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BIBLIOGRAPHY


Bowers, T.S., and Helgeson, H.C., 1985, FORTRAN programs for generating fluid inclusion isochors and fugacity coefficients for the system H₂O-CO₂-NaCl at high pressures and temperatures


Cline, J.S., and Bodnar, R.J., 1994, Direct evolution of brine from a crystallizing silicic melt at the Questa, New Mexico, molybdenum deposit: Economic Geology, v. 89, p. 1780-1802.


Davidson, G. J., Large, R. R., Kary, G. L., and Osborne, R., 1989, The deformed iron-formation-hosted Starra and Trough Tank Au-Cu mineralization; a new association from the Proterozoic eastern succession of Mount Isa, Australia The geology of gold deposits; the perspective in 1988 v. 6, p. 135-150.

Day, W.C., Seeger, C.M., and Rye, R.O., 2001, Review of the iron oxide deposits of Missouri; magmatic end members of the iron oxide Cu-Au-U-REE deposit


Hack, A.C., and Mavrogenes, J.A., 2006, A synthetic fluid inclusion study of copper solubility in hydrothermal brines from 525 to 725 °C and 0.3 to 1.7 GPa: Geochimica et Cosmochimica Acta, v. 70, p. 3970-3985.


Helgeson, H.C., 1992, Effects of complex formation in flowing fluids on the hydrothermal solubilities of minerals as a function of fluid pressure and
temperature in the critical and supercritical regions of the system H$_2$O:

the thermodynamic of aqueous electrolytes at high pressures and temperatures:
IV. Calculation of activity coefficients, osmotic coefficients, and apparent molal
and standard and relative partial molal properties to 600°C and 5 kbar: American

**Hemley, J.J., Cygan, G.L., Fein, J.B., Robinson, G.R., Jr., and D’Angelo, W.M.,
1992**, Hydrothermal ore-forming processes in the light of studies of rock
buffered solutions. I, Iron-copper-zinc-lead sulfide solubility relations:

of studies in rock-buffered systems: II. Some general geologic applications:
Economic Geology, v. 87, p. 23-43.

**Henley, R.W., 1984**, Metals in hydrothermal fluids: in Henley, R.W., Truesdell, A.H.,
and Barton, P.B. (Eds). Fluid-mineral equilibria in hydrothermal systems:
Reviews in Economic Geology, v.1, p. 115-126, Society of Economic
Geologists.

controlling copper solubility and chalcopyrite deposition in the Sungun porphyry
copper deposit, Iran: Mineralium Deposita, v. 34, p. 770-783.

**Hitzman, M. W., Oreskes, N., and Einaudi, M. T., 1992**, Geological characteristics
and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits.: 

T.M., Ed., Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A

**Hollister, L.S., 1988**, On the origin of CO$_2$-rich fluid inclusions in migmatites: Journal
of Metamorphic Geology, v. 6, p. 467-474.

**Hollister, L.S., 1990**, Enrichment of CO$_2$ in fluid inclusions in quartz by removal of
H$_2$O during crystal-plastic deformation: Journal of Structural Geology, v.12, p.
895-901.


Irwin, J.J., and Roedder, E., 1995, Diverse origins of fluid inclusions at Bingham (Utah, USA), Butte (Montana, USA), St Austell (Cornwall, UK) and Ascension Island (mid-Atlantic, UK), indicated by laser microprobe analysis of Cl, K, Br, I, Ba + Te, U, Ar, Kr and Xe: Geochimica et Cosmochimica Acta, v. 59, p. 295-312.


Mark, G., Williams, P.J., Oliver, N.H.S., Crookes, R.A., Valenta, R.K., and Gow, P.A., 1999, Characteristics and Origin of the Ernest Henry Iron Oxide-Copper-
Gold Hydrothermal System: Results of the 1999 Collaborative SPIRT Research Project (Unpublished), James Cook University.


Nash, J.T., 1976, Fluid inclusion petrology, data from porphyry copper deposits and applications to exploration: USGS professional paper 907D.


Cu-Au district: STOMP: Structure, Tectonics and Ore Mineralisation Processes Abstract Volume, EGRU Contribution 64, p. 100.


Rubenach, M.J., 2005b, Relative timing of albitization and chlorine enrichment in biotite in Proterozoic schists, Snake Creek anticline, Mount Isa Inlier, Northeastern Australia.


