Final Report

What are the Fundamental Characteristics of Mineralised (Trans-lithospheric) Fault Systems?

Project A1

Frank P. Bierlein (editor)

Constructed model sections across the Palmerville Fault illustrating a steeply eastward-dipping Palmerville Fault. Modelled gravity response is draped over block model.
“What are the fundamental characteristics of mineralised (trans-lithospheric) fault systems?”

Final Project Report

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Summary

The Architecture A1 Project was funded by the pmd*CRC for 3 years, commencing in May 2002. Research partners were Monash University and Geoscience Australia. Participants, their duration of involvement and percentage of committed time are illustrated in Figure 1.

![A1 Project - Participants](image)

Figure 1: Project participants and time committed during the lifetime of the A1 Project; J.H. = Jon Hronsky; G.B. (2) = Graeme Broadbent & Graham Begg; J.D. = Jon Dugdale; M.E. = Mike Etheridge; F.R. = Francois Robert; R.S. = Roric Smith. Ivo Vos and Anthony Morey are integrated PhD students; projected completion dates as shown.

The principal aim of the project has been to understand why some faults systems are mineralised and why others are barren, and whether a mantle component is essential to form major ore deposits. The objective of the study has been to determine, and rank, a set of critical parameters that could be applied to identify favourable conduits for ore-forming fluids and whether these fault systems are likely to be metallogenically well-endowed with respect to precious and base metal mineralisation.

The project ‘template’ (Figure 2) illustrates the conceptual framework of the multidisciplinary project that has revolved around the combination of, and feedback between, key area studies and database development for the purpose of providing input into modelling scenarios, and delivering key parameters to industry partners.
Figure 2: The A1 Project ‘template’.

The project comprised of several stand-alone modules. Deliverables versus output and achievements for each of these modules are presented separately in a series of sections following this Summary. The schedule of work undertaken within each module is shown in Figure 3.

Figure 3: Schedule for work plan within the A1 Project.
Deliverables versus output and achievements

1. Integrated data base of fault characteristics and spatially associated mineral deposits

In response to feedback from industry sponsors in May 2002 (commencement of project), the project plan was revised to concentrate initial research efforts on development of database (global, independent of commodity or time), rather than the selection and study of specific key areas and fault pairs. Design of the database structure was completed in December 2002 and an ‘Entry form’ uploaded on the secure pmd*CRC Twiki web site on 02 Dec 2002. ‘Proof of concept’ was achieved via the initial interrogation of the database. Integration of the F4 (mineral deposits) data base was initiated but remains incomplete due to a lack of resources. Similarly, development of a web-enabled version to allow universal data entry and interrogation was put on hold in August 2004 (with the database containing 132 individual fault entries) until a unified CRC database protocol becomes available to enable full functionality of the database. No unprompted entries were obtained from pmd*CRC participants over the 24 month period. Interrogation of the database (Fig. 4) has illustrated that while a useful exercise, the information contained in the database (as is) is not capable of highlighting critical parameters. This in itself is a worthwhile finding and the database remains a very useful source of information, e.g., for the purpose of comparing, via the query builder, an ‘unknown’ structure with analogous examples contained in the database.

![Database interrogation (example)](image)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mineralised faults</th>
<th>Unmineralised faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence of magmatism along fault</td>
<td>58 (72.5%)</td>
<td>26 (50%)</td>
</tr>
<tr>
<td>Presence of ophiolites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- uncertain</td>
<td>8 (10%)</td>
<td>4 (7.7%)</td>
</tr>
<tr>
<td>- magmatic</td>
<td>10 (12.5%)</td>
<td>14 (26.9%)</td>
</tr>
<tr>
<td>Magmatism associated with Au</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- major felsic/intermediate</td>
<td>38 (70.4%)</td>
<td></td>
</tr>
<tr>
<td>- bimodal</td>
<td>2 (3.7%)</td>
<td></td>
</tr>
<tr>
<td>- no magmatism</td>
<td>14 (25%)</td>
<td></td>
</tr>
<tr>
<td>Source of fluid: magmatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- in gold-mineralised systems</td>
<td>48 (60%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Geodynamic regime</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- compressional/transpressional</td>
<td>69 (86.3%)</td>
<td>37 (71.2%)</td>
</tr>
<tr>
<td>- extensional/transtensional</td>
<td>5 (6.3%)</td>
<td>10 (19.2%)</td>
</tr>
</tbody>
</table>

Figure 4: Example output generated by Boolean interrogation of the Tectonic Targets data base.
2. Geochemical, geological (structural-tectonic), and geophysical data sets for faults in key areas

Comprehensive data sets have been obtained, and integrated with existing data sets, for key faults and their surrounding regions in study areas in the Mt Isa Inlier (Mt Isa Fault), the Hodgkinson – Broken River Province (Palmerville Fault), and the Menzies – Boorara region in the Yilgarn Craton (Bardoc Tectonic Zone) (Fig. 5). In addition, preliminary Re-Os data have been obtained from five mafic intrusions in the Woods Point region of the western Lachlan Orogen (Governor Fault) to assess the provenance of the igneous rocks, and their role in the generation of one of Victoria’s richest gold fields. Results to date from the Woods Point region are inconclusive and await additional work.

