Termitaria as regolith landscape attributes and sampling media in northern Australia

Anna Elizabeth Petts

BSc (Hons) Earth Sciences, University of Melbourne, 2002

School of Earth & Environmental Sciences, Department of Geology & Geophysics

University of Adelaide

26th May, 2009
CONTENTS

Abstract ....................................................................................................................... xiii
Declaration ................................................................................................................... xv
Acknowledgements .................................................................................................... xvii

1 Introduction............................................................................................................ 1
  1.1. Aims and approach of this study................................................................. 3
  1.2. Termites, termitaria and the regolith: a review......................................... 4
  1.2.1. Introduction....................................................................................... 4
  1.2.2. Pedolith modification and termites....................................................... 6
  1.2.3. Termite biogeochemistry................................................................. 12
  1.2.4. Termites and mineral exploration....................................................... 12
  1.2.5. Termites in the landscape................................................................. 15
  1.3 Geology of the Tanami region....................................................................... 19

2 Methods ............................................................................................................... 22
  2.1 Regolith-landform mapping......................................................................... 22
  2.1.1 Regolith-landform mapping approaches............................................. 23
  2.2 Termitaria sampling methodologies............................................................ 27
  2.2.1 Surveying termites and termitaria in northern Australia....................... 27
  2.2.2 Termitaria sampling............................................................................. 30
  2.2.3 Labwork and sample preparation......................................................... 31
  2.3 Geochemical analysis and assaying............................................................. 33
  2.3.1 Termitaria geochemistry (XRD and XRF)........................................... 33
  2.3.2 Termitaria geochemistry (ICP-MS and ICP-OES).................................. 33

3 Coyote Au-deposit, Western Australia................................................................ 36
  3.1 Introduction.................................................................................................. 36
  3.1.1 Geology and mineralisation................................................................. 37
  3.1.2 Landscape............................................................................................ 37
  3.1.3 Climate................................................................................................. 39
  3.1.4 Land use and vegetation..................................................................... 39
  3.2 Coyote tenement scale regolith-landform map............................................ 40
  3.2.1 Regolith-landform units..................................................................... 42
  3.2.2 Summary of the regolith and Landforms of Coyote Au-deposit, Western
    Australia............................................................................................................... 52
  3.3 Termite speciation studies.......................................................................... 55
  3.3.1 Descriptions of A. vitiosus mounds at Coyote Au-deposit.................... 57
  3.3.2 Descriptions of D.rubriceps mounds at Coyote Au-deposit.................. 60
  3.3.3 General distribution of termite mounds.............................................. 62
  3.3.4 Discussion: associating termitaria distribution with regolith-landforms  66
  3.4 Termitaria geochemistry and mineralogy at Coyote Au-deposit................. 68
  3.4.1 Termitaria mineralogy at Coyote Au-deposit...................................... 68
  3.4.2 Interpretation of Coyote termitaria geochemical results...................... 69
  3.4.3 Termitaria geochemistry from transect sampling.............................. 71
  1.2.6. Interpretation of Coyote termitaria geochemical results............... 84
  3.4.4 Distinguishing influences on geochemical patterns.......................... 85
  3.4.5 Detailed termitaria survey, CT300..................................................... 90
  3.5 Spinifex chaff sampling and results........................................................... 108
  3.5.1 Chaff geochemistry results............................................................... 108
  3.5.2 Spinifex chaff geochemistry interpretation...................................... 120
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5.3</td>
<td>Discussion of termitaria and chaff geochemical results at the Coyote Au-deposit</td>
<td>125</td>
</tr>
<tr>
<td>3.6</td>
<td>Discussion of regolith-landform mapping and geochemical results at Coyote Au-deposit, WA</td>
<td>130</td>
</tr>
<tr>
<td>4</td>
<td>Titania Au-Prospect, Northern Territory</td>
<td>132</td>
</tr>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>132</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Geology and mineralisation</td>
<td>133</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Landscape</td>
<td>136</td>
</tr>
<tr>
<td>4.1.3</td>
<td>Climate</td>
<td>136</td>
</tr>
<tr>
<td>4.1.4</td>
<td>Land use and vegetation</td>
<td>137</td>
</tr>
<tr>
<td>4.2</td>
<td>Regolith-landform mapping</td>
<td>137</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Regolith-landform Units</td>
<td>138</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Summary of the regolith and landforms of Titania Au-prospect, Northern Territory</td>
<td>150</td>
</tr>
<tr>
<td>4.3</td>
<td>Termitaria studies</td>
<td>151</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Termite Speciation</td>
<td>151</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Spatial distribution of termitaria at Titania Au-prospect</td>
<td>160</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Discussion: associating termitaria distribution with regolith-landforms</td>
<td>163</td>
</tr>
<tr>
<td>4.4</td>
<td>Titania termitaria geochemistry and mineralogy</td>
<td>166</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Termitaria mineralogy</td>
<td>166</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Titania mound geochemistry</td>
<td>170</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Detailed termitaria geochemical survey at Titania Au-prospect</td>
<td>203</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Investigation into termite speciation and geochemistry at Titania Au-prospect (from Petts et al., 2008)</td>
<td>225</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Soil sample collection at Titania Au-prospect</td>
<td>234</td>
</tr>
<tr>
<td>4.4.5</td>
<td>Chaff geochemical sampling at Titania Au-prospect</td>
<td>258</td>
</tr>
<tr>
<td>4.4.6</td>
<td>Discussion of Titania Au-prospect geochemical sampling program</td>
<td>271</td>
</tr>
<tr>
<td>4.5</td>
<td>Discussion of Titania Au-prospect regolith-landform mapping and geochemical results</td>
<td>276</td>
</tr>
<tr>
<td>5</td>
<td>Other sites: Adelaide River – Pine Creek region</td>
<td>279</td>
</tr>
<tr>
<td>5.1</td>
<td>Introduction</td>
<td>279</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Geology</td>
<td>280</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Landscape</td>
<td>281</td>
</tr>
<tr>
<td>5.1.3</td>
<td>Climate and land use</td>
<td>282</td>
</tr>
<tr>
<td>5.2</td>
<td>Regolith–landform study</td>
<td>283</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Glencoe</td>
<td>283</td>
</tr>
<tr>
<td>5.2.2</td>
<td>McKinlay</td>
<td>287</td>
</tr>
<tr>
<td>5.2.3</td>
<td>John’s Hill</td>
<td>289</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Great Northern and Great Western</td>
<td>290</td>
</tr>
<tr>
<td>5.3</td>
<td>Relating biota to regolith: termitaria distribution</td>
<td>292</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Termitaria as regolith–landform attributes</td>
<td>292</td>
</tr>
<tr>
<td>5.4</td>
<td>Termitaria geochemistry</td>
<td>292</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Known mineralisation</td>
<td>293</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Transect sampling results</td>
<td>303</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Interpretation of results</td>
<td>322</td>
</tr>
<tr>
<td>5.5</td>
<td>Conclusion: exploration and geochemistry</td>
<td>325</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Recommendations for mineral exploration</td>
<td>325</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Termitaria speciation and geochemistry at Adelaide River – Pine Creek</td>
<td>326</td>
</tr>
<tr>
<td>5.6</td>
<td>Conclusion</td>
<td>333</td>
</tr>
</tbody>
</table>
6 Model of relationships between termites and the underlying substrate within a landscape context .................................................................................................................. 335
6.1 Surficial expression of subsurface topography and geology .......................... 335
6.2 Conceptual model for termitaria–pedolith interactions ............................. 337
  6.2.1 Termitaria–regolith interaction model for Coyote Au-deposit .............. 337
  6.2.2 Termitaria–regolith interaction model for Titania Au-prospect ........... 339
6.3 Geochemical properties of Top End termitaria ........................................... 340
7 Summary and conclusion ............................................................................. 342
  7.1 Future directions ..................................................................................... 342
  7.2 Conclusion .................................................................................................. 343

