IOCG mineralisation and alteration

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IOCG Workshop
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Outline

1. Summaries of IOCG deposits:
   - Olympic Dam
   - Prominent Hill
   - Carrapateena

2. Regional & deposit alteration

3. Targeting higher grade Cu-Au
Fe oxide Cu-Au (IOCG) deposits: A descriptive definition of a diverse class

- Cu, Au, ± U, LREE, Ag, CO₃, F, P, Ba, Co association
- Cu-Fe sulfides & Au spatially assoc with abundant (>10%) magnetite and/ or hematite
- Hydrothermal quartz << Fe-oxides; sulfides << Fe-oxides
- Local alteration is potassic (Kfs, bt), hydrolytic (ser, chl), and/ or carbonate; regional alteration is Na-Ca
- Epigenetic, structurally-controlled hydrothermal replacements, vein stockworks, breccias
- Distal from coeval igneous intrusions; various hostrocks
- Fluids: hypersaline, & separate lower salinity brines, ± CO₂
  (based on Hitzman et al., 1992; Hitzman, 2000; Haynes, 2000)
Gawler IOCG deposit grade-tonnages in perspective

Global & Australian IOCG deposits Cu grade-tonnage

Size, Mt (proved, probable, inferred)

0.1 1 10 100 1000 10000

0.1 1 10

Sossego
Salobo
Cand
Cristalino
Alemao
Mina Justa
EH
Khetri
Osborne
Moonta
Eloise
Peko
Gecko
Warrego
Selwyn
Prom. Hill

Carajas, Brazil

OD (761 Mt @ 1.5% Cu, 0.6kg/t U$_3$O$_8$, 0.5g/t Au)

OD resource

3.81Bt @ 1.1%Cu

Australian deposits

Global & Australian IOCG deposits Cu grade-tonnage


I O C G W o r k s h o p , F e b 2 0 0 6

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Olympic Cu-Au province: IOCG deposits & prospects

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

Lithostratigraphy

- Hiltaba Suite granitoid (1595-1570 Ma)
- Mafic intrusions
- Gawler Range Volcanics
- Mafic Gawler Range Volcanics
- Wallaroo Gp - metasedimentary & metavolcanic rocks
- Intrusive rocks, mainly felsic; mafic
- Hutchison Gp & equivalents; BIF
- Undifferentiated Archaean to Palaeoproterozoic rocks
- IOCG(U) deposit or prospect

Prominent Hill
OLYMPIC DAM
Acropolis
Wirrda Well
Emmie Bluff
Carrapateena
Wallaroo

100 km

Geoscience Australia
1. Summaries of IOCG deposits of the Gawler Craton
After Reynolds (2000)
Olympic Dam geochronology

From Jagodzinski (2005)
Olympic Dam 1: fracturing & incipient brecciation of granite host

chlorite-hematite veins/replacements
**Olympic Dam breccia-hosted Cu-U-Au**

**Copper ore**
- Chalcopyrite-pyrite zone
- Bornite-chalcocite zone
- Hm-qtz-ser-chl-sulfides

**Heterolithic, multistage breccias**
- Altered volcanic
- Cpy-hm clast

**Scale**
- 2 cm
Olympic Dam: formation model (Haynes et al., 1995)
Olympic Dam faults

Regional & deposit structure
(based on Sugden, 1992; Cross et al. 1993; Widdup et al. 2004)

NNE fault

WNW dextral shear

Olympic Dam Breccia Complex & diatremes

Late syn- to post-ODBC E-W faults

From Widdup et al. (2004)
Model for Mine Area A breccias (from Conor, 2004)
Prominent Hill discovery 2001:
101 Mt @ 1.5% Cu 0.55 g/ tAu + 21 Mt @ 1.2 g/ tAu

Magnetic (background) + gravity (contours)

Sources: Minotaur + MESA Journal (January 2003)

>0.5% Cu, projected to surface
Prominent Hill - plan geology and alteration (courtesy PIRSA & Minotaur)

0.5% Cu projected to surface

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Prominent Hill – section geology and alteration
(courtesy PIRSA & Minotaur)

- 37m @ 0.69 g/t Au
- 50m @ 2.02% Cu 0.63 g/t Au
- 209m @ 1.54% Cu 0.93 g/t Au
Prominent Hill planned open cut mine; production in 2009

Source: Oxiana website (2005)
• MIM drilled Salt Creek anomaly to NW in 1970’s; hm-ser alt’n
• MIM re-entered in JV with Terramin Aust Ltd & Rudy Gomez; defined Carrapateena gravity anomaly in 2002-2003
• MIM MDAS survey looked discouraging; MIM pulled out
Carrapateena – gravity contours (0.1 mgal) and residual magnetics

- Early 2005 - RMG Services drills CAR1 and CAR2, co-funded by PACE
- Oct 2005 - TeckCominco takes ownership
- $18m to be spent on drill-out

(Source: PIRSA - AMEC, 2005)
Carrapeteena CAR02: 178 m @ 1.83% Cu, 0.6 g/ t Au

Upper zone: 73 m @ 2.9 % Cu, 0.4 g/ t Au from 476 m

(hemaitic breccia with disseminated bornite)

2 cm

505.0 m

(hematite)

5-6% Cu

bornite

2 cm

507.4 m

(photos with permission of TeckCominco; assay results from RMG Services, PACE, 2005)
Carrapeteena CAR02: 178 m @ 1.83% Cu, 0.6 g/ t Au

Lower zone: 33 m @ 1.5 % Cu, 0.7 g/ t Au to 641 m (chalcopyrite zone)

(photos with permission of TeckCominco; assay results from RMG Services, PACE, 2005)
2. Regional and deposit alteration
Olympic Cu-Au province, eastern Gawler Craton