Investigations into the lithological and structural characteristics of gold deposits within the Bardoc Tectonic Zone (BTZ) and Boorara Shear Zone (BSZ) in the Eastern Goldfields Province of the Yilgarn Craton has provided preliminary implications for why the BTZ-BSZ is not as mineralised as the Boulder-Lefroy Shear Zone (BLSZ) Results to date imply that gold mineralisation chiefly occurred relatively early (D2) within the deformation history of the region (Figs. 6, 7). However at Paddington, there are two phases of gold mineralisation. One is associated with D2 and the other is associated with a local NNW–SSE-directed shortening event (DNS) that has been interpreted to occur between D2 and D3. These findings are in contrast with other regional studies of gold endowment within the Eastern Goldfields, which have reported that gold mineralisation occurred late (D3-D4) within this terrane. Furthermore, no large-scale strike-slip faulting (D3) has been observed and late oblique faults (D4) are unmineralised.

Figure 5: Location of key areas of the A1 Architecture Project.
Associating gold mineralisation with relatively early D2 and DNS deformation provides important relative timing constraints on gold mineralisation within the BTZ. Ongoing work concentrates on Re-Os dating of selected Au-bearing sulphides within the BTZ, and a detailed understanding of the sulphide (± Au) paragenesis of mineralised and unmineralised samples from the BTZ, including detailed systematic stable S-isotope study of these mineralised and unmineralised sulphides.

A sub-study within this project (undertaken in collaboration with the I-2 Project) has tested the hypothesis that fault roughness may be one important factor that can affect the endowment of faults in a base metal province, and whether such an approach might provide a useful aid at the area selection scale in mineral exploration. The fractal nature of fault surfaces suggests that fractal methods to measure fault roughness may be appropriate to test the hypothesis, as implemented herein for the Proterozoic Mount Isa Inlier (Fig. 8). Base metal deposits in this inlier are strongly associated with major faults, and studies at individual deposits confirm the strong control on mineralization by faults. Fractal analysis shows that the roughest faults studied are endowed with orders of magnitude more metal/km² than the smoothest faults. Intermediate roughness faults have from none to significant mineral endowments. The rougher faults are also longer. Roughness, but not length per se, is suggested to control mineralization. The relation between roughness and length suggests that as faults grow, they become rougher. Roughness appears to be one important factor that determines mineral endowment of major faults in base metal provinces. An exciting implication of this conclusion is that fault roughness could be used as an exploration tool on a large scale in this and similar terranes where fault geometry can be mapped in detail.
Integration of geophysical and geochemical data was done to test the statute of the Mt Isa Fault Zone as a Palaeoproterozoic terrane-bounding suture. Forward modelling of gravity data shows that basement rocks on either side of the Mount Isa Fault Zone have similar densities. These interpretations are consistent with geochemical observations and Sm-Nd data that suggest that basement lithologies on either side of the Mount Isa Fault Zone are geochemically and isotopically indistinguishable from each other, and that the Mount Isa Fault is unlikely to represent a suture zone that separates discrete Palaeoproterozoic crustal fragments. Our data indicate that the crustal blocks on both sides of the Mt Isa Fault Zone must have been within close proximity of each other since the Palaeoproterozoic, and that the Western Fold Belt was part of the (ancestral) North Australian Craton well before the ~1.89 – 1.87 Ga Barramundi Orogeny. The approach applied herein demonstrates the value of multi-disciplinary investigations to the critical assessment of long-lived Proterozoic fault systems which, due to sparse exposure and/or without methodical analysis, are commonly assumed to represent terrane-bounding sutures. The results of this study also impact on crustal-scale models for the development of shale-hosted massive sulphide Pb-Zn-Cu mineralisation and whether trans-lithospheric faults are an important ingredient for the development of this deposit type. Contrary to speculations that the Mt Isa Fault Zone must have cut the entire crust to account for its coincidence with major shale-hosted massive sulphide Pb-Zn-Ag-Cu orebodies, the data presented herein suggest that these deposits formed in the absence of mantle plumbing systems.

