The Ida Shear Zone

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Summary of the Ida and Zuleika Shear Zones

Gold deposits along the Ida and Zuleika Shear Zones share some similarities, in that, in both areas, mineralization is late in the structural history, and structurally controlled in areas of increased complexity. Economic gold concentrations are preferentially sited at intersections between N-S and NNE-SSW ductile and brittle-ductile structures and the dominant NNW fabric, in particular where there are either low viscosity rocks (shales or ultramafic rocks), or high viscosity or brittle rocks (granites or dolerites). Gold mineralization in both corridors also show a similar chemical signature; for instance ubiquitous potassium, sulphur and silica enrichments, and anomalous arsenic concentrations at shale-hosted deposits.

Although, high-grade, shear-zone hosted deposits have been exploited along both structures, the main factor limiting the development of giant gold deposits would appear to be amphibolite facies metamorphism during or before mineralization. This not only diminishes the competency contrast between lithological units, but also, when accompanied by high strain, produces a pervasive foliation and parallelism of structures and lithologies, thus decreasing heterogeneities which could have focused mineralizing fluids.

Study of deformation of the Ida and Zuleika Structural Corridors suggest that deformation in the Kalgoorlie Terrane resulted from the interaction between a regional ENE-WSW shortening and indentation of competent granitoid blocks into their weaker greenstone matrix. Such interactions at the Terrane and Domain scales is via shear zone and fold rotation, as well as lateral and vertical escape of greenstone sequences on the sides of batholiths. Westward indentation of the large mass of granitoids north of Kalgoorlie into the Southern Cross Terrane explains the intense pure shear flattening with a small dextral component determined along the Ida Shear Zone, as well as the broad flexure of the Zuleika Shear Zone, which has sinistral movement on its northern part and exhumation on its central part around Kundana.

2.5.1. The Ida Shear Zone

Introduction

The Ida Structural Corridor (ISC) is a regional lineament, ~500 km long, on the western side of the Eastern Goldfields Terrane (Fig. 2.5.1) purported to separate the Eastern Goldfields Terrane from the older Southern Cross Terrane (Williams 1974, Gee et al. 1981), either reflecting terrane accretion, or representing the boundary of an early extensional basin into which 2.7-2.66 Ga mafic- ultramafic and felsic rocks were extruded.

The central portion of the Ida Structural Corridor is a narrow zone of high strain developed along the linear Ularring Greenstone Belt (Wyche 2000) that includes the Ida Shear Zone (the term Ida Shear Zone is used in preference to the more common 'Ida Fault', because it better reflects the attributes of the structure). This module has focused on the Ida Shear Zone, and accompanying strain corridor, as part of its regional efforts to understand the evolution of the Kalgoorlie Terrane and gold mineralisation. The structure was selected because of its regional importance as a potential terrane boundary, and also because its poor gold endowment contrasts strongly with that of the Boulder-Lefroy Shear Zone.

On aeromagnetic images, the Ida Structural Corridor can be traced north and south of the Ularring Greenstone Belt. The northward continuation can be traced on the west side of the Agnew-Wiluna belt as the Waroonga Shear Zone (Platt et al. 1978), while the southern continuation correlates with the western margin to the Coolgardie, Widgiemooltha and Chalice Greenstone Belts.

The Ularring Greenstone Belt is further subdivided into local geographic centres (Fig 2.5.2), namely, from north to south, Mt Alexander, Mt Ida, Riverina and Davyhurst and was selected for study because it incorporates lithologies considered to be representative of the two terranes. The greenstone belt is bounded to the east by the Riverina Gneiss, which is a strongly foliated gneiss that yields a strong linear magnetic fabric that extends along strike for >100km and it is bounded to the north and west by granitoids (Fig 2.5.2). The Honours Thesis work by Embry (1999) was funded by this project and details the Riverina region with a detailed geological map (available for consultation and copying at UWA, Department of Geology and Geophysics Theses Library, Ms J. Bevan, tel. 08 9380 2681).

Previous Work

The geology of the Ida Structural Corridor, from Davyhurst to Mt Ida, was described by Gibson (1904, 1906), Johnson (1950) and Tomich (1956). Focussing primarily on gold mineralisation, particularly at Timoni (Copperfield), and Riverina gold mines, little attention was paid to poorly exposed crustal breaks, although Tomich (1956) highlighted a contrast between a western 'jaspelite' bearing series and an eastern epidiorite series of greenstones within the Ularring belt. Williams (1974) determined that a "linear disruption" defined by the Ida Structural Corridor marked a change in lithology and structural orientations, while noting that the corridor itself was disrupted by granitoid intrusions.

The discovery of the Bottle Creek gold deposit in the Mt Ida area in 1983 led to increased interest in the belt. In his report on Bottle Creek, Legge et al. (1990) placed the Ida Shear Zone at the contact between the eastern margin of the Ularring Belt and the Riverina Gneiss. Wyche and Witt (1992), and Wyche (2000), both suggested that a terrane boundary might correlate with the western extent of ultramafic rocks in the Riverina and Davyhurst areas, which are accompanied by a zone of high strain. No previous detailed structural work on the ISZ has been published, while geochemical analyses of the rocks in the region are limited to a study around the Bottle Creek environs (Binns 1988), and a study in the Riverina area by Embry (1999). The Davyhurst area was mapped and described by Witt and Wyche (1992), and the Riverina area by Embry (1999) and Wyche (2000). The central (Mt Ida region) and northern (Mt Alexander region) sectors have recently been mapped by AGSO (Ballard, Mt Mason, and Mt Alexander 1:100,000 sheets).

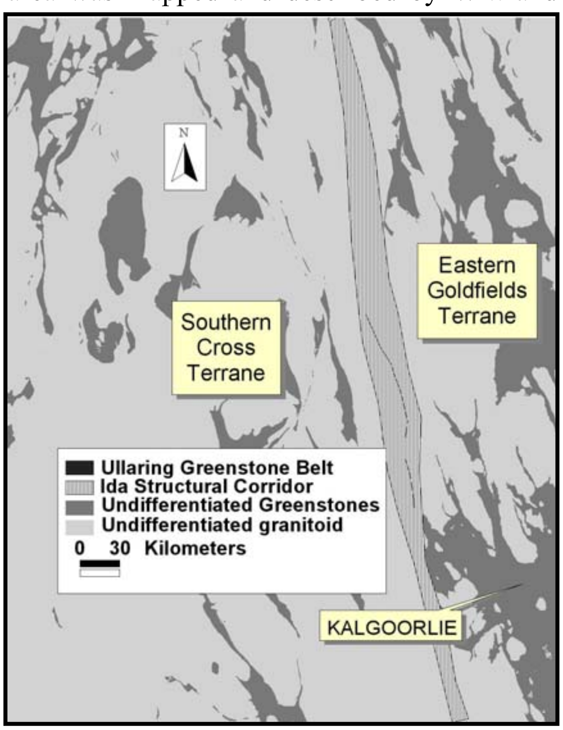

Fig. 2.5.1. The central Yilgarn Craton showing the trace of the Ida Structural Corridor and its relationship to the Eastern Goldfields and Southern Cross Terranes.