Rubenach, M.J., Foster, D.R.W., Evins, P.M., Blake, K.L., and Fanning, C.M., in press. Age constraints on the tectonothermal evolution of the Selwyn Zone, Eastern Fold Belt, Mount Isa Inlier: Precambrian Research

Rubey, W.W., and Hubbert, M.K., 1959, Role of fluid pressure in mechanics of overthrust faulting I. Mechanics of fluid-filled porous solids and its applications


Schmidt, C., Rosso, K.M., and Bodnar, R.J., 1995, Synthetic fluid inclusions XIII. Experimental determination of PVT properties in the system H2O + 40 wt% NaCl + 5 mol% CO2 at elevated temperatures and pressure: Geochimica et Cosmochimica Acta, v. 59, p. 3953-3959.


Williams, P.J., Barton, M.D., Johnson, D.A., Fontbonte, L., de Haller, A., Mark, G., Oliver, N.H.S., and Marschik, R., 2005, Iron oxide copper-gold deposits; geology, space-time distribution, and possible modes of origin: in Hedenquist,

Williams, P.J., Broman, C., Dong, G., Mark, G., Martinsson, O., Mernagh, T.P., Pollard, P.J., Ryan, C.G., and Tin Tin Win, In Press, PIXE characterisation of Fluid Inclusion Brines from Proterozoic Fe Oxide-Bearing Cu-Au Deposits, Norrbotten (Sweden) and the Cloncurry District (NW Queensland).


Williams, P.J., Prendergast, W.J., and Dong, G., 1998, Late orogenic alteration in the wall rocks of the Pegmont Pb-Zn deposit, Cloncurry district, Queensland, Australia: Economic Geology, v. 93, p. 1180-1189.


Yardley, B.W.D., 2005, Metal concentrations in Crustal Fluids and Their Relationship to Ore Formation: Economic Geology, v. 100, p. 613-632.


APPENDIX A - Microthermometry Data

Data is interpreted and discussed in Chapter 2.

Teu  Eutectic temperature / first melting temperature
Tm (aq)  Final melting temperature of ice
Tm (CO₂)  Final melting temperature of CO₂
Th V (CO₂)  Homogenisation temperature of CO₂ (L → V)
ThV  Homogenisation temperature of vapour phase
TdSyl  Dissolution temperature of Sylvite daughter mineral
TdHal  Dissolution temperature of Halite daughter mineral
TdFPS  Dissolution temperature of Ferropyrosmalite daughter mineral
TdCal  Dissolution temperature of Calcite daughter mineral
TdUkn  Dissolution temperature of unknown daughter mineral/s
TD  Decrepitation temperature
Th  Final homogenisation temperature
DATA APPENDICES HAVE BEEN REMOVED
DATA APPENDICES HAVE BEEN REMOVED
DATA APPENDICES HAVE BEEN REMOVED
CO2 INCLUSIONS

DATA APPENDICES HAVE BEEN REMOVED
### 40_M12: CB Inclusion

Inclusion Volume: 754 µm³
Vapour Volume: 127.8 µm³
Vapour Volume %: 16.95

CO₂ : 95%  
N₂ : 5%

<table>
<thead>
<tr>
<th>CO₂ mass (x10⁻¹² g)</th>
<th>103.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂ mass (x10⁻¹² g)</td>
<td>5.4</td>
</tr>
</tbody>
</table>

**Daughter Phases:**

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (g/cm³)</th>
<th>Volume (µm³)</th>
<th>Mass (x10⁻¹² g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>2.17</td>
<td>125.0</td>
<td>271.3</td>
</tr>
<tr>
<td>Sylvite</td>
<td>1.99</td>
<td>44.7</td>
<td>89.0</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>2.72</td>
<td>54.6</td>
<td>148.5</td>
</tr>
</tbody>
</table>

Total Volume: 224.3 µm³
Daughter Vol %: 29.7

**Liquid Volume:**

Liquid Volume: 401.9 µm³  
Liquid Mass (x10⁻¹² g): 602.9

Liquid Volume %: 62.4 (for ρ = 1.5 g/cm³)

**Solute and solvent masses**

<table>
<thead>
<tr>
<th>mass NaCl</th>
<th>308.63</th>
<th>30.81</th>
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</thead>
<tbody>
<tr>
<td>mass KCl</td>
<td>126.33</td>
<td>12.61</td>
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<tr>
<td>mass FeCl₂</td>
<td>60.29</td>
<td>6.02</td>
</tr>
<tr>
<td>mass CaCO₃</td>
<td>148.51</td>
<td>14.83</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>249.22</td>
<td>24.88</td>
</tr>
<tr>
<td>mass CO₂</td>
<td>103.2</td>
<td>10.30</td>
</tr>
<tr>
<td>mass N₂</td>
<td>5.4</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**TOTAL**

