Intrusive history and volatile evolution of the Endeavour porphyry Cu-Au deposits, Goonumbla district, NSW, Australia

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CODES SRC
Centre for Ore Deposit Research
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Abstract

The Goonumbla Volcanic Complex (GVC) of central-west New South Wales, Australia, is part of the Ordovician Macquarie Island Arc. The upper unit of the GVC, the Wombin Volcanics, comprises submarine shoshonitic lavas and associated volcaniclastic rocks, and hosts four economic porphyry Cu-Au deposits, Endeavour 22 (E22), E26, E27 and E48. Together these deposits have a combined ore reserve of 63.6Mt @ 1.1% Cu and 0.5g/t Au. Mineralisation is centred on thin, pipe-like quartz monzonite porphyry (QMP) complexes that intruded the Wombin Volcanics in an extensional regime towards the end of the Late Ordovician.

Despite being some of the smallest economic porphyry deposits in the world in terms of tonnage and cross-sectional area, detailed pit mapping and drillcore logging has led to the recognition of eight intrusive phases within the QMP complexes of the Endeavour deposits. The oldest intrusive phase is a coarse-grained, equigranular monzodiorite intrusion that is restricted to the deeper parts of E26. This intrusion has a sheared contact with the next oldest phase, equigranular to weakly porphyritic biotite quartz monzonite (BQM) intrusions, which are recognised at all four deposits. A series of three variably felsic QMP phases emplaced over a short period of time after the BQM comprise the central QMP complexes: 1) volumetrically minor early- and late-mineral biotite phryic QMP (B-QMP) dykes and dykelets, 2) volumetrically dominant syn-mineral K-feldspar phryic QMP intrusions (K-QMP) and 3) less abundant syn-to late-mineral augite-biotite K-feldspar phryic QMP (KA-QMP) intrusions, which intruded the cores of the K-QMP bodies. Basaltic trachyandesite dykes and augite phryic monzorute porphyry ("zero" porphyry) dykes at E26 represent post-mineral phases of intrusive activity associated with the Endeavour deposits. Mafic dykes of uncertain age also intrude the Endeavour deposits.

Four main stages of hydrothermal activity have been recognised at each deposit. The Early Stage, associated with the intrusion of the BQM and comprising biotite-magnetite alteration of the host volcanic rocks and K-feldspar alteration of the BQM, overprinted pre-mineral albite-sericite alteration assemblages in the BQM and host volcanic rocks at each deposit. Transitional Stage vein dykes, brain rock and other related anisotropic textures formed during the transition from magmatic to hydrothermal activity. Main Stage sulphide mineralisation at all four deposits is spatially and temporally associated with the K-QMP, and to a lesser extent, KA-QMP intrusions and their associated orthoclase alteration assemblages, which are characterised by multiple generations of quartz, K-feldspar and sulphide veins. Late Stage phyllic alteration is magmatic-hydrothermal in origin and comprises sericite-quartz-Cu-sulphide-carbonate-haematite...
Abstract

assemblages. Part of the distal carbonate-quartz-sericite-base-metal sulphide propylitic assemblages may be associated with the proximal phyllic assemblage. A second generation of phyllic alteration is related to minor late stage faulting. Weak to moderate post-mineral propylitic alteration assemblages associated with the thermal collapse of the Endeavour systems are the last alteration event related to the QMP intrusive complexes.

Fluid inclusions in quartz from early, transitional, main and late stage veins have been analysed from all four deposits. Microthermometric results indicate that the Endeavour deposits were emplaced to depths between 1000 and 1700m below the palaeo surface. Early, metal-rich magmatic – hydrothermal fluids, were typically hot (>550°C) and had salinities of ~60 wt% NaCl ± KCl eq., whereas those associated with transitional “magmatic” quartz were slightly cooler (550 – 500°C), though still as saline. Fluids that produced the transitional “hydrothermal” quartz had average calculated salinities of ~55wt% NaCl + KCl eq. and circulated at temperatures of ~500°C; they were more metal-rich than the equally saline, cooler (~460°C) fluids associated with the main mineralising event. These relationships are interpreted to imply that transitional hydrothermal fluids represent the ore-carrying fluids, which cooled and thus precipitated metal sulphides during the main mineralising event of the Endeavour deposits. Late stage fluids were the coolest (350 – 400°C) and least saline (~40 wt% NaCl eq.) and had elevated K and Ca contents compared to other fluids; features consistent with wallrock buffering of cooling magmatic – hydrothermal fluids.

