

The Zuleika Shear Zone

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2.5.2. The Zuleika Shear Zone

Introduction

The Zuleika Shear Zone was selected for this study because of its intermediate gold endowment and its location between the Boulder-Lefroy and Ida Shear Zones. A high strain corridor can be traced on aeromagnetic images, from a northern limit on the SW margin of the Mt Pleasant Dome, to its southern limit west of Democrat, a distance of ~200km. The Ballard Shear Zone has been interpreted to represent the northward continuation of the Zuleika Shear Zone (Legge 1990, Wyche and Witt 1992).

During the course of this study, we visited the northwest deposits of Chadwin, Ant Hill and Bullant, the central deposits of Centenary, Strezlecki and Barkers at the Kundana camp, and Cave Rocks at the southern end, as well as regional outcrops. This report incorporates existing data with our new data, and provides a new insight into the role of the Zuleika Shear Zone during deformation of the Kalgoorlie Terrane, and associated mineralisation.

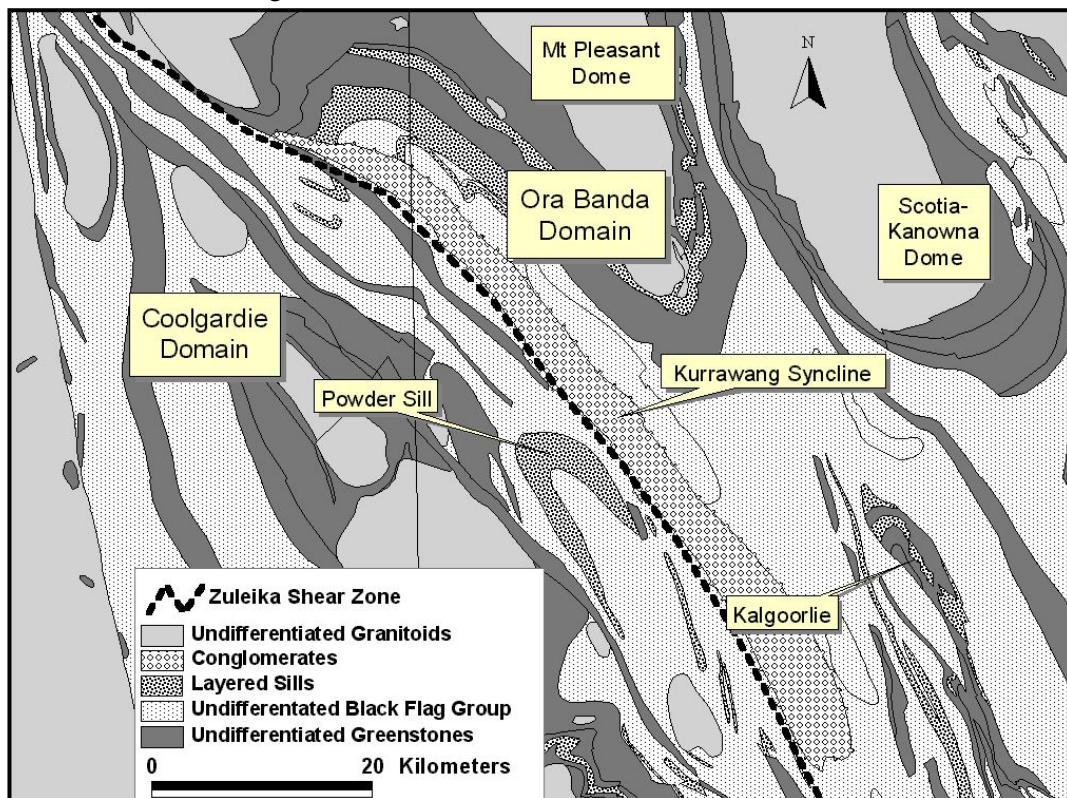


Fig. 2.5.14. Simplified geological map of the northern portion of the Zuleika Shear Zone (modified after Groenwald et al 2000), highlighting the major features discussed in this section of the report. Note the broad curvature of the Zuleika Shear Zone, and corresponding curvature in the Kurrawang Syncline.

Previous Work

Portions of the Zuleika Shear Zone have been documented within the Davyhurst (Swager 1994), Bardoc (Witt 1990), Kalgoorlie (Hunter 1993), and Yilmia (Hunter 1993) 1:100,000 GSWA map sheets. The Zuleika Shear Zone was delineated by these workers as a curved zone, forming the western boundary to the Kurrawang Syncline where it strikes NW and rotates to a more southerly trend to the south (Hunter 1993) cutting west of the Merougil sedimentary rock sequence that forms a synclinal structure similar to that of the Kurrawang Syncline. Swager (1994) defined the Zuleika Shear Zone as a domain boundary fault, separating the Coolgardie Domain from the Ora Banda and Kambalda Domains (2.5.14).

Sparse outcrops of strongly deformed rocks indicate the zone to be as much as 1km wide. On the Bardoc 1:100,000 map, Witt (1990) estimated the width to be between 100m and 1km, and noted that deformation was located between an ultramafic unit to the SW and a sedimentary rock to the NE, although the contact is not exposed. Tripp (2000) studied the ZSZ in the Ant Hill, Bullant, Porphyry and Wattlebird gold deposits on the northwestern section of the shear zone, and concluded that the structure was a zone of interlinked, anastomosing, mylonitic fabric, of sinistral displacement, which preferentially partitioned along lithological contacts and internal heterogeneities such as pillow margins.

Swager (1994) also reported sinistral asymmetries within the zone, a feature also noted by Witt (1993) at Hawkins Find and Zuleika. Witt (1993) documented moderately plunging (~45NW) mineral lineations at these locations, while those at Bullant and Wattlebird are sub-horizontal (Tripp 2000). Stratigraphic mismatch and lack of cross cutting relationships hamper the estimation of the amount of displacement along the shear zone (Swager 1994).

Witt (1993) documented widespread porphyry dykes in the vicinity of the Zuleika Shear Zone and Tripp (2000) described porphyry intrusions preferentially intruded into ultramafic rocks, and interpreted these to be syn- to late-shearing, based on the wrapping and truncation of shear fabrics.

Results from the 1991 and 1999 Yilgarn seismic surveys indicate that the Zuleika Shear Zone itself is not reflective, but displacement of planes cut by it lead to the interpretation that it dips to the east (Goleby et al 2000).

Stratigraphy and Metamorphism

As noted above, the ZSZ is a boundary between the Ora Banda and Coolgardie Domains. The Ora Banda Domain, situated to the NW of the Zuleika Shear Zone, has a well-defined stratigraphy described by Witt (1990), and not repeated here. It is important to note, however, that the Ora Banda Domain includes a significant ultramafic sequence known as the Walter Williams Formation, which has been recognized in several greenstone belts (Hill et al 1995), including the eastern portion of the Ullaring Greenstone Belt, as previously mentioned. The two uppermost layers in the ultramafic-mafic sequence, termed the Bent Tree and Victorious Basalts, crop out along, and define, the NE margin of the Zuleika Shear Zone. In the context of the ZSZ and its gold deposits, the two basalt sequences, and rocks at the base of the Black Flag Formation, are particularly important. Particularly important is the role of the Centenary Shale, which is a recognized marker horizon at the interface between the Victorious Basalt, and the Black Flag Formation (Beeson, pers. comm.) within the Ora Banda Domain, and hosts a significant proportion of the mineralisation at Kundana. In the vicinity of the shear zone these rocks are exposed, dipping steeply to the SE, and attenuated.