1001.60 100.00

**Fluid Composition:**

<table>
<thead>
<tr>
<th>Mass Na⁺</th>
<th>121.41</th>
<th>Mass Cl⁻</th>
<th>187.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass K⁺</td>
<td>66.26</td>
<td>Mass Cl⁻</td>
<td>60.07</td>
</tr>
<tr>
<td>Mass Fe²⁺</td>
<td>26.56</td>
<td>Mass Cl⁻</td>
<td>33.72</td>
</tr>
<tr>
<td>Mass Ca²⁺</td>
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</tbody>
</table>

TOTAL Cl⁻ 281.02

<table>
<thead>
<tr>
<th>Mass CO₃</th>
<th>89.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass CO₂</td>
<td>103.20</td>
</tr>
<tr>
<td>Mass N₂</td>
<td>5.43</td>
</tr>
<tr>
<td>Mass H₂O</td>
<td>2057.73</td>
</tr>
</tbody>
</table>

**TOTAL** 2810.11

**45.77 Wt % Salts**
### 852_1_1: MS Inclusion

Inclusion Volume: 584.95 µm³
Vapour Volume: 53.2 µm³
Vapour Volume %: 9.09

#### Daughter Phases:

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (g/cm³)</th>
<th>Volume (µm³)</th>
<th>Mass (x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>2.17</td>
<td>296.3</td>
<td>643.0</td>
</tr>
<tr>
<td>Sylvite</td>
<td>1.99</td>
<td>64.0</td>
<td>127.4</td>
</tr>
<tr>
<td>Ferropyrosmalite</td>
<td>3.12</td>
<td>34.7</td>
<td>108.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>395.0</strong></td>
<td></td>
<td><strong>67.5</strong></td>
</tr>
</tbody>
</table>

Liquid Volume: 136.8 µm³
Liquid Mass (x10⁻¹²g): 205.1
Liquid Volume %: 23.38 (for ρ = 1.5 g/cm³)

#### Solute and solvent masses

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass NaCl</td>
<td>=643 + (0.0062 x 205.1)</td>
<td>644.24</td>
</tr>
<tr>
<td>mass KCl</td>
<td>=127.4 + (0.0322 x 205.1)</td>
<td>133.97</td>
</tr>
<tr>
<td>mass FeCl₂</td>
<td>=0.1 x 205.1</td>
<td>20.51</td>
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<tr>
<td>mass CaCl₂</td>
<td>=0.4482 x 205.1</td>
<td>91.94</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>=(0.0803 x 108.3) + (0.4134 x 205.1)</td>
<td>93.49</td>
</tr>
<tr>
<td>mass FeO</td>
<td>=(0.4908 x 108.3)</td>
<td>53.14</td>
</tr>
<tr>
<td>mass MnO</td>
<td>=(0.0471 x 108.3)</td>
<td>5.10</td>
</tr>
<tr>
<td>mass MgO</td>
<td>=(0.0038 x 108.3)</td>
<td>0.41</td>
</tr>
<tr>
<td>mass SiO₂</td>
<td>=(0.3421 x 108.3)</td>
<td>37.04</td>
</tr>
<tr>
<td>Mass Cl</td>
<td>=(0.0404 x 108.3)</td>
<td>4.37</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1084.21</strong></td>
<td><strong>108.25</strong></td>
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</tbody>
</table>

#### Fluid Composition:

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
<th>(x10⁻¹²g)</th>
<th>Molarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass Na⁺</td>
<td>253.43</td>
<td>mass Cl⁻</td>
<td>390.82</td>
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<tr>
<td>mass K⁺</td>
<td>70.26</td>
<td>mass Cl⁻</td>
<td>63.70</td>
</tr>
<tr>
<td>mass Fe²⁺</td>
<td>50.34</td>
<td>mass Cl⁻</td>
<td>11.47</td>
</tr>
<tr>
<td>mass Ca²⁺</td>
<td>33.21</td>
<td>mass Cl⁻</td>
<td>58.73</td>
</tr>
<tr>
<td>mass Mg²⁺</td>
<td>0.25</td>
<td>mass Cl⁻</td>
<td></td>
</tr>
<tr>
<td>mass Mn²⁺</td>
<td>3.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mass Si⁴⁺</td>
<td>17.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL Cl⁻</strong></td>
<td><strong>529.10</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mass O</td>
<td>32.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mass H₂O</td>
<td>93.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1084.21</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