Current interpretation of the Ida Shear Zone is largely based on seismic data (Drummond et al. 1993, Swager et al. 1997, Drummond et al. 2000). The structure is interpreted to dip moderately to the east (~30°), and to penetrate to 25 km beneath the surface (Drummond et al. 1993). It is one of only a few structures that the seismic data depicts as cutting an apparent detachment fault imaged at the base of the greenstones. A gradual eastward thickening of the crust has been interpreted from the seismic study, and broadly coincides with the position of the Ida Shear Zone (Drummond et al. 1993). This crustal thickening, combined with an easterly decrease in metamorphic grade, led Swager et al. (1997) to interpret the Ida Shear Zone as a late stage normal fault and suggested that greenstones of the Kalgoorlie Terrane once extended west of the Ida Shear Zone, but were subsequently uplifted and eroded.

Stratigraphy

Three distinct stratigraphic sequences are recognised across strike within the Ularring Belt (Fig 2.5.2). The western sequence consists of interbedded banded iron formation (BIF) and mafic volcanic and possible sedimentary units, which dip moderately to steeply east. The presence of BIF in greenstone belts throughout the Southern Cross Terrane, and their scarcity in the Norseman-Wiluna Belt, have been used to correlate this package with supracrustal rocks to the west (Wyche and Witt 1992).

The central sequence is dominated by thick (<1km), monotonous, east-dipping mafic rocks ranging from fine- to medium-grained (basaltic to doleritic texture), with occasionally preserved pillow structures. Several coarse-grained differentiated mafic intrusive rocks of undetermined dimensions were intruded along the eastern portion of this sequence (van der Borgh, thesis in prep). A series of intermediate to felsic intrusive rocks are also present in this area. In the Mt Ida area (Fig. 2.5.2), the felsic rocks are intensely foliated, tabular bodies, in places discordant to stratigraphy. Individual dykes are several metres thick and persist for several hundred metres along strike. In the Mt Alexander area to the north (Fig. 2.5.2), intrusive rocks tend to be more ovoid and less foliated, and preserve intrusive relationships.

The eastern sequence consists of thinner (5-50m) layers of mafic and ultramafic and interbedded fine-grained sedimentary rocks, tightly folded around NNW- to N-trending, sub-vertical axial planes such as the major Kurrajong Anticline, which incorporates much of the eastern sequence and contains the Copperfield Granite at its core (Figs. 2.5.2 and 2.5.9).

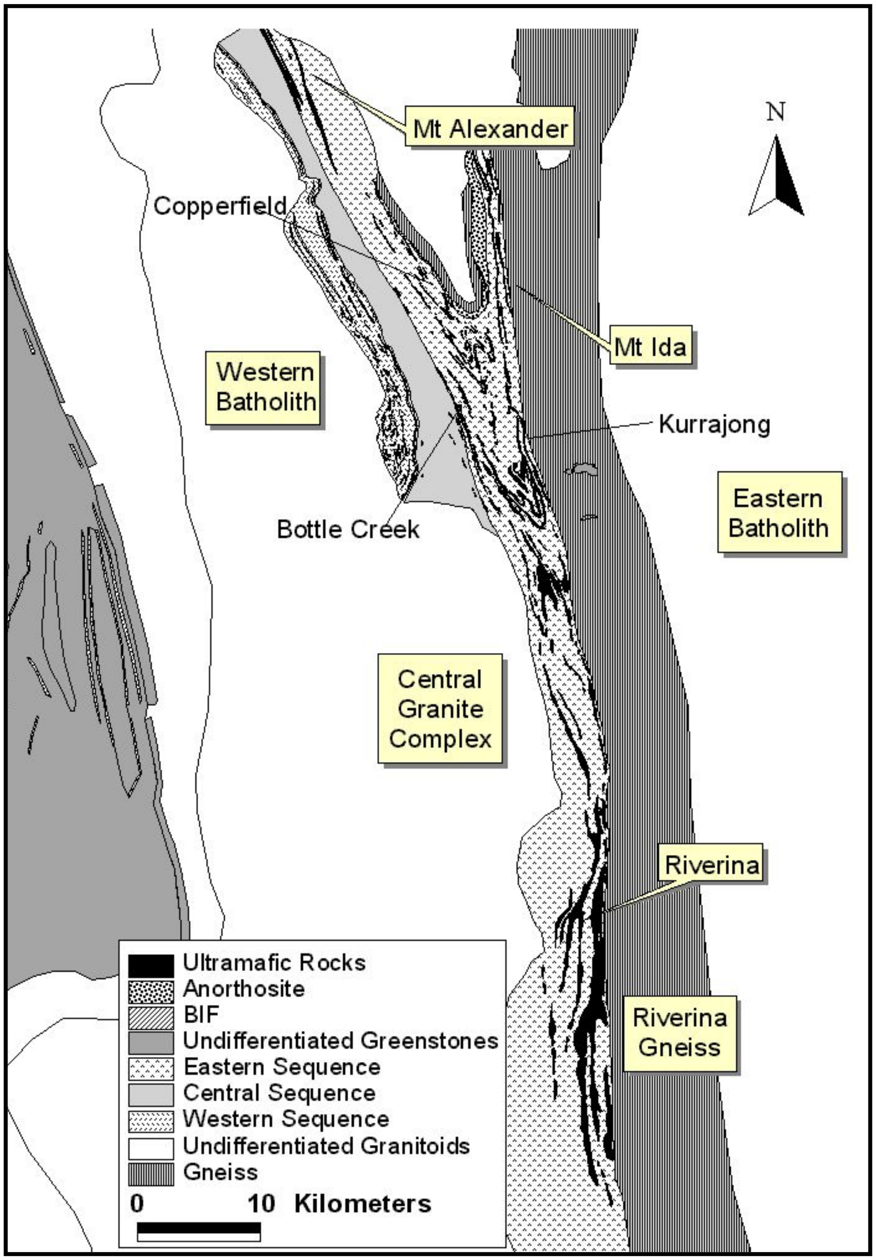

Fig. 2.5.2. Interpretative solid geology map of the Ularring Greenstone Belt, and the principal regions discussed in the text.

The ultramafic rocks of the eastern sequence at Kurrajong, close to Mt Ida, have been correlated with the Walter Williams Formation (Hill et al. 1995), an extensive (35x150km) ultramafic-mafic package that can be traced along discontinuous outcrop all the way to Ora Banda, east of the Zuleika Shear Zone. The eastern sequence was correlated with similar rocks at Lawlers to the north, and Murrin Murrin to the east of the Keith Kilkenny Fault (Rattenbury 1993). Such interpretations, if correct, imply that the eastern sequence belongs to the supracrustal rocks of the Kalgoorlie Terrane, and that this sequence covers much of the Eastern Goldfields.

In the Mt Ida area, several large porphyritic bodies intrude the ISZ. These, or similar, porphyries can be observed in costeans and intermittent outcrops for >14km northward along the strike of the ISZ. Where observed, the porphyries contain a pervasive foliation, which is consistent with that of the shear zone. The porphyries host mineralisation at Bottle Creek. In the Riverina area, the Clarks Well monzogranite is interpreted to cut the shear zone and to be undeformed (Wyche 2000). A U-Pb zircon SHRIMP age determination yielded 2640±8 Ma and was used to constrain the minimum age of movement along the Ida Shear Zone (SHRIMP U-Pb on zircon; Nelson 1995). However, as discussed in this report on (*Section 2.3)*, the error bar on this age covers nearly the entire duration of the Kalgoorlie Orogen (D_2-D_4). Pegmatite dykes are common in the Mt Alexander and Riverina sectors, but absent in the Mt Ida sector. These crosscut the Ida Shear Zone at high angles, and appear to be undeformed.