The Palmerville Fault in northeastern Queensland forms a major terrane-bounding structure that may have controlled the evolution of the adjacent Palaeozoic Hodgkinson Province, the northernmost part of the Tasman Fold Belt System in eastern Australia. The nature and subsurface expression of the Palmerville Fault remain poorly constrained and models for contrasting geometries exist. In addition to structural field and microscopic observations, we combined results from multi-scale wavelet edge analysis (‘worming’), forward modelling of regional magnetic and gravity data, and geochemical data sets to develop an improved understanding of the nature and subsurface geometry of the Palmerville Fault. Results from ‘worming’ suggest a steeply dipping geometry for the Palmerville Fault. Based on constraints from field observations and ‘worming’, we have generated a number of sections across the Palmerville Fault and forward modelled their magnetic and gravity response to compare with the observed magnetic and gravity response. Our results show that the Palmerville Fault represents a steeply eastward-dipping structure that may become listric at depth (implying the presence of Proterozoic basement underneath the Hodgkinson Province). Our findings imply that the Palmerville Fault was a first-order normal fault that controlled Early-Middle Palaeozoic basin development in the Hodgkinson Province. Subsequently, the fault acted as a (mid-crustal) décollement zone accommodating basin inversion in the Hodgkinson Province during the Late Palaeozoic. These results provide important constraints on the tectonic evolution of the Hodgkinson Province in northeastern Australia and also demonstrate the strength of multi-disciplinary research in areas of low-data density.

### 3. Development of geophysical targeting tools

Potential field investigations, including multi-scale edge analysis (‘worming’), were carried out in both low and high data density terrains (Hodgkinson – Broken River; Yilgarn) to assess their usefulness in predictive mineral exploration.

Initial assessment of broad-scale worms in the selected study area within the Yilgarn Craton suggested a southward continuity of the BTZ into the Boorara rather than the Abattoir Shear
Zone. This preliminary interpretation was also supported by evidence obtained from the detailed Paddington worms. Further geophysical investigation of the BTZ and the Boorara and Abattoir Shear Zones is necessary before definitive conclusions can be drawn about their continuity. Geophysical targeting research in the Yilgarn Craton has also been examining the magnitude of faults and potential field gradients derived from worming, and evaluated their impact on the distribution of gold deposits. Assessment of the influence of fault length illustrates that there is a positive correlation with proximity to long faults. Gravity worm data have been evaluated in a similar fashion, using length and upward continued height ("persistence") (Fig. 9). The results demonstrate a strong increase in gold content per unit area with proximity to long strike length gravity worms, and corresponding with decreasing search areas. Interestingly, gold deposit locations also display a pronounced association with penetrative edges and with edges that have a high density contrast (i.e. ‘warm’ worms).

Almost as a consequence of lack of proven mineral potential of the key study area in NE Queensland, the geology of the Hodgkinson – Broken River is relatively poorly understood and surface and 3D datasets are sparse. From this perspective, the role of geophysics is instrumental in defining the structural form, depth extent, kinematic evolution and ultimately, factors leading
to fluid pathways and mineral potential of faults and adjacent regions. Specifically, forward modelling of magnetic and gravity data supports normal movement on an easterly dipping Palmerville Fault, with minor later-stage back-thrusting associated with the Mitchell Fault Zone (Fig. 10). From a mineral potential viewpoint, the significance of this simple model fit is still to be investigated, and has been tested using the FLAC 3D modelling template (see below). One possible repercussion is that while the fault may still have provided a fluid conduit, there are no compounding features and subsequent dilation zones to provide traps for mineralisation. Potential-field studies are also redefining the significance of other tectonic elements in these provinces, most notably the Alice Palmer Structure. Multi-scale edge analysis supports similar timing for these structures with both bifurcated by an undefined east-west feature.

**Mapping fluid pathways using seismic methods:** A sub-study led by B. Drummond and B. Goleby at Geoscience Australia considered how to use geophysical tools for the empirical mapping of fluid pathways within mineral systems. Work to date has demonstrated that large seismic reflection responses are possible from ordinary amounts of alteration. The investigation also found that regions where detachment formation is not so pervasive have reflections that can be interpreted to result from alteration and anisotropy caused by fluid flux. For example, in the Laverton/Leonora region, sub-horizontal reflectors and linked concave upwards reflectors similar to those in the antiforms around Kalgoorlie are observed, and these might be targeted as potential foci for upward moving ore-bearing fluids (Fig. 11). A future project will attempt to extend this study to the use of magnetic and gravity methods, including a consideration of the sensitivity of each method as usually deployed, eg., from an aircraft or on the ground, and in the presence of noise.
4. Data-driven prospectivity maps for specific key areas (Yilgarn Craton); assessment of the concept of data-driven prospectivity maps as a potentially powerful predictive tool in exploration

A method of systematically analysing data from global mineral deposits and ordering them into their natural groups was developed using both self-organised maps and biological principles and software, and then used to define the class of "orogenic gold deposits" in the Yilgarn Craton, and identify deposits outside the group that should be excluded from the analysis. To establish such groups, SOM, PATN and PAUP analyses were be applied to data from global mineral deposits. These showed i) the importance of a global context, ii) that traditional classifications are broadly correct but inadequately define or describe deposit types, and iii) what the main characters are that define these groups. Applied to an area such as the Yilgarn Craton, which hosts many styles of deposits, such an approach can aid in defining deposits of a single, coherent group.

