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Structural geometry of a thick-skinned fold-thrust belt termination: the Olary Block in the Adelaide Fold Belt, South Australia

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The Olary Block comprises a set of Palaeoproterozoic to Mesoproterozoic basement inliers that were deformed together with the Neoproterozoic sedimentary cover of the Adelaide Geosyncline during the *ca* 500 Ma Cambro-Ordovician Delamerian Orogeny. Balanced and restored structural sections across this region show shortening of less than 20%. These basement inliers represent the interface between a region of thick-skinned deformation bordering the Curnamona Craton to the north and a region of thin-skinned deformation to the south and west in the Nackara Arc. The basement inliers represent upthrust segments of the subsided basin margin with the sedimentary package thickening to the south and to the west. Earlier formed extensional faults provided the major strain guides during Delamerian shortening. An early phase of east–west shortening is interpreted to be synchronous with dextral strike-slip deformation along basement-relay structures (e.g. Darling River lineament). During progressive shortening the tectonic transport direction rotated into a northwest to north direction, coeval with the onset of the main phase of thin-skinned fold deformation in the adjacent Nackara Arc.

KEY WORDS: Adelaide Fold Belt, Delamerian Orogeny, Nackara Arc, Olary Block, structural geology, Willyama Inliers.

INTRODUCTION

Much effort has been expended on understanding the geometry and kinematics of foreland fold-thrust belts, following the classic work of Chapple (1978), Hsu (1979), Rodgers (1995), Price (1981) and Boyer and Elliot (1982). It is now well understood that such belts commonly show more or less complete detachment of a variably deformed cover sequence from a relatively undeformed basement sequence. Nevertheless there are numerous examples of foreland fold-thrust belts where basement is involved in the deformation (Rodgers 1987, 1995). As pointed out by Rodgers (1995) the factors that control basement involvement in such deformation remain poorly understood and the elucidation of these factors remains an important challenge for structural geologists. Of particular interest to this problem are regions where deformation switches from basement-involvement (thick-skinned) to basement-detached (thin-skinned). In this paper we discuss the structural geometry of such a transition.

The Adelaide Fold Belt in South Australia is a foreland fold-thrust belt that forms the western part of the *ca* 500 Ma Delamerian Orogen, comprising deformed Neoproterozoic and Cambrian sedimentary rocks of the Adelaide Geosyncline (Sprigg 1952; Preiss 1987; Coney *et al.* 1990; Flöttmann *et al.* 1994; Marshak & Flöttmann 1996) fringing the margins of the Gawler and the Curnamona Cratons (Figure 1). Regional variations in deformation style and intensity across the orogen are most notably manifested in the involvement of older crystalline basement (Preiss 1986; Sandiford *et al.* 1998; Paul 1998; Paul *et al.* 1999). Basement is exposed as variably deformed and metamorphosed, partly fault-bound inliers in the Mt Lofty Ranges, the Olary Block and the Mt Painter Block in the northern Flinders Ranges (Preiss 1986, 1995). Recent studies concerned with the geology of exposed basement inliers have focused on the Mt Lofty Ranges and the northern Flinders Ranges (Sandiford *et al.* 1992; Flöttmann *et al.* 1994; Paul *et al.* 1999). In the Olary Block the principal processes responsible for basement reactivation are largely unconstrained. Despite the fact that the Olary Block represents a well-exposed example of thick-skinned deformation within a foreland fold-thrust belt the structural geometry of the region has received relatively little attention prior to this study. Thus, the principal aim of this paper is the documentation of the geometry of Delamerian structures in and around the Olary Block. Particular focus is on the geometry of deformation and the quantification of shortening associated with the reactivation of the inliers. We begin by reviewing the stratigraphic and structural setting of the Olary Block and the adjacent Nackara Arc using newly collected structural data. Then, we attempt to quantify shortening and exhumation using balanced and restored regional cross-sections. This provides a geological and geometrical framework necessary to understand key aspects of the structural evolution of the region.

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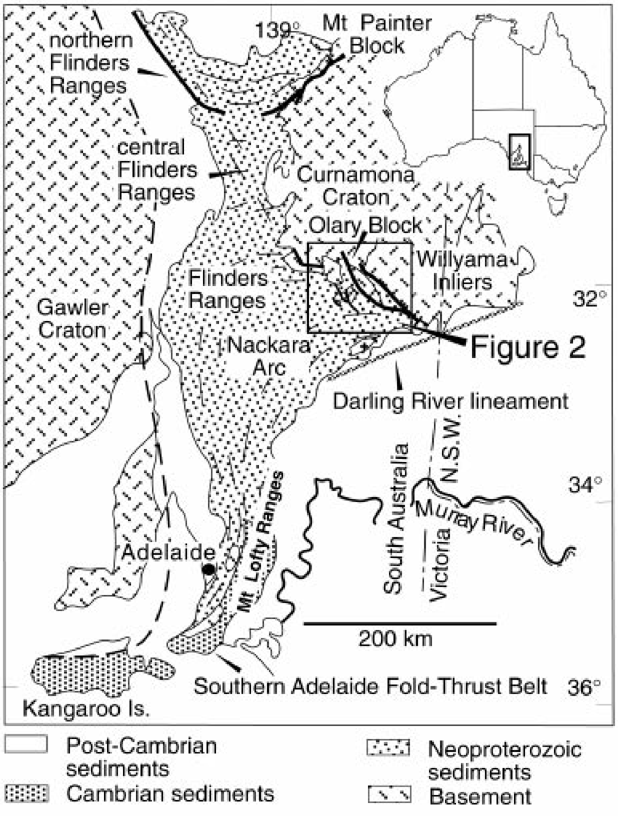


Figure 1 Regional map of the Adelaide Fold Belt exposed in the Mt Lofty and Flinders Ranges, including the main stratigraphic units. Location of Figure 2 is indicated.

