Nature of the Kimban Orogeny across northern Eyre Peninsula

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Introduction

The northeastern Eyre Peninsula contains a spectacular contrast in magnetic intensity that demarcates the boundary between the Spencer and Cleve domains of the southern Gawler Craton (Figs 1, 2). This region has been interpreted to contain a number of regional mylonite zones corresponding to splays of the Kalinjala Mylonite Zone, one of the major crustal-scale shear zones of the eastern Gawler Craton (Parker 1980; Parker et al. 1993). Indeed, previous workers have interpreted the magnetic intensity contrast to be the northern extension of the Kalinjala Mylonite Zone sensu stricto and for this structure to define the boundary between the Cleve and Spencer domains (Ferris, Schwarz and Heithersay 2002). Since this region includes within it the Middleback Range iron ore resources, along with a number of gold, copper–gold, uranium and base metal prospects including the Menninnie Dam prospect, understanding the nature of the basement and structures that dissect it has implications for models of mineral potential in this region.

The northern Eyre Peninsula is also of particular geoscientific interest at present with a number of collaborative research programs underway between PIRSA, Geoscience Australia and the University of Adelaide. A major seismic traverse across the northern Eyre Peninsula has recently been conducted as part of Geoscience Australia's Onshore Energy Security Program. PIRSA re-mapping of the PORT AUGUSTA 1:250 000 map area has been ongoing since 2006, with a focus on Hiltaba-related alteration systems (McAvaney 2008). A geochronology program is also underway to define the age of major stratigraphic units and igneous phases in this region. An exciting and unexpected result from this work has been the recent discovery of Mesoarchaean (~3150 Ma) orthogneiss in the vicinity of the Middleback Range (Fraser et al. 2008).

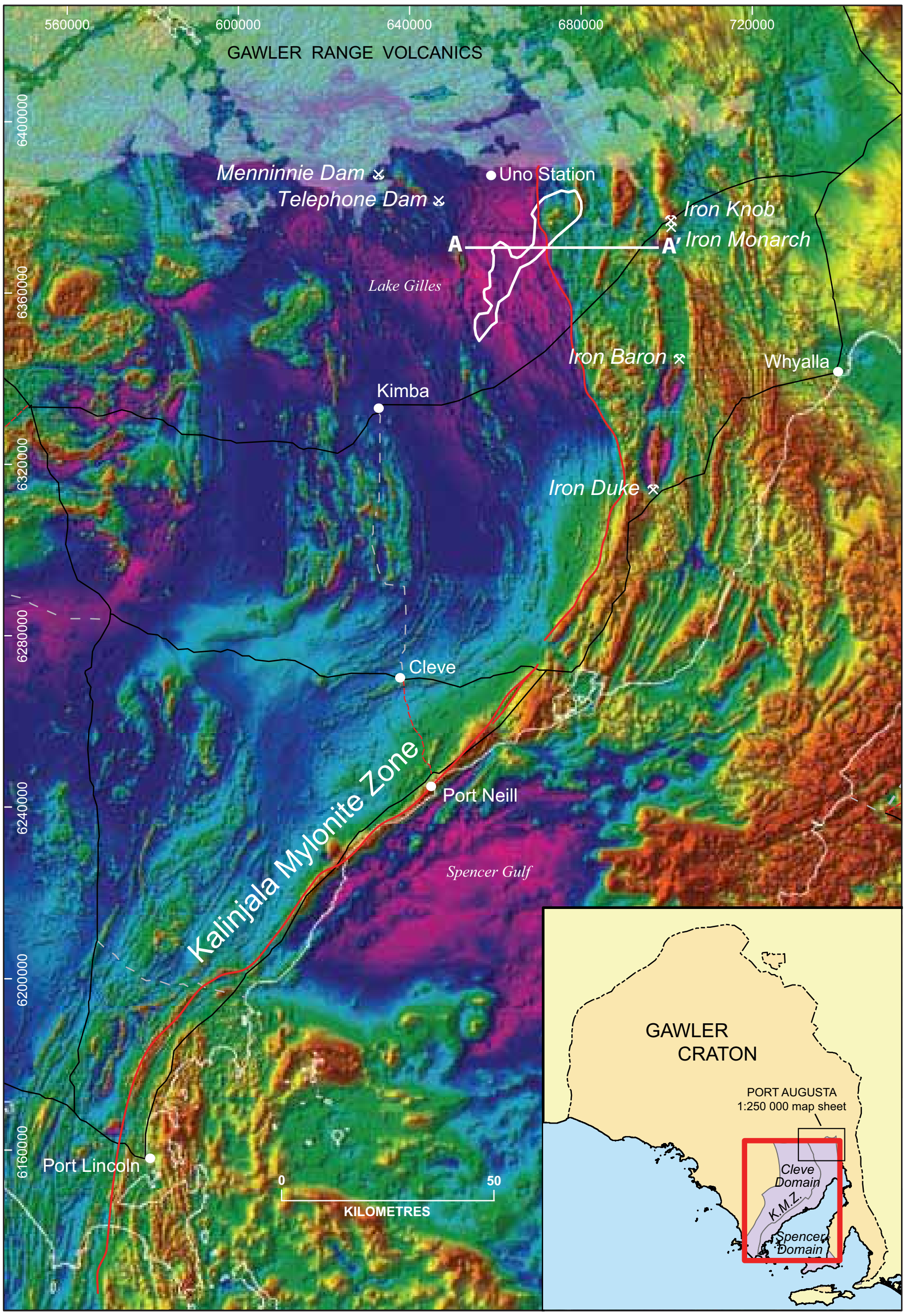

Figure 1 *Total magnetic intensity (TMI) image of the eastern Eyre Peninsula, showing the location of the Kalinjala Mylonite Zone of Parker (1980), together with the TMI transect of Figure 2. Location of outcropping Gawler Range Volcanics shown as transparent fill. Inset shows location relative to the Gawler Craton boundary and the location of the Cleve and Spencer domains within the southern Gawler Craton.*

