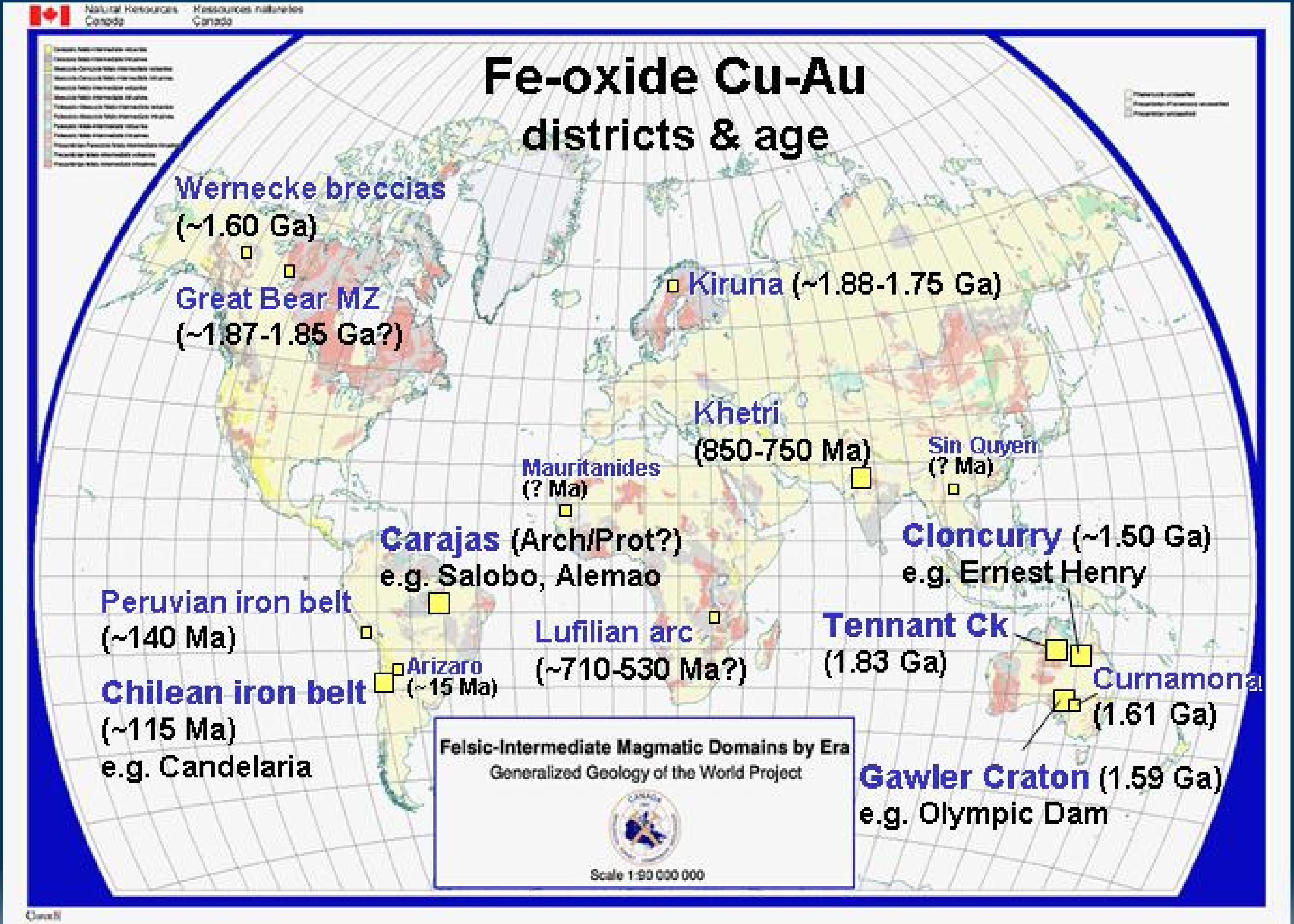
Australian Government

Geoscience Australia

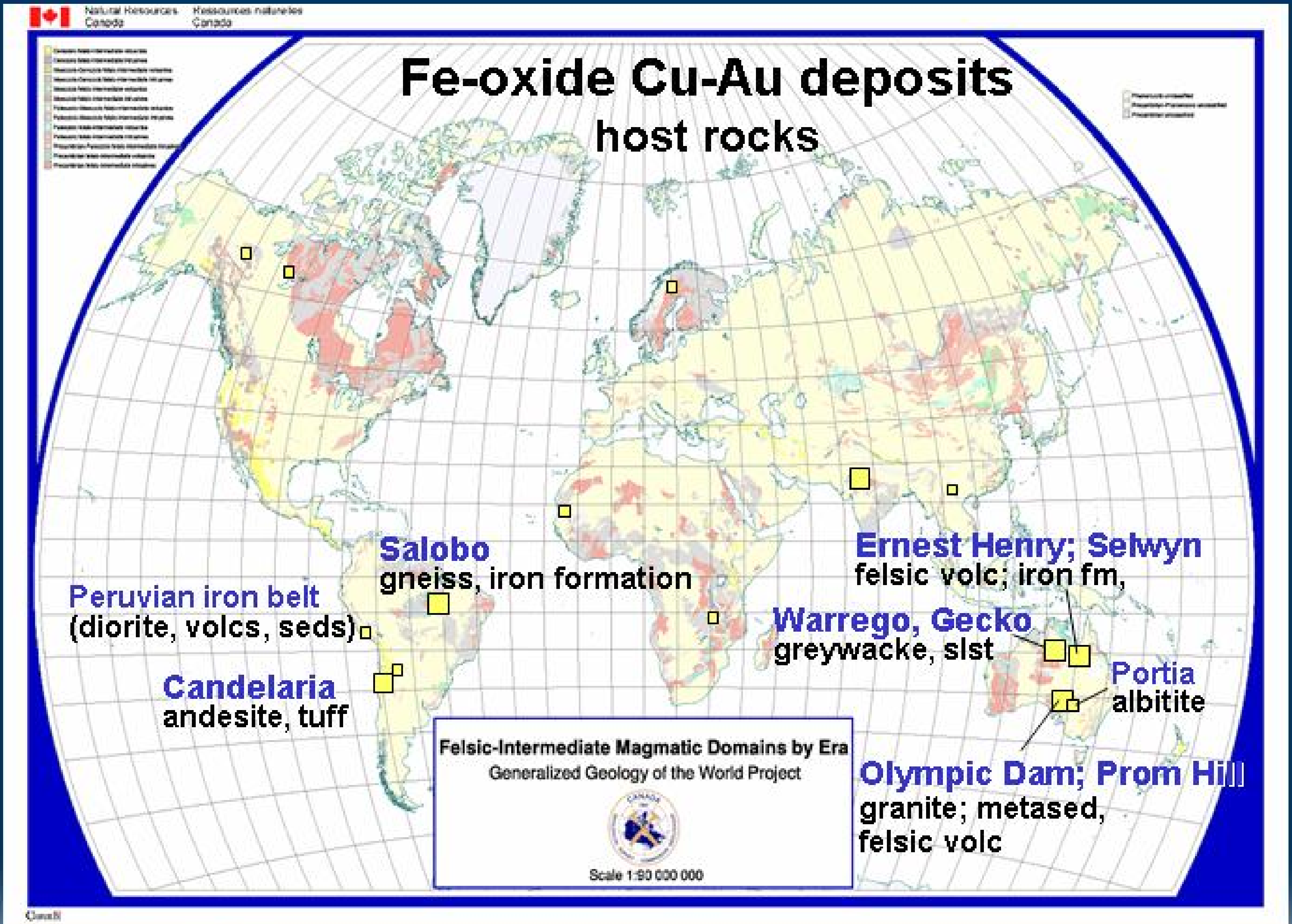
Iron Oxide Cu-Au deposits: An Australian perspective on their unifying characteristics

Roger Skirrow

Geoscience Australia



Natural Resources Canada
Ressources naturelles Canada
Fe-oxide Cu-Au
districts & age
Wernecke breccias
(~1.60 Ga)
Great Bear MZ
(~1.87-1.85 Ga?)
Kiruna (~1.88-1.75 Ga)
Khetri
(850-750 Ma)
Sin Quyen
(? Ma)
Mauritanides
(? Ma)
Carajas (Arch/Prot?)
e.g. Salobo, Alemao
Cloncurry (~1.50 Ga)
e.g. Ernest Henry
Peruvian iron belt
(~140 Ma)
Lufilian arc
(~710-530 Ma?)
Tennant Ck
(1.83 Ga)
Arizaro
(~15 Ma)
Chilean iron belt
(~115 Ma)
e.g. Candelaria
Curnamona
(1.61 Ga)
Felsic-Intermediate Magmatic Domains by Era
Generalized Geology of the World Project
Scale 1:80 000 000
Gawler Craton (1.59 Ga)
e.g. Olympic Dam



Natural Resources Canada
Ressources naturelles Canada
Fe-oxide Cu-Au deposits
host rocks
Salobo
gneiss, iron formation
Peruvian iron belt
(diorite, volcs, seds)
Candelaria
andesite, tuff
Ernest Henry; Selwyn
felsic volc; iron fm,
Warrego, Gecko
greywacke, slst
Portia
albitite
Olympic Dam; Prom Hill
granite; metased,
felsic volc
Felsic-Intermediate Magmatic Domains by Era
Generalized Geology of the World Project
Scale 1:90 000 000

IOCG deposits are diverse!

So, what unites them?

Deposit characteristics

- **Cu, Au, Ag, U, REE, CO_3, F, Ba, Mo, Bi, Co association**
- **Sulfides & Au spatially assoc with abundant (>10%) magnetite and/or hematite**
- **Potassic, sodic-potassic and/or hydrolytic local alteration**
- **Epigenetic: hydrothermal replacements, veins, breccias**

(Hitzman et al., 1992; Hitzman, 2000; Haynes, 2000)

Prominent Hill (Minotaur Resources website)

But what processes & regional characteristics are shared by IOCG districts?

An Australian perspective -

Constant 1. Cu-Au during *later tectonothermal* events, coeval with felsic-mafic magmatism.

Constant 2. Chemically *diverse host sequences* incl. early Fe; regional Na-Ca, and/or Fe-ox alteration.

Constant 3. Crustal-scale *fault network*; re-activated orogens.

Constant 4. *Two distinct fluids:* magnetite- & hematite-stable.

West Peko Cu-Au-Bi, Tennant Creek

Why are IOCG deposits so diverse?

An Australian perspective (cont.) -

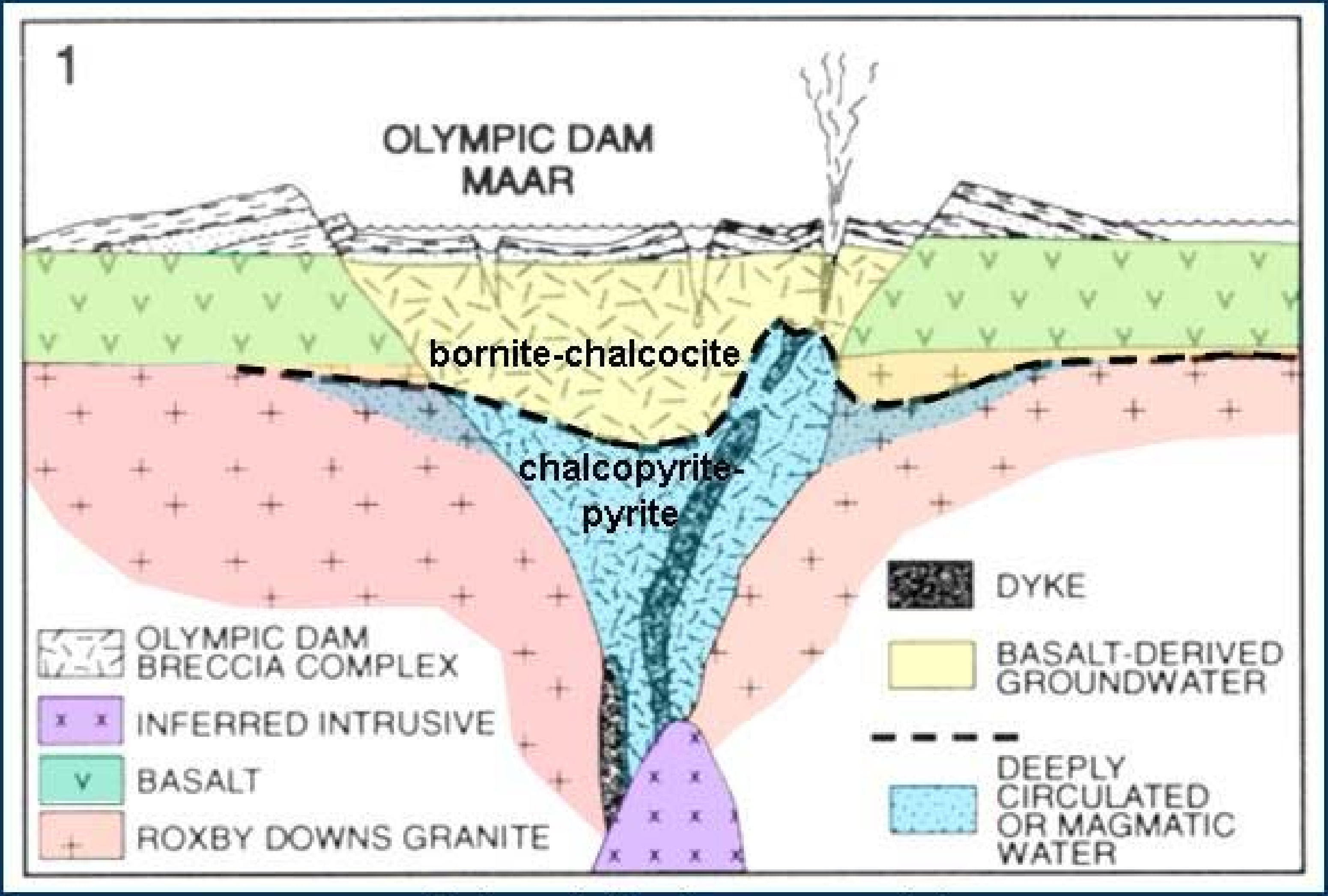
Variables: **Host composition, depth, fluid-fluid-rock interplay**