REGIONAL GEOLOGICAL FRAMEWORK

In the Adelaide Fold Belt (Figure 1), Palaeoproterozoic to Mesoproterozoic cratonic basement is overlain by a thick Neoproterozoic sedimentary package of the Adelaide Geosyncline that consists of basal carbonates, evaporites and clastics, glaciomarine deposits and postglacial sequences, followed by Early Cambrian deposits (Preiss 1987). Deposition of Neoproterozoic sediments is a consequence of widespread extensional deformation that followed the cessation of global Grenvillian/Musgravian Orogenesis and led to the breakup of the Rodinia supercontinent. In South Australia Neoproterozoic extension is manifested by the emplacement of mafic dykes, such as the northwest–southeast-trending Gairdner Dyke Swarm on the eastern Gawler Craton and the little Broken Hill gabbro located in the Broken Hill Block. Baddeleyite from these dykes has yielded an age of *ca* 827 Ma, which is interpreted to mark the timing of initial northeast–southwest-directed Neoproterozoic rifting of the Adelaide Geosyncline (Wingate 1998; Gibson 1998). Syndepositional faulting led to the accumulation of great thicknesses of sediment in various sub-basins, with depocentres tending to shift laterally through time (Preiss 1987, 1995; Paul *et al.* 1999), alternating with more widespread sedimentation during thermal sag phases (Jenkins 1990). Deposition was terminated by the *ca* 500 Ma Delamerian Orogeny to form the Adelaide Fold Belt (Figure 1), now exposed in the Mt Lofty and Flinders Ranges and Kangaroo Island in South Australia (Figure 1).

Strain intensity varies significantly across the orogen being highest in the Mt Lofty Ranges (southern Adelaide Fold-Thrust Belt: Figure 1) where large-scale folds (Mancktelow 1990; Jenkins 1990; Flöttmann *et al.* 1994) and mylonitic reverse faults accommodate shortening that locally exceeds 50% (Flöttmann *et al.* 1994; Marshak & Flöttmann 1996; Flöttmann & James 1997) (Figure 1). There, exposed basement inliers form part of a high-strain imbricate thrust fan linked to the reactivation of extensional structures and the intrusion of syntectonic granites along the western foreland margins of the Neoproterozoic Adelaide Geosyncline and the Cambrian Kanmantoo Basin that fringe the Gawler Craton to the east (Sandiford *et al.* 1992; Flöttmann *et al.* 1994; Marshak & Flöttmann 1996) (Figure 1). In the Nackara Arc (Figure 1), Delamerian shortening led to the formation of an arcuate belt (Marshak & Flöttmann 1996) where shortening is in the order of ~6% (Sandiford *et al.* 1998; Paul 1998). The northern Flinders Ranges (Figure 1) are characterised by intermediate deformation intensity with shortening averaging ~11% (Sandiford *et al.* 1998; Paul *et al.* 1999). The involvement of basement along the northwestern margin of the Curnamona Craton (Mt Painter Block: Figure 1) is a consequence of the inversion of Neoproterozoic extensional faults, associated with an anomalously high geothermal gradient due to exceptional enrichments in heat-producing elements in the basement (Sandiford *et al.* 1998; Paul 1998; Paul *et al.* 1999).

The basement inliers of the Olary Block in South Australia (eastern, central, western Weekeroo inliers, Plumbago area, Kalabity area and Outalpa Inlier) together with the Broken Hill region in New South Wales are collectively referred to as the Willyama Inliers, and form the interface between the Curnamona Craton and the adjacent Nackara Arc (Figures 1, 2). The Willyama Inliers comprise the Palaeoproterozoic Willyama Supergroup and Mesoproterozoic I- and S-type granites deformed during the *ca* 1600 Ma Olarian Orogeny (Clarke *et al.* 1986, 1987; Flint & Parker 1993).

The internal structure of inliers in the Olary Block is dominated by a strong east- to northeast-trending structural pattern developed during the Mesoproterozoic Olarian Orogeny (D_1–D_3) (Clarke *et al.* 1986, 1987). The regional Delamerian structure is dominated by two distinct phases of deformation, which are recorded in Neoproterozoic sequences (Berry *et al.* 1978; Clarke *et al.* 1986). The early, 'D_4' phase includes the formation of north–south-trending upright 'F_4' folds (Berry *et al.* 1978) and an associated axial planar schistosity that pre-dates the formation of east–west- and southwest–northeast-trending 'F_5' folds (Berry *et al.* 1978). As documented by Clarke *et al.* (1986), Delamerian folding not only affected the Neoproterozoic sedimentary rocks but also warps the basement on a regional-scale. Basement–cover boundary faults occur dominantly along the western side of the inliers, whereas eastern basement margins generally preserve intact unconformities. Metamorphic conditions during Delamerian deformation reached greenschist facies (biotite grade), with biotite occurring in the axial planar foliations of F_4 folds (Paul 1998). The subsequent development of chlorite and muscovite in syn- to post-F_5 age shear zones along the western basement margins indicates retrogression by this time.

