Proterozoic sediment-hosted copper deposits

Geological framework and copper mineralisation in South Australia

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Introduction

In sediment-hosted mineralised systems, a clear understanding of both basin and basement architecture is critical to resolving the generation and geometry of fluid flow systems. In South Australia, fundamental crustal-scale structures and regional thermo-magmatic events within basement rocks have had a direct influence on Neoproterozoic and Cambrian basin development as well as providing focussing mechanisms and possibly energy required to drive fluid convection. The link between basement and basin frameworks and the need to consider both elements is demonstrated clearly on the Stuart Shelf, where Neoproterozoic-hosted copper systems bear a close spatial relationship to mineralised and/or intensely altered basement rocks.

I have attempted to summarise the South Australian geological framework within an *event-stratigraphy* plot (Fig. 1: presented as a separate Corel Draw file), which highlights temporal and spatial relationships between orogenesis, thermo-magmatic events, regional chronostratigraphic events (such as glacial periods) as well as basin evolution and geometry. The plot is constructed as a staggered W to E section across South Australia and relates strata and 'events' of Palaeoproterozoic to Cambrian age. This summary is intended to be used as a template for basin and fluid modelling as well as providing a means of comparison between mineralising systems in Zambia and other parts of Australia.

The following review is sourced from a broad literature database concerning stratigraphy, basin evolution and copper systems in South Australia. Maps and geophysical images are sourced from largely PIRSA's GIS and geophysical databases. The bulk of the interpretation is that of survey, academic and industry geologists, however I have made a number of additional observations on large-scale structural geometry and possible fluid flow mechanisms. The first part of the review involves the geological framework of the Palaeoproterozoic - Cambrian system, with particular emphasis placed on the structural development at various times throughout this period. Although the event stratigraphy plot links Palaeo- Mesoproterozoic units across South Australia, the summary below focuses mainly on basement rocks of the Stuart Shelf–Galwer Craton areas. The second part is concerned with copper mineralisation within Neoproterozoic and younger packages. Details of two end-members of this diverse copper system (Stuart Shelf and southern Adelaide Fold Belt regions) are presented to highlight the various styles and interpretations of the origin of copper.

Geological Framework

Palaeoproterozoic

The distribution of Palaeoproterozoic rocks is shown in Figures 1 & 2. They occur mainly on the cratonised portion of the Eyre Peninsula, but also to the east of the Adelaide 'Geosyncline' within the Willyama and

Mt Painter & Mt Babbage Inliers. Small thrust-bounded inliers are situated within the southern part of the Adelaide 'Geosyncline'. Structural geometry is poorly constrained beneath the Stuart Shelf, with no known structures clearly attributable to the Kimban Orogeny (1845–1710Ma). It is probable however, that the core of the Kimban Orogen, which includes highly strained and metamorphosed metasediments and syn-orogenic granites of the Cleve Subdomain on eastern Eyre Peninsula, extends underneath the Stuart Shelf (Parker, 1990). This interpretation is supported by presence of Hutchison Group metasediments, probable chronostratigraphic equivalents of Lincoln Complex granites and Wandearah Metasiltstone in drill core in the Mt Gunson, Olympic Dam regions (Reeve et al., 1990). Structures worthy of note are the KD_3 (third phase of the Kimban Orogeny) mylonite zones which form a semi-continuous northeast striking structural corridor along the edge of the Eyre Peninsula, but display a marked anticlockwise swing to meridional strikes near Whyalla on the south-western margin of the Stuart Shelf (Fig. 2). These mylonite zones coincide with the highest grade 'root zone' of the west-directed Kimban Orogen and are considered to represent major crustal shear zones (Parker, op cit.).

Although the KD_3 mylonite zones clearly imbricate and deviate from their regional NE trend near the southern margin of the Stuart Shelf (perhaps recording the effects of more a meridionally oriented crustal fabric), there is significant circumstantial evidence to suggest that a major crustal discontinuity persists in a north-easterly direction below post-Kimban strata. Evidence for this feature is discussed further in following sections and is recorded in rocks as young as the earliest Phanerozoic. The crustal discontinuity, which is termed here *the Kalinjala-Paralana structural corridor* and is considered to extend from southern Eyre Peninsula to the Mt Painter region, coincides roughly with the southern limit of Stuart Shelf sedimentation. It also correlates with part of the transcontinental G8 structural corridor of O'Driscoll (1985).

Early Mesoproterozoic

Early Mesoproterozoic Gawler Range Volcanics (GRV:1600–1580Ma) record a major magmatic-thermal event to have affected the Gawler Craton, basement to the Stuart Shelf package and parts of the Willyama and Mt Painter & Mt Babbage Inliers (Fig. 1): the Gawler Range volcano-plutonic event (GRVPE). The present distribution of rock units related to this event defines an ENE-trending, >200km wide, 700km long zone extending from the western Gawler Craton beneath the Adelaide Geosyncline to the Curnamona Province (Parker, 1990).

Tectonism during the GRVPE in the Galwer Craton and Stuart Shelf regions involved only extension and thermal subsidence (Parker, 1990). This is in contrast to roughly coeval and possibly genetically related magmatism in the Willyama Inliers (Wyborn et al., 1998) where weakly to moderately deformed granites where emplaced synchronously with the third retrogressive phase of the Olarian Orogeny (OD_3: Flint and Parker, 1993). There is also evidence to suggest that effects of OD_3 may have been recorded as far west as the Moonta-Wallaroo region of the Yorke Peninsula (Fig. 1), where Hiltaba Suite granites possess a weak NE striking cleavage and textural relationships suggestive of syn-tectonic emplacement within ENE striking mylonite zones.

Regional gravity, aeromagnetic and geological datasets from the Stuart Shelf–Gawler Craton regions demonstrate that the volcanic component of the GRVPE is largely confined to an elliptical nucleus, with the plutonic component distributed around the margins (Fig. 3). Gow et al. (1993) interpreted this distribution of rock types in the central and northern Stuart Shelf areas to reflect juxtaposition of different stratigraphic levels of the volcano-plutonic complex across a major WNW trending, vertical fault zone. That is, the deeper-level plutonic root of the complex being preserved in the Olympic Dam province to the north and shallower level extrusive-dominated portion of the complex to the south and extending towards the Mt Gunson area. Gow et al. (op. cit.), did

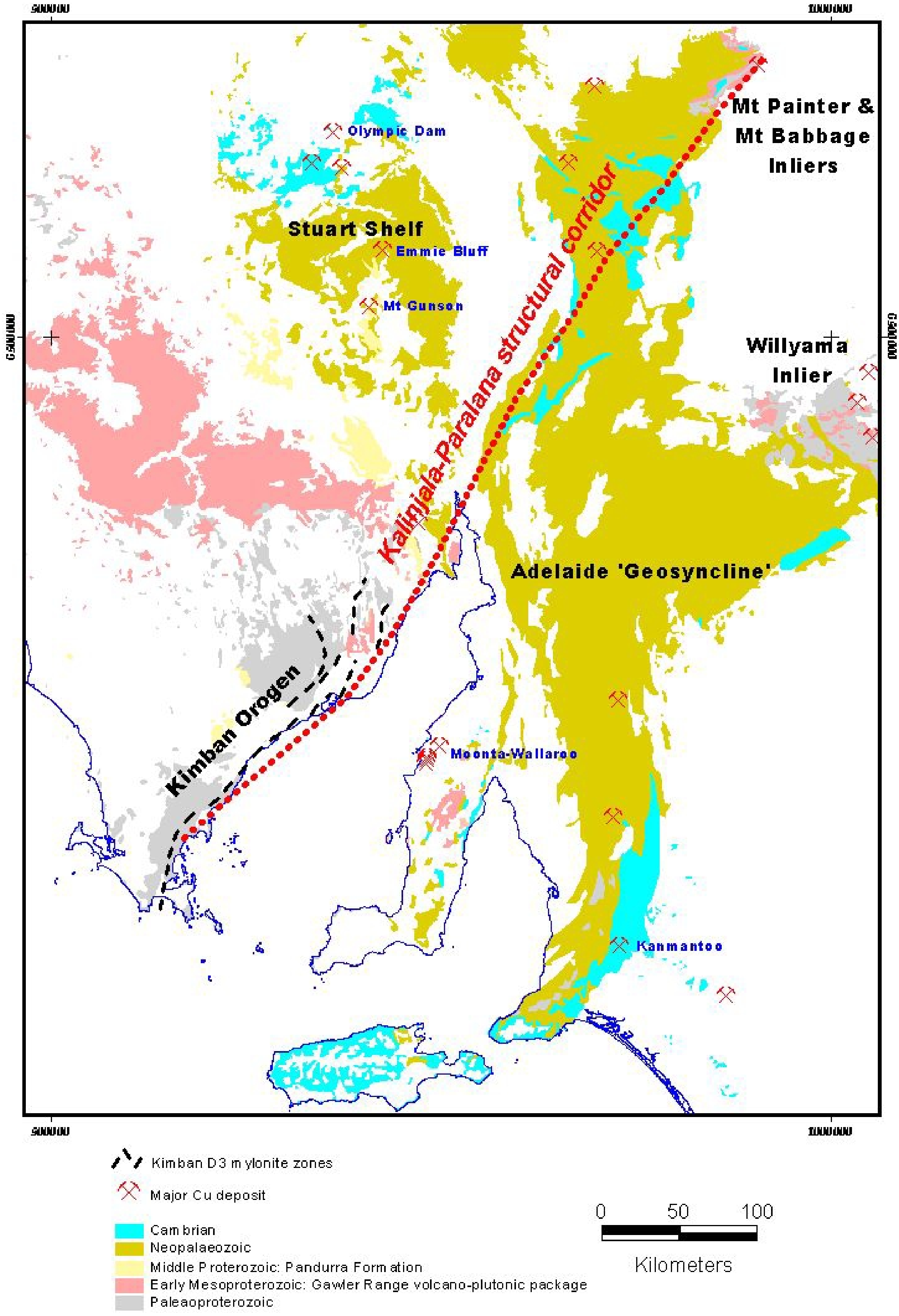

Figure 2. Distribution of basic Palaeoproterozoic–Cambrian stratigraphic elements.

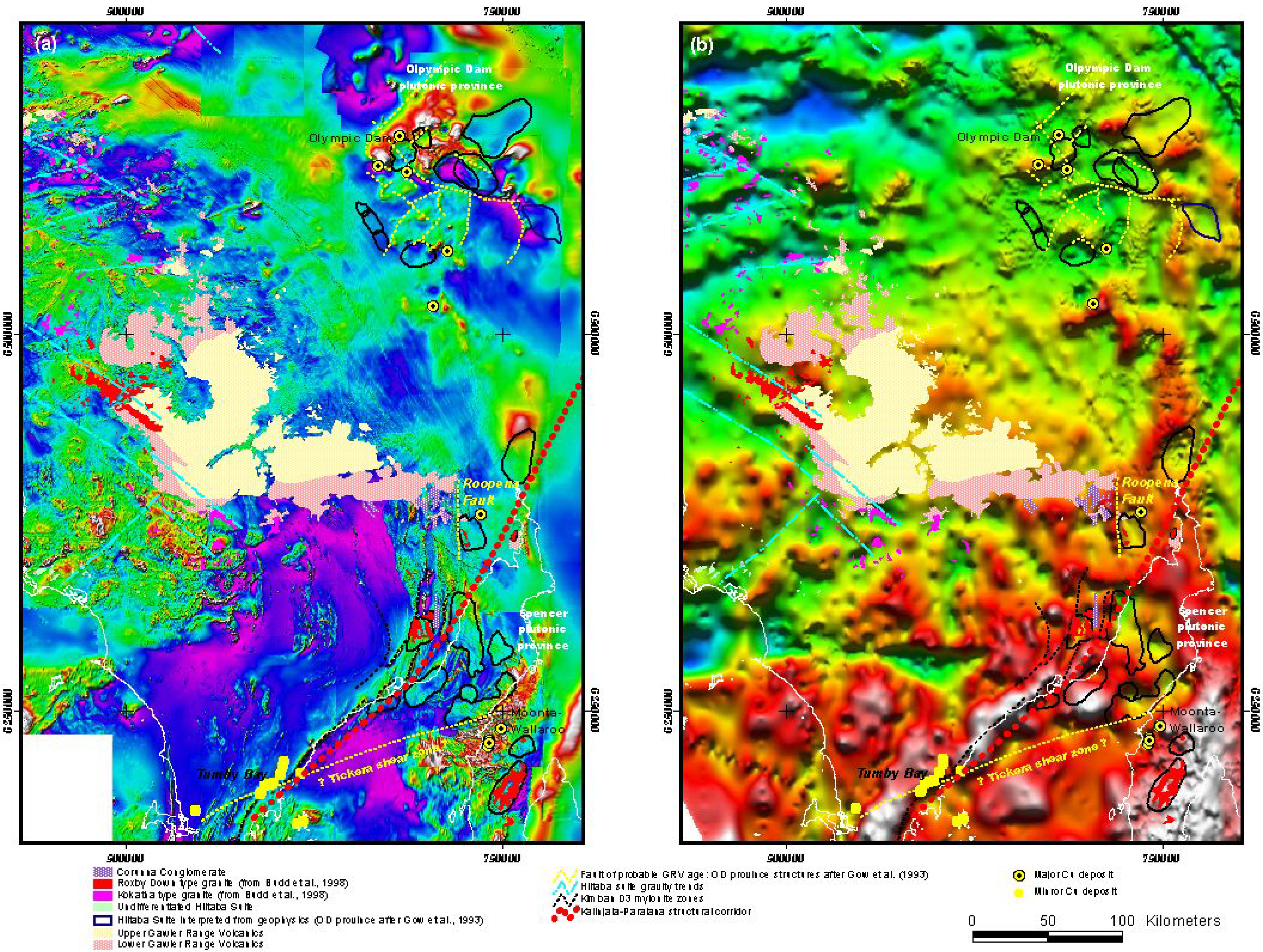

Figure 3. Distribution of rocks and structures related to the Gawler Range Plutonic Event in the Stuart Shelf – Gawler Craton region. (a) TMI aeromagnetics and (b) residual gravity reveal major plutonic provinces in the Olympic Dam and Spencer Gulf regions. Images sourced from the PIRSA geophysical dataset.

not speculate on the relative ages of regional faulting and magmatism, however there is circumstantial evidence to indicate that the GRVPE occurred under the influence of a stress field involving regional NE–SW to NNE-SSW directed extension. For example, there is some suggestion of structural control of GRVPE granitoids in the Galwer Craton as indicated by their spatial association with sub-linear WNW to NW trending gravity troughs (Fig.3). A similar geometry was noted by Gow et al. (op cit) on the southwestern margin of the Olympic Dam province, where a linked array of granites possess a clearly defined NW trend. Furthermore, a major NW trending feeder dyke has been interpreted by Blissett (in Flint, 1993) as the feeder for part of the Lower GRV on the southern Stuart Shelf. The timing of this event is also grossly compatible with the third phase of Olarian deformation recorded in the Willyama Block, where NE trending folds and U-bearing retrograde shear zones formed under regional NW-SE compression.

Composition and distribution of GRVPE granites

Granites related to the GRVPE (Hiltaba Suite) can be separated into two broad geochemical types: strongly oxidised (haematite-magnetite) and fractionated **Roxby Downs type** and the less oxidised (ilmenite-titanomagnetite) and fractionated **Kokatha type** (Budd et al., 1998). The Roxby Downs type is anomalously enriched in radiogenic heat producing elements such as U and Th (Budd op cit.) and is considered to be spatially and possibly genetically related to Fe-oxide Cu-Au deposits at Olympic Dam and Moonta-Wallaroo.

Only the Roxby Downs type granites are known to form part of basement to the Stuart Shelf sequence. The distribution of these granites as determined from geological and geophysical datasets reveals two major, near surface plutonic complexes (Fig. 3). The Olympic Dam plutonic complex (or Burgoyne batholith of Reeve et al., 1990) occurs at the northern margin of the Stuart Shelf where it hosts and/or sourced hydrothermal fluids to Fe-oxide Cu-Au deposits at Olympic Dam, Acropolis, Wirrda Well and Emmie Bluff. The principal structural fabric in this region trends WNW to NW (Anderson, 1980; Gow et al., 1993). In the area north of Olympic Dam, both NW- and NE-trending basement features in magnetics are transected by dykes probably relating to the Neoproterozoic Gairdner Dyke Swarm (Anderson, op. cit.). Timing of these is structures is constrained principally by their association with zones of intense Fe-metasomatism related to the GRVPE. At the regional scale, this is demonstrated by sub-linear to curvaceous zones of anomalously high magnetic response, considered by Gow (op. cit.) to reflect fault controlled deposition of magnetite. At Olympic Dam, the long axes of many haematitic breccia zones are approximately aligned in a WNW direction and probably reflect the geometry and position of extensional and/or transcurrent faults related to regional scale rifting. It is likely that structures of this type, now evident as lineaments, were the loci for hydrothermal and intrusive activity (Reeve et al., 1990).

A second major shallow level plutonic complex (informally referred to herein as the Spencer plutonic complex) occurs at the southern margin of the Stuart Shelf, and extends offshore below Spencer Gulf (Fig. 3). Most of the offshore granites, clearly defined in gravity and aeromagnetic datasets, are tentatively included within the Roxby Downs suite on the grounds of their spatial association with granites of this type outcropping on the coasts of Yorke and Eyre Peninsulas. However, at least some of these offshore granites belong to the slightly younger Spilsby Suite (~1530Ma: Fanning and Rankin, 1994) which crop out as islands in southern Spencer Gulf. The only field evidence known to myself which relates the emplacement Spencer granites to specific structures occurs near Wallaroo (as alluded to in the previous section), where variably strained granite and pegmatite shows evidence of progressive incorporation within, and subsequent overprinting of, mylonitic fabrics within a ENE-striking shear zone along the southern margin of the Tickera Granite. This shear zone is tentatively projected ESE below Spencer Gulf along a line of elongate gravity depressions to Tumby Bay on eastern Eyre Peninsula, where it dextrally offsets the Kalinjala Mylonite Zone (Fig. 3). At a broader scale, the Spencer plutonic complex is seen to occupy a wedge situated between this shear zone an the Paralana-Kalinjala structural corridor, which may have existed as a site of gross crustal dilation during the 1600–1530Ma period.