References ............................................................................................................. 345

Appendix A- Glossary of terms ............................................................................ 353
Appendix B- Analytical Detection Limits .............................................................. 356
Other Appendices C, D, E, F and G ..................................................................... 358

LIST OF FIGURES

Figure 1.1 Typical regolith profile ........................................................................ 7
Figure 1.2 Model of soil modification due to the bioturbative activities of termites 10
Figure 1.3 Vegetation and soil biota as potential mechanisms for metal mobility 15
Figure 1.4 Simplified map of the Granites-Tanami region .................................... 20

Figure 2.1 Main mound-building termite populations across Australia .............. 28
Figure 2.2 a) Sampling of termitaria in the field b) Preparing samples for analysis 31
Figure 2.3 Equipment used to separate spinifex chaff from residual termitaria material 32

Figure 3.1 Location Map for the Coyote Au-deposit, WA .................................. 36
Figure 3.2 Cross-section 482300E of Coyote gold deposit ................................... 38
Figure 3.3 Coyote Au deposit within an alluvial flood plain (Aap) border .......... 41
Figure 3.4 Orthophoto of the Coyote Au-deposit and locations of RLU field sites 41
Figure 3.5 Map of the regolith-landform setting of the Coyote Au deposit, WA 43
Figure 3.6 Surface materials and landscape view for the CHpd1 regolith-landform unit 46
Figure 3.7 Typical surface materials for the CHpd2 regolith–landform unit ....... 47
Figure 3.8 Ferruginised gravels exposed at surface, CHpd2 ................................. 47
Figure 3.9 Landscape and typical termitaria sample site (right) for the CHpd3 RLU 47
Figure 3.10 Typical surface materials and view of CHpd4 RLU ........................... 48
Figure 3.11 Coarse colluvial clasts typical of CHpd5 regolith-landform units .... 48
Figure 3.12 Landscape view of a CHpd5 unit ....................................................... 49
Figure 3.13 Regolith materials typical of the CHed1 units ................................ 50
Figure 3.14 CHed1 after rain, just south of the drilling area at Coyote Au-deposit 50
Figure 3.15 Regolith materials typical of the CHed2 regolith-landform unit ...... 50
Figure 3.16 Representative landscape settings of CHed1 RLU at Coyote Au-deposit 51
Figure 3.17 Regolith materials and landscape setting of the Aed1 RLU .......... 52
Figure 3.18 Regolith materials and landscape setting the Aed2 RLU ................. 53
Figure 3.19 Anthropogenically-disturbed RLU at the Coyote Au-deposit ........... 53
Figure 3.20 Images from the north (CT012) and south (CT130) of the study area 54
Figure 3.21 Cloudy surface water during an annual rainfall event in January 2006 55
Figure 3.22  Termitaria height in graduated colours across Coyote-Au deposit transects

Figure 3.23  *A. vitiosus* mounds at the Coyote Au-deposit

Figure 3.24  Rebuilding of nests

Figure 3.25  Variation in colour of *A. vitiosus* nests

Figure 3.26  Harvested chaff within an *A. vitiosus* mound, Coyote Au-deposit

Figure 3.27  Nests built by *D. rubriceps*

Figure 3.28  The outer nest walls of *D. rubriceps* nests

Figure 3.29  Indurated soil surrounding a *D. rubriceps* nest

Figure 3.30  Sampled mounds showing the interior structure of the *D. rubriceps* nest