5. Critical parameters for identifying metallogenically-endowed fault systems

Population of the tectonic targets database was a prerequisite for reliable identification and ranking of factors that control fault endowment. Failure to obtain a statistically meaningful number of entries (>500) has prevented more comprehensive and rigorous interrogation of the
A1 database, thus precluding the recognition, and ranking of critical parameters. Nonetheless and using orogenic gold mineralisation as an example, first-pass interrogations via multivariant, phenetic and phylogenetic analysis (see above) revealed a conjunction of factors that appears to be common to the majority of mineralised faults contained in the data base. Interrogation of major fault and mineral deposit databases largely confirms the relative importance of empirically-derived, critical and permissive parameters for mineralisation, such as proximity to crustal-scale faults, anticlinal hinge zones, dilational jogs, fault roughness, strong rheological contrasts and metamorphic grade (Figs. 12, 13). Presence and concurrence of these parameters appear to determine the extent of metallogenic endowment of a given fault system and segments thereof.

Figure 12: GIS analysis illustrating spatial relationship between gold deposits and fault bend and jogs in the Eastern Goldfield Province, Yilgarn Craton.
6. Development of scenarios for pmd*CRC Modelling Program

The development of generic modelling scenarios within the A1 Project was dependent on database functionality, and governed by computational and budgetary constraints. These constraints have delayed commencement of this module until early 2005. FLAC 3D modelling of the Palmerville Fault in the Hodgkinson Province has been used as an initial test case to assess the evolution of a 1st-order, poorly-endowed fault in a low data density terrain (Fig. 14). Results from our modelling confirm geological and geophysical interpretations, and provide insights into the loci of dilation and fluid flow with varying geometries. These results prove useful in understanding why the major Palmerville Fault itself remained barren, with mineralisation occurring in parallel second-order faults.

Figure 14: Overall Palmerville Fault model architecture representing a block of crust 50 km wide, 50 km long and 5 km deep – a) Base architecture with two lithologies and three through going faults showing the model setup in plan view (top) and cross-section (bottom); b) Variations on the base architecture with three lithologies and no faults (top) and three lithologies, two through...
going faults and a fault segment covering half the blocks length.

Furthermore, additional insights can be gained on the tectonic evolution of the Hodgkinson Province based on an augmented understanding of the processes that control mineralisation in the province.

7. Mineral potential of the Hodgkinson – Broken River Province; PhD study by I. Vos (completion by October 2005)

As part of the multi-disciplinary approach to predicting the mineral potential of major fault systems applied herein, this PhD study has focused on the poorly studied, low data-density regions of the Hodgkinson and Broken River Provinces in northeastern Queensland, Australia. Both provinces are bound and transected by numerous major fault systems, the majority of which are poorly exposed. Our results indicate that through integration of available datasets and new field observations, plausible assumptions on the nature of these fault systems and their mineral potential can be made. Characteristics of epigenetic gold systems in the two provinces have also been investigated, and have focused on sulphide paragenesis, structural relationships and fluid inclusion studies of gold-antimony deposits in the Hodgkinson and Broken River provinces. Strong similarities between the deposits in both provinces allow for inter-regional correlation, which, in turn, provides important insights into the tectonic evolution of the northern portion of the Tasman Fold Belt System. The ‘orogenic’ style of gold mineralisation and relative timing of gold deposition in both provinces imply that gold mineralisation was formed during several episodes of deformation in a subduction-accretion system that developed along the Pacific margin of Palaeozoic Australia.

8. Mineral potential of the Bardoc Tectonic Zone; PhD study by A. Morey (completion in mid-2006)

This project aims to apply the A1 objectives to the Eastern Goldfields Province of the Archaean Yilgarn Craton. This has been implemented by studying the Bardoc and Boorara shear systems. These shear systems are major gold-bearing trans-crustal faults, but they are apparently not as mineralised as the nearby Boulder-Lefroy Shear Zone (BLSZ). Ongoing work has been focussing on three gold deposits within the late-Archaean Bardoc Tectonic Zone (BTZ) Western Australia, namely Paddington, New Boddington and Yunndaga. The styles, characteristics and relative timing of deformation and gold mineralisation have been constrained at each of these deposits. These local events have then been correlated to provide an understanding of regional controls of gold mineralisation within the BTZ. Results to date imply that gold mineralisation chiefly occurred relatively early (D2) within the deformation history of the region, which is in contrast to other regional studies. However at Paddington, there are two phases of gold mineralisation. One is associated with D2 and the other is associated with a previously unrecognised NNW–SSE-directed shortening event (DNS) that has been interpreted to occur between D2 and D3. These findings are in contrast with other regional studies of gold endowment within the Eastern Goldfields, which have reported that gold mineralisation occurred late (D3-4) within this terrane. Furthermore, no large-scale strike-slip faulting (D3) has been observed and late oblique faults (D4) are unmineralised. Associating gold mineralisation with relatively early D2 and DNS deformation provides important relative timing constraints on gold mineralisation within the BTZ, and also has implications for understanding why the BTZ-Boorara Shear Zone is not as mineralised as the BLSZ.

