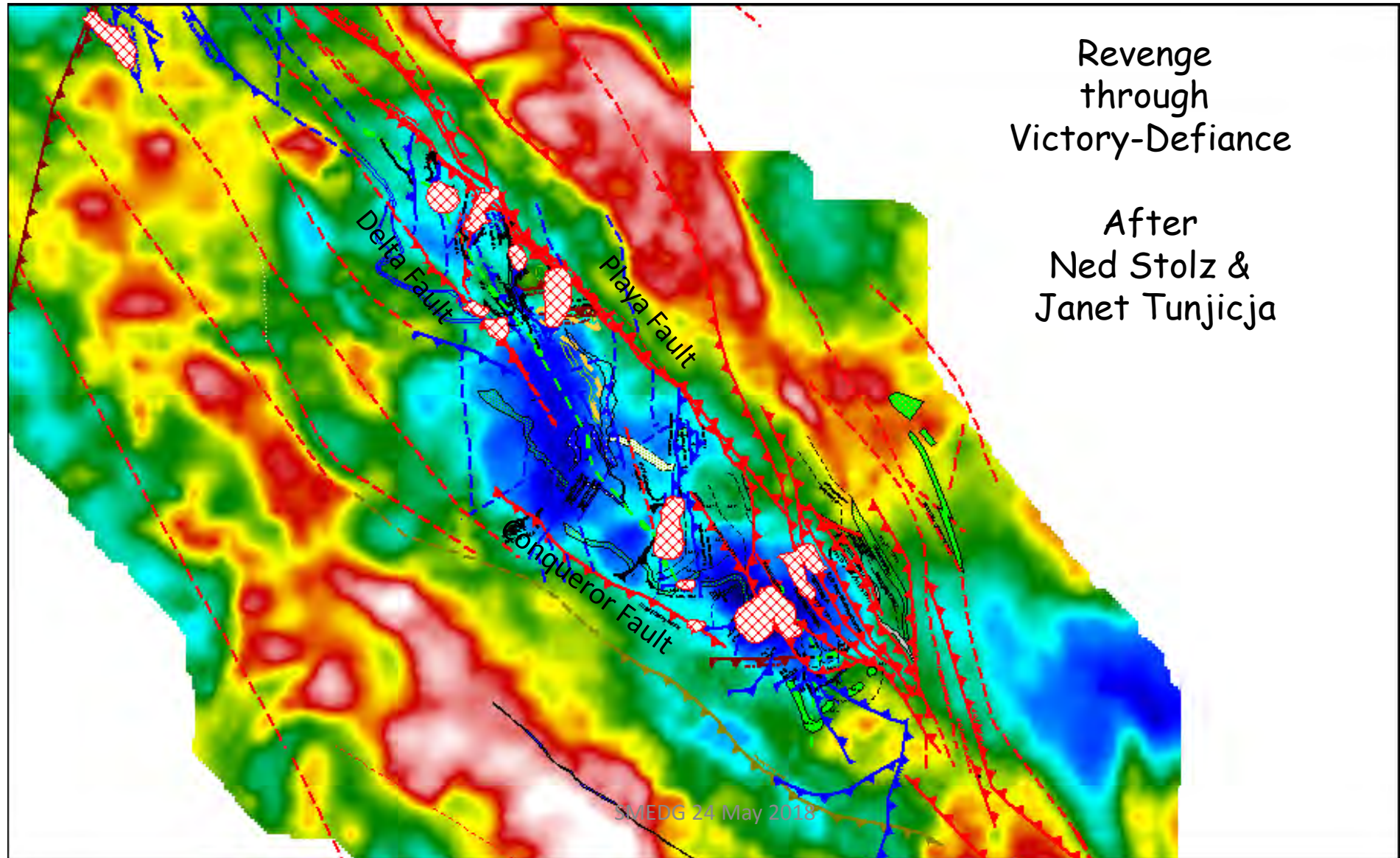
# Section through Intrepide

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