Figure 3.31  Termite height vs. northing for the three transects mapped at Coyote

Figure 3.32  Derivative map detailing zones of speciation for *D. rubriceps*

Figure 3.33  Combined regolith-landform and speciation zones map

Figure 3.34  Mineral assemblages for the Transect 0 termitaria

Figure 3.35  Sampling transects utilised at Coyote Au-deposit in February 2006

Figure 3.36  Patterns of elemental distribution within Fraction 1 termitaria samples at Coyote Au-deposit

Figure 3.37  Distribution of elements (Ag, As, Au, Ba) across Coyote Au-deposit

Figure 3.38  Distribution of elements (Bi, Cr, Cu) across Coyote Au-deposit

Figure 3.39  Distribution of elements (Fe, Mg, Mo, Ni) across Coyote Au-deposit

Figure 3.40  Distribution of elements (Pb, Sb, Sc and Zn) across Coyote Au-deposit

Figure 3.41  Distribution of elements (Al, Ga, Mg) across Coyote Au-deposit

Figure 3.42  Distribution of elements (B, Mn, Se) across Coyote Au-deposit

Figure 3.43  Distribution of elements (Cd, Hg, K, La) across Coyote Au-deposit

Figure 3.44  Distribution of elements (Na, Sr, Th, Li) across Coyote Au-deposit

Figure 3.45  Species comparison of Ag values between *A. vitiosus* and *D. rubriceps*

Figure 3.46  Species comparison of As values between *A. vitiosus* and *D. rubriceps*

Figure 3.47  Species comparison of Au values between *A. vitiosus* and *D. rubriceps*

Figure 3.48  Species comparison of Co values between *A. vitiosus* and *D. rubriceps*

Figure 3.49  Species comparison of Cu values between *A. vitiosus* and *D. rubriceps*

Figure 3.50  Species comparison of Mo values between *A. vitiosus* and *D. rubriceps*

Figure 3.51  Geochemical map displaying the response of Ag within the Fraction 1 of termitaria collected in January 2006

Figure 3.52  Geochemical map displaying the response of Al within the Fraction 1 of termitaria collected in January 2006

Figure 3.53  Geochemical map displaying the response of As within the Fraction 1 of termitaria collected in January 2006

Figure 3.54  Geochemical map displaying the response of Au within the Fraction 1 of termitaria collected in January 2006

Figure 3.55  Geochemical map displaying the response of Ba within the Fraction 1 of termitaria collected in January 2006

Figure 3.56  Geochemical map displaying the response of Bi within the Fraction 1 of termitaria collected in January 2006

Figure 3.57  Geochemical map displaying the response of Ca within the Fraction 1 of termitaria collected in January 2006

Figure 3.58  Geochemical map displaying the response of Cd within the Fraction 1 of termitaria collected in January 2006

Figure 3.59  Geochemical map displaying the response of Co within the Fraction 1 of termitaria collected in January 2006

Figure 3.60  Geochemical map displaying the response of Cr within the Fraction 1 of termitaria collected in January 2006

Figure 3.61  Geochemical map displaying the response of Cu within the Fraction 1 of termitaria collected in January 2006

Figure 3.62  Geochemical map displaying the response of Fe within the Fraction 1 of termitaria collected in January 2006
Figure 3.63 Geochemical map displaying the response of Ga within the Fraction 1 of termitaria collected in January 2006

Figure 3.64 Geochemical map displaying the response of Hg within the Fraction 1 of termitaria collected in January 2006

Figure 3.65 Geochemical map displaying the response of K within the Fraction 1 of termitaria collected in January 2006

Figure 3.66 Geochemical map displaying the response of La within the Fraction 1 of termitaria collected in January 2006

Figure 3.67 Geochemical map displaying the response of Mg within the Fraction 1 of termitaria collected in January 2006

Figure 3.68 Geochemical map displaying the response of Mn within the Fraction 1 of termitaria collected in January 2006

Figure 3.69 Geochemical map displaying the response of Mo within the Fraction 1 of termitaria collected in January 2006

Figure 3.70 Geochemical map displaying the response of Na within the Fraction 1 of termitaria collected in January 2006

Figure 3.71 Geochemical map displaying the response of Ni within the Fraction 1 of termitaria collected in January 2006

Figure 3.72 Geochemical map displaying the response of P within the Fraction 1 of termitaria collected in January 2006

Figure 3.73 Geochemical map displaying the response of Pb within the Fraction 1 of termitaria collected in January 2006

Figure 3.74 Geochemical map displaying the response of Sb within the Fraction 1 of termitaria collected in January 2006

Figure 3.75 Geochemical map displaying the response of Sc within the Fraction 1 of termitaria collected in January 2006

Figure 3.76 Geochemical map displaying the response of Se within the Fraction 1 of termitaria collected in January 2006

Figure 3.77 Geochemical map displaying the response of Sr within the Fraction 1 of termitaria collected in January 2006

Figure 3.78 Geochemical map displaying the response of Te within the Fraction 1 of termitaria collected in January 2006

Figure 3.79 Geochemical map displaying the response of Th within the Fraction 1 of termitaria collected in January 2006

Figure 3.80 Geochemical map displaying the response of Ti within the Fraction 1 of termitaria collected in January 2006

Figure 3.81 Geochemical map displaying the response of Tl within the Fraction 1 of termitaria collected in January 2006

Figure 3.82 Geochemical map displaying the response of U within the Fraction 1 of termitaria collected in January 2006

Figure 3.83 Geochemical map displaying the response of V within the Fraction 1 of termitaria collected in January 2006

