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The characterisation of granite deformation events in time across the Eastern Goldfields Province, Western Australia

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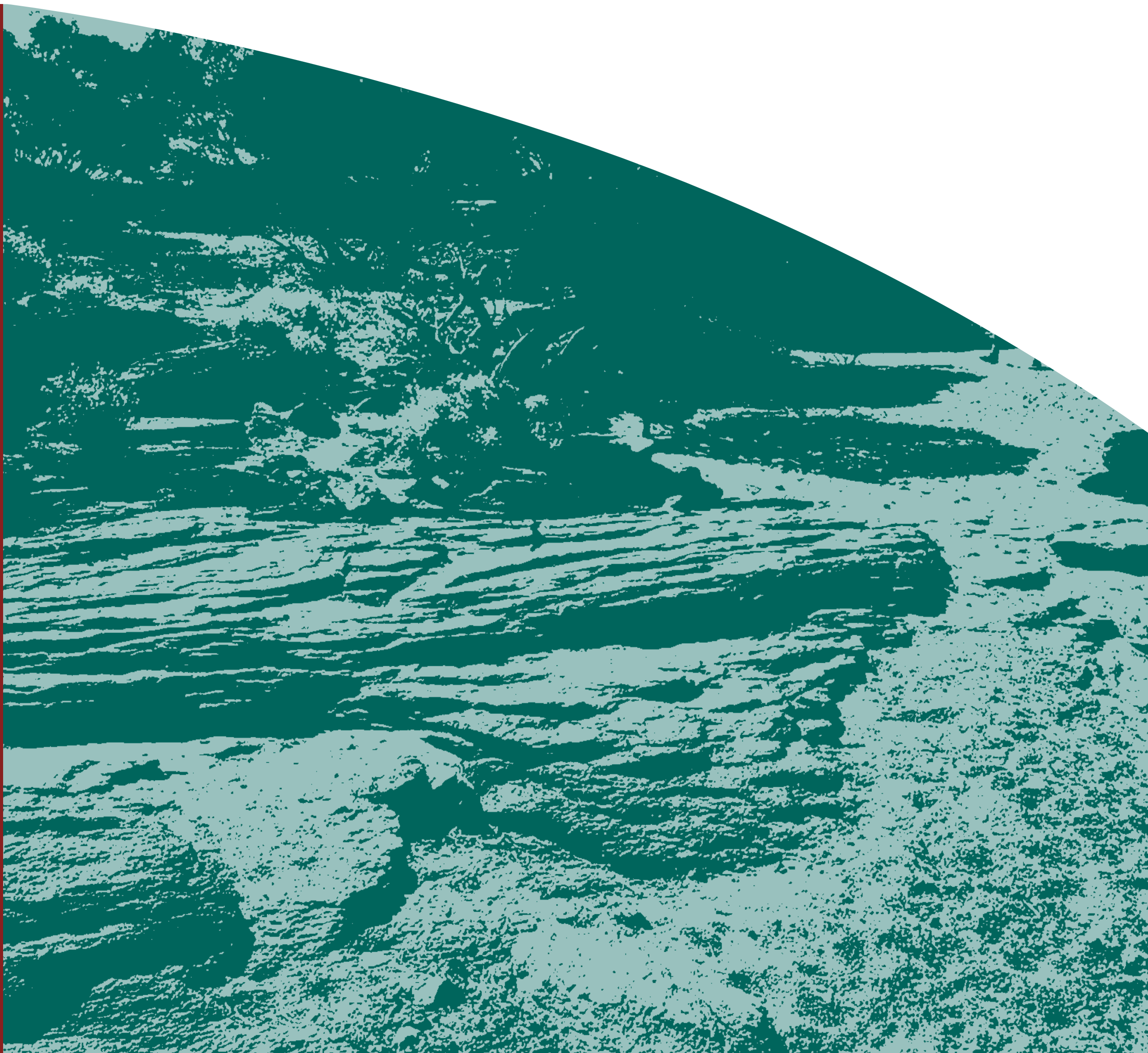

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Scope and aims of project

The established deformation paradigm for the Eastern Yilgarn Craton (EYC) has largely been developed from observations of overprinting relationships in the greenstone belts (Swager, 1989, 1997; Swager et al., 1992; Williams, 1993). Broadly, the recognised deformation (compressional history) involved early D_1 recumbent folding and thrusting during N-S shortening, followed by E-W shortening through large-scale upright D_2 folding and thrusting, then a period of strike-slip D_3 faulting with associated folding, followed by continued regional D_4 transpressive oblique and reverse faulting. Some authors have proposed early, intermediate, and late periods of extension throughout parts of this compressive history (Table 1).