In this paper we summarise field observations from the region between Iron Knob in the Middleback Range and Uno Station, in particular the northern margin of Lake

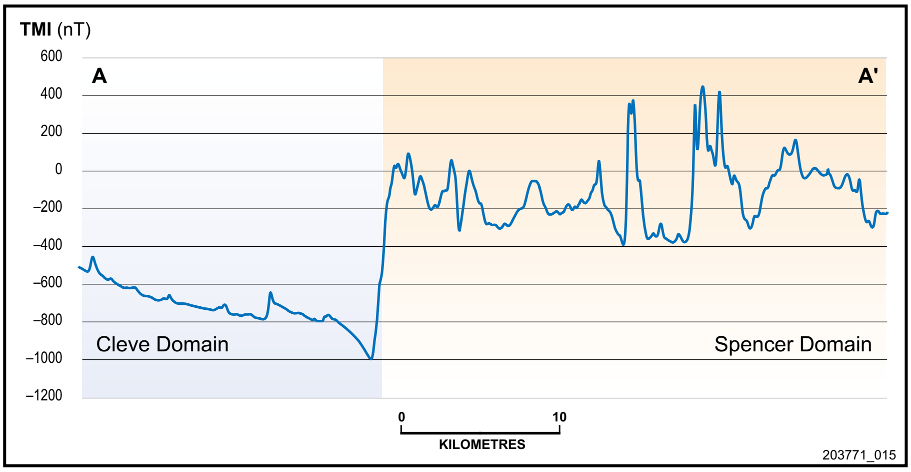

Figure 2 *Variation in TMI for a subset of data from the South Australia Exploration Initiative B4 survey with regional magnetic gradient removed. The Cleve Domain has an average TMI value of –712.7 ± 95.7 nT, in comparison to the Spencer Domain which has an average value of –118.1 ± 165.9 nT. Line of section is located in Figure 1.*

Gilles (Fig. 1). This paper is motivated by a desire to provide field observations to assist the forthcoming seismic interpretation. This is particularly important since the last detailed mapping program in this area occurred in the 1980s and the most recent PIRSA mapping of the Lake Gilles region show Lincoln Complex rocks occurring on both sides of the major magnetic boundary (Weste 1996), which does not assist in interpretation of the origin of this boundary. Redefinition of the outcropping lithologies in this region has therefore been a focus of the current mapping program. Furthermore, recent discussion on the geology of this portion of the Gawler Craton has included speculation that the Kalinjala Mylonite Zone may represent a significant crustal boundary that may, or may not, represent a palaeosuture zone recording juxtaposition of two entirely different crustal blocks (Betts and Giles 2006; Howard et al. 2006; Payne et al. in press). With these speculations in mind it was thought timely to revisit the field geology to provide further constraints on the evolution of this portion of the eastern Gawler Craton.

Geological setting

The southern Spencer Domain is dominated by granitic to charnockitic intrusives of the 1850 Ma Donington Suite. In the northern Spencer Domain, chemical and clastic sediments of the Hutchison Group are present in the Middleback Range. Structurally adjacent to these sediments lies the granitic gneiss recently dated at ~3150 Ma (Fraser et al. 2008) and informally known as the 'Cooyerdoo granite'. The presence of this Mesoarchaean basement in the northern Spencer Domain is a major difference between it and the adjacent Cleve Domain. Overlying the Hutchison Group and occurring to the east of the Middleback Range are a series of volcano-sedimentary sequences including the Broadview Schist and Myola Volcanics (~1790 Ma), and the younger Wallaroo Group, Moonabie Formation and McGregor Volcanics (~1745 Ma). These lithologies are intruded by Mesoproterozoic Gawler Range Volcanics and Hiltaba Suite and include the hematite-dominated alteration and brecciation within the Cultana Subsuite (McAvaney 2008).

The Cleve Domain is comprised of generally N–S-trending, deformed and metamorphosed metasedimentary and meta-igneous material that includes a Neoarchaean to earliest Palaeoproterozoic basement termed the Sleaford Complex. This basement was intruded by the ~2000 Ma felsic precursor to the Miltalie Gneiss and subsequently overlain by a sequence of Palaeoproterozoic platform to continental sediments. Previously these sediments were interpreted to all belong to the Hutchison Group and were considered to have been deposited before ~1850 Ma, as defined by the age of deformed and recrystallised rhyodacites of the 1866 ± 10 Ma Bosanquet Formation within the uppermost Hutchison Group (Rankin, Flint and Fanning 1988; Fanning, Reid and Teale 2007). Recently, however, this metasedimentary material has been shown to include a sequence of younger rocks deposited after ~1790 Ma (Jagodzinski et al. 2006), which has complicated the stratigraphic position of the Hutchison Group and is the subject of ongoing work (Szpunar et al. 2007). Mesoproterozoic felsic magmatism of the Gawler Range Volcanics and Hiltaba Suite intrudes these lithologies, most typically in the northernmost Cleve Domain, where they are associated with the polymetallic deposits of Menninnie Dam and Telephone Dam (Higgins, Berg and Hellsten 1990).