$\delta^{34}$S values for the Endeavour sulphides range from -19.7 to +0.7‰ (mean -5.1‰; standard deviation 2.7‰); those for sulphates range from +4.4 to +21.8‰ (mean +9.2‰; standard deviation 4.2‰). The isotopic compositions of sulphate – sulphide pairs and temperature estimates from the fluid inclusion study were used to establish that the initial $\delta^{34}$S$_{mag}$ of the magmatic – hydrothermal fluid was ~+1.5‰. A broad temporal and lateral zonation towards heavier isotopic compositions in sulphides with time and distance from the cores of the Endeavour deposits is interpreted to reflect wallrock buffering as the systems cooled. The extremely negative $\delta^{34}$S values may reflect local sulphide precipitation from hyper-oxidised ore fluids with H$_2$S:SO$_2$ ratios much less than the original magmatic – hydrothermal fluid.

Biotite halogen contents indicate that the magmas that produced the BQM and QMP intrusions were depleted in Cl and enriched in F relative to the magmatic – hydrothermal fluids that produced Cl-rich secondary biotite. These magmatic – hydrothermal fluids also caused Cl-enrichment in many of the primary biotite phenocrysts in the K-QMP intrusions. Apatites in regional intrusions are relatively Cl-poor and Fe-rich compared to the F- and Fe-depleted apatites in the BQM and QMP intrusions associated with the Endeavour deposits. The higher F contents of biotites and apatites, and lower Fe contents of apatites in ore-related intrusions are consistent with higher degrees of fractionation in these intrusions compared to regional intrusions.
Abstract

Geochemical characteristics of the regional volcanic and intrusive rocks define a systematic trend consistent with high-temperature magmatic fractionation of basaltic trachyandesite through trachyte, with increasing K$_2$O and decreasing TiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, CaO and MgO contents with increasing SiO$_2$ contents. These trends continue through to the QMP intrusions associated with the Endeavour deposits. However, while there is progressive fractionation through the sequence of ore-related QMP intrusions, a direct progression by fractionation from the BQM intrusions to the QMP intrusions is not indicated. Contrary to previous models that invoke the BQM as the parent stock from which the QMP phases emanated, this study shows that the Ba, Sr, Rb, Y, Nb and Zr contents of the BQM preclude it from generating the trace element compositions characteristic of the QMP complexes solely by crystal fractionation. The REE patterns of QMP phases are also not explainable by crystal fractionation effects alone. Instead, the QMP complexes and associated alteration and mineralisation assemblages at E22, E26, E27 and E48 are interpreted to have formed in response to the emplacement of a series of mafic shoshonitic melts into the base of a crystallising, zoned, monzodiorite to monzonite magma chamber. Episodic movement along deep-seated, mantle-tapping (?) structure(s), possibly the Lachlan Transverse Zone, could have triggered the emplacement of these mafic shoshonitic melts. Related movements on shallow-crustal fault systems above the magma chamber probably caused instantaneous depressurisation and the repeated simultaneous egress of melt (QMP) and exsolved aqueous fluid into dilatant zones. Localised fracturing and additional volatile exsolution from the QMP melt is thought to have led to the formation of the narrow QMP complexes and associated Cu-Au-bearing stockwork veins and related orthoclase alteration. The volatile-rich aqueous fluid partitioned LREE preferentially to MREE, preferentially to HREE, resulting in the development of distinctive "u-shaped" REE patterns of the ore-related intrusions.
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# Table of Contents