# Karen Connors, 2002



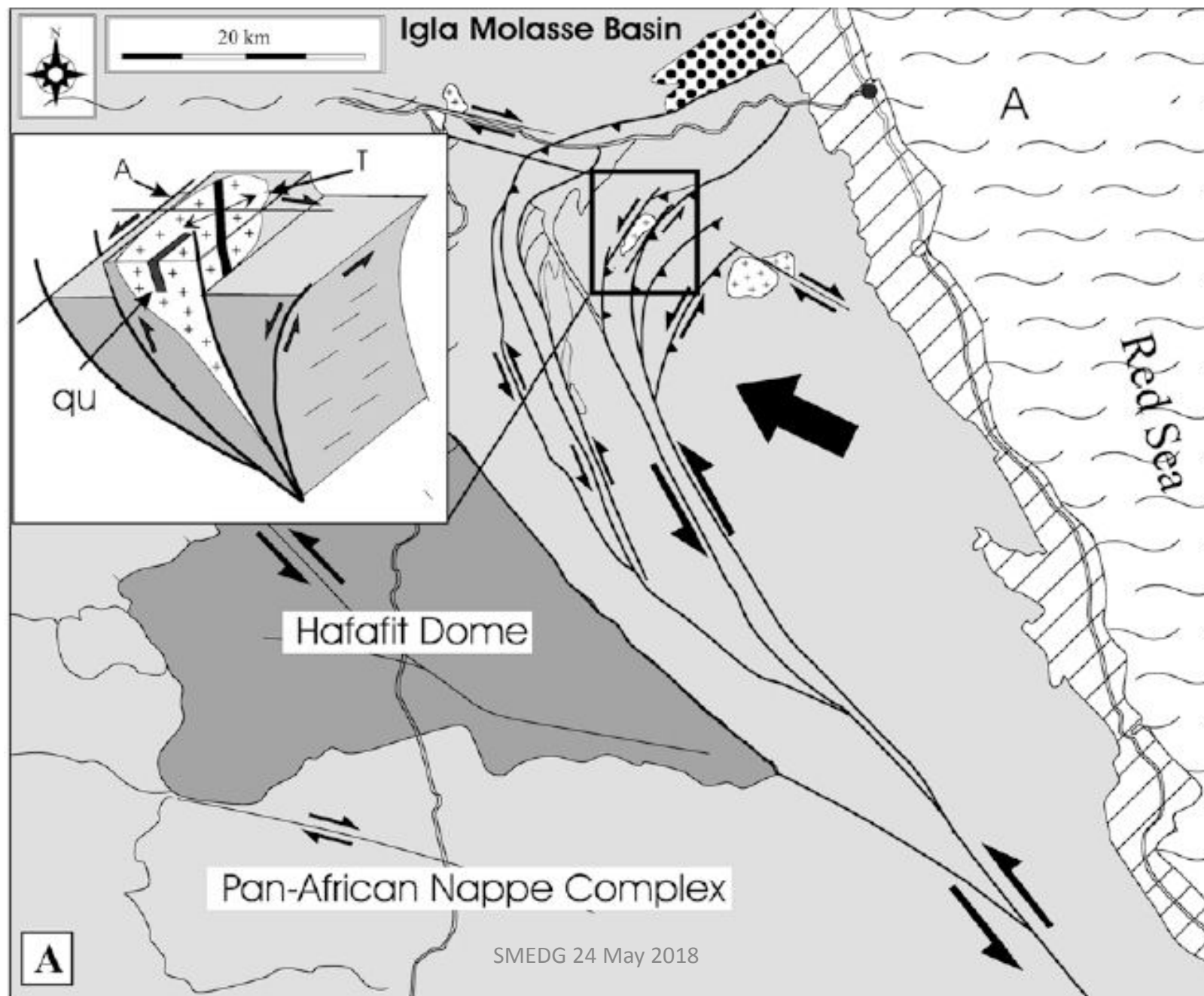
# Interplay of