Constants + Variables → **Spectrum from reduced to oxidised deposits**

Constants + Variables → **Range from low-T brittle to high-T ductile styles**

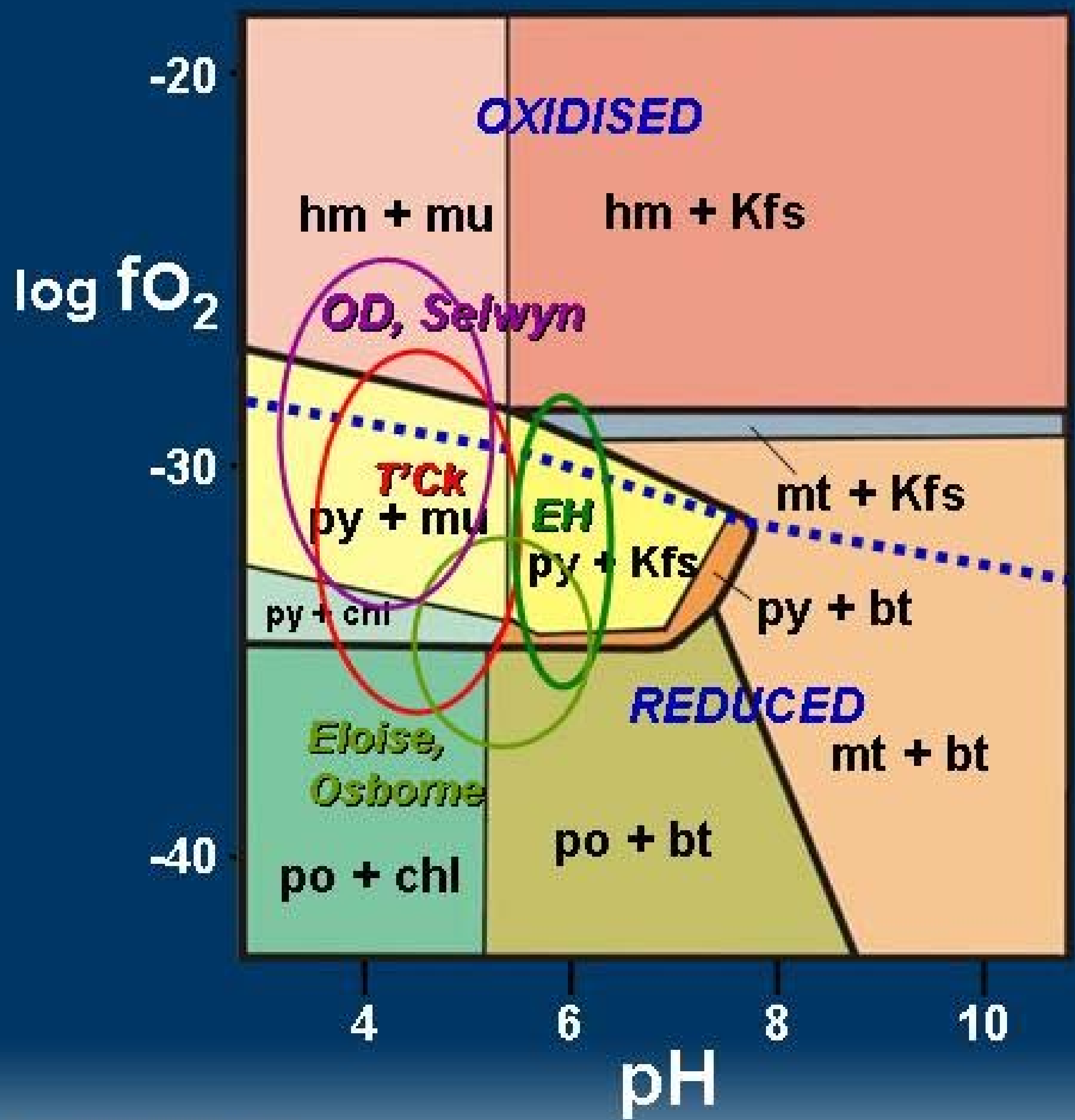
Ernest Henry Cu-Au: shear- & breccia-hosted, magnetite-cpy-rich

Olympic Dam: breccia-hosted, shallow, hematitic



Haynes et al. (1995) fluid mixing model

Australian IOCG: Summary of mineralogical diversity



Tennant Creek

Cloncurry

Olympic Dam

300°C, 1.5 kb

$m_{total\ sulfur} = 0.003$

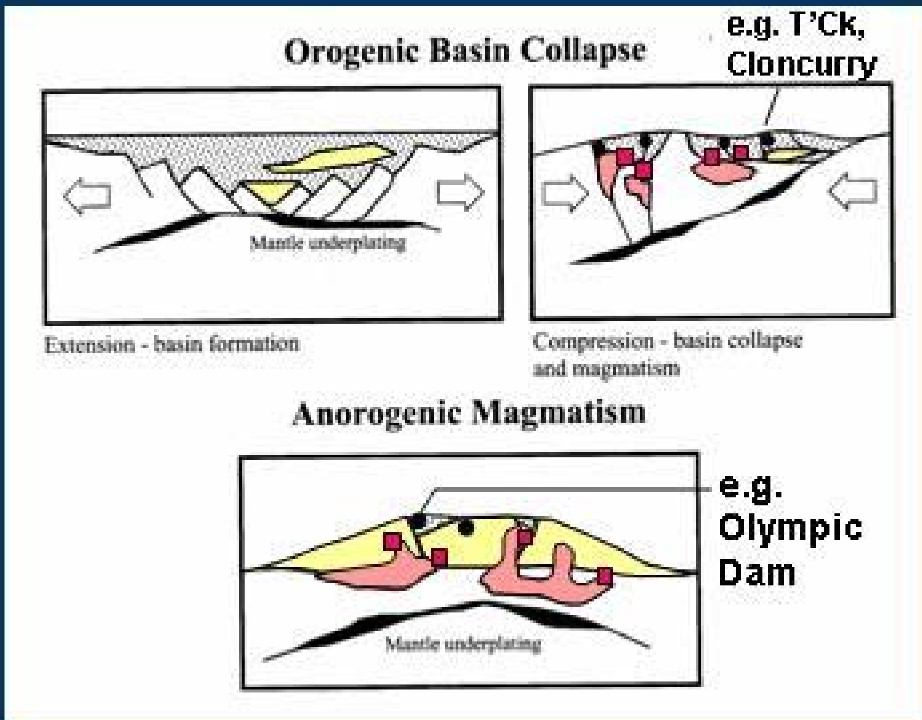
$a_{K+} = 0.1$

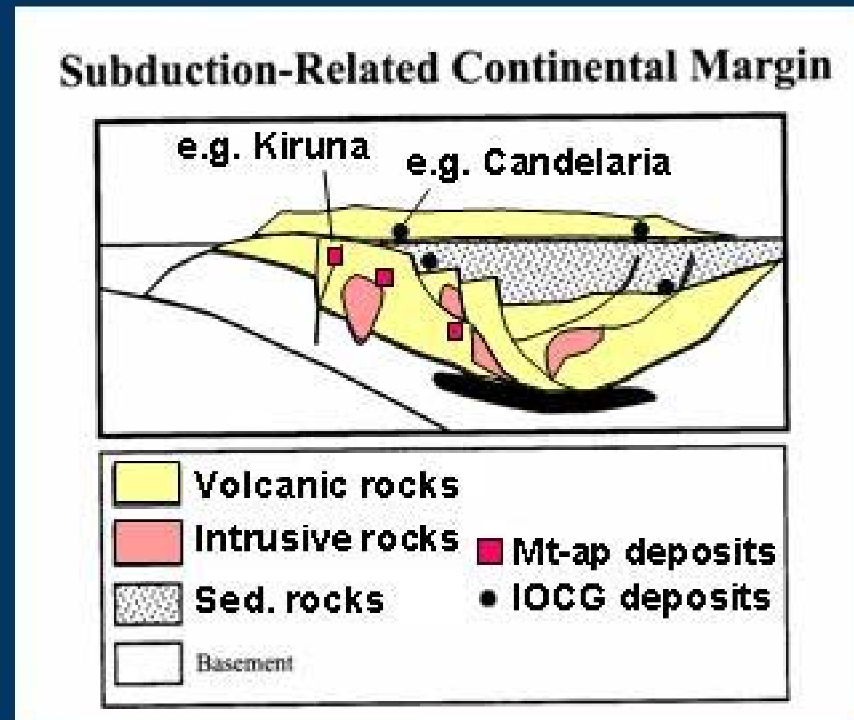
Unifying Characteristics of IOCG

Constant 1. Cu-Au during *later tectonothermal* events, coeval with felsic-mafic magmatism

IOCG tectonic settings

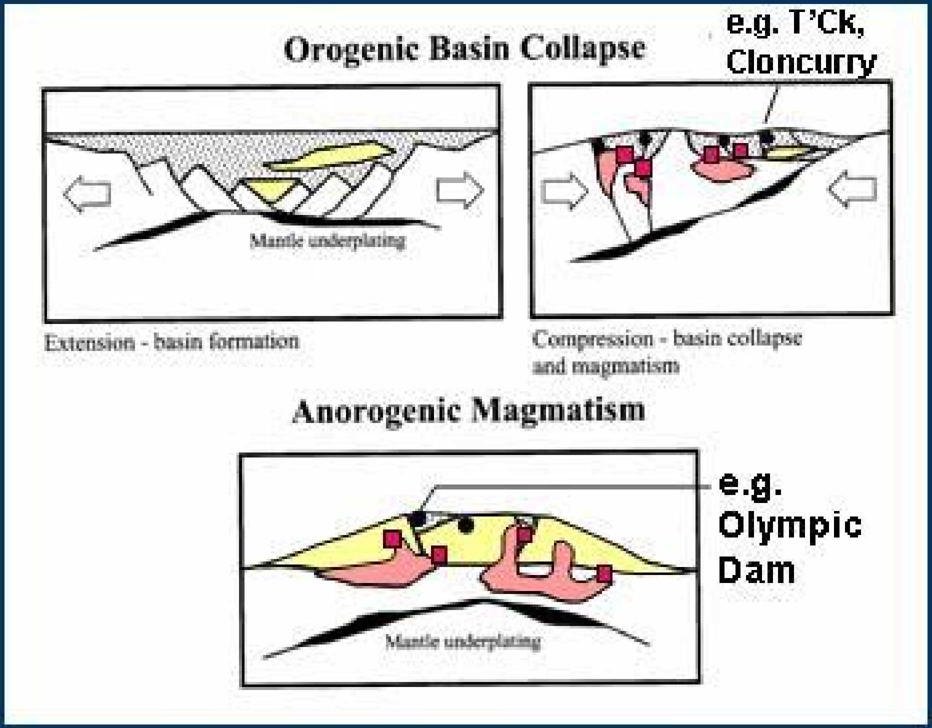
(Hitzman, 2000)

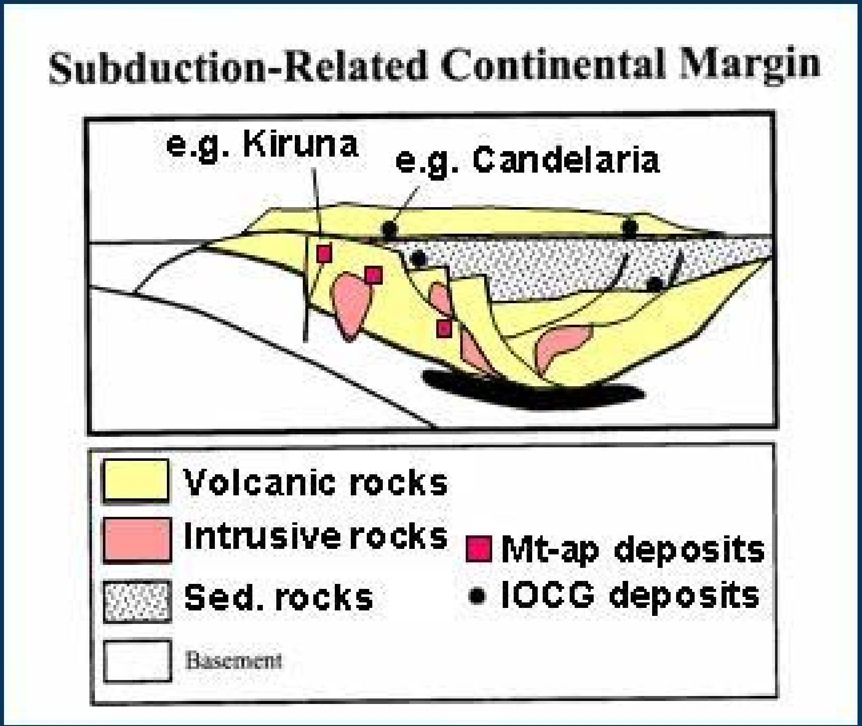


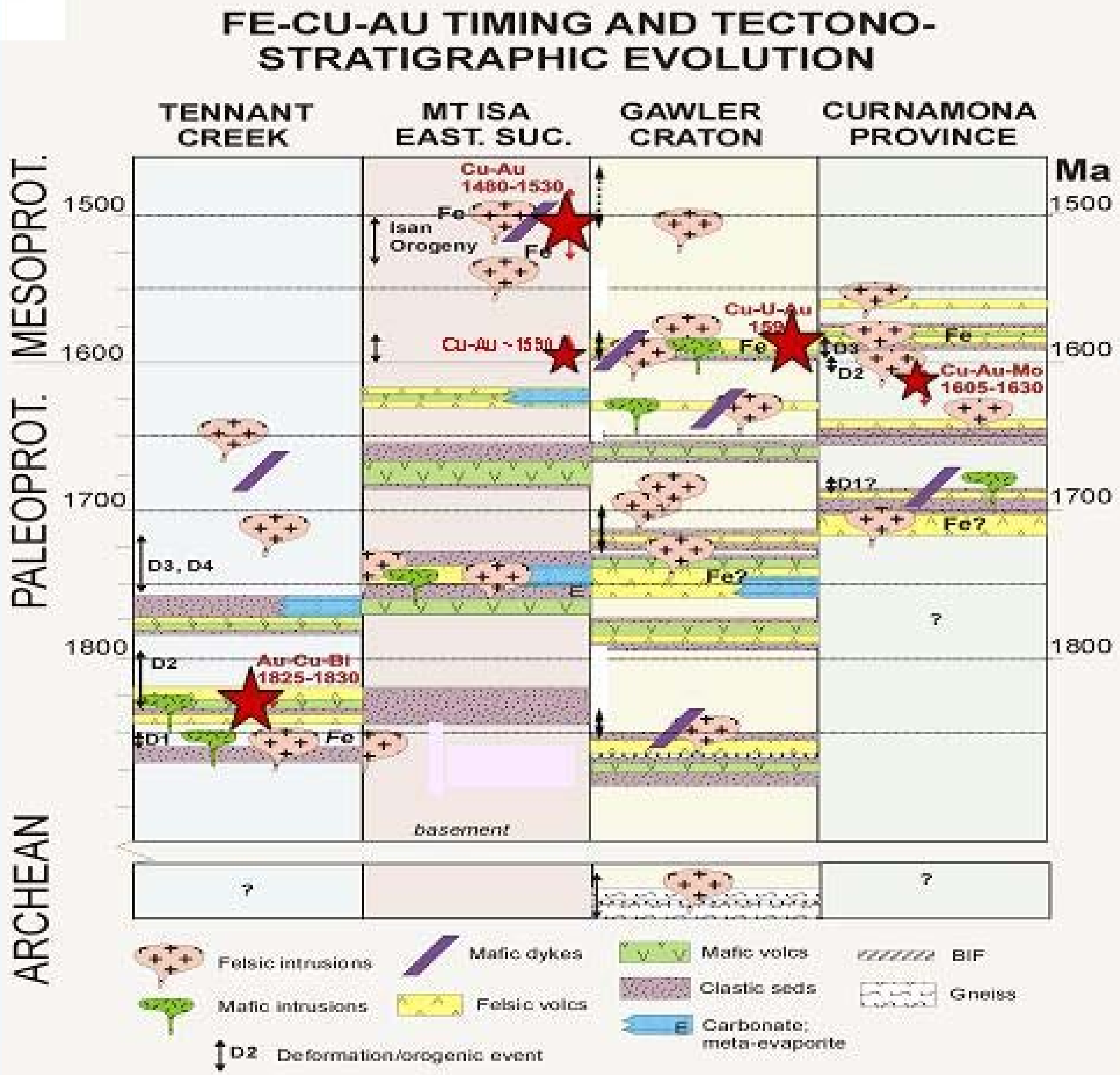


IOCG tectonic settings

(Hitzman, 2000)