81.07 Wt % Salts
### 15_1_3: MS Inclusion

Inclusion Volume: 154.6 µm³
Vapour Volume: 4.2 µm³
Vapour Volume %: 2.72

### Daughter Phases:

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (g/cm³)</th>
<th>Volume (µm³)</th>
<th>Mass (x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>2.17</td>
<td>64.0</td>
<td>138.9</td>
</tr>
<tr>
<td>Sylvite</td>
<td>1.99</td>
<td>9.3</td>
<td>18.5</td>
</tr>
<tr>
<td>Ferroprosmalite</td>
<td>3.12</td>
<td>6.8</td>
<td>21.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80.1</strong></td>
<td></td>
<td><strong>105.5</strong></td>
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</tbody>
</table>

Liquid Volume: 70.4 µm³
Liquid Mass (x10⁻¹²g): 105.5
Liquid Volume %: 45.5 (for \( \rho = 1.5 \) g/cm³)

### Solute and solvent masses

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass NaCl</td>
<td>=138.9 + (0.0062 x 105.5)</td>
<td>139.53</td>
</tr>
<tr>
<td>mass KCl</td>
<td>=18.5 + (0.0322 x 105.5)</td>
<td>21.90</td>
</tr>
<tr>
<td>mass FeCl₂</td>
<td>=0.1 x 105.5</td>
<td>61.35</td>
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<tr>
<td>mass CaCl₂</td>
<td>=0.4482 x 105.5</td>
<td>47.30</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>=0.0803 x 21.1 + (0.4134 x 105.5)</td>
<td>45.32</td>
</tr>
<tr>
<td>mass FeO</td>
<td>=0.4908 x 105.5</td>
<td>51.79</td>
</tr>
<tr>
<td>mass MnO</td>
<td>=0.0471 x 105.5</td>
<td>4.97</td>
</tr>
<tr>
<td>mass MgO</td>
<td>=0.0038 x 105.5</td>
<td>0.40</td>
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<td>mass SiO₂</td>
<td>=0.3421 x 105.5</td>
<td>36.10</td>
</tr>
<tr>
<td>Mass Cl</td>
<td>=0.0404 x 105.5</td>
<td>4.26</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>412.93</strong></td>
<td>41.23</td>
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### Fluid Composition:

<table>
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<tr>
<th>Mass</th>
<th>(x10⁻¹⁰g)</th>
<th>(x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass Na⁺</td>
<td>54.89</td>
<td>0.5489</td>
</tr>
<tr>
<td>mass K⁺</td>
<td>11.49</td>
<td>0.01149</td>
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<td>mass Fe²⁺</td>
<td>67.29</td>
<td>0.06729</td>
</tr>
<tr>
<td>mass Ca²⁺</td>
<td>17.08</td>
<td>0.001708</td>
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<tr>
<td>mass Mg²⁺</td>
<td>0.24</td>
<td>0.0000024</td>
</tr>
<tr>
<td>mass Mn²⁺</td>
<td>3.85</td>
<td>0.000000385</td>
</tr>
<tr>
<td>mass Si⁴⁺</td>
<td>16.87</td>
<td>0.000001687</td>
</tr>
<tr>
<td><strong>Total Cl⁻</strong></td>
<td>163.86</td>
<td>0.16386</td>
</tr>
<tr>
<td>mass O</td>
<td>32.04</td>
<td>0.003204</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>45.32</td>
<td>0.004532</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>412.93</strong></td>
<td>0.0041293</td>
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</table>

<table>
<thead>
<tr>
<th>Molarity</th>
<th>m Na⁺</th>
<th>m K⁺</th>
<th>m Fe²⁺</th>
<th>m Ca²⁺</th>
<th>m Mg²⁺</th>
<th>m Mn²⁺</th>
<th>m Si⁴⁺</th>
<th>m Cl⁻</th>
<th>m O</th>
<th>m H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>m Na⁺</td>
<td>6.67</td>
<td>0.73</td>
<td>3.42</td>
<td>1.08</td>
<td>0.02</td>
<td>0.17</td>
<td>1.52</td>
<td>18.56</td>
<td>5.26</td>
<td>6.84</td>
</tr>
</tbody>
</table>