The Kimban Orogeny

The major orogenic phase to have affected the Palaeoproterozoic units in both the Cleve and Spencer domains is the 1730 to 1690 Ma Kimban Orogeny. The Kimban Orogeny is characterised by a number of features that imply it developed during a largely transpressional tectonic regime (e.g. Goscombe et al. 2003), including: dramatic variations in metamorphic grade across- and along-strike reflecting differential exhumation along deep-seated shear systems (Dutch, Hand and Kinny 2008); a persistent subhorizontal stretching lineation related to both early bulk constriction and later flattening (Vassallo and Wilson 2002); and the presence of a major crustal-scale shear zone from which a number of other shear zones are interpreted to splay (Parker 1980; Parker et al. 1993). These shear systems are interpreted to have formed part of a macro-scale flower structure between 50 and 100 km wide and 200 km long, effectively encompassing the entire eastern Eyre Peninsula (Hand, Reid and Jagodzinski 2007).

Field observations

Spencer Domain

On northern Eyre Peninsula, the Spencer Domain is typified by a feature-rich, generally high-magnetic signature with distinct magnetic high bodies and a NNW-striking structural grain (Figs 3b, 4a). Within the Middleback Range the banded iron formations are generally tightly to isoclinally folded about subhorizontal axes (Fig. 5a) and typically show subhorizontal intersection lineations related to this folding (Fig. 5b). Similar folding about a subhorizontal axis is also observed within the Katunga Dolomite (Fig. 5c). Iron formation occurs in structural contact on both sides of the ranges with a white to cream coloured quartzofeldspathic gneiss (Fig. 5d). This unit has been interpreted as either quartzite or 'Lincoln Complex' granite (Yeates 1990). We consider this gneiss to be a more weathered equivalent of the 3150 Ma Cooyerdoo granite based on petrological similarity; however, further work is underway to define the extent of the Mesoarchaean material.

The exposure directly to the west of Iron Knob is sparse and consists of a biotite-rich granitic gneiss (Fig. 6a) interlayered with pods of sheared amphibolite. The NNE-trending gneissosity is tightly to isoclinally folded, wraps K-feldspar megacrysts and is steeply dipping. Amphibolite varies from fine to coarse grained and constitutes up to 10% of the rock volume. Locally the amphibolite contains thin (<10 mm) layer-parallel granitic veins representing comagmatism or syntectonic granitic intrusion. The absolute age of this granite is unknown at present.

To the west of this granitic gneiss is the hornblende-bearing Burkitt Granite that defines a prominent magnetic high (Figs 3, 6b). The Burkitt Granite yielded a Rb–Sr age of 1655 ± 61 Ma and a K–Ar hornblende age of 1687 Ma (Webb et al. 1986). The Burkitt Granite is massive in texture, suggesting it intruded either late syn- or post Kimban Orogeny.

A N–S, 10 by 2 km magnetic anomaly below the northeastern margin of Lake Gilles was recently investigated by *PACE*-supported drilling. Here, diamond drillhole LED001 intersected a buried undeformed granodiorite of unknown age (Fig. 3; Faulkner 2007). The granodiorite is medium to coarse grained and magnetite-rich (Fig. 6c), and contains mafic schlieren and leucocratic bands and mafic enclaves. The granodiorite is a discrete magnetic body bounded by sharp contacts with surrounding magnetic textures, suggesting that it is likely fault-bounded.

Along the northern margin of Lake Gilles, west of drillhole LED001, are a series of low, variably weathered outcrops of foliated granite and amphibolite which intrude minor metasedimentary units comprising quartzofeldspathic gneiss and rare zones of mica schist (Fig. 4). No geochronology is available for these metasedimentary units, which may be part of the Hutchison Group or another package. The gneissic foliation of the metasediments is folded by tight to isoclinal folds, and shows structures such as foliation boudinage and C' shear bands (Fig. 6d) indicative of non-coaxial deformation. The metasedimentary material is volumetrically minor, and appears to be restricted to the westernmost part of the Spencer Domain. Leucogranite intrudes both parallel and oblique to the gneissic foliation (Fig. 6d).

Foliated leucogranite in this region is mica-poor and dominated by recrystallised quartz ribbons that wrap K-feldspar augen (Fig. 6e). The NNW-trending fabric is steeply dipping and contains a weakly developed subhorizontal stretching lineation. Kinematic indicators, including σ-type porphyroblasts and C–C' fabrics, show both sinistral and dextral shear sense. This fabric is folded by tight to isoclinal folds observed at scales up to 5 m in amplitude (Fig. 6f), which is likely to account for the apparent inconsistency in shear sense indicators in these localities.

Pods of amphibolite up to 50 m wide (Fig. 4a) are interleaved with the leucogranite. These are composed of coarse plagioclase phenocrysts wrapped by a biotite–hornblende foliation. The amphibolite constitutes ~10% of the rock mass, similar to the proportion of amphibolite observed NW of Iron Knob described above.

Cleve Domain

The actual boundary between the Cleve and Spencer domains is represented by a narrow (<1 km wide) zone of no exposure. Outcrops to the immediate west of the magnetic boundary are dominated by strongly weathered quartzitic gneisses, presumably representing metasedimentary protoliths. Interleaved with these metasedimentary gneisses is homogenous, quartz–feldspar granitic gneiss (Fig. 7a). Deformation within these gneisses is particularly intense, with abundant evidence for isoclinal folding, and notably an axial planar foliation developed within these folds (Fig. 7b).