West of the ZSZ, in the area of Dunnsville (northern section of the shear zone), the stratigraphy has been correlated with that of the Coolgardie Domain (Swager 1994) and consists of a lower basalt and dolerite, overlain by 600m of ultramafic flows and interflow sediments. These mafic-ultramafic rocks are overlain by the Spargoville Formation, which is defined as the felsic volcanoclastic lower section of the Black Flag Group by Krapez et al (2000). To the SW of Kundana, these intermediate to felsic volcanoclastic rocks are intruded by a differentiated dolerite termed the Powder Sill. The stratigraphy of the Coolgardie Domain differs from that of the Ora Banda Domain in that it lacks the Upper Basalt horizons between the ultramafic rocks and the Black Flag Group (Hunter 1993).

An overview of metamorphism in the Kalgoorlie Terrane was presented by Witt (1993). In his metamorphic map (Fig. 2.4.1), much of the Ora Banda Domain is indicated to be low- to mid- greenschist facies, and amphibolite facies rocks occur proximal to the granite domes. West of the ZSZ, metamorphic facies is generally higher than to the east, but the greenschist

facies/amphibolite facies isograd cuts the shear zone to the SW of Kundana. The Spargoville Formation is depicted in Witt's (1993) map to be upper greenschist to lower amphibolite facies. Because the isograd cuts the shear zone at a high angle, the ZSZ does not mark a change in metamorphic facies.

Regional Folds

The Kurrawang Syncline forms the NE margin to much of the arcuate central and northern portions of the ZSZ. The axial trace of this fold is parallel to the arcuate shear zone (Fig 2.5.14). To the SW of the Zuleika Shear Zone, a corridor of intensified deformation is characterized by a broad-scale synclinal structure (the Powder Sill Syncline), and minor folds within the Spargoville Formation (Fig. 2.5.14). These folds are well defined in aeromagnetic imagery.

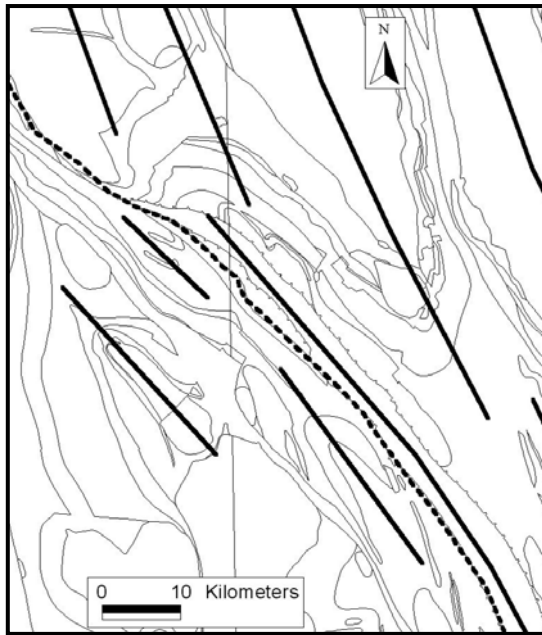


Fig. 2.5.15. Lithological contact map of the area depicted in Fig. 2.5.14, showing the orientation of major folds in the region. Note the obliquity of fold traces adjacent to, and SW of, the Zuleika Shear Zone, relative to those to the NE (see text for explanation). Note also similar orientation of the SW folds to the orientation of the Zuleika Shear Zone.

The open Powder Sill Syncline in the center of the corridor contrasts with increasingly tighter folds towards the ZSZ. At Kundana, rocks that belong to the Powder Sill define a tight anticline with attenuated limbs, as revealed by recent drilling (S. Halley pers. comm.). The NE limb of this anticline forms the SW margin of the ZSZ, where it is in faulted contact with the upper greenstone units of the Ora Banda Domain.

Northeast of the Kurrawang Syncline, fold structures defining the Mt Pleasant Dome trend ~N25W (Fig. 2.5.15), and formed in response to regional D_2 . The axial traces of these folds are markedly oblique to the N45W-trending folds SW of the ZSZ outlined above (Fig.

2.5.15). The difference in the orientations of these folds is central to understanding deformation in this region and will be dealt with in later discussion.

Late Brittle-Ductile Structures

Numerous N-S to NNE-SSW oriented faults in the region are observable on aeromagnetic images. Several of these can be traced along strike for over 50 km, while many are more than 10 km long. Tripp (2000) defined three principal orientations, a N-S set, a NE-SW set and an E-W set which closely match those in the Ida Structural Corridor. Offsets range from a few metres to a maximum of hundreds of metres, and the sense of displacement is consistently dextral for the N-S and NE-SW sets, and sinistral for the E-W set (Tripp 2000). Furthermore, Tripp (2000) reported the sets of faults to have mutual overprinting relationships, to be brittle-ductile in style, and to crosscut the Zuleika Shear Zone.

Field Observations

Owing to sparse outcrop and degraded sample material, structural analysis of the Zuleika Shear Zone for this project has concentrated on open pit exposures. Ten pits considered to be within the Zuleika Shear Zone were visited over a strike length of ~200 km, from Chadwin in the north to Cave Rocks in the south. Drill core from the recently discovered Raleigh deposit was also observed and sampled for SEM work and microstructural analysis. In this section only the major findings will be described. Full description of the data assembled will be presented in van der Borgh's PhD thesis. For descriptive purposes, individual mines are grouped into geographical camps, namely Chadwin, Bullant, Kundana and Cave Rocks (Fig. 2.5.16).

Chadwin. The Chadwin pit is oriented N45W in its longest dimension, and is located a few hundred meters south of the margin of the Siberia Granite. The pit exposes the contact between interleaved quartzo-feldspathic sedimentary rocks and ultramafic rocks to the SW, and the Victorious Basalt to the NE. A pegmatite dyke lies close to the contact. The western sequence is isoclinally folded and the axial planar cleavage strikes ~N70W and dips 54S, and fold axes plunge ~30/160. The ultramafic layers are boudinaged and boudin necks plunge moderately WNW.