fluids-architecture



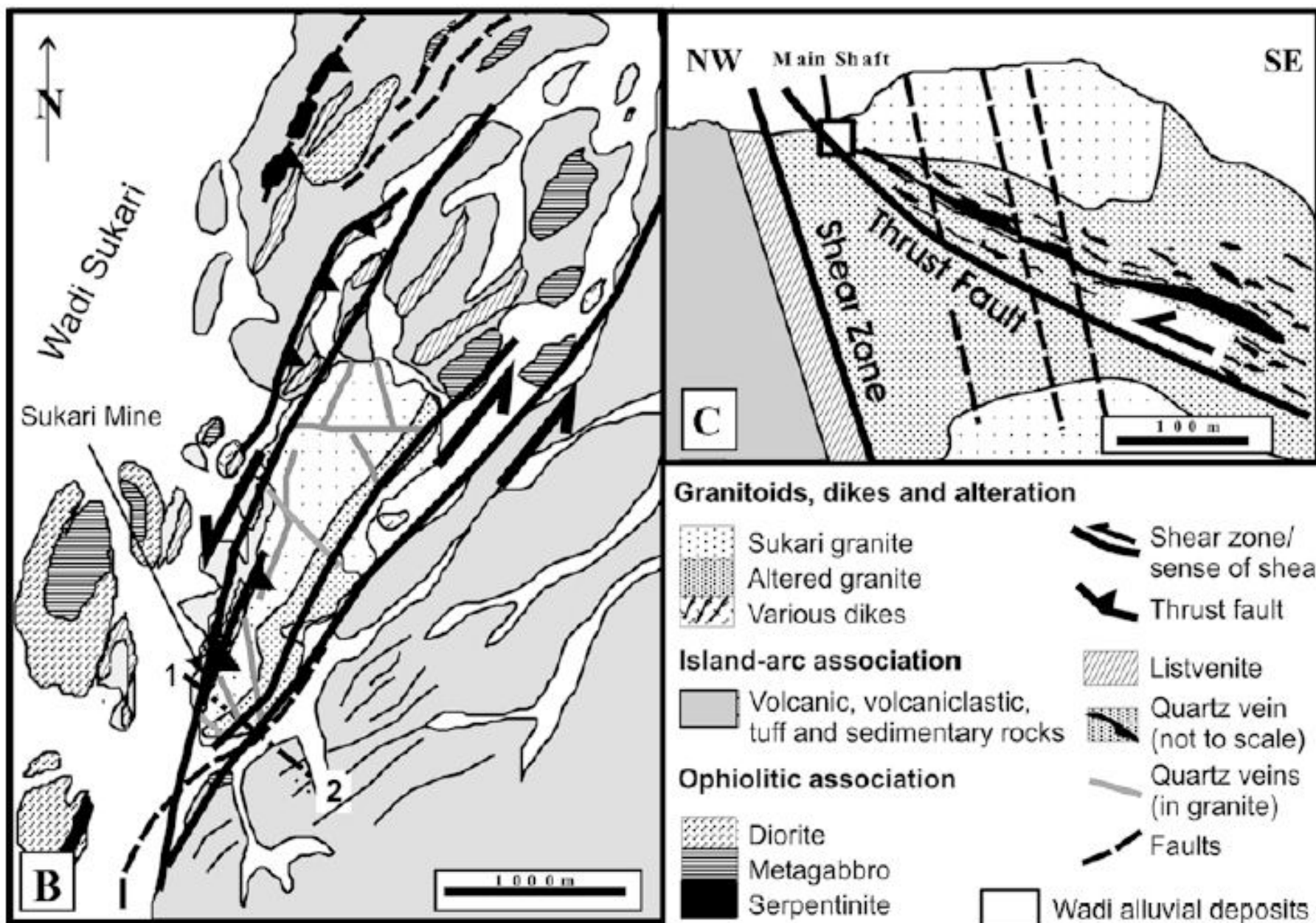
## OROGENIC GOLD Fluid Pathways and Drivers