From May 01, 2005 until completion, this PhD project will be undertaken under the auspices of the Y4 Project.
A brief assessment of the application of critical parameters to predictive mineral exploration, and their use in exploration in key areas and analogous areas elsewhere

Recent advances in the acquisition, processing and integration of large and diverse data sets has enabled mineral exploration to increasingly shift from relying on a largely field-based, empirical approach to the application of computer-based and conceptual strategies. This has led to the development of a variety of techniques that use knowledge- and/or data-driven approaches to efficiently extract exploration-relevant factors from multi-disciplinary datasets, and integrate these into mineral prospectivity maps at the local to regional scale (cf review in Knox-Robinson, 2000). Several studies have illustrated the use of GIS as an efficient vehicle for conceptual mineral exploration in areas of the Australian continent that are characterised by poor exposure, such as the Yilgarn Craton, Lennard Shelf, Pine Creek Inlier and the southern New England Orogen (e.g., Wyborn et al. 1994; Knox-Robinson and Groves, 1997; Brown et al., 2000; D’Ercole et al., 2000; Gardoll et al., 2000). These studies variably considered lithology, metamorphic grade, major structures, geometry of geological bodies, geophysical criteria, and spatial relationships to construct prospectivity maps at the camp to regional scale. Prospectivity analyses in these studies were largely based on the coincidence of empirically-based, diagnostic and permissive criteria (weight-of-evidence), and the use of artificial neural networks that employ pattern recognition and classification via the simultaneous analysis of all input parameters. In contrast to the approach used in these studies, the strength of prospectivity assessment in this investigation lies in the regional- to terrane-scale integration and novel, multi-variant testing of knowledge-driven and data-driven parameters. This method successfully queries, illustrates, and quantifies the empirical spatial relationship between orogenic gold deposits and faults, and also recognises the critical parameters that likely determine the location and size of deposits along well-endowed structures.

Fault control on mineral deposits is commonly manifest, but is just one piece of the puzzle to unravelling concepts on ore genesis and deposition. Using the example of gold mineralisation in the Yilgarn Craton, “fertile” or prospective positions along fault systems are commonly those with a perceived increased fracture intensity, permeability and roughness, such as dilational relay ramps, cross-faults, areas of maximum displacement, reactivation and post-seismic failure (e.g., Zhang et al., 2001; Betts and Lister, 2002; Cox and Ruming, 2004). Additional factors that are well-known in the exploration context in the Yilgarn Craton include: proximity to crustal-scale faults, regional anticlinal hinge zones, dilational jogs, strike changes, strong rheological contrasts and metamorphic grade. A characteristic spacing of large deposits along major faults is also apparent, at least in the case of the Boulder-Lefroy Shear Zone (Weinberg et al., 2004). Development and interrogation of a faults database applied herein confirm the findings of these empirical studies, and indicate that the majority of well-endowed major fault systems in the Yilgarn Craton and elsewhere represent highly non-planar, discrete ‘damage zones’ that record a complex kinematic history. Permeability contrasts, lithological and metamorphic heterogeneities, the presence of suitable seals and sinks, steep complexity gradients, and the overall geometry of the fault systems play key roles in determining their metallogenic endowment.

Major metallogenically important faults are commonly steep and possibly transcrustral, as demonstrated by a close spatial association of mantle-derived magmas along many of these structures. On the other hand, many of these structures that are sub-vertical at shallow crustal levels have a listric geometry at greater depth. This has implications for their capability to transect the lithosphere and extent to the asthenosphere, thus tapping mantle-derived fluid reservoirs. Mantle-driven processes are probably important in the formation of world-class
ore deposits but the quantitative significance of mantle dynamics remains to be demonstrated. Where there is little direct evidence for a well-endowed fault to penetrate the lithospheric mantle, late-stage decoupling of the fault might have occurred along a more ductile lower crustal layer. The demonstrated influence of faults and potential field (gravity) gradients on gold distribution in the Yilgarn Craton confirms the spatial link between orogenic gold mineralisation and deep-seated, major faults. Although seismic surveys reveal that many or most of the steep faults exposed in the eastern Yilgarn Craton are listric and merge with a flat lying reflector lower in the crust (e.g., Goleby et al., 2004), and therefore do not tap the mantle directly, we demonstrated that there is general association between major gold deposits and ‘deep’ and ‘long’ worms. This strongly suggests that large-dimension edges can provide a first-order area selection filter for exploration, especially in areas of poor exposure. As with databases, however, the validity of the interpretations is limited by the quality of input data (i.e., data density) and the scale of application.