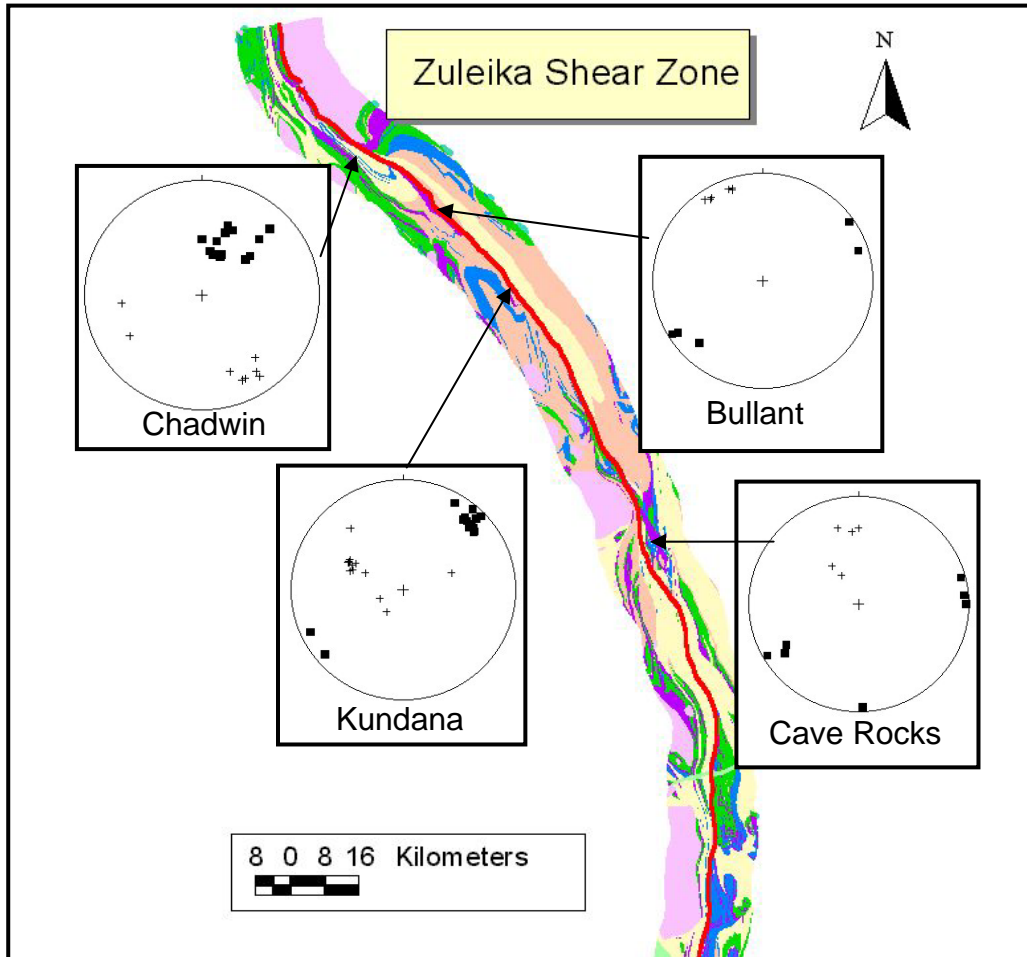
Rocks in this pit are strongly elongated and locally give rise to *l*-tectonites and sheath folds. *S-C* fabric and asymmetries around porphyroclasts indicate NW-directed thrusting, parallel to the lineation. A shear fabric striking N40-45W and dipping 70SW is developed along the axis of the pit, at the contact between the two sequences. The parallelism of the long axis of the pit

with this shear zone suggests that it hosted the mineralisation, although this could not be confirmed. The hornblende-plagioclase ($An_{>85}$) mineralogy of the Victorious Basalt implies low- to mid-amphibolite facies metamorphism.

Wattlebird and Bullant. The pit at Wattlebird exposes a 25 m wide, high-Mg pillow basalt juxtaposed against ultramafic rocks. A 10-15 m wide shear zone at the contact is interpreted by Tripp (2000) to represent the Zuleika Shear Zone. Small, attenuated porphyries are observed in the ultramafic schist, while a chlorite-biotite schist in the basalt hosts gold mineralisation. Pillows become increasingly flattened and attenuated towards the zone of shearing, and have long axes parallel to the shear foliation, which in this zone strikes $\sim N30-40W$, and dips $>80E$, with a gentle north plunging stretching lineation (Fig. 2.5.16). Highest gold grades occur in a $\sim 20m$ -wide, N-S trending vein array, where the ZSZ is intersected by a N-S trending brittle-ductile fault (Tripp 2000).

At Bullant, the pit is developed wholly within high-Mg pillowed basalt, which is a thickened version of that seen at Wattlebird. The basalt is cut by a series of 0.5-20m-wide ductile shears zones that Tripp (2000) interpreted to be the Zuleika Shear Zone. The average strike-orientation of these shear zones is $N28W$ with a dip of $88/SW$ ($n = 28$: Tripp 2000), with gentle to moderate north plunging lineations, all of which was confirmed by our own measurements. In all instances, *S-C* fabric and asymmetries showed sinistral sense of shear (Tripp 2000). High-grade mineralisation at Bullant is also associated with the intersection of the main shear zone and a cross-cutting, NNE orientated, brittle-ductile fault. The foliation in the cross-fault has *S-C* fabric and asymmetries around porphyroclasts indicative of dextral shear sense. The westernmost lode-structure has a dextral jog that is coincident with the intersection of this cross-fault, and also correlates with higher gold tenure. Ore minerals and fine grains of free gold are hosted in quartz-carbonate veins or disseminated in silicates in sheared rocks. Biotite and carbonate are the principal alteration minerals, while ore minerals include galena, sphalerite, pyrrhotite, pyrite and marcasite (Tripp 2000).

Kundana. The Kundana camp incorporates numerous deposits, with mineralisation now recognized along a 14 km strike length, and a total resource $>6Moz$ (S. Halley pers. comm.). Shearing and mineralisation occur along two sub-parallel trends. An eastern line follows the trace of the Centenary Shale, which, owing to the presence of the Ora Banda Domain's



Victorious and Bent Tree Basalt to the SW, lies in that Domain. The western line lies within the Coolgardie Domain and is limited to the SW by the Powder Sill.

Fig. 2.5. 16. Lower hemisphere equal area projections of structural measurements from the four mine camps visited during this study. Black squares are poles to foliations, crosses are lineations.

The stratigraphy and structures have been segmented and displaced by a series of ~N-S trending brittle-ductile shear zones, and brittle faults with quartz breccias, which show a consistent dextral offset, with up to 600 m displacement. The correlation between N-S faults and gold deposits is typified at Kundana, although the role of the structures in the mineralisation process is obscure. Economic mineralisation is invariably hosted in structures that follow the regional NNW-NW trend, while the N-S to NNE-SSW structures very rarely contain economic gold values. However, grades tend to increase in the vicinity of the N-S and NNE-SSW structures, suggesting a possible relationship between mineralisation and these cross-cutting structures.

Eastern Line (Centenary Shale). The North and South Pits at the Kundana main camp show similar mineralisation styles, and lithological and structural characteristics. Mineralisation

occurs in ribboned, crack-seal veins within the *Centenary Shale*. Ore minerals include pyrite, pyrrhotite, arsenopyrite, and base metals such as galena, sphalerite and scheelite (S. Halley, pers. comm.). An arsenopyrite halo is often observed around the veins.

South Pit exposes a 200m-wide zone of gradational shearing, which incorporates the Centenary Shale at its core, the Victorious Basalt to the SW, and an intermediate volcanoclastic rock to the NE. The shear fabric in the shale and Victorious Basalt is sub-parallel to the contacts, striking N45°W and dipping steeply SW, with well-defined stretching lineation that plunges moderately north (Fig. 2.5.16). In the basalt, the lineation is defined by plagioclase grains, which are significantly flattened and elongated. Plagioclase grains have been wholly replaced by sericite. Chloritoid ‘spots’ are elongate in a similar orientation. A sub-parallel lineation in the shale is defined by stretched clasts, and voids that may represent weathered pyrites.