- Arabian Nubian Shield hosts numerous inversion structures
- The molasse basin near Sukari is preserved in the footwall of a major fault. The preservation of the highest part of the sedimentary stratigraphy in the footwall of a major fault is a classic indicator of basin inversion.
- Sukari porphyry is hosted in a postive flower structure at a bend in the major suture
- Uplift and erosion of the hangingwall of the porphyry complex during magma emplacement will promote rapid fluid release in deep magma chambers that are exsolving these fluids

# OROGENIC GOLD Fluid Pathways and Drivers



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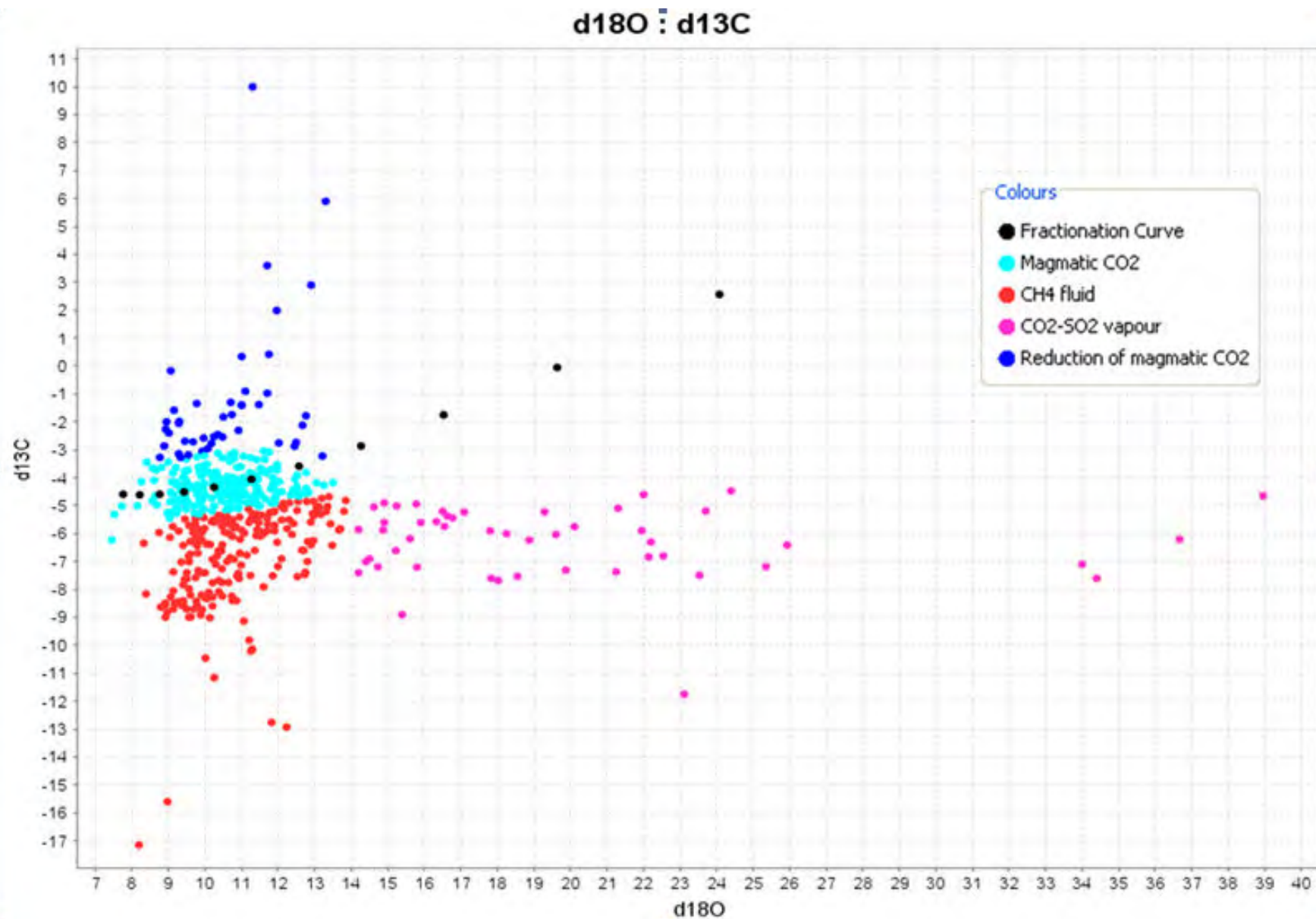
**DEPOSITION MECHANISMS**