Although a direct relationship of the Spencer plutonic complex granites with copper mineralisation is yet to be proven, a genetic association with copper at Moonta-Wallaroo (including anomalous Au and U) has been inferred by Connor (1995). Similarly, it could be argued that anomalously high levels of alteration, haematisation and sporadic copper occurrences in Lower GRV from the Roopena and Cultana areas (northern end of the Spencer plutonic complex: Flint, 1993) relates to their proximity to both Roxby Downs type granites (and possibly the Kalinjala - Paralana structural corridor).

'South Australian Heat Flow Anomaly'

Broadly corresponding with, but also extending outside the known distribution of Roxby Downs type granites is a domain of markedly elevated surface heat flow: South Australian Heat Flow Anomaly (SAHFA: Neumann et al., in press). Highest values within the relatively sparse data occur on the southern and northern margins of the Stuart Shelf, extending eastward into the Adelaide Geosyncline in the vicinity of the shoulder of the Willouran Trough and reaching a maximum in the Mt Painter province (Fig. 4). Elevated heat flow values also occur in the region of Adelaide, with slightly lower values extending around the eastern margin of the Nackara Arc (Adelaide Geosyncline) and into the Willyama Iniers. Neumann et al. (op. cit.) argue that the elevated heat flow is derived from an anomalous enrichment of heat producing elements in the crust (as opposed to contribution from mantle heat flow). Their review of lithogeochemical characteristics of rock types present in South Australia demonstrates elevated U, Th and K abundances within Proterozoic granites and furthermore, progressive enrichment of these elements (and hence heat production) with time until the Mesoproterozoic. They site the Hiltaba Suite granites of the eastern Galwer Craton and Stuart Shelf regions as well as the geochemically similar but slightly younger, 1580–1550Ma granite suite at Mt Painter as the most significant contributors to the heat flow anomaly.

In addition to the obvious implications for thermally driven convective cells within the Adelaide 'Geosyncline' and Stuart Shelf packages, the distribution of the heat flow anomaly and its apparently intimate association with Mesoproterozoic granites allows us to make inferences on the nature and composition of the middle and upper crust beneath Neoproterozoic cover. Of particular interest, therefore, are the elevated heat flow values in region of the Willouran Trough, which imply that Neoproterozoic metasediments are floored by Palaeo-Mesoproterozoic basement enriched in radiogenic elements, potentially including granites of Hiltaba type compositions and ages.

Middle Mesoproterozoic

Middle Proterozoic red-bed fluviatile-dominated sedimentary units of the Pandurra Formation form the base of the Stuart Shelf package. They are dominated by medium to coarse-grained lithic sandstones, quartzite, pebble conglomerate and minor shale derived largely from underlying GRV units (Mason et al., 1978; Cowley, 1993).

The Pandurra Formation occupies a 120km wide graben like depression (Parker, 1983) with an overall tilt to the NE. It is characterised by highly variable thicknesses and an upper regolith surface which records multiple deep weathering and/or erosional events, the earliest of which probably predated deposition of the Adelaidean package. Although facies changes were noted across NW trending faults by Parker (op. cit.), Cowley (1993) showed the internal stratigraphy and sedimentary facies to be consistent across most structures and accordingly interpreted thickness variation to have resulted from post-depositional faulting and erosion (Fig. 5).

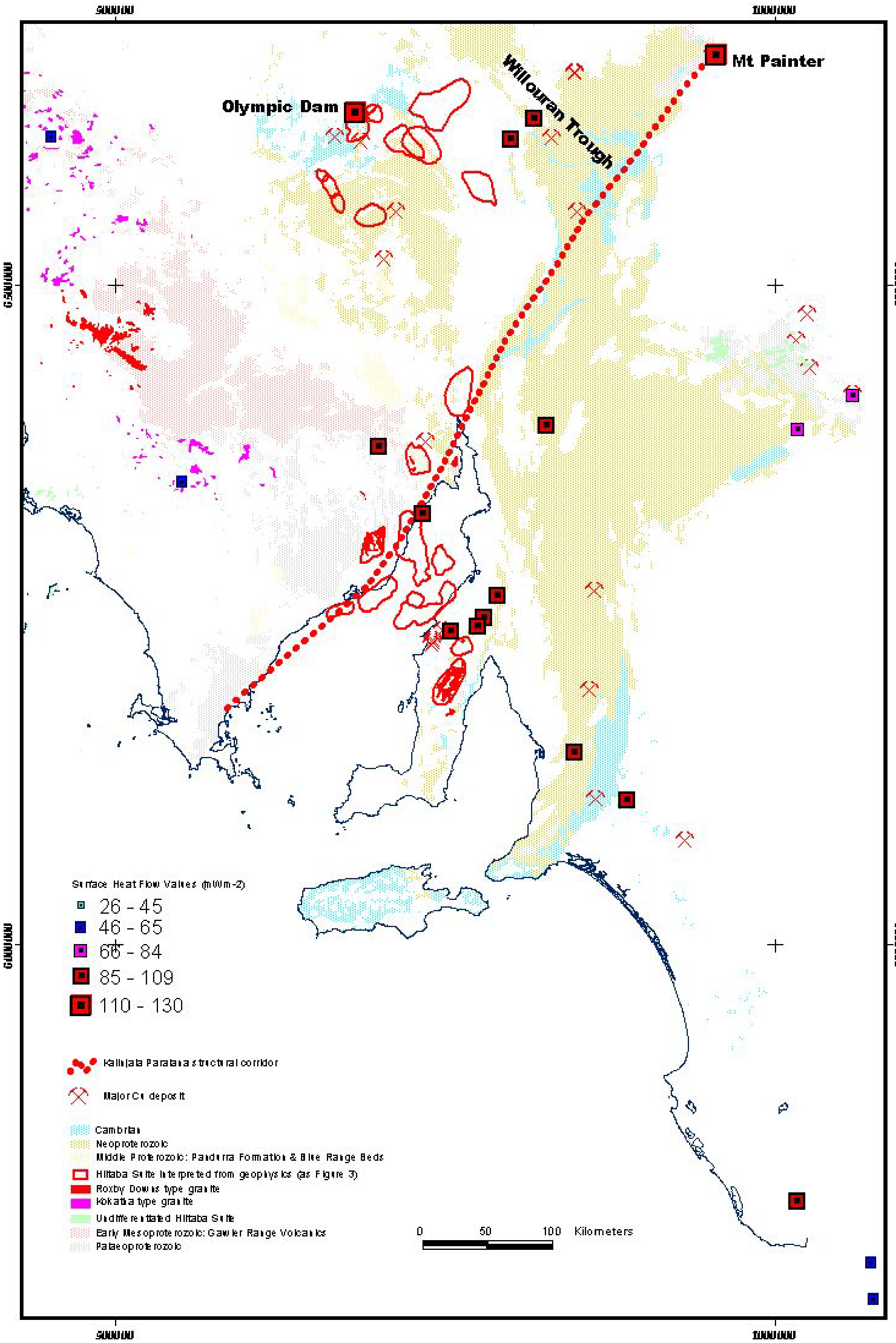

Figure 4. Surface heat flow values and their distribution with respect to Hiltaba Suite Granites. Anomalously high values coincide with Roxby Downs type granites on the Stuart Shelf and Yorke Peninsula. By contrast values are relatively low in the areas of Kokatha type granites on the Galwer Craton and potential geochemical equivalents in the Willyama Inlier.

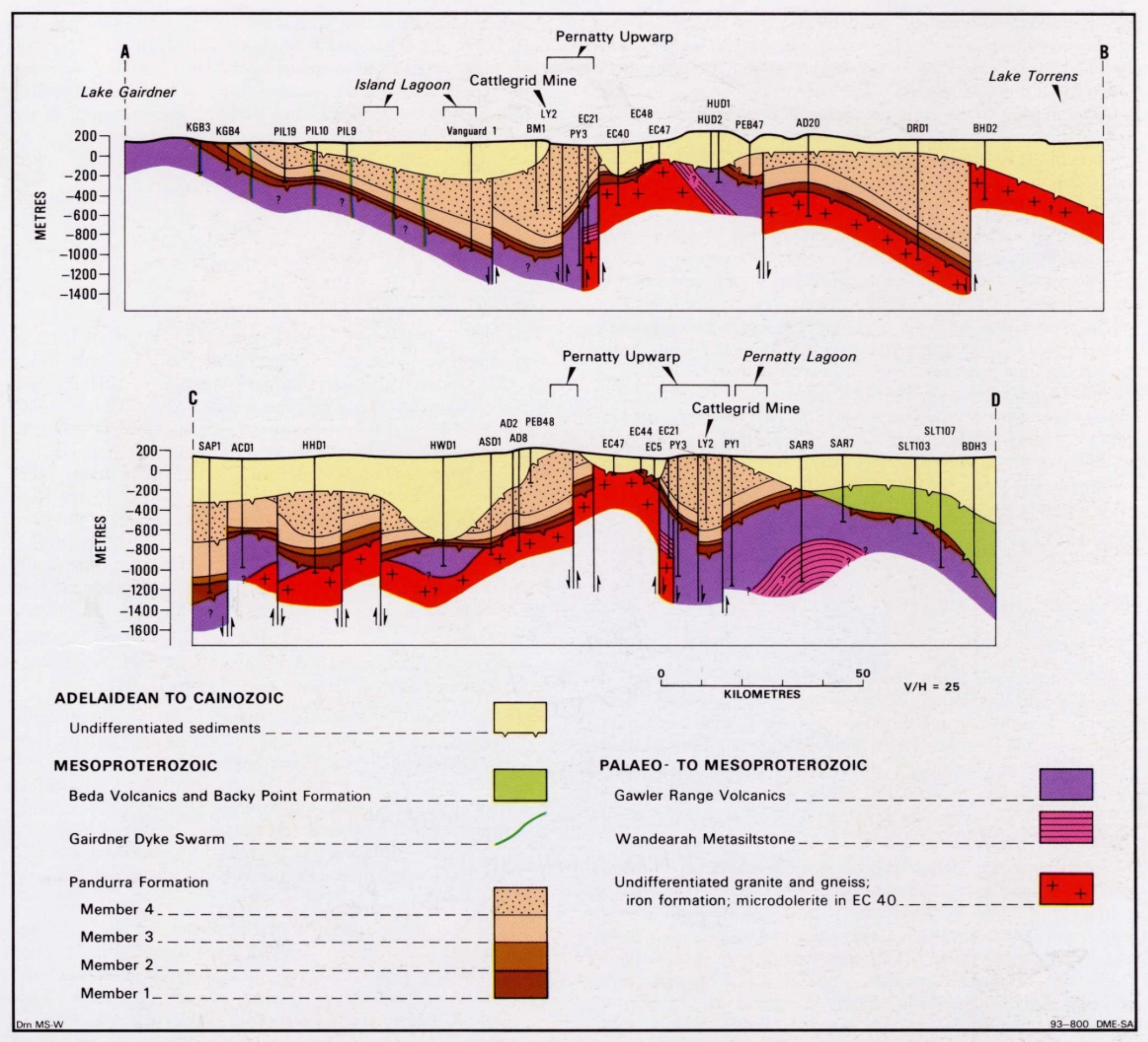

Figure 5. SW-NE (top) and NW-SE (bottom) cross sections of the Stuart Shelf showing marked thickness variation within the upper part of the Pandurra Formation. Variable thickness corresponds largely to block faulting and erosion during the Neoproterozoic (sourced from Cowley, 1991 *in* Flint et al., 1993).

Neoproterozoic-Cambrian

Deposition of Neoproterozoic-Cambrian package was accommodated in series of rift, sag and ultimate foreland basins that record the breakup of the Rodinian supercontinent which commenced ~830Ma through to the major Delamarian inversion event at ~510Ma (Powell et al., 1994; Preiss, 2000). Detailed mapping, facies analysis, provenance studies and reconstruction of basin architecture prior to Delamarian shortening throughout the well exposed portions of the Neoproterozoic stratigraphy within the Adelaide Geosyncline have provided the bases for a rigorous model of basin development. Thus, in contrast to older packages, the position, geometry and temporal relationships between basin-forming elements are well-constrained. Detailed reviews of Neoproterozoic-Cambrian basin development can be found in Preiss (1987, 2000) and Paul et al. (1999), and form the bases for the summary presented below.

Regional Structural Geometry

The classical tectonic subdivision of the Adelaide Fold Belt erected by Rutland et al. (1981) was based largely upon variations in structural style related to Delamarian shortening (Fig. 6). Basement-involved fold and thrust tectonics was restricted to the southern Fleurieu Arc and Northern Flinders domain, where shortening occurred in the order of 50% and 10% respectively. By contrast, the northern portion of the Fleurieu Arc and its transition into the Nackara Arc is characterised by "thin-skinned" geometries with open, upright to slightly inclined decollement folds generated above detachment surfaces contained within evaporitic horizons at the base of the Neoproterozoic package. The Central Flinders domain records the lowest strains in the Adelaide Fold Belt and is characterised by open dome and basin folding. The condensed Neoproterozoic package on the Stuart Shelf is almost unaffected by Delamarian tectonics, with bedding dips rarely exceeding 15°.

It is generally agreed that the variation in structural style outlined above is directly attributable to the geometry of Neoproterozoic and Early to Middle Cambrian basins (Fig. 6), although details of individual interpretations differ to some extent (Clarke and Powell, 1989; Flottmann et al., 1994; Flottmann et al., 1995; Marshak and Flottmann, 1996; Flottmann and James, 1997; Paul et al., 1999). The critical elements of Neoproterozoic-Cambrian basin architecture shown in Figures 1 & 6 and are summarised as follows:

- Development of two 'first-order', deeply subsident Neoproterozoic sub-basins separated by a fundamental NE trending crustal discontinuity coinciding with the Kalinjala–Paralana structural corridor.
- This structural discontinuity is manifest by the Paralana fault system, distribution of fault-controlled diapiric breccias and marked thickness variation within the Neoproterozoic sedimentary pile (Figs 7, 8). It is considered to have been active as a major transfer structure during Neoproterozoic NE-SW directed extension.
- The two main sub-basins were initially bounded by major zones of NW striking growth faulting defined by the Norwest Fault in the north (Figs 7, 8) and the Crystal Brook Lineament and MacDonald Fault Zone to the south. Distribution of strata within the northern and southern sub-basins correlates broadly with the Northern Flinders zone and Nackara Arc respectively.
- 'Second-order' depocentres within each sub-basin migrated with time: in the northern sub-basin, narrow rift zones were translated and rotated along the trace of the Paralana fault system (Fig. 7).
- The Central Flinders zone coincides with a condensed Neoproterozoic succession which accumulated in the footwall of the Paralana fault system.
- The margin of the southern sub-basin migrated westward with time towards the meridional Torrens Hinge Zone (THZ) which became active a zone of major basin growth during the Torrensian.
- The nature of the THZ is more ambiguous in the north (primarily due to Quaternary cover), however thickness of late Neoproterozoic strata

suggests that the Norwest Fault remained as the principal basin-bounding structure.

- Sedimentation on the Stuart Shelf, an uplifted stable block bounded to the east by the THZ and south by the Kalinjala -Paralana structural corridor, was episodic and largely platformal throughout the Neoproterozoic. Despite significant lower Neoproterozoic NE–SW directed extension as evidenced by the Gairdner Dyke Swarm, a substantial rifted basin failed to develop on the Stuart Shelf. Growth structures are poorly preserved in this region, however evidence of 'basement' emergence and erosion along with sedimentation within small, partly confined topographic depressions indicates active block faulting by at least the middle Neoproterozoic.
- Rotation of the axis of extension towards NW–SE during the Early Cambrian resulted in extensional reactivated the Paralana fault system and generation of the deeply subsident Kanmantoo Trough in the southern Adelaide Fold Belt. Growth faults bounding the Kanmantoo Trough, in particular the Kangaroo Island Shear Zone and Williamstown-Meadows Fault, were oriented E–W and NE–SW respectively. These structures may reflect extensional reactivation of Mesoproterozoic crustal discontinuities oriented similarly to that which extends from Tumby Bay to Wallaroo beneath Spencer Gulf.

Summary of Basin Development and Associated Facies Architecture

The Neoproterozoic–Cambrian stratigraphy of the Adelaide Fold Belt and Stuart Shelf is divided into a three-fold super-group classification.

***Warrina Supergroup*:** Onset of rifting and Neoproterozoic basin development is recorded by the Callanna Group (Fig. 1), a mixed succession of quartzo-feldspathic sandstone and conglomerate, stromatolitic and evaporitic dolomite, laminated pyritic and carbonaceous siltstone, rare felsic volcaniclastics and basaltic lavas. A thick package accumulated in rapidly subsiding troughs adjacent to the Paralana Fault at Mt Painter and the Norwest Fault in the Willouran Ranges. South of the Kalinjala-Paralana structural corridor, the Callanna Group is largely restricted in its present distribution to inclusions within diapiric breccias. Chrono- and partly lithostratigraphic equivalents on the Stuart Shelf include the Backy Point Beds and Beda Volcanics, possibly extending from a line connecting the Roopena Fault to Pernatty Lagoon eastward to the THZ (Mason et al., 1978). The lack of diapiric breccias on the Stuart Shelf implies that evaporitic dolostones were not deposited in this region. The basalts, which presently occur as small isolated exposures (significant thicknesses locally along the Paralana Fault) and as xenoclasts within diapiric breccias, and to which the Gairdner Dyke Swarm represent subvolcanic feeder structures, are considered to be erosional remnants of a once voluminous flood basalt province (Fig. 1) derived from decompressional melting of a mantle plume (Barovich and Foden, 2000).

Detrital zircon populations in lower Callanna Group sandstone indicate derivation from local source regions, with age spectra peaks of 1600, 1680 and 1840Ma consistent with emergent areas on the Gawler and Curnamona Cratons (Fig. 9: Ireland et al., 1998).