Figure 3.84 Geochemical map displaying the response of Zn within the Fraction 1 of termitaria collected in January 2006

Figure 3.85 Tukey plots displaying the geochemical results for detailed survey and termitaria samples for the elements Al, Cu, Bi, Fe, Hg, Mg, Na, P and Sb

Figure 3.86 Tukey plots displaying the geochemical results for detailed survey and termitaria samples for the elements Ag, As, Au, Co, Cu, Mo, Ni, Sr, and Zn

Figure 3.87 Patterns of elemental distribution within Fraction 1 termitaria samples at Coyote Au-deposit

Figure 3.88 Geochemical maps displaying results of spinifex chaff analysis for Pattern 1 elements, including As, Au, Ba and Mg, at Coyote Au-deposit

Figure 3.89 Geochemical maps displaying results of spinifex chaff analysis for Pattern 1 elements, including Ni, Mo, and P, at Coyote Au-deposit
Figure 3.90 Geochemical maps displaying results of spinifex chaff analysis for Pattern 2 elements, including Al, Co, Fe and Ga, at Coyote Au-deposit

Figure 3.91 Geochemical maps displaying results of spinifex chaff analysis for Pattern 2 elements, including Hg, K, La and Pb, at Coyote Au-deposit

Figure 3.92 Geochemical maps displaying results of spinifex chaff analysis for Pattern 2 elements, including Sc, Ti, Tl and V, at Coyote Au-deposit

Figure 3.93 Geochemical maps displaying results of spinifex chaff analysis for Pattern 3 elements, including Ca, Cu and Sr, at Coyote Au-deposit

Figure 3.94 Geochemical maps displaying results of spinifex chaff analysis for Pattern 4 elements, including Ag, B, Cr and Cd, at Coyote Au-deposit

Figure 3.95 Geochemical maps displaying results of spinifex chaff analysis for Pattern 4 elements, including Mn, Na, S and Sb, at Coyote Au-deposit

Figure 3.96 Geochemical maps displaying results of spinifex chaff analysis for Pattern 4 elements, including Se, Th, U and Zn, at Coyote Au-deposit

Figure 3.97 N-score plots of geochemical results for Coyote Au-deposit for the elements Fe, Al, Au and Ti

Figure 3.98 Scatterplot of geochemical results for Coyote Au-deposit for the elements Fe, Al, Au and Ti

Figure 3.99 Tukey plots displaying geochemical results for spinifex chaff samples and termitaria for the elements Ag, Al, Bi, Co, Cr, Cu, Fe, Ga, and K

Figure 3.100 Tukey plots displaying geochemical results for spinifex chaff and termitaria samples for the elements As, Au, Ba, Hg, Mo, Na, Ni, P and S

Figure 3.101 Tukey plots displaying geochemical results for spinifex chaff and termitaria samples for the elements La, Mg, Pb, Th, and U

Figure 3.102 Tukey Plots displaying geochemical results for spinifex and termitaria samples for the elements Se, Sr and Zn

Figure 4.1 Location of Titania Au-prospect, NT

Figure 4.2 Simplified geological cross section of the Titania Au-prospect

Figure 4.3 Sketch regolith cross-section of Titania Au-prospect

Figure 4.4 Derivative regolith-landform map of Titania Au-Prospect

Figure 4.5 Regolith-landform mapping and termitaria sampling sites at Titania

Figure 4.6 Regolith-landform map of the Titania Au-Prospect

Figure 4.7 Coarse to very coarse colluvial gravels of the CHfs1 RLU

Figure 4.8 Characteristic medium-to-coarse polished Fe-lag common to the CHfs2 RLU

Figure 4.9 Fine-to-medium well-sorted colluvial material within

Figure 4.10 Indurated ferruginous lag within the north-western CHpd1 RLUs

Figure 4.11 Typical surficial sediments (left) and landscape setting of CHpd2 RLUs

Figure 4.12 Regolith and landform setting for the CHed1 unit

Figure 4.13 Typical representation of the CHed2 regolith materials

Figure 4.14 Costean within surficial sediments

Figure 4.15 Regolith materials and landscape setting of a typical Aaw unit

Figure 4.16 Typical regolith and landform setting of an Apd1

Figure 4.17 Exposed regolith carbonates within an Apd RLU at Titania Au-prospect)

Figure 4.18 Alluvial depositional plain 2 unit (Apd2)

Figure 4.19 Regolith and landform images characteristic of an AOpd unit

Figure 4.20 Typical ISps1 sediments and landscape setting and vegetation assemblage

Figure 4.21 Aeolian sediments within a sand plain (ISps2)

Figure 4.22 Vegetated dunes (ISud1, 2) with dune crest not visible

Figure 4.23 Comparison of juvenile *N. triodiae* mounds and nests constructed by *D. rubriceps*

Figure 4.24 The outer walls of an *N. triodiae* nest

Figure 4.25 Middle-aged and mature *N. triodiae* mounds

Figure 4.26 A view of the interior of the outer lobes of *N. triodiae* mounds

Figure 4.27 *N. triodiae* mounds are associated with *M. glomerata* plants
Figure 4.61 Location of the TID01 and TID02 field sites at Titania Au-prospect

Figure 4.62 Individual lobes sampled for the detailed survey at site TID01TM of an *N. triodiae* mound at the Titania Au-prospect

Figure 4.63 Sampled lobes on the north-western side of TID01TM

Figure 4.64 TID01TM lobe geochemistry ICP-MS assay results for elements Al, As, Au, Ca, Co, and Cu