Fig. 2.5.17. Core from a high-grade intersection on the Centenary Line, showing a 30cm quartz vein within the strongly foliated Centenary Shale. Note the folded veins in the Shale, with axial-planes parallel to the foliation (width of view ~60cm).

Veins within the shear zone are folded and boudinaged (Fig. 2.5.17). The lineation is constant in orientation from the less deformed margin to the core of the shear zone. An *S-C* fabric and asymmetries indicate oblique sinistral shear sense at South Pit but not at North Pit. On the western wall of North Pit, a second structure, the K2B, is exposed along the contact of the Victorious Basalt and underlying Bent Tree Basalt. Here, we measured a steep west-dipping

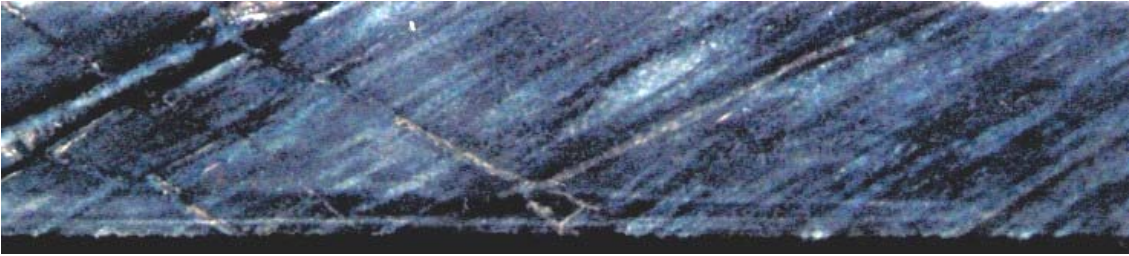


Fig. 2.5.18 Half-core from the Centenary line showing brecciation of the main shear fabric in the Victorious Basalt by mineralized veinlets, indicating that at least part of the mineralisation at Kundana was post the main phase of shearing (length of core is 20 cm).

foliation striking N50W, and a lineation in the Victorious Basalt plunging 70/S along the foliation plane. Asymmetries around the grains showed a consistent west-side-up (reverse) sense of shear. North and South Pits are displaced by a N-S striking fault with dextral offset.

Although the gold mineralisation occurs within the shear zone, there are several lines of evidence to suggest that mineralisation occurred later than the main phase of deformation. Figure 2.5.18 depicts a drill core through sheared Victorious Basalt at South Pit. The shear fabric is brecciated by quartz veinlets that are orientated both parallel, and at high angles, to the shear fabric. The veins host ore sulphides and have biotite selvages and are not sheared.

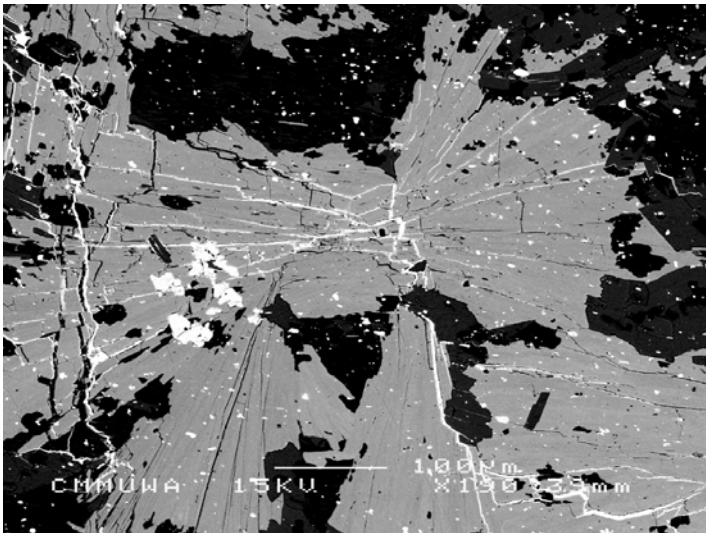


Fig. 2.5.19. SEM image of a chloritoid grain (grey) being brecciated and replaced by sulphides (white). Cross-cutting relationships such as these indicate that at least part of the mineralisation at Kundana post-dated the main phase of shearing.

The veinlets show mutual cross-cutting relationships indicating simultaneous formation, and clearly post-date the main shear fabric. Furthermore, the SEM image in Fig. 2.5.19, depicts a chloritoid grain which is aligned parallel to the shear fabric, brecciated and replaced by sulphides.

Western Line (Barkers-Strezlecki-Raleigh). The Barkers, Strezlecki and Raleigh pits are located approximately 250 m SW of the Eastern Line and define the Western Line. The Strezlecki Main vein is a laminated quartz vein (Fig. 2.5.20b), typically 0.5 m wide, and averages ~55g/t Au locally reaching above 100 g/t. The laminae represent slices of host-rock that became incorporated into the vein during multiple fracturing episodes. Petrographic analysis of the vein indicates laminae commonly take the form of stylolites (Fig 2.5.21)

The ore at Raleigh and Strezlecki consists of a pair of parallel veins that are developed along the upper and lower surfaces of a 2-14 m wide, moderate SW-dipping felsic sedimentary unit. This unit has been offset along the Lucifer Fault, which strikes N10W, dips sub-vertically, and has a total dextral displacement of ~600 m (J. Beeson, pers. comm.). The Raleigh and Strezlecki veins pinch out to the north and south respectively, as they approach the Lucifer Fault.

At Strezlecki, the Main vein sits between the upper contact of the felsic sedimentary unit and the Powder Sill. The vein strikes ~N50W and dips ~60SW (Fig. 2.5.20a). An intensely foliated biotite-rich layer is developed along the margins of the vein, and dips steeper than the vein (e.g. N50W/74SW). Laminae within the main vein are oblique to the strike of the vein (e.g. N35W), and have been interpreted to signify sinistral shear sense during vein formation (John Beeson, pers comm.). A stretching lineation on one lamina was measured to plunge 28/320. An increase in the number of laminations within the vein correlates with increased Au values (John Beeson, pers comm.).

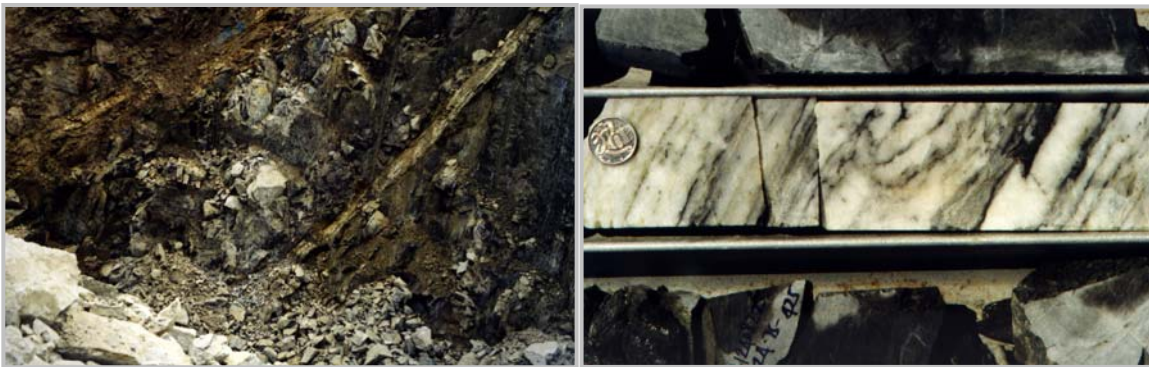


Fig. 2.5.20. a) Looking NW at the moderately SW-dipping Strezlecki Main Vein (top-right to bottom-middle). The Powder Sill forms the hangingwall, while a felsic sedimentary rock forms the footwall. In this exposure the vein is ~30 cm wide, and the vertical height is 5m. b) Half-core showing a portion of the laminated vein at Raleigh, coin for scale.