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract ........................................................................................................................................ iii</td>
</tr>
<tr>
<td>Acknowledgements ...................................................................................................................... vi</td>
</tr>
<tr>
<td>Table of Contents ........................................................................................................................ vii</td>
</tr>
<tr>
<td>List of Figures ............................................................................................................................ xii</td>
</tr>
<tr>
<td>List of Tables ................................................................................................................................ xv</td>
</tr>
<tr>
<td>1 INTRODUCTION ......................................................................................................................... 1</td>
</tr>
<tr>
<td>1.1 Preamble ................................................................................................................................... 1</td>
</tr>
<tr>
<td>1.2 This study ............................................................................................................................... 3</td>
</tr>
<tr>
<td>1.2.1 Objectives .......................................................................................................................... 3</td>
</tr>
<tr>
<td>1.2.2 Methods .............................................................................................................................. 3</td>
</tr>
<tr>
<td>1.3 Background .............................................................................................................................. 4</td>
</tr>
<tr>
<td>1.3.1 Location and environment ................................................................................................... 4</td>
</tr>
<tr>
<td>1.3.2 Exploration and mining history ............................................................................................ 6</td>
</tr>
<tr>
<td>1.3.3 Nomenclature ....................................................................................................................... 8</td>
</tr>
<tr>
<td>1.3.4 Ore reserves ......................................................................................................................... 8</td>
</tr>
<tr>
<td>1.4 Previous work .......................................................................................................................... 10</td>
</tr>
<tr>
<td>1.5 Thesis organisation ................................................................................................................. 11</td>
</tr>
<tr>
<td>2 GEOLOGICAL SETTING ........................................................................................................... 12</td>
</tr>
<tr>
<td>2.1 Introduction ............................................................................................................................ 12</td>
</tr>
<tr>
<td>2.2 Tectonic setting ......................................................................................................................... 12</td>
</tr>
<tr>
<td>2.2.1 Precambrian to pre-Ordovician Volcanic Belts ................................................................ 13</td>
</tr>
<tr>
<td>2.2.2 Early Ordovician to Early Silurian .................................................................................... 16</td>
</tr>
<tr>
<td>2.2.3 Post-Ordovician history of the Lachlan Fold Belt .............................................................. 18</td>
</tr>
<tr>
<td>2.3 Other Macquarie Arc-related mineral occurrences ................................................................ 20</td>
</tr>
<tr>
<td>2.4 Local geology .......................................................................................................................... 21</td>
</tr>
<tr>
<td>2.4.1 The Goonumbla Volcanic Complex .................................................................................... 21</td>
</tr>
<tr>
<td>2.4.1.1 Nelungaloo Volcanics ..................................................................................................... 21</td>
</tr>
<tr>
<td>2.4.1.2 Goonumbla Volcanics .................................................................................................... 22</td>
</tr>
<tr>
<td>2.4.1.3 Wombin Volcanics ......................................................................................................... 24</td>
</tr>
<tr>
<td>2.4.2 Volcanic rocks east of the Parkes thrust ............................................................................ 25</td>
</tr>
<tr>
<td>2.4.3 Cover sequence .................................................................................................................... 25</td>
</tr>
<tr>
<td>2.4.4 Structure and metamorphism ............................................................................................... 25</td>
</tr>
<tr>
<td>2.4.4.1 Local faulting and folding ............................................................................................... 25</td>
</tr>
<tr>
<td>2.4.1.3 Lineaments ..................................................................................................................... 27</td>
</tr>
<tr>
<td>2.5 Summary ................................................................................................................................ 27</td>
</tr>
</tbody>
</table>
3 INTRUSIVE HISTORY

3.1 Introduction................................................................. 29
3.2 Deposit geology............................................................ 29
3.3 Intrusions of the Endeavour deposits.............................. 31
3.3.1 Intrusion classification.................................................. 31
3.3.2 Features common to porphyry intrusions of the QMP complexes............................................... 34
3.4 Intrusive history of the Endeavour deposits......................... 36
3.4.1 Monzodiorite............................................................. 36
3.4.2 Biotite quartz monzonite................................................. 37
3.4.3 Quartz monzonite porphyry intrusions............................ 42
3.4.3.1 Biotite phryic QMP (B-QMP)........................................ 45
3.4.3.2 K-feldspar phryic QMP (K-QMP).................................... 45
3.4.3.3 Augite-biotite, K-feldspar phryic QMP (KA-QMP)............... 50
3.4.3.4 Timing relationships..................................................... 51
3.4.3.5 Microgranite.......................................................... 53
3.4.3.6 Seriate to equigranular micromonzodiorite dykes.................. 55
3.4.4 Minor dykes............................................................. 55
3.4.4.1 Seriate to equigranular micromonzodiorite dykes................. 55
3.4.4.2 Microsyenite dykes..................................................... 55
3.4.4.3 Quartz microsyenite to microgranite (aplite)...................... 55
3.4.4.4 Post mineral zero porphyry dykes................................. 36
3.4.4.5 Mafic dykes............................................................ 58
3.4.7 Other rocks in the QMP complexes................................. 59
3.4.7.1 Breccia pipes.......................................................... 59
3.4.7.2 Pebble dykes......................................................... 59
3.5 Discussion......................................................................... 60
3.6 Summary.......................................................................... 63

