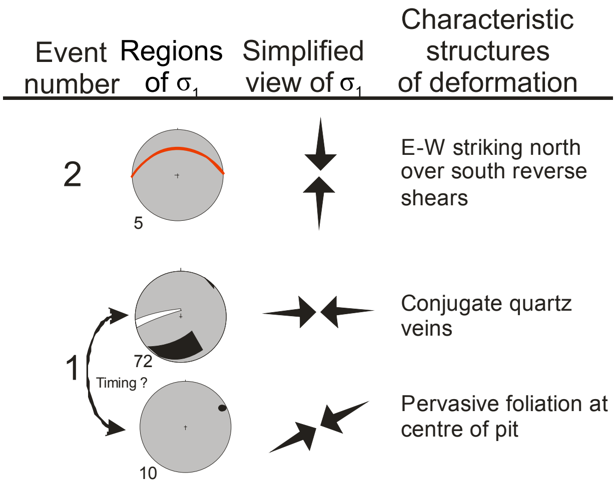
Bottle Tree Creek

The Bottle Tree Creek deposit is located 10 km south of the Copperfield Mining Centre, and is located on the Ida Fault System at the western boundary of the Kalgoorlie Terrane. The deposit is hosted by carbonaceous shales close to a contact between a lower sequence of BIF, mafic volcanic rocks, conglomerate and quartzite, and an upper sequence of mafic and ultramafic rocks with minor interflow sediments intruded by porphyry. Both sequences dip steeply to the east. The mineralisation is hosted by the sheared sulphidic and graphitic ‘Emu formation’ black shale (Robertson, 2003).

The pit is deeply weathered and access was limited to a couple of ramps. The observed shear in the centre north wall dipped steeply west not east as reported (cf. Robertson, 2003). Most of the structures that were able to be measured were conjugate veins in the east and west walls. These conjugate quartz veins overprint a steeply ENE-dipping penetrative foliation, interpreted to be a flattening foliation during ENE-oriented contraction. The flattening of pillows (see photograph above) becomes progressively more intense into the centre of the pit (together with foliation intensity). These pillows face west. The palaeostress resolved from the Stage 2 veins is approximately E-W and the timing in relation to the penetrative fabric is uncertain. The last stage of deformation is the development of S-directed reverse faults of low displacement (Fig. 51).

Figure 51: Summary structural stratigraphy of Bottle Tree Creek



View north of steeply W-dipping fabrics and shears

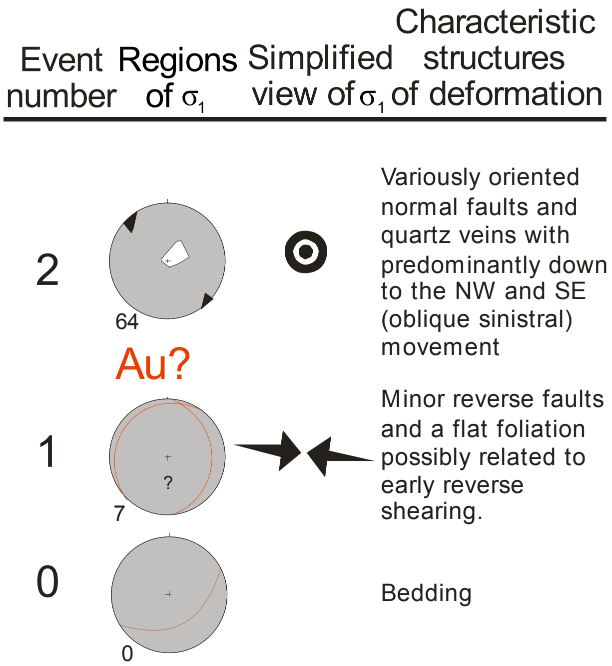
Key Point:
Well constrained flattening during ENE to E-oriented contraction associated with gold on the Ida Fault System.

Bellevue

The Bellevue group of gold mines are located 40 km north of Leinster on the northern edge of Lake Miranda. The mines are hosted by greenstones of the Yakabindie belt, which comprise the Mt Goode Basalt (upper) and the 2736±3 Ma (Lance Black, GA unpublished data) Kathleen Valley Gabbro (lower). The open pits visited include Paris and Westralia. The rock type in both pits is the Mt Goode Basalt, which is fine- to coarse-grained basalt (locally pillowed).

Gold is reported on N- to NNW-trending shear zones and associated thin quartz veins (Liu et al., 2002). The Bellevue shear zone is the main mineralised structure, and it is interpreted as a reverse fault (Fig. 52). The most obvious structural elements in the pit are the late-stage normal faults of variable orientation. These overprint Stage 1 reverse faults that record ~E-W contraction and have down throws mostly to the NW and the SE. The main fabrics in the pits are associated with this Stage 2 extension, with well-developed flattening of pillows and S-C fabrics recorded. The kinematics of the pits are dominantly sinistral normal on these structural elements (see Appendix of Bellevue poster for details).

Figure 52: Summary structural stratigraphy of Bellevue.



Dolerite intruding pillow basalt with normal fault at contact

S-C fabrics with extensional shear

Key Point:
Despite being an old sequence (~2730 Ma) the structural history is relatively simple

Key Learnings and Synthesis

Introduction

The principal question being asked of this study is: what is the difference between the structural history of one terrane versus another? The approach throughout this study (as detailed in the Introduction section) has been to treat each site alone and to build up a structural stratigraphy for the site. The next step was to correlate from site to site within a pit and establish a synthesis of the structural stratigraphy of that pit. The next step was to correlate between pits and granite sites across a terrane, with reference to the regional geological map patterns, geochronological knowledge, geochemical type of granite (cf. Champion and Sheraton, 1997), potential field geophysical images (especially magnetics), and seismic data. The final stage has been to assess how similar or different the three terranes, Burtville, Kurnalpi and Kalgoorlie (Fig. 1), are. The essential conclusion from this work is that there the terranes have experienced a similar structural history, and that events can be matched across time and space for the entire transect of this study. The synthesis banner (Appendix 3.1.1) provides immediate visual comparison of the terranes of the Eastern Yilgarn Craton. The implication of these observations is that the 'Terranes' of the Eastern Yilgarn are not separate crustal block that have been accreted.

One of the major problems with the terrane accretion hypotheses is the recognition that the main terrane boundary (Ockerburry Fault System) between the Kalgoorlie and Kurnalpi Terranes has mostly extensional kinematics (see also Blewett et al., 2002). The boundary between the Kurnalpi and Burtville Terranes (Hootanui Fault System) does have contraction and transpression, and may represent accretion of disparate blocks as evidenced by the variation in basalt geochemistry north of the Turnback Fault System. However even in this case the structural histories of the Kurnalpi and Burtville Terranes are similar.

The following section is a temporal progression from the oldest events to the youngest events.

Deformation event history through time

The D1 event of Swager (1997) was established in the Kalgoorlie and Kambalda area on the basis of stratigraphic repetitions across E-W striking thrusts that were thought to pre-date D2. There has been debate as to the polarity of this event, with both top to the north and top to the south movements inferred. In the central and northern Eastern Yilgarn, many workers have 'failed' to find this D1 event (e.g., Beardsmore, 2000; 2002; Wyche and Farrell, 2000; McIntyre and Martyn, 2005). Furthermore, Blewett et al. (2004) re-examined the map patterns used as the basis for the interpretations in the southern Eastern Yilgarn Craton and were able to show that the structures mapped as 'D1' thrusts cut F2 folds and were therefore younger not older. Similar map patterns occur around Kanowna Belle and the Fitzroy Fault.

