Mapping, magnetics and microscopes: Understanding the setting of VAMS mineralisation in the Ordovician Girilambone Group, western NSW

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Overview

• Location
• Why and what
• Geological overview
• Outcomes
• Genetic model
• Exploration guide
• Summary
Location

- Bourke
- Cobar
- Nyngan
- Tottenham
- Queanbeyan
Why and what

- Poor mapping resolution
  - Continue 100k mapping
- Cu-rich deposits (e.g. Tritton) poorly constrained
  - Syngenetic or orogenic?
- Multi-discipline
  - Mapping
  - Potential field modelling
  - Mineral systems study
  - Research project
    - M. Econ. Geology (CODES)
- Collaboration
  - Industry
  - Geoscience Australia

Source: Burton et al. 2012, Gilmore et al. in prep, Hegarty in prep
Geological overview

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<th>Era</th>
<th>Age (Ma)</th>
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<td>Sil</td>
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<td>Ord</td>
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</table>

**Modern drainage**
- Gravel, silcrete, basalt

**Great Aust. Basin**
- Midway granite

**Tabberabberan Orogeny**
- Mulga Downs Gp?

**Cobar def'n?**
- Cobar S-Gp

**Benambran Orogeny**
- Ballast Fm
- Long Fm

**Girolambone Gp**
- Narrana Fm

Source: Hegarty (in prep.), Burton et al. (2012), Gilmore et al. (in prep).
Geological overview

- Early Ordovician
  - Widespread extension
  - Back arc setting
- Turbidite deposition
- MORB-affinity mafic rocks

Source: Foster and Gray 2000

Source: Foster and Goscombe (2013), Geosciences 3 (3), Geoscience Australia – Shaping A Nation.
Mapping – turbidites

- Poor surface exposure ...
- Interbedded sandstone, siltstone and claystone
  - Minor chert horizons
- Thicker quartz-rich sand horizons
  - Same provenance as turbidites
  - Channel(s) across fan?
  - Metamorphosed to quartzite

- Metamorphosed – lower greenschist
- Deformed – asymmetric folding

1 Fraser et al. 2014
Mapping – biostratigraphy

- Conodonts in chert and siliceous siltstone

Thanks to Dr Ian Percival
Mapping – mafic rocks

- Basalts and mafic schists$^{1,2}$
  - Ocean island basalts
  - Mid-ocean ridge basalt
- Ultramafic rocks$^{3,4}$
  - ‘Alpine style’ harzburgite
  - ‘Alaskan style’ complexes

1 – Burton 2011, Burton 2014, Barron et al. 2007, Bruce 2013

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Mapping – silica-iron rocks

• More extensive than previously mapped
  – The ‘pink quartzite’ of Smith and Hopwood in the 1970s

• 3 things about them ...
  – Magnetic
  – Same deformation fabrics & geometry as surrounding turbidites
  – Look identical to those over ore zones
Mapping – structure

- Main deformation event was the Benambran Orogeny ~440 Ma
  - Ar-Ar evidence (Fergusson et al. 2005)
Mapping – potential field models

- Magnetic and gravity models (Hegarty 2013)
  - Known mafic rocks on margins of gravity highs
  - High density basement – a large mafic intrusion at 5km?

Hegarty (2013)
Mapping – summary

• Two packages of turbidites
  – Early Ordovician (Narrama Fm)
    • Mafic and ultramafic rocks
    • Coarser grained
    • Hosts mineralisation
    • Hosts silica-iron rocks
      – Magnetic
    • Chert and quartzite markers
  – Middle Ordovician (Ballast, Lang)
    • Finer grained

• Consistent structure regionally
  – F3 fold axis
Mineralisation

- Range of interps!
  - Syngenetic VAMS
  - 1970s, 2010s
  - Orogenic
  - 1990s, 2000s

- Tritton resources
  - 50 Mt @ 2% Cu\(^1\)
  - >755 000t Cu

- Mined and identified resources\(^2\)

- ‘Very large’ deposit on global VAMS scale\(^3\)

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1 - Jones 2012, 2 - Straits 2012, 3 – Galley et al. 2007

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Mines & Wines | Queanbeyan Bicentennial Hall, NSW
Mineralisation – consistent features

• Host
  – Turbiditic metasedimentary rocks

• Footwall
  – Mafic schist (ex-basalt) and sills
  – MORB-affinity \(^1,2\)

• Hangingwall
  – Silica-iron rocks overlie ore
  – Mass flow with massive sulfide clasts at Tritton \(^3\)

1 - Burton 2011, 2 – Burton 2014, 3 - Jones 2012
Mineralisation – consistent features

- Mineralisation
  - Massive sulfide (cpy–py) zone
  - Pyrite-rich banded zone
  - Sub-economic veins in FW
  - Cu rich (elevated Au, Zn, Ag)

- Zoned alteration
  - Proximal Fe- to distal Mg-chlorite in FW
  - Silicification of the ore zone
  - Carbonate-altered HW

1 - Jones 2012

Mineralisation – consistent features

Deformation

• Mineralisation deformed the same as turbidites
  – i.e. mineralisation predates Benambran Orogeny
• Some remobilisation of chalcopyrite
• Late brittle faults
Mineralisation – age evidence?