Detrital contribution from the Gawler Craton continued south of the Paralana-Kalinjala structural corridor as rifting recommenced with deposition of the basal Burra Group. Facies architecture at this time (early Torrensian) is highly asymmetric from west to east, with alluvial fan deposits sourced from the newly activated THZ passing upwards and laterally to the east into prograding delta front sandstones and shallow marine siltstone and shale (Fig. 1). In the Northern Flinders, proximal facies including conglomerate, pebbly quartzite and dolomitic siltstones sourced most probably from the Curnamona Craton were deposited in half grabens adjacent to the Paralana Fault. Activation of the Norwest Fault as a major basin bounding structure was still clearly evident however, with an extreme thickness contrast for Burra Group metasediments of 600m and 5300m either side of this structure (Figs 7, 8) noted by Paul et al. (1999).

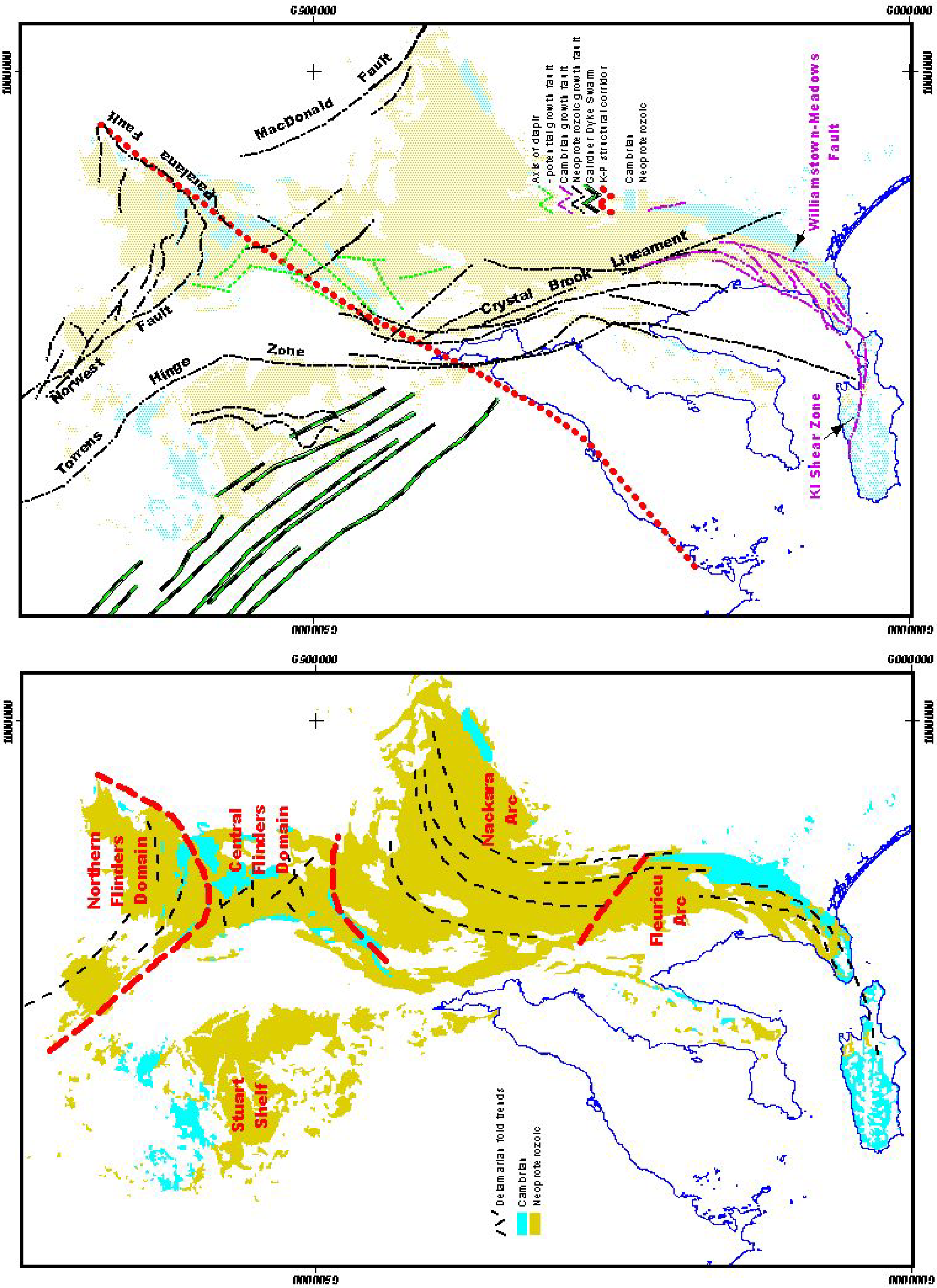

Figure 6. Structural domains of the Adelaide Fold Belt (left). Structural patterns are directly related to fundamental basin-bounding fault systems formed or reactivated during deposition of the Neoproterozoic– Early Cambrian system (right).

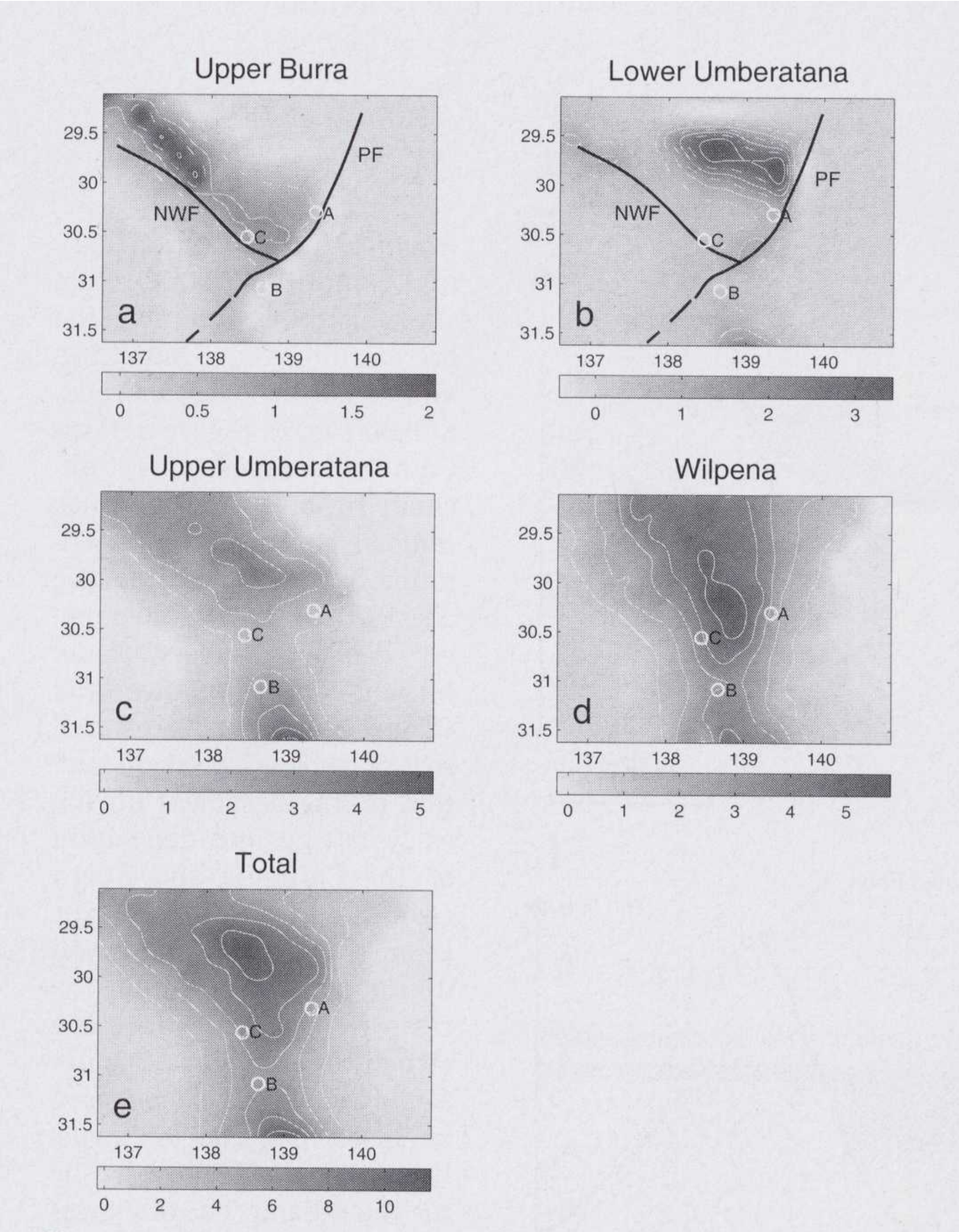

Figure 7. Isopach maps of the Northern and Central Flinders domains highlighting fundamental controls of the Norwest (NWF) and Paralana Faults (PF) on basin evolution (sourced from Paul et al., 1999).

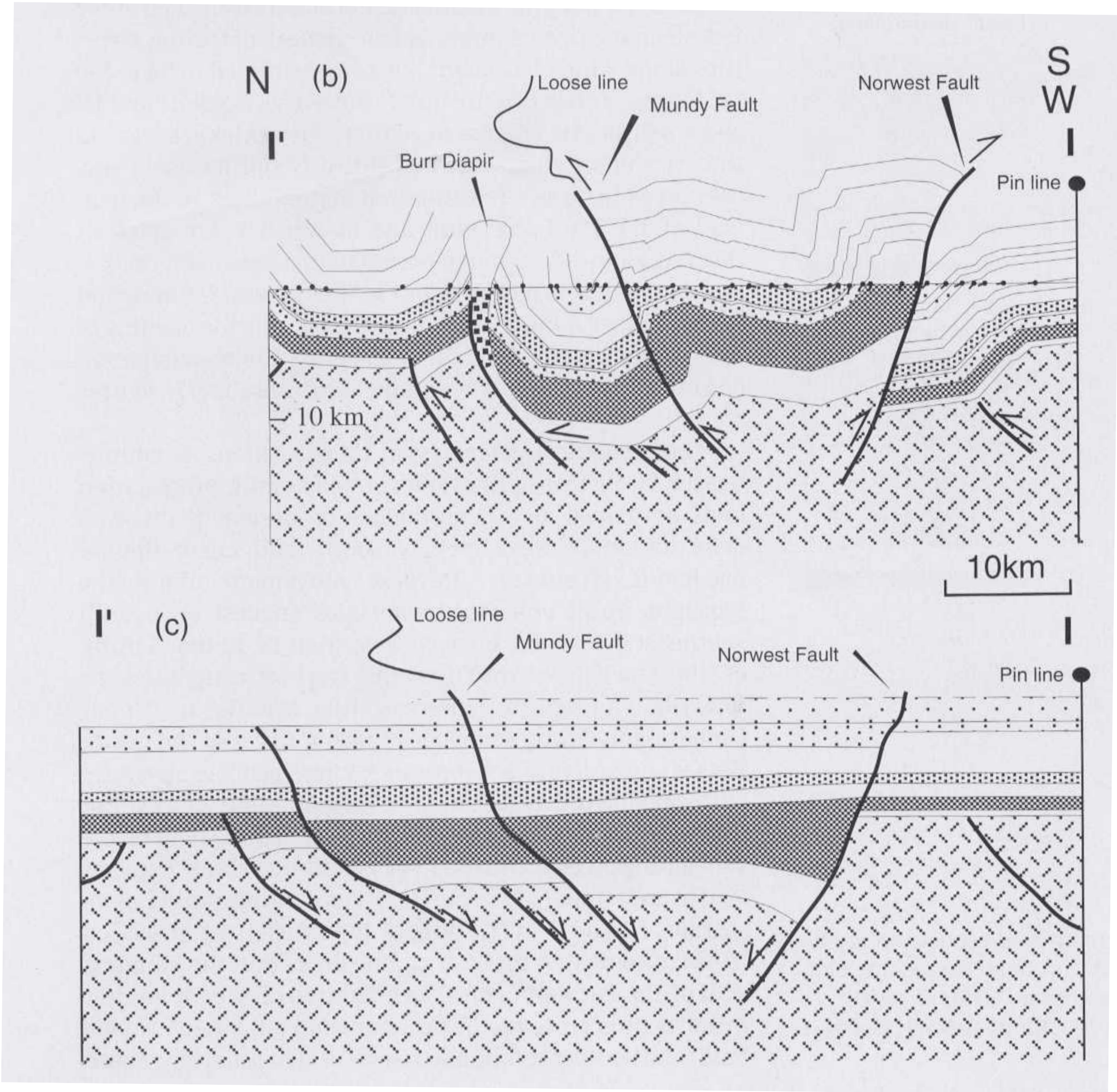

Figure 8. Restored sections across the across the Norwest (top) and Paralana Fault (bottom) systems. Sections highlight significant basin growth during deposition of lower stratigraphic levels and exhumation during Delamarian inversion (sourced from Paul et al., 1999).

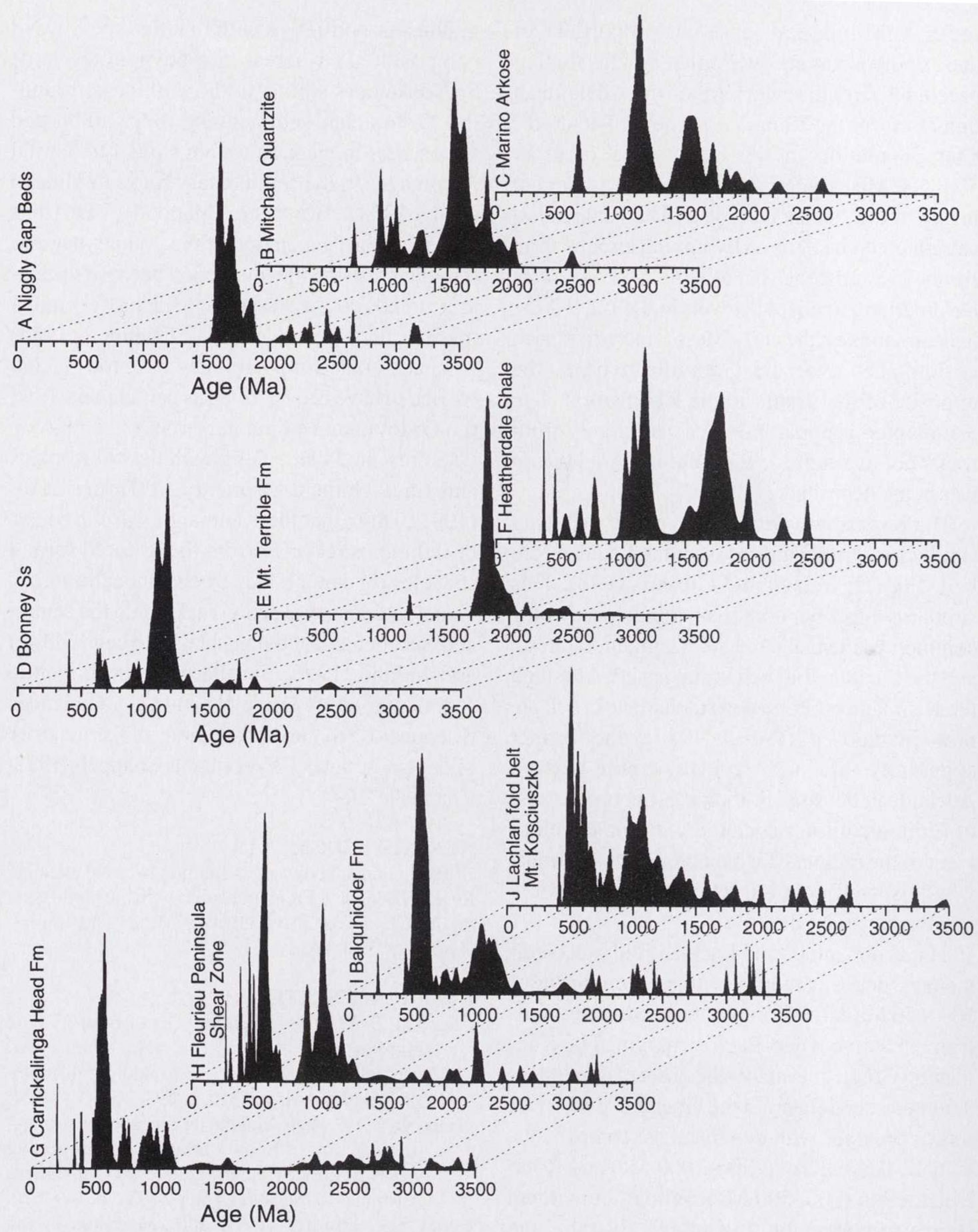

Figure 9. Detrital zircon age spectra. A-I are relevant to this study and demonstrate progressive shifts in source regions with basin evolution. Lowermost Neoproterozoic sandstones (A) are derived exclusively from local terrains with zircon ages consistent with Gawler Craton and/or Curnamona Province sources. A progressive enrichment of Grenvillian aged zircons (~1200 Ma) throughout the Burra – Wilpena cycles (B-D) indicates increasing contribution from exotic sources (potentially Musgrave Block *see Figure 1*). The sudden appearance of a 700-500 Ma detrital component at the onset of early Cambrian rifting (F-I) marks a fundamental change in basin development, with probable southerly contribution from the Ross Orogen. (after Ireland et al., 1998)

The middle portions of the Burra Group are carbonate-dominated, with paralic, lagoonal to very shallow marine conditions persisting during deposition of the Skillagolee Dolomite. Local facies variation and carbonate breccia units spalled from fault scarps indicate continued syn-depositional fault activity. Subsequent marine transgression is recorded by a resurgence of prograding deltaic sand wedges across laminated siltstone and dolomitic siltstones.

The early Sturtian Belair Subgroup marks the top of the Burra Group and comprises highly feldspathic cross-bedded sandstone at the base passing up to laminated siltstone. Detrital zircon populations within the basal arkosic units are in part analogous to those in the lower Callanna sandstones (with peaks at 1560, 1640 and 1820Ma), but has an additional contribution from a Grenvillean source (Fig. 9: Ireland et al., 1998). This change in provenance to source areas exotic to the immediate Adelaide Fold Belt is consistent with a broadening of the zone of rifting into the Sturtian. Potential Grenvillian source areas include the Musgrave Block and Albany–Frazer Belt.

Deposition during Torrensian times appears to be entirely restricted to the Adelaide Fold Belt, with no evidence of sedimentation on the Stuart Shelf.