In this report, unequivocal evidence for **early** major contraction in a N-S direction is not described. However, a post D3 contraction that was N-S to NW-SE is described. D1 in this report refers to extension, or the De of Swager (1997).

D1: long-lived extension and basin formation

One of the immediate impressions when viewing a geological or geophysical map of the Eastern Yilgarn Craton is the prominent NNW-trending grain. Many workers have interpreted this grain to be a function of the regional contractional 'D2' event, that was thought to be oriented ENE-WSW (e.g., Gee, 1979, Swager et al., 1989, Swager, 1997, Myers, 1997).

The grain is more fundamental than simply a contractional event. The grain is reflected in the broad distribution of the greenstone stratigraphy (Swager et al., 1992; Swager, 1997), the granite types (Champion and Sheraton, 1997), and the Sm-Nd isotopes of the granites (Fig. 53). Figure 53 shows the pronounced NNW-trending grain (Cassidy and Champion, 2004). A 'corridor' of youngest ages corresponds approximately to the western Kurnalpi terrane or Gindalbi Domain (Fig. 1). The isotope map could be interpreted in terms of an ENE-facing extensional rift. This rift and the youngest TDM ages correspond to the youngest arc material (see Module 1). Figure 54 show the general age progression of arcs from ~2715 to ~2680 Ma from east to west in the Kurnalpi Terrane. The oldest sequences are located in the east of the Eastern Yilgarn Craton, possibly representing basement fragments, the rifted shoulders from an older western nucleus (Youanmi Terrane?). These older sequences are exposed in the Burtville Terrane (see Module 1).

The geodynamic setting envisaged is one dominated by ENE-facing extension, with a W-dipping slab (located to the east) driving extension via a roll-back mechanism. Adjustments (shallowing) of the slab likely controlled the location of the active arc (younging to the west), and may have controlled the position of back-arc depocentres (around Kalgoorlie) and their rates of subsidence and accommodation (Fig. 54).

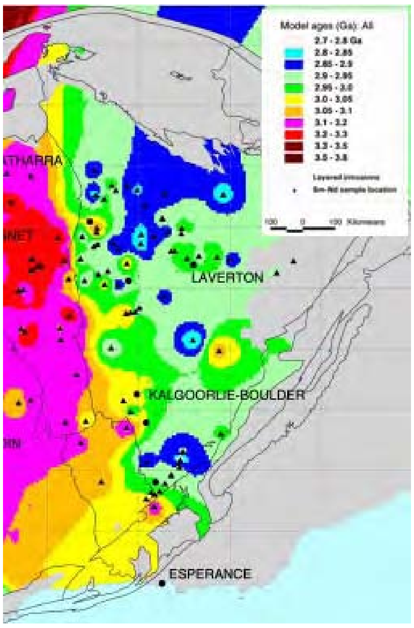


Figure 53: Fundamental architecture of the Eastern Yilgarn is revealed in the crustal residence ages (TDM). Note the NNW-oriented grain marked by the Ida Fault System located around the orange-green colour change. 'Cooler' colours are younger TDM ages. After Cassidy and Champion, 2004).

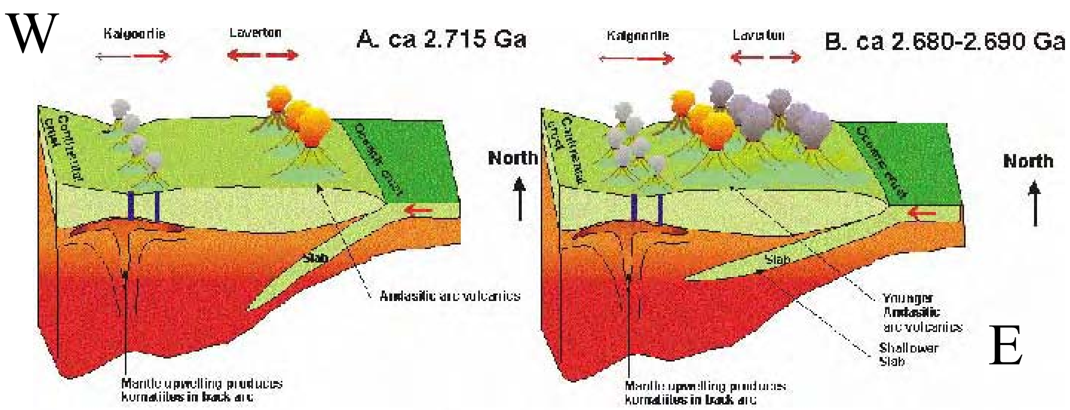


Figure 54: Schematic diagram illustrating NNW-trending tectonic grain controlled by the distribution of arc/backarc rocks. Migration of arcs to west through shallowing of subduction slab (after Cassidy and Champion, 2004)

The distribution of ultramafic rocks (komatiite) in the Kambalda area change markedly across NNW-trending faults (Fig. 55). The inference is that the architecture was extensional, and controlled the emplacement and deposition of the lower parts of the Kambalda sequence at around 2700 Ma (Karen Conners, written communication, 2004).

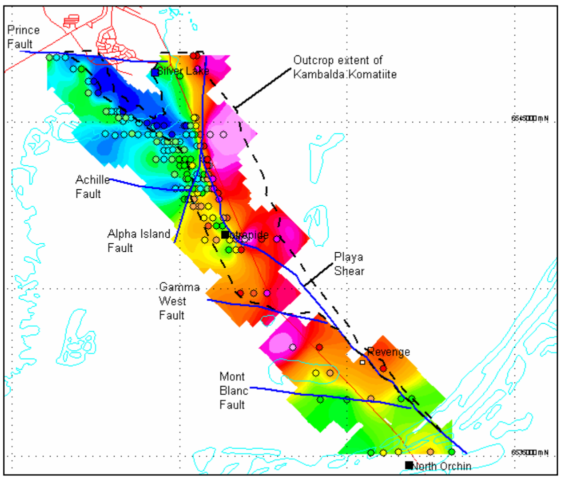


Figure 55: Colour contour map of komatiite thickness variations around the St Ives area (Kambalda), cool colours are thin (200-300 m), warm colours are thick (>1000 m). Note the NNW-grain to the image, reflecting the original extension architecture. Acknowledgements to Karen Conners (St Ives Goldfields).

Swager and Griffin (1990) noted a similar difference in the distribution of the so-called Upper Basalt above the Kambalda Komatiite. For example, across the NNW-trending Lefroy Fault System (Champion, 2004) in the Borrara Domain the Upper Basalt is absent, with the Kalgoorlie Sequence (Black Flags) lying directly upon komatiite. A similar relationship occurs with the distribution of mafic sills, with thick sills present in the Kambalda and Ora Banda Domains, and almost totally absent in the Boorara Domain. Many of these mafic sills intrude the Kalgoorlie Sequence, suggesting that extensional control was exerted with an E-W polarity through the entire greenstone up to (and probably including – see later) the Late Basin Sequences.

Krapěz et al. (2000) described a number of unconformities in Kalgoorlie Sequence, with a prominent angular discordance at around 2675 Ma (Fig. 56). Tilting during extension may account for the development of the topography and therefore high points for erosion and preservation as angular unconformities (as opposed to contractional folding events).