Mylonite zones within the leucogranite are distinctively lineated (L-tectonites), with recrystallised quartz –feldspar ± muscovite defining a pervasive fabric (see also Dunn, Foy and Craven 1982). The presence of mylonite zones in this vicinity is evidence for a distinct localisation of strain at or near the zone that defines the magnetic boundary.

To the west of the magnetic boundary the Cleve Domain is typified by a low, relatively bland magnetic response. However, in detail there are subtle features within the geophysical response that represent lithological contrasts, which appear to define large-scale N–S-trending folds. These folds are more obvious further west, in the vicinity of Menninnie Dam and Telephone Dam, where iron formations have a strong magnetic response and define large-scale N–S- to NW–SE-trending folds with amplitudes in the order of 5 to 10 km (Fig. 1). This zone is dominated by metasedimentary lithologies mapped as Hutchison Group, unnamed felsic gneisses and minor granite. The full stratigraphic sequence of the Hutchison Group is present in this geophysical zone including quartzite, banded iron formation, silicified carbonate and schist (Fig. 4b). U–Pb SHRIMP dating of zircons from a forsterite marble within drillhole LG-DDH2 (Fig. 3) gave a maximum depositional age of 2009 ± 10 Ma (Jagodzinski 2005), which is consistent with other maximum depositional ages from the Hutchison Group obtained from elsewhere in the Cleve Domain (Fanning, Reid and Teale 2007).

To the west of the boundary, within the western magnetic-low zone proper, prominent ridges in the landscape are composed of grey to white pyritic and sericitic quartzite (Fig. 4b). These quartzite units located on the western margin of Lake Gilles are massive, with bedding difficult to discern, and are extensively fractured (Fig. 7c). Massive to finely banded iron formation is also present and is interlayered at the metre-scale with quartzitic and calcsilicate horizons (Fig. 7d). Mica–quartz–feldspar ± garnet schist is also locally present (Fig. 4b). In this vicinity, the gneissic foliation trends WNW and is

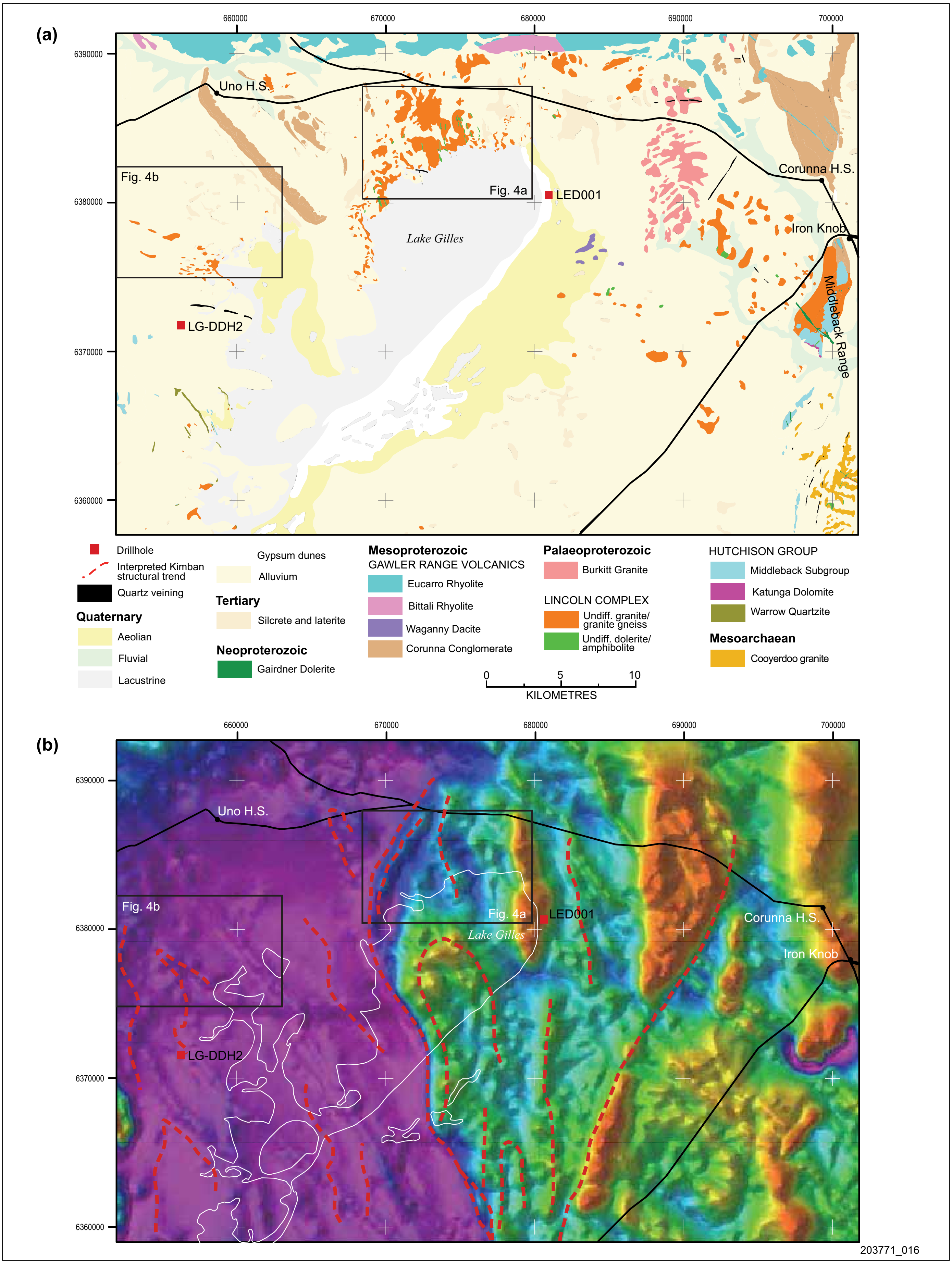

Figure 3 *Regional geology of the Lake Gillies area.* ***(a)*** *Existing geological mapping of the northern Middleback Range and Lake Gilles area (after Weste 1996), and* ***(b)*** *corresponding TMI signature. Insets show extent of Figures 4a and 4b.*