Figure 4.65 TID01TM lobe geochemistry ICP-MS assay results for elements La, Mg, Pb, Th, U and Zn

Figure 4.66 TID01 soil sampling locations around the *N. triodiae* mound

Figure 4.67 Tukey plots of elements within soils and termitaria at TID01

Figure 4.68 Tukey plots of elements within soils and termitaria at TID01 with overlapping geochemical results

Figure 4.69 TID02 termitaria and soil sampling locations around *D. rubriceps* mound

Figure 4.70 Sampling locations for the TID02 mound samples

Figure 4.71 TID02TM geochemical assay results for elements Al, Au, Ba, Ce, Fe, Rb, S, and Th

Figure 4.72 Locations for the TID02 soil samples

Figure 4.73 Plots of overlapping elements Bi, Cr, La, Mo, Nd, Pb, Pr, Sm and Th for termitaria and soil samples at TID02

Figure 4.74 Tukey plots of the elements Al, As, Au and Zn for termitaria and soil samples at TID02

Figure 4.75 Locations of the paired sample study sites, Titania prospect

Figure 4.76 Maximum pathfinder and ore element results for each termite species

Figure 4.77 Pathfinder and ore element results for termite species

Figure 4.78 Comparison of select geochemical results for termitaria species at Sites 001-004

Figure 4.79 Termitaria species comparison for Sites 005-008

Figure 4.80 Termitaria species comparison for Sites 009-010

Figure 4.81 Amended termitaria species comparison for Site 007

Figure 4.82 Location of site observations made in October

Figure 4.83 Elemental patterns of soil geochemical results based on their distribution within Transect 3 at Titania Au-prospect

Figure 4.84 Elemental concentrations of Au within soils at Titania

Figure 4.85 Elemental concentrations of Al within soils at Titania

Figure 4.86 Elemental concentrations of As within soils at Titania

Figure 4.87 Elemental concentrations of Ba within soils at Titania

Figure 4.88 Elemental concentrations of Bi within soils at Titania

Figure 4.89 Elemental concentrations of Ca within soils at Titania

Figure 4.90 Elemental concentrations of Ce within soils at Titania

Figure 4.91 Elemental concentrations of Co within soils at Titania

Figure 4.92 Elemental concentrations of Cr within soils at Titania

Figure 4.93 Elemental concentrations of Cu within soils at Titania

Figure 4.94 Elemental concentrations of Fe within soils at Titania

Figure 4.95 Elemental concentrations of Ga within soils at Titania

Figure 4.96 Elemental concentrations of In within soils at Titania

Figure 4.97 Elemental concentrations of K within soils at Titania

Figure 4.98 Elemental concentrations of La within soils at Titania

Figure 4.99 Elemental concentrations of Mg within soils at Titania

Figure 4.100 Elemental concentrations of Mn within soils at Titania

Figure 4.101 Elemental concentrations of Mo within soils at Titania

Figure 4.102 Elemental concentrations of Na within soils at Titania

Figure 4.103 Elemental concentrations of Nd within soils at Titania

Figure 4.104 Elemental concentrations of Ni within soils at Titania

Figure 4.105 Elemental concentrations of Pb within soils at Titania

Figure 4.106 Elemental concentrations of Pr within soils at Titania
Figure 4.107 Elemental concentrations of Rb within soils at Titania

Figure 4.108 Elemental concentrations of S within soils at Titania

Figure 4.109 Elemental concentrations of Sm within soils at Titania

Figure 4.110 Elemental concentrations of Sn within soils at Titania

Figure 4.111 Elemental concentrations of Sr within soils at Titania

Figure 4.112 Elemental concentrations of Th within soils at Titania

Figure 4.113 Elemental concentrations of Tl within soils at Titania

Figure 4.114 Elemental concentrations of U within soils at Titania

Figure 4.115 Elemental concentrations of V within soils at Titania

Figure 4.116 Elemental concentrations of Y within soils at Titania

Figure 4.117 Elemental concentrations of Zn within soils at Titania

Figure 4.118 Distribution of Pattern 1 elements including Al, As, Cr and Fe for spinifex chaff samples at Titania

Figure 4.119 Distribution of Pattern 1 elements including K, Mg, Na and U for spinifex chaff samples at Titania

Figure 4.120 Distribution of Pattern 2 elements including Au and Se for spinifex chaff samples at Titania

Figure 4.121 Distribution of Pattern 3 elements including Ag, Mo, Ni and Y for spinifex chaff samples at Titania

Figure 4.122 Distribution of Pattern 4 elements including Ca, Cu, Hg and La for spinifex chaff samples at Titania

Figure 4.123 Distribution of Pattern 4 elements including Sn, Sr, Th and Zn for spinifex chaff samples at Titania

Figure 4.124 N-score plots of geochemical results for Titania for elements Fe, Al, Au and As

Figure 4.125 Scatterplot of geochemical results for Titania for elements Fe, Al, Au and As

Figure 4.126 Tukey plots displaying geochemical results for spinifex chaff and termitaria samples for elements Ag, Al, Bi, Co, Cr, Cu, Fe, Ga and K

Figure 4.127 Tukey plots displaying geochemical results for spinifex chaff and termitaria samples for elements La, Pb, S, Sn, Th, U, and V

Figure 4.128 Tukey plots displaying geochemical results for spinifex chaff samples and termitaria samples for elements As, Au, Ba, Ca, Mg, Mo, Na, Pd and Zn

Location map of five study sites in the Adelaide River–Pine Creek region, NT

Figure 5.2 Geology of the Pine Creek Region

Figure 5.3 Landscape and termitaria of the Glencoe minesite

Figure 5.4 Surface materials and landscape view of a CHep unit at Glencoe Au-Mine