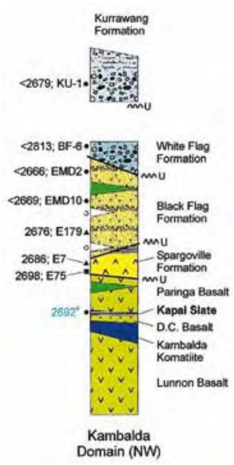


Figure 56: Schematic stratigraphic column of the NW Kambalda Domain (after Krapěz et al., 2000). Note the unconformities in the sequence indicating ongoing deformation (tilting).

Alternatively, the differences in stratigraphic thickness between domains reflect excision by detachments, especially near the base of the Kalgoorlie Sequence or Black Flag Formation (Blewett, et al., 2004a).

The external granites record a major melting and exhumation event at around 2675-2672 Ma (Cassidy et al., 2002). The development of significant gneissic fabric elements have been dated across the entire Eastern Yilgarn, irrespective of terrane or domain. Summaries of the granite events are found in Appendix 3.3, with brief descriptions outlined above. The fabric elements developed at this time include melanosome-leucosome differentiated layering, which are commonly isoclinally folded and transposed. When unfolded of the effects of later upright folding, these isoclinal folds were likely recumbent and have the geometry of lower-plate folds developed during vertical flattening and extension (Fig. 57). See Appendices 3.1.1 and 3.1.2 for the temporal and spatial maps of their distribution.

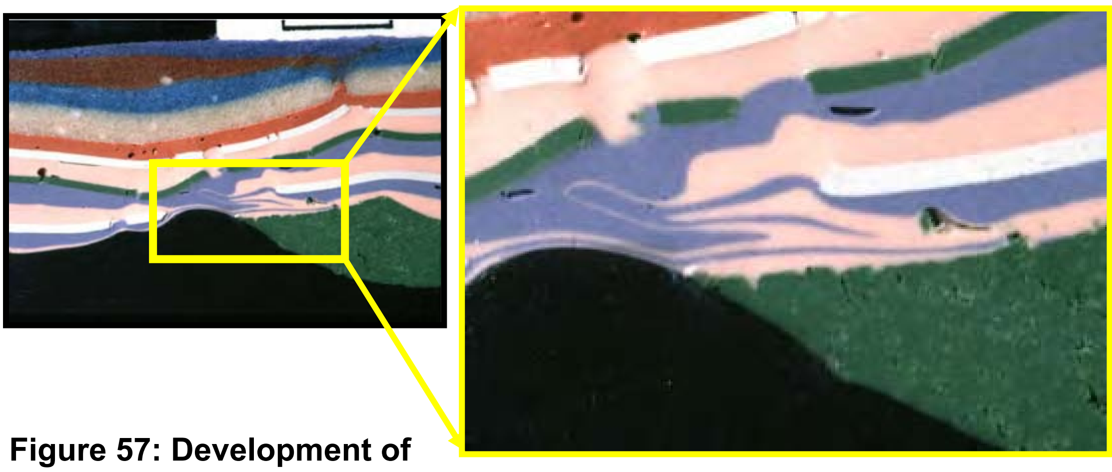


Figure 57: Development of recumbent folds in ductile lower plate (after Harris et al., 2002).

The widespread nature of this thermal event suggests that it reflects a fundamental stage in the extensional evolution of the orogen. Granites and their overlying detachments had not become emergent for the purposes of providing detritus until Late Basin times (see Module 2), indicating the extensional unroofing had further to develop after 2665 Ma (see later).

In summary, the D1 event was extensional with a dominantly ENE-directed polarity (Fig. 58). The timing of the event likely includes the earliest greenstone rock record (2800 Ma) through to the onset of the first significant contraction at around 2665 Ma. A map of the 'intensity' and location of the D1 event (as identified in this study) is shown in Appendix 3.1.2. A CorelDraw (v.12) file layered by event is also available in Appendix 3, and this allows comparison and contrast of D1 with other events.

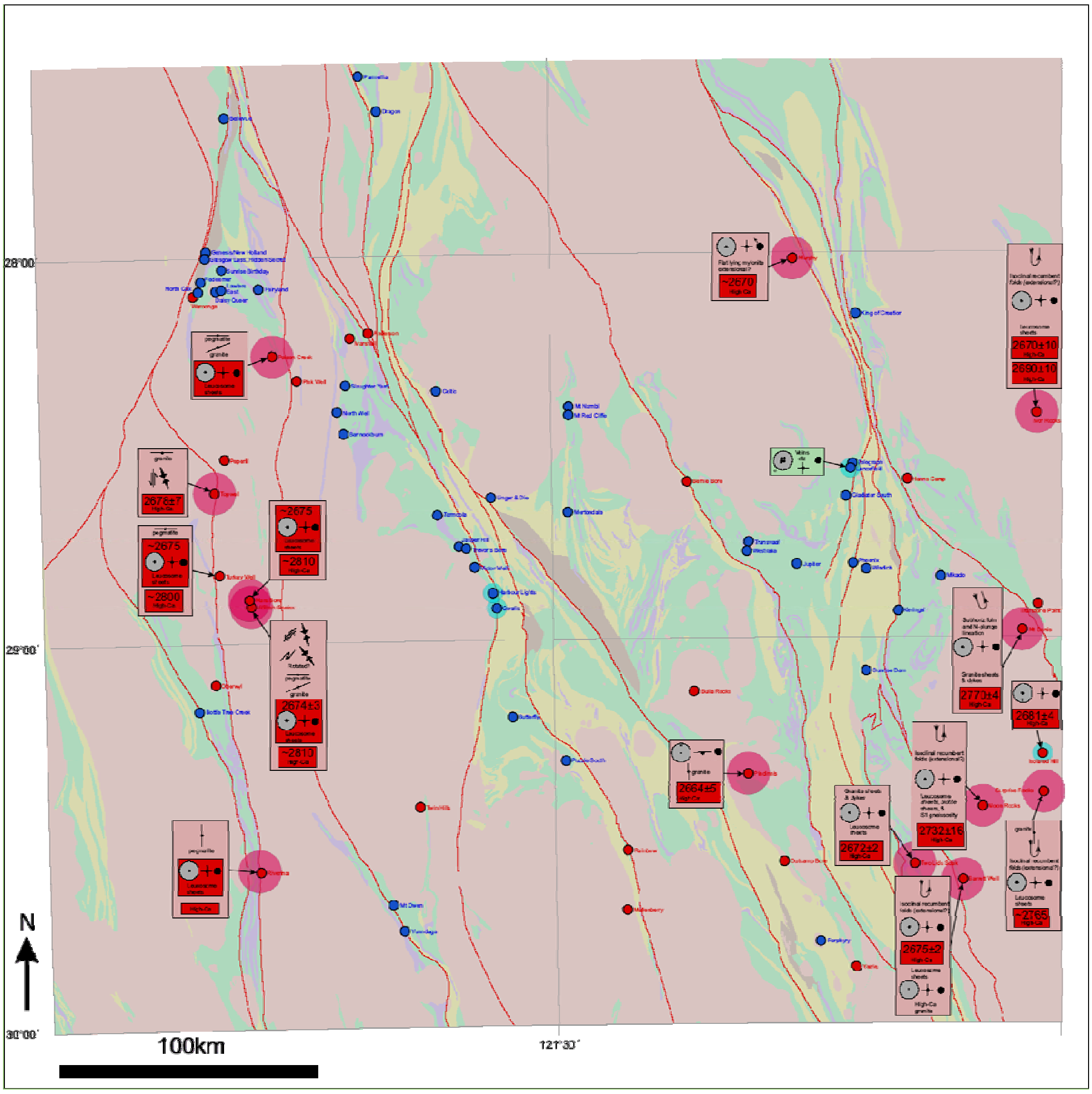


Figure 58: Map of D1 structures and their intensity across the study area at individual locations. Pink - granites, Yellow – sediments and felsic volcanics, Green – mafic-ultramafics, and Brown – late basins.
Intensity shown as size and colour of circles, with red (high strain), yellow (medium strain), and blue (low strain). See Appendix 3.1.10 for interactive maps