4 ALTERATION AND MINERALISATION........................................ 65

4.1 Introduction................................................................. 65
4.2 Previous work............................................................... 66
4.3 Terminology.................................................................... 68
4.4 Alteration and vein paragenesis........................................ 68
4.4.1 Pre-mineral alteration................................................... 69
4.4.2 Early Stage................................................................... 69
4.4.3 Distal propylitic alteration............................................... 73
4.4.4 Brain rock and anisotropic textures – Transitional Stage ......................... 73
4.4.5 Main Stage.................................................................. 76
4.4.6 Late Stage................................................................... 79
4.4.6.1 Selective sericite overprint (L1)................................... 79
4.4.6.2 Fault-related phyllic alteration (L2 and L3)...................... 81
4.4.7 Post-mineral propylitic alteration................................. 83
4.5 Sulphide mineralogy....................................................... 83
4.5.1 Sulphide minerals........................................................ 83
4.5.2 Sulphide zoning.......................................................... 86
4.5.3 Bornite clots.............................................................. 87
4.6 Discussion....................................................................... 91
4.6.1 Alteration and mineralisation assemblages..................... 91
4.6.2 Sulphide mineralogy.................................................... 92
4.6.3 Ore distribution.......................................................... 94
4.6.4 Origin of bornite clots................................................... 94
4.7 Summary....................................................................... 95
Table of contents

5 FLUID INCLUSIONS ................................................................. 96
  5.1 Introduction ........................................................................ 96
  5.2 Methods ............................................................................ 97
    5.2.1 Fluid inclusion classification ........................................ 97
    5.2.2 Microthermometry .......................................................... 103
      5.2.2.1 Undersaturated (<23.3 wt% NaCl eq.) fluid inclusions (Types 1 and 2) ... 103
      5.2.2.2 Hypersaline (>23.3 wt% NaCl eq.) fluid inclusions (Type 3) ... 103
    5.2.3 PIXE analysis ................................................................. 104
    5.2.4 Decrepitation analysis ................................................... 104
  5.3 Microthermometric results .................................................. 105
    5.3.1 Fluid inclusions in early quartz (EQ) ................................ 105
    5.3.2 Fluid inclusion in transitional quartz ............................ 108
      5.3.2.1 Fluid inclusions in transitional magmatic quartz (TMQ) ... 108
      5.3.2.2 Fluid inclusions in transitional hydrothermal quartz (THQ) ... 108
    5.3.3 Fluid inclusions in main quartz (MQ) ............................. 109
    5.3.4 Fluid inclusions in late quartz (LQ) ............................... 110
  5.4 PIXE results ..................................................................... 111
  5.5 Decrepitation results .......................................................... 115
  5.6 Pressure-depth estimates .................................................... 119
  5.7 Discussion ......................................................................... 123
    5.7.1 Comparison with previous studies of the Endeavour deposits ... 123
    5.7.2 Comparison with other porphyry deposits ..................... 125
    5.7.3 Fluid evolution in the Endeavour systems ..................... 126
  5.8 Summary .......................................................................... 129

6 SULPHUR ISOTOPES ............................................................. 131
  6.1 Introduction .................................................................... 131
  6.2 Methods ........................................................................... 131
  6.3 Results ............................................................................ 133
    6.3.1 Early sulphides .......................................................... 133
    6.3.2 Transitional magmatic sulphides and sulphates ............ 136
    6.3.3 Transitional hydrothermal/ main sulphides and sulphates .. 136
    6.3.4 Late sulphides and sulphates ....................................... 140
  6.4 Discussion ....................................................................... 140
    6.4.1 84S values for sulphate - sulphide pairs ....................... 140
    6.4.2 Spatial and temporal 84S zonation .............................. 144
    6.4.3 Comparison with other deposits .................................. 146
  6.5 Summary ....................................................................... 149

7 MINERAL CHEMISTRY .......................................................... 150
  7.1 Introduction .................................................................... 150
  7.2 Biotite ............................................................................ 151
    7.2.1 Methods .................................................................... 151
    7.2.2 Biotite compositions .................................................. 151
    7.2.3 Biotite halogen chemistry .......................................... 154
    7.2.4 Fugacity ratios .......................................................... 155
    7.2.5 Discussion ................................................................... 157
  7.3 Apatite ............................................................................ 158
    7.3.1 Methods .................................................................... 158
    7.3.2 Apatite compositions ................................................... 159
      7.3.2.1 Apatites from the intrusions related to the Endeavour deposits ... 159
8 GEOCHEMISTRY AND PETROGENESIS