A second, parallel vein, (the footwall vein) is developed along the lower surface of the felsic unit, where it is in contact with an intermediate volcanoclastic rock. The stratigraphic

position of the footwall vein at Strezlecki is equivalent to the position of the main vein at Raleigh. Down dip lineations were observed in several discrete shears along the NE wall of the pit, and in proximity to the footwall vein.

Biotite and chlorite are the principal alteration minerals, with carbonate and epidote forming a minor component. Ore minerals observed include pyrite, galena, chalcopyrite and scheelite. SEM analyses indicate that gold and galena show a close spatial relationship, often forming along, or in close proximity to, stylolitic laminae (Fig 2.5.21), and occasionally along cracks in pyrite.

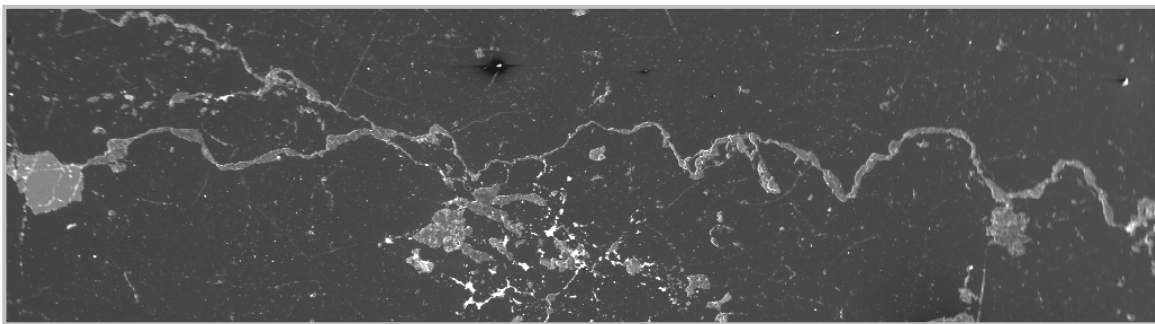


Fig. 2.5.21. SEM image of a sample from a laminated vein at Strezlecki, highlighting the stylolitic form of a lamina. The bright material (bottom-centre) is gold and galena, which generally occur together as aggregates close to, or along, the laminae (width of view is 3.5 mm).

The laminated vein at Barkers has an average trend of N50-60W and dips from 75-85SW. An additional structural component at Barkers is the N-S trending 21-Mile Fault, which intersects the southern end of the pit. The fault is developed along a gabbro-sedimentary rock contact, and has a strong ductile fabric that strikes N8E and dips 70-80E. A very shallow stretching lineation and well-developed *S-C* fabric indicate movement along the fault to have been dextral strike slip. The fault was associated with mineralisation several hundred metres south of the main mineralized trend, and represents a rare occurrence of mineralisation on this trend alone.

Cave Rocks. The Cave Rocks pit is ~65 km south of Kundana and exposes a turbidite (greywacke) package to the east, and ultramafic rocks to the west, separated by a dolerite that hosted the mineralisation. The sedimentary rocks are tightly folded, with vertical axial planes and axial planar cleavage striking N-S. Stretched clasts throughout the sedimentary sequence define a lineation plunging ~30N. The dolerite deformed in a ductile manner, and has a foliation striking N30W and dipping 65E with a stretching lineation plunging down dip. More than one deformation is recorded by the dolerite as reflected by several foliation planes, and no clear

tectonic history could be derived as yet. Detailed sampling and microstructural study will be required. Discrete sub-vertical shear zones (~10cm wide) are developed in the ultramafic rock, and trend ~N15W. A stretching lineation plunges 28N along the shear planes, although no asymmetries could be recognized to confirm a shear sense.

Discussion

The Zuleika Shear Zone juxtaposes the Ora Banda Domain against the Coolgardie Domain. The shear zone is developed along a disrupted and attenuated anticlinal corridor that separates two broad, coherent synclines, and was the locus for significant strain partitioning. No marker exists on both sides of the shear zone that would constrain the amount of displacement along it.

The structure is defined by a zone of intense deformation, approximately 1km wide, within which lithological contacts were the dominant loci for shearing. This is typified at Kundana, where at least five steeply west-dipping shear zones are recognized along different lithological contacts. The most central one of these marks the stratigraphic break between the two Domains, juxtaposing the lower surface of the NE-facing Bent Tree basalt, against intermediate volcanoclastic rocks belonging to the Coolgardie Domain.

Steeply plunging lineations and *S-C* fabric asymmetry at Kundana, suggest reverse and oblique-reverse movement. Dominant sinistral strike slip movement was not recorded by us, although it has been interpreted from fold asymmetries within the mine (J. Beeson, pers comm.). However, we documented sinistral strike slip at Bullant/Ant Hill to the NW.

With the exception of Bullant, gold mineralisation along the Zuleika Shear Zone is located at lithological contacts, and reflects the gross pattern of strain partitioning observed along the structure. In the northerly deposits at Bullant, ultramafic rocks and porphyries are present, although it is the mafic lithologies that host the ore. A notable feature of the Kundana camp is the absence of these two rock-types in all known deposits, which is atypical in the Kalgoorlie Terrane. Instead, competency contrast is provided by the presence of low viscosity shales and doleritic rocks.

Biotite is a major alteration mineral in all camps, highlighting the ubiquitous relationship between potassic alteration and gold mineralisation. Carbonate alteration is significant in the regions where ultramafic rocks are present. A relationship between anomalous arsenic values and shale-hosted deposits is highlighted at Kundana, where deposits hosted in the Centenary Shale are associated with an arsenic anomaly, while those along the Western Line lack this anomaly. This is despite the close proximity of the two Lines, their similar temporal relationships, and the presence of similar ore-related sulphides on both Lines. The *As*-shale relationship strengthens the observations along the Ida Shear Zone as outlined earlier in this report.

Gold mineralization at Kundana took place after shearing and foliation development, as exemplified by cross-cutting veinlets and brecciation. Economic mineralisation within one of the

cross-faults (i.e. the 21 Mile Fault at Barkers), implies that some of the cross-faults were active during, or prior to, mineralisation. In contrast, Tripp (2000) suggested that mineralisation commenced during the formation of the shear zone at Bullant, but continued during the formation of cross-faults that cut or displace the main shear fabric.