In summary, three well-defined sequences can be intermittently traced for the strike length of the greenstone belt (Fig. 2.5.2). The western sequence differs from the others by the presence of BIFs, while the eastern sequence includes extensive ultramafic rocks in the sequence that is related to the Walter Williams Formation at Ora Banda. All sequences are highly attenuated, and, like other regions, they were intruded by mafic sills and porphyries.

Regional Metamorphism

Mafic rocks throughout the Mt Ida and Mt Alexander areas consist of the assemblage amphibole (hornblende or actinolite), plagioclase, ilmenite and titanite. Chlorite forms a minor, retrograde component in some rocks and epidote is rare. Most rocks contain some mineral alignment defining a foliation, although igneous textures are occasionally preserved, such as the inherited ophitic texture (Fig 2.5.3). Plagioclase compositions of An_{50-90}, and rare epidote and absent garnets in the mafic rocks, together suggest low to mid-amphibolite facies metamorphism.

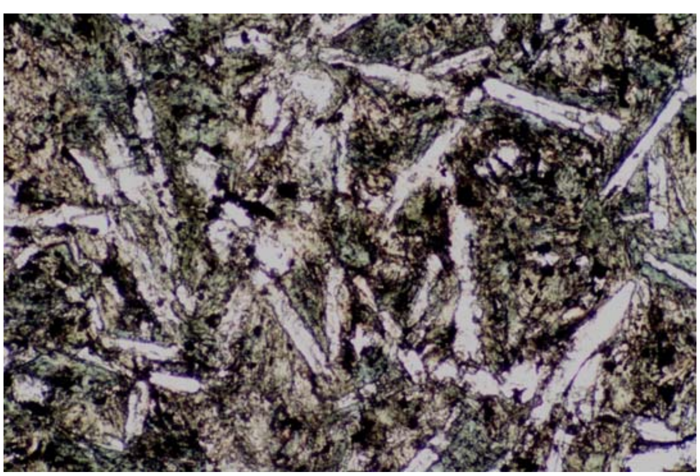

Fig. 2.5.3. A fine grained mafic rock from the Ularring Greenstone Belt, showing an inherited ophitic texture defined by igneous plagioclase laths in a groundmass of metamorphic amphibole, after pyroxene (width of view is 2mm).

Spinifex and cumulate textures are preserved in ultramafic rocks, although the mineralogy is now metamorphic, with massive ultramafic rocks consisting of the assemblage serpentine + magnetite ± tremolite. Sedimentary rocks proximal to the Copperfield Granite are reportedly amphibolite facies (Tomich 1956), and include garnet schists, and staurolite and andalusite schists, which decrease in grade with increased distance from the granitoid (Tomich 1956).

Geochemistry

During the project, a geochemical study was conducted, in collaboration with Dr Derek Wyman (University of Sydney), to define whether basaltic rocks on either side of the Ida Shear Zone are geochemically distinct and therefore belong to different terranes, or different extrusive events (van der Borgh et al., in prep). Fine-grained mafic rocks, considered to be meta-basalts, were sampled throughout the Ularring Greenstone Belt. These were combined with the Riverina data of Embry (1999), and data made available by Stephen Wyche (GSWA), which extended the dataset into greenstone belts within the Southern Cross Terrane. A brief summary of some of our findings follows:

Based on Zr/Y ratios <4.5, the basalts are all tholeiites according to the criteria used by Barrett et al. (1993) for the Archaean Noranda Mine Sequence, Canada. The tectonic discrimination plot of Pearce and Cann (1973) indicates that the mafic rocks from both terranes are typical of basalts deposited in an ocean floor or island arc environment. Although there is overlap of the data from both sides of the ISZ, the chemistry does indicate that many of the basalts to the east are distinct from those to the west. This is illustrated in a plot of V versus Sc (Fig. 2.5.4), in which many of the eastern samples lie along a trend with their ultramafic counterparts, whereas those to the west lie along a different trend line, probably as a result of pyroxene fractionation (van der Borgh et al., in prep).

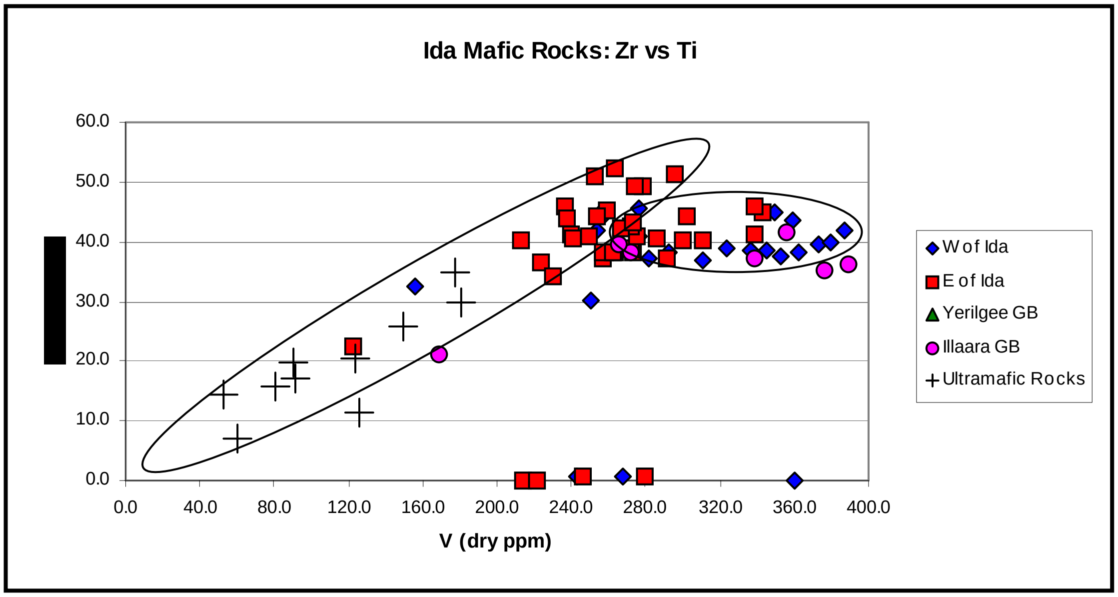

Fig. 2.5.4. Plot of V-Sc for basalts from the Ularring Greenstone Belt, and the Yerilgee and Illaara Greenstone Belts in the Southern Cross Terrane. Most basalts from the eastern sequence (squares) plot along the same trend line as the ultramafic rocks (crosses) in the eastern sequence, whereas basalts to the west of the fault (diamonds), including those from within the Southern Cross Terrane (circles), plot along a different trend.

The geochemistry highlighted a group of ten mafic samples with unusually high REE enrichment, characterized by high Y concentrations between 50 and 1000ppm compared to typical values for basalts of ~25ppm (Hall 1996). SEM analyses revealed the presence of rare-earth phosphates in these samples, including xenotime and monazite. Two attempts to date the phosphates, were unsuccessful, owing to very low *U* and *Th* contents in the phosphate grains. The geochemical aspects of the study will be dealt with in more detail in van der Borgh's PhD Thesis.