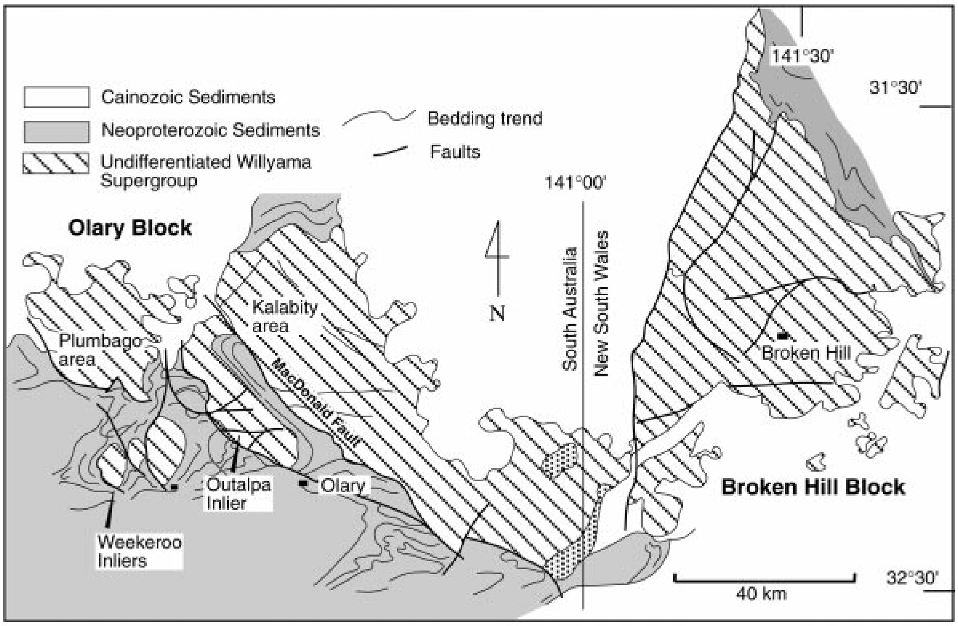


Figure 2 Regional map of the Willyama Inliers (after Flint & Parker 1993).

STRATIGRAPHIC RELATIONSHIPS

Basement inliers of the Olary Block are fringed by Neoproterozoic sedimentary rocks of the Burra, Umberatana (Pualco Tillite, Benda Siltstone, Wilyerpa Formation, Tapley Hill Formation, Farina Subgroup and Yerelina Subgroup) and Wilpena Groups (Forbes 1991). In the vicinity of the inliers the lowermost Callanna Group is generally absent but is locally developed as a 400 m-thick sequence of quartzites and schists, collectively known as the Cutana beds outcropping southeast of the Olary Block (Forbes 1991). A basal conglomerate of the Burra Group generally defines the unconformity along the eastern margins of the Weekeroo and Outalpa Inliers (Forbes 1991). The western fault-bounded margins of the Weekeroo Inliers are juxtaposed with glacials and siltstones of the Wilyerpa Formation (e.g. along western margin of the western Weekeroo Inlier). Towards the south and west, in the Nackara Arc, outcropping Neoproterozoic rocks comprise Burra Group to Wilpena Group (Preiss 1986; Forbes 1991). There, the thickness of the Burra Group varies between 3 and 5 km (Preiss 1986, 1987), while the estimated thickness of the younger sequences varies from 13 km just south of the Olary Block to ~6 km to the west and ~10 km to the southwest (Preiss 1986, 1987; Paul 1998). The thickness of the Callanna Group in the Nackara Arc is unconstrained but may be as much as 3–6 km (Marshak & Flöttmann 1996). If so, the Nackara Arc contains the thickest succession of Neoproterozoic sedimentary rocks in the Adelaide Geosyncline, averaging ~14 km. Cambrian strata of the Hawker and Lake Frome Groups are exposed only to the northwest of the arc (Dalgarno & Johnson 1966; Preiss 1986).

In order to provide the appropriate framework for section balancing we have re-evaluated the thickness of all stratigraphic units along two perpendicular lithostratigraphic sections (Figure 3). The north–south section (Figure 3b) shows the Burra Group is between ~0.8 and 5 km thick increasing to the southeast. The Lower Umberatana Group (including Sturtian glacials and the Wilyerpa Formation) is 1.3 km thick in the north, increasing to ~4 km immediately south of the Weekeroo Inliers then decreasing to ~1.3 km in the vicinity of the Anabama Granite. The Tapley Hill Formation increases from ~1 km in the north to ~2.6 km south of the Weekeroo Inliers. While poor exposure of the younger sequences precludes rigorous assessment of their thickness, we estimated they increase from ~2–3 km in the north to ~6 km in the south of the Weekeroo Inliers. The thickness of the lowermost Callanna Group south of the Olary Block is unconstrained. Following Marshak and Flöttmann (1996) we consider that it thickens southwards from as much as ~4 km south of the central Weekeroo Inlier, to ~5.5 km further south. The total thickness of the Neoproterozoic succession is therefore between 5 and 10 km increasing to at least 15 km, and possibly as much as ~20 km, south of the Weekeroo Inliers, depending on the thickness of the Callanna Group. The east–west section (Figure 3c) shows the thickness of Burra Group sedimentary rocks is between ~0.8 km in the east, increasing locally to 2.6 km. Local variations in thickness coincide spatially with the western margins of the Outalpa, eastern Weekeroo, central Weekeroo and western Weekeroo Inliers. West of the western Weekeroo Inlier, the thickness decreases to ~1.2 km but then increases to ~2.6 km further west. The Sturtian glacials and the Wilyerpa Formation of the Lower Umberatana Group have a thickness of 4 km in the east increasing locally to 4.6 km to the west. West of the western Weekeroo Inlier, the Lower Umberatana Group decreases to ~2.5 km, but increases again to ~3 km further west (Figure 3c). The increased thickness to the east coincides with the MacDonald Fault (Figure 3c). Further east of the fault, Neoproterozoic sequences start with early Marinoan sedimentary rocks (Preiss 1986), implying that this eastern part was emergent during early rifting. Thickness constraints for younger sequences (Upper Umberatana Group and Wilpena Groups) again are sparse and have been estimated to be ~3–4 km across the section width (Figure 3c). The Callanna Group exists in the western