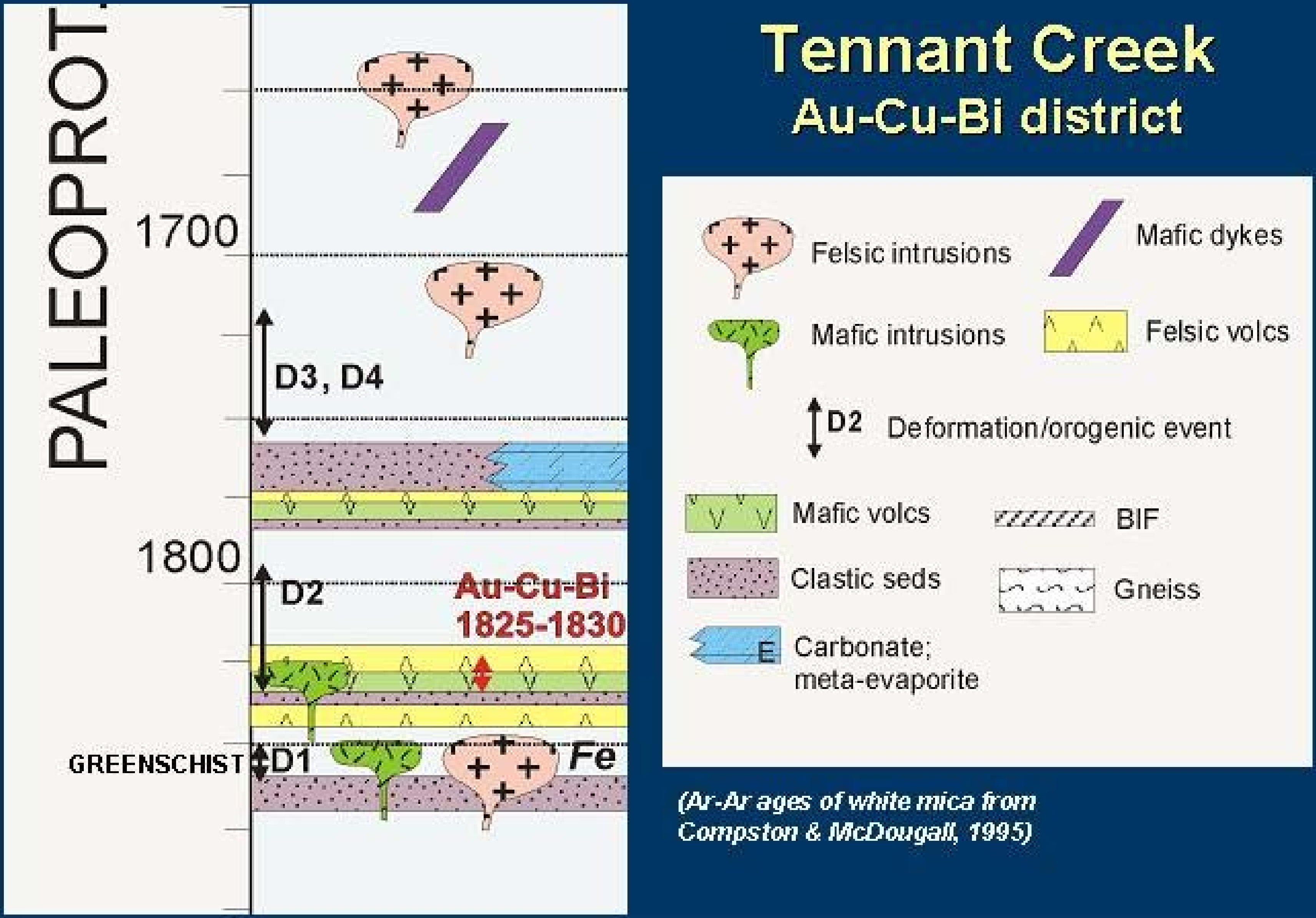




(Skirrow, 1999)

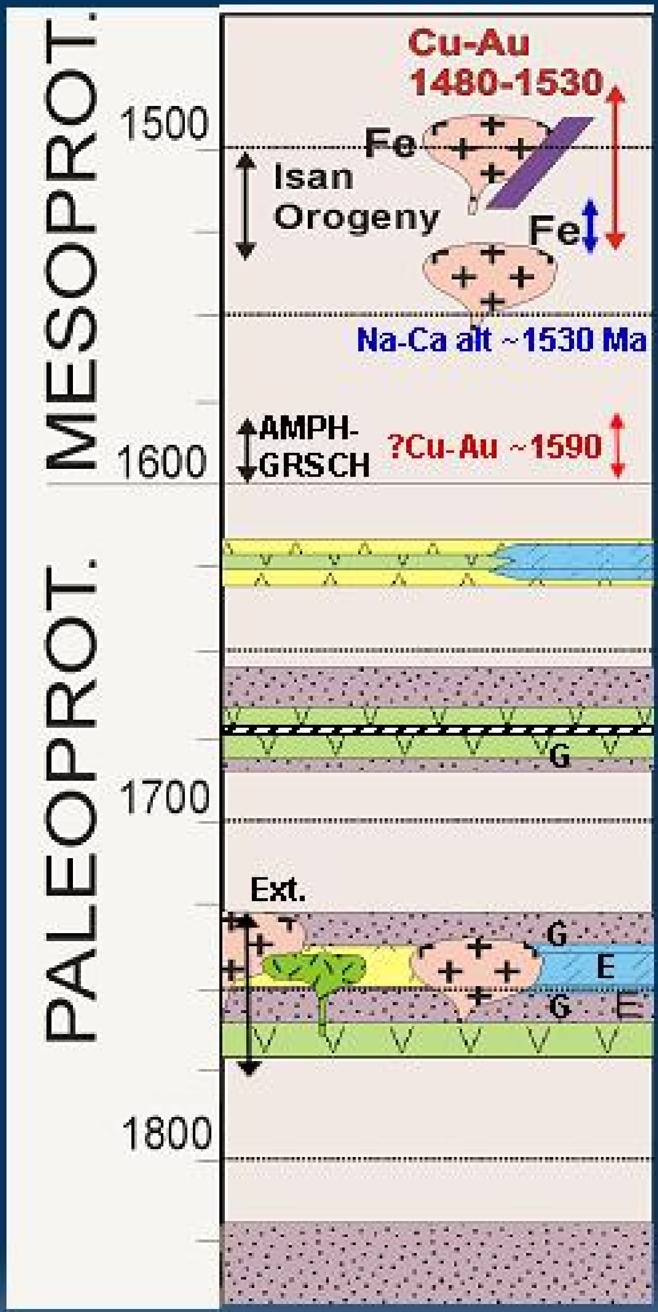
1600 ± 15 Ma Cu-Au event(s)

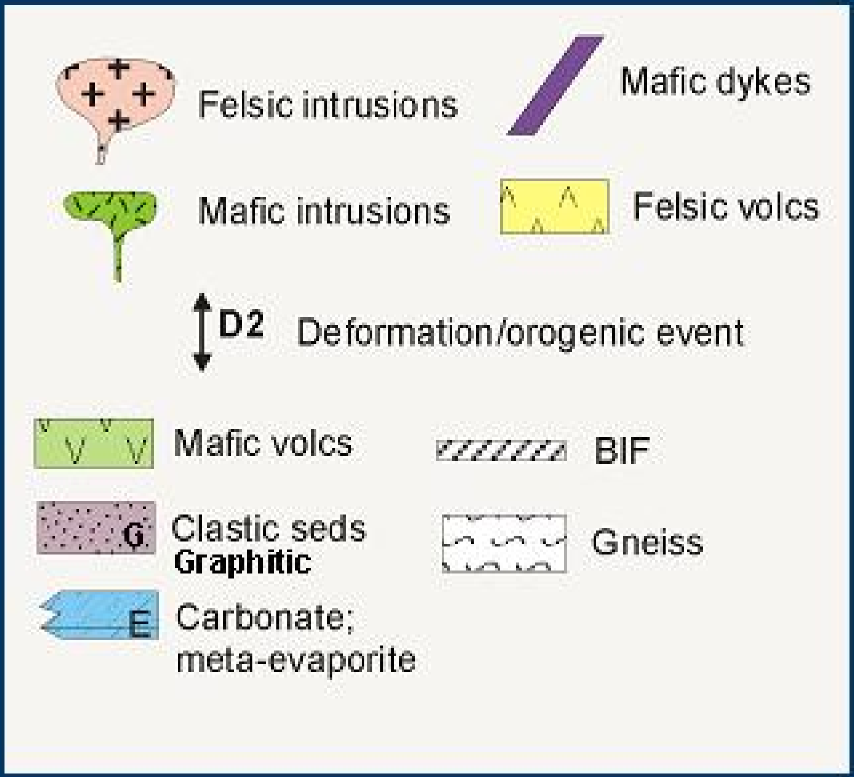
Tennant Creek
Au-Cu-Bi district



(Ar-Ar ages of white mica from Compston & McDougall, 1995)

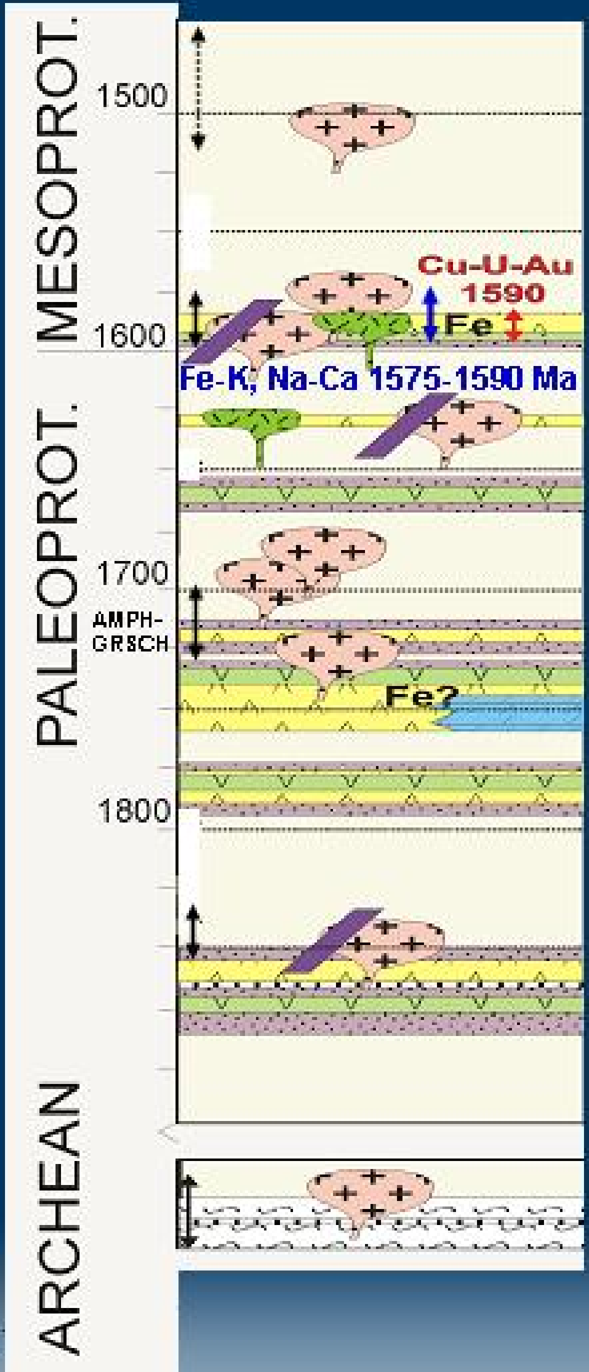
Mt Isa
Eastern Succession

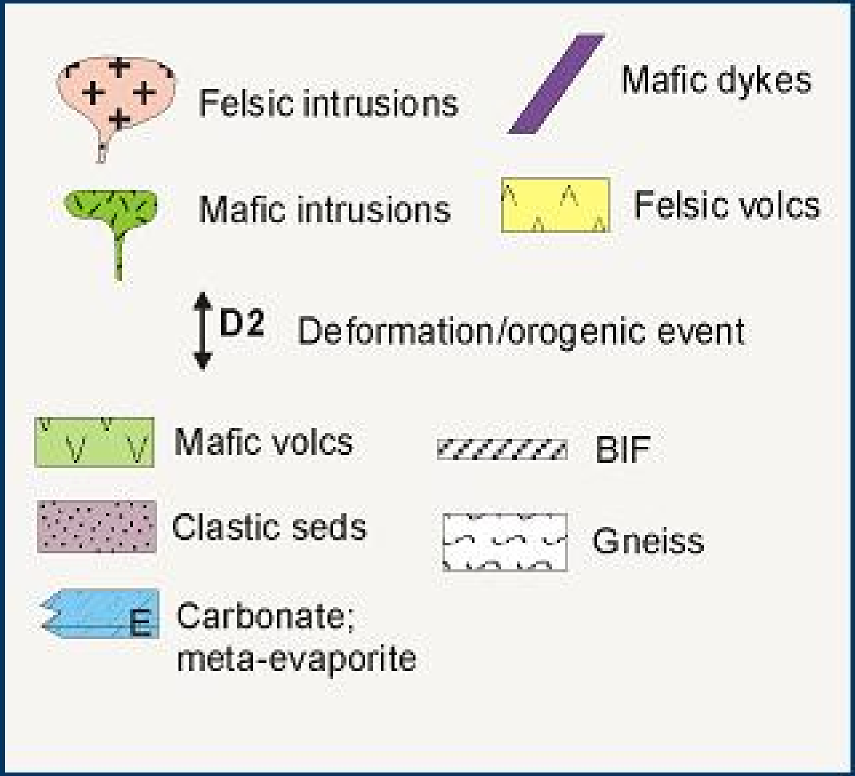




(alteration & sulfide mineral ages from Perkins et al., 1998; Gautier et al., 2001)