D2/D3: competing contraction and extension

One of the major difficulties in understanding the D1 extension is when it ended and when D2 contraction began. Part of the problem has been the general assumption that many of the upright broad folds that are cored by granites were developed solely by

‘D2’ contraction. A further problem is that the D3 event following this contraction was also extensional with an essentially E-W polarity. One of the consequences of the large amount of extension in the orogen is the impact on crustal thickening – or lack of it. If correct, then lack of crustal thickening has implications for understanding the geodynamics of the Yilgarn.

In areas where D2 is absent, the D1 and D3 events have become indistinguishable (see Appendix 3.1.1). In the majority of cases D2 and D3 display an inverse spatial distribution hence establishing timing between these two events is very difficult.

D2 contractional examples

Clear examples of D2 contraction are recorded around the Laverton area, and the include Windich and Phoenix deposits (Appendix 3.1.1) which are hosted by the Granny Smith Stage 1 Late Basin. Other examples include Telegraph, Transvaal, and further west, Porphyry (probably), Mertondale and Butterfly, which are hosted in older sequences. The fabric elements include a penetrative S2 foliation that strikes NNW and generally dips steeply east, N-S dextral shears, conjugate quartz vein arrays (from which ~E-W $\sigma 1$ can be inferred), and folds.

At many of the granite sites, D2 is represented by upright asymmetrical (Z-shaped) folds, and N-S dextral shear zone transposition of, D1 extensional fabric elements (Appendix 3.1.1). There appears to be a general change from folding to shearing in the ‘external’ granites. These fabric elements were observed across the entire Eastern Yilgarn (Blewett et al., 2004a). The overwhelming kinematics of overprinting shear zones, together with the asymmetry of the earlier F2 folds dextral (Blewett et al., 2004a), suggest that far-field kinematic framework was one of dextral transpression onto an NNW-trending architecture.

In regions away from the influence of granite domes, in general the D2 contraction involved predominantly N-S dextral reworking of a NNW-oriented grain. Exceptions are localised sinistral shearing at Mt Owen and Yunndaga near Menzies and Mertondale east of Leonora. The former two localities are dominated by a NW-trending grain (rather than N-S as elsewhere), and influenced by a NW-trending limb of a regional S-plunging anticline (Appendix 3.1.3).

The general dextral transpressional sense of shear during D2 is in contrast to previous interpretations. Swager (1997), Chen et al. (2001) interpreted D2 to be associated with <u>sinistral</u> shear. Their general proposition has been that during ~E-W contraction a NNW-trending fabric, when steepened following folding and thrusting, will fail in a sinistral mode with ongoing contraction.