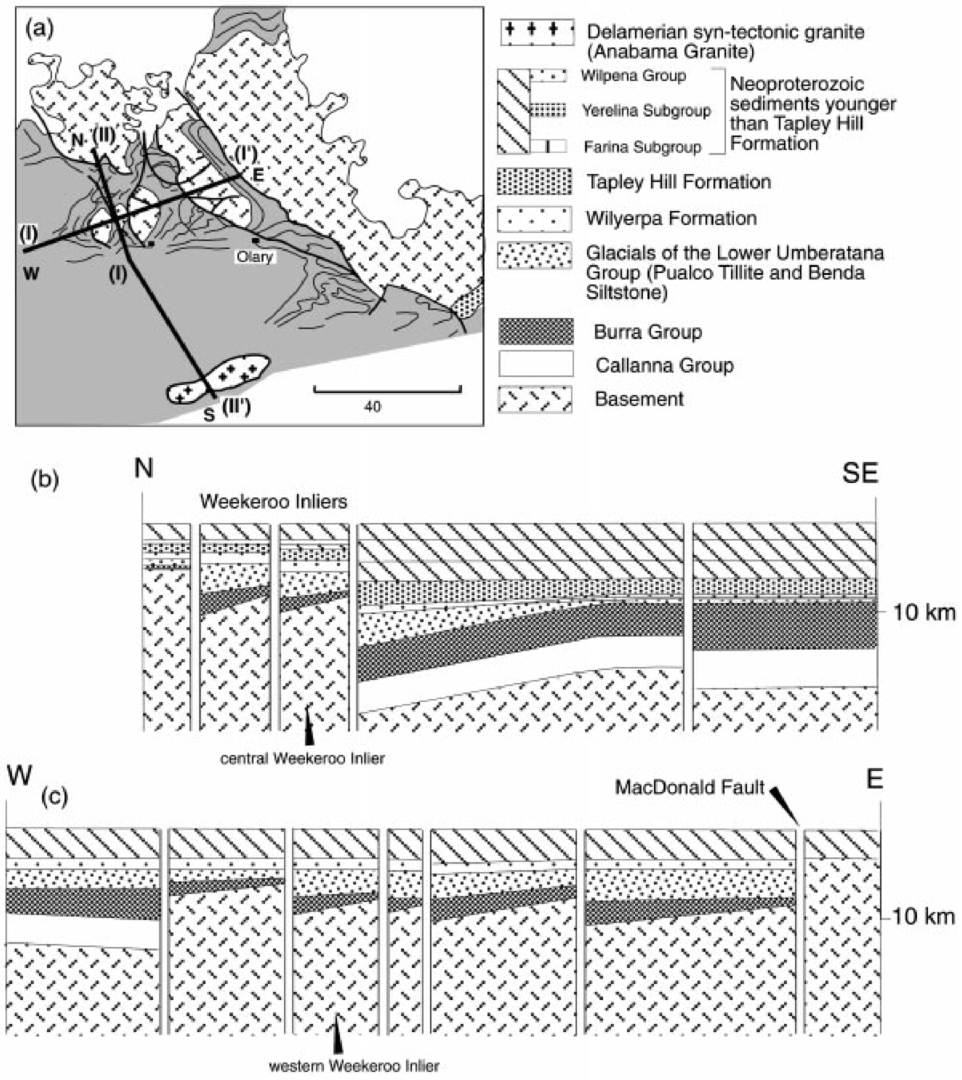


Figure 3 Lithostratigraphic columns of Neoproterozoic sedimentary rocks. (a) Location of lithostratigraphic columns and sections. (b) North–south-oriented standard lithostratigraphic column across the Olary Block and the northeastern Nackara Arc. (c) East–west-oriented standard lithostratigraphic column across the Olary Block and the eastern part of the Nackara Arc.

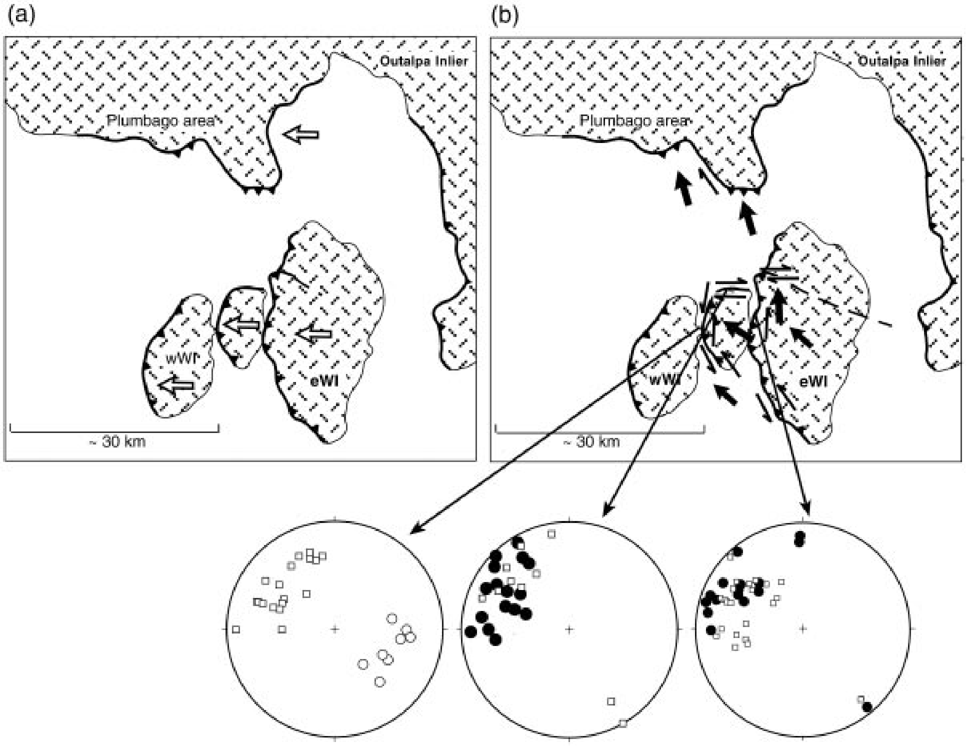
part of this section (Preiss 1987) where it may be up to ~4 km thick (Figure 3c). The total thickness of the Neoproterozoic succession, east of the MacDonald Fault is ~3 km. West of the MacDonald Fault, the total thickness is between 8.3 and 10 km, decreasing to 6.6 km west of the western Weekeroo Inlier. Further to the west, sedimentary thickness increases to ~14 km and possibly even more depending on the thickness of the Callanna Group.