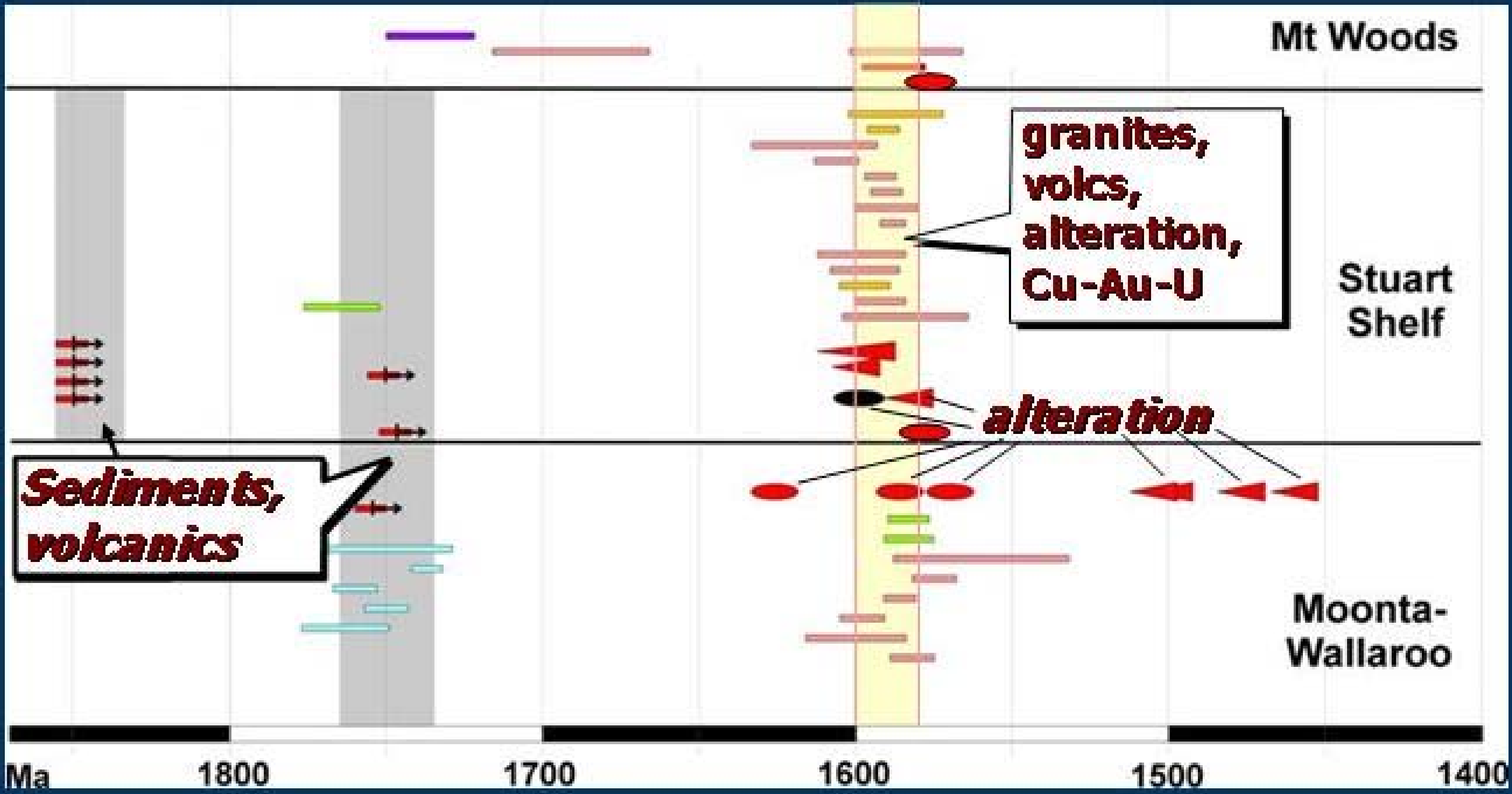
Gawler Craton
Olympic Cu-Au province





(alteration & mineralisation ages from Johnson & Cross, 1995; Raymond, 2002; Skirrow et al., 2002)

Olympic Cu-Au province: event timing

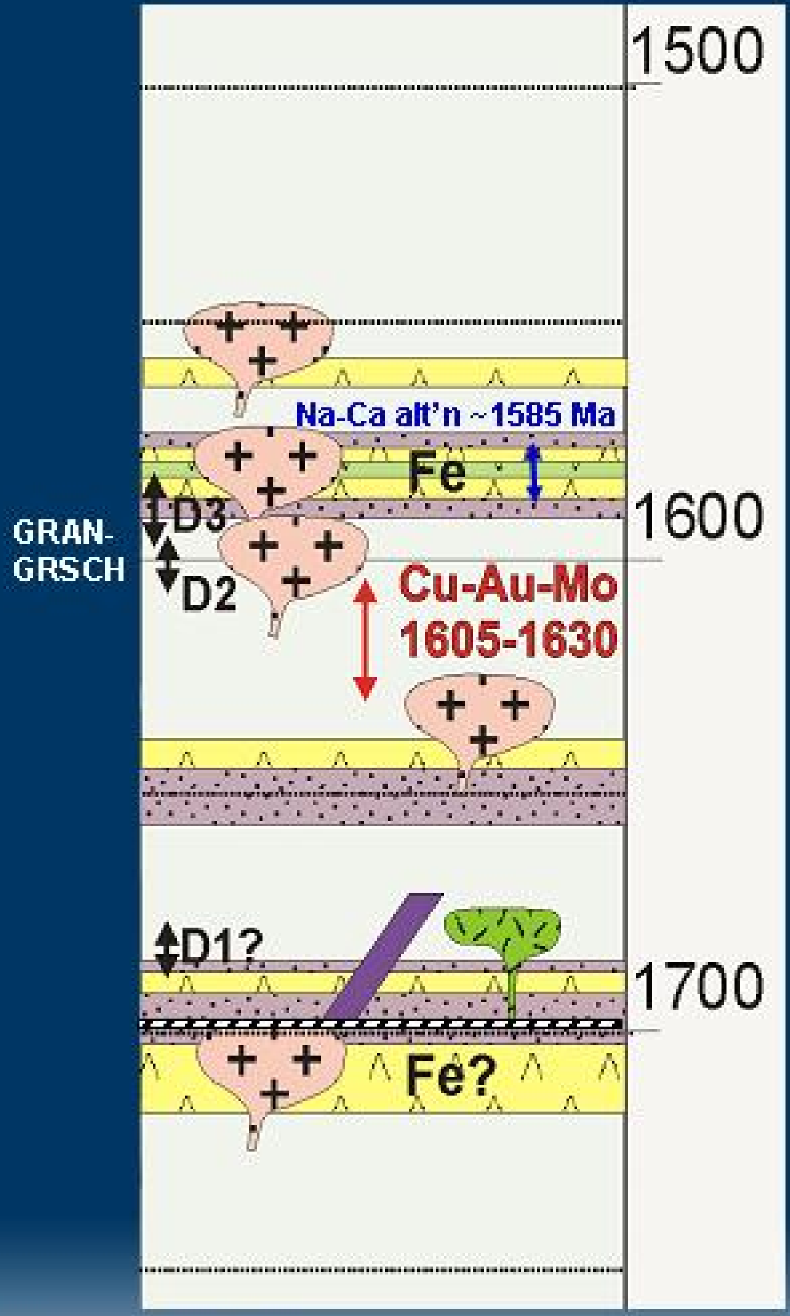


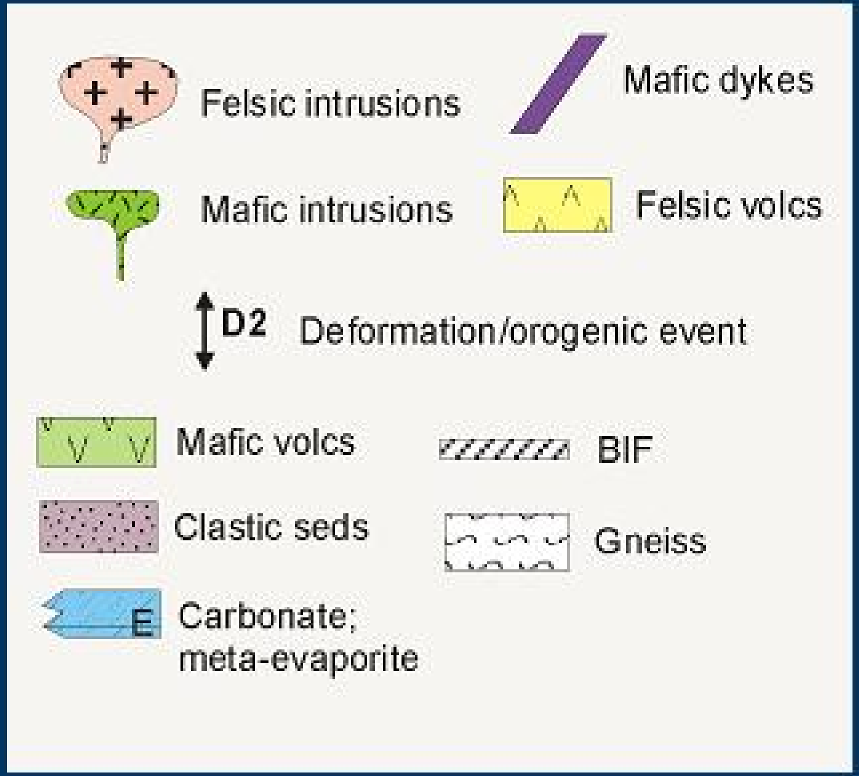
Time, Ma

(new results in red; ◄ = Ar-Ar, all other data: U-Pb)

(E. Jagodzinski, G. Fraser, O. Raymond, R. Skirrow, E. Bastrakov)

Curnamona Prov.
Olary Domain – ?minor CuAu





(alteration & sulfide mineral ages from Skirrow et al., 2000)

Unifying Characteristics of IOCG

Constant 1. Tectonothermal evolution

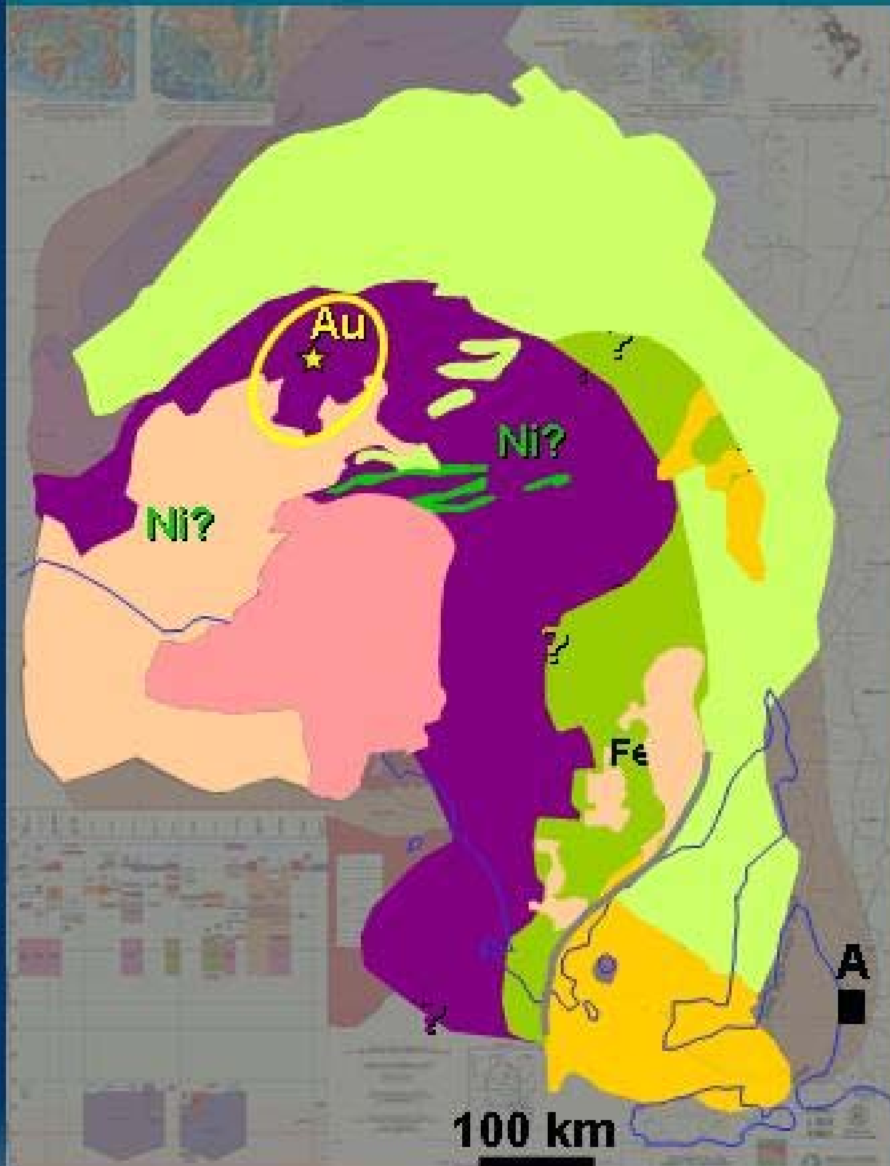
- Major Cu-Au broadly overlaps with *later* tectonothermal events in each IOCG prov.
- Broadly coeval felsic (I-type) -mafic magmatism, IOCG, and regional Na-Ca, Fe alteration (K-rich in Olympic region)
- Earlier tectonothermal events are higher metamorphic grade than during IOCG