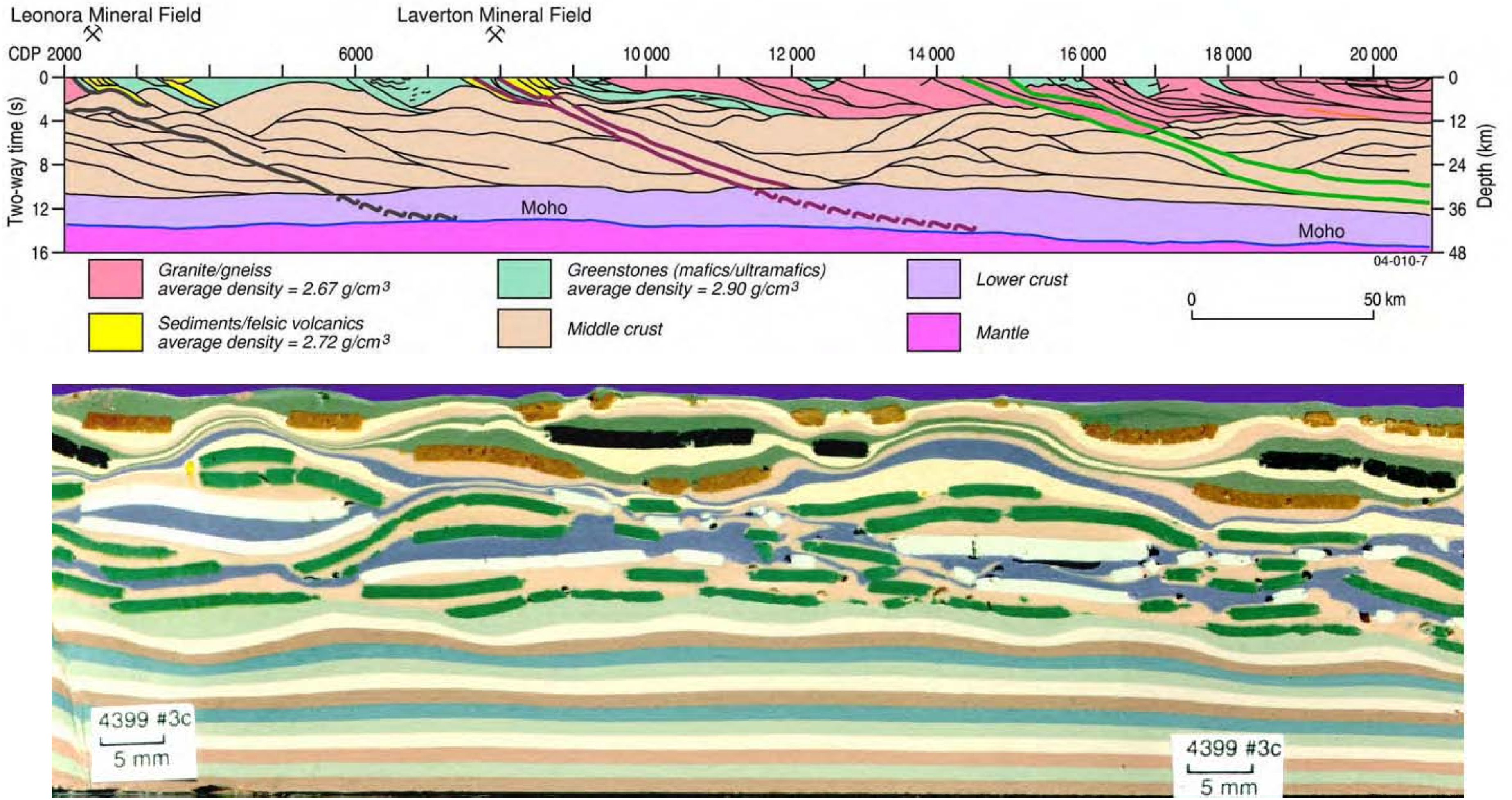


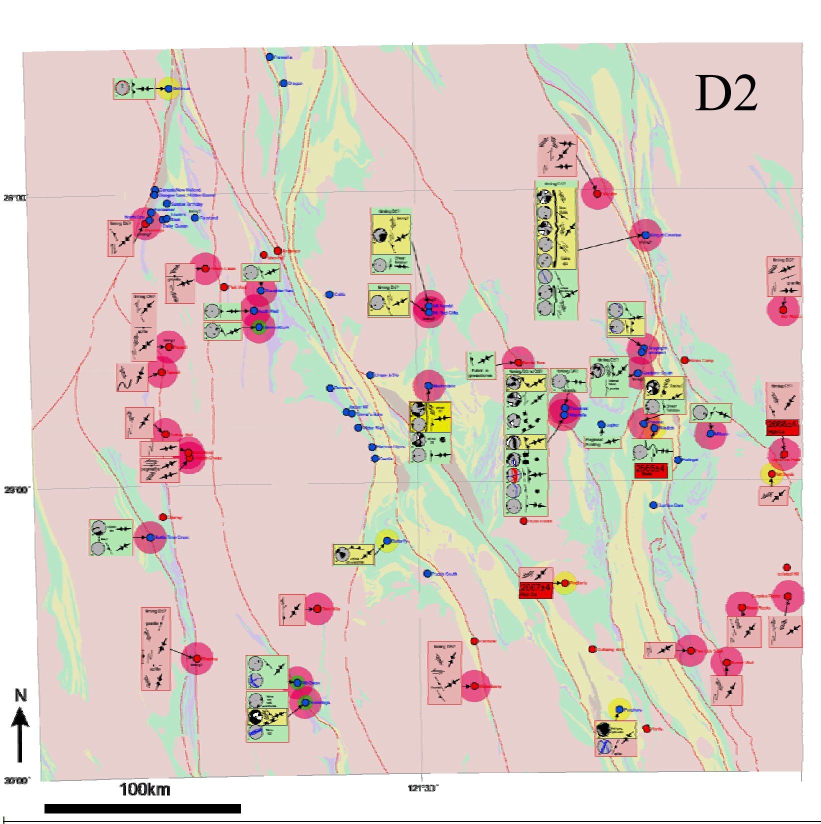
Figure 59: Simplified interpretation of seismic line 01AGSNY1 from Leonora to Lake Yeo. Note the similarity of seismic geometry to the extensional analogue model from Harris et al. (2002).

Another common view has been that D2 contraction involved folding and thrusting. This view has been influenced by the observation that most of the large regional folds (many are granite cored) plunge gently to the NNW or SSE (see later about development of granite-cored folds during extension). This 'D2-thrust' view has also been influenced by the interpretation that the architecture imaged in the seismic reflection data (Fig. 59) represent a fold and thrust belt (Goleby et al., 1993, Drummond et al., 2000; Blewett et al., 2002, 2003). Later it will be shown that much of the architecture imaged by the seismic reflection surveys is extensional. For thrust-dominated systems, the orientation of $\sigma 3$ will be steep to vertical allowing the vertical stacking of thrust sheets. Associated fold plunges will be subhorizontal, parallel to $\sigma 2$ and 90º from $\sigma 1$. The accurate mapping of $\sigma 1$ and $\sigma 3$ by the PT-dihedra method (Czarnota and Blewett, 2005) has shown that many of the stress axes reveal that D2 involved both dextral strike- to oblique-slip and reverse faulting or thrusting (Appendix 3.1.3). The overall kinematic régime during D2 was likely to be transpressional with development of both strike-slip and dip-slip movements. Transpressional systems partition strain into strike- and dip-slip panels, and lineations developed in this framework are both down dip and along strike.

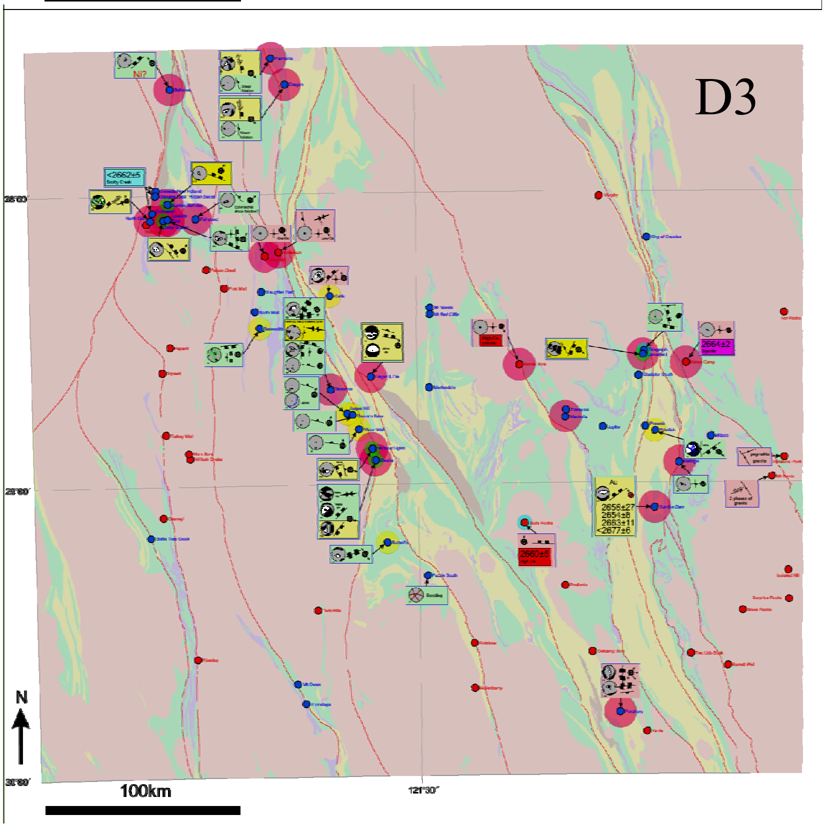
D2/D3 intensity and outline of the problem

The enigma regarding the relationship between D2 and D3 is particularly apparent when one contrasts the location and intensity of the respective events in a transect from east to west across the Kalgoorlie Terrane (Fig. 60). Around the Leonora area in the east, the prominent fabric element is an intense L/S- and S-tectonite developed under down-to-the-east extension (Williams et al., 1989; Williams and Whitaker, 1993). This area of greenstones (basalts and ultramafic rocks) is adjacent to a moderately E-dipping margin of the Raeside Batholith (Fig. 9). Logically one would expect this to be favourably oriented to intense E-W shortening, with folding and thrusting of the greenstones against and over the large granite batholith. The simplest interpretation is that D2 contraction occurred, and was essentially obliterated by a later (D3) and very intense extensional event. Contrast this with further west (see Slaughter Yard to Mt Owen in Appendix 3.1.1), where the main fabric appears to be caused by flattening and contraction during a classical Swager (1997) D2 event. In this location, there is limited evidence for extensional fabric elements (D3 or other), apart from limited switching at Bannockburn. Further west around the Lawlers Anticline (see Fairyland to North Cox in Appendix 3.1.1), the prominent fabric element is again extensional.

For the purposes of this report, the hypothesis forwarded is that large-scale (basin forming) extensional events are D3 and related to a return to the geodynamics present during pre-D2 times. Intra-contractional extensional switching (e.g., Mertondale and Westralia pits) is considered within the D2 event. The constraints on this interpretation are: a few sites localities at which compression pre dates major extension; for example: at the Porphyry deposit, the lack of regional D2 along the eastern flank of the Raeside Batholith, and the observation that late basins unconformably overlay a pre-folded sequence (Blewett et al., 2004b). The majority of these folds have been linked to extension (see discussion below) however folds north of Pig Well seem to be too tight to have developed purely due to extension. The core of the Mt Margaret anticline has a tighter fold in the greenstones than the adjacent batholith.