Variations in the thickness of the Burra Group coincide with the MacDonald Fault as well as faults along the western basement margins (Figure 3c). These observations imply that the western margins of the inliers acted as extensional faults with the bulk of sediments accumulated in the hangingwall of a set of east–dipping extensional faults. The increase from 3.3 to ~10 km across the MacDonald Fault also indicates substantial growth faulting, with deposition in the hangingwall of a steeply west-dipping fault. A relatively condensed sedimentary succession to the west of the western Weekeroo Inlier marks a basement high that separates an eastern depocentre from the Nackara Arc. Figure 3 demonstrates that the deposition of Neoproterozoic sediments was dominantly controlled by northwest–southeast-trending structures, and north–south-trending structures which now define the western margins of inliers in the Olary Block. Both fault sets played a prominent role during early rift-related deposition. Two dominant structures, one south of the Weekeroo Inliers (here called the ‘Southern boundary fault’) and one west of the inliers (here called the ‘Western boundary fault’) appear to have been active throughout the entire Neoproterozoic.

REGIONAL STRUCTURAL CROSS-SECTIONS

The results of the previous section have identified several major structures, including the Southern and Western boundary faults, the MacDonald Fault and faults along the western margins of the exposed inliers, across which we have constructed balanced and restored structural cross-sections. The structures associated with the reactivation of the three Weekeroo Inliers (Figures 2, 3) indicate progressive deformation manifested by the formation of folds in the Neoproterozoic cover and shear zones along the western as well as northern basement–cover contacts (Figure 4). A first phase of approximately west-directed shortening (D_4) is responsible for the formation of north–south-trending F_4 folds and an associated axial planar biotite foliation. The second, retrogressive phase (D_5) is interpreted to be a

Figure 4 Simplified sketch showing the orientation of the principal stress direction during Delamerian D_4 (white arrows) and D_5 (black arrows); strike-slip movement is shown by solid half-arrows. Orientation data (lower hemisphere projection) of Delamerian structural elements are indicated. ●, bedding planes in Neoproterozoic sequences; □, shear zone cleavages; ○, transport lineations on shear cleavage planes; wWI, western Weekeroo Inlier; eWI, eastern Weekeroo Inlier.



consequence of northwest-directed oblique shortening. It initially produced F_5 folds, but further progressive shortening was accommodated by oblique slip along east-dipping, north–south-trending oblique sinistral, as well as east–west-trending, south-dipping oblique dextral retrograde shear zones (Figure 4). The bulk of the deformation is concentrated in discrete, hydrated shear zones along the western and, to a lesser extent, northern basement–cover contacts where basal Neoproterozoic sequences are locally overturned.

In order to quantify Delamerian shortening, two cross-sections have been constructed perpendicular to the trends of F_4 (Weekeroo–MacDonald Fault transect, Figure 5) and F_5 folds (Plumbago–Anabama transect, Figure 6), paralleling the lithostratigraphic columns shown in Figure 3. We have used the Burra Group, the Lower Umberatana Group and the uppermost limit of the Neoproterozoic sedimentation (Pound Quartzite) for the balancing procedure. The horizontal and vertical scales in both transects are equal. Details of the balancing methodology have been outlined

