The role of unmixing in magnetite ± copper deposition in Fe-oxide Cu-Au systems

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Introduction

The process of unmixing appears to play a critical role in the precipitation of magnetite ± copper in Fe-Oxide Cu-Au systems in the Eastern Fold Belt of the Mt Isa Block. Co-existing multi-solid brine and halite-bearing liquid CO₂-rich fluid inclusions that have undergone unmixing have been recognized at Osborne Cu-Au and Starra Au-Cu mines. This process has also been recognized at Lightning Creek prospect, an Fe oxide system that is demonstrably magmatic in origin (Perring et al., 2000).

A combination of microanalytical tools including conventional microthermometry, Laser Raman spectroscopy, and proton induced X-ray emission (PIXE) were utilized to study the composition of fluid inclusions from the Osborne Fe-Oxide Cu-Au deposit. Element concentrations in fluid inclusions were determined using the CSIR-GEMOC PIXE nuclear microprobe at CSIRO, North Ryde. Gas composition of vapour bubbles was determined using the Laser Raman spectroscope at Geoscience Australia, Canberra.

General Geology

The Osborne deposit is located 195 km southeast of Mount Isa and is owned by Placer Pacific Limited. In 1996 Osborne had a total measured and indicated mineral resource of 11.3 Mt @ 2.9% Cu, 1.18 g/t Au (Adshead et al., 1998). The deposit is hosted within a multiply deformed sequence of upper amphibolite facies metamorphic rocks, including feldspathic psammites, pelites, metasedimentary gneisses, amphibolites, and pegmatites of the Mount Isa Eastern Sucession. The deposit can be divided into the ‘Western’ and ‘Eastern’ domains based on differences in the host rocks and mineralization characteristics. The western domain contains the bulk of the Cu-Au mineralization, occurs at the contact between a banded ironstone formation and feldspathic psammite, and is dominated by a hematite-magnetite-pyrite mineral assemblage. The eastern domain mineralization is not spatially associated with the ironstones, forms a discrete body hosted within strongly silicified rocks, and exhibits a more reduced pyrrhotite-magnetite±pyrite assemblage.

Fluid Inclusion Types

Pre-syn mineralization quartz contains primary to pseudosecondary hypersaline fluid inclusions that are associated with silica flooding. In the western domain these commonly coexist with high density halite-bearing liquid CO₂ inclusions providing clear evidence of fluid unmixing (Figure 1). Two end member fluid inclusion types include multi-solid brine (LVnS, n=4-6) and halite-bearing liquid CO₂ (LCO₂nS, n=3-5; Figure 2). The multi-solid brine inclusions typically consist of liquid,
vapour (5 vol %), halite, sylvite, lesser CaCl solid, one or two ferropyrosmalite phases (Fe-rich and Fe-poor), an unidentified <1µm opaque phase (possibly chalcopyrite), magnetite, and rare calcite. Many liquid CO₂ inclusions contain halite, sylvite, ferropyrosmalite and calcite. The multi-solid brine inclusions have salinities of 33-60 wt % NaCl equivalent and homogenize primarily by ferropyrosmalite dissolution or less commonly vapour disappearance at 260-505°C (Table 1). Total homogenization for liquid CO₂ inclusions occurred between 308 and 375°C. CO₂ homogenisation temperatures ranged from -10 to 29°C.

Figure 1. Clear evidence of fluid unmixing into aqueous brine and high density carbonic fluids is observed at the Osborne deposit. Note the presence of a large magnetite phase in one of the inclusions, demonstrating a direct association of unmixing with magnetite precipitation. PIXE analyses of the magnetite-bearing inclusions in this trail indicate the presence of copper in direct association with the magnetite (Refer to Figure 3).

Figure 2. Multi-solid (A & B) and LCO₂-rich (C) fluid inclusion associated with pre to syn-mineralisation unmixing at Osborne Cu-Au deposit. Fpy = ferropyrosmalite, NaCl = Halite, KCl = Sylvite, Cal = Calcite, Mgt = Magnetite.