Further reduction of the search area can be aided via the application of straightforward probability tests that assess the empirical spatial relationship between, for example, orogenic gold and a number of structural elements. These show endowment can be correlated with the intersections of anticlines by major, highly non-planar faults. In addition, buffer analysis reveals that gold is preferentially associated with smaller (2nd- and 3rd-order) faults that are within close proximity of major (1st-order) faults. The recognition that size is important is not new, nor is that small faults preferentially host the gold (e.g., Groves et al., 1998). However, it is the combination of small faults under the influence of large faults that seems to be the key in understanding where orogenic gold is preferentially distributed. Penetrative structure presumably provides the pathway for accessing metal sources, and these metals migrate or diffuse away from large faults to depositional sites on small faults. The findings of this study illustrate the strong permeability (and/or temperature, redox) control on orogenic gold distribution and confirm empirical observations that have related the late-stage origin of gold deposition in dilational positions to major fault growth episodes (“golden aftershocks” of Cox and Ruming 2004).

The range of prospectivity analyses applied herein confirms the usefulness of a multi-disciplinary approach and demonstrates the power of a variety of targeting drivers being tested. In particular, applying these targeting drivers in combination has several advantages over approaches that use Boolean logic (i.e., prospective/non-prospective) or Bayesian-type weights of evidence modelling (e.g., Knox-Robinson, 2000) in that they allow for the distinction between multiple degrees of prospectivity, or ‘fertility’. However, further work is needed to take the predominantly regional- to terrane-scale parameters considered herein and apply them in project generation activities. In doing so, additional geological (e.g., fault parameters such as the role of intersections and dip directions), geochemical (e.g., camp-scale hydrothermal alteration patterns, fluid physio-chemistry) and geophysical data sets (e.g., aeromagnetics, edge gradient amplitude variations) which impact at prospect scale need to be investigated.

The types of spatial and statistical analyses undertaken in the course of this project are best undertaken on deposits of one genotype and with similar controls. To establish such groups, SOM, PATN and PAUP analyses can be applied to data from global mineral deposits. These show i) the importance of a global context, ii) that traditional classifications are broadly correct but inadequately define or describe deposit types, and iii) what the main characters are that define these groups. Applied to an area such as the Yilgarn Craton, which hosts many styles of deposits, such an approach can aid in defining deposits of a single, coherent group,
although itself comprising a number of sub-groups which may be interesting to investigate further.

Ultimately, the combination of parameters documented in this study with camp- to regional-scale, knowledge- and data-driven GIS prospectivity analyses, ground-proofing and output from probabilistic numerical modelling scenarios should enable the development of vertically-integrated, conceptual targeting strategies. Improved area and target selection, in turn, will provide the minerals industry with the means to conduct predictive exploration more cost-effectively at a variety of scales and also significantly increase the chance of discovery.

**Implications for predictive mineral targeting**

The integration of multi-scale exploration targeting with conceptual research is becoming increasingly important. With this in mind, the studies conducted in the course of this project were aimed at addressing fundamental issues relevant to predictive targeting. It is hoped that via the synthesis of data sets, and linking between geological, geophysical and geochemical disciplines, the output generated herein is leading towards a significantly improved understanding of the fundamental geometrical and kinematic characteristics of metallogenically endowed fault systems that can be applied in predictive mineral discovery. The key outcomes of this work can be summarised as follows:

- The A1 Tectonics Targets data base provides a useful resource and interrogation serves to confirm the importance of parameters that are likely to influence the endowment of major faults, and spatially associated 2nd- and 3rd-order structures. But the information contained in the data base as is remains insufficient to clearly define, let alone rank potentially critical parameters.

- Interrogation of major fault and mineral deposit databases via multi-variant, phenetic and phylogenetic analysis largely confirms the relative importance of empirically-derived, critical and permissive parameters for mineralisation, such as proximity to crustal-scale faults, anticlinal hinge zones, dilational jogs, fault roughness, strong rheological contrasts and metamorphic grade.

- Prospectivity mapping of structural elements shows that elevated endowment can be correlated with the intersection of major faults and regional anticlines and fault jogs, particularly those of a dilatant nature.

- Presence and concurrence of these parameters determine the extent of metallogenic endowment of a given fault system and segments thereof.

- Mantle-driven processes are probably important in the formation of world-class ore deposits but the quantitative significance of mantle dynamics remains to be demonstrated. Where there is little direct evidence for a well-endowed fault to penetrate the lithospheric mantle, late-stage decoupling of the fault might have occurred along a more ductile lower crustal layer.