Heysen Supergroup: An extensive erosional surface exists at the base of the Heysen Supergroup and angular discordances are particularly great in the central and northern Flinders regions (Coats and Dalgarno, 1983; Preiss, 1987). Coats and Preiss (1987) described erosional truncation of tight folds and angular unconformities in the order of 90° in the Willouran Ranges and a fossil regolith developed above overturned lower Warrina strata at Depot Creek. The nature of the forces leading to these high angle unconformities remains poorly understood, with gravity driven processes, tilt block rotation and minor compressive deformation offered by Preiss (op cit.) as possible explanations. A basin inversion event, albeit localised and relatively mild would have had significant implications for fluid flow within the Warrina Supergroup and requires further evaluation.

Despite the ambiguity of the lower contact, Heysen Supergroup rocks record unequivocal rift and sag tectonics which were considered by Powel et al. (1994) and Preiss (2000) to relate to marked acceleration in the breakup of the Rodinian super-continent.

Sturtian glacial deposits at the base of the sequence were largely confined to deep, narrow rift basins adjacent to the Curnamona Province (eg. Yudnamutana Trough), with a maximum of 9km of strata accumulating at Mt Painter (Fig. 1). Paul et al. (1999) recognised a progressive eastward and anticlockwise shift in depocentres throughout the Warrina cycle and earliest Heysen Supergroup packages, which they considered to have resulted from dextral displacement along the Paralana Fault system and synthetic WNW striking growth faults. The age of Sturtian glaciation event is not well constrained, with an upper age limit provided by Rb-Sr whole rock isochron of 750 ± 50Ma from the overlying Tapley Hill Formation (Webb and Coats, 1980).

The Tapley Hill Formation comprises laminated calcareous to carbonaceous siltstone and reflects a fundamental change in basin geometry, with significant broadening of the basin, and the first major marine transgression of earlier rift shoulders and cratonic blocks (Stuart Shelf and Curnamona Province). This change in basin geometry is reflected by provenance of detrital zircons from sandstones in the lower Heysen Supergroup, which record a dominant input from an exotic Grenvillian source region (Fig. 9: Ireland et al., 1998) at the expense of local basement sources of the Gawler Craton and Curnamona Provinces. This change in provenance potentially marks a swing away from detrital contribution from local rift shoulders, to more distal source regions (eg Musgrave Block and/or Albany Frazer Belt) fed by basin axial drainage systems. Local topographic expression during deposition of the Tapley Hill Formation is indicated by coarse grained facies adjacent to growth faults and slumping on the margins of emerging diapirs sourced from lower Warrina levels (Preiss, 1987). Similarly, on the

Stuart Shelf, local tectonic uplift is indicated by lapping of Tapley Hill Formation onto Pandurra Formation within the core of the Pernatty Upwarp.

The Tapley Hill Formation is succeeded by the Upalinna Subgroup, an eastward deepening system of shallow water platformal red-bed dominated siliciclastics and carbonates which interfinger with and pass laterally into more basinal siltstone dominated facies deposited under anoxic conditions. Significant tectonism and fault-controlled deposition of the basinal facies is most pronounced in the northern Flinders domain where voluminous breccia units (containing clasts as low as Burra Group levels) were shed from the THZ, Norwest Fault and parallel structures (Coats and Dalgarno, 1983).

Basinal conditions persisted throughout the Marinoan glaciation event within the northern Flinders domain and Nackara Arc where pebbly diamictite and dropstone facies occur in associated with laminated, commonly pyritic siltstone (Coats and Preiss, 1987; Preiss, 2000). By contrast, marginal marine to emergent conditions are recorded on the central Flinders domain and Stuart Shelf. Haematitic aeolian sandstones deposited on the Stuart Shelf transgress the Pernatty Upwarp at the Cattle Grid Mine where they are underlain by a periglacial regolith surface (characterised by cryogenic breccia and sand wedges) developed on Mesoproterozoic Pandurra Formation (Tonkin and Williams, 1983; Williams, 1998).

The uppermost Neoproterozoic package (Wilpena Group) consists of two upward shallowing cycles (Preiss, 2000). The oldest of the two cycles commenced with a post-glacial "cap carbonate" facies followed by basinal siltstone-dominated Brachina Formation and ultimately eastward deltaic progradation of the ABC Quartzite. Reactivation of the THZ, MacDonald Fault and Paralana Hinge Zone during middle and upper portions of the cycle is evidenced by localised but significant accumulation of sediment adjacent to these structures (Preiss, 1987). Basinal facies on the central Flinders domain accumulated in partly fault-controlled, NE-trending troughs (Preiss, op. cit.) in the region of Paralana Fault system, possibly indicating reactivation of this structural corridor and generation of isolated pull-apart basins.

Marine transgression at the base of the second cycle is recorded by red and green siltstones of the Bunyeroo Formation. A tuff-like layer occurs 80m above the base containing shock lamellae in quartz and micro shatter cones interpreted to be debris related to the Lake Acraman impact site (Fig. 1: Gostin et al., 1986). Rapid basin deepening and incision of pronounced basin slopes is indicated in the central and northern Flinders domains by enigmatic but conspicuous submarine canyon structures within the overlying Wonoka Formation. Canyons cut up to 1.8km into underlying strata (von der Borch and Grady, 1983) providing a minimum depth to basin floor and suggestion of connection with a deep ocean and significant continental break-up at Wonoka time (Preiss, 2000). Basinal facies of the Wilpena Group display relatively consistent thickness distributions, with a broad, apparently un-bounded SE dipping slope extending away from the Kalinjala–Paralana structural corridor (indicated by isopach maps; *see* Coats and Preiss, 1987) possibly indicating transition into a true passive margin setting. The uppermost portion of the Adelaidean system is dominantly arenaceous, comprising shallow water cross-bedded sandstones of the Pound Subgroup. Thickness distribution highlights *en echelon* NW trending elongate troughs displaced across the Paralana Hinge Zone (*see* Preiss, 1987). Detrital zircon populations show a near unique Grenvillian source component (Ireland et al., 1998) suggesting dominant axial drainage patterns, most probably derived from emergent Musgrave Block to the north-west.

Moralana Supergroup: Early to mid-Cambrian strata are preserved in two basins: the Arrowie Basin in the northern Flinders domain, extending westward onto the Stuart Shelf and eastward into the Curnamona Province (Fig. 10); the Stansbury Basin to the south corresponding largely with the Fleurieu Arc. After a depositional hiatus at the end of the Neoproterozoic, platformal siliciclastic and carbonate sedimentation re-commenced in the Early Cambrian with the lower Hawker and Normanville groups. Progressive deepening of the basin and potential onset of rifting is recorded in the upper parts of the Normanville Group by carbonaceous shale and renewed mafic magmatism (Heatherdale Shale and Truro Volcanics respectively). The main rifting phase (constrained by a 526 ± 4Ma U-Pb zircon age from a tuffaceous unit within the Heatherdale Shale) is recorded in the Stansbury Basin by the Kanmantoo Group, a rapidly deposited, turbidite-dominated package up to 8km thick. A marked unconformity between the Kanmantoo and Normanville Groups is evident in the south of the Fleurieu Arc, whereas conformable relationships at this boundary occur northward. Tectono-stratigraphic equivalents of the Kanmantoo Group in the Arrowie Basin are ambiguous and arguments in favour of the red-bed dominated Billy Creek Formation (Daily, 1970; Preiss, 2000) and the underlying carbonate–siltstone–greywacke package of the upper Hawker Group (Jenkins, 1990; Haines and Flottmann, 1998) have both been presented.

A swing to roughly NNW–SSE directed extension deviates from persistent NE–SW extension throughout much of the Neoproterozoic (Fig. 6). This fundamental change in basin geometry is marked also by northerly directed palaeoflow (Jenkins, 1990; Haines et al., 1996) and an abrupt change in source areas as indicated by zircon age spectra (Fig. 9). The appearance of a 500–700Ma peak largely absent in Precambrian strata was considered by Ireland et al. (1998) to record emergence of the Ross Orogen in Antarctica.

Margins of the Kanmantoo "trough" have been interpreted largely via removal of the effects of Delamarian shortening, which reveals significant stratal growth across NE striking fault zones within the Fleurieu Arc (Williamstown–Meadows Fault: Fig. 11) and E–W striking fault zones on Kangaroo Island (Flottmann et al., 1994; Flottmann and James, 1997). Constraints on basin geometry at Kanmantoo time in the Arrowie Basin are weak. It is interesting to note however, that the maximum preserved thickness of the upper Hawker Group defines an elongate NE-trending trough (Wopfner, 1970) which coincides roughly with the trace of the Kalinjala-Paralana structural corridor (Fig. 12).

Cessation of rift-related sedimentation occurred in response to plate convergence recorded by the Delamarian Orogeny. The presence of a clastic wedge or foreland basin which records the exhumation of the Delamarian fold-and-thrust belt has only been considered critically in recent times and remains a contentious issue. Jenkins (1990) considered that a flexural basin developed westward of the advancing thrust front, a model which has been upheld more recently by Haines and Flottmann (1998) and Belperio et al. (1998). Haines and Flottmann (op cit.) argued on sequence stratigraphic, biostratigraphic and chronological grounds that the "red-bed" packages which form the uppermost part of the Moralana Supergroup and are distributed about the western and northern margins of the Delamarian Orogen record a fundamental change in sedimentation and are the most likely candidates for syn-orogenic foreland deposition (Fig. 13).

Delamarian Orogeny

The effects of the Delamarian Orogeny are most intense in the southern Adelaide Fold belt, where the structural style is characteristic of a NW-directed, basement-involved fold and thrust belt (Marshak and Flottmann, 1996). Variable, but generally lower strains are recorded throughout the remainder of the Adelaide Fold Belt, Willyama Inliers and Mt Woods Inlier. The western limit of the orogen is defined roughly by the THZ, with platformal sediments on the Stuart Shelf remaining effectively undeformed. Zonation of high temperature, low pressure metamorphism (Sandiford et al., 1990) roughly mimics strain intensity, with sillimanite and locally migmatite grade occurring within the core of the orogen along the eastern Mt Lofty Ranges, passing progressively into mid-greenschist facies towards the foreland. Anomalously high grade metamorphism

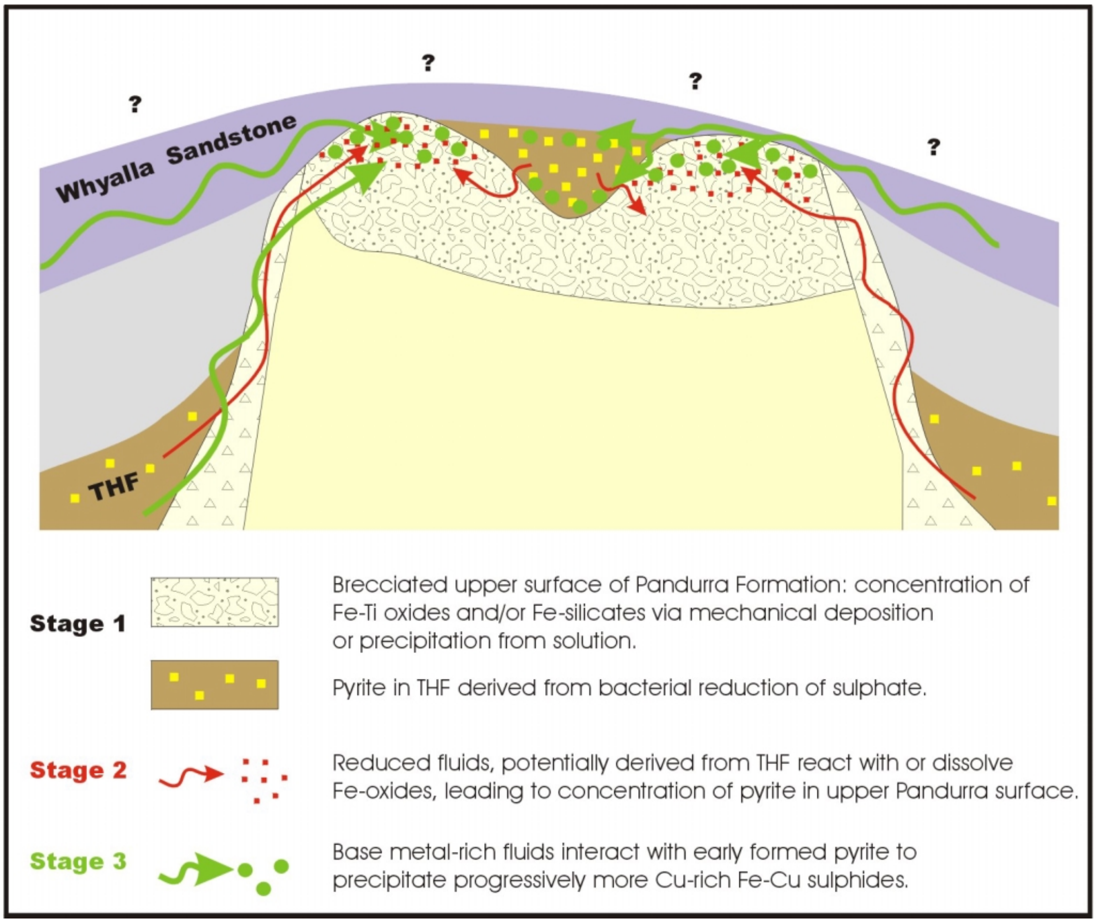

Figure 10. Cambrian basin development.

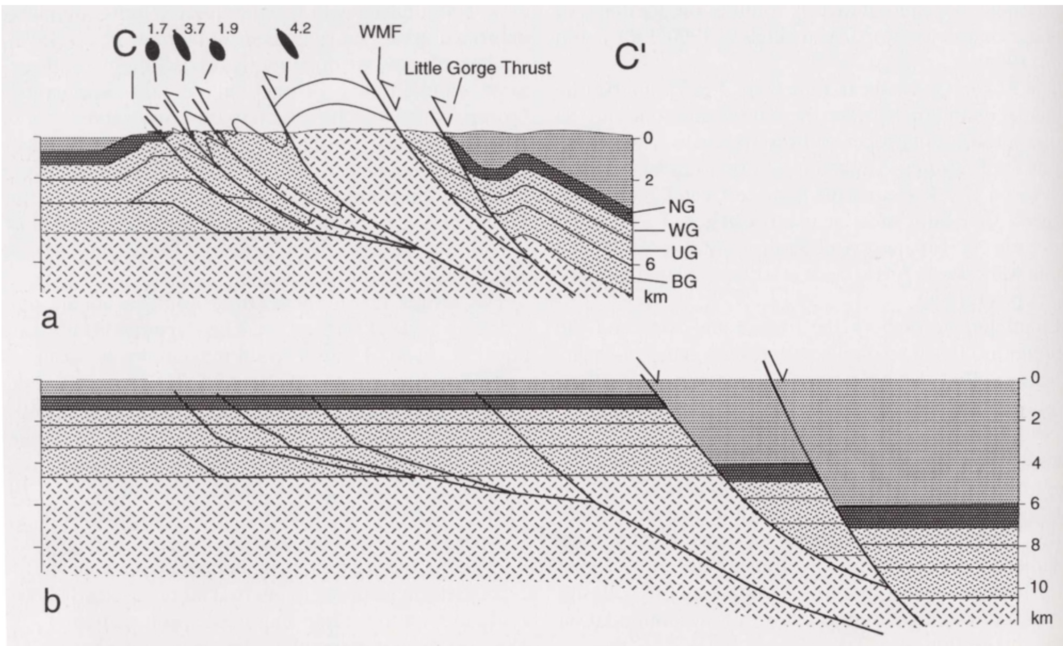

Figure 11. Balanced WNW-ESE section across the southern Fleurieu Arc demonstrating basement-involved (stippled) inversion of a major Cambrian basin-bounding growth fault (Williamstown-Meadows Fault). Cambrian stratigraphy shown as uppermost layer in restored section. (after Flottmann and James, 1997).

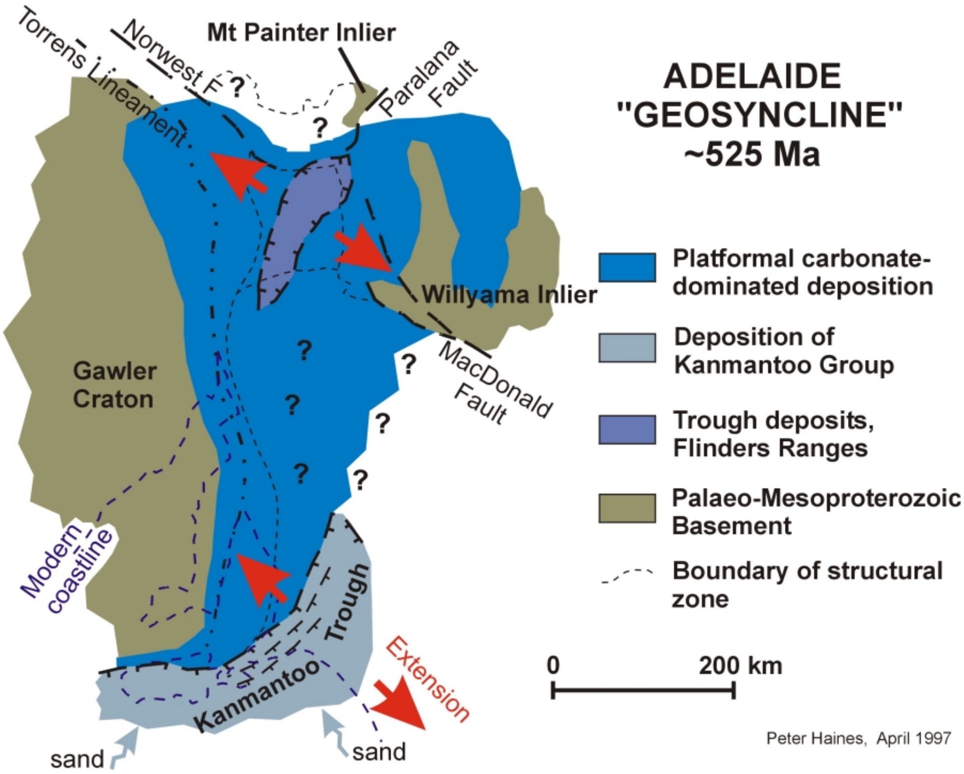

Figure 12. Distribution of platformal and basinal facies deposited during Early Cambrian rifting. Location of Flinders Ranges basinal deposits is based upon isopach maps from Wopfner (1970) and shows apparent rifting along the trace of the Kalinjala-Paralana structural corridor (modified from Haines and Flottmann, 1998).