- Hosted by Early Ordovician Narrama Formation
  - Biostratigraphy
  - Supported by detrital zircon provenance\(^1\)

- Plus Pb isotope model ages\(^2,3\)
  - Mostly Late Cambrian to Early Ordovician
  - Minor Devonian

Research project

• Significance of silica-iron rocks
  – Formation? Are they exhalative?
  – Mineralised v non-mineralised
  – Exploration vector?

• Mineralisation
  – Formation?

• Tools
  – Sulfur isotopes
  – Petrophysics
  – Pyrite geochemistry
    • Laser ablation ICPMS
Silica-iron rocks

- Exhalative or exhalite
- Worldwide feature with VAMS
  - Time and space
  - Typically overlie ore levels
  - Laterally extensive
- Form from ‘hydrothermal input to ongoing sedimentation’\(^1\)
- Geochemistry of magmatism influences type
  - Felsic systems = barite
  - Mafic systems = jaspers

\(^1\) – Gibson et al. 2007

Slack (2010) USGS
Silica-iron rocks

- Only in Early Ordovician Narrama Fm.
- Always near mafic or ultramafic rocks
- Layered quartz and iron oxides
- Same structure as turbidites
- 57 to 94% SiO$_2$
- 2 to 10% Fe$_2$O$_3$
- Variable magnetite content but still most magnetic rocks regionally
  - Average magnetic susceptibility
    1452 x 10^{-5} SI
  - Maximum 52 100 x 10^{-5} SI
Silica-iron rocks

- Those associated with mineralisation are geochemically distinct
  - Positive Eu anomaly when normalised to chondrite
  - Relative enrichment in REE
  - Elevated Cu and Ag
  - Narrow range of sulfur isotopes
    - 10.2 and 12.8‰
    - Reduced seawater sulfate source
    - (other silica-iron biogenic source)

- In summary ...
  - Silica-iron rocks are magnetic
  - Those associated with mineralisation can be discriminated geochemically
Mineralisation

- Sample from banded pyrite ore at Tritton
- Chalcopyrite within early pyrite
  - Magmatic source
- Sn (Ag-In) with Cu
  - Mafic source
- Ni v Co ratio
  - Seawater source
- U-Th rims
  - Seawater source
Mineralisation v silica-iron

- Pyrite geochemistry
  - As you go up sequence ...
    - Lower temperature
    - Increased sediment input
- Sulfur isotopes
  - Consistent across zones
- Deformation
  - Same fabrics and geometry
- Exhalative horizons formed from same process as mineralisation

Legend: Δ = footwall, O = laminated ore zone, ● = copper-rich ore zone, ■ = massive sulfide, □ = silica-iron horizon.

Sulfur isotopes across Tritton ore zone (‰)

Volcanic, magmatic and hydrothermal

Sedimentary and mafic source rocks

Co (ppm)

Ni (ppm)
Mineralisation - how did it form?

- Early Ordovician extension
- Hydrothermal cell driven by magmatism (MORB)
- Fluid from magma, seawater, sediments
- Metal precipitation as cooled by seawater in sediment pile
  - Subseafloor replacement
- Exhalites are spent fluids

Huston (2002)
Mineralisation - how did it form?

- A syngenetic origin – volcanic-associated massive sulfide (VAMS)
  - Mafic-siliclastic\(^1\) or pelitic–mafic-hosted (Besshi-type) Cu\(^2\)
- Preservation aided by sediment pile and ongoing sedimentation
- Deformed in Benambran Orogeny
  - Remobilisation of chalcopyrite, not hot enough to effect pyrite

Source: 1 – Piercey (2007), Downes et al. (2011)
So how do you find one ... an exploration guide

• **Stratigraphic corridor**
  -- Look in the Narrama Formation
    • FW – mafic (MORB not OIB)
    • HW – quartzite, exhalative
  -- Use regional magnetic data
    • Most likely exhalative horizons
    • Look at REE, Eu, Cu, S-isotopes
  -- Electrical geophysics
    • AEM / DHEM (e.g. Collins 2001)

• **Structure**
  -- Regional-scale (F3) folding
    • Structural repeats?
  -- Ore body geometry
Exploration guide

• Helix Resources Limited discovered Collerina VAMS in 2014
• Between Budgery and Tottenham
• GSNSW trend used to identify potential targets under cover

Source: Helix, ASX announcement 01/04/2015
Summary

• Girilambone Group hosts significant VAMS mineralisation

• Understanding the setting and style of mineralisation is critical to develop exploration models for further discovery

• Integration of geoscientific observations at different scales

• Communication between geologists
  • Government
  • Industry
  • Academia
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