## OROGENIC GOLD Deposition Mechanisms

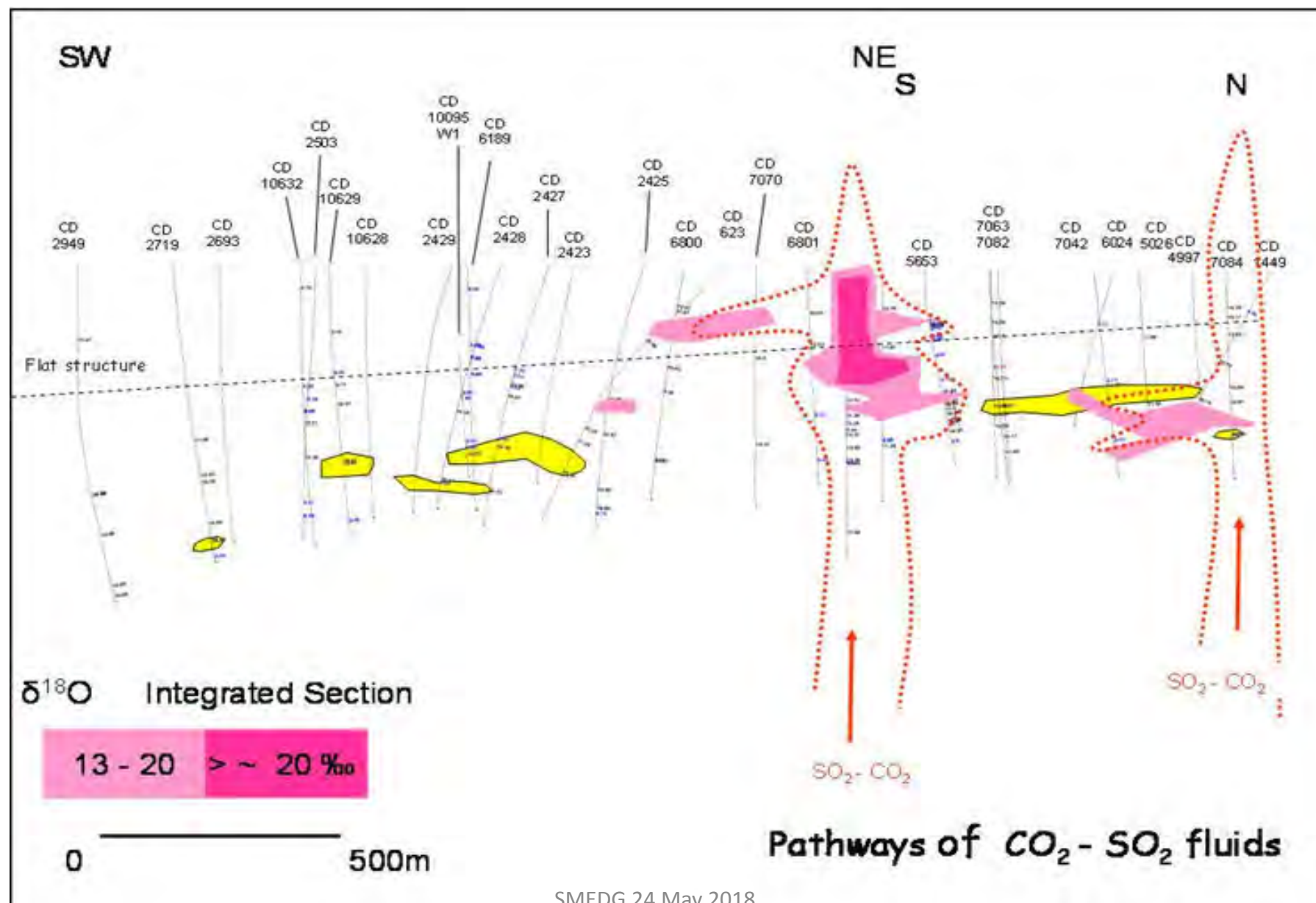
- The architecture is host to a reduced host rock equilibrated fluid preserved beneath a seal
- The arrival of oxidised magmatic fluid into the reduced host rock fluid causes precipitation of gold from thio-sulphate complexes by reduction of sulphate to sulphide
- Locally this fluid mixing produces hydrothermal precipitated carbon by the reaction