Stratigraphy and metamorphism. The presence of the Walter Williams Formation (WWF) in both the Ora Banda Domain and along the eastern part of the Ularring Greenstone Belt (Hill et al 1995) implies that the Zuleika and Ida Shear Zones both delineate the western margin of sequences containing the *same* sequence of ultramafic volcanic rocks. In the Mt Ida area, we observe the WWF and rocks beneath it as they are exposed in the Kurrajong Anticline, whereas at Ora Banda the WWF and rocks above it are exposed (i.e. in the Mt Pleasant syncline).

Folds. Folds adjacent to, and SW of, the shear zone, in the Zuleika-Kunanalling Corridor have NW axial traces that are at a small angle to the shear zone (Fig. 2.5.15). These trends are oblique to NNW-trending regional scale axial traces of the Ora Banda Domain and the margins of the main batholiths to the NE (Fig. 2.5.15). This obliquity is here interpreted as resulting from the rotation of regional D2 folds within the Kunanalling-Zuleika Corridor during shearing and deformation. Both orientations of folds are cut by through going brittle-ductile fault sets, which places an upper constraint of the relative timing of the rotational phase of deformation. Rotations are also observed on the southern end of the Mt Pleasant Dome, whereby the trace of the axis of the dome rotates in a counter-clockwise direction as it nears the Zuleika structural Corridor. There are several features in the geology of the Ida, Zuleika and Kunanalling areas that suggests that a process of indentation of competent granitoid blocks into weaker greenstone corridors has played an important role in the structural evolution of the area. These will be detailed below, but most striking is the broad curvature of the Zuleika corridor, the accompanying folding of the southern tips of the large batholiths as they approach the Zuleika Shear Zone; and local deviation of the Ida Corridor trend around the Central Granite.

The Zuleika-Kunanalling Corridor. The Zuleika Shear Zone (ZSZ) at Kundana is predominantly a reverse shear zone, with steeply plunging lineations on steep, W-dipping foliation planes. In many localities, movement was oblique, with a small dextral or sinistral strike-slip component, that varies according to deviations of strike from N45W which corresponds to precise down dip lineations as observed in the Streszlecki pit and is interpreted to be perpendicular to the direction of maximum shortening. By contrast, further north at Bullant

and Ant Hill, movement was predominantly sinistral along gently plunging lineation. In order to understand deformation in this zone, it is necessary to zoom out and investigate the deformation in the Zuleika Deformation Corridor, a zone approximately 20 km wide bounded in the east by the ZSZ and in the west by the Kunanalling Shear Zone.

This corridor contrasts with the less deformed Ora Banda Domain to the NW, and the Coolgardie Block to the SE which has an internal fabric discordant to the regional NW to NNW fabric. The corridor is well defined in aeromagnetic images (Fig. 2.5.22) and includes folds with axial traces trending ~ NW. While folds in the centre of the corridor are broad, they tighten towards both bounding shear zones. Lineaments in the NW end of Fig. 2.5.22 suggests a possible broad sinistral component as determined at Bullant and Ant Hill.

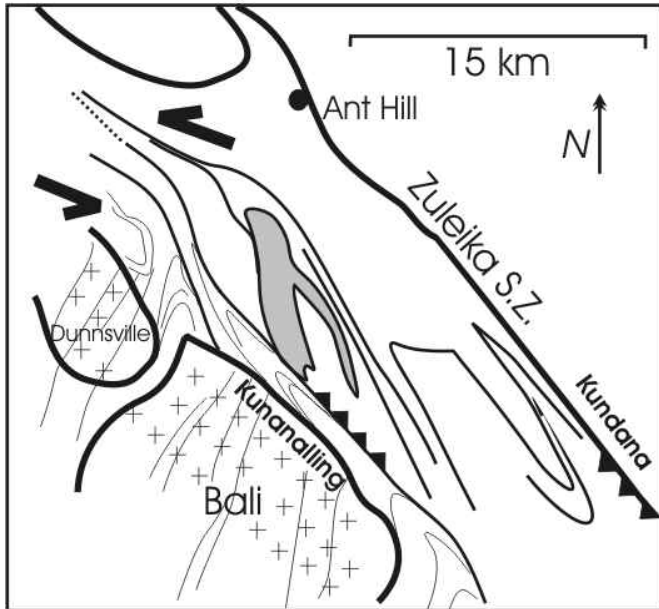


Fig. 2.5.22. The Zuleika-Kunanalling Corridor, limited to the west by the Dunnsville and Bali Granites and to the east by the Ora Banda Domain. Opposite vergence on reverse shear zones at Kundana and Kunanalling accompanied by tight folds suggest the block was exhumed in relation to surrounding areas. The angle between fold traces and the trend of the corridor suggests a possible sinistral component of deformation as was documented at the Ant Hill area.

During this project, open-pits (Kunanalling, London, Blue Bell) along the narrow band of intense folding in the vicinity of the Kunanalling Shear Zone and Bali Granite (Fig. 2.5.22) were studied. This area has been studied by Hunter (1993), who by linking ultramafic rock exposures on either side of the Kunanalling Shear Zone suggested a 12km sinistral movement. This shear sense was not confirmed here. Exposures in the open pits are characterized by NW-striking foliation dipping steeply NE, accompanied with approximately down dip mineral and stretching lineation (Fig. 2.5.23). Sense of shear indicators (S-C fabric) suggests SW-thrusting, and in the Kunanalling open pit, ultramafic rocks were thrust over pillow basalts and tight, west-verging folds were also documented (Fig. 2.5.23).

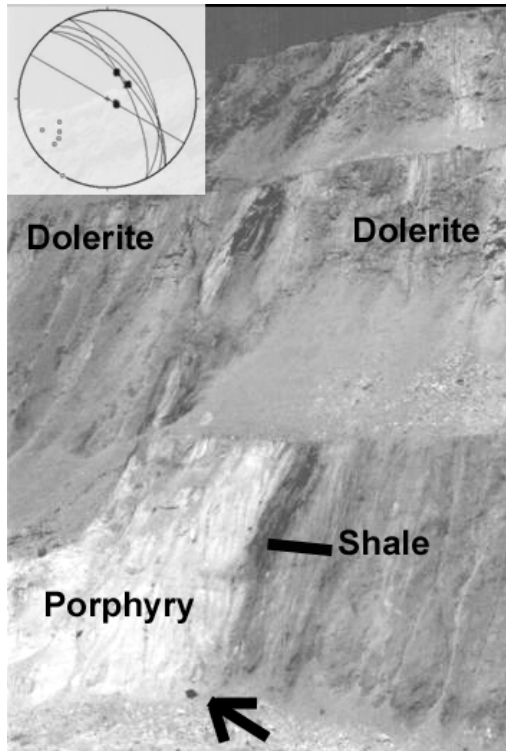


Fig. 2.5.23. A porphyry and a narrow shale layer (darker band) define a tight fold enclosed by dolerite on the SW face of the Kunanalling open pit. Insert: lower hemisphere equal area stereo projection of foliation (N30W/60NE; great circles), their poles (plus signs) and the approximately down dip mineral and stretching lineation (black squares on the great circles). Arrow points to a bag as scale.