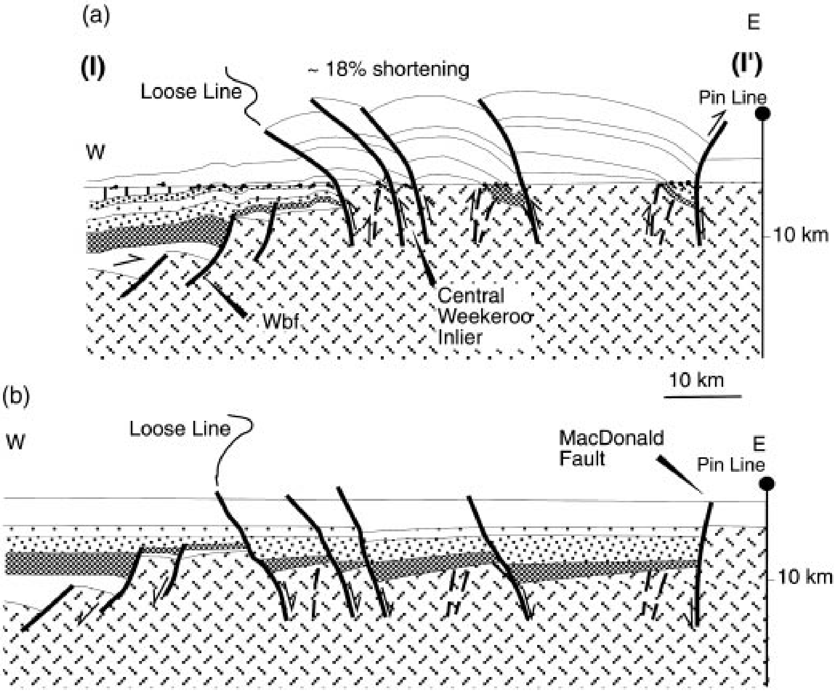


Figure 5 Weekeroo–MacDonald Fault transect (I–I′); see Figure 3a for location. (a) Balanced Weekeroo–MacDonald Fault transect. (b) Restored Weekeroo–MacDonald Fault transect. Note the segmentation of basement during early deposition of the Burra and Umberatana Groups. Note also that fault coincides with loose line. Fault was chosen as loose line due to insufficient structural data along the western margin of the western Weekeroo Inlier. Wbf, Western boundary fault.

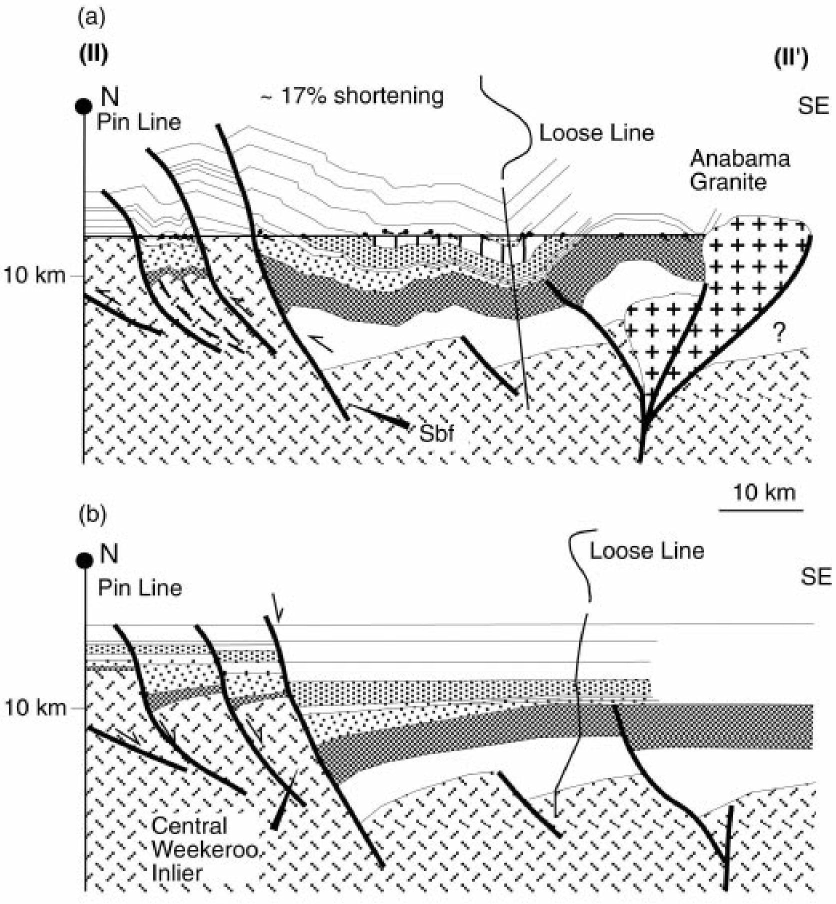


Figure 6 Plumbago–Anabama transect (II–II′); see Figure 3a for location. (a) Balanced Plumbago–Anabama transect. (b) Restored Plumbago–Anabama transect. Kink in loose line due to the mobilisation of the Callanna Group. Sbf, Southern boundary fault.

in Paul *et al.* (1999) and are based on the procedures proposed by Woodward *et al.* (1989). We note that the region of interest contains some evidence for oblique slip, although this is largely subsidiary to dip-slip displacements. Standard section-balancing procedures require that the sections are drawn within 5° of the tectonic transport direction. In view of the strike-slip component of the displacement these cross-sections are not fully balanceable or restorable. However, the sections given are the best possible description of the geology in light of the available data.

Weekeroo–MacDonald Fault transect

The eastern part of the Weekeroo–MacDonald Fault transect (Figure 5a; section I–I′ on Figure 3a) is interpreted as a series of basement culminations that have been thrust to the west over the Neoproterozoic cover, located between the MacDonald Fault in the east and an area of relative weak deformation in the west. Deformation in the eastern part of Weekeroo–MacDonald Fault transect is mainly accommodated by a series of steep, east-dipping faults along which the Weekeroo and the Outalpa Inliers are exhumed. The overall geometry of the eastern portion is interpreted to resemble a flower-structure, accommodated by both east- and west-dipping faults, the latter inferred at depth (indicated as dashed lines in Figure 5b). Reverse, west-directed movement resulted in preservation of Neoproterozoic sedimentary rocks as narrow corridors between the individual inliers. The MacDonald Fault in the east of Figure 5 is a major, near-vertical structure with kinematic indicators suggesting dominantly dextral strike-slip as well as west-directed reverse slip (Marshak & Flöttmann 1996; Clarke & Powell 1989). In the western part of the Weekeroo–MacDonald Fault transect, low-amplitude folds reflect only weak shortening, interpreted to be accommodated by a regional subhorizontal décollement in the Callanna Group (Figure 5a) (Marshak & Flöttmann 1996). Below this décollement, original west-dipping extensional faults are shown with relatively little reactivation, consistent with a deformation style that was essentially thin-skinned (Figure 5a). A basement high, characterised by very weak deformation separates thin-skinned deformation in the west from thick-skinned deformation in the east of the section. The overall shortening in this section is ~18%.