- Modelling of potential field (gravity, magnetics) gradients can successfully illustrate the spatial link between mineralisation and deep-seated, major faults and provides a reliable first-order area selection filter for exploration, especially in areas of poor exposure.
On the basis of current data sets, the Mt Isa Fault can be interpreted as either an inverted extensional fault or a late-orogenic thrust. However, our data show that the Mount Isa Fault is not likely to define the surface expression of a Barramundi-aged transcrustal suture. The fault is unlikely to have cut the entire crust, with spatially related, major shale-hosted massive sulphide Pb-Zn-Ag-Cu deposits probably formed in the absence of mantle plumbing systems.

Roughness appears to be one important factor that determines mineral endowment of major faults in base metal provinces. Fault roughness can potentially be used as a regional-scale exploration tool.

The Palmerville Fault is an inverted, first-order growth fault that controlled Early-Middle Palaeozoic basin development in the Hodgkinson Province. Orogenic gold endowment of the Palaeozoic Hodgkinson-Broken River Province is likely to be controlled and limited by the presence of Proterozoic, crustal-character Proterozoic basement underneath the basin.

Major differences between the Boulder-Lefroy Shear Zone (BLSZ) and the less well-endowed Bardoc Tectonic Zone (BTZ) include i) gold deposits in the latter are cited within a first-order major shear zone, and not located on a second- or third-order splay structures, which is the case for e.g. the Kalgoorlie Gold Camp along the BLSZ; ii) the relatively competent units that are favourable hosts for gold mineralisation are markedly narrower across strike within the BTZ/BSZ – they are tens of metres wide as opposed to hundreds of metres wide within the Fimiston Pit, BLSZ; iii) a potentially different shear zone evolution, that is, an apparent lack of major strike-slip deformation during the structural evolution of the BTZ; and iv) an apparent lack of Te within the Au-bearing minerals from the BTZ; gold-bearing minerals from the Kalgoorlie Camp (BLSZ) are associated with Te-bearing minerals. Multi-staged gold mineralisation events occurred relatively early within the deformation history of the BTZ system.

If the effects of the 3D nature of faults and shear zones are not taken into account, strong seismic reflections from faults and shear zones will result in an overestimate of the amount of alteration and/or the anisotropy of phyllosilicate minerals caused by fluids moving along the faults and shear zones.

The implication of this is that the seismic method should be able to image the flow paths in gold mineral systems by mapping the physical property changes caused by alteration along the flow paths; fluid flux does not have to be extreme.

Zones of high fluid flux at supralithostatic pressures would be an excellent locus for focussing the formation of detachment surfaces.

Physical modelling suggests that fluids would break out of such regions into dipping high strain zones that project towards the surface; they should be reflective in seismic sections.

Reflectors that might be interpreted as spill zones are seen beneath Kalgoorlie, Mount Pleasant, Sons of Gwalia and possibly Kanowna Belle in the Yilgarn Block and possibly also the Marimo fault in the Eastern Succession in Mount Isa.
• In regions where detachments did not form or are no longer recognised, spill zones have been interpreted for 9 km depth under Laverton, and at deep levels elsewhere along the Laverton/Leonora seismic line.

• The potential implications of theoretical considerations, as well as yet unanswered key questions can be addressed and tested effectively via the development of numerical modelling scenarios.

• Integration of the approach applied in this study with deposit- to regional-scale computer-based methodologies provides an effective tool in the construction of prospectivity maps applicable to predictive mineral exploration.

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References cited


Appendices
(see attached DVD for digital appendices)

Conference abstracts, reports and publications:

- Mt Isa Inlier
  - SHRIMP U-Pb dating of zircons in 3 samples from pre-Barramundi basement rocks in the Western Fold Belt of the Mount Isa Inlier (F. Bierlein, L. Black). See annual report to 30/06/04, pp. 5-7.

- Hodgkinson – Broken River Province


Overview of the geology of the Amanda Bel goldfield (I. Vos; unpublished report).


- **Yilgarn Craton**


**Fluid pathway study**


**Tectonic Targets Data base**

- Data base spreadsheet (as current in April 2005; Excel format)
- Preliminary data base interrogation (see quarterly report to September 30, 2004)
Centre – Extended Abstracts from the June 2004 Conference, Geoscience Australia, Record 2004/09, p. 115-118.

Quarterly and Annual Reports

- Annual Report to June 30, 2003
- Annual Report to June 30, 2004
- Quarterly report (30/06/02)
- Quarterly report (30/09/02)
- Quarterly report (31/12/02)
- Quarterly report (31/03/03)
- Quarterly report (30/09/03)
- Quarterly report (31/12/03)
- Quarterly report (31/03/04)
- Quarterly report (30/09/04)
- Quarterly report (31/12/04)

Posters

- Structure and mineralisation of the Menzies-Boorara Shear Zone. 17th AGC, Hobart, February 2004 (A. Morey).
- Why is the Menzies-Boorara Shear Zone not as well endowed as the Boulder-Lefroy Shear Zone? SEG 2004 Meeting, Perth, September 2004.
- The mineral potential of major fault systems: a case study from NE QLD, Australia. SEG 2004 Meeting, Perth, September 2004 (I. Vos).
- Structural and metallogenic characteristics of gold deposits in the Amanda Bel goldfield, Broken River Province, NE Queensland, Australia. 17th VUESC Conference, Melbourne, September 2003 (I. Vos).
- Reconstruction of the evolution of the Tasmanides in eastern Australia, with special emphasis on the 440 Ma event. Annual Review Meeting Canberra, December 2002 (i. Vos).