Structure and Shearing-Related Metamorphism

The Ida Shear Zone (ISZ). The four regions of the ISZ studied in detail (Fig. 2.5.2) over a strike length of 150 km, exhibit the same structural history and a similar sequence of rocks. Generally the shear zone is 100-200 m wide, and the shear fabric is formed along a sequence of alternating ultramafic and mafic flows and interbedded shales along the western side of the Eastern Sequence. The eastern margin of the shear zone is delineated by a gradual decrease in fabric intensity, commonly towards an ultramafic cumulate, and to the west by the appearance of monotonous pillowed basalt.

The progressive deformation of the ultramafic rocks results first in the flattening of serpentine and magnetite grains, followed by a gradual increase in the modal abundance of tremolite and *Mg*-chlorite at the expense of serpentine. In the most deformed regions, serpentine and magnetite are absent, and the paragenesis is tremolite + actinolite + *Fe*-chlorite. The breakdown of magnetite seems to have liberated *Fe* for chlorite, while *Mg* from *Mg*-chlorite was taken up by actinolite. Thus, shearing has led to the destruction of magnetite and the associated signature in aeromagnetic imagery. The increase of water-poor tremolite at the expense of water-rich serpentine implies deformation was accompanied by devolatilization as reflected in the decrease of LOI from 9.5 wt% in the least deformed rocks, to 4.5 wt% in the core of the shear (ven der Borgh, PhD Thesis in prep).

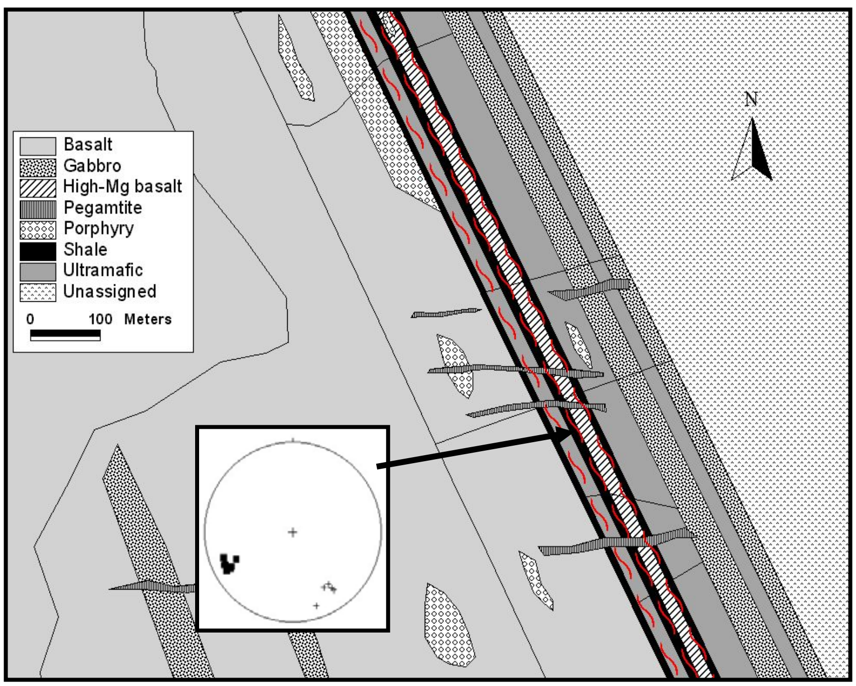

Fig. 2.5.5. Solid geology map of the Ida Shear Zone in the Mt Alexander region, showing the trace of the shear zone along the contact between thinly bedded units of the eastern sequence and massive basalt to the west. The shear zone is marked in the figure by the thick black lines representing shale layers. The lower hemisphere stereographic projection represents structural measurements from within the shear zone (squares are poles to the foliation, crosses are lineations).

The map in Fig. 2.5.5 details the stratigraphic and structural observations from the Ida Shear Zone in the Mt Alexander region, and is representative of observations along the strike length of the structure. The shear zone is typically sited along the contact between thinly bedded mafic-ultramafic rocks and interbedded shales to the east, with massive basalt to the west. The foliation consistently dips steeply to the east, and contains a gently south plunging mineral lineation (stereonet insert in Fig. 2.5.5). A lack of asymmetries within the shear zone indicates that the deformation is primarily the product of pure strain.

The Riverina Gneiss. The Riverina Gneiss extends along the entire eastern margin of the Ularring Greenstone Belt (Fig. 2.5.2). It is characterized by a banded magnetic fabric that delineates a ~6km-wide belt in aeromagnetic images and was interpreted by Legge et al. (1990) to be a major crustal break. The gneissic banding is very strong for several kilometres in width, suggesting very high strain (Figs. 2.5.6 and 2.5.8).

Fig. 2.5.6. a) Outcrop of Riverina Gneiss at Kurrajong highlighting the gently plunging mineral lineation. b) Polished slab of gneiss from the above locality, showing gneissic banding and lack of consistent asymmetries, indicating deformation was a product of essentially pure shear (scale bar in cm)

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The gneissic banding strikes N-S (Fig. 2.5.9 stereonet insert), and contains an intense, sub-horizontal mineral lineation in all outcrops observed (Fig. 2.5.6a). Embry (1999) depicted porphyroblasts showing dextral asymmetry. By contrast we found that the majority of porphyroclasts in the gneiss have either opposing or poorly developed asymmetries, indicating intense flattening or pure shear deformation (e.g. 2.5.6b).

SHRIMP U-Pb dating of fourteen zircon grains separated from the gneiss yielded an age for the zircon cores, interpreted as the crystallization age of the granite precursor, of 2806±5Ma (Fig. 2.5.7). Interpretation is based on the fact that zircon cores are euhedral, well zoned, and of similar habit, indicating a likely common igneous origin. Also the ages are well centred around the average age and lack a wider age spread common in a xenocrystic population. Rim overgrowths, which cross-cut core zoning on six crystals, yielded an age of 2667±15Ma, which is interpreted to represent a resetting age caused by metamorphism or hydrothermal alteration. This interpretation is based on the fact that the concordant analyses have high *Th/U* ratios, consistent with metamorphic or hydrothermal recrystallisation (N.J. McNaughton, pers comm.), the overgrowths are not concentrically zoned as would be expected from magmatic overgrowths, and no cores yielded the younger age. The implications of these two ages are discussed below.

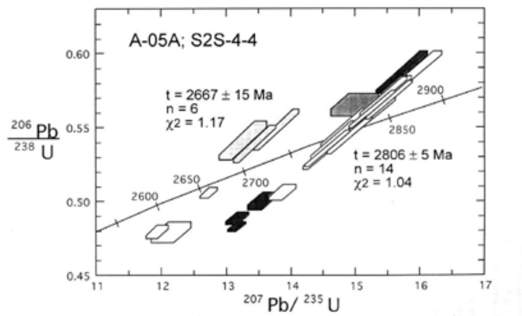

Fig. 2.5.7. Results of SHRIMP U-Pb zircon age determination of the Riverina Gneiss.