Unifying Characteristics of IOCG

Constant 2. Host sequence composition

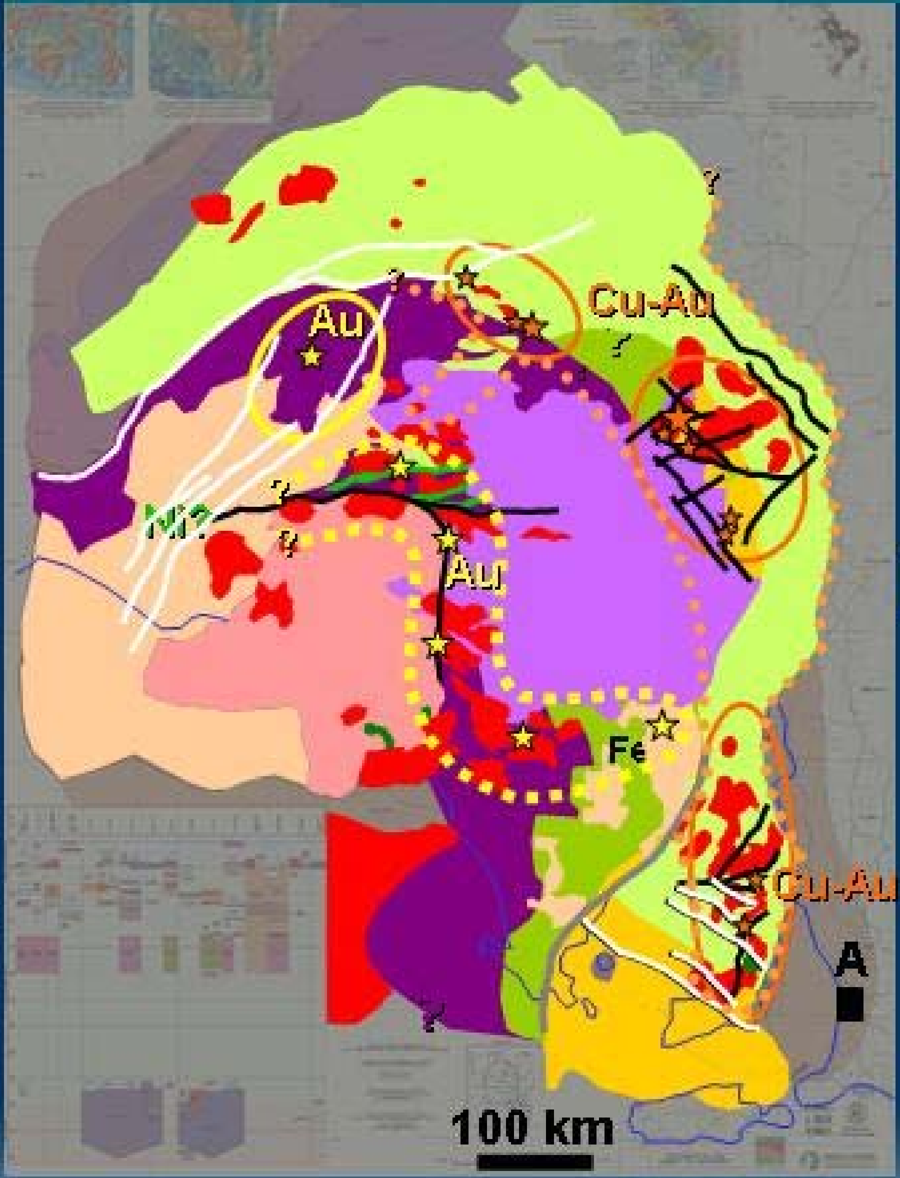
- *Chemically diverse:* volcanic, siliciclastic (commonly volcanic-derived) & chemical seds (carb, BIF ± evap ± graphite); older granitoids, etc
- *Fe-rich* protoliths in parts

2. Gawler Craton events & IOCG settings



- 2900?-2520 Ma: Archaean seds, volcs, incl. komatiites
- Au mineralisation, pre- or syn-2440 Ma metamorphism
- <2000-1850 Ma: BIF, carbonates, siliciclastics
- 1850 Ma: granitoids, syn-orogenic
- <1850-1740 Ma: siliciclastics, felsic volcs, BIF
- ~1720-1670 Ma: granitoid and mafic intrusions, syn-orogenic shear zone – Kimban Orogeny
- ~1620 Ma: I-type granitoids

2. Gawler Craton events & IOCG settings



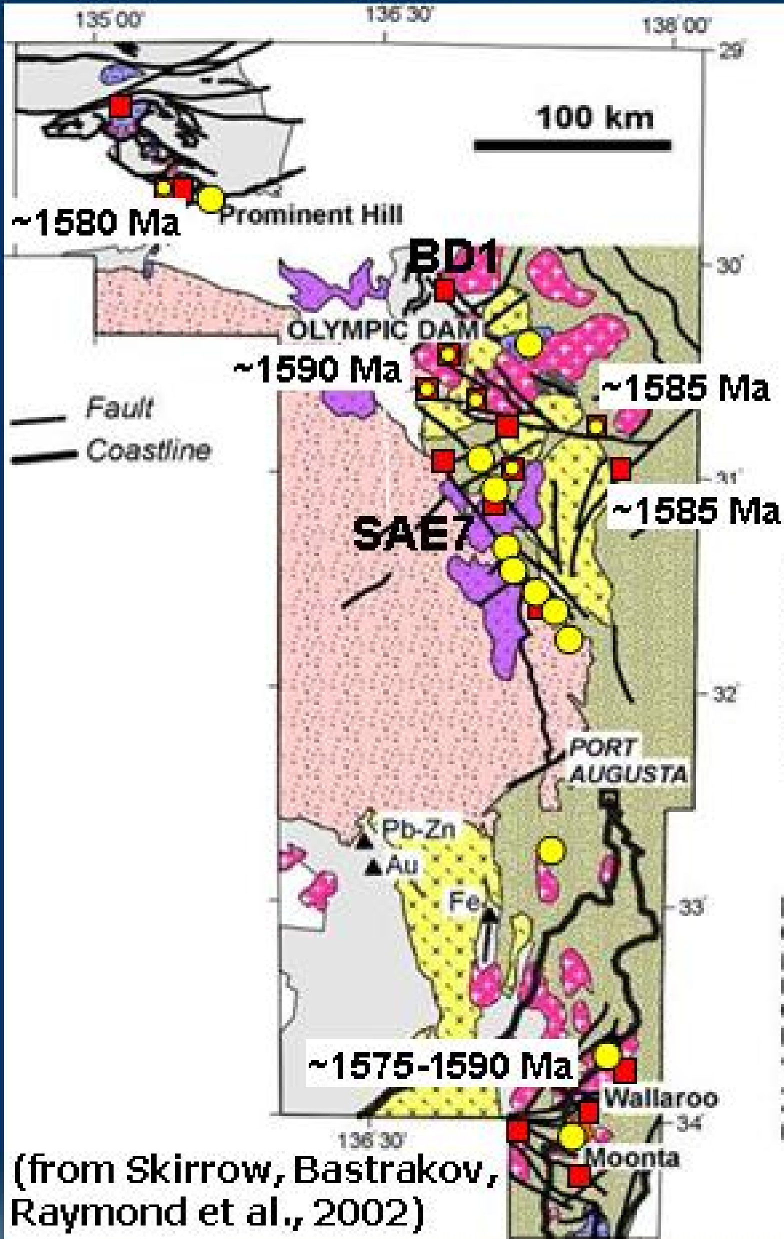
- ~1590 Ma: Gawler Range Volcanics (bimodal)
- ~1590-1575 Ma: Hiltaba Suite granitoid and mafic intrusions; faults
- ~1590 Ma: Olympic Cu-Au province; 3+ 'footprints'
- ~1590-1580 Ma: Central Gawler Au province
- ~1530-1450 Ma: shear zones

Unifying Characteristics of IOCG

Constant 2. Host sequence composition

- *Chemically diverse:* volcanic, siliciclastic (commonly volcanic-derived) & chemical seds (carb, BIF ± evap ± graphite); older granitoids, etc
- *Fe-rich* protoliths in parts
- Later *regional alteration:* addition and/or redistribution of Fe, Na, Ca, K
- Genetic relationship of regional alt'n to Cu-Au remains unclear

2. Olympic Cu-Au province – regional alteration



(from Skirrow, Bastrakov, Raymond et al., 2002)

Alteration types

- Magnetite – alk feld – calcsil
  Magnetite – biotite ± Cu-Au
- Hematite – ser – chl – carb
  ± Cu-Au-U
- Hm overprinting magnetite

MESOPROT.
- Hiltaba Suite granitoid (1595-1570 Ma)
- Mafic intrusions
- Gawler Range Volcanics
- Mafic Gawler Range Volcanics

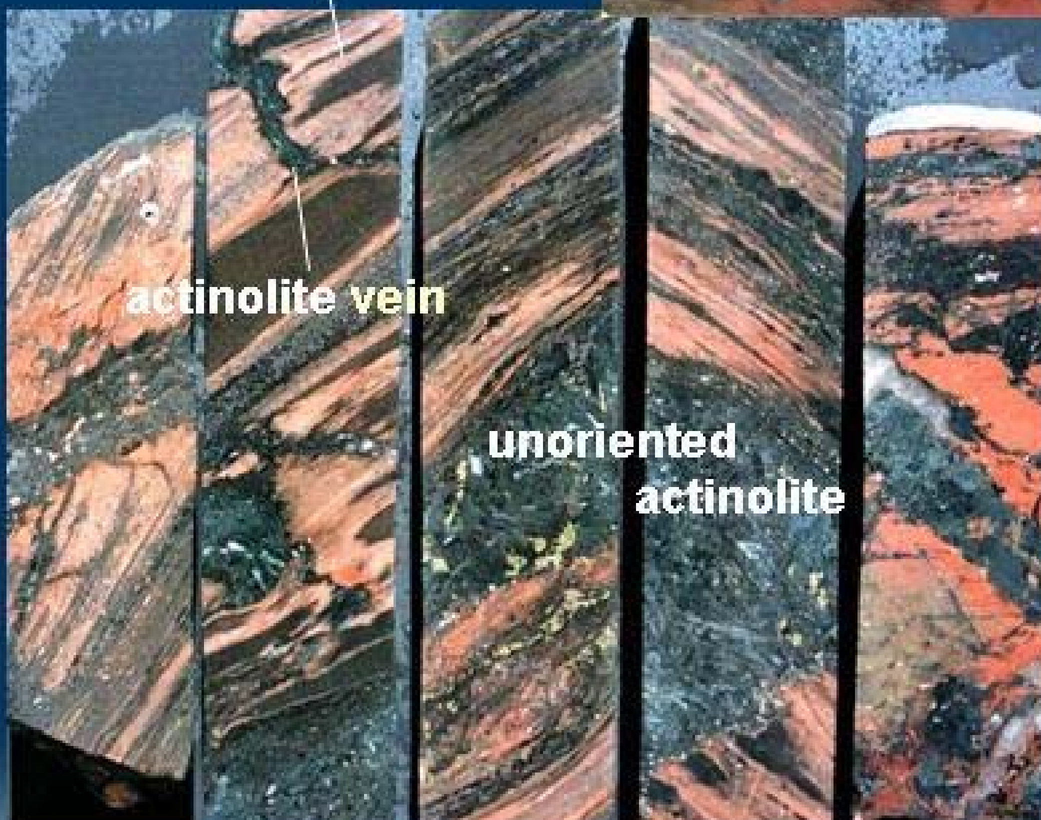
PALAEOPROT.
- Wallaroo Gp - metasedimentary & metavolcanic rocks
- Intrusive rocks, mainly felsic; mafic
- Hutchison Gp & equivalents; BIF

- Undifferentiated Archaean to Palaeoproterozoic rocks

GAWLER CRATON
Regional Na-Ca-Fe & Fe-K-Ca alteration

K-feldspar – magnetite
-pyrite-titanite-actinolite
(~1590-1575 Ma)

albite infiltrating foliation



Moonta-Wallaroo
district (DDH 160)

2. Regional Na-Ca-Fe alteration

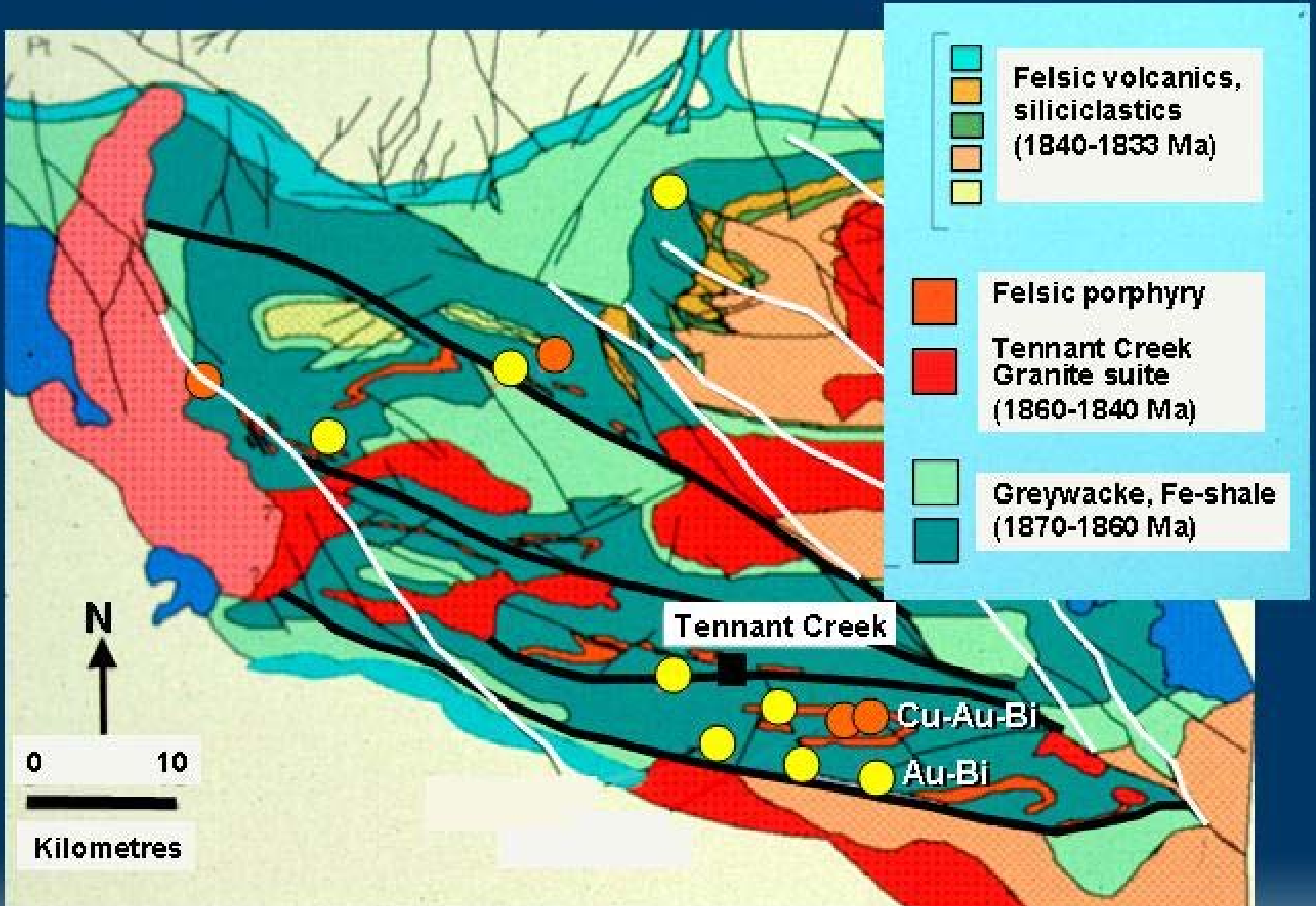
(albitite in amph ± mt ± cpx ± titanite matrix)