Figure 5.5 Surface materials brought to surface by burrowing and landscape view at Glencoe Au-Mine

Figure 5.6 Surface materials and landscape view of an Apd unit for location GLT020 at Glencoe Au-Mine

Figure 5.7 Landscape setting of the McKinlay Au-prospect

Figure 5.8 Surface materials and landscape view of an AOpd unit at the McKinlay Au-prospect

Figure 5.9 Surface materials and example of a sampled N. graveolus termitaria and Landscape view of Aap unit for location MCK002 at McKinlay Au-prospect

Figure 5.10 Landscape and termitaria of the Glencoe mine site

Figure 5.11 Close-up view of the D. rubriceps termitaria sampled at JHT01 directly overlying the John’s Hill Au-prospect

Figure 5.12 Surface materials, sampled termitaria and landscape view of a CHep unit at John’s Hill Au-prospect

Figure 5.13 Exposed bedrock within an erosional hill at the historic Great Northern Au-prospect

Figure 5.14 Costean at Great Western Au-prospect
Figure 5.15 Sampled termitaria at Great Northern Au-prospect
Figure 5.16 Fraction 1 geochemical results for termitaria samples collected proximal to mineralised bedrock at Glencoe Au-prospect, NT, for the elements Au, As, Mo and U
Figure 5.17 Fraction 1 geochemical results for termitaria samples collected proximal to mineralised bedrock at Glencoe Au-prospect, NT, for the elements Ni, Cu, Pb and Sn
Figure 5.18 Fraction 1 geochemical results for termitaria samples collected proximal to mineralised bedrock at Glencoe Au-prospect, NT, for the element Zn
Figure 5.19 Fraction 1 geochemical results for two termitaria samples collected proximal to mineralised bedrock at Great Northern Au-prospect, NT, for the elements Au, As, Mo and U
Figure 5.20 Fraction 1 geochemical results for two termitaria samples collected proximal to mineralised bedrock at Great Northern Au-prospect, NT, for the elements Ni, Cu, Pb, Sn and Zn
Figure 5.21 Fraction 1 geochemical results for termitaria samples collected at Glencoe Au-prospect, NT, for the elements Au, As, Mo and U
Figure 5.22 Fraction 1 geochemical results for termitaria samples collected at Glencoe Au-prospect, NT, for the elements Ni, Cu, Pb and Sn
Figure 5.23 Fraction 1 geochemical results for termitaria samples collected at Glencoe Au-prospect, NT, for the element Zn
Figure 5.24 Fraction 1 geochemical results for termitaria samples collected at John’s Hill Au-prospect, NT, for the elements Au, As and Mo
Figure 5.25 Fraction 1 geochemical results for termitaria samples collected at John’s Hill Au-prospect, NT, for the elements U, Ni and Cu
Figure 5.26 Fraction 1 geochemical results for termitaria samples collected at John’s Hill Prospect, NT, for the elements Pb, Sn and Zn
Figure 5.27 Fraction 1 geochemical results for termitaria samples collected at Great Northern Au-prospect, NT, for the elements Au, As and Mo
Figure 5.28 Fraction 1 geochemical results for termitaria samples collected at Great Northern Au-prospect, NT, for the elements U, Ni and Cu
Figure 5.29 Fraction geochemical results for termitaria samples collected at Great Northern Au-prospect, NT, for the elements Pb, Sn and Zn
Figure 5.30 Fraction 1 geochemical results for termitaria samples collected at McKinlay Au-prospect, NT, for the elements Au, As, and Mo
Figure 5.31 Fraction 1 geochemical results for termitaria samples collected at McKinlay Au-prospect, NT, for the elements U, Ni and Cu
Figure 5.32 Fraction 1 geochemical results for termitaria samples collected at McKinlay Au-prospect, NT, for the elements Pb, Sn and Zn
Figure 5.33 Tukey plot generated using results from all samples collected over mineralisation, for the elements Au, As, Mo, U, Ni, Cu, Co, Pb and Sn
Figure 5.34 Tukey plot generated using results from all samples collected over mineralisation, for the elements Sr, Th, Mg, Mn, Fe, Cr, Zn, Al, Ca and Na
Figure 5.35 Tukey plot generated using results from all samples along the four sampling transects for the elements Au, As, Mo, U, Ni, Cu, Co, Pb, and Sn
Figure 5.36 Tukey plot generated using results from all samples along the four sampling transects for the elements Sr, Th, Mg, Mn, Fe, Cr, Zn, Al and Ca
Figure 5.37 Tukey plot generated using results from all samples along the 4 sampling transects for the REE Pr, La and Sm
Figure 6.1 Model for termitaria–regolith interactions at Coyote Au-deposit, WA
Figure 6.2 Model for termitaria–regolith interactions at Titania Au-prospect, NT
LIST OF TABLES