# OROGENIC GOLD Deposition Mechanisms

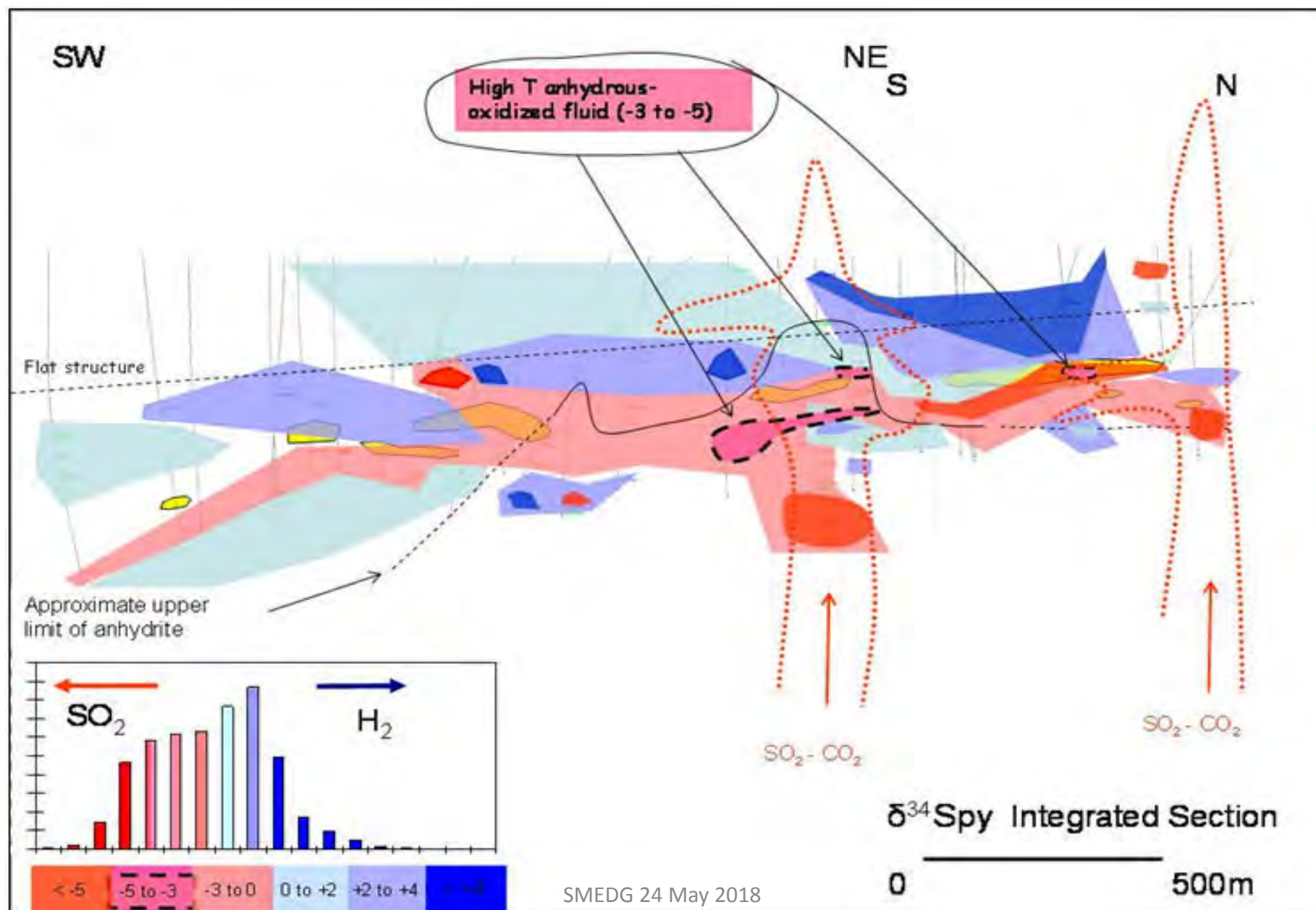