Area of next slide
Regional to deposit-scale alteration

- Magnetite–alk feld–calcsil + Cu-Au
- Magnetite–biotite + Cu-Au

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

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Regional- to deposit-scale magnetite alteration, minor Cu

Granite cutting alteration

Kfs-mgt

host
sed

Olympic Dam region

mgt-act-py-carb

Olympic Dam region

Moonta-Wallaroo

albitisation along foliation in seds

actinolite

Moonta-Wallaroo

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Regional to deposit-scale alteration

- Magnetite–alk feld–calcsil $\pm$ Cu-Au
- Magnetite–biotite $\pm$ Cu-Au
- Hematite–ser–chl–carb $\pm$ Cu-Au-U
- Hm overprinting magnetite (but synchronous at OD; Haynes et al., 1995)

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

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Carrapeteena CAR02: 178 m @ 1.83% Cu, 0.6 g/ t Au

Middle zone: 58 m @ 0.9 % Cu, 0.9 g/ t Au
(granite-chalcopyrite zone)

Chlorite-hematite-sericite altered granite clasts in breccia

(photo with permission of TeckCominco; assay results from RMG Services, PACE, 2005)
Prominent Hill

hematite-sericite alteration + Cu-sulfides, Au (LREE, U)

IOCG districts have mgt, but hm-ser is better for OD / PH style

DP003 463-464m: 30% Fe, 2.9% Cu, 0.9 g/t Au, 8g/t Ag
Chalcocite and Bornite within flow banded hematite breccia

Source: Minotaur Resources website, 2003
3. Targeting higher grade Cu-Au

How to target IOCG deposits under cover?

Olympic Dam - under 300m of cover
Mapping alteration undercover with potential-field inversion modelling

Olympic Cu-Au province alteration
- Magnetite–alk feld–calcsil + Cu-Au
- Magnetite–biotite + Cu-Au
- Hm overprinting magnetite

(from Skirrow, Bastrakov, Raymond et al., 2002)
District scale targeting: mapping alteration using inversion modelling (Nick Williams, GA)

Total Magnetic Intensity

Gravity

Total magnetic intensity (nT)

Contours of 0.5% ‘sulfides+hematite’ at -500 m

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Mapping alteration undercover by 3D inversion of magnetic and gravity data.
Mapping alteration undercover by 3D inversion of magnetic and gravity data

2D slice of 3D inversion model for mgt at ~-500m

Anomalous Magnetite (contour for > ~2% vol.)

Anomalous ‘hematite’ (contour for > ~2% vol.)
Mapping alteration undercover by inversion of magnetic and gravity data

Basement geology

Archaean metaseds

Olympic Dam

Anomalous magnetite (> ~2% vol.)

Anomalous hematite (> ~2%)

IOCG alteration controlled by major NW-WNW fault zones (less so by lithology);

& Many untested ‘hm’ anomalies
OK, but which ‘hematite’ anomalies have potential for major IOCG?

And, which parts of these alteration systems might contain higher grade Cu-Au mineralisation?

Turn now to geochemistry for deposit scale targeting.
Discriminating fertile from minor alteration systems & deposits using neodymium & sulfur isotopes

Minor Cu or barren: Crustal = local input? (e.g. from granites, metaseds)

Major deposit has mantle input, so look for primitive mafics in district

OD data: Johnson & McCulloch (1995); Eldridge & Danti (1994); other data: Skirrow et al. submitted

Discriminating fertile from minor alteration systems & deposits using neodymium & sulfur isotopes

hm + minor Cu

Gabbro (1760 Ma)

Mantle derived mafic (1590, OD)

hm + Cu

Olympic Dam

OD mt

whole rock \( \varepsilon_{\text{Nd}} \) (1590 Ma)
Deposit scale targeting: higher grade Cu-Au zones

Magnetite-rich alteration with minor chalcopyrite like this . . . is commonly altered to hematite-chlorite-sericite by fluids like this . . .

Fluid inclusions
(Bastrakov et al., submitted)
Deposit scale targeting: higher grade Cu-Au zones

What if we chemically model this scenario?

Oxidised Cu-Au-free brine

Chalcopyrite

Cu=0.1%

Au=0.1 g/t

250°C

Magnetite

(Bastrakov et al., submitted)

What if we chemically model this scenario?

Oxidised Cu-Au-free brine

Chalcopyrite

Cu=0.1%

Au=0.1 g/t

250°C

Magnetite

(Bastrakov et al., submitted)
Magnetic Sus. (emu)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Vol. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalcocite</td>
<td></td>
</tr>
<tr>
<td>Bornite</td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td></td>
</tr>
<tr>
<td>Pyrite</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>Hematite</td>
<td></td>
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</tbody>
</table>

Total Cu = 2.7%

Au = 1 g/t

higher grade Cu-Au in ‘de-mag’ zone ‘adjacent’ to magnetite

(Bastrakov et al., submitted)
Deposit scale targeting: higher grade Cu-Au zones

Basement geology

Anomalous magnetite (> ~2% vol.)

Anomalous hematite (> ~2%)

search contacts & edges of ‘hematite’ zones
Conclusions – targeting IOCG mineralisation

New methods (inversion modelling; geochemical tools) can reduce risk in IOCG exploration in covered terranes.

Hematite-sericite-chlorite-carbonate alteration with or without ‘earlier’ magnetite-bearing alteration is a key ingredient for shallow-crustal (OD, PH, Car) style IOCGs.

District to deposit scale targeting: gradients are good! Search contact zones of hematitic alteration in ‘fertile’ systems (e.g. those with syn-alteration mafic dykes).

Look out for other associated (?) mineralisation styles – epithermal, porphyry, skarn.
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