Table 1.1  Types of termites found in northern Australia       18
Table 2.1  Key to size fractions used for sample preparation and geochemical analysis  32
Table 3.1  Main termite species and mound morphology at Coyote Au-deposit  57
Table 3.2  Summary of nest characteristics for A. vitiosus at Coyote Au-deposit  58
Table 3.3  Summary of the mound characteristics of D. rubriceps at Coyote Au-deposit  60
Table 3.4  Key to average termitaria heights for all three transects 63
Table 3.5  Fraction 1 XRD mineralogy results for select termitaria samples at Coyote Au-deposit  69
Table 3.6  Fraction 2 XRD mineralogy results for select termitaria samples at Coyote Au-deposit  69
Table 3.7  Fraction 3 XRD mineralogy results for select termitaria samples at Coyote Au-deposit  69
Table 3.8  Thin section an XRD mineralogy of logged core from drillholes CYGT001, CYGT002  71
Table 3.9  Summary of correlation coefficients calculated from termitaria sample analytical results for Fraction 1 samples, Coyote Au-deposit  74
Table 3.10  Summary of threshold values and spatial distribution patterns for the Fraction 1 termitaria geochemistry analytical results  75
Table 3.11  Summary statistics for the detailed termitaria sampling at Coyote Au-deposit 103
Table 3.12  Correlation coefficients for Fraction 1 termitaria geochemical results from CT300, Coyote Au-deposit  107
Table 3.13  Summary statistics for the geochemical results of sampled spinifex chaff obtained at Coyote Au-deposit  110
Table 3.14  Correlation coefficients for the spinifex chaff geochemical results, Coyote Au-deposit  121
Table 4.1  Summary of termite species and mound morphology at Titania Au-prospect  152
Table 4.2  Summary of the mound characteristics of N. triodiae mounds at Titania Au-prospect  152
Table 4.3  Summary of the mound characteristics of A. vitiosus  156
Table 4.4  Summary of the mound characteristics of D. rubriceps  158
Table 4.5  Average termitaria height calculated from fieldsite data for Titania Au-prospect 161
Table 4.6  Fraction 1 XRD mineralogy results for select termitaria samples at Titania Au-prospect 168
Table 4.7  Fraction 2 XRD mineralogy results for select termitaria samples at Titania Au-prospect 169
Table 4.8  Fraction 3 XRD mineralogy results for select termitaria samples at Titania Au-prospect 170
Table 4.9  Summary description of the main sample sites at Titania Au-prospect  171
Table 4.10  Summary of correlation coefficients calculated from termitaria sample analytical results for Titania Au-prospect  174
Table 4.11  Summary of the maximum, average and threshold values, and spatial pattern for each element within the Fraction 1 termitaria samples 177
Table 4.12  Summary of the maximum, average and threshold values, and spatial pattern for each element for the Fraction 2 termitaria samples  184
Table 4.13  Summary of the maximum, average and threshold values, and spatial pattern for each element within the Fraction 3 termitaria samples  192
Table 4.14  Summary statistics for TID01 detailed geochemical study at Titania Au-prospect  208
Table 4.15  Correlation values for TID01 termitaria lobe samples  209
Table 4.16 Comparative summary statistics for the TID01 soil and termitaria geochemical results at Titania Au-prospect

Table 4.17 Comparative summary statistics for the TID02 termitaria and soil geochemical results at Titania Au-prospect

Table 4.18 Select soil geochemistry results for TID02

Table 4.19 Particle size analysis results from 4 study sites at Titania Au-prospect

Table 4.20 Summary of the mean, minimum and maximum values, anomaly threshold and spatial pattern for Fraction 1 soil geochemical results

Table 4.21 Summary of the mean, minimum and maximum values, anomaly threshold and spatial pattern for Fraction 2 soil geochemical results

Table 4.22 Summary of the standard deviation, mean, minimum and maximum values for Pattern 3 elements within Fraction 3 soil sample geochemical results

Table 4.23 Comparative study of Transect 3 soil and termitaria geochemical results

Table 4.24 Summary statistics for Titania Au-prospect spinifex chaff samples

Table 5.1 Termitaria and regolith–landform affiliations for the Adelaide River-Pine Creek region

Table 5.2 Summary results for key pathfinder and ore elements at Glencoe Au-prospect

Table 5.3 Summary statistics for key pathfinder and ore elements at Glencoe

Table 5.4 Significant correlation values for Fraction 1 termitaria samples overlying mineralisation at the Glencoe Au-prospect

Table 5.5 Summary results for key pathfinder and ore elements at the John’s Hill Au-prospect

Table 5.6 Summary results for key pathfinder and ore elements at the Great Northern Au-prospect

Table 5.7 Significant correlation values for Fraction 1 termitaria samples overlying mineralisation at Great Northern Au-prospect

Table 5.8 Summary results for key pathfinder and ore elements at the Great Western Au-prospect

Table 5.9 Summary statistics for key pathfinder and ore elements along the sampling transect for Fraction 1 termitaria samples at the Glencoe Au-prospect

Table 5.10 Significant correlation values for Fraction 1 termitaria samples at the Glencoe Au-prospect

Table 5.11 Summary statistics for key pathfinder and ore elements along the sampling transect for Fraction 1 termitaria samples at the John’s Hill Au-prospect

Table 5.12 Significant correlation values for Fraction 1 termitaria samples at the John’s Hill Au-prospect

Table 5.13 Summary statistics for key pathfinder and ore elements along the sampling transect for Fraction 1 termitaria samples at the Great Northern Au-Prospect

Table 5.14 Significant correlation values for Fraction 1 termitaria samples at the Glencoe Au-deposit

Table 5.15 Summary statistics for key pathfinder and ore elements along the sampling transect for Fraction 1 termitaria samples at the McKinlay Au-Prospect

Table 5.16 Significant correlation values for Fraction 1 termitaria samples at the McKinlay Au-Prospect

Table 5.17 Recommended elemental suite for termitaria geochemical sampling

Table 5.18 Mounds sampled at the Adelaide River–Pine Creek study sites, with a breakdown of species sampled across all four transects

Table 6.1 Regolith–landform-termitaria spatial associations, Tanami region
Abstract