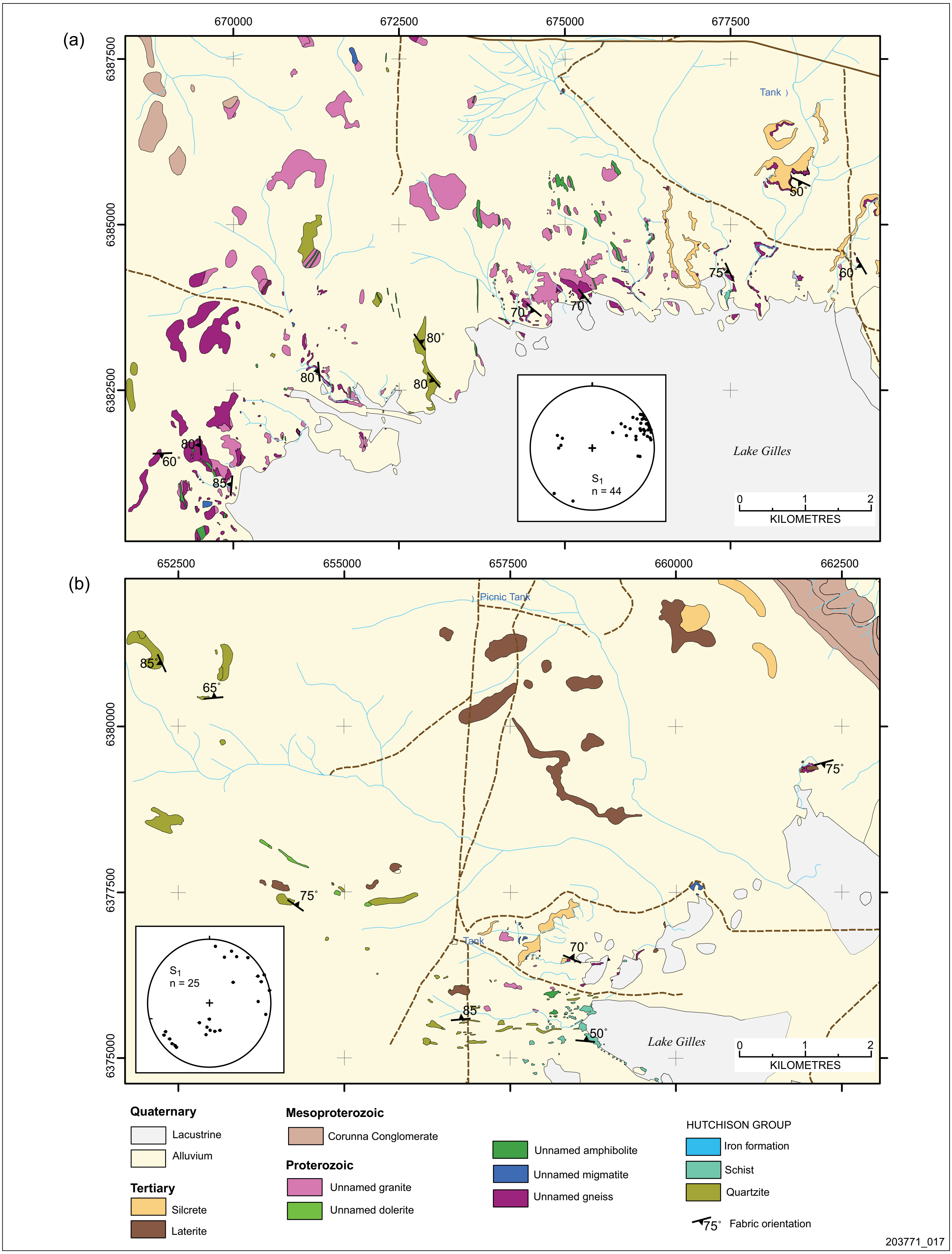

Figure 4 *Revised geology of (a) the northern margin of Lake Gilles in the Spencer Domain and (b) Eurilla Hill area in the Cleve Domain. Basement polygons are adapted from mapping by Dunn, Foy and Craven (1982). Stereonets show poles to the principal structural fabric (S1) on equal area, lower hemisphere projections.*

***Figure 5** Representative photographs of rocks from the Middleback Range, within the Spencer Domain. **(a)** Tight folding of banded iron formation within the Iron Duke Mine. View looking to the north. **(b)** Prominent subhorizontal fold axis related to the folding shown in (a). **(c)** Tight folding within the Katunga Dolomite, Hutchison Group, Katunga Hill. View looking to the south. **(d)** View looking south of contact between interpreted Mesoarchaean granitic gneiss in the west with tightly folded and altered banded iron formation in the east, Iron Monarch Mine.* *(Photos 407561–564)*

thus slightly discordant to the foliation trends to the east of the magnetic boundary.