PowerPoint presentations

- Mt Isa PDT Meeting, Mt Isa, March 2005
• Coupled deformation and fluid flow modeling of a listric fault geometry: implications for the Palmerville Fault, northeast QLD, Australia. ARRC CSIRO, Perth, March 2005 (I. Vos).

• Mt Isa SHRIMP U-Pb analysis, Mt Isa I-New workshop, Townsville, December 2004.

• 440 Ma gold mineralisation: insights from the Lachlan Fold Belt and beyond. GSV Tasmanides workshop, Melbourne, December, 2004 (I. Vos).

• A multi-disciplinary study of the tectono-metallogenic evolution of the Tasman fold belt system in NE Queensland. Presentation to WMC, November 2004 (I. Vos).

• Yilgarn PDT Meeting, Perth, November 2004.


• Gold mineralisation potential in the Tasman Fold Belt System, Northeastern Queensland, Australia. IGC Florence, August 2004 (I. Vos).

• The mineral potential of major fault systems: case studies from Northeastern Queensland, Australia. Barossa Meeting, June 2004 (I. Vos).

• Yilgarn worms; Barossa Meeting, June 2004 (B. Murphy).

• Structure and mineralisation of the Menzies-Boorara Shear Zone – implications for variations in the gold potential of a major fault system, Barossa Meeting, June 2004 (A. Morey).


• Broken River Province talk, 17th AGC, Hobart, February 2004 (I. Vos).

• Yilgarn projects workshop, Perth, December 2003.


• A1 data base SOM analysis, November 2003.

• Mt Isa workshop, Mt Isa, November 2003.

• ERC Meeting presentation, Melbourne, May 2003.

• Review Meeting presentation, Canberra, December 2002.

• Baragwanath Seminar, November 2002.

• pmd*CRC workshop presentation, Melbourne, July 2002.

Data sets, reports and publications not included elsewhere

• Petrographic report on 24 basement (pre-Barramundi Orogeny) rock samples from the western succession, Mt Isa Inlier.

• Summarised Re-Os data of 5 whole-rock samples from mafic-intermediate dykes in the Woods Point region.


Proceedings volume and field guide, MORE-SGEG conference, Orange, NSW, GSA Abstracts no.74, p.141-144.

- List of samples collected for SEM, Sm-Nd, NAA and fluid inclusion analysis from the Hodgkinson – Broken River Province (I. Vos; xls).
- Geochemical analysis of whole-rock samples of Palaeozoic basalts in the Broken River province (I. Vos; unpublished report).
- Neutron activation data for samples from the Hodgkinson – Broken River Province (I. Vos; xls). See NAA Analysis folder on DVD
- Sm-Nd data for six samples of Palaeozoic basalts from the Hodgkinson Province (I. Vos; xls).
- Microthermometric fluid inclusion data for vein quartz from the Northcote goldfield, Hodgkinson Province (I. Vos; xls).
- Microthermometric fluid inclusion data for vein quartz from the Amanda Bel goldfield, Broken River Province (I. Vos; xls).
- Amanda Bel goldfield electron microprobe data (I. Vos).
- Whole-rock geochemistry, Ethel deposit, Northcote goldfield (I. Vos).
- Forward modeling of the Palmerville Fault (I. Vos; jpeg and bmp).
- FracSis output for Flac 3D modeling of Palmerville Fault (I. Vos). See FracSis folder on DVD
- Magnetic and gravity edge gradient modeling of Hodgkinson – Broken River Province (M. Barlow; jpeg and bmp). See Worm image folder on DVD
- Summary of preliminary scanning electron microprobe results (A. Morey; ppt).
- Neutron activation data for samples from the Menzies – Boorara Shear Zone (A. Morey)
- Upward continued geophysical edge gradient modelling interpretation of Menzies – Boorara Shear Zone (A. Morey; tiff). See Geophysics - A. Morey folder on DVD
- Preliminary $\delta^{34}$S data for sulphides from the Menzies – Boorara Shear Zone (A. Morey; xls).
- List of samples collected for SEM, NAA and $\delta^{34}$S analysis from the Menzies – Boorara Shear Zone (A. Morey). Drill samples

Fluids F4 Project reports (prior to August 2004; authored by Terry Lees)

- September 2002 Quarterly Report
- December 2002 Quarterly Report
- March 2003 Quarterly Report
- Annual Report 2002
- Annual Report 2003