This study is aimed at providing a new deformation framework for the granites of the EYC. Granites form >60% of the surface expression of the province, so a more thorough understanding of their tectonic history is critical to our understanding of the evolution of the province. There are advantages of using deformed granites for establishing a time-space-event history. Granites have—

a well defined chrono-chemical framework across the entire province (pseudo-stratigraphy) (Champion & Sheraton, 1997);
a ductile mineralogy of quartz and feldspar that readily 'accepts' deformation;
multiple phases of granite, as sheets and dykes, which provide excellent markers for defining the subtleties of many of the events (especially the later ones);
exposure at various structural levels in the upper crust; and
a good U-Pb zircon geochronological database as a reference framework (Nelson, 1997; Fletcher, et al., 2001; Dunphy et al., 2003; Black et al., 2004).

The scope of the study is to systematically describe the overprinting relationships of structures in granites for a range of structural levels and geographical positions (sites) for the major structural domains or terranes (Southern Cross, Kalgoorlie, Gindalbi-Kurnalpi-Laverton, and Merolia). The area chosen was the central EYC exposed in the area of the 1:250 000 scale map sheets of Leonora, Laverton, Menzies and Edjudina. This study area was chosen because new solid geology mapping (Whitaker and Blewett; 2002), new seismic reflection profiling (Goleby et al., 2002), and the available comprehensive geochronological database. The area also provided a different perspective for the regional deformation history to that determined from the better studied Kalgoorlie region (Swager, 1989).

The approach was to systematically study the various structural elements for a range granite ages, with the granite age to be used as a time marker at each site. At each site, the structural elements before (cut by the dated phase) and after (overprint the dated phase) were systematically mapped and described. These structural elements form the data (available as separate data sheets) that were used to correlate events with adjacent sites in the same domain. These domain-wide event histories were also correlated to construct a new EYC deformation framework. Each stage of correlation becomes more interpretative. However, the original site data have been 'preserved' for evaluation and further testing.

Table 1: Current deformation framework

Greenstones	Granites
Greenstone deposition	
De early extension	early granites (2685-75)
D1 N-S compression	
Late basins	post-D1 pre-D2 porphyry (2675)
D2 **(E-W compression)**	syn-D2 granite (ca. 2660)
MAIN EVENT	
	post-D2 granite (> 2660)
D3 *(*ENE compression)	
extensional collapse	late-tectonic granite (< ca. 2660)
D4 (E-W compression)	
	post-tectonic granite (2620-2600)

Source: Archibald et al., 1978; Swager, 1989, Witt & Swager, 1989; Williams, 1993; Hammond & Nesbit, 1992; Swager et al., 1997

Method

More than 30 representative sites of the central EYC were visited. These sites lie between the Ida Fault in the west and the eastern edge of the exposed EYC. They included granites external and internal to the greenstones (Fig. 1).

The granites provide maximum and minimum ages for the various deformation events (represented by observable structures elements such as foliations, folds, shear zones, lineations, etc.). The local deformation history (as a series of separate episodes) was documented for each site (usually an area of around 1 hectare or less). At each site, structural observations of superposition and overprinting relationships determined the chronology of the various structural elements. The earliest (oldest) structural elements are given attributes of D1, the second is D2, and so on to the youngest Dn, where n is the number of 'events' identified at the site (Fig. 2).

No structural elements have been directly dated. The absolute ages of the various granite phases provide maximum or minimum ages for the structural elements depending on their relative overprinting relationship to the host granite. For example, a dated granite phase that cross-cuts a structure provides a chronological minimum for these earlier structures. In contrast, structures that cross-cut a dated granite phase have a maximum possible age equivalent to the granite age. By dating several phases in one outcrop and by dating different sites of different ages, the temporal constraints of the various structural elements (events) are further refined. Direct dating of events is possible where granitic dykes are intruded into active shear zones.