In one spectacular locality, intensely weathered iron formation is intruded by garnet-bearing leucogranite (Fig. 7e). The iron formation and interlayered quartz–carbonate rocks containing quartz-rich layers are boudinaged and deformed by submetre-scale tight to isoclinal folds. The garnetiferous leucogranite is both concordant and discordant to the gneissic foliation within the iron formation, and contains rafts of deformed metasedimentary material (Figs 7e, f). Locally this leucogranite contains a weak foliation indicating it is likely to have intruded during the late stages of deformation. This syntectonic leucogranite is interpreted to have been locally derived from partial melting of the underlying sedimentary package and is therefore akin to similar phases of the c. 1730–1720 Ma Moody Suite (e.g. Yunta Well Leucogranite; Schwarz 1999).

Discussion

Origin of the magnetic contrast between the Spencer and Cleve domains on northern Eyre Peninsula

The Spencer Domain is dominated by magnetite-rich meta-igneous lithologies such as biotite-bearing orthogneiss and hornblende-bearing granite (e.g. Burkitt Granite), together with amphibolite units. In contrast, the Cleve Domain is dominated by magnetite-poor metasediments, with significantly less igneous material, which, where observed, appear to be dominantly muscovite ± garnet leucogranites that could be derived from partial melting of a ?local metasedimentary source. These lithological differences between the two domains presumably account for their distinct magnetic signatures.

Structural geometry across the northern Eyre Peninsula

One of the most striking features of the deformation across northern Eyre Peninsula is the persistent subhorizontal

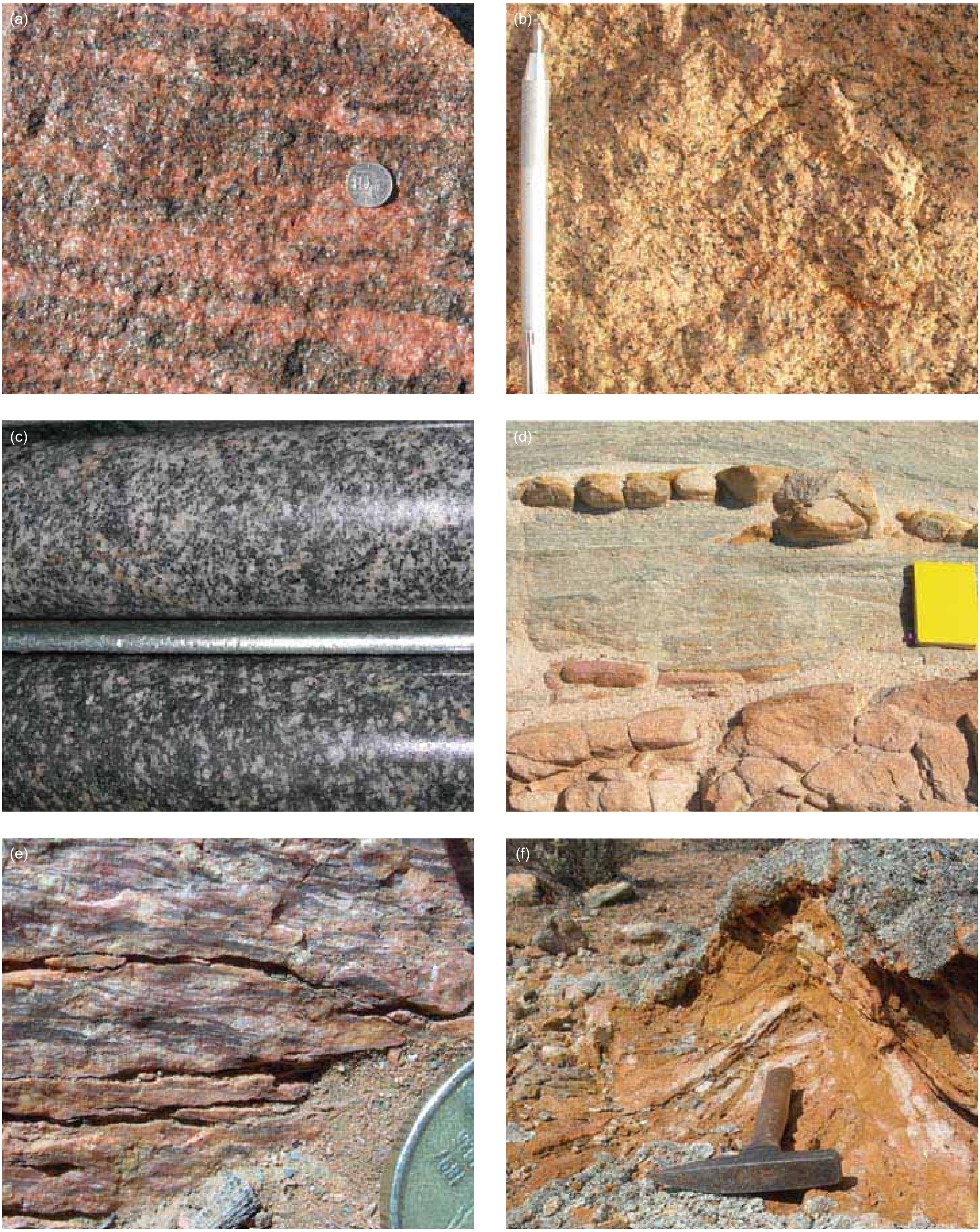

***Figure 6** Representative photographs of rocks from the Spencer Domain. **(a)** Unnamed granite gneiss, showing K-feldspar megacryst and biotite-defined, migmatitic foliation. **(b)** The Burkitt Granite. **(c)** Granodiorite from drillhole LED001. **(d)** Leucogranite intruding into sheared quartzofeldspathic metasedimentary rocks. Leucogranite at top of view is isoclinally folded, with the lower limb sheared out. **(e)** Detail of shear fabric within foliated leucogranite. Note quartz ribbon development and bulk dextral kinematics. **(f)** Tight fold in foliated leucogranite on the northern margin of Lake Gilles. Hammer lies along fold axis which is subhorizontal.* (Photos 407565–570)

linear fabric elements, principally fold axes and stretching lineations. These linear features represent the direction of maximum elongation and are indicative of strain within a dominantly strike–slip deformation system. While in most localities the absolute age of the deformation is unconstrained by geochronology at present, it is most likely that the majority of the deformation occurred during the Kimban Orogeny.