**62.84 Wt % Salts**
15_1_15: MS Inclusion

Inclusion Volume:  703.6 \, \mu m^3 
Vapour Volume:  68.6 \, \mu m^3 
Vapour Volume %:  9.75

### Daughter Phases:

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (g/cm^3)</th>
<th>Volume (\mu m^3)</th>
<th>Mass (x10^{-12}g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>2.17</td>
<td>179.7</td>
<td>389.9</td>
</tr>
<tr>
<td>Sylvite</td>
<td>1.99</td>
<td>49.3</td>
<td>98.1</td>
</tr>
<tr>
<td>Ferropyrosmalite</td>
<td>3.12</td>
<td>65.5</td>
<td>204.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>294.5</strong></td>
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</table>

**Daughter Vol %:**  41.9

Liquid Volume:  340.5 \, \mu m^3 
Liquid Mass (x10^{-12}g):  510.8 
Liquid Volume %:  48.4 
(for \( \rho = 1.5 \, g/cm^3 \))

### Solute and solvent masses

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10^{-12}g)</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
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<td>389.9 + (0.0062 \times 510.8)</td>
<td>393.12</td>
</tr>
<tr>
<td>KCl</td>
<td>98.1 + (0.0322 \times 510.8)</td>
<td>114.55</td>
</tr>
<tr>
<td>FeCl_2</td>
<td>(0.1 \times 510.8)</td>
<td>51.08</td>
</tr>
<tr>
<td>CaCl_2</td>
<td>(0.4482 \times 510.8)</td>
<td>228.92</td>
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<tr>
<td>H_2O</td>
<td>(0.0803 \times 204.4) + (0.4134 \times 510.8)</td>
<td>227.55</td>
</tr>
<tr>
<td>FeO</td>
<td>(0.4908 \times 204.4)</td>
<td>250.68</td>
</tr>
<tr>
<td>MnO</td>
<td>(0.0471 \times 204.4)</td>
<td>24.06</td>
</tr>
<tr>
<td>MgO</td>
<td>(0.0038 \times 204.4)</td>
<td>1.94</td>
</tr>
<tr>
<td>SiO_2</td>
<td>(0.3421 \times 204.4)</td>
<td>174.73</td>
</tr>
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<td>(0.0404 \times 204.4)</td>
<td>20.63</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1487.25</strong></td>
<td><strong>148.49</strong></td>
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</tbody>
</table>

### Fluid Composition:

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<thead>
<tr>
<th>Mass</th>
<th>(x10^{-12}g)</th>
<th>(x10^{-12}g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass Na^+</td>
<td>154.64</td>
<td>mass Cl^-</td>
</tr>
<tr>
<td>mass K^-</td>
<td>60.08</td>
<td>mass Cl^-</td>
</tr>
<tr>
<td>mass Fe^{2+}</td>
<td>217.36</td>
<td>mass Cl^-</td>
</tr>
<tr>
<td>mass Ca^{2+}</td>
<td>82.68</td>
<td>mass Cl^-</td>
</tr>
<tr>
<td>mass Mg^{2+}</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>mass Mn^{2+}</td>
<td>18.63</td>
<td></td>
</tr>
<tr>
<td>mass Si^{4+}</td>
<td>81.67</td>
<td></td>
</tr>
<tr>
<td>**TOTAL Cl^-</td>
<td>488.39</td>
<td><strong>M Cl^-</strong></td>
</tr>
<tr>
<td>mass O</td>
<td>155.07</td>
<td><strong>M O</strong></td>
</tr>
<tr>
<td>mass H_2O</td>
<td>227.55</td>
<td><strong>M H_2O</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1487.25</strong></td>
<td></td>
</tr>
</tbody>
</table>

57.55 Wt % Salts
36B_51: MS Inclusion

Inclusion Volume: 1082.8 µm³
Vapour Volume: 67.7 µm³
Vapour Volume %: 6.25

**Daughter Phases:**

<table>
<thead>
<tr>
<th>Species</th>
<th>Density (g/cm³)</th>
<th>Volume (µm³)</th>
<th>Mass (x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>2.17</td>
<td>583.7</td>
<td>1266.6</td>
</tr>
<tr>
<td>Sylvite</td>
<td>1.99</td>
<td>103.5</td>
<td>206.0</td>
</tr>
<tr>
<td>Ferropyrosmalite</td>
<td>3.12</td>
<td>101.7</td>
<td>317.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>788.9</td>
<td></td>
</tr>
</tbody>
</table>