Figure 1: Location of field sites in the central Eastern Goldfields Province

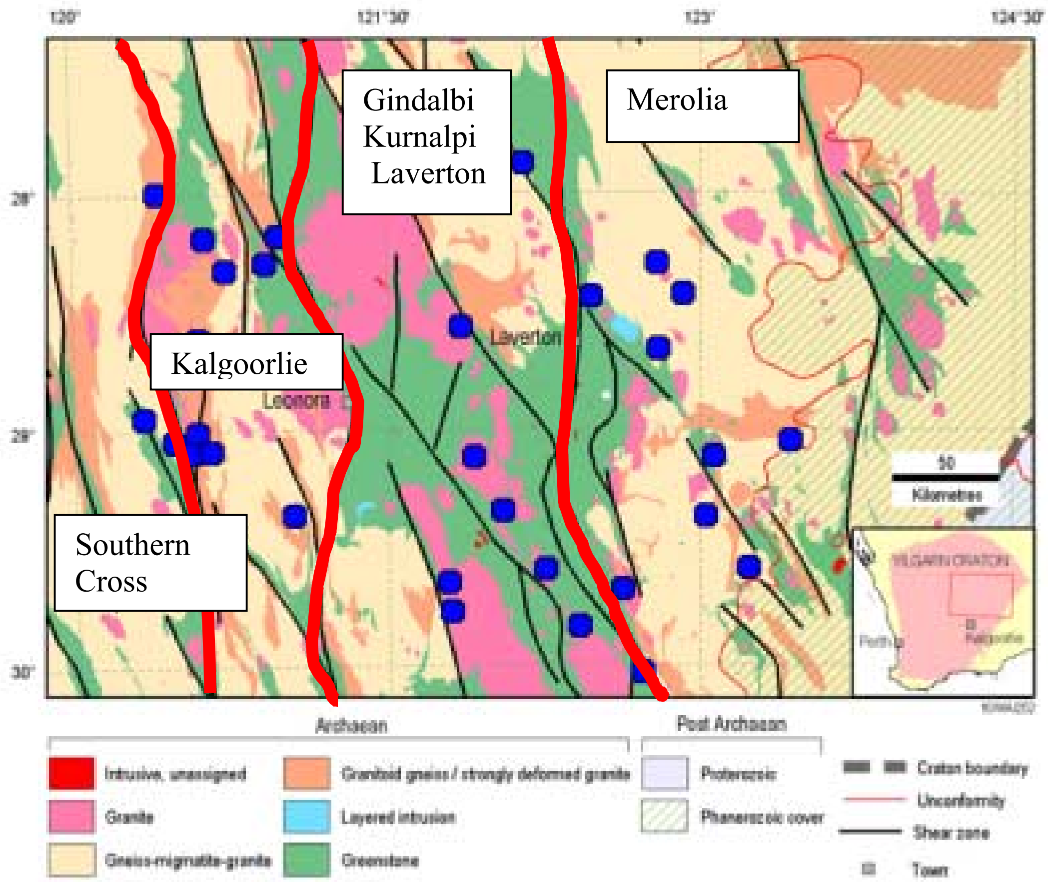