The Ballard Shear Zone. In this report, the term Ballard Shear Zone is used to describe a zone of shearing that is developed along the contact between the Riverina Gneiss and the Ularring Greenstone Belt (Fig. 2.5.9). The contact strikes N10W, and is therefore slightly oblique to the N-S gneissic fabric.

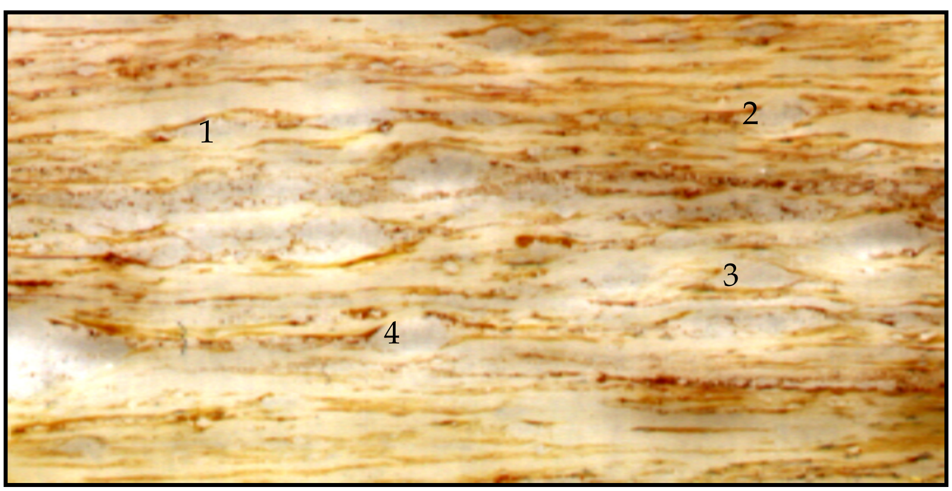

Fig. 2.5.8 Scanned thin-section of the Ballard Shear Zone. Horizontal C-fabric and ENE-WSW S-fabric, in conjunction with asymmetries around quartz porphyroclasts (e.g. 1,2,3 & 4), indicate dextral shear-sense. Width of image is 2 cm.

We studied this shear zone at Kurrajong, where it is ~200m wide and incorporates several rock types, including ultramafic and mafic rocks, porphyries and the margin of the Riverina Gneiss. The shear fabric strikes ~N25W, is sub-vertical, and contains a stretching lineation that plunges gently both north and south. Shearing of gneiss along the margin of the Riverina Gneiss has resulted in a quartz-mica schist, as a result of extensive recrystallisation of plagioclase and quartz. Asymmetries around porphyroclasts, S-C fabrics, and rotations of porphyroclasts indicate dextral sense of shear (Fig. 2.5.8). The paragenesis and nature of shearing make it distinct from the broader Riverina Gneiss.

The Kurrajong Anticline. The core of the Kurrajong Anticline (Fig 2.5.9) reflects, in a relatively small area, the regional deformation undergone by the Kalgoorlie Terrane. The lowermost units in the stratigraphy are an amphibolite layer and an anorthosite layer, which are folded around the Copperfield Granite. Around the margin of the granite, a strong gneissic fabric is consistently parallel to the contact and a strong mineral lineation, affecting all minerals, plunges ~30S. The orientation of the lineation is parallel to the axis of the fold, and similar features are observed in the greenstones adjacent to the granite where amphiboles are parallel to the stretching lineation in the granite.

The greenstone corridor to the east of the granite strikes N-S and has dextral kinematic indicators, while the western corridor strikes NW and has sinistral indicators. In many areas however, particularly close to the granite contacts, shearing and flattening has been intense and asymmetries or other kinematic indicators could not be determined.

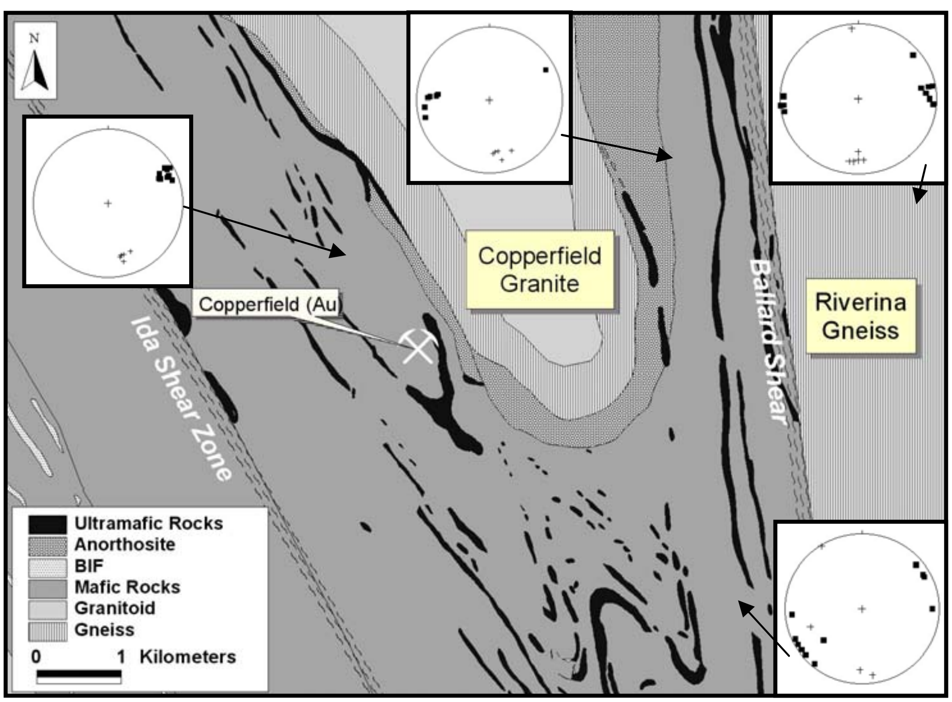

Fig. 2.5.9 Magnetic interpretation of the Kurrajong Anticline in the Mt Ida area. Note the variation in the orientation of foliations in the Riverina Gneiss and adjacent greenstones.

The change in sense of shear as a function of strike on either side of the granite, reflects the regional pattern of deformation observed of the Norseman-Wiluna Belt, where NW-striking shear zones generally register a sinistral movement, Zuleika and Boulder-Lefroy Shear Zones (e.g. *Section 2.4*, and Swager 1997), while NS or NNE-striking shear zones register dextral movement (Waroonga Shear Zone, Platt et al. 1978). This pattern will be discussed in *Section 2.7* where it will be suggested that the two sets represent conjugate shear zones, resulting from D_3 regional deformation event driven by ENE-WSW shortening.

Brittle-Ductile Structures. The Ularring Greenstone Belt contains three sets of brittle-ductile and brittle structures that are observed both on aeromagnetic images and in the field. A set of NNE-SSW brittle-ductile shear zones offset stratigraphy by tens to hundreds of metres. They are recognised in occasional outcrops as a spaced cleavage (Fig. 2.5.10). Macro- and micro-scale asymmetries associated with these shears consistently show dextral shear sense (Fig. 2.5.10). A second set characterized by NE-SW faults are observed, although unlike the previous set, they have a more localised distribution, for example along the eastern margin of the Copperfield Granite. Offsets are rarely more than tens of metres, and displacements are consistently dextral. These structures have not been observed in outcrop.