This study provides one of the first accounts of the relationships between termites, termitaria and the pedolith, towards developing their application as a biogeochemical sampling medium for mineral exploration. Mapping regolith–landforms, termitaria, and the associated termitaria biogeochemistry show that termites are an integral control on the organisation of trace metals in the landscapes of northern Australia. In particular, termites are important for transporting geochemical signatures from depth, through the pedolith and to the ground surface. This occurs by way of bioturbative and constructional activities of the mound-building termites, which in this study included *Nasutitermes triodiae, Amitermes vitiosus, Drepanotermes rubriceps, Tumulitermes hastilis* and *T. pastinator*. Termitaria from these species are mappable regolith–landform attributes at the local scale; this highlights their specific preferences for colony sites, such as access to vegetation, drainage, and the availability of construction materials. The mound-building termites featured in this study are also soil modifiers, altering the pedolith terms of both structure and chemistry. Developing an understanding of these processes has helped to refine a model for pedolith development through biotic processes, which is applicable to subtropical and tropical climatic regions, where termites act as important ecosystem engineers. This research project fills a niche for new scientific investigation of deeper regolith profiles and associated terrains; it moves away from theories of shallow soil development overlying an abioc deep regolith, towards understanding pedolith development as wholly biotically driven. For mineral explorers this means that ore-related elements, such as Au, As and Zn, are re-organised and moved towards the land surface in settings such as buried Au-deposits and mineralisation in the Tanami region, and Pine Creek Orogen. A key finding within the study of the application of this technique is that the fine, silt-clay (<79 µm) from termitaria is capable of accurately delineating the surficial expression of buried Au mineralisation. Termitaria can therefore provide an accessible surficial biogeochemical sampling media that can be used in mineral exploration programs.
Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis (as listed below*) resides with the copyright holder(s) of those works.

Signed,

Anna E. Petts

26\textsuperscript{th} May, 2009
Acknowledgements

Most of all, I would like to acknowledge my supervisors Dr Steven Hill and Ms Lisa Worrall, for being absolutely awesome, inspiring and patient, as well as being fantastic mentors and friends.

For the companies which have supported my project, financially and through assistance with analyses or have provided feedback on my research directions, or have assisted with information and travel — Newmont Asia-Pacific Limited, in particular Dr Nigel Radford and Dr Simon Bolster; Tanami Gold NL and Dr James Andersen; Anglo American, Barrick Gold, CRCLEME, Geoscience Australia, the employees of Twigg Gold Ltd. Also to the Department of Geology & Geophysics at the University of Adelaide for the award of the Eric Rudd Travel Scholarship in 2006, and to the SA Division of the Geological Society of Australia for financial support to attend conferences.

Thankyou to the researchers involved in the Tanami Collaboration Project over the years, including Dr Brad Pillans, Dr Dirk Kirste, Dr John Joseph, Dr Tony Eggleton, Nathan Reid, Simeon Robinson, Sally Moon, and Dr Martin Smith. To some inspirational CRCLEME researchers and supporters of my research, including Gerry Govett and Colin Dunn, and also Steve Rogers, Graham Taylor, David Gray, Ian Roach, Mehrooz Aspandiar, Colin Pain, Graham Heinson, Rob Hough, Ravi Anand, and Ryan Noble. At Geoscience Australia — Liz Weber, and Bill Pappas for such fantastic assistance with labwork and analyses. For support from the Tropical Savannas CRC — David Garnett, Tracey Dawes-Gromadzki, Peter Jacklyn, and especially Gus Wanganeen for assistance with termite identification, and Mark Raven at CSIRO.

To the CRCLEME researchers and students, and University of Adelaide co-conspirers and friends — John Wilford, Dr Vanessa Wong, Luisa Ruperto, Karen Hulme, Robert Dart, Nathan Reid, Aaron Brown and family, Beau Rule, Dr Ian Lau, Greg Lawrence, Adrian Fabris, Matthew Gray, Lachlan Gibbins, David Haberlah, Michael Neimanis, Stephan Thiel, Rachel Meier, Dr Caroline Forbes, Dr Guillaume Backe, Helen Alexander, Dr Graham Baines, Dr Mark Tingay, Dr Ros King, Kerrie Deller, Jessie Davey, Andreas Schmidt-Munn and his family, Dr Alan Collins and family, Dr Martin Hand, Dr Karin Barovich, Mike Hatch, Bunchy and Megan, Dr Galen Halverson and family, and the PhD and honours students of the University of Adelaide who have kept me smiling these last four years. I would also like to thank my Melbourne friends, including Bence, Kate, Kat, Lauren, Jules, Hannah, Ben, Mel, and Stefan for their inspiration and also, for their patience and love.

The Petts-Rwueling-Enright Family, and close relatives, who have been both my motivation and my distraction, and have brought me so much love and happiness throughout this experience — Ray, Nancy, Howard & Carmen and the boys, John, Loz, Aunty Jeanette and James, The Herring Family, The Ruweler Family, The Enright Family, Cheri and Michelle, Nick and Ryan, Suzy and the girls, Bronx and Ralph. Also, much thanks to the families and friends in Wagga Wagga and around the world who lent so much support and whose inspiration and memory have been with me during this journey. And massive thank yous to Simon for being so patient, and helpful, in giving advice and support during the final stages of my research project.
The author acknowledges also the assistance of Valerie Mobley of LynxEdit, who provided professional proofreading advice. The service included assistance with language and formatting illustrations, and checking for completeness and consistency in the text. This editing service was performed within the guidelines of the current Australian Standards for Editing Practice (ASEP), for the standards C and D.
Dedication

This thesis is dedicated to the strong, intellectual, wonderful women who have touched my life and given me the inspiration, and motivation, to achieve in whatever I choose to do. This is for you, Nancy Sue and Bette Belle.

Mom, Grandma, Friend, Listener, Loved.