8.1 Introduction ............................................................................................................. 168
8.2 Geochronology ......................................................................................................... 169
8.3 Whole rock major and trace element geochemistry of the GVC ......................... 171

8.3.1 Regional GVC rocks ............................................................................................. 171
8.3.1.1 Major elements .................................................................................................. 171
8.3.1.2 Trace elements .................................................................................................. 174

8.3.2 Ore-related E22, E26, E27 and E48 intrusions .................................................. 176
8.3.2.1 Major elements .................................................................................................. 176
8.3.2.2 Trace elements .................................................................................................. 179

8.3.3 Normalised multi-element plots .......................................................................... 181
8.3.3.1 Regional volcanic and intrusive rocks of the GVC ......................................... 181
8.3.3.2 Intrusions associated with ore deposition ....................................................... 183

8.3.4 Interpretation ......................................................................................................... 183
8.3.5 Other intrusions in the Endeavour porphyry complexes .................................. 185
8.3.5.1 Aplitic rocks ........................................................................................................ 185
8.3.5.2 E48 microgranite ............................................................................................... 186
8.3.5.3 E26 monzodiorite ............................................................................................... 186
8.3.5.4 Post-mineral zero porphyry dykes ..................................................................... 186
    Basaltic trachyandesite dykes ................................................................................. 187
    Zero porphyry monzonite dykes ........................................................................... 187

8.4 Rare earth element geochemistry ............................................................................ 188
8.4.1 Regional GVC rocks ............................................................................................. 188
8.4.2 Intrusive rocks associated with the Endeavour deposits ................................... 190

8.4.3 Interpretation ......................................................................................................... 192
8.4.3.1 REE abundances ............................................................................................... 192
    Modelled fractionation effects .............................................................................. 193
    Magmatic fluid exsolution .................................................................................... 196
    Eu anomaly ............................................................................................................. 198
    Discussion ............................................................................................................... 199

8.5 Radiogenic isotopes ................................................................................................ 200
8.6 Summary .................................................................................................................. 203

9 CONCLUSIONS AND GENETIC MODEL .................................................................. 205

9.1 Introduction .............................................................................................................. 205
9.2 Volatile exsolution and migration in magma chambers ........................................ 205
9.3 Island arcs ............................................................................................................... 209
9.4 Mafic shoshonitic magmas ...................................................................................... 210
9.5 Previous models for the Endeavour deposits ........................................................ 212
9.5.1 Heithersay and Walshe, 1995 ............................................................................ 212
9.5.2 Blevin and Morrison, 1997 ............................................................................... 214
9.5.3 Limitations of previous models .......................................................................... 216

9.6.1 Stage 1 – Monzodiorite emplacement .................................................................. 218
9.6.2 Stage 2 – Intrusion of the BQM magma chamber .............................................. 219
9.6.3 Stage 3 - QMP emplacement and ore formation ......................................................... 219
  9.6.3.1 Stage 3a - QMP complex emplacement ............................................................. 219
  9.6.3.2 Stage 3b - Ore formation .................................................................................... 220
  9.6.3.3 Stage 3c - Sericite overprint and distal propylitic alteration .......................... 221
9.6.4 Stage 4 - Post-mineral alteration assemblages and intrusions ................................. 223
9.7 Fertile melt production in the Endeavour QMP complexes ........................................ 224
  9.7.1 BQM magmatism .................................................................................................... 224
  9.7.2 QMP melt production and Cu-Au porphyry-style mineralisation .......................... 226
  9.7.3 Commingled basaltic trachyandesite and mafic monzonite porphyry .................... 228
9.8 Recommendations for further work ........................................................................... 231

10 REFERENCES ............................................................................................................... 233

APPENDICES

A1 Pit maps
A2 Borehole logs

B1 Fluid inclusion data - microthermometric results
B2 Fluid inclusion data - decrepitation results

C1 Sulphur isotope analyses
C2 Empirical correction for bornite

D1 Electron microprobe analyses - biotite
D2 Electron microprobe analyses - apatite

E1 Whole rock XRD and XRF analyses
E2 Whole rock ICP-MS REE analyses
E3 Radiogenic isotope data
E4 $^{40}$Ar/$^{39}$Ar dating