Intensity shown as size and colour of circles, with red (high strain), yellow (medium strain), and blue (low strain). See Appendix 3.1.10 for interactive maps



Intensity shown as size and colour of circles, with red (high strain), yellow (medium strain), and blue (low strain). See Appendix 3.1.10 for interactive maps

Figure 60: Map of D2 (upper) and D3 (lower) structures and their intensity across the study area at individual locations. Pink - granites, Yellow – sediments and felsic volcanics, Green – mafic-ultramafics, and Brown – late basins.

Alternatively, both contraction and extension are coeval (cf. Lin, 2005) and are developed in different places depending on the role of granites and their perturbation of a regional contractional stress field (see Figures 61, 62). Lin (2005) has recently described synchronous vertical and horizontal tectonics in the development of a single set of structures in the NW Superior Craton of Canada. Lin (2005) suggests vertical tectonics (extension) was important in setting up fluid pathways for the Late Archaean gold mineral system.

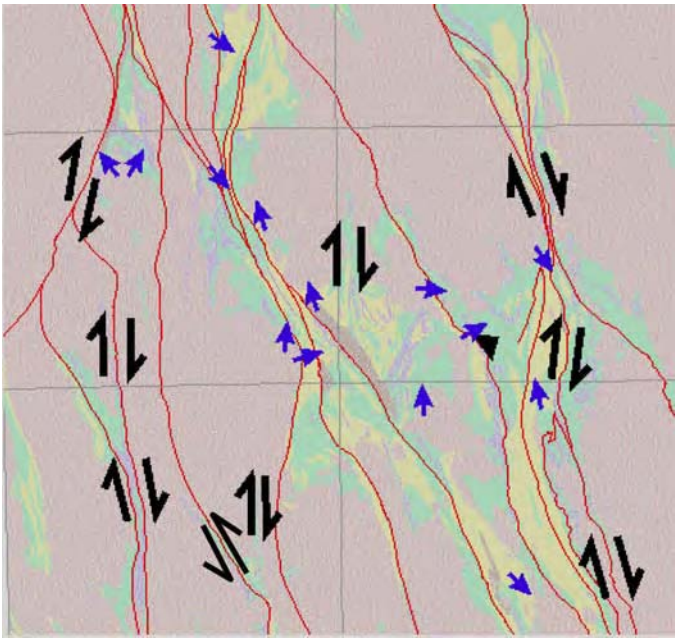


Figure 61: Major D2 and D3 kinematics. Black shear sense arrows indicate major D2 transpression kinematics. Blue arrows indicate D3 extension vectors.

Role of granites in D3 extension

Both the Leonora and Lawlers areas are dominated by large granite batholiths in the cores of regional N-plunging anticlines. Both areas appear to lack unequivocal evidence (at the mesoscale for contractional deformation (see Appendix 3.1.1, 3.1.3). These regional upright folds appear to have developed at the same time as contraction elsewhere (especially in the centres of the terranes). The role of granites during D2 contraction in localising extensional deformation can not be underestimated. Figure 63 is from Harris et al. (2002) and shows the development of upright (gently plunging) folds adjacent to extensional shear zones. The models of Harris *op cit.* are obviously developed in plasticine, but the resultant geometries bear an uncanny resemblance to the deep crustal seismic reflection profiles (Goleby et al., 1993; 2003; Blewett et al., 2003). The broad antiforms in these models (Fig. 63) may be analogous to the broad antiforms such as the Mt Margaret, Raeside, and Lawlers Anticlines (Fig. 9). In the analogue modelling, these antiforms are cored by more ductile material (the more competent layers such as the brown and black markers) boudinage. This inference may suggest that magmatism at the time of extension may be required to reduce the lower-plate viscosity to facilitate this doming.

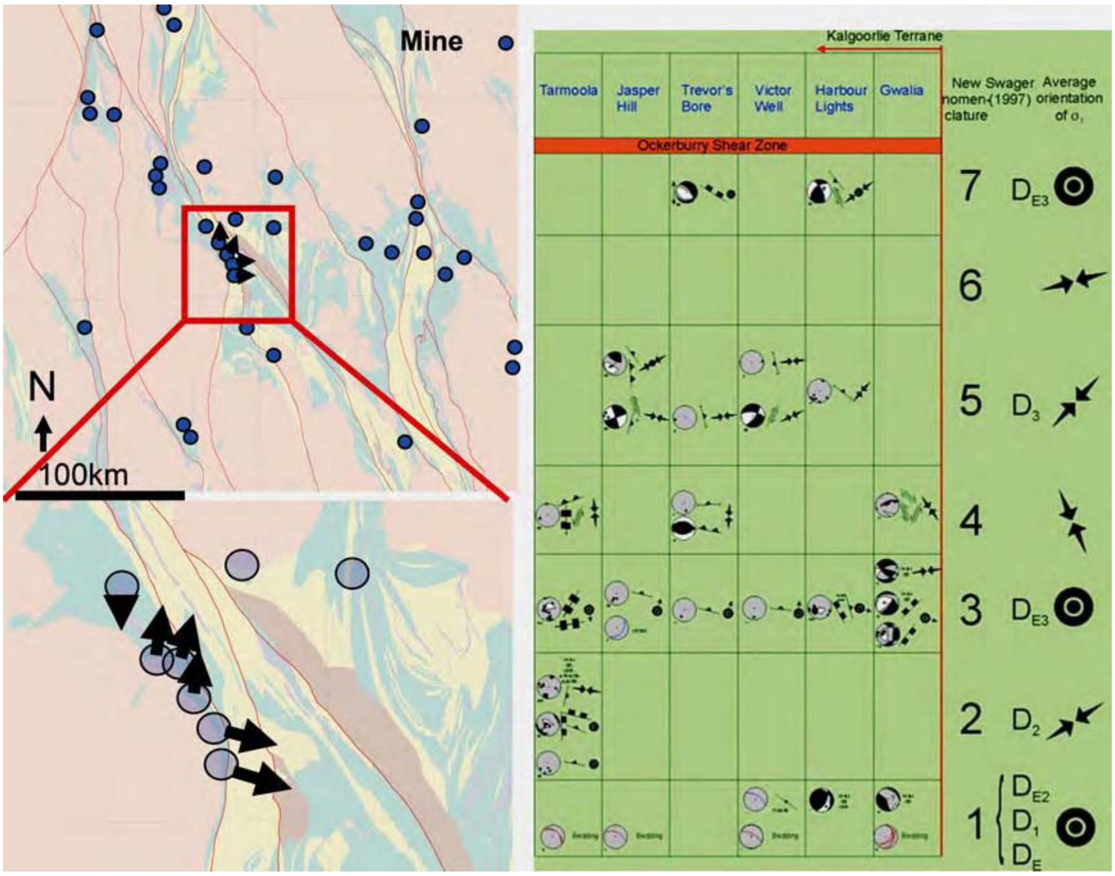


Figure 62: Lack of D2 compression on Ockerburry Fault System around Leonora. Notice switching between compression and extension at Tarmoola.