Unifying Characteristics of IOCG

Constant 3. Crustal-scale fault network

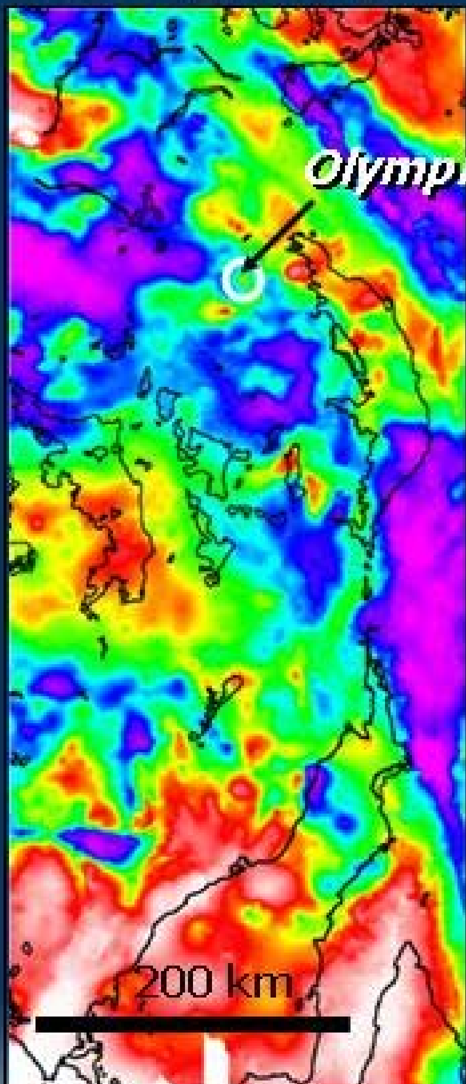
- Developed during early orogenic events
- Faults reactivated during Cu-Au formation
- 3D architectures will provide clues to geodynamic settings of IOCG districts

3. Crustal-scale fault network – Tennant Creek Inlier

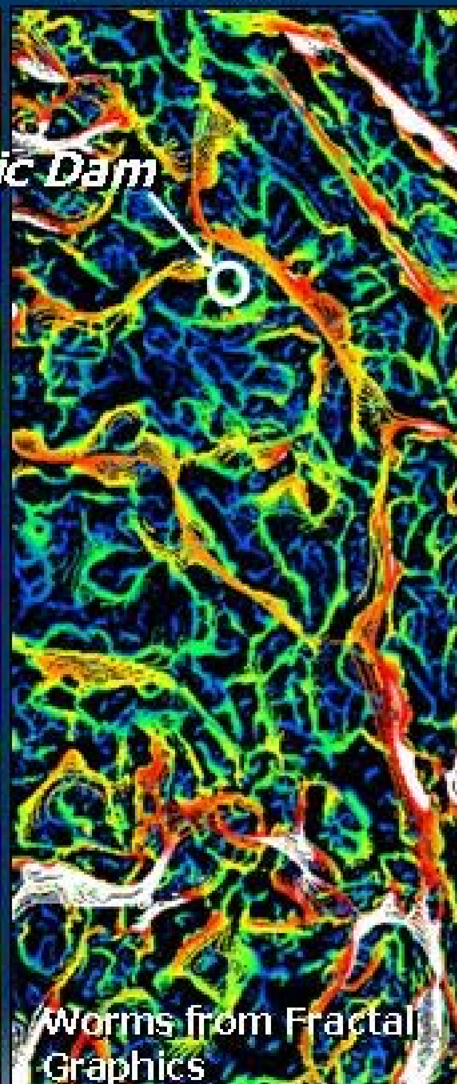


3. Crustal-scale fault network – Olympic Cu-Au prov.

OCGP gravity



Gravity edges or 'worms'

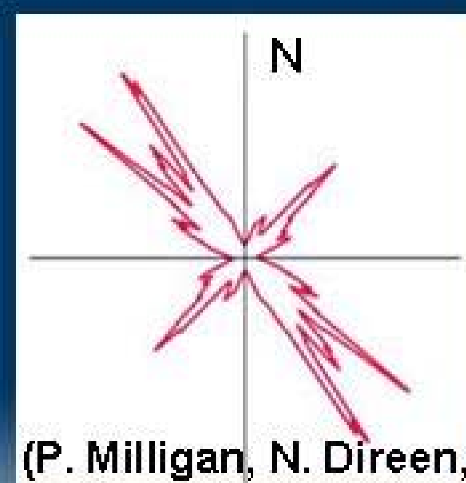


Structure - conjugate NW & NE worm/fault network

NW edges: red

NE edges: blue

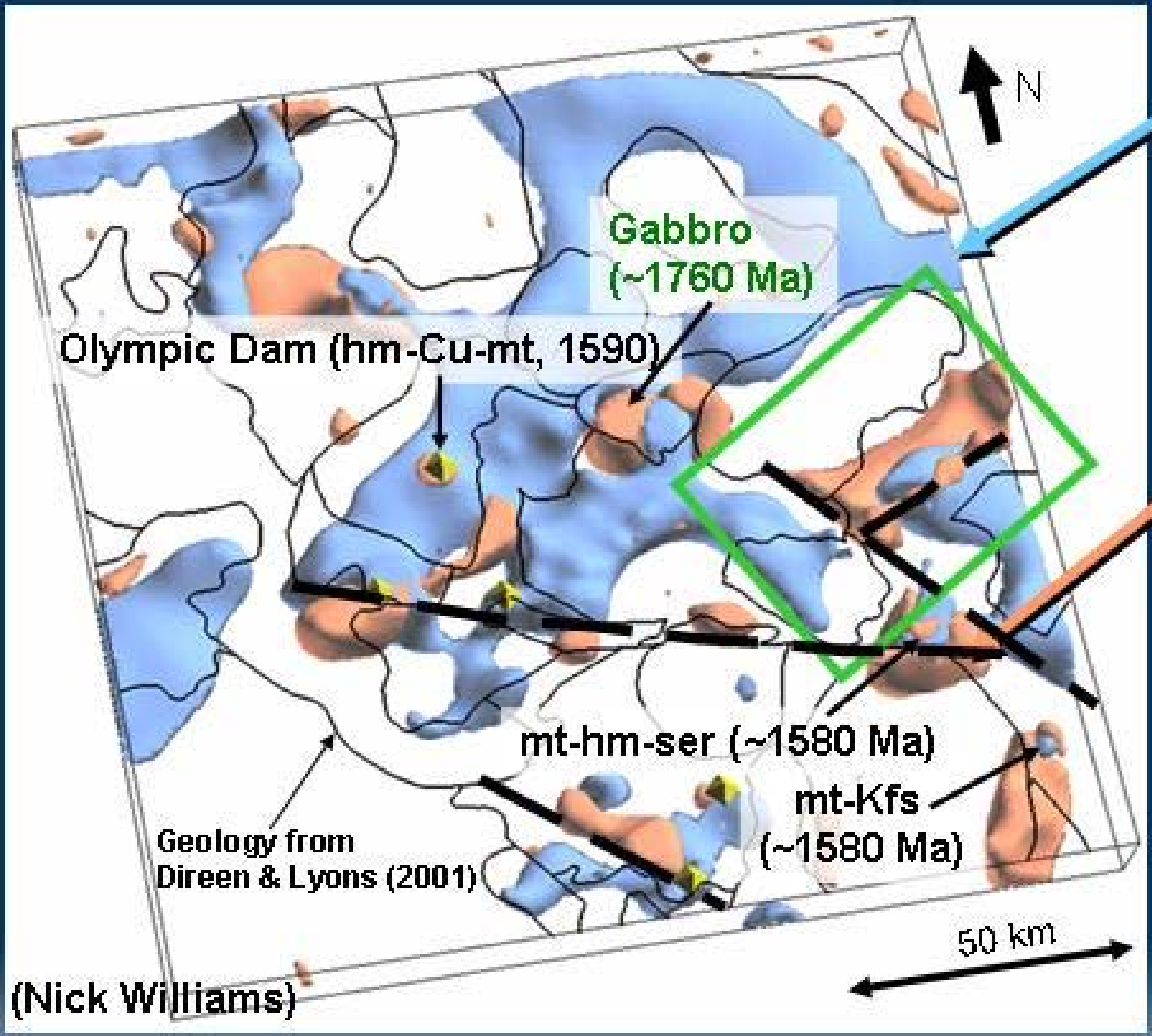
(major structures only)



Edge azimuth histogram

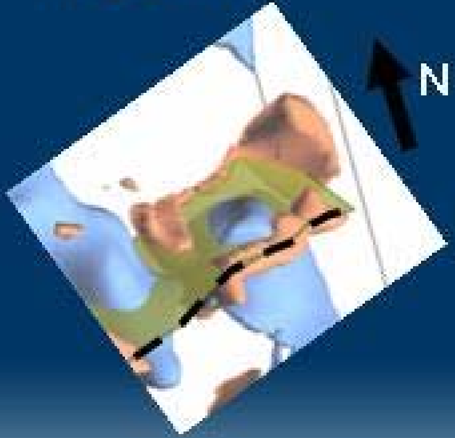
3. Crustal-scale fault network – Olympic Cu-Au prov.

Inversion isosurfaces of mag. sus & density: magnetite & hematite alteration partly controlled by 1580-1590 Ma faults?



1% "magnetite" (includes all susceptible minerals as their magnetite equivalent)

1% "haematite" (includes haematite, sulphides, amph/px, and remanent magnetism)



Unifying Characteristics of IOCG

Constant 4. Two contrasting fluid types:

A. Hypersaline, 350-500°C, intermediate-oxidation (mt-stable) to reduced, Fe, K $\pm$ CuAu $\pm$ H_2S

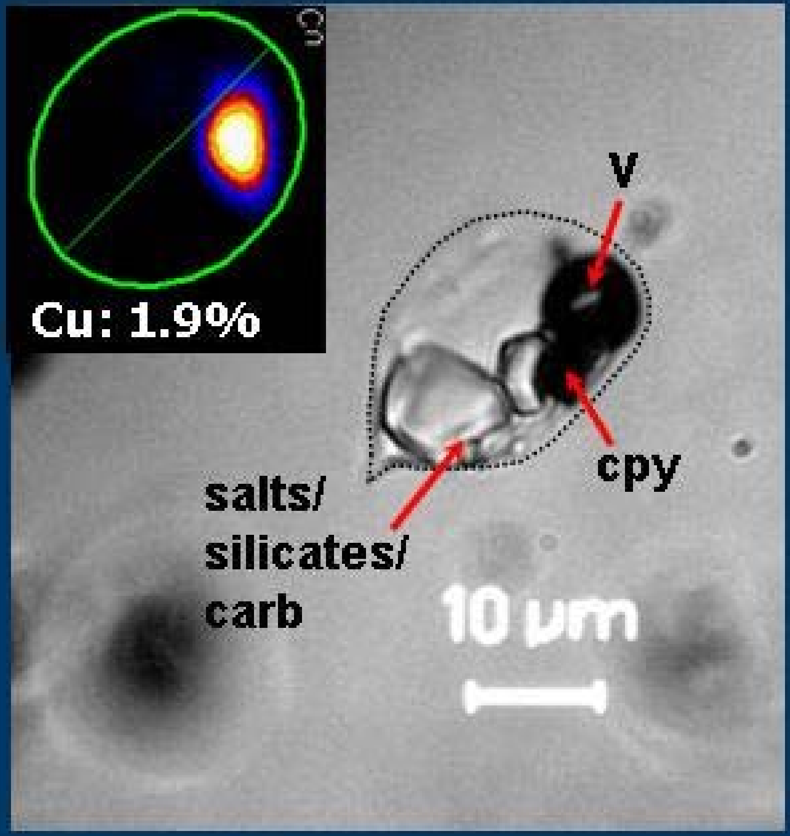
B. Moderate salinity, 150-250°C, oxidized (hm-stable)

- Many systems also have CO_2 (Pollard, 2000)

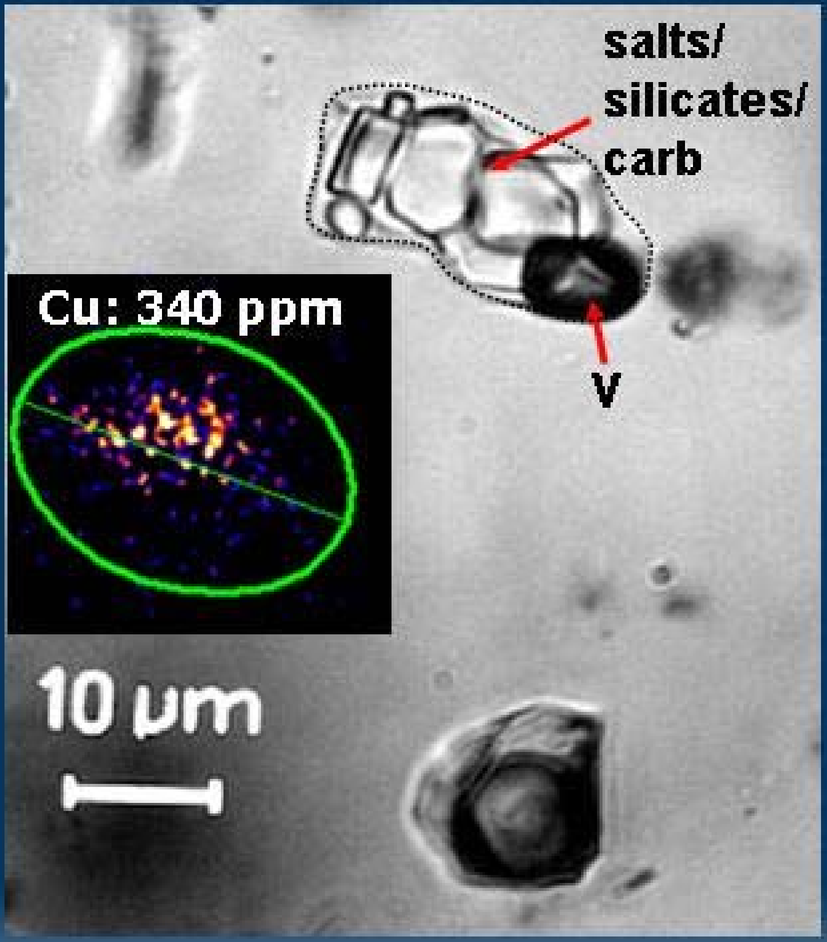
4. Olympic Cu-Au province: 350-500°C Cu-bearing brines

(Titan prospect)