The restored section (Figure 5b) shows that deposition of early rift sequences in the east was accommodated by east-dipping basement structures and a near-vertical dipping MacDonald Fault with a throw of ~8 km. This eastern depocentre is separated from the thick sequences in the more open depositional realm of the Adelaide Geosyncline further west by a basement high characterised by relatively condensed sedimentation. Sediments thicken towards the west across the Western boundary fault, which is therefore interpreted as a major west-dipping growth fault during Callanna and Burra Groups times.

Plumbago–Anabama transect

The Plumbago–Anabama transect (Figure 6a; section II–II′ on Figure 3a) shows increasing strain intensity from weakly deformed, openly folded Neoproterozoic sequences in the south, towards folded and faulted sequences truncated by the central Weekeroo Inlier. Deformation along the section line is accommodated mainly by a set of steeply south-dipping basement structures forming an imbricate fan. The two northern faults undercut the basement inliers, with the central Weekeroo Inliers being reactivated and thrust northwards onto the Lower Umberatana Group (Figure 6a). North of the central Weekeroo Inlier shortening decreases dramatically with open folds in the overlying cover rocks interpreted as fault-propagation folds developed above south-dipping, second-order imbricate thrusts (Figure 6a). The antiformal structure south of the loose line in Figure 6a marks an increase in deformation intensity, in the vicinity of the intrusive Anabama Granite. The restored section in Figure 6b shows a dramatic change in thickness from approximately 8 km to perhaps as much as 20 km across the Southern boundary fault implying that deposition of cover sequences was accommodated by a series of south-dipping growth faults most active during deposition of the early rift-related sequences. The overall shortening in this section is ~17%.

DISCUSSION

The data provided in the previous sections imply that the Delamerian structural geology of the Olary Block is significantly influenced by the reactivation of basement-rooted, former extensional faults. Three major faults (MacDonald Fault, Southern boundary fault and Western boundary fault) bound the Olary Block to the east, south and west, with the latter two significantly controlling the deposition of the Callanna and Burra Groups into the Nackara Arc (Figures 1, 2, 5, 6). The total increase in thickness of the sedimentary package across these faults is substantial, indicating a dramatic increase in Neoproterozoic extension to the west and south. The general distribution of Neoproterozoic sedimentary rocks defines a north-tapering sequence, with the deposition of 14 km, and possibly as much as ~20 km, of sedimentary rocks in the hangingwall of the Southern boundary fault. This is suggestive that the Olary Block represents an incised, subsiding basin margin to the open depositional realm of the Adelaide Geosyncline (Figure 7a). Early segmentation of the basin margin occurred during Willouran and Torrensian rifting. The present geological relationships suggest that during basin formation extension was accommodated by east-, northwest- and north-trending extensional faults (Figure 7b). South of the Weekeroo Inliers, significant extension was probably accommodated by sinistral strike-slip deformation along approximately northeast-trending transfer faults (e.g. Darling River lineament: Preiss 1987) (Figure 7a, b). Interestingly, the formation of Neoproterozoic extensional faults in the Olary Block