Figure 63: Illustration of centrifuge modelling of upright antiforms (domes) developed during extension. These may be viewed as analogues for the development of the granite-cored such as Mt Margaret, Raeside, and Lawlers. The development of the folding is not diapirism, but gravitational instability facilitated rising batholiths in an extensional environment.

D2/D3 Extension and formation of Late Basins

The traditional paradigm has been that the Late Basins are pre-'D2' as they are deformed by a 'D2' event (Swager and Griffin, 1990; Swager et al., 1992; Swager, 1997, Krapěz et al., 2000; Weinberg et al., 2003). D2 in these workers definition was the first ~E-W contraction.

Blewett et al. (2004b) demonstrated that the Late Basins lay unconformably on a prefolded sequence deformed by the first ~E-W contraction. They labelled this early event D2a, and gave two regional examples. The first example in the Kalgoorlie Terrane was the N-plunging regional syncline-anticline pair at Ora Banda and its relationship with the overlying Kurrawang Basin (Fig. 64a). The second example in the western Kurnalpi Terrane was the S-plunging upright Corkscrew Anticline at Welcome Well, and its relationship to the Pig Well Basin (Fig. 64b).

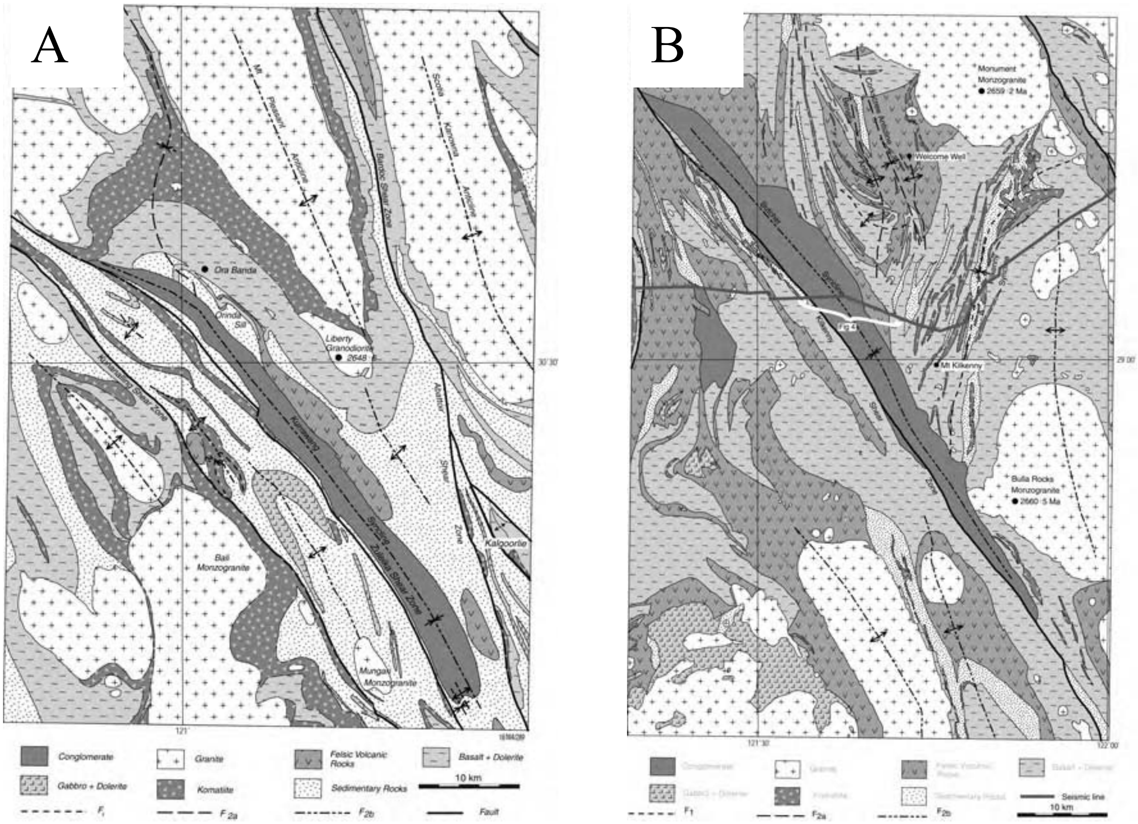


Figure 64 a, b: Simplified Geological Maps of the Late Basins (A–Kurrawang and B–Pig Well) overprinting the Ora Banda Anticline and Corkscrew Anticline respectively (after Blewett et al., 2004b).

Blewett et al.'s *op cit.* observations were important in that they showed that D2-style folds were developed in the basement to the Late Basins, and not necessarily D1 contraction (*cf.* Swager, 1997). One question not addressed by Blewett et al. was the mode of formation of these D2a folds, the assumption being that they were developed solely in contraction.

A study of structures around the Lawlers Anticline and adjacent Scotty Creek Late Basin has raised the question whether the NNW-SSE trending upright folds cut by

Late Basins are developed under contraction or extension. The same geometric relationship as described for the Kurrawang and Pig Well basins seem to hold true at Lawlers. That is a Late Basin unconformably overlies a pre-folded (NNW-SSE trending) mafic-dominated sequence, and the basin itself is deformed by a E-W contraction.

However the question has been raised by this study as to the mode of formation of the Lawlers Anticline itself. Could it be that the Lawlers anticline is related to extension as opposed to compression? It is difficult to unequivocally identify early E-W contraction around the Lawlers region. The region is dominated by down-to-the-E, -NE, and -N extensional fabric elements (see Appendix 3.1.1 from Fairyland to North Cox). The Lawlers Anticline is cored by a coarse-grained granite, which raises the question as to the role of the granite in the development of the fold. Similar questions could be asked with respect to the Mt Margaret Anticline and the development of the Stage 2 Wallaby Basin and possibly the Stage 1 Granny Smith Basin. McIntyre and Martin (2005) suggested that the Late Basins in the Laverton area were developed as upper-plate rift basins above a detachment related to 'extrusion' of the Mt Margaret Batholith to the north.

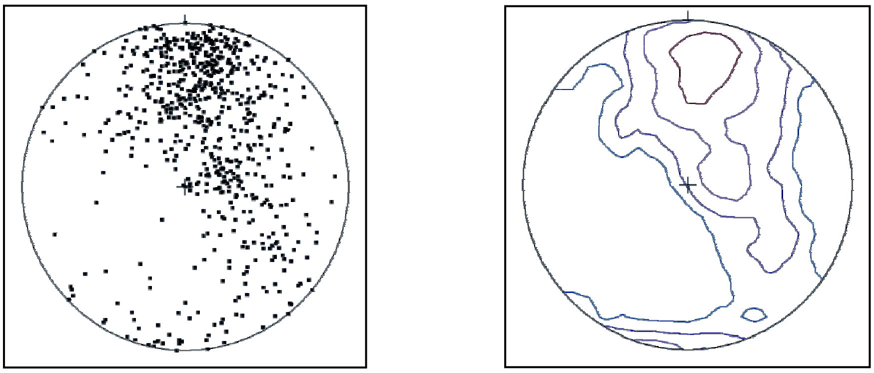


Figure 65: Stereonet of lineations in granites and greenstones around the Lawlers Anticline (generated from data in Beardsmore, 2002). Note that the main population plunges gently north, this is parallel to the hinge of the regional fold (and the shape of granite at depth). A second sub-population plunges steeply ENE. Note the lack of W- and SW-plunging lineations.