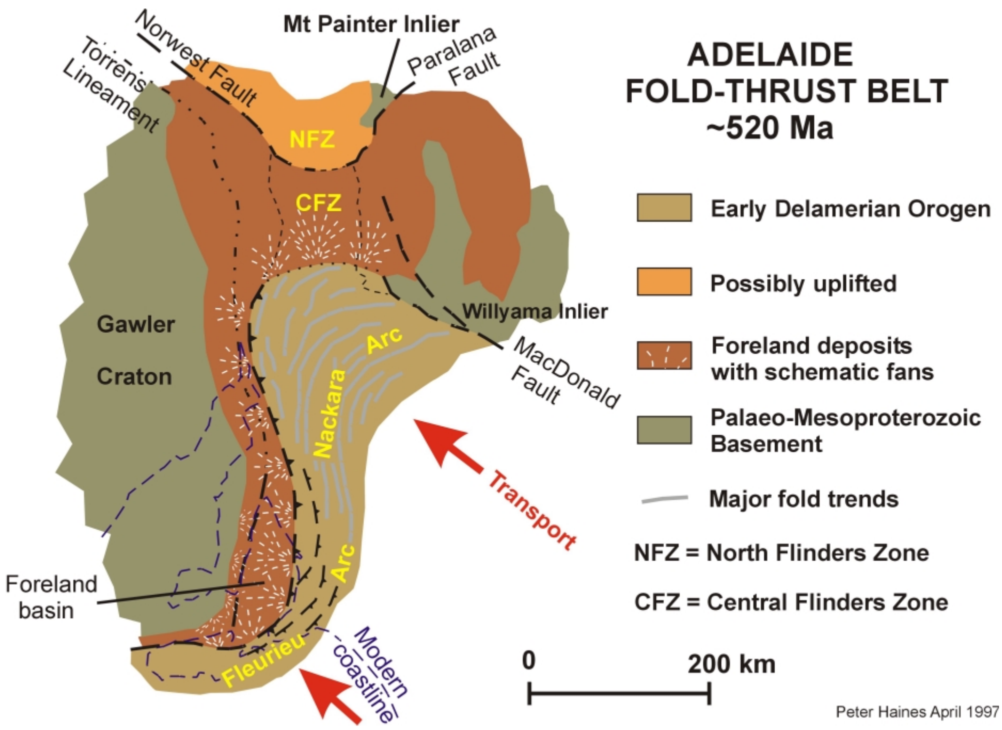

Figure 13. Schematic diagram showing proposed distribution of foreland 'red-bed' deposits outboard of the Delamarian Orogen (modified from Haines and Flottmann, 1998).

(amphibolite grade) occurs within lower Adelaidean strata around the margin of the Mt Painter Inlier, attributed to emplacement of Delamarian granites by Coats and Blissett (1971). However, Sandiford et al. (1998) favoured the combined effects of extraordinarily high heat producing basement granites and a thick, insulating sedimentary package to account for this apparently 'unconformity-related' metamorphic zonation.

Timing of deformation phases is constrained by syn-orogenic granites and their temporal relationships with various cleavage forming events. The most widely regarded minimum age for the onset of orogenesis is provided by the Rathjen Gneiss (516 ± 4Ma), a syn-tectonic granitoid which records all deformation phases of the Delamarian. I and S type granitoids accompanied the main compressive phases of deformation from 516–500Ma and subsequent relaxation and extension was accompanied by post-tectonic A type granites and mafic intrusives from 490–480Ma (Belperio et al., 1998).

Adelaidean Cu System

Overview

Copper mineralisation with the Neoproterozoic and Early Cambrian sequences is diverse in terms of its stratigraphic position, host rock, geometry and style, and degree of metamorphism. Deposits are invariably small in terms of world standards, commonly associated with low tonnage, high grade secondary ores, with Mt Gunson and Kanmantoo being the most economically important examples of primary ore mined in recent times (both of which are discussed in detail in following sections).

A large number of the deposits occur within relatively reduced shale-dominated facies, including the Tapley Hill Formation, Bunyeroo Formation and parts of the Burra and Kanmantoo Groups. Less common are carbonate hosted deposits occurring within the Wywyana Formation and Skillagolee Dolomite, sandstone-hosted mineralisation within the Pandurra Formation and Whyalla Sandstone, and basalt-hosted Cu occurrences within the Wooltana and Beda Volcanics (Fig. 1). As noted by Johns (1975) a significant number of deposits are hosted by diapiric breccias derived from evaporitic sediments at the base of the Warrina Supergroup. These occur mainly in the Northern and Central Flinders domains and include the major historical workings at Blinman.

Few deposits are strictly stratiform, as mineralisation transgresses layering in detail or is at least partially contained within veinlets. Stratabound occurrences are grossly tabular, largely restricted to a particular stratigraphic level at the deposit scale and range from low temperature, potentially early diagenetic deposits on the Stuart Shelf and low grade portions of the Adelaide Fold Belt, to high temperature skarn-type mineralisation at Mt Painter. The majority of deposits are discordant to bedding however, and are related to veins or disseminations within diapiric breccias, along fault zones or within high strain ductile deformation zones. Metamorphic grade of deposits ranges from effectively unmetamorphosed on the Stuart Shelf to amphibolite facies at Mt Painter and Kanmantoo.

There is a broad, macroscopic coincidence of many Cu occurrences with the margins or platformal shoulders of Adelaidean sub-basins (Figs 14, 15). Major growth structures with which Cu appears spatially associated include the Kalinjala-Paralana structural corridor, bounding structures of the Willouran and Yudnamutana Troughs, the MacDonald Fault Zone, major bounding structures of the Kanmantoo Trough (Talisker Fault and Kangaroo Island Shear Zone) and the enigmatic Pernatty Upwarp on the Stuart Shelf. Interestingly however, the Torrens Hinge Zone, arguably the most conspicuous and influential Neoproterozoic structural element, is largely devoid of Cu mineralisation (although this may simply reflect exposure of inappropriate levels of the stratigraphy).

Despite this apparent association with growth faults,

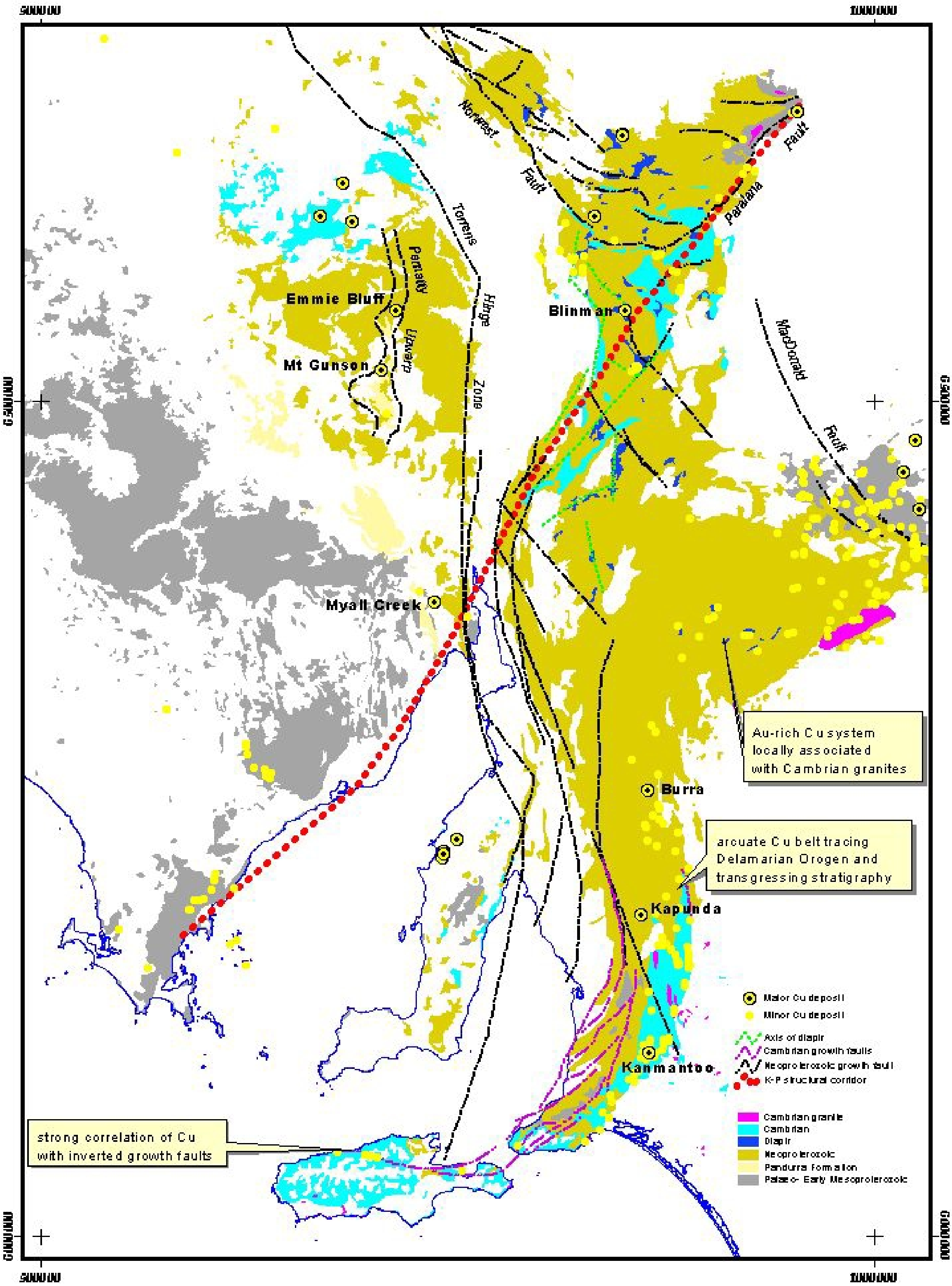

Figure 14. Distribution of Cu occurrences. Note broad association with growth faults, Kalinjala-Paralana structural corridor and the inner arc of the Adelaide Fold Belt.

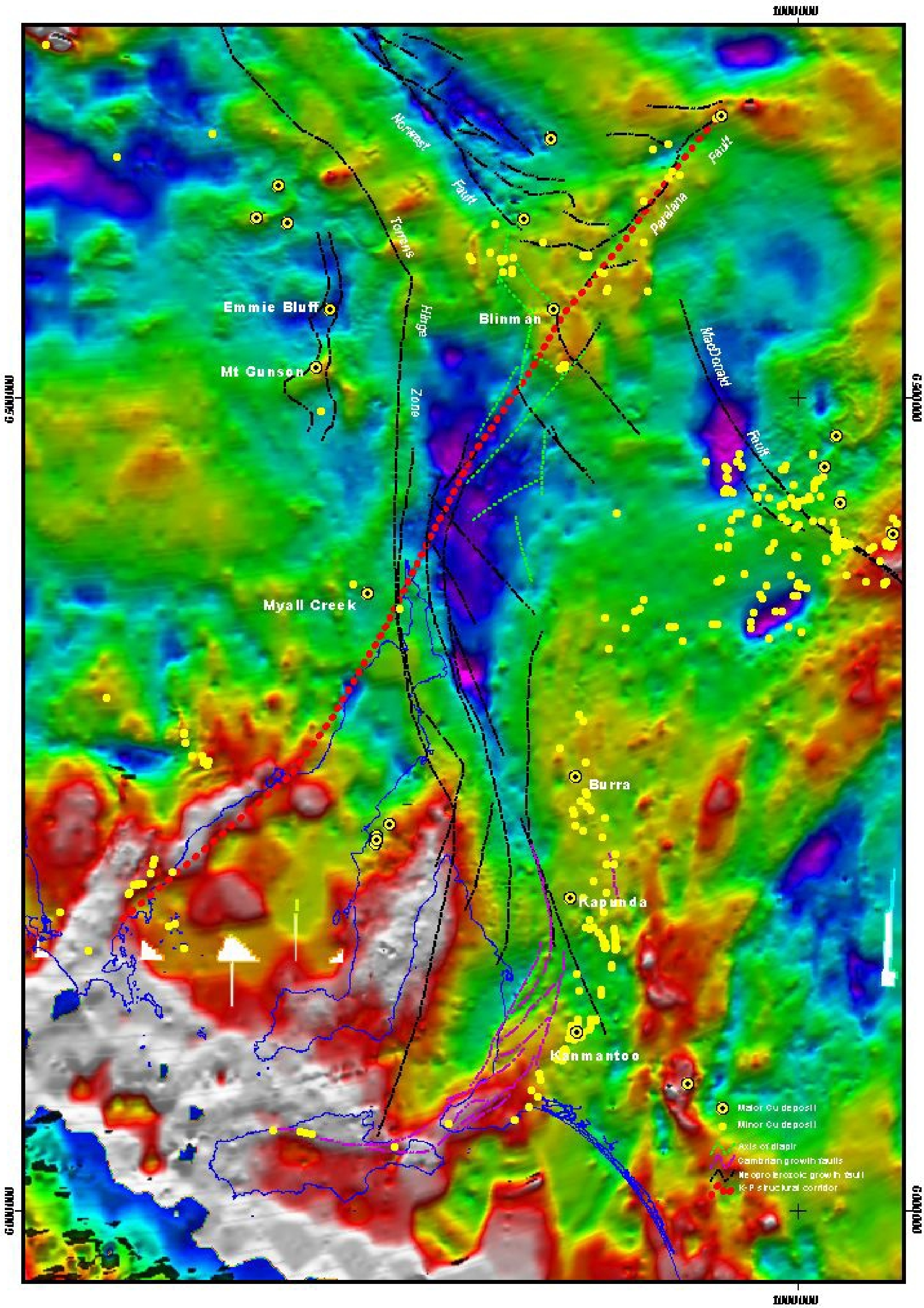

Figure 15. Cu occurrences overlain on Bouguer gravity image (PIRSA geophysical database). Note distribution of Cu on platformal margin of the northern Flinders depocentre.

the role of syn-depositional tectonism in the genesis of Cu deposits is unclear. For example, it can be argued that for many deposits Cu precipitation at least, is significantly younger that its host package. Even in the most convincingly syngenetic-early diagenetic deposits, those that occur on the Stuart Shelf, Cu-sulphides were consistently precipitated late in the mineral paragenesis (eg. Knutson et al., 1983), leading Mason (1982) to argue that the only syngenetic sulphide at the Myall Creek deposit was pyrite. Furthermore, at Mt Gunson nearly identical ore mineral assemblages occur at two distinct stratigraphic levels separated by at least 50 million years. In higher grade portions of the belt such as the Mt Painter province (arguably also the Fleurieu Arc), Cu-sulphides hosted mainly in the lower Warrina Supergroup, are intimately associated with the Delamarian peak metamorphic assemblage (Fairburn, 1982), with temperatures of sulphide precipitation having occurred in the range of 400°–550°C (as indicated from S-isotope data and fluid inclusion studies on quartz from mineralised veins: Ypma, 1976).

With the exception of the Pernatty Upwarp, a common association of the 'mineralised' growth faults mentioned above, is that they were all significantly inverted during Delamarian Orogenesis. This association raises the obvious question of the involvement of the Delamarian Orogeny in ore genesis. Did the basin-bounding structures simply form conduits to fluids expelled from strata during the inversion process? In favour of this argument is the structurally controlled nature of many deposits, evidence for hydrothermal mineralising fluids (with temperatures ranging 150°–550°C: Hall et al., 1986; Ypma, op. cit.), as well as the extensive belt of Cu deposits which trace the core of the fold belt. These latter deposits do not show a relationship to known growth faults, but form an arc which transgresses several stratigraphic levels from the Heysen to Moralana Supergroups. Thus at the macroscopic scale, some deposits show a much closer association with Delamarian structures than any particular level of the stratigraphy. On the other hand, evidence against late-stage basin inversion-related mineralisation is the lack of hydrothermal alteration associated with significant stratiform deposits such as Kapunda and those on the Stuart Shelf (Lambert et al., 1987). Furthermore, the delicate stratiform character of some fine-grained sediment-hosted deposits (such as Copper Claim; Lambert et al., 1984) is difficult to reconcile in a model which requires pumping of fluids through a consolidated, relatively impermeable medium.

In the following sections, I present details of the geology and possible origins associated with two end-members of the South Australian Cu system: the Stuart Shelf Cu Province and considerably higher metamorphic grade deposits contained within Cambrian sequences of the Fleurieu Arc.

Stuart Shelf Copper Province

Introduction and Regional Setting

The Stuart Shelf comprises a crudely rhomb-shaped 'platform' of Mesoproterozoic to Cambrian (dominantly siliciclastic) sediments, distinguishable from their lithostratigraphic equivalents in the Adelaide 'Geosyncline' by markedly condensed thicknesses and consistently low metamorphic grade and strains. Its eastern and southern margins are respectively defined by the sinuous THZ and the intersection of this tectonic feature with the enigmatic Kalinjala-Paralana structural corridor (Fig. 16). Structural controls on the western margin are more ambiguous where the Stuart Shelf package may simply lap onto rocks of the Gawler Craton. However, the crude NW trending boundary between the Pandurra Formation and the Gawler Range Volcanics at the southwestern margin of the 'platform' closely parallels the trace of the Gairdner Dyke Swarm, favouring at least partial structural control on the present day distribution of rock packages.