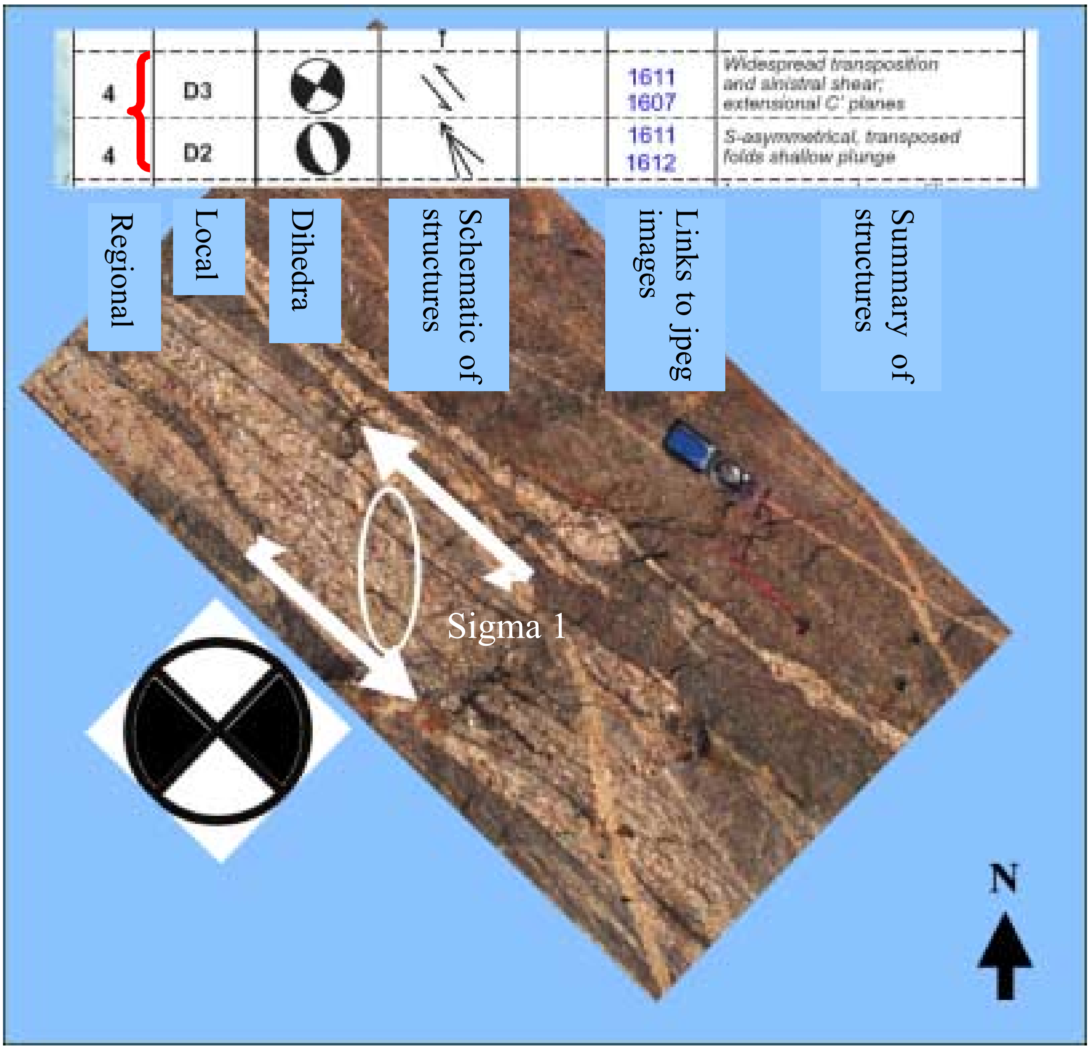
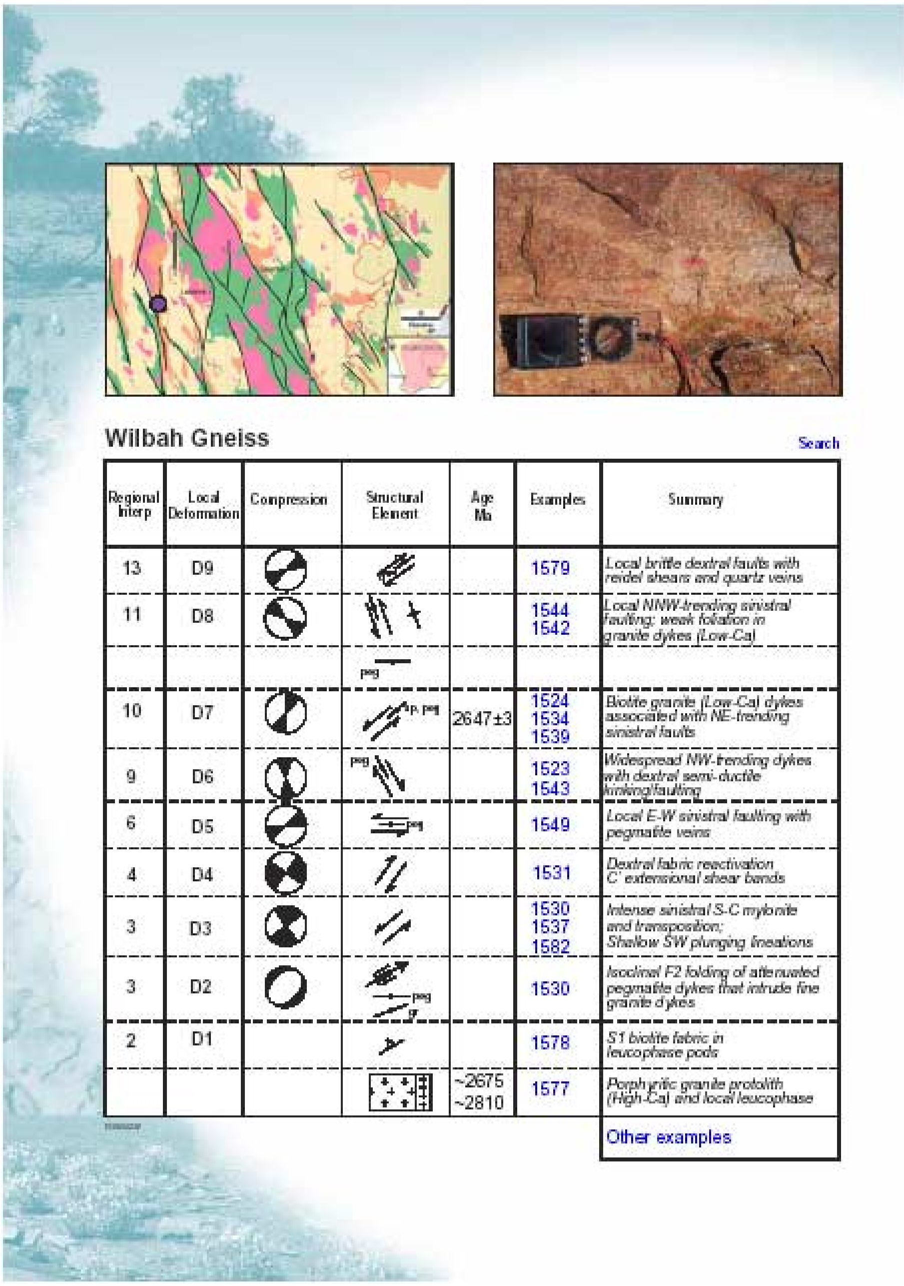