Beardsmore (2002) showed in a very comprehensive mapping study of the Lawlers region that the main foliation transects the axis of the regional fold (Fig. 66a). Also revealing in this study was the pattern of lineations (Fig. 65b). They plunge gently to the N in the north, becoming progressively steeper NE and finally steeply E-plunging along the eastern limb of the fold (Fig. 66b). In contrast, the western limb of the fold does not have down-dip lineations like its eastern counterpart. Rather, the lineations plunge gently S and are more akin to strike-slip (Beardsmore, 2002).

This pattern of foliations and lineations is not consistent with diapirism. The lineations are not radial as there are few if any down-dip lineations on the western limbs across the Eastern Yilgarn. This is not simply a sampling problem as Beardsmore (2002) has systematically encircled the Lawlers Anticline (Fig. 66b).

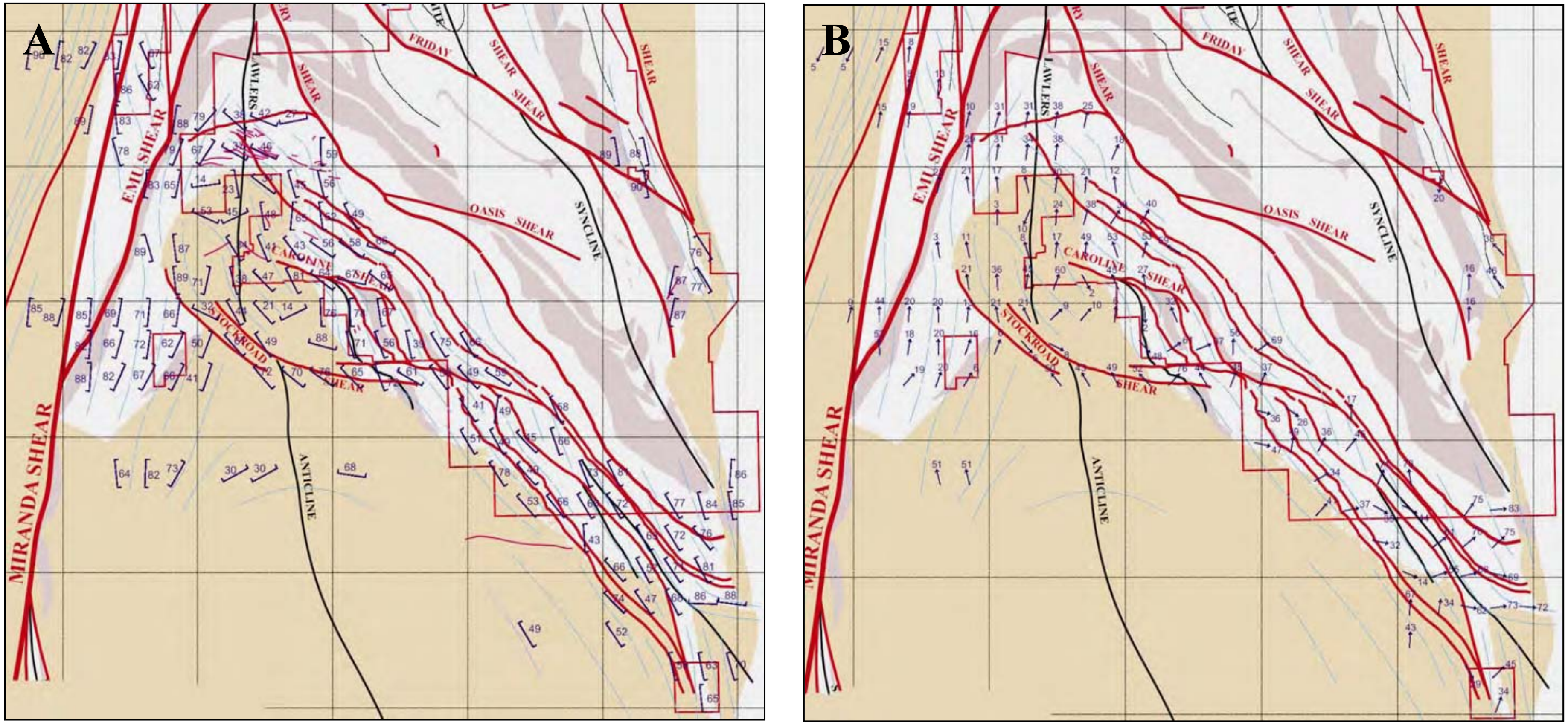


Figure 66a, b: A-Map of the main foliation and the main lineation in the Lawlers region (after Beardsmore, 2002). The red lines are major faults, and many were observed to have normal or extensional kinematics on them in this study. Note that the foliation transects the fold axial trace (black line). The foliation is therefore overprinting (is later than) the development of the fold. B-Map of lineation trajectories showing the gentle (hinge parallel) plunge in the centre and north, and the steepening and rotation of the plunge to east on the SE limb of the fold (see Fig. 65).

Figure 67: Photographs of the core of the Lawlers Anticline showing a gentle N-dipping penetrative foliation 'S1' and associated stretching lineation (rods), and folding about upright gentle N-plunging 'F2' folds.

In the Lawlers area, there is a question regarding whether there is only one foliation. Beardsmore (2002) suggested that there might be two populations, one shallow NE-dipping, and another steeper and striking NNW. He also plotted up the shallow fabrics in the granites and showed that they lay on girdle with a pole (fold axis) that plunged 23º to 359 (cf. Fig. 66b). Blewett noted similar relationships in the leucogranites in the innermost nose of the Lawlers Anticline (Fig. 67), where two stages of deformation are recorded. Beardsmore (2002) also noted dextral shearing on the steeper NNW-trending fabric (which we would interpret as D5 dextral – see later). The map patterns of the Lawlers Anticline (Fig. 66), especially the SW limb, show that the Lawlers Tonalite (~2665 Ma) intruded into an already domed sequence. This suggests that the magmatism was concentrated into incipient antiforms, and that the extension and doming was likely a long-lived process.

The Lawlers Anticline is therefore interpreted to record extensional uplift and exhumation, with doming and magmatism at ~2665 Ma. The overlying greenstones were domed and tilted and overprinted by extensional down to the N-, NE- and E-dipping extensional shear zones. Shear was accommodated on structures such as the Cascade Shear in the Sunrise Birthday pit (Fig. 66), and was associated with gold mineralisation. Similar extensional shear zones include the Stockyard and Caroline shears (Fig. 66). These faults have **apparent** sinistral offset in map patterns, which when resolved kinematically, is the result of normal offsets on NE-dipping markers. This extensional mode explains the paradox for Beardsmore (2002) of the steep down-dip lineations he recorded on these shears, and negates the need for an additional deformation event to explain the geometry and relationships.

Beardsmore (2002) also described the 'rolling' of the stratigraphy on the eastern limb of the Lawlers Anticline. He noted that the lowest units dipped on average 35º to the NE, while the upper units dipped more than 75º to the NE. This change in dip was interpreted to be a function of back rotation during NE-over-SW thrusting. An alternative interpretation presented here is that this change in dips reflects the position of the stratigraphy with respect to the C' shear planes, and the footwall uplift and doming common to extensional systems (see Fig. 68). Mesoscale examples are exposed at Sunrise Birthday and the distribution of ore shells at Fairyland follow this trend. This mineralisation trend at Fairyland suggests that the distribution of lithology caused by extension places is a strong control on the later contractional mineralisation.