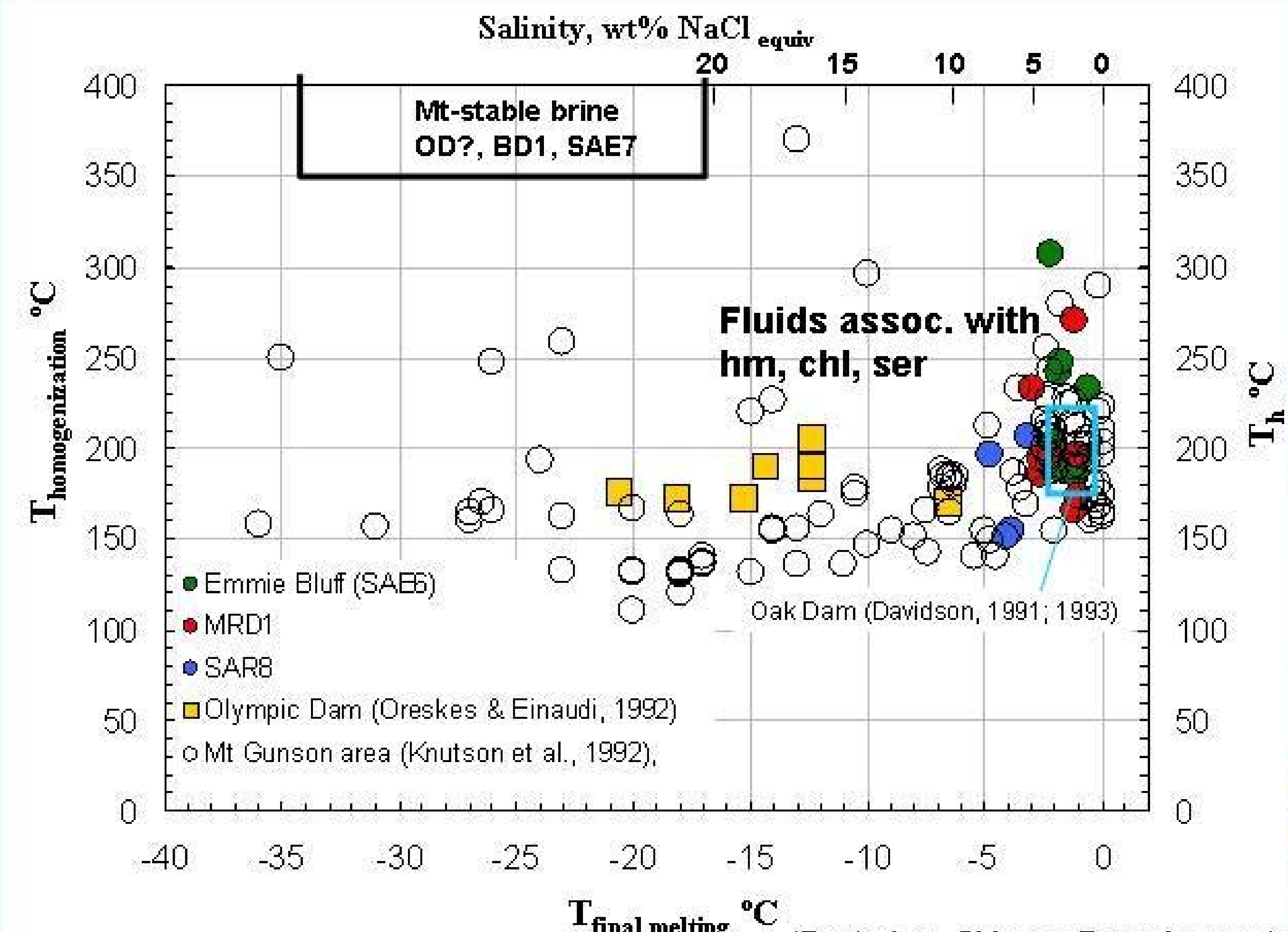
Magnetite-qtz-amp-Kfs-ap-py (trace cpy)



(Bastrakov, Skirrow, Ryan, in prep.)

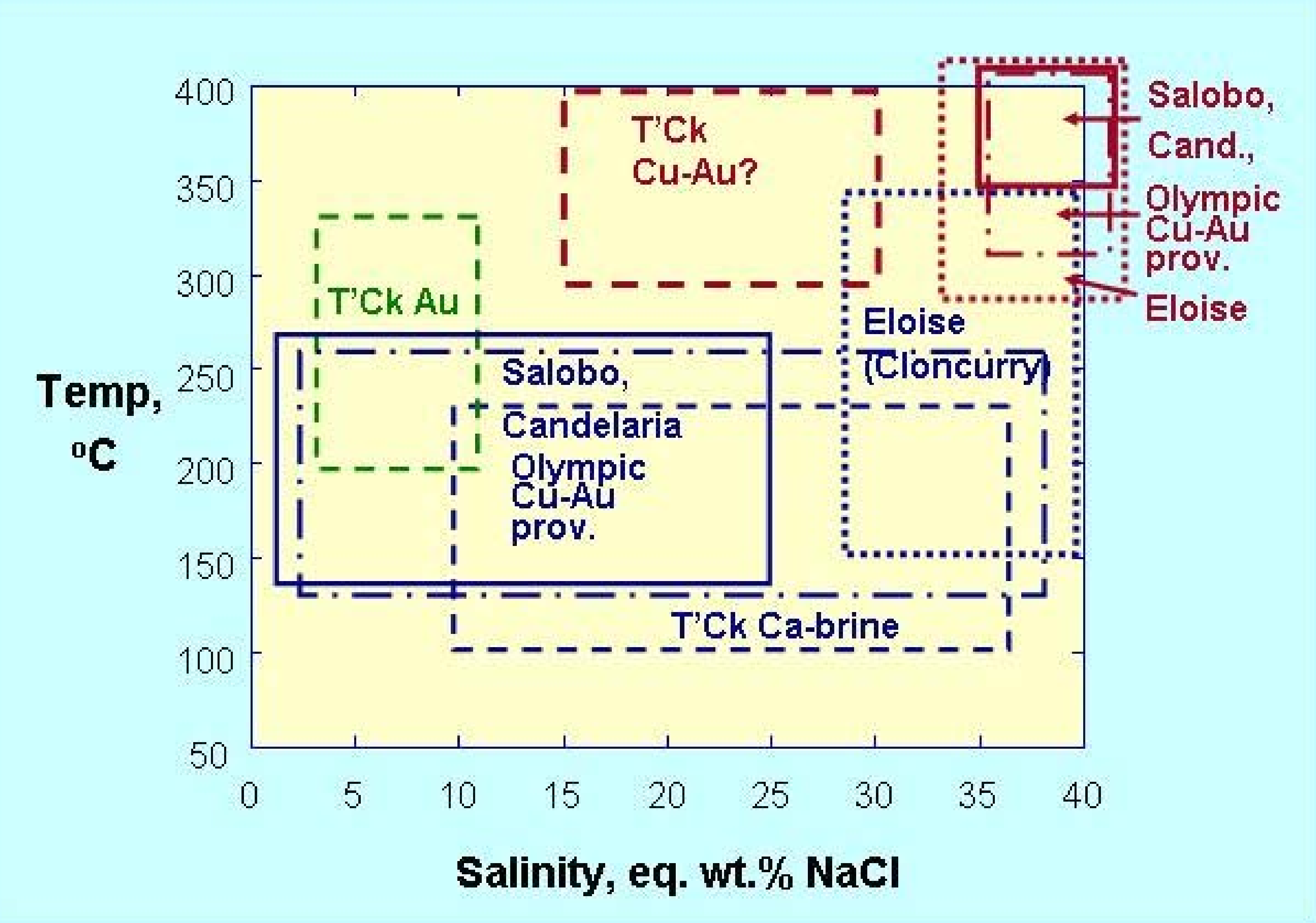


4. Olympic Cu-Au province: Two fluids



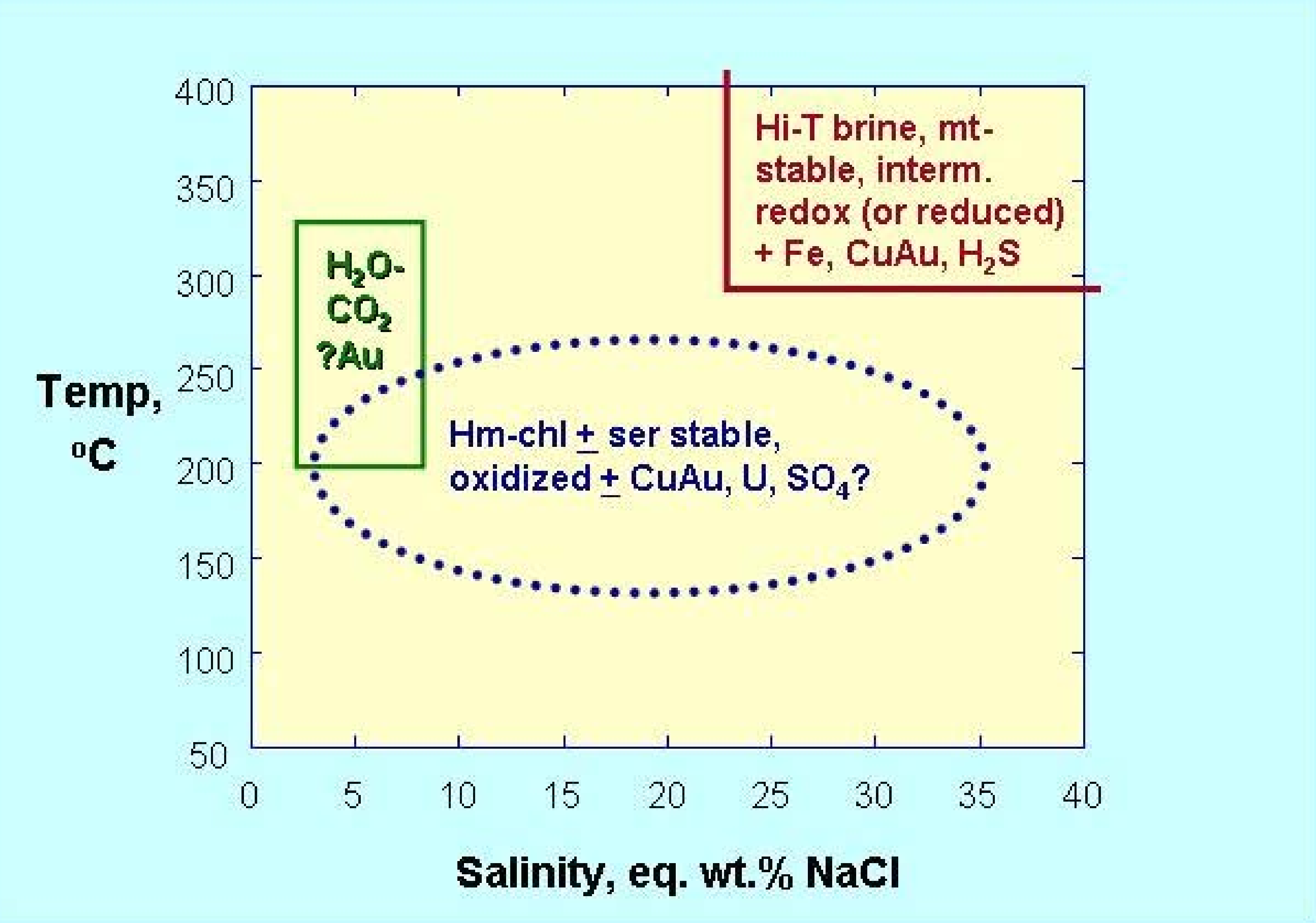
(Bastrakov, Skirrow, Ryan, in prep.)

4. IOCG districts: Two fluids



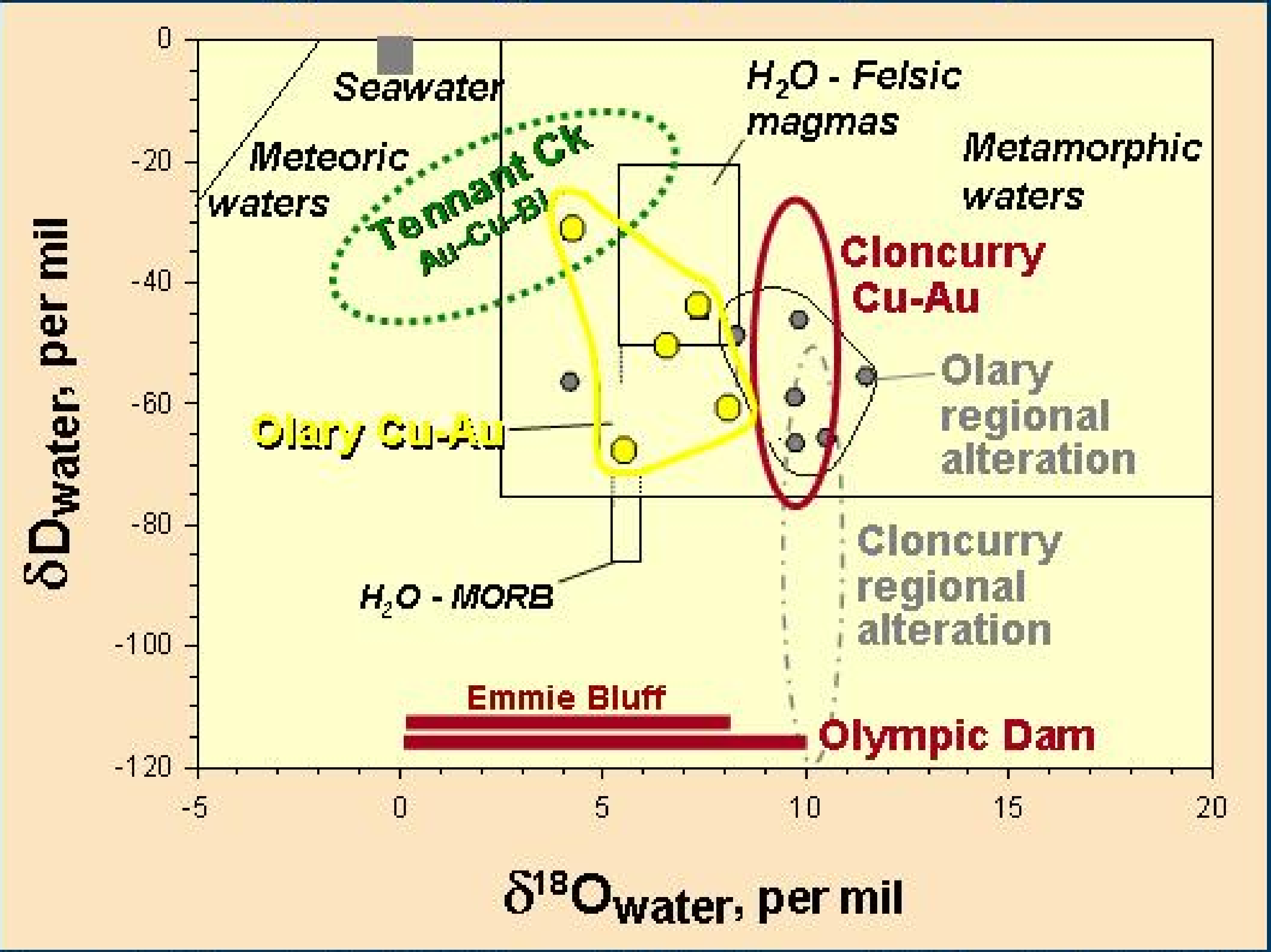
Tennant Creek: Huston et al. (1993), Skirrow (1993), Khin Zaw et al. (1994), Skirrow & Walshe (2002); Eloise: Baker (1998); Salobo: Requia & Fontbote (2000); Candelaria: Marschik et al. (2000)

4. IOCG fluids - synthesis



Origins of Cu-Au ore fluids in IOCG deposits

Oxygen-hydrogen isotopes – hybrid inputs?