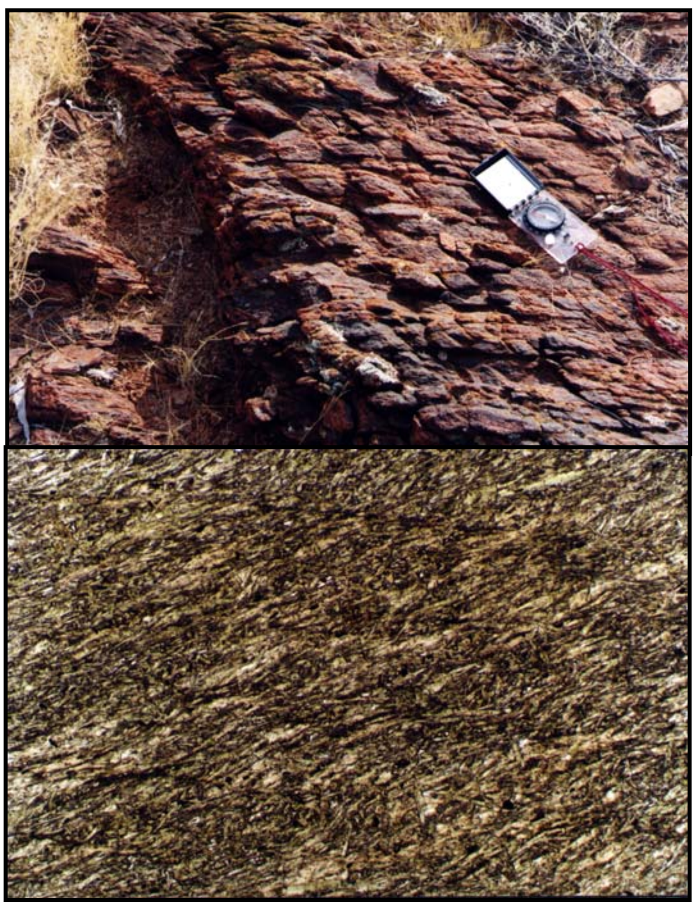

Fig. 2.5.10. a) Early, Ida Shear Zone foliation (horizontal in view) is overprinted by a later spaced NE-SW cleavage, (depicted by orientation of compass). b) Photomicrograph from the above outcrop, showing the same shear fabric (diagonal top right-bottom left) being overprinted by the NE-SW *spaced cleavage (horizontal). Note the rotations of the early fabric into the late cleavage showing dextral asymmetry.*

The third set consists of ~E-W brittle faults, which also tend to have a localized distribution, such as at the southern end of the Copperfield Granite and along its western margin. This set is usually recognised in the field by buck quartz veins and brecciation of wall rocks. Epidote alteration is observed where the faults are developed in mafic rocks. They consistently show sinistral displacement.

Deviations from Main Trend: Indentation. The Ida Structural Corridor deviates from its dominant regional trends around the Central Granite Complex, CGC (Fig 2.5.11). The main trend of lithological contacts, the trace of the fold hinge of the Kurrajong Anticline, and the fabric defining the Ballard Shear Zone, are all rotated by ~20º, counter clockwise they approach the CGB. Deflection of the Riverina Gneiss resulted in the development of conjugate fractures dominated by a set of N70W strike-slip faults with sinistral offsets of up to 600m as interpreted from aeromagnetic imagery, and dextral NE faults with undetermined offset (Fig 2.5.12). We interpret the deflection to be the result of progressive shortening of the greenstones as the CGC, representing a competent indentor to the west, impacted upon them.

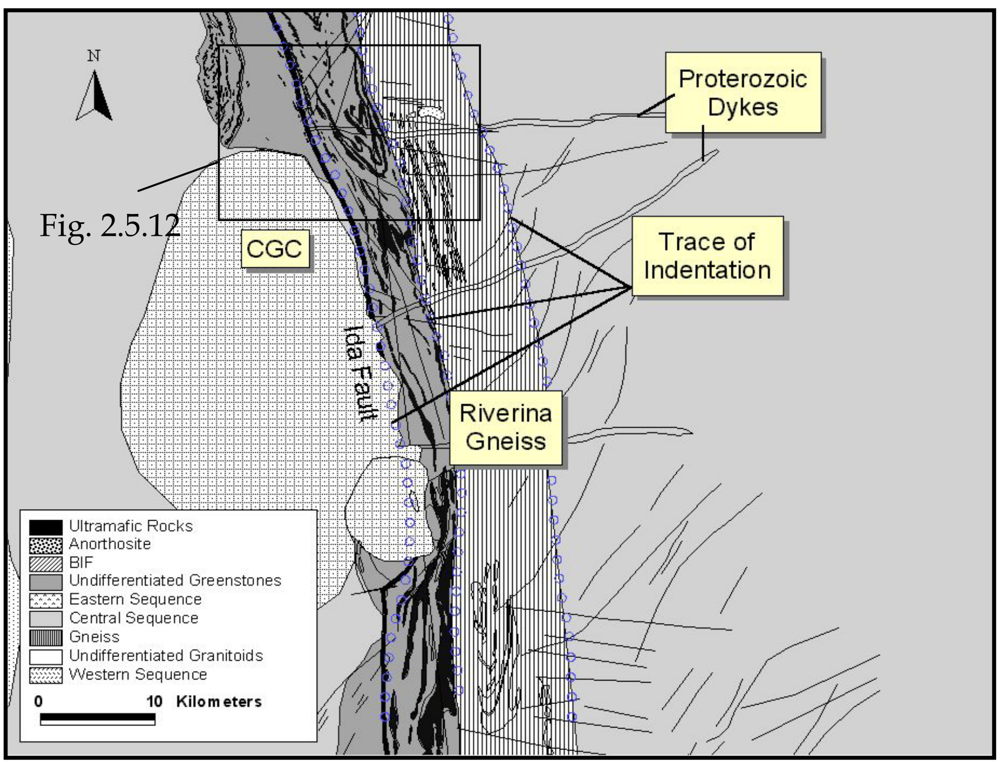

Fig. 2.5.11. Interpretive map of the Central Granite Complex (CGC), located in the area between Mt Ida and Riverina. The image highlights the trace of the 'indentation' observed in the greenstones and gneiss adjacent to the CGC, and the conjugate structures that developed in the gneiss and Eastern Batholith in response to the indentation.

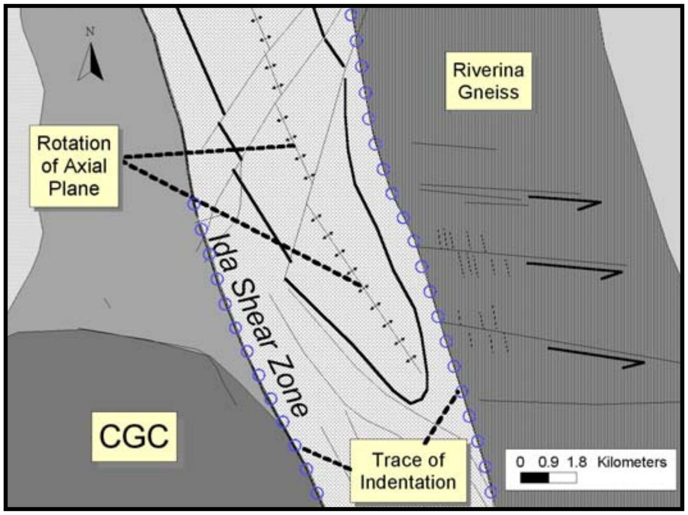

Fig. 2.5.12. Schematic interpretation of the northern part of the CGC, highlighting the 20ºcounter-clockwise rotation of the Kurrajong Anticline, and associated NNE dextral faults that have accommodated the rotation of blocks. Notice how indentation of the gneiss was accommodated by sinistral ~E-W structures. These structures delineate the northernmost extent of the indentation, which can be observed southwards for ~40 km.