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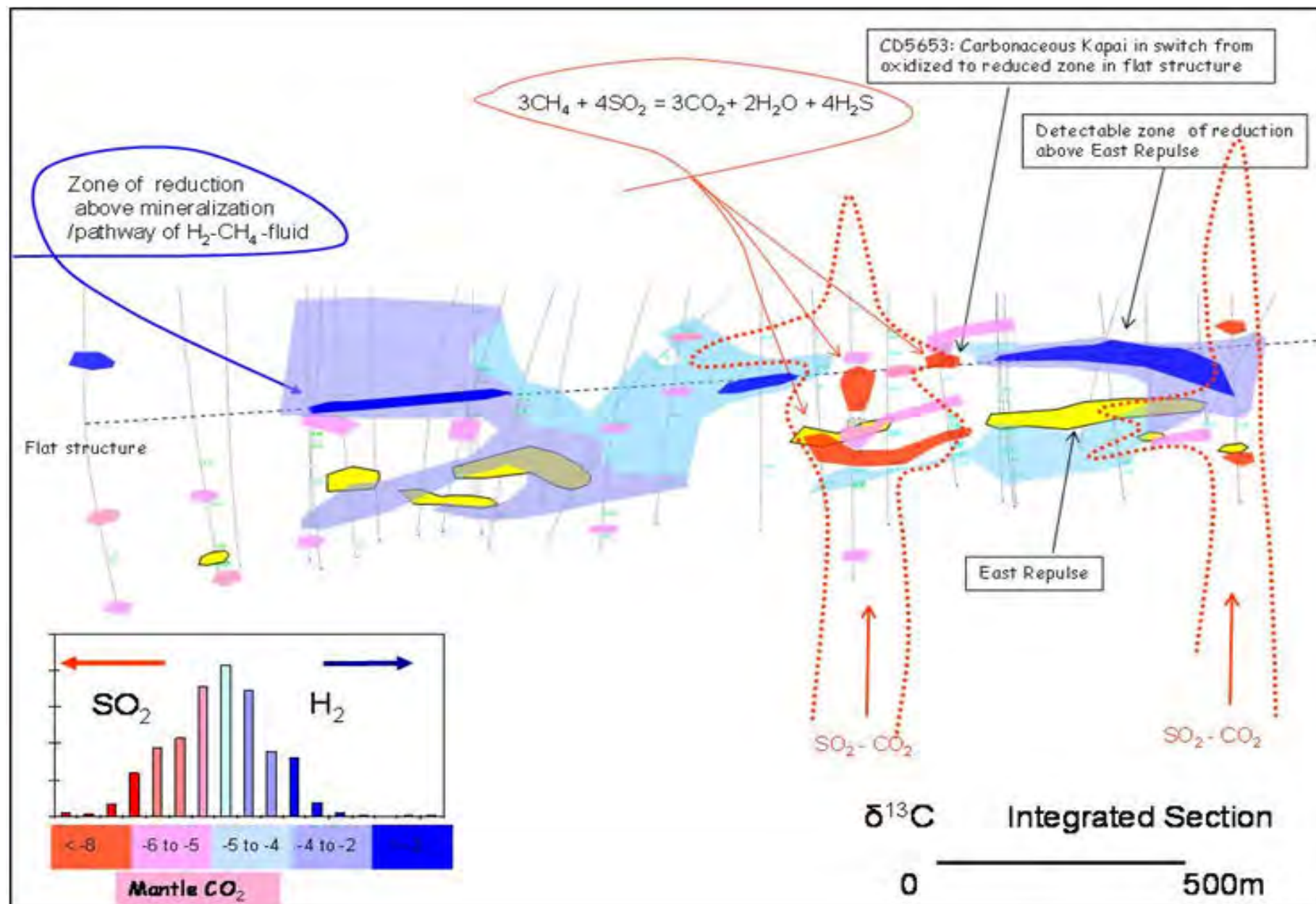


