Metaexhalites, seafloor alteration and retrograde processes from metamorphosed deposits, Aileron Province

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Also thanks to:
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Basin-hosted massive sulfide deposits

Range of tectonic settings, most older deposits get deformed as basins close and are buried.

- Island Arc Porphyry & assoc. Skarn deposits
- Back-arc Basin SEDEX Zn-Pb-Ag
- Continental Arc Porphyry, & Skarn deposits
- Foreland Basin MVT deposits

VMS Deposits
- Accretionary Wedge with VMS deposit
- Partial Melting
- Devolatilisation
- Descending Slab

Increasing metamorphism, deformation, alteration

HYC Broken Hill
Palaeoproterozoic Aileron Province

- ca 1.80-1.79 Ga Cu-Ag-Pb-Zn mineralisation
- forming in contiguous belt of basin successions
- located on southern margin of the tectonically active NAC
- metamorphosed: upper amphibolite to granulite facies

Huston et al. 2017
Metamorphosed, deformed, altered deposits & host rocks

Range of syngenetic/diagenetic mineralisation styles: many unconfirmed; eg VAMS, VHMS, Broken-Hill type carbonate-replacement

Green Parrot and Reward, Jervois mineral field (BHT)

Edwards Creek (VAMS)

Oonagalabi carbonate (replacement or VAMS?)

Patmungala beds, (?VMS)

Basin floor-related Mg, Fe, Mn alteration

Basin-floor hydrothermal alteration

Mg-rich, Si-poor assemblages

anthophyllite

Cord-opx rock

sapphirine

Banded iron

garnetite

Mag-amphibole-spinel rock

Garnet-biotite rocks

Fe and Mn-rich alteration
Epigenetic (peak-$P$ metamorphism) magnetite-chlorite + copper

Reward deposit, Jervois mineral field

Rockface prospect, Jervois mineral field

prograde garnet-biotite assemblage

altered chlorite-magnetite rock (chloritised pseudomorphs of garnet)

Johnnies Reward deposit
Three alteration styles from Jervois:

• garnetites
• tourmalinites
• magnetite-chlorite

Their significance for ore-forming processes
Jervois mineral field: syn-sedimentary ores

Syn-sedimentary stratabound Cu-Ag-Pb-Zn hosted in metasedimentary Bonya Metamorphics. Metamorphosed: upper amphibolite facies; boudinaged and layer-parallel to main foliation.
Jervois mineral field: epigenetic ores

Epigenetic Cu-Ag mineralisation, overprints main foliation and later folding
**Metaexhalites and associated Fe-Mn alteration**

Unusual metamorphosed Fe-, Mn-, B- and P-rich rocks

Almost monomineralic

Host or spatially associated with base metal mineralisation

Garnetite (coticule)

Tourmalinite

Apatite-rich rock

Garnet-Biotite rock

Banded Iron (Algoma)
Metamorphosed hydrothermal chemical sediments

Hot metal-rich fluids exhale on or near cool subaqueous basin floor

Fe-Mn-rich muds = garnetite or garnet-biotite rock; B-rich muds = tourmalinite

Metaexhalites commonly associated with VMS and BHT deposits

Heimann et al 2009
Reward Cu-Ag-Pb-Zn deposit
Anomalous Fe and Mn enrichment
Anomalous Fe and Mn enrichment
Anomalous Fe and Mn enrichment

Ferruginous, manganiferous schist (oxidised)
abundant garnet and magnetite (primary)
This zone also hosts garnetites
Tourmalinites
Tourmalinites

Thin: commonly < 1m layered quartz-tourmaline bands deformed by main foliation, interlayered in schist

Peters et al 1985

LOOKING WEST

AGES 2017
Spotting metaexhalaltes
important: they indicate fossil hydrothermal fluid zones and nearby ore easily weathered (e.g., ferruginous/manganiferous schist) or mistaken for more common rock types (amphibolite, chert, graphitic sediments, BIF)
Potential across the Aileron to find more
Garnets and garnetites

Several garnet phases found regionally; only some link to syn-sedimentary mineralisation. (Unusual stratabound banded garnet or garnet-dominant massive assemblages)

Unmineralised garnet-bearing calc-silicate and schist ($S_2$ foliated)
Garnets and garnetites

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Metalliferous garnet-biotite schist
Hylogger results: garnets at Reward deposit

unmineralised schist/metacarbonate

Mineralisation

Smith et al 2016
Hylogger results: garnets at Reward deposit

60m garnet-zone: unusual chemistry

- **Spessartine**: Mn-Al-rich
- **Grossular**: Ca-Al-rich
- **Andradite**: Fe-rich, Al-poor

Smith et al 2016
Potential geochemical ore vectors

Potential for use of trace elements, and other metamorphic minerals
Staurolite, gahnite, tourmaline, magnetite

