Palaeoproterozoic copper mineralisation in the Aileron Province: New findings on temporal, spatial and genetic features

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Palaeoproterozoic Aileron Province

Polymetamorphosed (granulite to greenschist facies) and polydeformed terrain
Largely metasedimentary packages ca 1860 to 1740 Ma
Magmatism ca 1820-1700 Ma

Scrimgeour, 2013
Several hundred Cu-associated deposits, prospects & occurrences
Temporal, spatial and genetic characteristics poorly understood
What are the key features? Timing and genesis? Are they linked?
Copper in the Palaeoproterozoic Aileron Province

Reconnaissance fieldwork, structural mapping, petrology, geochemistry, isotope analyses, geochronology…
….combined with NTGS regional mapping and historical data
Regional location
Jervois Cu-Ag(Pb-Zn) deposits

eg 26.7 Mt @ 1.12% Cu, 16.6 g/t Ag (+ Pb-Zn resource)

- ca 1790 Ma
  subaqueous basin-hosted, volcanic-associated (mafic), high-T, low-P metamorphism (syngenetic massive sulfides)

- ca 1755 Ma
  regional peak-pressure metamorphism (re-crystallised ore)

- ca 1705 Ma
  epigenetic event (remobilised ore)

Bennett, 2015
Jervois Cu-Ag(Pb-Zn) deposits

Still uncertain....

- Tectonic setting
- Marine or non-marine environment?
- Influence of bimodal volcanism?
- Exhalative or inhalative mineralisation?
Jervois Cu-Ag(Pb-Zn) deposits

New tourmaline isotopic & chemical results

(1) tourmalinite (syngenetic)

2) quartz-tourmaline veins (epigenetic)

Very low $\delta^{11}$B

- Fe-rich

- Qtz-turm vein

- tourmalinite

- tourmalinite

- Qtz-turm vein
Boron isotopes

\[ \delta^{11}B (\text{‰}) \]

-20 0 +20 +40

Cont Crust

MORB + mantle

Crust

\[ \partial^{11}B (\text{‰}) \]

1/5
Boron isotopes

\[ \delta^{11}B \text{ (‰)} \]

-20

<table>
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<th>Cont</th>
<th>Crust</th>
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- Isotopically heavy boron
  - Seawater, marine sediments, altered volcanics & clastic metasediments

Modern seawater
Boron isotopes

\[ \delta^{11}B (\%) \]

-20  |  0  |  +20  |  +40

| Crust |  Cont | Non-marine evaporites | Granites and pegmatites | Granitic veins |

Isotopically heavy boron

Isotopically light boron

MORB + mantle

Cont

Crust

\[ \delta^{11}B (\%) \]
Boron isotopes

- Cont Crust
- MORB + mantle
- Pegmatites cross-cutting borates
- Marine carbonates & evaporites
- Altered volcanics
- Clastic metasediments
- High-P metamorphic rocks
- Modern seawater
- Non-marine evaporites
- Granites and pegmatites
- Granite-related veins
- Isotopically light boron

Quartz-tourmaline vein, Jericho W mine
Quartz-tourmaline vein near Cox’s Find
Tourmalinite near Reward
Tourmalinite near Reward
Boron isotopes

Very low $\delta^{11}$B

Related to granites or non-marine evaporites

Coincidental?

Potential non-marine setting is not trivial
Cu-W-Mo Bonya Hills/Jinka Plain

Molyhil = 4.7 Mt @ 0.28 % WO₃, 0.13 % Mo

- Over 120 Cu, W and W-Mo vein and skarn occurrences
- Molyhil skarn deposit (ca 1725 Ma) best understood, minor sulfides
- Other mineralisation not well understood…
  W considered related to granites and pegmatites, Cu origins unknown
Cu-W-Mo Bonya Hills/Jinka Plain

New results of reconnaissance fieldwork (updated MODAT)

Spatial associated with metagabbro and metasediments containing calc-silicate rock
Cu-W-Mo Bonya Hills/Jinka Plain

eg Bonya deposit: 38m @ 4.4% Cu;
Jericho prospect: 600 t/vertical metre; ≤ 1% WO₃

New results: logging & geochronology

Epigenetic Cu-W event ca 1730-1705 Ma
Linked to granite and pegmatite intrusions

Bonya Cu: Re-Os moly 1726 ± 8 Ma
Associated with metagabbro and pegmatites
Cu-Fe in quartz veins cross-cut S₂ foliation
No Pb-Zn like Jervois; granite trace elements

Jericho W: no direct age
Pegmatite Pb-Pb apatite age 1680 ± 40 Ma
(within error of Molyhil W-Mo deposit)
Granite trace elements ± Cu
Calc-silicate, granite or veins host scheelite

metagabbro
orthogneiss
pegmatite
qtz vein

scheelite
pegmatitic quartz vein

Calc-silicate, granite or veins host scheelite
Cu-bearing fluorite-quartz veins & breccias

eg Austin = 3m @ 0.18% Cu

Several regional examples
Contain Cu & Fe sulfides and iron oxides
Ages unknown but epigenetic and granite-hosted

Potential ‘IOCG’ systems but lack strong evidence for fluid sources and regional sodic-calcic alteration
Cu-bearing fluorite-quartz veins & breccias

New results: mafic link to copper

Altered mafic, Austin deposit, Illogwa

Mafic Xenolith in granite, Jinka Plain

Mafic amphibolite, Perenti prospect, NW Huckitta

Metagabbro body near Reward deposit, Jervois
Cu-bearing fluorite-quartz veins & breccias
Jinka Plain

New results: huge fluid volumes!