Figure 2: Outline of the method using dihedra to constrain σ₁ as a way of separating successive events by major switches in palaeostress



Estimated or schematic fault solutions (P-T dihedra) have also been developed for each phase (Fig. 2). These are similar to the better known earthquake focal mechanism solutions (see Angelier, 1994—fig. 4.34, pg. 74). These solutions are presented as lower hemisphere stereographic representations of where σ_1, σ_2, and σ_3 are likely to be for that particular event. In these diagrams, σ_1 is located in the black quadrants (T-dihedron). This fault plane solution analysis aids the identification of conjugate structures *vs*. overprinting structures, and clearly shows where there has been a significant change in either the stress field (a new event), or a rotation of the site with respect to the stress field. Where there has been no significant change in quadrant or dihedral that contains σ_1 in a successor event (e.g., D2 to D3 in Fig. 2), then the regional deformation event is assumed to have remained and a new event has not been recorded at this stage (e.g., 4 which represents D4 in the regional compilation of Fig. 2).

Figure 3: Example of a site compilation (data sheet) of local events D1 to D9, compared to the regional framework.



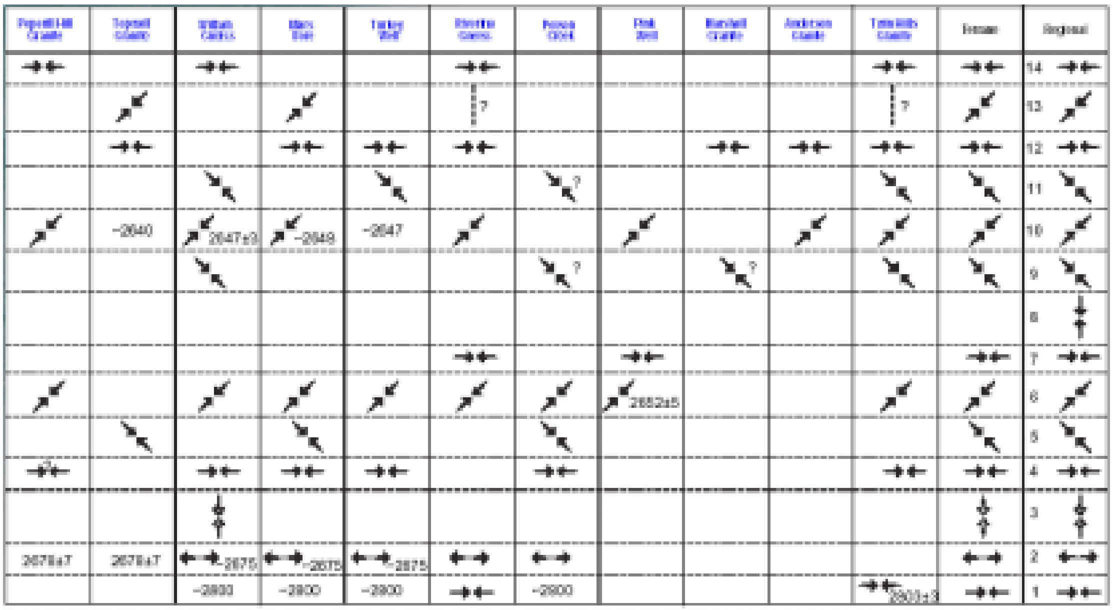
Wilbah Gneiss Search

Regional Interp	Local Deformation	Compression	Structural Element	Age Ma	Examples	Summary
13	D9				1579	*Local brittle dextral faults with reidel shears and quartz veins*
11	D8				1544 1542	*Local NNW-trending sinistral faulting; weak foliation in granite dykes (Low-Ca)*
			peg			
10	D7		p, peg	2647±3	1524 1534 1539	*Biotite granite (Low-Ca) dykes associated with NE-trending sinistral faults*
9	D6		peg		1523 1543	*Widespread NW-trending dykes with dextral semi-ductile kinking/faulting*
6	D5		peg		1549	*Local E-W sinistral faulting with pegmatite veins*
4	D4				1531	*Dextral fabric reactivation C' extensional shear bands*
3	D3				1530 1537 1582	*Intense sinistral S-C mylonite and transposition; Shallow SW plunging lineations*
3	D2		peg g		1530	*Isoclinal F2 folding of attenuated pegmatite dykes that intrude fine granite dykes*
2	D1				1578	*S1 biotite fabric in leucophase pods*
				~2675 ~2810	1577	*Porphyritic granite protolith (High-Ca) and local leucophase*
						Other examples

Figure 3 shows that at each field site there is a description of the structures defining the local event, linked jpeg images illustrating (blue highlighted text shows links) the structures, the ages of events, a simplified schematic of the structure, a possible palaeostress dihedra, a local event label (D1 etc), and a correlation with the regional framework. This preservation of the data, without interpretation, permits the reinterpretation of the data by other users.