Macroscopic Structural Controls on Cu Distribution

There have been repeated associations made between the distribution of Cu deposits (of varying style and

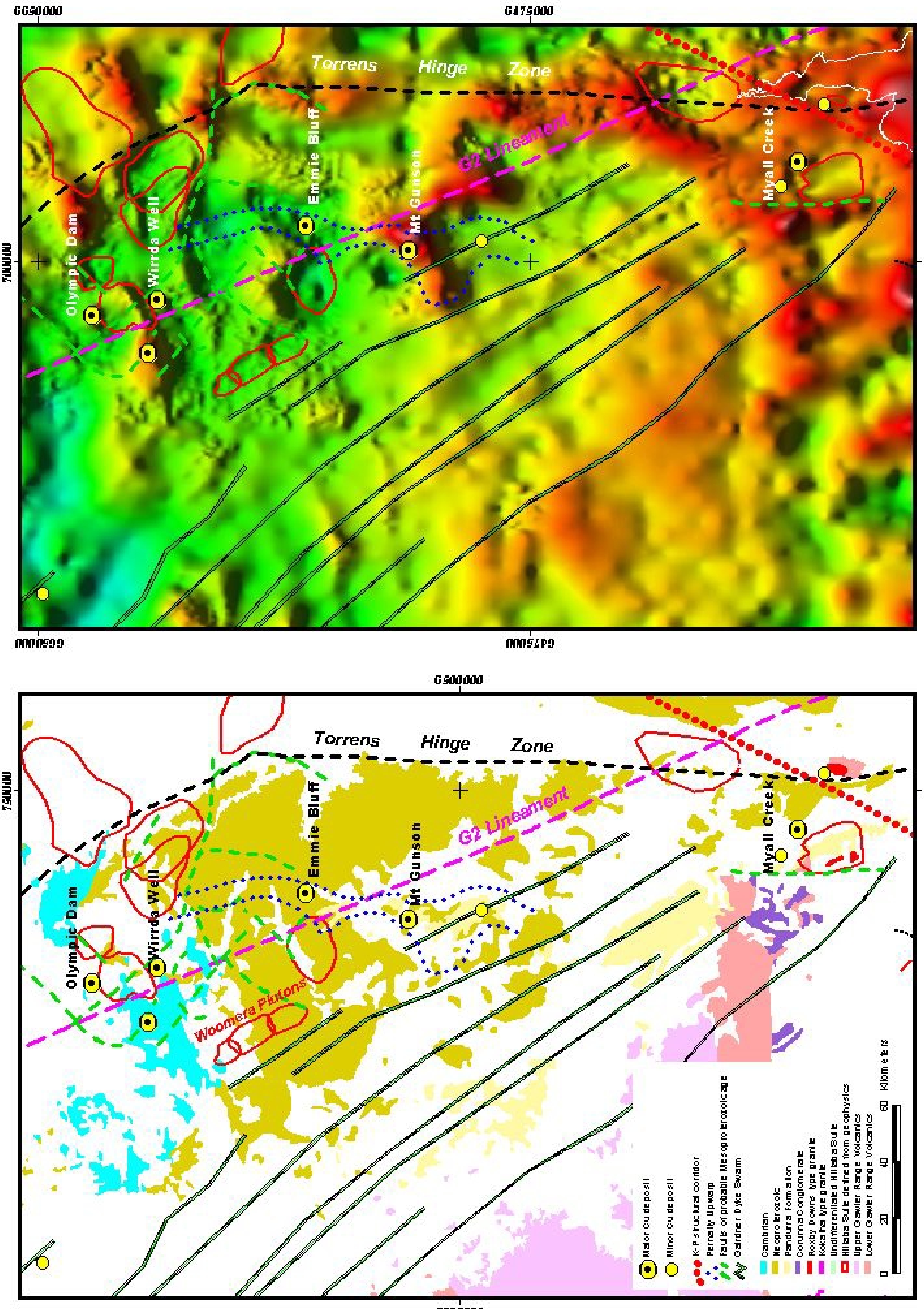

Figure 16. Geology, Cu occurrences and structural framework of the Stuart Shelf. Cu mineralisation has a spatial association with Hiltaba Suite granites at Emmie Bluff and Myall Creek, whereas Mt Gunson overlies altered basaltic units of the Lower Gawler Range Volcanics (shown as high density anomaly in residual gravity image).

ages) and lineaments (Knutson et al., 1983; Maiden et al., 1984; O'Driscoll, 1985; Lambert et al., 1987; Lintern et al., 1999). In general, these authors have interpreted lineaments as fundamental crustal structures which were multiply reactivated and formed fluid focussing elements throughout the Mesoproterozoic to the earliest Phanerozoic. Thus, structural lineaments have been proposed a fundamental genetic link between copper mineralisation of vastly different styles and ages. Knutson et al. (op cit), for example, highlighted the alignment of Olympic Dam, Mt Gunson, Myall Creek and Moonta-Wallaroo (Emmie Bluff could also be included within this group) within a crude NNW-trending corridor and invoked a "… long acting zone of deep crustal weakness …" to explain the apparent linear distribution of these deposits. Although this link is perhaps overly simplistic as there is no single macroscopic structural element apparent in geological or geophysical datasets to directly relate these deposits, it cannot be discounted entirely as there remains a crude parallelism of the mineralised 'corridor' with a fundamental Neoproterozoic tectonic feature, the THZ.

The internal structural geometry and development of the Stuart Shelf has been discussed in some detail in previous sections and is summarised below with further reference to the distribution of Cu deposits. Principal macroscopic structural orientations within and close to the margins of the Stuart Shelf (Fig. 16) include:

- NNW-trending G2 structural corridor (O'Driscoll, 1985) – a continental scale zone connecting prominent gravity lineaments at the western margin of the Mt Woods Inlier (northern SA) and that defining the Crystal Brook Lineament (western margin of Nackara Arc): encompasses hydrothermal Cu mineralisation at Olympic Dam, Wirrda Well, Emmie Bluff and sediment-hosted Cu mineralisation at Mt Gunson, Emmie Bluff (possibly also Kapunda)
- Crudely N- to NNE-trending Pernatty Culmination, a palaeotopographic feature, emergent by the Sturtian at least (see below): direct spatial association with sediment-hosted Mt Gunson and Emmie Bluff deposits.
- Prominent NW-trending structural fabric defined by the Gairdner Dyke Swarm: no obvious control on Cu mineralisation, but rough coincidence of NE limit of fabric in aeromagnetics with Mt Gunson.
- Localised and crude NW- to WNW- and NE-trending lineaments in the Olympic Dam province defined by alignment of the "Woomera Plutons" and discontinuous magnetic 'highs' defining fault-controlled zones of Fe-metasomatism: spatial and probable genetic association with Mesoproterozoic hydrothermal Cu deposits and possibly Emmie Bluff sediment hosted deposit.
- NE- to N-striking lineaments along the southern margin of the Stuart Shelf defined by KD_3 mylonite zones and the Kalinjala–Paralana structural corridor: tenuous spatial association with anomalous Cu mineralisation and Fe-metasomatism along the Roopena Fault, sediment-hosted and fault-controlled Cu mineralisation at Myall Creek and diapir-hosted Cu at Blinman.
- ENE-trending gravity lineament west of Moonta-Wallaroo: crude spatial association with Moonta-Wallaroo Cu lodes and minor Cu mineralisation at Tumby Bay (Fig. 3).

Association of Cu mineralisation with Hiltaba Suite Granites: A genetic association of Hiltaba Suite granites with the earliest phase (at least) of Fe-oxide Cu mineralisation on the Stuart Shelf is well established (Reeve et al., 1990; Gow et al., 1993; Gow et al., 1994). Although, a genetic association with Cu contained within the Neoproterozoic sediments is much more tenuous, there remains a conspicuous spatial association of sediment-hosted Cu mineralisation with skarn-like hydrothermal mineralisation in Wandearah Metasiltstone at Emmie Bluff and hydrothermal alteration/Fe-metasomatism and Hiltaba Suite granites in the southern Stuart Shelf region around Myall Creek. In the Myall Creek area, Tapley Hill Formation-hosted Cu mineralisation occurs both along veined fault zones (Pandurra and

Point Lowly Copper Mines) and as stratabound accumulations (Myall Creek Prospect). At each mine or prospect, mineralisation occurs within 15 km of outcropping Hiltaba Suite granite and in the case of the Pandurra Mine, within 10 km of base- and precious metal-bearing (up to 8.8% Cu), haematite altered lower Gawler Range Volcanics and Wandearah Metasiltstone (Flint, 1993). There are no known Hiltaba Suite granites in the vicinity of the Mt Gunson group of deposits, however Knutson et al. (1992) documented potentially co-magmatic, haematite-chlorite-carbonate-K felspar altered and LREE, Th and U enriched lower GRV at the base of the Meso-Neoproterozoic sedimentary package. Are these spatial relationships merely fortuitous, or is there a direct link?

A large-scale association of Hiltaba Suite granites and the Stuart Shelf is also evident in terms of granite composition and crustal heat flow. As pointed out in a previous section, there is a broad coincidence of 'Roxby Downs type' Hiltaba Suite granites and anomalously elevated surface heat flow values on the Stuart Shelf. Moreover, the western margin of the Stuart Shelf coincides with a transition to less radiogenic 'Kokatha-type' Hiltaba Suite granites and markedly lower surface heat flow values (although the latter data are very sparse). It could be argued therefore, that the basement to the Neoproterozoic package on the Stuart Shelf (and indeed the entire Adelaide 'Geosyncline') is 'anomalous' in terms of both its heat producing capability and its Cu abundance. Thus a link may be found to exist between Hiltaba Suite granites and heat-driven fluid circulation systems within the Neoproterozoic cover. This is an important aspect of the sediment hosted Cu systems and must be considered in the framework of the project.

Details of Individual Deposits

Stratigraphic Position: Copper mineralisation on the Stuart Shelf is mainly associated with the Pandurra (Cattle Grid Mine) and Tapley Hill Formations (Myall Creek, Emmie Bluff, Windabout, Sweet Nell prospects), with relatively minor concentrations occurring in the brecciated surface of the Beda Volcanics, lower portions of the Whyalla Sandstone and Tregolana Shale (Fig. 1). The most economically significant (but infrequent) of these deposits involve sandstone/breccia-hosted styles of mineralisation at the unconformable contact of the Pandurra Formation and Whyalla sandstone. Mineralisation within the carbonaceous-calcareous siltstone dominated Tapley Hill Formation is basically stratiform, however veinlet-hosted and/or dissemin-ated Cu-sulphides occur within a basal "white sandstone" package at Myall Creek.

Deposit	Stratigraphic Position	Size and Grade
Cattle Grid (Mt Gunson)	Brecciated interface of Pandurra Fm and Whyalla Sandstone	resource of 5.6Mt at 2.1% Cu at 1% cuttoff
Windabout	Black calcareous shale of the Tapley Hill Fm	with indicated resource of 18.75Mt at 0.96% Cu and 0.05% Co
Emmie Bluff	Black calcareous shale and siltstone of the Tapley Hill Fm; minor Cu in Pandurra Fm and Whyalla Sandstone	inferred resource 24Mt at 1.3% Cu
Sweet Nell	Black calcareous shale of the Tapley Hill Fm	inferred resource 350000t at 1.2% Cu
MG14	Black calcareous shale of the Tapley Hill Fm	indicated resource 1.1Mt at 1.7% Cu
Cattle Grid South		inferred resource 700000t at 1.7% Cu
Myall Creek	White sandstone and black shale at base of Tapley Hill Fm	intersections of >0.5% to 1.5% Cu, no resource estimation

Local Structural or Palaeotopographic Features: Local facies variations, in part controlled by syn-depositional palaeotopographic features, appear to have a fundamental control on the distribution of Cu mineralisation (eg. Maiden et al., 1984). The most conspicuous of these features is the Pernatty Upwarp (Johns, 1975), a roughly N-S trending series of horst blocks cored by Pandurra Formation sandstone and spatially associated with the Mt Gunson group of deposits and Emmie Bluff (Figs 16, 17). In detail, the 'upwarp' is controlled by NW- and NNE-striking faults, largely defined from geophysical datasets. At Mt Gunson, Tapley Hill Formation strata generally pinches out against the Pernatty Upwarp, in part due to uplift and erosion, but probably also due to original depositional constraints. Rare NW-trending elongate 'basins' containing remnants of mineralised Tapley Hill Formation strata occur upon the crest of the horst block (eg. MG14). Faulting was active and the core of the horst block clearly emergent during the Marinoan glacial period however, as indicated by a periglacial brecciated regolith developed in the upper surface of the Pandurra Formation (Williams, 1998).

Mason (1982) recognised coincident thickness and facies variation within the Tapley Hill Formation and underlying Backy Point Beds and Beda Volcanics (lower Warrina Supergroup) in the Myall Creek area. He alluded to accumulation of the Adelaidean sequence within eastward thickening, N-S trending half-grabens developed on a Pandurra Formation substrate. Erosional unconformities occur both at the base of the Warrina Supergroup and Tapley Hill Formation. Greater thicknesses of Tapley Hill Formation strata (including localisation of the mineralised basal white sandstone member) occur where the unconformity at the base of this package cuts down into more readily eroded Backy Point Beds, producing N-S trending 'palaeovalleys' (Fig. 18). In contrast to the Mt Gunson group of deposits, there is no Cu mineralisation over 'topographic highs'.

Mineralisation

The **Cattle grid** orebody is tabular, measuring 1500x700m in plan and averaging 4.5m thick. Sulphides are dominated by chalcocite, bornite, chalcopyrite, pyrite, galena and sphalerite which occupy a secondary porosity developed as fracture, vug and intraclast infilling within the periglacial breccia situated at the top of the Pandurra Formation (Knutson et al., 1983; Tonkin and Williams, 1983). Mineralisation drops off rapidly into lower portions of the Pandurra Formation, where sulphides occur mainly as replacement of Fe-Ti oxide minerals. Grade correlates broadly with the intensity of brecciation and is restricted to zones in which the Pandurra Formation is directly overlain by the Whyalla Sandstone (ie. where the Tapley Hill Formation is absent). Minor, poddy high grade mineralisation extends upwards into the overlying Whyalla Sandstone where Cu sulphides form a cement or in some instances replace detrital Fe-Ti oxides (Knutson et al., op. cit; Maiden et al., 1984). No evidence exists for hydrothermal alteration.

Knutson et al. (op. cit.) recognised replacement textures and a paragenesis of sulphide minerals within the secondary porosity which involved replacement of pyrite and Cu-Fe sulphides by progressively more Cu-rich phases and ultimately sphalerite-galena. They interpreted this paragenesis in terms a history of crystallisation–solution–recrystallisation.

Mineralisation in Tapley Hill Formation-hosted deposits is restricted mainly to the unconformable base of the package, however sporadic elevated grades also occur at the top. Principal sulphides are the same as those in sandstone-hosted deposits (although tennanite is a conspicuous phase at Myall Creek) and display a similar paragenesis, with progressive replacement of pyrite by Cu-sulphides (Mason, 1982; Knutson et al., 1983; Lambert et al., 1984). Pyrite possesses colloform, framoidal and euhedral habits commonly preserved within cores of rounded chalcopyrite-bornite bodies. Sulphide mineralisation is generally coarser grained and

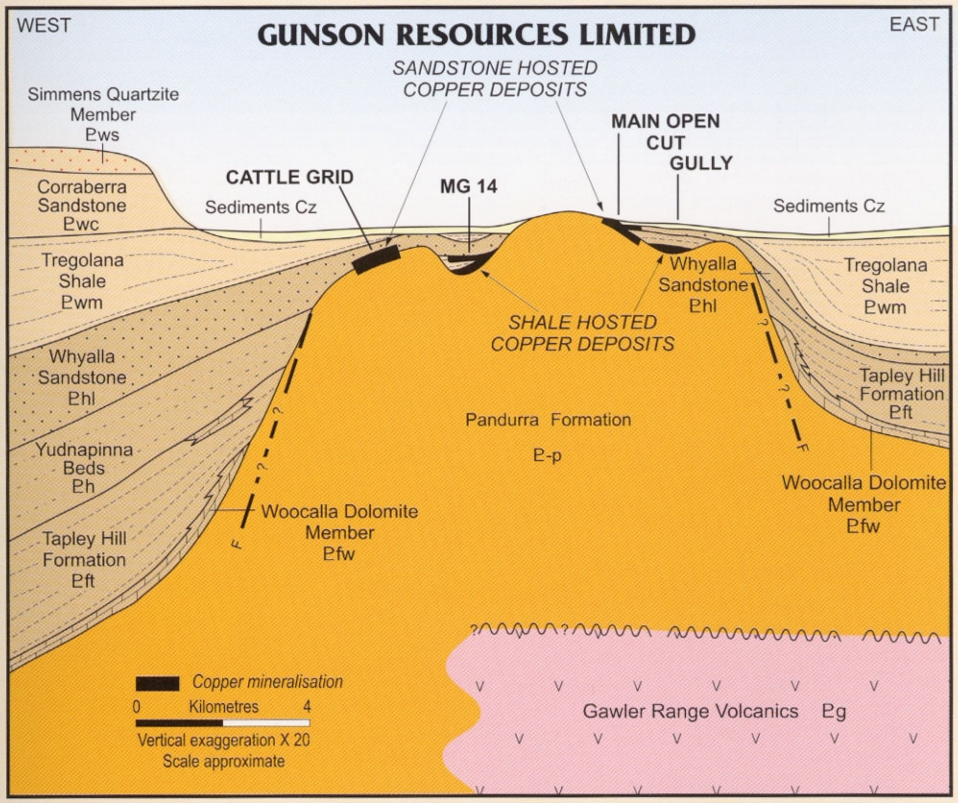

Figure 17. Cartoon showing thinning of Neoproterozoic strata and distribution of Cu mineralisation within Tapley Hill Formation dolomitic siltstones and Whyalla Sandstone on an elevated horst block: Pernatty Upwarp.