Liquid Volume: 226.2 µm³
Liquid Mass (x10⁻¹²g): 339.3
Liquid Volume %: 20.89 (for ρ = 1.5 g/cm³)

**Solute and solvent masses**

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass NaCl</td>
<td>1266.6 + (0.0062 x 339.3)</td>
<td>1268.73 126.67</td>
</tr>
<tr>
<td>mass KCl</td>
<td>206.0 + (0.0322 x 339.3)</td>
<td>216.89 21.65</td>
</tr>
<tr>
<td>mass FeCl₂</td>
<td>= (0.1 x 339.3)</td>
<td>61.35 6.13</td>
</tr>
<tr>
<td>mass CaCl₂</td>
<td>= (0.4482 x 339.3)</td>
<td>152.07 15.18</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>(0.0803 x 317.3) + (0.4134 x 339.3)</td>
<td>165.75 16.55</td>
</tr>
<tr>
<td>mass FeO</td>
<td>(0.4908 x 317.3)</td>
<td>166.53 16.63</td>
</tr>
<tr>
<td>mass MnO</td>
<td>(0.0471 x 317.3)</td>
<td>15.98 1.60</td>
</tr>
<tr>
<td>mass MgO</td>
<td>(0.0038 x 317.3)</td>
<td>1.29 0.13</td>
</tr>
<tr>
<td>mass SiO₂</td>
<td>(0.3421 x 317.3)</td>
<td>116.07 11.59</td>
</tr>
<tr>
<td>Mass Cl</td>
<td>(0.0404 x 317.3)</td>
<td>13.71 1.37</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>2178.37 217.49</td>
</tr>
</tbody>
</table>

**Fluid Composition:**

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
<th>(x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass Na⁺</td>
<td>499.08</td>
<td>mass Cl⁻</td>
</tr>
<tr>
<td>mass K⁺</td>
<td>113.75</td>
<td>mass Cl⁻</td>
</tr>
<tr>
<td>mass Fe²⁺</td>
<td>156.48</td>
<td>mass Cl⁻</td>
</tr>
<tr>
<td>mass Ca²⁺</td>
<td>54.93</td>
<td>mass Cl⁻</td>
</tr>
<tr>
<td>mass Mg²⁺</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>mass Mn²⁺</td>
<td>12.38</td>
<td></td>
</tr>
<tr>
<td>mass Si⁴⁺</td>
<td>54.26</td>
<td></td>
</tr>
<tr>
<td>**TOTAL Cl⁻</td>
<td>1017.96</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass</th>
<th>(x10⁻¹²g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass O</td>
<td>103.02</td>
</tr>
<tr>
<td>mass H₂O</td>
<td>165.75</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>2178.37</td>
</tr>
</tbody>
</table>

Molarity

<table>
<thead>
<tr>
<th>Molarity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>m Na⁺</td>
<td>12.93</td>
</tr>
<tr>
<td>m K⁺</td>
<td>1.41</td>
</tr>
<tr>
<td>m Fe²⁺</td>
<td>1.36</td>
</tr>
<tr>
<td>m Ca²⁺</td>
<td>0.65</td>
</tr>
<tr>
<td>m Mg²⁺</td>
<td>0.01</td>
</tr>
<tr>
<td>m Mn²⁺</td>
<td>0.10</td>
</tr>
<tr>
<td>m Si⁴⁺</td>
<td>0.91</td>
</tr>
<tr>
<td>m Cl⁻</td>
<td>24.74</td>
</tr>
<tr>
<td>m O</td>
<td>3.10</td>
</tr>
<tr>
<td>m H₂O</td>
<td>4.57</td>
</tr>
</tbody>
</table>

**84.06 Wt % Salts**
APPENDIX C - Laser Raman Data
Methodology is detailed in Chapter 2, section 2.3.2
Data is discussed in and interpreted in Chapter 2, section 2.4.3

DATA APPENDICES HAVE BEEN REMOVED
APPENDIX D - NOBLE GAS AND HALOGEN DATA
Methodology is detailed in Chapter 3, section 3.2
Data is discussed and interpreted in Chapter 3, section 3.4