Estimate incl. qtz/flu solubility

Jinka $\geq 1.92 \text{ km}^3$

Veins post-date host granite ca 1715 Ma
Cu-bearing fluorite-quartz veins & breccias
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Veins post-date host granite
ca 1715 Ma
Home of Bullion (Cu-Zn-Pb) deposit

2.5 Mt @ 1.8 % Cu, 2 % Zn, 36 g/t Ag, 1.2 % Pb, 0.14 g/t Au
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New results

- Metamorphosed massive sulfide (VMS) mineralisation
- Pb model ca 1825 Ma
- Magnetite-rich
- Hosted in Bullion Schist (metasedimentary rocks, chlorite schist and amphibolite)
- Host mafic and felsic units ca 1825 Ma

andalusite-chlorite schist

cpy-py-sph-mag

cpy-py-sph with chl, bt, mag
Home of Bullion (Cu-Zn-Pb-Ag) deposit

- Structurally complex
- Mineralisation intensely folded at $F_1$
- $S_{\text{main}}$ foliation ($D_2$) overprints $F_1$
- 2 further deformation events

with permission of Kidman Resources Ltd
Mount Hardy Copper Field

eg Mt Hardy = 12m @ 0.65% Cu, 0.39% Pb, 0.87% Zn
Mount Hardy and Brown’s deposits

eg Mt Hardy = 12m @ 0.65% Cu, 0.39% Pb, 0.87% Zn

New results

• Cu-only or Cu(Pb-Zn)
  Pegmatite and quartz vein-related
  Pb model ca 1820 Ma

• Metamorphosed & deformed
  At least two events

• Deposit pegmatite ages:
  ca 1820-1800, 1750, 1550 Ma
  (Re-Os mo, U-Pb Zrn/Mnz LA-ICPMS)
  Crystallisation & deformation

• Regional granite & pegmatite ages:
  ca 1820-1810 Ma, 1790 Ma, 1577 Ma
Aileron Province sulfide $\delta^{34}$S results

$\delta^{34}$S values for various sites:
- Jervois Cu-Ag-(Pb-Zn) (n = 101)
- Bonya Cu mine (n = 11)
- Marrakesh Cu (n = 20)
- Xanten Cu (n = 1)
- Petra Cu (n = 1)
- Molyhil W-Mo (n = 19)
- Jinka Cu (n = 8)
- Perenti Cu (n = 11)
- Austin Cu (n = 12)
- Mount Hardy Cu-Zn-Pb (n = 27)
- Home of Bullion Cu-Zn-Pb (n = 36)
- Coles Hill Cu-Pb-Zn (n = 15)

$n = 262$

cpy, py, po, mo, cc, sph, gn, bn
Aileron Province sulfide $\delta^{34}$S results

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cpy, py, po, mo, cc, sph, gn, bn

Hoefs, 1980
Aileron Province sulfide $\delta^{34}$S results

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Mt Isa SEDEX 1.67 Ga
Broken Hill ca 1.69 Ga
VMS ca 1.8 Ga

Suggests predominantly magmatic S source

n = 262
cpy, py, po, mo, cc, sph, gn, bn
REGIONAL SUMMARY

- Range of **syngenetic** and **epigenetic** Cu (and W) mineralisation styles spanning ca 1.82 to ca 1.7 Ga
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- Copper and sulfur link to mafic (& felsic) intrusions; sources: active (magmatism) and passive (leaching)
REGIONAL SUMMARY

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Why?
Active plate margin ca 1860 to 1760 Ma

Broadly west-east trending orogenic collision event

Giles et al 2002
Betts et al 2015
Active plate margin ca 1860 to 1760 Ma

Broadly west-east trending orogenic collision event

Giles et al 2002
Betts et al 2015
An example of an orogenic P-T-t-mineralisation history
An example of an orogenic P-T-t-mineralisation history

Need to explain:
* syngenetic Cu-Ag(Pb-Zn)*
& epigenetic Cu and W
Orogenic P-T-t path for JERVOIS RANGE

Weisheit et al 2016
Orogenic P-T-t path for JERVOIS RANGE

ca 1790 Ma

BASIN/VOLCANIC PROCESSES:

Sedimentation
Shallow magmatism
HTLP metamorphism
Non-marine back-arc setting?
Syngenetic Cu-Ag(Pb-Zn) minz
Orogenic P-T-t path for JERVOIS RANGE

ca 1755 Ma

NORMAL SHEARING

Peak-P metamorphism
Deformation of syngenetic mineralisation and host rocks

Wet solidus is not crossed
Orogenic P-T-t path for JERVOIS RANGE

ca 1730 Ma

LATE- MELT EMLACEMENT:
Epigenetic Cu and W
Granite magmatism & fluids
Jervois rocks don’t cross wet solidus so can’t melt…
Where does the melt come from?
Orogenic P-T-t path for JINKA PLAIN

Long fractionation time allows generation of W-Mo-rich melts
These migrate and intrude into cooler crust (JERVOIS RANGE area)

LATE- MELT EMBLACEMENT:

Higher heat-gradient

Jinka rocks cross wet solidus after 1790 Ma
Don’t return until after 1755 Ma

…So melts can form, but can’t crystallise until after 1755 Ma
Broadly… are similar P-T-t path applicable elsewhere?
Copper in the Palaeoproterozoic Aileron Province

- Range of syngenic and epigenetic Cu-related mineralisation from ca 1.82 Ga to ca 1.7 Ga
- Cu and S link to mafic rocks (active and passive)
- Apparent W-E spatial-temporal trend
- Very broadly… mineralisation linked to orogenesis… active plate margin in the southern NAC… but importantly…effects differ over time and space
Thank you

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