Laser Raman Results
Laser Raman highlighted the presence of solid phases including: Fe-rich and Fe-poor ferropyrosmalite, calcite, magnetite and up to 3 separate salt phases. This technique also indicated the absence of gases from the brine inclusions. Coexisting liquid CO₂ inclusions were dominantly CO₂ bearing with minor N₂ and CH₄.

**PIXE Results**

PIXE analyses of the inclusions described above reveal that Cu displays a strong spatial association with a Fe-rich rod-shaped ferropyrosmalite phase and to a lesser degree with magnetite (Figure 3). A second round-shaped Fe-poor ferropyrosmalite phase contains significantly less Cu when present. Multi-solid brine inclusions with higher levels of Cu exhibit a strong spatial association between Fe, Cu, Zn, Pb and Rb. Despite both inclusion types containing similar concentrations of calcium, in the multi-solid brine inclusions Ca is located in the liquid phase. In contrast the liquid CO₂-rich inclusions contain Ca in a calcite solid phase only.

![Image](image.png)

*Figure 3. Location of Cu in multi-solid fluid inclusions. Cu is associated with magnetite in sample 36b_21. Cu is associated with a Fe-rich, rod-shaped ferropyrosmalite phase in sample 36b_22.*

**Discussion**

Fluid inclusion studies from Fe-oxide Cu-Au deposits have documented the existence of both hypersaline aqueous and low-salinity CO₂-rich fluids associated with sodic-calcic alteration and mineralisation (Pollard, 2000) and have been interpreted to have formed by unmixing of an original H₂O-CO₂-NaCl-CaCl fluid (Adshead., et al. 1998). These previous studies have revealed both inclusions in the one sample but have not displayed unambiguous coexistence of the two in the same populations. Here we have shown clear examples of co-existing hypersaline aqueous and high salinity CO₂-rich fluid inclusions occurring along single trails from pre-syn-mineralisation quartz associated with both magnetite and minor chalcopyrite (Figure 1). The unmixing occurred under conditions of high P-T of >500°C and ~0.5 GPa when placed on the NaCl,CaCl₂-H₂O-CO₂ triplot of Shmulovich and Graham (2004).
Studies of the Starra Au-Cu deposit (Rotherham et al., 1998) reveal the presence of primary multi-solid inclusions (containing liquid, vapour, halite, ferropyrosmalite, calcite, and magnetite) and liquid CO\(_2\) inclusions associated with ironstones. The inclusion types are comparable to those coexisting at Osborne. Furthermore, Perring et al. (2000) noted comparable co-existing primary 'magmatic' fluid inclusions in albite-magnetite-quartz sills. PIXE analysis of the brine inclusions revealed high levels of Cu (1.0-1.9 wt %). Further studies by Williams et al. (2003) revealed that Cu is in the ferropyrosmalite.

Unmixing is a critical process in early magnetite-rich ± Cu deposition, based on its presence at Osborne Cu-Au mine, Starra Au-Cu mine and Lightning Creek prospect. The source of fluid is debatable but Lightning Creek is demonstrably magmatic and may imply magmatic processes occurring at Starra and Osborne.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Starra</th>
<th>Osborne</th>
<th>Lightning Creek</th>
</tr>
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<tbody>
<tr>
<td>Reference</td>
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<td>Adshead, 1995</td>
<td>Perring et al., 2000</td>
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<tr>
<td>Inclusion Type</td>
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<td>Multisol. CO(_2)-rich</td>
<td>Multisol. CO(_2)-rich</td>
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<td>Est. Depth</td>
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<td>7 km (2.1 kbar)</td>
<td>&gt;6.25 km (&gt;1.5-&gt;2.5kbar)</td>
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Table 1. Comparison of co-existing multi-solid and CO\(_2\)-rich fluid inclusions from Starra Au-Cu mine, Osborne Cu-Au mine and Lightning Creek prospect.

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References


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