DATA APPENDICES HAVE BEEN REMOVED
APPENDIX E - PIXE DATA

DATA APPENDICES HAVE BEEN REMOVED
APPENDIX F - LA-ICP-MS DATA
Methodology is detailed in Chapter 4, section 4.2.2
Data is discussed in and interpreted in Chapter 4, sections 4.3 & 4.4

DATA APPENDICES HAVE BEEN REMOVED
APPENDIX G - HCh control file algorithms

Model results are presented and discussed in Chapter 5.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Current temperature (°C)</td>
</tr>
<tr>
<td>P</td>
<td>Current pressure (bars)</td>
</tr>
<tr>
<td>I</td>
<td>Current step number</td>
</tr>
<tr>
<td>N</td>
<td>Current wave number</td>
</tr>
<tr>
<td>[1]</td>
<td>Input composition (1 = first, 2 = second, etc)</td>
</tr>
<tr>
<td>[A]</td>
<td>Bulk composition of aqueous phase in system from current wave, previous step</td>
</tr>
<tr>
<td>[S]</td>
<td>Bulk composition of solid phase in system from current wave, previous step</td>
</tr>
<tr>
<td>[*]</td>
<td>Current total system bulk composition (all phases)</td>
</tr>
</tbody>
</table>

[1] = rock  
[2] = fluid1  
[3] = fluid2

Unless otherwise specified all models are isothermal and isobaric at 600 °C and 3000 bars.

Basic Model Algorithms (after Cleverley and Oliver, 2005)

- **Fluid Mixing model - rock buffered (Figure 5.1A)**

  Initial Step:  
  \[ [*] = [2] + (0.1*[1]) \]

  General Step:  
  \[ [*] = ([2]^{i/50}) + ([3]^{1-(i/50)}) + (0.1*[1]) \]

  Stop when: i=50

- **Batch Reaction model for variable fluid rock ratios (Figure 5.1B)**

  Initial Step:  
  \[ [*] = [1] + ([2]*10^{-6}) \]

  General Step:  
  \[ [*] = [1] + ([2]*(10^{-i-6})) \]

  Stop when: i=10

- **Fluid Mixing model - Isobaric Cooling (Figure 5.1C)**

  Step Series 0, Initial Step:  
  
  T= 600  
  P= 3000  
  \[ [*] = [1] + (0.1*[2]) \]

  Step Series 0, General Step:
\[ T=600 \\
P=3000 \\
[\star] = ([1]*((i/50))) + ([3]*((1-(i/50)))) + (0.1*[2]) \]

Stop when: i=50

Step Series N, Initial Step
\[ T = T-(10*N) \]
\[ P = 3000 \]
\[ [\star] = [1] + (0.1*[2]) \]

Step Series N, General Step
\[ T = T-(10*N) \]
\[ P = 3000 \]
\[ [\star] = ([1]*((i/50))) + ([3]*((1-(i/50)))) + (0.1*[2]) \]

Stop when: N=30

- **Flow-through model (Figure 5.1D)**

  Initial Step:
  \[ [\star] = [2] \]

  General Step:
  \[ [\star] = [A] + ([1]*0.015*i) \]

  Stop when: i=20

- **Flush model (Figure 5.1E)**

  Initial Step:
  \[ [\star] = [1] \]

  General Step:
  \[ [\star] = [S] + (0.1*[2]) \]

  Stop when: i=20

Specific fluid mixing models (Section 5.4.3.1)

- **Model 1 (Figure 5.6)**

  Initial Step:
  \[ T=400 \]
  \[ P=2000 \]
  \[ [\star] = [2] + [3] \]

  General Step:
  \[ T=400 \]
  \[ P=2000 \]
  \[ [\star] = [A] + (0.1*[1]) \]

  Stop when: i=20

- **Model 2 (Figure 5.7)**

  Initial Step:
  \[ T=400 \]
  \[ P=2000 \]
\[ [*] = [2] + [3] \]

**General Step:**

\[ T=400 \]
\[ P=2000 \]
\[ [*] = [A] + (0.1*[1]) + ([3]*(i/20)) \]

Stop when: \( i=20 \)

---

- **Model 3 (Figure 5.8)**

  **Initial Step:**
  
  \[ T=400 \]
  \[ P=2000 \]
  \[ [*] = [1] + [2] \]

  **General Step:**
  
  \[ T=400 \]
  \[ P=2000 \]
  \[ [*] = [S] + [A] + ([3]*(i/20)) \]

  Stop when: \( i=20 \)
DATA APPENDICES HAVE BEEN REMOVED