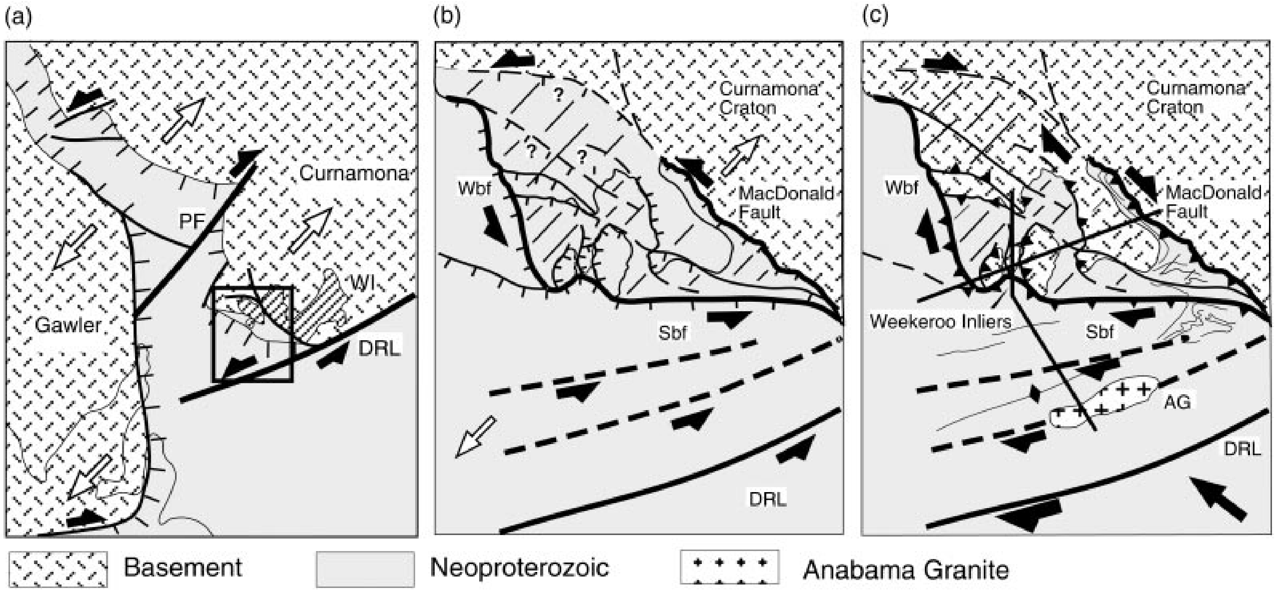


Figure 7 Interpreted evolution of the northeastern margin of the Adelaide Geosyncline. (a) The main structural features that accommodated Willouran and Torrensian rifting (modified after Preiss 1986). White arrows indicate the constant northeast–southwest extension. Hatched area indicates the position of the Willyama Inliers. Thick black arrows indicate relative movement along major transfer faults. DRL, Darling River lineament; PF, Paralana Fault; WI, Willyama Inliers. Inset indicates location of (b). (b) Interpreted evolution of the northeastern margin of the Adelaide Geosyncline during Willouran and Torrensian rifting. The outline of the Olary Block is indicated. Thick solid and dashed lines indicate principal extensional structures active during early rifting and deposition [based on Forbes (1991), Preiss (1986) and aeromagnetic data analysis]. Northern limit of the Willouran–Torrensian sedimentation is not constrained but assumed where indicated. Thick black arrows indicate relative movement along major structures during the buildup of a transtensional regime and the segmentation of the basin margin. Wbf, Western boundary fault; Sbf, Southern boundary fault; AG, Anabama Granite. Hatched area indicates the basin margin area north of the Southern boundary fault and east of the Western boundary fault. (c) The main reactivated structures during the inversion. Thick black arrows indicate relative movement along major structures during northwest-directed shortening (indicated as black arrow in the lower right corner). Trend of bedding and folds in Neoproterozoic sequences is indicated as thin solid lines. Hatched area indicates the basin margin area north of the Southern boundary fault and east of the Western boundary fault. Thick, solid straight lines represent the section lines of the structural cross-sections in Figures 5 and 6.

appear not to be controlled by earlier, Olarian structures which generally trend approximately northeast (Paul 1998).

Reactivation of the basin margin during the Delamerian Orogeny is manifested in the inversion of the primary extensional faults, which had a profound control on the style, geometry, as well as intensity of deformation (Figure 7c). The main structural characteristics are two sets of tight folds in the Neoproterozoic cover and steep-dipping reverse faults, the latter forming an imbricate fan of basement slices, in part resembling a flower-structure geometry. Most of the shortening was localised across north-trending structures along which basement is thrust westwards over younger Neoproterozoic cover sequences. The two-phase deformation suggests an overall, northwest-directed tectonic transport (Figures 4, 7c). Initial west-directed transport (D_4) is inferred to have accompanied the dextral reactivation of the Darling River lineament during the early stages of Delamerian shortening. This is consistent with the interpretation of Clarke and Powell (1989) who postulated that basement wrenching was the main controlling factor for the observed deformation in the Olary Block and Nackara Arc (Figure 7c). During this early shortening, most of the deformation north of the Southern boundary fault was concentrated along the MacDonald Fault and approximately north-trending, steeply dipping, former extensional faults, and evidenced in the formation of north–south-trending F_4 folds in the Neoproterozoic cover. During progressive shortening, wrench faults south of the Southern boundary fault ceased accommodating movement and the strike-slip dominated regime modified into an overall transpressional regime, with the tectonic transport direction rotating into a northwesterly and then a northerly direction (D_5). This phase is interpreted to be responsible for the formation of the flower-structure geometry in the eastern portion of the Weekeroo–MacDonald Fault section (Figure 5a) and was probably synchronous with the intrusion of the Anabama Granite (Figure 7c). South and west of the Southern and Western boundary faults, in the Nackara Arc deformation was probably accommodated primarily along stratigraphically controlled décollements in the Callanna Group (Marshak & Flöttmann 1996).

One important point resulting from the above compilation is that basement-involved deformation is linked to the reactivation of pre-existing structural anisotropies. Based on the observation that faults in the Olary Block accommodated basement deformation while faults in the Nackara Arc were inactive, the sharp transition between basement-involved deformation and basement-detached deformation shows that the presence of pre-existing faults alone was insufficient to localise deformation. This suggests that fault reactivation appears to be influenced by another process that modulates the mechanical response on a regional scale. This could be facilitated by such things as variations in thermal regime or the restricted distribution of suitable detachment horizons (such as evaporites within the Callanna Group). While a detailed evaluation of these alternatives is beyond the scope of this paper and, in any case, would be limited by our poor knowledge of stratigraphic variations at depth, we note that there is some evidence to suggest that the relatively sharp transition from basement-involved deformation in the Olary Block to basement-detached deformation in the Nackara Arc coincides with a regional decrease in the recorded crustal heat flow. The heat flow in the Nackara Arc is ~64 mWm^{-2} some 10 mWm^{-2} lower than average for the Willyama Inliers (Cull 1982). The factors controlling this regional variation in heat flow are poorly constrained but are probably due to primary variations in heat production in the basement or to variations in heat production associated with crustal attenuation during basin formation. Recently Sandiford *et al.* (1998) and Paul *et al.* (1999) have argued that variations in deformation intensity and style across the Mt Lofty and Flinders Ranges, in particular basement-involved deformation in the northern Flinders Ranges at the Mt Painter Block, reflect not only the geometry of the pre-Delamerian basin architecture, but are also a consequence of anomalous enrichment of heat-producing elements in the basement. In particular Sandiford *et al.* (1998) have shown that such anomalously enriched basement, buried under a thick sedimentary blanket, will produce significant increases in the thermal regime of the deep crust and upper mantle which can have a profound thermal weakening effect. Hence, it is conceivable that variations in basement heat production/heat flow may be reflected in the observed lateral variations in deformation intensity and style across the basement-involved Olary Block and the basement-detached Nackara Arc.

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