At the broad scale, structures within both domains generally trend N–S; however, there is considerable local deviation from this. For example, the gneisses to the west of Iron Knob which have a NE-trending fabric and the metasedimentary rocks of the northeastern Cleve Domain which trend WNW. If these fabrics are Kimban in age, and not an earlier orogenic phase, then this may suggest that progressive deformation has localised deformation into shear zones that have isolated some lithological units, causing the earlier fabrics within them to be reoriented with respect to the later structural trends. Such a process may be analogous to the deformation partitioning that occurs at the micro-scale about syntectonic porphyroblasts, which preserve an earlier foliation within them that is buffered from the reworking associated with the ongoing deformation (e.g. Passchier and Trouw 1996).

The lack of outcrop at the boundary presents problems for interpreting the actual nature of the contact between the two geophysical zones. Nevertheless, magnetic fabrics within the Spencer Domain appear to terminate at a low angle to the boundary between the domains (Fig. 3). Assuming that structural and magnetic trends within the Spencer Domain reflect Kimban Orogeny deformation, this suggests that the boundary structure was active during the final stages of the Kimban Orogeny, and possibly later. Furthermore, our qualitative identification of greater strain localisation at approximately the location of the geophysical boundary suggests that this represents a zone of more intense deformation. Therefore, it is possible that this boundary is the northern extension of the late Kimban Orogeny structure identified to the south and known as the Kalinjala Mylonite Zone.

It should be noted that some authors have used the term ‘Kalinjala Shear Zone’ to refer to a zone of intense deformation that is localised along the western margin of the Donington Suite in the southern Eyre Peninsula (e.g. Vassallo and Wilson 2002; Dutch, Hand and Kinny 2008). This ‘shear zone’ is conceptually differentiated from the ‘mylonite zone’ of Parker (1980) which is defined by retrograde mineralogy and developed during the late stages of the Kimban Orogeny. We prefer to use the term Kalinjala Mylonite Zone to define the actual boundary between the Spencer and Cleve domains in the vicinity of Lake Gilles, while recognising that this mylonite zone developed within a broad zone of pervasive shear, i.e. non-coaxial deformation, across a large portion of the northern Eyre Peninsula that encompasses rocks from both domains.

Conclusion

While the main focus for mineral exploration within the Gawler Craton has been on the Mesoproterozoic mineralisation events related to Hiltaba Suite or Gawler Range Volcanics, it would be surprising if the Kimban Orogeny itself did not generate or at least localise mineralisation. The presence of reactive lithologies such as carbonates within the Hutchison Group and the recently recognised Mesoarchaean basement (Fraser et al. 2008), along with a complex shear zone network, suggest that remobilisation could be an important feature of the mineral systems associated with the Kimban Orogeny. The fact that some of the shear zones developed across the Eyre Peninsula are of crustal extent (Theil, Heinson and White 2005), and potentially therefore mantle-tapping, should also be considered in any mineral systems analysis of this region. The pattern of fluid flow during Kimban deformation, particularly in regions of medium- to low-metamorphic grades, should be of particular importance for defining possible structural traps for mineralisation.

Finally, an important question that needs to be addressed is whether the domain boundary represents a crustal-scale discontinuity, and if so does it represent a fundamental structure that juxtaposes two entirely different crustal domains, i.e. a suture? If this boundary does represent a reactivated suture, then the original domain juxtaposition must have occurred prior to the deposition of the Hutchison Group, since these sediments apparently occur on either side. The presence of contrasting heat flow values and different Mesoproterozoic mineral systems within the eastern versus central Gawler Craton (IOCG–U versus Au-dominated, Pb, and Zn) may reflect the presence of different lithospheric compositions across this region (Hand, Reid and Jagodzinski 2007). The magnetic boundary between the Spencer and Cleve domains, inferred here to represent the northern extension of the Kalinjala Mylonite Zone, may be the near-surface geophysical expression of such a crustal or lithospheric-scale boundary.