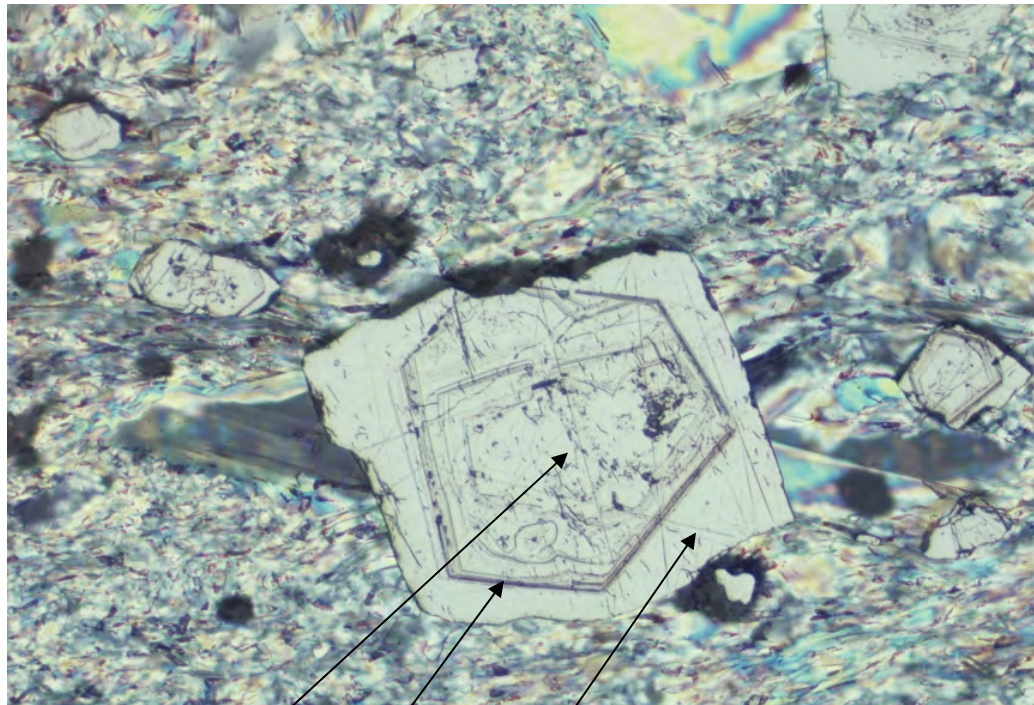


# OROGENIC GOLD Deposition Mechanisms



# OROGENIC GOLD Deposition Mechanisms





"Dirty" pyrite core

As-rich mid zone

"Clean" pyrite rim

All Pyrite grains at KB are zoned;  
In the ore zone,  $\delta^{34}\text{S}$  values in pyrite cores are negative (oxidised fluid),  
Distal to ore,  $\delta^{34}\text{S}$  values in pyrite cores are strongly positive,  
 $\delta^{34}\text{S}$  values in all clean rims are  $\sim +2$  per mil  
Pyrite growth at KB records a history of reduced fluids overprinting an oxidised fluid system.

**Spatial and temporal evolution from oxidised and alkaline to acid and reduced!!**

## OROGENIC GOLD Deposition Mechanisms

- Arabian Nubian Shield is host to major gold deposits. The gold deposits in the southern ANS (Tula Kapi, Zara) are free-milling. A giant gold deposit of the northern ANS (Sukari) requires fine grinding to 10 micron to liberate the gold
- Sukari shows at least two magma pulses and a alteration evolution from early biotite magnetite, through hematite to late albite-sericite-pyrite
- Sukari shows anhydrite at depth
- Sukari shows hydrothermal carbon in the footwall to high grade gold zones



# OROGENIC GOLD Deposition Mechanisms





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