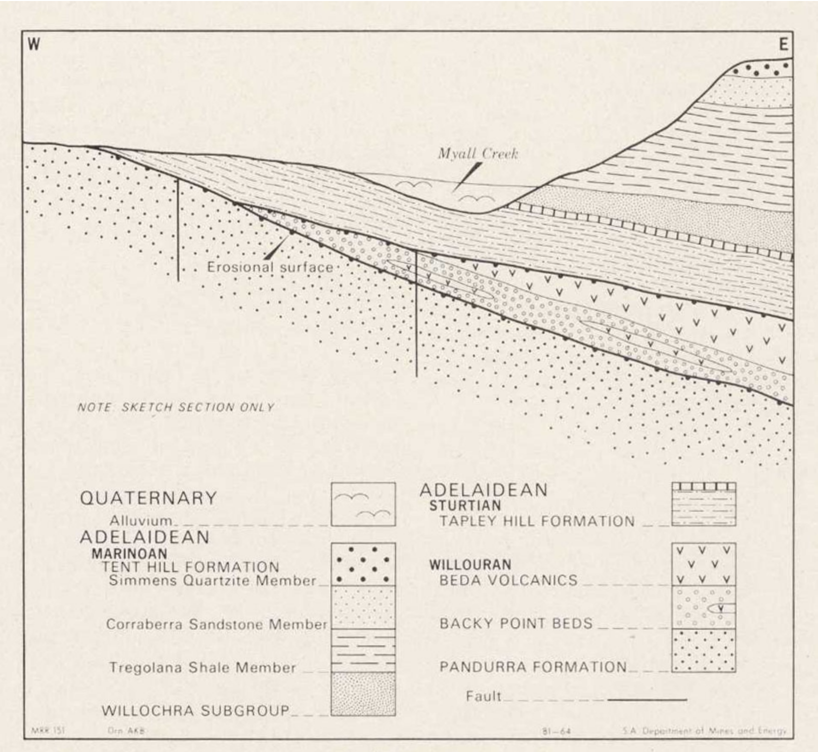

Figure 18. Cartoon showing stratigraphic relationships between Pandurra Formation and the Neoproterozoic package at Myall Creek. Greatest thickness of the Tapley Hill Formation, along with coincident Cu mineralisation, occurs where its basal unconformity cuts down into Backy Point Beds. Note that the Pandurra Formation is no longer considered to form part of the Adelaidean system (as shown). (sourced from Mason, 1982)

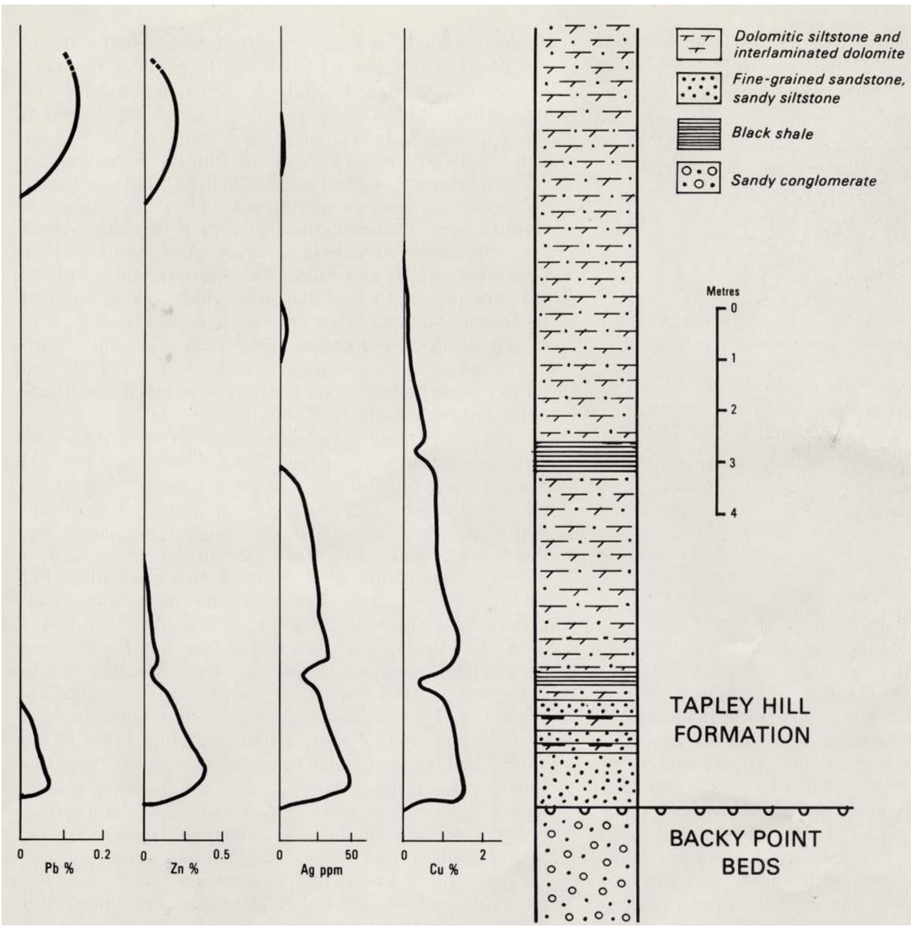

Figure 19. Vertical zonation of base and precious metal mineralisation within the lower part of the Tapley Hill Formation at Myall Creek. Mineralisation is concentrated within 'permeable' sandstone at the base of the package, with enrichment of disseminated and vein-hosted sphalerite and galena at the top (sourced from Lambert et al., 1984).

concentrated with more permeable horizons within the sedimentary pile: sandy and silty beds at Myall Creek (Fig. 19) and clastic mudstone layers at Mt Gunson.

Evidence exists for pre-lithification formation of mineralisation includes presence of sulphides within dewatering structures and wrapping of compacted sedimentary layers around partly replaced pyrite grains (Knuston et al., op. cit.). Dolomitic lithotypes display greater degrees of lithification during mineralisation as indicated by chalcopyrite, sphalerite and galena veinlets. At Myall Creek, Mason (op. cit.) documented a crude vertical textural and compositional zonation from lower Cu-Pb-Zn-Ag to higher level Zn-Pb-Ag mineralisation, in part reflecting the permeability of the host medium (Fig. 19). Within the basal sandstone horizon, base metal sulphides replace clastic grains or less commonly occur as disseminations throughout the matrix or within veinlets. As the package becomes thinner bedded and more dolomitic upsection, chalcopyrite becomes concentrated within silty lamellae or veinlets within dolomitic lamellae, ultimately giving way to sphalerite and galena. He also noted an inversely proportional relationship between the distribution and abundance of pyrite and base-metal sulphides. A similar vertical zonation occurs at Mt Gunson, where Cu is dominantly confined to upper and lower contacts of the Tapley Hill Formation, whereas Zn and Pb abundances extend further into the core of the package (Knutson et al., op cit.).

Geochemistry: Whole rock geochemical data are relatively sparse at the Cattle Grid Mine, with elemental associations being consistent with that expected from petrographic studies. That is, there is a positive correlation of Cu, Pb, Zn and S, and within lower, more weakly mineralised parts of the orebody, an association of Zr, Cu, Pb and Co, which is consistent with replacement of detrital heavy mineral phases by base-metal sulphides (Knutson et al., 1983). There is no correlation between Fe_2O_3 and SO_3 in the Pandurra Formation, suggesting Fe and S were introduced by different processes (ie. Fe introduced detritally or as a separate fluid infiltration event from S: Knutson et al., op cit.). A strong positive correlation of SO_3 and Fe_2O_3 in the overlying Whyalla Sandstone, however, may reflect a common source for these elements (ie. reworking of detrital pyrite from the Tapley Hill Formation as suggested by Knutson et al., op. cit.). Furthermore, positive correlation of Cu and SO_3 in both the Pandurra Formation and Whyalla Sandstone implies either coeval introduction of Cu and S or complete and/or consistent levels of replacement of pyrite by Cu.

Base-metal sulphides at the Cattle Grid mine contain light S-isotope values ($\delta^{34}S$ values of –15.1 to –3.7 permil). Knuston et al. (op cit.) interpreted these data to indicate S-derivation by biogenic sulphate reduction due mainly to the lack of evidence for elevated T during fluid infiltration (ie. thin sedimentary pile, no coeval magnetism, no evidence of hydrothermal alteration). The absence of organic matter within the sandstones however, suggests that S could not have been precipitated *in situ* by this process. However leakage from nearby carbonaceous siltstones remains a possible source.

Similar elemental associations occur within Tapley Hill Formation-hosted deposits (but including enrichment in As, Co and Ni, with elevated Mn and Ba in dolomitic units), with Fe and Ti depletion in mineralised zones at Myall Creek considered by Lambert et al. (1984) to reflect breakdown of Fe-Ti oxides. At Mt Gunson, greater interdependence of $C_{organic}$, Fe_2O_3 and SO_3 within pyritic zones compared to Cu-Fe sulphide zones is suggestive of: (1) sulphur production via bacterial reduction of sulphate, (2) loss of Fe and/or S during mineralisation and (3) separate sources for Cu and S (Knutson et al, op cit.). S-production via low T bacterial reduction of sulphate is supported by S-isotope values from base metal sulphides in the Tapley Hill Formation which display a wide and unsystematic variation (–3.6 to +44.6 permil) and isotopic disequilibrium between coexisting sulphide phases (Knutson et al., op. cit.; Lambert et al., 1984).

Ore Genesis: Concentration of base-metal mineralisation within more permeable units of the Tapley Hill Formation and the brecciated surface at the top of the Pandurra Formation has been put forward as evidence for early diagenetic, pre-compactional infiltration of ore fluids. This certainly appears to be the case for precipitation of early formed pyrite at least, which shows textural evidence of pre-lithification mineral growth.

In order to account for the apparent lack of correlation between S and Fe abundances in the Cattle Grid deposit, coupled with the textural evidence for late stage introduction of Cu-bearing fluids and the problems of carrying base metals in low T sulphide-bearing solutions, Knutson et al. (1983) constructed a complex mineralisation model involving multistage fluid infiltration and consequent precipitation-solution-recrystallisation (Fig. 20). They considered that Fe was originally deposited in the Pandurra Formation within the secondary porosity produced by weathering and/or glaciation. Fe was introduced in either particulate or solution form, potentially sourced from eroded Tapley Hill Formation strata, and deposited as oxides or silicates. Reduction of and dissolution of Fe-oxides and silicates then resulted from downward infiltration of fluids circulating through the Tapley Hill Formation, with transport along a decreasing pressure gradient along the margins of the Pernatty Upwarp leading to concentration of Fe-sulphides near the crest of the horst. Subsequent infiltration of Cu-bearing fluids, possibly along aquifers within the permeable Whyalla sandstone resulted in precipitation of Cu-sulphides within suitable chemical and physical (ie. permeable) traps.

Cu-mineralisation in the Tapley Hill Formation has some similarities to Kupferschiefer-style deposits: association of framboidal syngenetic pyrite, concentration of mineralisation above a disconformity involving fine-grained reducing basinal sediments overlying oxidised arenaceous units, vertical mineral zonation, and in the case of Myall Creek, concentration of Cu within a basal permeable sandstone (Mason, 1982; Knutson et al., op. cit.). Lambert et al. (1984) favoured a syngenetic origin of the Cu mineralisation involving reaction of metalliferous brines (having interacted with basement Cu concentrations or Cu-bearing basement lithotypes such as mafic volcanics) with biogenic H_2S in Tapley Hill Formation strata. Mason (op cit) and Knutson et al. (op. cit.) were more circumspect about invoking a syngenetic origin, however, noting the progressive replacement of early formed pyrite by Cu-rich phases. Furthermore, the apparent fundamental inter-relationship of Cu-mineralisation and permeable horizons suggested to Knutson (et al., op. cit.) that fluids were introduced during at least partial permeability loss in the sedimentary pile. The vertical zonation of metals with respect to the upper and lower, presumably permeable, disconformable contacts of sedimentary package is also difficult to resolve in terms of a syngenetic model.

Although the clear spatial association between Cu-mineralisation at Mt Gunson and the Pernatty Upwarp provides good evidence for the control of ‘basement highs’, both in terms of creating a fluid pressure gradient and producing fluid focussing geometries by pinch-outs of impermeable cap rocks, it is less obvious at Myall Creek. If the tectono-stratigraphic model presented by Mason et al. (op cit.) is correct, the deposit is situated well away from any growth fault and in the hangingwall of a half-graben system. Here the principal control on Cu-distribution appears to be the combined effects of localised erosional breaching of an impermeable cap rock (the Beda Volcanics) and coincident high permeable strata at the base of the reducing package.

Origin of the Cu remains poorly understood, however basement-hosted Olympic Dam style hydrothermally mineralised systems or mafic igneous sequences are obvious choices. Drilling below the Mt Gunson deposits intersected haematite-altered lower GRV mafic to intermediate units, which according to Knutson et al. (1992) are depleted in Cu relative to typical GRV abundances, raising the possibility of metal leaching. They suggested that if such a source

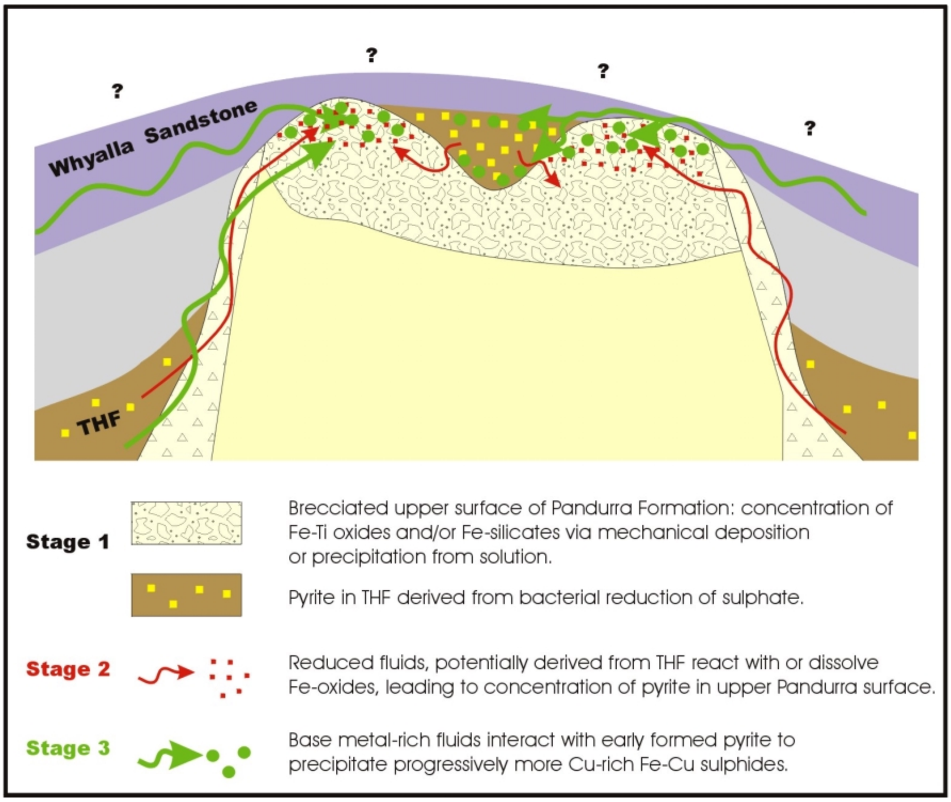

Figure 20. Cartoon showing multistage precipitation – dissolution – recrystallisation origin of Mt Gunson deposits as interpreted by Knutson et al. (1983).

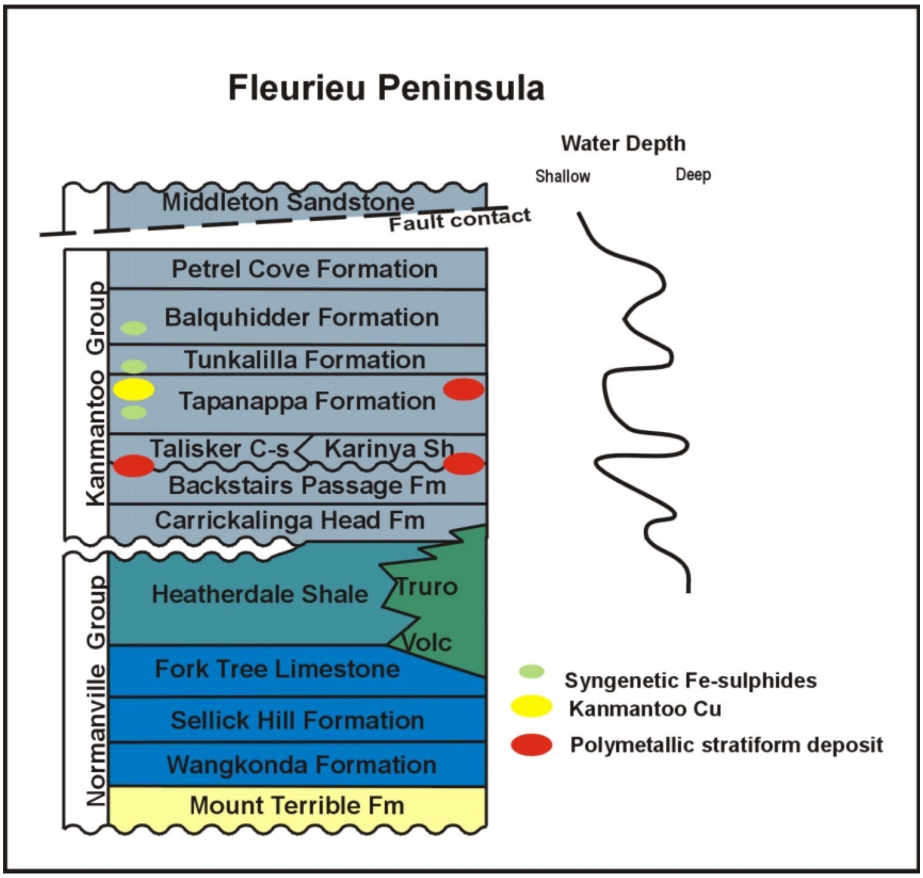

Figure 21. Early to Middle Cambrian stratigraphy of the Fleurieu Peninsula showing distribution of sulphide mineralisation and sequence boundaries as indicated by sharp increases in water depths (modified from Haines and Flottmann, 1998; Belperio et al., 1998).

rock was insufficiently buried as to allow protracted interaction with oxidative ground waters, metals could be repeatedly remobilised and concentrated in favourable geological environments in the cover sequence.

Cambrian-hosted Mineralisation

The Cambrian system is host to numerous low tonnage base metal deposits (Fig. 14). These include generally stratabound Pb-Zn ± Ag ± Au deposits and prospects of probable syngenetic origin (Seccombe et al., 1985; Belperio et al., 1998) and discordant, disseminated or crudely stratabound Cu ± Au lodes, the most economically significant of which is the Kanmantoo mine. Genesis of the latter is a fairly contentious issue and will be discussed in more detail below.