These observations suggest that deformation in the Kunanalling Shear Zone was characterized by west-directed thrusting and tight originally recumbent folding, and that these structures probably became steeper as shortening progressed. The sinistral movement previously inferred (Hunter 1993) is based on the incorrect procedure of linking two random parts of complexly folded ultramafic layer.

The symmetric pattern of strain distribution within the corridor between Kundana and Kunanalling, with fold tightening towards the two bounding structures and opposite thrust and fold vergence (Fig. 2.5.24) suggest that folding and thrusting developed broadly contemporaneously and led to the exhumation of the corridor as a *pop-up structure*. Because this deformation event led to a period of crustal thickening, it is most likely related to the regional D_2 event.

As noted above, in contrast to the dominantly reverse movement at Kundana, sinistral shearing along the ZSZ is well-developed at Ant Hill and Bullant, (Tripp 2000; and our own observations) 20 km northwest of Kundana. It could be that either the broad ZSZ lineament has been reactivated as a sinistral shear zone after reverse movement, like the BLSZ, or alternatively, the sense of shear changes along strike. This will be further discussed below in the section related to the indentation of the Coolgardie Block.

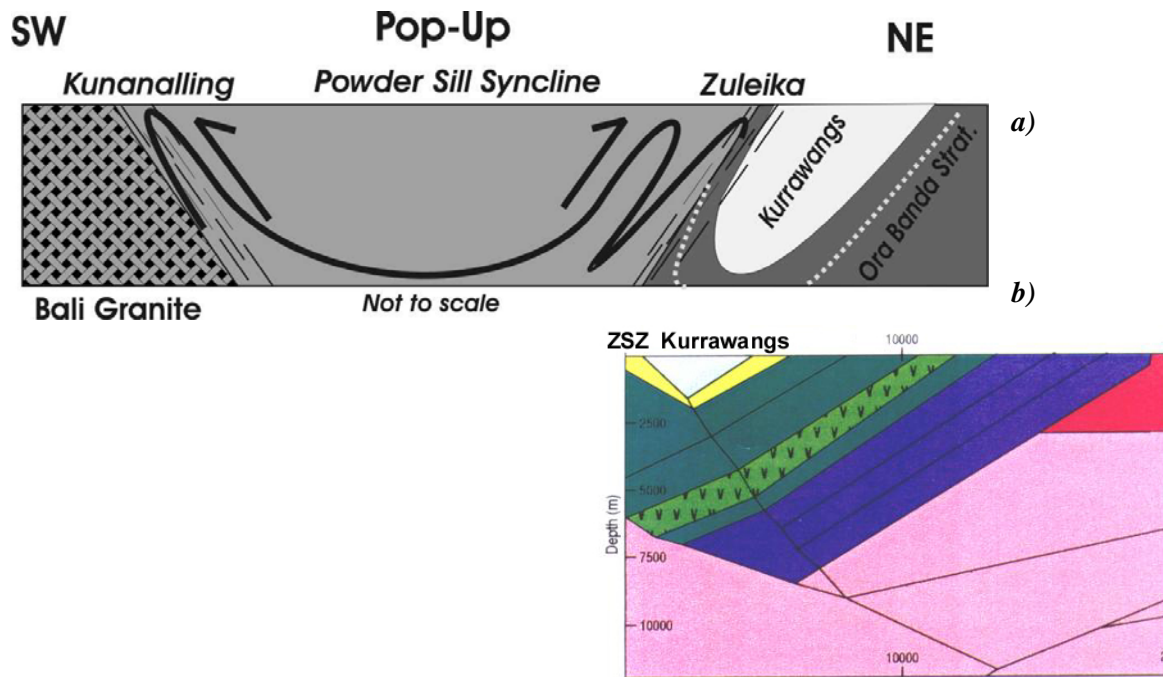


Fig. 2.5.24. a) Schematic profile from Kundana, on the Zuleika Shear Zone, to the Kunanalling pit, on the Kunanalling Shear Zone, 20 km to the west. The profile depicts the tightening of folds towards the shear zones, and their opposite vergence, defining a pop-up structure. Note that the Kurrawangs Sedimentary Sequence has been folded by the same event even though these sedimentary rocks lie in the much less deformed Ora Banda Domain. This profile is only slightly different from that of Hunter (1993), but here shear senses are added to the main shear zones. The profile compares poorly with the seismic interpretation in b) where the stratigraphy is virtually undisturbed by the Zuleika Shear Zone (Goleby et al. 2000).

Escape Tectonics and Deformation of the Kalgoorlie Terrane.

Several lines of evidence suggest that large granitoid-dominated masses may have controlled regional deformation, via a process of indentation. Firstly, we described the indentation pattern around the Central Granite Complex on the Ida Shear Zone (Section 2.5.1). Secondly, the Zuleika-Kunanalling Corridor defines a broad flexure and a pop-up structure around the granite dominated Coolgardie Domain. This is associated with a bend of the southern tip of the Siberia Batholith Granitoid, which suggests that the Coolgardie Domain moved eastwards. Thirdly, intensive flattening along the ISZ suggests that the large granite mass to the east may have flattened it against the large granite-dominated Southern Cross Terrane to the west.

A numerical model was designed to test whether some of these features could be explained by indentation of the large granite block north of Kalgoorlie (the Eastern Batholith, Fig. 2.5.2). The code ELLIPSIS developed by Louis Moresi (CSIRO) and run by Chris Wijns (UWA)