Reference fields from Taylor (1986), Sheppard (1986); Cloncurry fields from Mark et al. (2001); Olary data from Skirrow et al. (in prep.); Tennant Creek data from Wedekind (1990), Skirrow (1993); Gawler data from Gow (1996), Oreskes & Einaudi (1992)

Diversity of IOCG deposits

So much for the four Constants . . .

Why then are IOCG deposits so diverse?

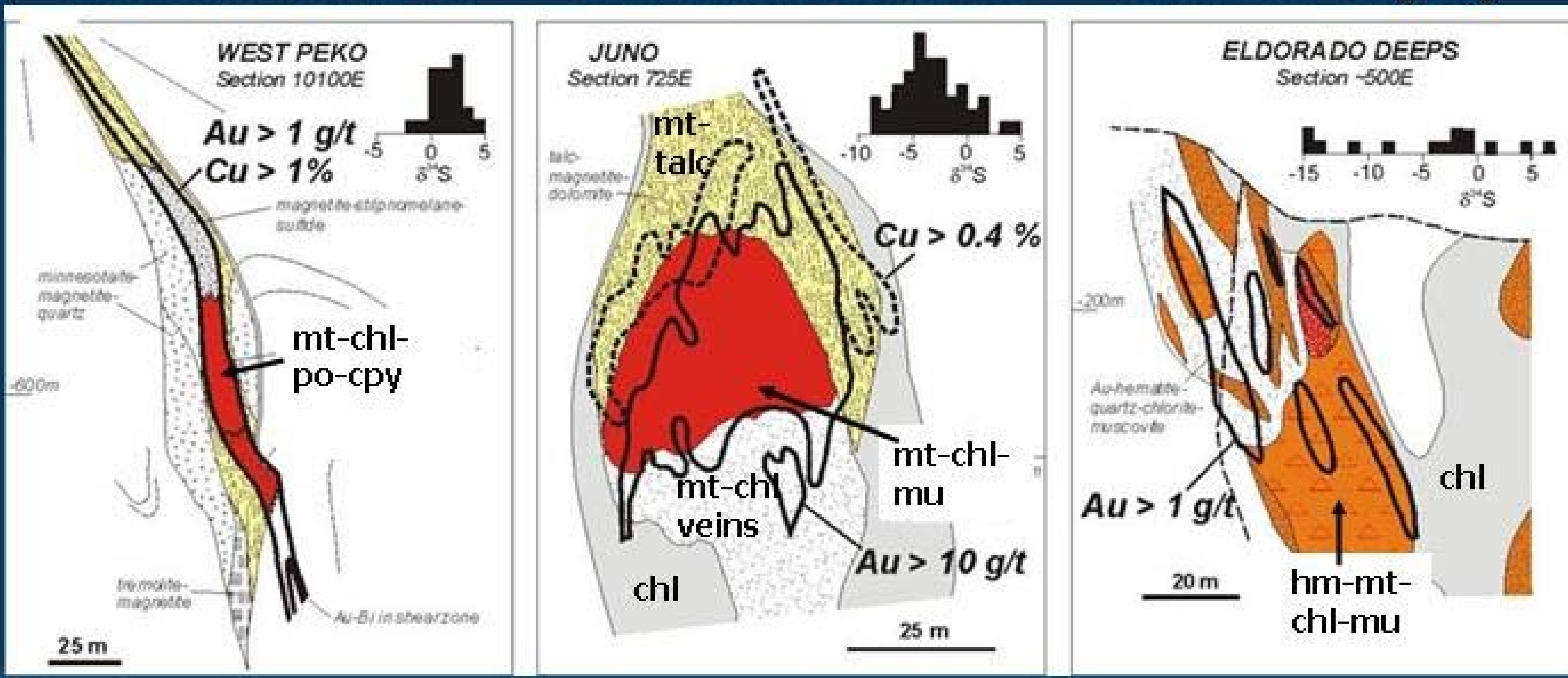
The Variables:

- **Host rock composition**
- **Depth of formation**
- **Fluid-fluid-rock interplay**

Tennant Creek Au-Cu-Bi deposits:

- **Similar host rocks, similar formation depths;**
- **Hence variation is driven by differing input of two end-member fluids**

Reduced Cu-Au-Bi | **Intermediate Au-Bi** | **Oxidized Au(-Bi)**



(Large, 1975; Skirrow, 1993, 2000)

Similar spectrum in Tennant Creek & Cloncurry IOCG districts

Reduced style ⟵ spectrum ⟶ Oxidised style

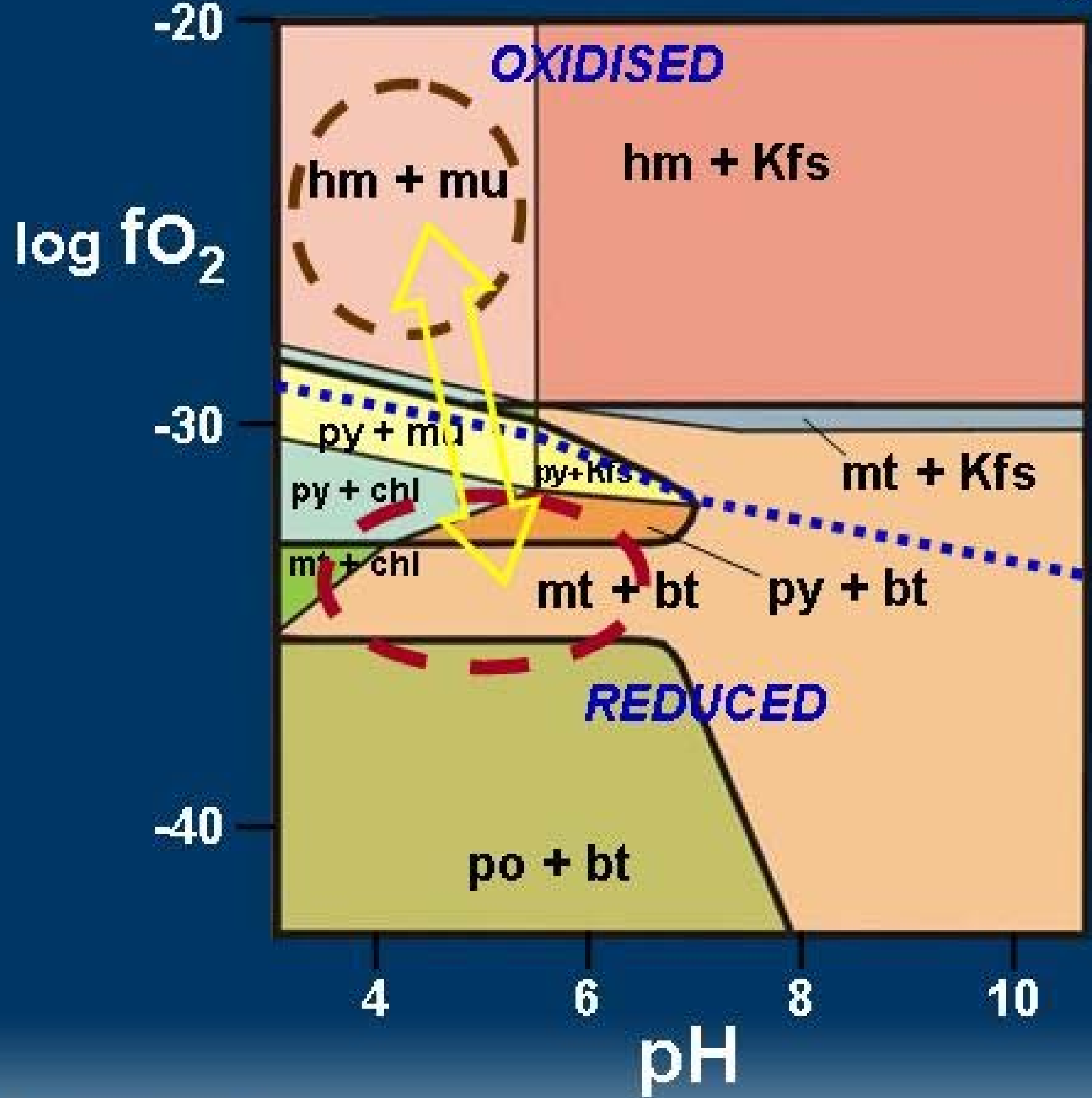
Tennant Ck Au-Cu-Bi

West Peko, Peko
Warrego
White Devil
Juno, TC8
Eldorado, Argo
Nobles Nob

Cloncurry Cu-Au

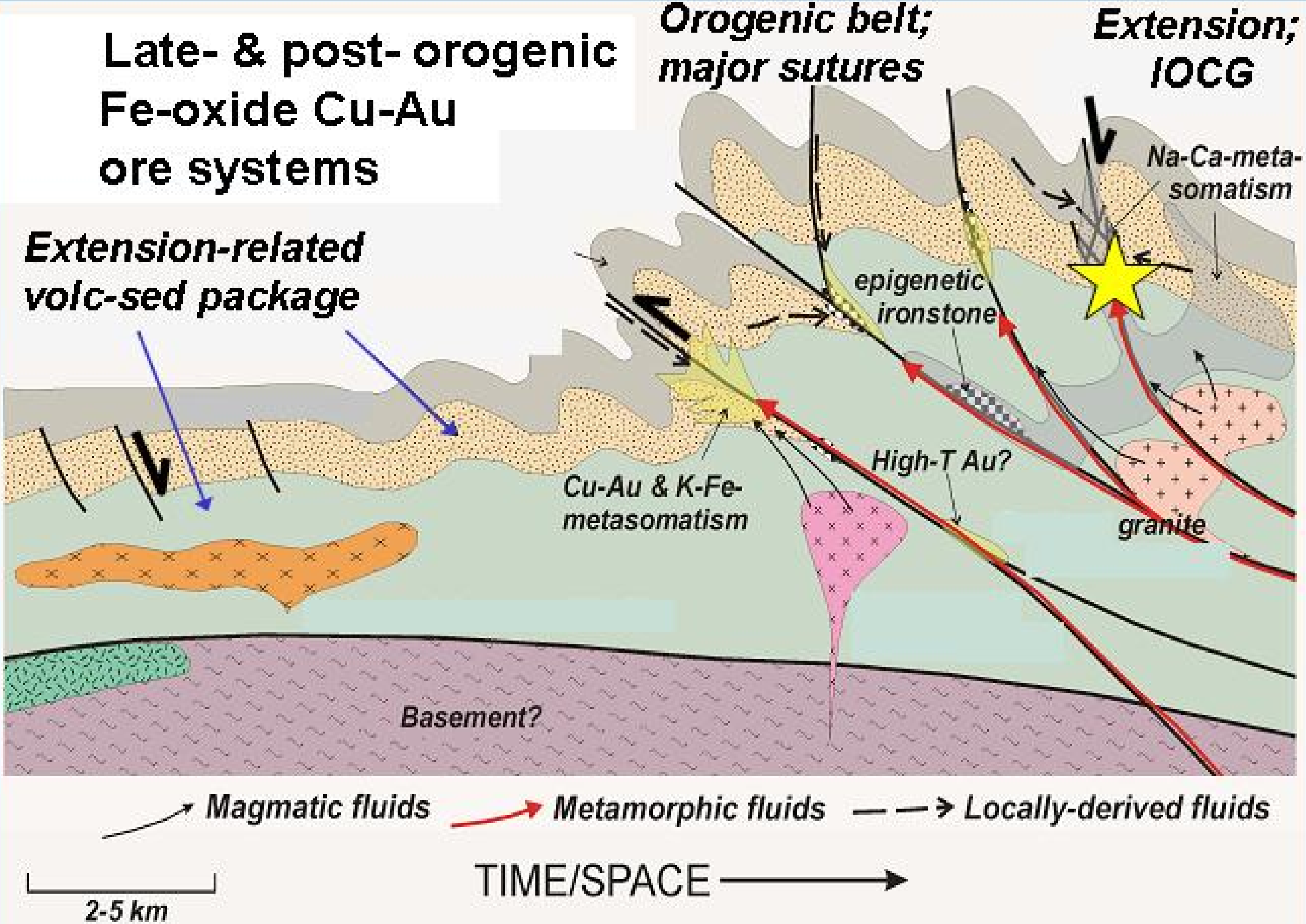
Eloise
Mt Elliott
⟵ Osborne ⟶
⟵ Ernest Henry ⟶
Starra
Great Aust.

Australian IOCG: Diversity due to variable fluid – fluid – rock interaction



300°C, 1.5 kb
$m_{total\ sulfur} = 0.0005$
$a_{K+} = 0.1$

Late- & post- orogenic Fe-oxide Cu-Au ore systems



Regional characteristics uniting IOCG districts

An Australian perspective

Constant 1. **Cu-Au during *later tectonothermal* events, coeval with felsic-mafic magmatism.**

Constant 2. **Chemically *diverse host sequences* incl. early Fe; then regional Na-Ca, and/or Fe-ox alteration.**

Constant 3. **Crustal-scale *fault network*; re-activated orogens.**

Constant 4. ***Two distinct fluids:* magnetite- & hematite-stable.**

Diversity among IOCG deposits

An Australian perspective -

Variables: **Host composition, depth, fluid-fluid-rock interplay**

Constants + Variables → **Spectrum from reduced to oxidised deposits**

→ **Range from low-T brittle to high-T ductile styles**

Acknowledgements

Geoscience Australia: A. Budd, E. Bastrakov, G. Fraser, G. Gibson, B. Goleby, L. Highet, D. Hoatson, E. Jagodzinski, L. Jones, R. Lane, P. Lyons, P. Milligan, M. Peljo, O. Raymond, R. Skirrow, M. Thomas, N. Williams, L. Worrall

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