Reward garnet

regional garnet

Smith et al 2016
Tourmalinites: boron isotopes

SIMS analyses
Tourmalinates: boron isotopes
Tourmalinites: boron isotopes

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

-20  
0   
+20  
+40  

heavy  

oceans
Tourmalinites: boron isotopes

- Crust
- MORB + mantle

$\delta^{11}B$ (‰)

- Light
- Heavy
- Oceans
Tourmalinites: boron isotopes

- MORB + mantle
- Cont Crust
- $\delta^{11}B$ (%)
- Marine carbonates & evaporites
- Altered volcanics
- Clastic metasediments
- Non-marine evaporites
- Granites and pegmatites
- Granitic veins

Oceans
Borate from non-marine evaporites (no S-type granites)

Trumbull et al in prep
McGloin et al in prep
Borate from non-marine evaporites (no S-type granites)

Broken Hill tourmaline: consistent $\delta^{11}B$ values

Similar geology: high thermal gradient, metaexhalites, non-marine evaporites

Slack et al 1989
Trumbull et al in prep
McGloin et al in prep
Importance of terrestrial evaporites and borate

Paleoenvironment is very specific to evaporate borate in salt pan
- arid, within ~25 degrees of equator
Areas of high relief and topography (intermontane basins; not sea level)
Isolated basins: not marine chemistry
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Salar deposits, Andes

intermontane, arid, geothermally-active isolated basins
Active or formerly active volcanic/geothermal areas required for anomalous boron
High salinity Li-rich brines: great for metal transport; B-rich = borate
Salton Sea Geothermal Field, USA

Ignore precise tectonic setting
Similarities to Broken Hill (Slack et al 1989) (and Jervois)
isolated high-T gradient basin, terrestrial evaporites, active bimodal magmatism at depth
Highly saline high temperature brines; active base metal deposition

Los Angeles

Geothermal wells drilled to 3-4 km depth: Encountered active greenschist hydrothermal metamorphism
Evaporites leached (hornfelsed) suggesting fluid release as connate brines;
remaining fluid inclusions indicate high temperature saline fluids
Deeper levels: garnet-actinolite-biotite assemblages

McKibben et al 1988
“Active metamorphism”

Basin floor

bimodal magmatism, Attutra Metagabbro
“Active metamorphism”

Basin floor → Lower greenschist

Highly soluble

bimodal magmatism, Attutra Metagabbro
“Active metamorphism”

Bimodal magmatism, Attutra Metagabbro

Basin floor

Lower greenschist


**“Active metamorphism”**

- Basin floor
- Lower greenschist
- Upper amphibolite
- tourmalinite
- garnetite
- Cu-Ag-Pb-Zn garnet-biotite schist
Copper-related magnetite-chlorite alteration

Epigenetic timing….distinct from syn-sedimentary ores

Cu-Ag±Au mineralisation (none or little Pb-Zn; remobilised)
Forms veins and massive textures
Younger timing, not deformed, veins cross-cut main foliation and later folds
Magnetite-chlorite alteration is problematic…
Peak-\( P \) metamorphism ca 1.76 Ga: upper amphibolite facies conditions
Chlorite removed before peak-$P$ metamorphism;

Magnetite-chlorite alteration not consistent with this $P$-$T$-$t$ path;
must have formed through retrograde, fluid-assisted process

Evidence for this
Hamburger Hill prospect

Away from syn- and post-metamorphic alteration (no veins, pegmatites)
Same polymetallic Cu-Ag-Pb-Zn as J-Fold
Garnet–biotite-rock
No magnetite/chlorite – consistent with $P$-$T$-$t$ path
What’s different about the J-Fold then?
Regionally **>50 epigenetic Cu** occurrences
Share same timing, structural control, host rocks as magnetite-chlorite-Cu in J-Fold
but magnetite, Pb and Zn enrichment appears unique to the J-Fold

Why is this?
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Why is this?
Fluid-assisted retrograde alteration at Rockface
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Garnet-biotite magnetite-chlorite-biotite magnetite-cpy-py-qtz cpy-py
Fluid-assisted retrograde alteration at Rockface

- Garnet-biotite
- Magnetite-chlorite-biotite
- Magnetite-cpy-py-qtz
- Cpy-py

Diagram showing the mineralogy:
- Grt (Garnet)
- Mag (Magnetite)
- Chl (Chlorite)
- Qtz (Quartz)
- Tur (Turquoise)
- Scale bar: 20 mm
Fluid-assisted retrograde alteration at Rockface

Does precursor syn-sedimentary alteration control magnetite-related Cu mineralisation?
Chemical/structural traps?
Do these processes deconstruct the genesis of one type of “IOCG” deposit?
Thank you

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