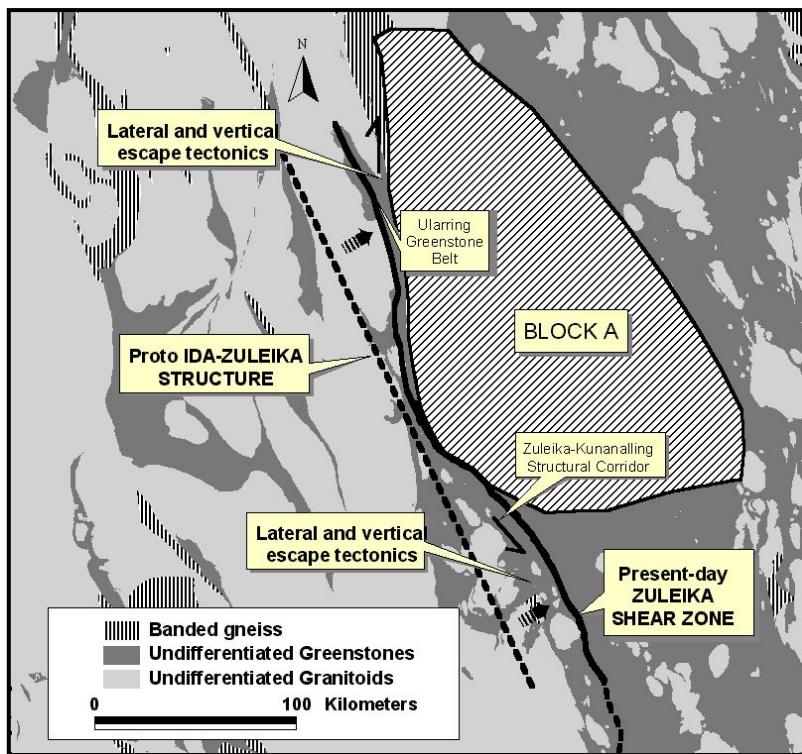
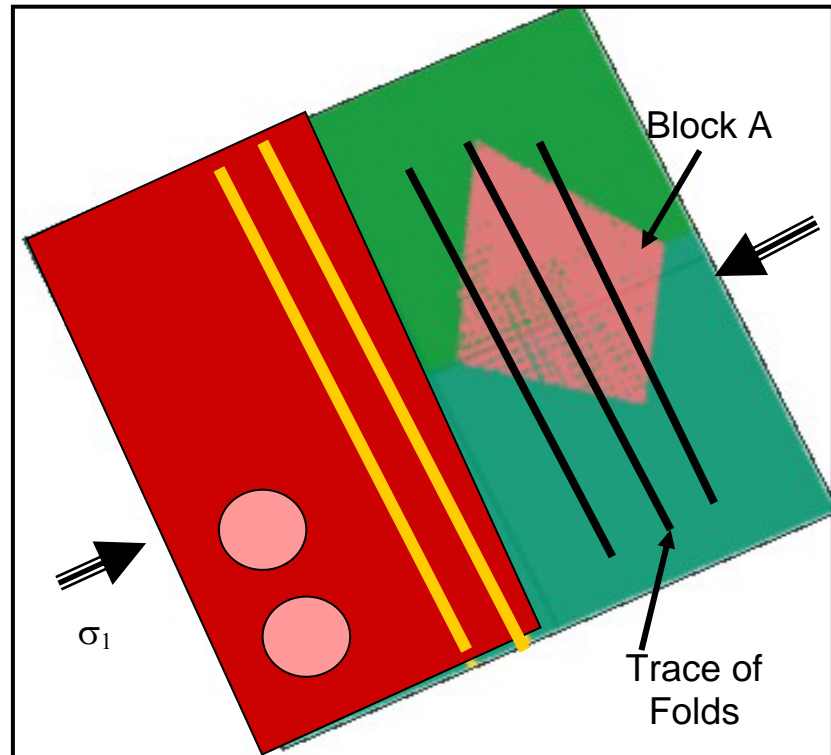


Fig. 2.5.25. Simplified geological map highlighting the principal features on which the ELLIPSIS model is based. Block A broadly defines the Eastern Batholith, which impinged upon the Southern Cross Terrane and surrounding greenstones, resulting in the lateral escape of the greenstone sequences.

was used for this purpose. The model consists of a competent, lozenge-shaped block (Block A, Fig 2.5.25 and 26), simulating the large, batholithic complex (the Eastern Batholith, Fig 2.5.2) to the north of Ora Banda and west of the Ularring Greenstone Belt. Block A is surrounded by a less competent matrix, representing the greenstone sequences of the Ida and Zuleika-Kunanalling Corridors. Greenstone sequences are bound to the west by a competent band simulating the

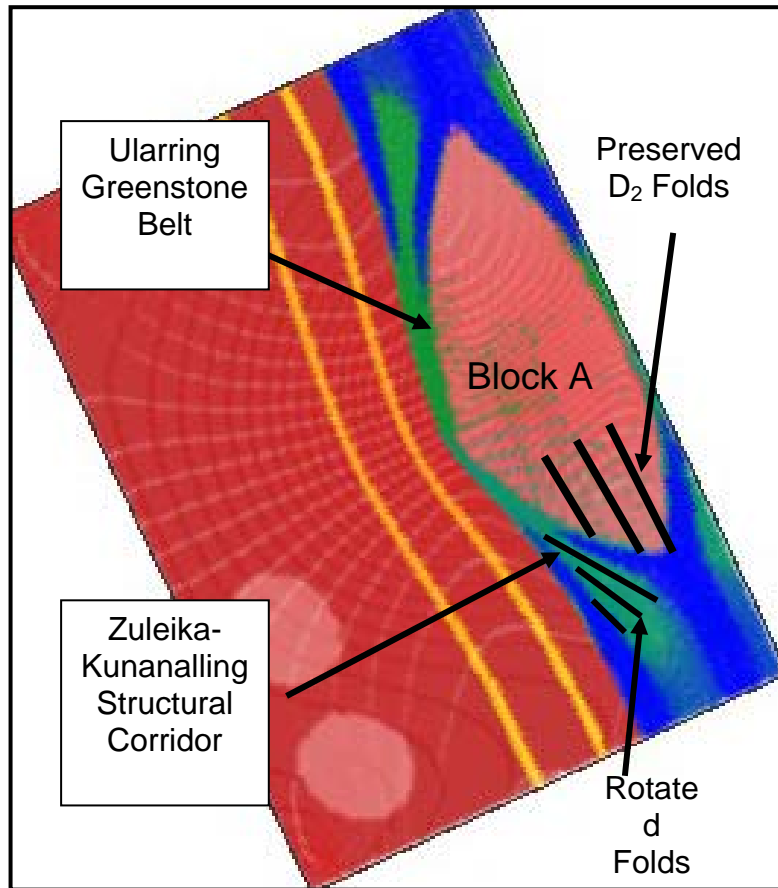
granite-dominated Southern Cross Terrane. Shortening was oriented ENE-WSW (Fig. 2.5.26), as concluded previously in this report.

Fig. 2.5.26. Starting configuration for the ELLIPSIS model to test the hypothesis for escape tectonics in the Kalgoorlie Terrane (see text for details). The model is rotated to match regional orientation.



As the indenting Block A approached the competent Southern Cross Terrane (Fig. 2.5.27) the intervening greenstone sequence was forced to escape laterally, causing the incompetent layer (greenstones) to wrap around Block A, rotating and tightening earlier folds and thrusts. Material immediately in front of the indenter, the region corresponding to the Ida Corridor, accommodated much of the deformation by means of intense flattening. Simultaneously, the Zuleika-Kunanalling Corridor, because of its position on the SW margins of the indenter Block A, was forced to escape towards the southeast by means of rotation and sinistral strike slip. Furthermore, the competent Southern Cross Terrane underwent a broad concave deflection, which caused the Coolgardie Block to move eastwards and led to a general shortening and pop-up of the Zuleika-Kunanalling Corridor. The model also suggests that the region to the NW of the indenter is characterized by a northeastward escape along dextral shear zones, and that is what has been described along the Waroonga Shear Zone (Platt et al. 1978).

Fig. 2.5.27. Result of the numerical model. Areas in green indicate high strain, and correlate well with the Ularring and Zuleika-Kunanalling Corridors (see text for details).



Thus, our simple model suggests that ENE-WSW directed crustal shortening driving the indentation of the competent granite batholith in the middle of the terrane, not unlike the indentation of India into southern Asia, is capable of explaining flattening along the Ida Corridor; the southeast escape and rotation of the Zuleika-Kunanalling Corridor defined by sinistral motion on the northern part of the ZSZ; the eastward motion of the Coolgardie Block and consequent pop-up of the central part of the Zuleika-Kunanalling Corridor; as well as dextral movement on the Waroonga Shear Zone. We suggest also that the Ida and Zuleika might once have been one and the same roughly linear shear zone that was bent into the present shape by the indentation of rigid blocks.