Acknowledgements

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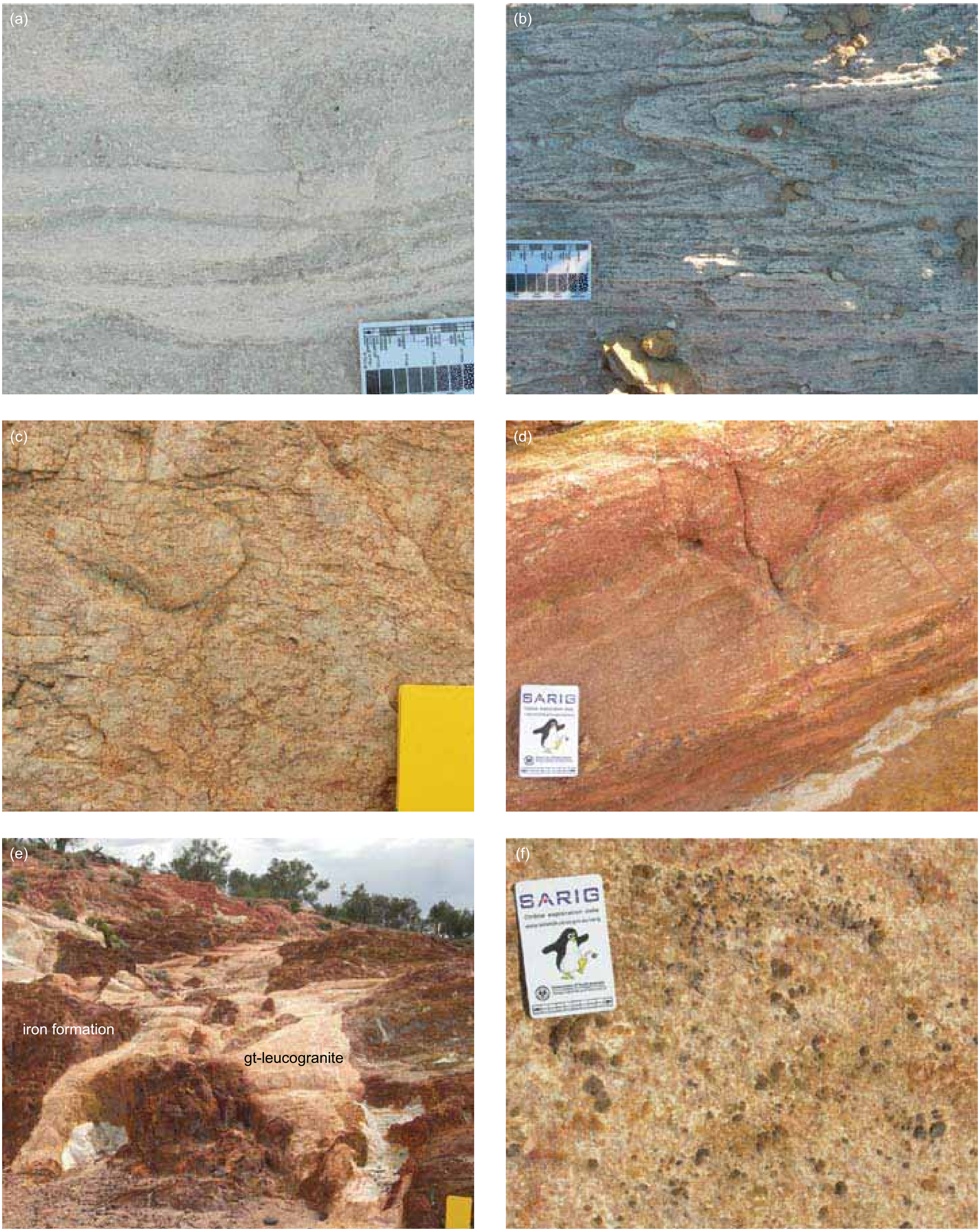

Figure 7 *Representative photographs of rocks from the Cleve Domain.* ***(a)*** *Detail of weathered (?) metasedimentary quartzitic gneisses (top of view), with layer parallel homogenous, quartz–feldspar granite gneiss. Note this granite gneiss defines an isoclinal fold.* ***(b)*** *Isoclinal folding within quartz-rich gneisses. Fold axis is subhorizontal.* ***(c)*** *Massive quartzite from an outcrop north of Uno Station.* ***(d)*** *Weathered quartz-rich, possible calcsilicate rock, interbanded with iron formation. Note boudinage of the more competent quartz-rich layer.* ***(e)*** *Banded iron formation intruded by garnet-bearing leucogranite. Note yellow notebook for scale.* ***(f)*** *Detail of weathered garnet-bearing leucogranite. (Photos 407571–576)*

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Guidelines facilitate communication between mineral explorers and landholders

Minerals Regulatory Guidelines | MG4

Guidelines for landholders: your rights in relation to mineral exploration and mining in South Australia

Version 1.4
August 2008

Minerals Regulatory Guidelines | MG7

Guidelines for mineral explorers: landholder liaison in South Australia

Version 1.0
August 2008

Two guidelines on landholder liaison and landholder rights have been updated to facilitate good communication between explorers and landholders in South Australia.

The Minerals Regulatory Guidelines are:

- *Guidelines for landholders: your rights in relation to mineral exploration and mining in South Australia, MG4.*
- *Guidelines for mineral explorers: landholder liaison in South Australia, MG7 (formerly Earth Resources Information Sheet M36).*

Information provided in these guidelines enables mineral explorers and landholders to be clearly and comprehensively informed of their respective rights and responsibilities in relation to the *Mining Act 1971*, and therefore facilitate better relations and improved access to land for the resources industry in South Australia.

It is recommended that minerals industry field staff become familiar with these guidelines and utilise them to assist in establishing and maintaining good relations with landholders. The guidelines are also being provided to pastoralists throughout the state.

The work has been a joint initiative between PIRSA, the South Australian Arid Lands Natural Resource Management Board and the South Australian Pastoral Board.

The guidelines are available for free download from the PIRSA Minerals website <www.minerals.pir.sa.gov.au>. Go to Licensing & Regulation, Mining Operations.

Hard copies are available from the PIRSA Customer Service Centre, phone +61 8 8463 3000, email <pirsa.customerservices@saugov.sa.gov.au>. (Please note that postage and handling may apply.)