Gold Deposits along the Ida Structural Corridor

Despite being poorly endowed in gold, more than one hundred mines are documented within 10km of the Ida Shear Zone but to date, no deposits have produced >500,000oz. In this section, we focus on three areas where gold production has exceeded 50,000 ounces, namely Copperfield (Fig. 2.5.9) and Bottle Creek in the Mt Ida area, and Iguana, south of Davyhurst.

Copperfield. The camp is located on the western margin, and towards the southern end, of the Copperfield Granite, approximately 2 km east of the Ida Shear Zone (Fig. 2.5.9). To date five parallel lode structures have been mined for a total production of >300,000oz, with the Timoni lode producing >250,000oz. Prior to the mid 1980s, the Timoni mine ranked in the top 12 producing mines in the Eastern Goldfields. All stratigraphic units in the camp, including amphibolite, anorthosite and ultramafic lithologies, host mineralisation.

The Timoni Lode is hosted in amphibolite. Mineralisation occurs in podiform quartz-carbonate veins up to 1m in thickness, enveloped in a biotite-carbonate schist. Mining continued to a depth of 300m, and for a strike length >500m. The majority of gold won was free in the quartz veins, with lesser amounts in pyrite sited along vein margins and alteration selvages. The structural controls on mineralisation are poorly documented and not well understood. The lode is disjointed by several ~E-W trending crosscutting structures, which have been variously interpreted to have been active pre- and post-mineralisation.

Features of the Timoni Lode in common with mineralisation elsewhere include the potassic alteration, a competency contrast owing to its proximity to the granitoid, and the intersectio of the lode by cross-structures. Furthermore, schistose ultramafic rocks are adjacent to the lode.

Bottle Creek. The three mines at Bottle Creek are located within the Ida Shear Zone. The pits are currently full of water and inaccessible, however the stratigraphic relationships (ultramafic-mafic-shale lithologies) and easterly dips that characterise the shear zone, as outlined above, are recognisable. The deposit was described by Legge et al. (1990), from which the following is taken. Mineralisation is hosted in a banded amphibolite that defines the upper part of the central sequence, and a porphyry. Shearing along the contact is intense, with the mafic mineralogy being altered to biotite-hornblende-chlorite-epidote-quartz schist, with garnet porphyroblasts, while the margin of the porphyry is quartz-sericite schist. Mineralisation is coincident with an arsenic anomaly (>500ppm), which is similar to many sediment hosted gold deposits in the Yilgarn. Unlike most orogenic lode gold deposits in the Yilgarn Craton, this mineralisation has a Ag/Au ratio >1. In general, gold grades in the primary zone rarely exceeded 3g/t, while silver grades in the areas of highest gold grade averaged >27g/t. Gold was very fine grained (<45µm diameter), occurring both as free particles, and as inclusions in quartz and sulphides. Gold distribution was very even, and without 'nugget' effects. The report does not detail the structural controls on mineralisation.

In some respects, this line of deposits contrasts with typical lode gold deposits, for example the Au/Ag ratio <1, and its location within the plane of a 1st-order Shear Zone. Similarities to lode-gold deposits include the ultramafic and porphyry associations. Furthermore, the deposits are situated within a corridor of NNE orientated structures with apparent dextral offset. However, not enough is known of the structure, metamorphism or metasomatism of the deposit to reliably compare these to mineralisation elsewhere in the Kalgoorlie Terrane.

Iguana. The Iguana deposit is located ~30 km south of Davyhurst, and 1.5 km east of the granite-greenstone contact, which marks the Ida Shear Zone in this area. The deposit is of particular interest as it is only ~15 km north of where the 1991 seismic traverse (EGF01) crossed the Ida Shear Zone. There are no published descriptions of the deposit. The pit is located in a sequence of interleaved ultramafic, mafic, and sedimentary rocks. Outcrop in the vicinity of the mine is very poor, and the open pit is intensely weathered, and no detailed mapping is available. The mine stratigraphy is dominated by amphibolite, consisting of *Mg*-hornblende, *Ca*-plagioclase ($An_{>80}$) and titanite. The amphibolite contains numerous grains of HREE-phosphate, including xenotime and other unidentified species as well as small zircon grains. Pyroxene-rich boudins are observed towards the central portion of the pit, and distinguished by their pale green weathering colour. Pegmatite dykes intrude the sequence.

The main shear fabric strikes N40W and dips 80SW. A consistent down-dip mineral lineation is defined by acicular amphiboles. Boudin necks in the pyroxene-rich lenses plunge gently north and south, and provide further evidence for vertical extension. Rare asymmetries around competent porphyroclasts indicate a west-side-up shear sense.

The shear fabric is overprinted by a gently dipping foliation (variable strike N60W to N10W, dipping 20-40NE). The origin of this late foliation is unknown, and clear shear sense indicators could not be found. We note however, that the seismic image depicted a gently E-dipping foliation at depth, south of this locality, which was interpreted to be a result of normal faulting (e.g. Swager 1997). Gold was won from quartz veins, with associated biotite alteration of the amphibole schist. The veins were sited within a narrow zone where the amphibolites have been boudinaged. Arsenopyrite is the main ore mineral, and gold is in these grains (SEM imaging). Gold has also been imaged in one of several potassium feldspar veinlets that brecciates the main shear fabric (Fig 2.5.13a&b). The veinlets are not sheared or rotated, indicating that mineralisation took place after the foliation developed