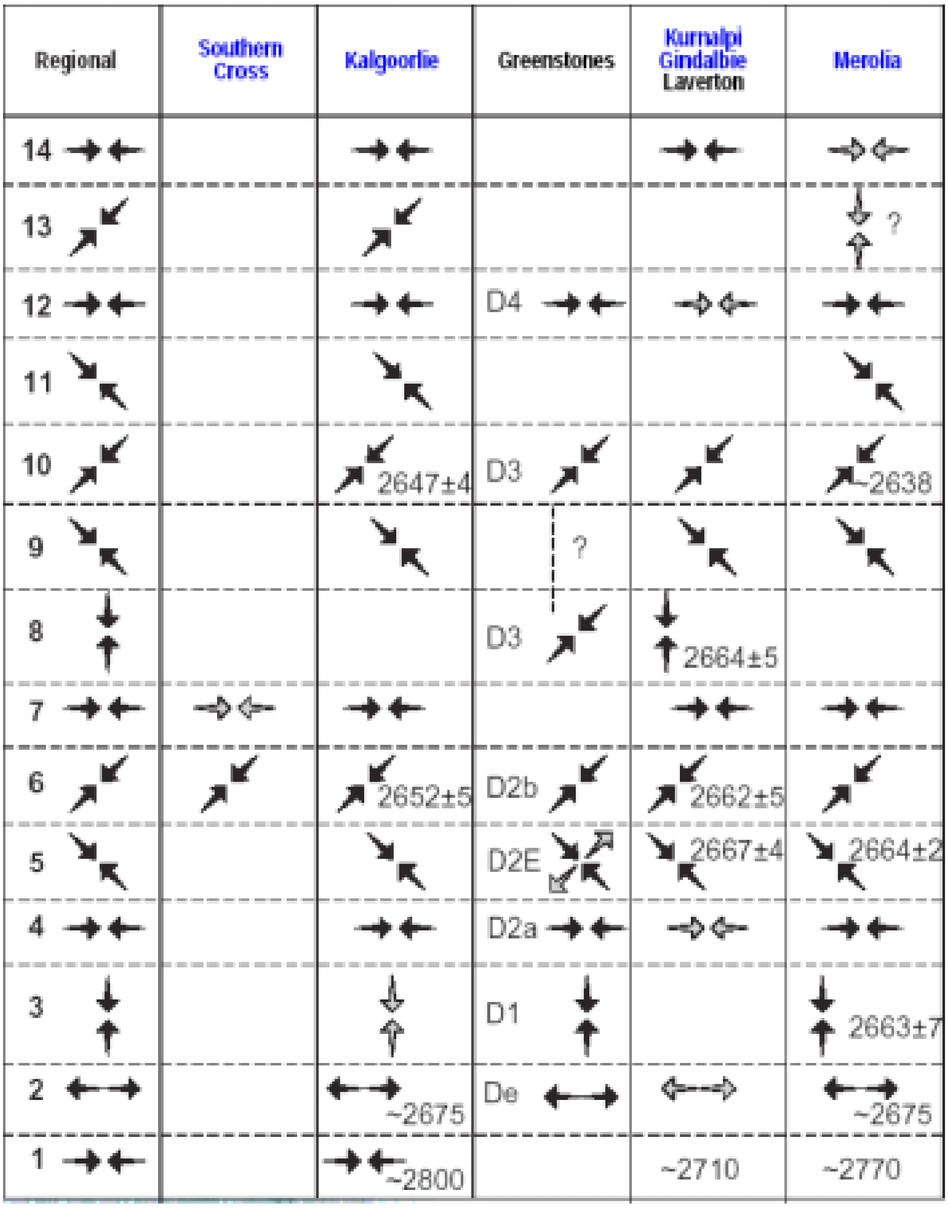
The next stage of this study was the correlation of the various relative structural event histories between the sites within a domain, or terrane, in order to develop a terrane-wide deformation framework (Fig. 4). The correlation was made using the estimate of the palaeostresses and their sequence of changes (which was remarkably consistent and predictable). This framework has a number of ages from the different sites, enhancing the robust temporal control of the framework. Individual sites are linked so one can quickly navigate to the data (e.g., Fig. 3) that were used to make the correlation and interpretation.

Figure 4: Terrane correlation chart for the Kalgoorlie terrane showing geochronology and possible σ_1 (as arrows) compared to the Regional D1 to D14 framework.



The final stage of the study is the correlation between the domains/terranes and the development of a regional or province-wide deformation framework with palaeostress axes and timing (Fig. 5). Comparing this new complex history (Fig. 5) with the greenstone deformation history (Table 1 and Blewett et al., 2004) shows that there are many similarities, and yet key differences.

Figure 5: New correlation chart based on the synthesis of the granite deformation history for the Eastern Goldfields terranes, compared to the greenstone deformation history from Blewett et al. (2004)