The majority of the deposits are hosted by relatively high metamorphic grade and strained portions of the Kanmantoo Group and in most cases conform to two or three specific levels of the stratigraphy: Tapanappa Formation, Talisker Calc-siltstone and Carrickalinga Head Formation (Fig. 21: Belperio et al., 1998). Belperio et al. (op. cit.) noted that some mineralised units are dominated by anoxic and pyritic basinal facies, the basal contacts of which coincide with major sequence boundaries followed by basin flooding. These workers also drew attention to the fact that many stratabound base metal and Fe-sulphide occurrences are situated at or immediately above sequence boundaries. However, this relationship does not appear to be universal and some of the more important Cu deposits such as Kanmantoo and Bremer, and Pb-Zn deposits including Aclare and Wheal Ellen occur at a common stratigraphic level within the upper part of the relatively shallow water Tapanappa Formation (Seccombe et al., 1985).

There are widely divergent views concerning importance of structural control on mineralisation. Seccombe et al. (1985) was unable to recognise any structural link with what they considered to be syngenetic primary base metal mineralisation (including the Kanmantoo mine) within the Tapanappa Formation (although they conceded that growth faulting and seismic pumping during basin formation may have played a role in generating fluid convection cells), whereas Oliver et al. (1998) considered the Kanmantoo deposit to have evolved entirely during the waning stages of the Delamarian Orogeny, its position and geometry having been largely structurally controlled. Parker (1986) stressed the importance of NW trending lineaments and shear zones on the distribution of important Cu deposits and on this basis drew a structural link between Neoproterozoic hosted mineralisation at Kapunda and Cambrian hosted mineralisation at Kanmantoo and Bremer. He did not however, shed much light on the possible origin or age of these lineaments. On Kangaroo Island and the southern Fleurieu Peninsula, there is a strong spatial association of minor disseminated and vein hosted base and precious metal mineralisation with the highly strained inverted basin margin faults: Kangaroo Island Shear Zone and Talisker Fault. These deposits are crudely stratabound, being contained within mylonitised members of Tapanappa Formation, Talisker Calc-siltstone and Tunkalilla Formation but are intimately associated with commonly layer-parallel structural fabrics. The Talisker Mine (As-Cu-Pb-Ag) for instance, comprises elongate quartz rich veins and shoots plunging parallel to a stretching lineation which records the transport direction during basin inversion (Belperio et al., op. cit).

Base metal occurrences lying outboard of the Delamarian Orogen are rare and generally insignificant. They are perhaps worthy of note, however, considering the position of Zambian Copper Belt deposits within and near the periphery of a major fold and thrust belt. Belperio et al. (1998) noted the presence of alternating redbed-to-marine transgressive cycles in the Cambrian shelf sequences on Yorke Peninsula and northern Kangaroo Island and highlighted the potential for Kupferschiefer type deposits associated with early diagenetic basin dewatering. They tentatively associated sporadic Cu values contained with Normanville Group equivalent sandstones on northern Kangaroo Island with this style of mineralisation.

Kanmantoo Mine

Introduction and Regional Setting: The main resource at Kanmantoo was mined from 1970 to 1976, yielding 4Mt of ore at 1% Cu. It is hosted within relatively fine grained Tapanappa Formation which was metamorphosed to amphibolite grade during the Delamarian Orogeny to form andalusite-staurolite-sillimanite-garnet schist. Oliver et al. (1998) recognised a progressive increase in metamorphic grade towards the mine, with peak temperatures estimated at 350°–450°C in outboard biotite zones to 600°–650°C in sillimanite zones. In addition, they showed that peak metamorphism occurred syn-D_2 away from the mine, but syn- to late D_3 at the mine itself. They attributed this temporal discrepancy between peak metamorphism and cleavage forming events to be the result of infiltration metasomatism late in the tectono-thermal history.

A number of small stratabound Pb-Zn deposits occur within vicinity of (up to 20km along strike), and at similar stratigraphic positions to Kanmantoo. Seccombe et al. (1985) and Spry et al (1988) considered that the largely bedding concordant Pb-Zn mineralisation originated syn-genetically as exhalative seafloor deposits.

Local Structural Geometry: Kanmantoo is situated in the core of an upright open to close, shallowly S-plunging syncline (Fig. 22). Orebodies occur as flattened podiform shoots which are discordant to bedding and pitch steeply northward within the axial planar schistosity of the fold (S_3 in the terminology of Oliver at al., 1998). In detail, the orebodies comprise quartz + chalcopyrite ± andalusite ± staurolite S_3-parallel veinlets and small bands of coarse grained sulphides (Parker, 1986; Oliver et al., op. cit.).

Mineralisation: The most common mineral assemblage according to Seccombe et al. (1985) is quartz-chlorite-garnet ± pyrrhotite ± chalcopyrite, with both magnetite and pyrite forming conspicuous phases in ore. On the basis of microtextural characteristics of the ore minerals, Seccombe et al (op cit) concluded that at least some of the chalcopyrite, pyrrhotite, magnetite and pyrite had formed prior to metamorphism. Microtextural evidence included preservation of colloform-like cores of chalcopyrite, pyrite and magnetite within more extensive, presumably recrystallised, chalcopyrite aggregates. Ore minerals were also shown to be strained at the grain-scale, with deformation textures including twinning, subgrain development and flame-like exsolution of secondary mineral phases within ore grains. By contrast, Oliver et al. (1998) stressed the intergrowth of chalcopyrite with peak metamorphic minerals such as andalusite and staurolite in veins. They make no comment on the apparent pre-metamorphic mineral textures interpreted by Seccombe et al. (op cit.).

Geochemistry: A regional geochemical halo around the mine defined by whole rock elemental abundances and O-isotope characteristics was recognised by Oliver et al. (1998). The principal aspects of this halo involves progressive depletion of Ca and Na at the expense of enrichment of Fe, Cu and S in the vicinity of the mine. This geochemical trend, apparently dominated by Fe-metasomatism, was considered to be reflected in rock mineral assemblages which show loss of regionally developed muscovite as the orebody is approached and growth of more Fe-rich staurolite and garnet.

There is also a gradual decrease in $\delta^{18}O$ values (in pelitic rocks) from 13.5 to 8.3 permil as the mine is approached over a distance of 20km. Oliver et al. (op. cit.) interpreted this variation as having occurred in response to up-temperature fluid flow and progressive equilibration between rocks and fluids as the latter migrated from lower-T biotite zones to higher-T sillimanite zones near the mine. At the mine itself, there is a further and marked depletion in $\delta^{18}O$ values with calculated O-isotope values for fluids in equilibrium with the mine rocks of 6.4 to 9.3 permil.

Sulphur isotope studies carried out by Seccombe et

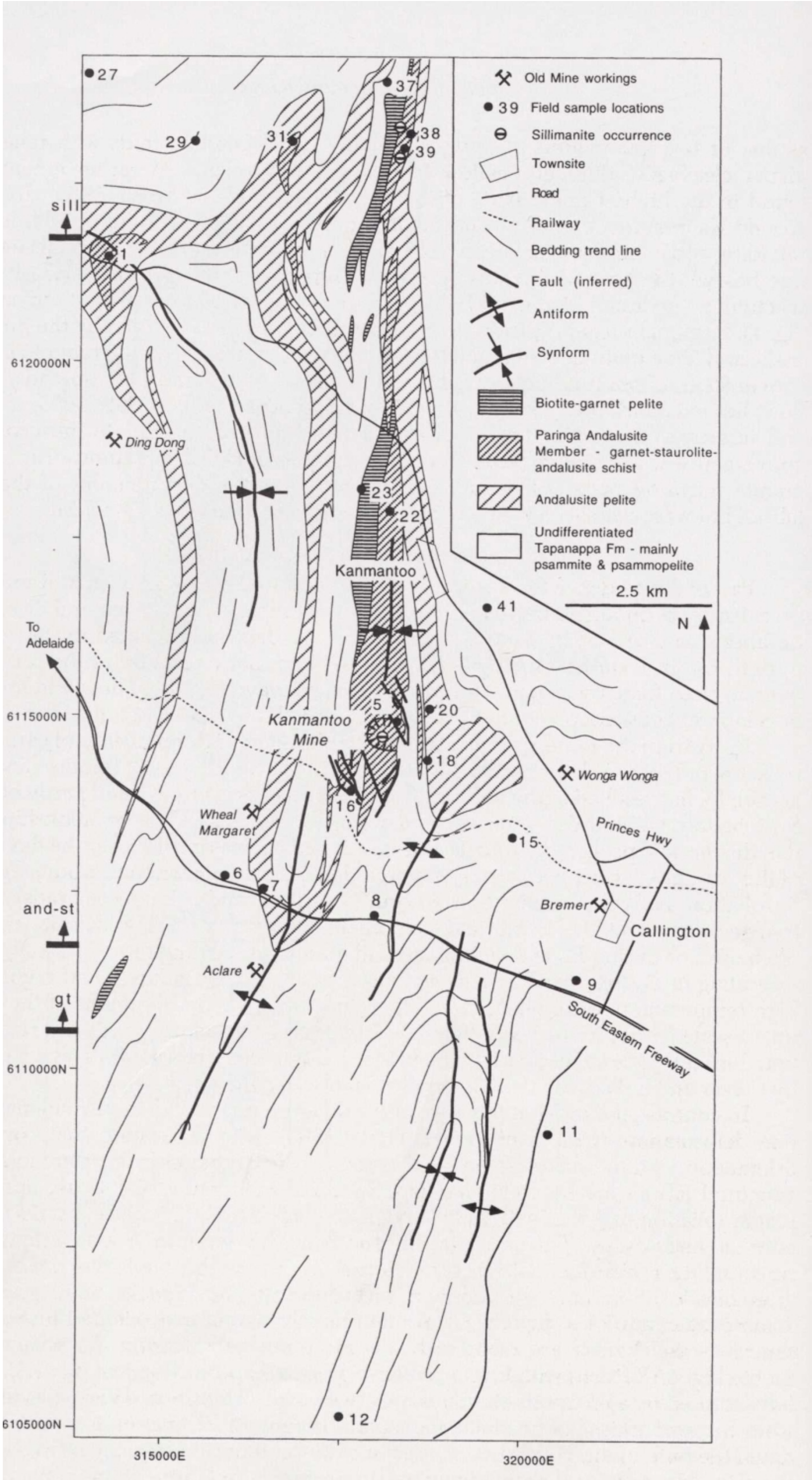

Figure 22. Geological map of the Kanmantoo Mine region showing structural geometry and local variation in metamorphic grade (sourced from Oliver et al., 1998).

al. (1985) at the mine yielded $\delta^{34}S$ values of 3.5 to 12.4 permil. They recognised isotopic disequilibria among coexisting sulphide minerals (apparently common at relatively low temperatures) and significant isotopic variation within and among individual ore lenses, characteristics they suggested indicate that metamorphism had not obliterated the pre-existing isotopic distribution.

Ore Genesis: The syngenetic model proposed by Seccombe et al. (1985) relied heavily on the recognition of pre-metamorphic ore textures, the disequilibrium S-isotope fractionations and the similar stratigraphic positions of both discordant Cu and stratabound Pb-Zn mineralised systems. The model provided a genetic link between these two styles of mineralisation by interpreting the Cu deposits as having formed in near surface feeder vents (stockwork, vein or disseminated orebodies) for hydrothermal metalliferous fluids which ultimately exhaled onto the sea floor. Thus they considered the present pipe-like orebodies at Kanmantoo to have undergone only relatively minor geometric modification during the Delamarian Orogeny. Sulphur was considered to have had a bimodal source resulting from the interaction of deeply circulating, isotopically modified Cambrian seawater ($\delta^{34}S$ ~30 permil) and strongly $\delta^{34}S$ depleted biogenic sulphur ($\delta^{34}S$ ~ –17 permil) derived from pyritic carbonaceous shales at deeper levels of the stratigraphic pile (resulting the $\delta^{34}S$ values of 3 to 12 permil recorded at the mine). Variation in isotopic composition in the orebodies was interpreted to have resulted from varying degrees of mixing between the sulphur sources as well as differences in the oxidation state of the hydrothermal fluids.

The syn-metamorphic model proposed by Oliver et al. (1998) used textural evidence to demonstrate structurally controlled precipitation of copper minerals during peak metamorphism. That they did not appear to adequately address the pre-metamorphic ore textures interpreted by Seccombe et al. (op. cit.) seems to weaken their argument however. The ore genesis model involves a two-component fluid flow system (Fig. 23): (1) regional metamorphic fluids driven toward the site of ore deposition by a thermal gradient (as indicated by decreasing $\delta^{18}O$ values), and (2) localised Fe-rich metasomatic fluid resulting in major element modification (ie. removal of Ca, Na and addition of Fe, S, Cu). The second of these fluids was considered to have been sourced from syn-orogenic granites crystallising during or soon after peak metamorphism. They considered that Seccombe's S-isotope data were more consistent with sulphur sourced from a $\delta^{34}S$-enriched igneous suite or mixing of such a fluid with sulphur from surrounding metasediments.

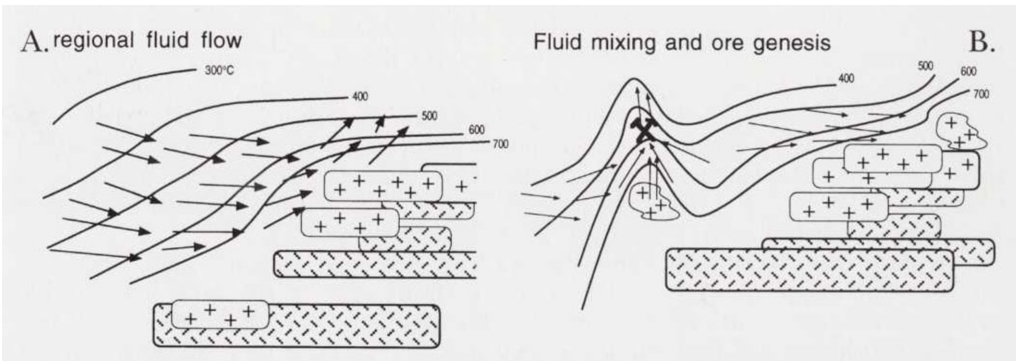

Figure 23. Cartoon of hydrothermal model for the genesis of Kanmantoo Mine. The model involves interaction of two distinct fluids: (A) regional up temperature fluid flow, possibly driven by emplacement of distal granitoids; (B) local granite derived fluid causing recrystallisation, major element metasomatism and ore genesis (sourced from Oliver et al., 1998).

Summary

- Major structures developed and/or reactivated during the Palaeoproterozoic and early Mesoproterozoic played an important role in the distribution of GRVPE magmatism and hydrothermal alteration. Their influence probable extends to the geometry and evolution of Neoproterozoic and Cambrian rift basins. The Kalinjala-Paralana structural corridor is considered to be a conspicuous example of these structures on the grounds of spatial relationships to important geological features of Palaeoproterozoic to Cambrian ages: ie. Kimban KD_3 mylonite zones; Spencer plutonic complex; anomalous alteration within GRV; distribution of surface heat flow values; major Neoproterozoic basin-bounding structures; locus for Delamarian basement-involved basin inversion; distribution of Cu deposits within the Neoproterozoic package.

- There is a close spatial association of Roxby Downs-type granites on the Stuart Shelf and Gawler Craton and highly anomalous surface heat flow values. Kokatha-type granites on the other hand, occur in areas of relatively low surface heat flow values. Although data in the Adelaide 'Geosyncline' is relatively sparse, it could be argued that that radiogenic element enriched granites or volcanic units of similar composition to the Roxby Down type extend beneath thick Neoproterozoic cover toward the Curnamona Province. Apart from the obvious implications for thermal weakening of the crust and localisation of subsequent rift centres, the distribution of "hot" basement is likely to have had a significant bearing on the generation and geometry of thermally driven convection cells within the cover sequence. This model is attractive in that the energy source is not transient and may be expected to have resulted in multiple fluid flow events, potentially accounting for wide lateral and vertical distribution of Cu deposits with the Neoproterozoic–Cambrian stratigraphy.

- The Neoproterozoic–Cambrian succession records multiple rift and sag phases related to breakup of the Rodinian Supercontinent. Neoproterozoic rift phases occurred during protracted NE–SW extension. Early basin development occurred in the form of two major 'first order' sub-basins (coinciding roughly with the Northern Flinders domain and Nackara Arc) bounded by NW trending growth faults and a NE trending transfer system, the latter coinciding with the Kalinjala-Paralana structural corridor. With continued continental break-up, depocentres transgressed early rift shoulders and platformal areas, while detrital sources shifted from local cratonic margins to more distal regions. The onset of Early Cambrian rifting marks a fundamental change in basin geometry and direction of crustal extension to NW-SE. This is reflected by an abrupt shift in detrital zircon populations which record southerly contribution from the Ross Orogen.

- The Delamarian Orogeny (515–480Ma) resulted in basement-involved inversion of Neoproterozoic – Cambrian basins in the northern and southern Adelaide Fold Belt. Thin-skinned fold-and-thrust tectonics prevailed throughout much of the Nackara Arc, whereas the Neoproterozoic platformal areas (Central Flinders domain and Stuart Shelf) remained relatively unaffected by the shortening event. Foreland sedimentation is potentially restricted to the outer arc of the thrust front and is manifest by 'red-bed' clastic-dominated sequences.

- Neoproterozoic- and Cambrian-hosted Cu deposits display a broad spatial association with: (i) inverted basin-bounding growth faults; (ii) platformal sequences on the margins of major rift depocentres; (iii) inner arc of the Delamarian fold-and-thrust front. These relationships, coupled with evidence of local Cu precipitation from high temperature hydrothermal fluids, raises the possibility of syn-orogenic thrust-generated fluid flow and mineralising systems. There is a fairly strong argument for syn-tectonic hydrothermal mineralisation at Kanmantoo and Mt Painter, however that they are not simply seeing remobilisation of older stratiform Cu cannot be discounted, particularly considering the stratabound nature of some of these styles of deposits. Lower temperature deposits on the Stuart Shelf and outer parts of the Adelaide Fold Belt, which lack a hydrothermal signature are more difficult to explain by this process. These deposits do not appear to be strictly syngenetic however, as they display consistent late-stage precipitation of Cu in their ore mineral parageneses and may show a symmetrical vertical metal zonation related to upper and lower unconformable contacts of the host sequence.

- Thermo-haline convection is another potential energy source which could have driven fluid circulation at various stages of basin evolution. Although not discussed in this review, the close association of Cu with diapiric structures suggests that this mechanism should be considered for small scale fluid systems at least.

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