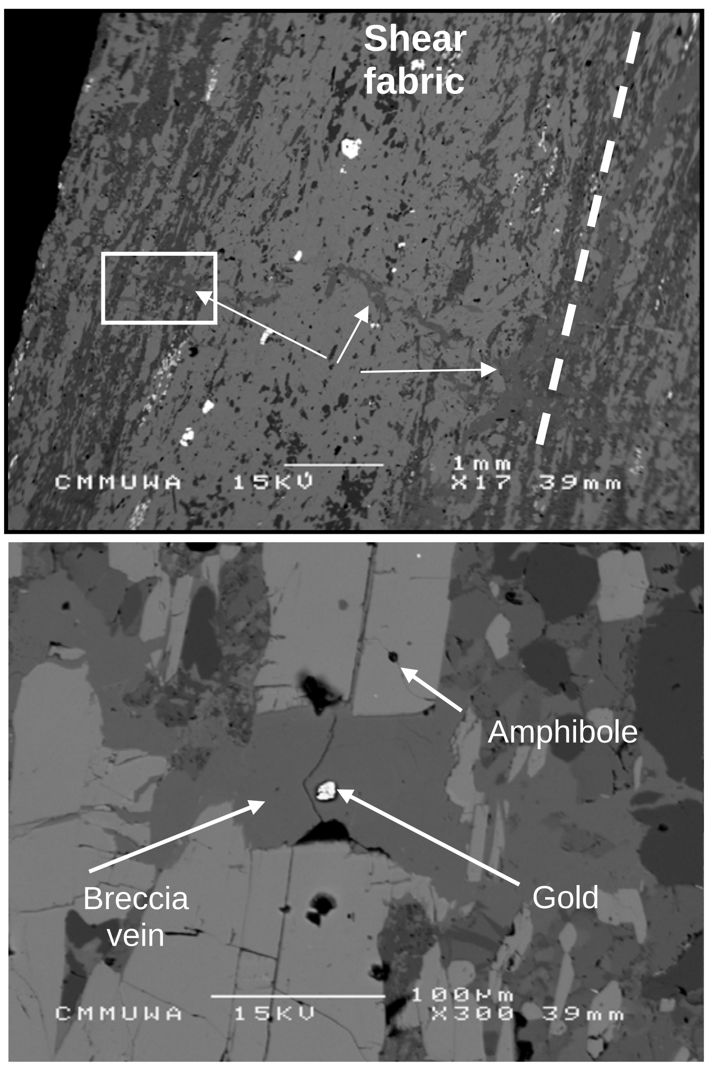

Fig. 2.5.13. Scanning Electron Microscope images of a) the shear fabric at Iguana, highlighting the potassium feldspar breccia veins that cross-cut the main shear fabric, and are themselves undeformed. b) Inset in (a), showing a potassium feldspar breccia-vein hosting a gold inclusion. The undeformed nature of the veinlet, and presence of gold, indicate mineralisation post-dated the main shearing event at Iguana.

In summary, the deposits along the Ida Shear Zone have some characteristics similar to those elsewhere in the Kalgoorlie Terrane, such as: a) the As-anomalies in the two deposits in proximity to sedimentary horizons (i.e. Bottle Creek and Iguana), and the absence of an As-anomaly at Copperfield, where no sediment is present; b) potassic alteration; and c) pyrite and arsenopyrite as the main sulphide mineralogy. Mineralisation at Iguana and Copperfield post-dates the formation of the regional shear fabric. Decreased contrast in the behaviour of rock types under deformation at amphibolite facies conditions, as compared to greenschist facies conditions, might be the single most significant cause for the decreased endowment along this shear zone.

Discussion

The Ida Shear Zone is an intra-greenstone structure within the more extensive Ida Structural Corridor. Strain developed along a stratigraphic break where massive, pillowed tholeiitic basalts to the west, meet a sequence of thinly bedded basalts and ultramafic rocks. The continuity of the ultramafic-mafic stratigraphy along the eastern half of the Ularring Greenstone Belt and possibly into the Ora Banda Domain supports earlier interpretations (Hill et al. 1995, Rattenbury 1993) that it belongs to the Eastern Goldfields Terrane. This interpretation contrasts with suggestions that a major crustal break exists along the margin of the Riverina Gneiss, at the eastern margin of the Ularring Greenstone Belt (Legge et al. 1990).

Contrasting stratigraphy on either side of the ISZ as mapped here suggest that it represents a terrane boundary between the Southern Cross Terrane, which includes banded iron formations in its stratigraphy, with the Norseman-Wiluna Belt, which includes ultramafic rocks in its stratigraphy. Unfortunately, although the geochemistry of basalts highlights different fractionation in rocks on either side of the ISZ, it did not positively discriminate the basaltic sequences on either side. Furthermore, no dateable volcanic rocks have been found to determine any age differences the sequences might have. The fact that the Ida Shear Zone is a fundamental stratigraphic break will be used at the end of this section to build a new model for deformation along the eastern margin of the Eastern Goldfields Terrane.

Lithologies and fabrics in the shear zone consistently strike ~330 and dip ~70E. The south plunging lineation in the Mt Ida and Mt Alexander regions is sub parallel to the axis of the Kurrajong Anticline which controls the orientation of the greenstones in the northern part of the Ularring Greenstone Belt. The structures are interpreted to be a result of intense straining, with a sub-horizontal or gently south plunging extensional direction associated with folding and flattening of the rock sequence as a result of pure shearing with a minor dextral component.

A late, gently east dipping foliation was documented at Iguana. Owing to its proximity to the position of the seismic traverse, it may represent what was imaged in the seismic reflection survey. However, because this foliation was not observed elsewhere in the Ularring Greenstone Belt, there is a possibility that it represents a relatively local feature. An alternative interpretation for the shallow dipping seismic reflector is that it represents a listric fault that links upwards with the steeply dipping foliation characteristic of the outcropping Ida Shear Zone. Neither interpretation is fully satisfactory as yet, and more structural information and detailed seismic imaging of this important boundary zone is required to further elucidate its nature at depth.

The ages determined from the Riverina Gneiss are broadly consistent with older ages reported from gneisses on the eastern side of the same batholithic mass (west of Leonora, Witt 2001) suggesting that a significant portion of the batholith, including the gneissic margins, represent older continental crust that formed the basement for the 2.7 Ga extrusive and sedimentary sequences.

In some respects, the deformation observed in the Ida Corridor differs slightly from some of the other regions we have documented, and largely reflects the metamorphic conditions that accompanied deformation. Typically, rocks within the deformed corridor are intensely deformed indicating pervasive deformation, and even though competency contrasts between rock types was sufficient to trigger large scale folding (e.g. Kurrajong Anticline; a fold around a granite core), and local boudinage, it was not nearly as strong as in greenschist facies areas, where low-viscosity talc-schist and shales coexists with brittle porphyry dykes and dolerite sills. Brittle fracturing and rock brecciation, though it exists locally, is relatively uncommon in the Ida Corridor.

In general, the major structural features observed in the Ularring Belt are entirely consistent with the pattern of deformation we have observed elsewhere in the Kalgoorlie Terrane. The sinistral and dextral pair of shear zones observed along the western and eastern margins of the Copperfield Granite reflects the influence of the varying orientation of the granite margins in controlling the shear sense in an environment of ENE-WSW shortening. ENE-WSW shortening, and sub-horizontal stretching axis oriented parallel to the regional fabric, is similar to the regional D_3 while upright and tight folds, and reverse movement such as at Iguana, suggest a component of crustal thickening, which probably relates to the regional D_2. In the Ida Corridor these two phases are not as distinct as they are in the Boulder-Lefroy Shear Zone. It is argued here that because the ISZ is oriented nearly perpendicular to the maximum shortening axis during D_2 and D_3 most of the shear recorded is pure shear, with little difference between the structures developed during the two phases

The later, brittle-ductile and brittle fault sets that overprint the regional fabric are assigned to the regional D_4 and are similar in their orientation, shear sense, and physical character, to those in other parts of the Terrane (see *Zuleika Shear Zone* below).

We conclude that the deformation pattern in the Ida Structural Corridor is a function of the interaction between a long-lived regional shortening event, and the presence and geometry of pre-existing granitoids, during peak-metamorphic and retrograde conditions. Deformation along the Corridor occurred in an environment of high strain, in which shear sense was a function of the orientation of pre-existing contacts, such as those along granite margins.