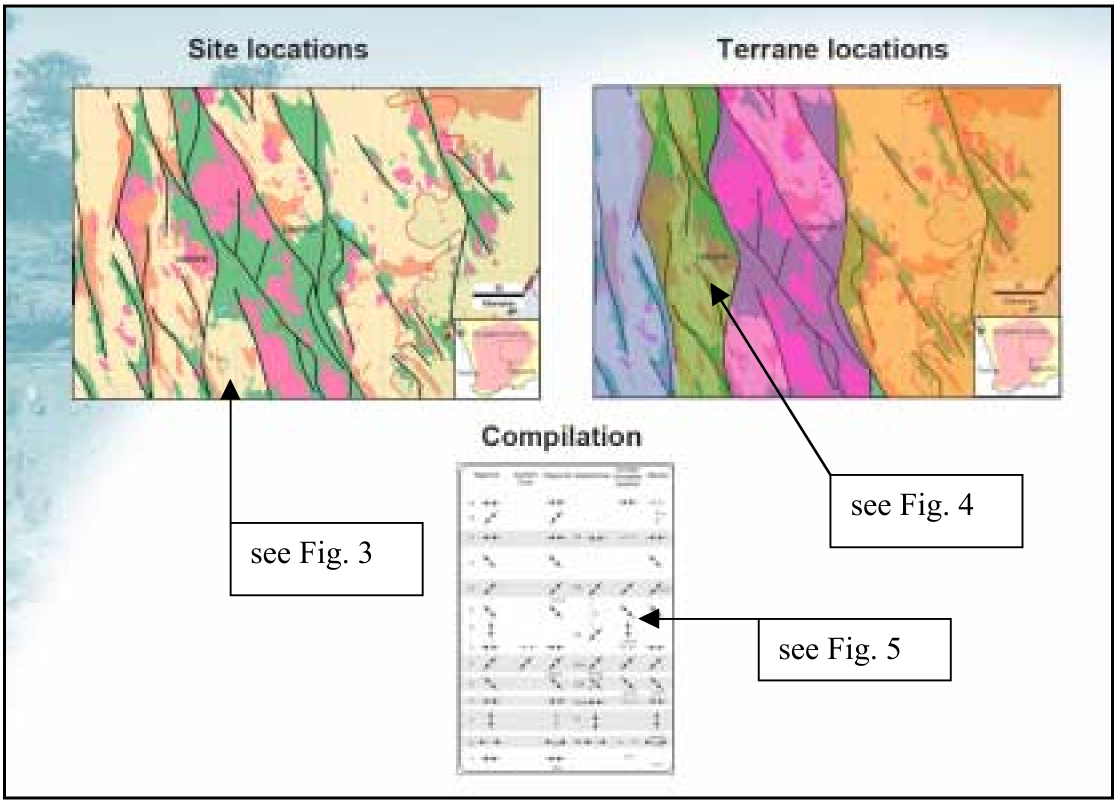
Navigation of the CD or website

The document has been developed in the Adobe® Acrobat® pdf format for both CD or online use. The pdf format allows for linking between screens, so the user can examine the report in time or space. For example, the user is given a three-way choice (Fig. 6):

1) field site locations,
2) a high degree of interpretation is found in the terrane compilation, and/or
3) a new correlation chart (compilation) of the terrane event history.

Access is via a mouse click and the user will be taken to the relevant screen. Using the back button or previous view button will return the user to the previous screen. This is particularly useful when looking at the jpeg photographs from the individual sites.

Figure 6: Three-way access to the report with increasing levels of interpretation.



Implications and new findings

The granite study worked well and consistent overprinting relationships were matched across large areas and through time to develop the new framework. There are a number of new results from this study—

- There was a widespread major melting (metamorphic) event at ~2675 Ma with gneiss development (Regional S2 – Fig. 5) that, when restored, suggests these metamorphic fabrics were subhorizontal. These fabrics may correlate with the De extensional events of Hammond and Nesbitt (1992) and Williams, (1993).
- There is a consistent N–S compression and recumbent folding of the Regional S2 gneissic fabric (Regional D3).
- An E–W shortening event (Regional D4) was followed by NW–SE shortening event (Regional D5). This switch may be a function extension with the development of a vertical σ_1 (D_{2E} of Blewett et al., 2004) that is not readily resolved from the essentially 2D outcrops of the granites.
- The timing of the D_{2b} event (Regional D6) is younger in the west than in the east, implying diachronous deformation. Regional D6 is the 'main' D2 compressional event articulated by most workers (see Table 1 and references therein).
- There was a significant switch to NW–SE compression prior to or associated with the intrusion of the Low Ca granites at around 2650-2640 Ma. This event is being increasingly 'discovered' in the greenstones (Roberto Weinberg pers comm., 2003).
- There was a more complex history of palaeostress switching during the late brittle deformation events (Regional D10 to D14). Traditionally, these events have been 'lumped' into a single D4 event of NE–SW compression (Table 1).

Future work

Future tests will compare this regional framework with studies of detailed sites within the greenstones (especially around the mine sites). This granite deformation framework is valid for the greenstones because it is constructed from granites that intruded into the greenstone sequences. Therefore, stresses mapped in the granites by this study will have propagated through the surrounding greenstones. An untested hypothesis that might be answered by this framework is whether deformation was diachronous across the EYC.

Critical relationships have been identified and these will be targeted for future age dating. Also, the granite dyke-hosted (syn-magmatic) shear zones will be investigated for age dating, to determine the absolute ages of the structures.

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