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Resolving the nature and geometry of major fault systems from geophysical and structural analysis: The Palmerville Fault in NE Queensland, Australia

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Abstract

The Palmerville Fault in northeastern Queensland, Australia, forms a major terrane-bounding structure that probably had a major influence on the evolution of the adjacent Palaeozoic Hodgkinson Province, the northernmost part of the Tasman Fold Belt System in eastern Australia. The nature and subsurface expression of the Palmerville Fault remain poorly constrained and models for contrasting geometries exist. In addition to structural field and microscopic observations, we have combined results from multi-scale wavelet edge analysis ('worming'), forward modelling of regional magnetic and gravity data, and geochemical data sets to develop an improved understanding of the nature and subsurface geometry and depth extent of the Palmerville Fault. Results from 'worming' suggest a steeply dipping geometry for the Palmerville Fault. Based on constraints from field observations and 'worming', we have generated a number of sections across the Palmerville Fault and forward modelled their magnetic and gravity response to compare with the observed magnetic and gravity response. Our results show that the Palmerville Fault represents a steeply eastward-dipping structure that may become listric at depth (suggesting the presence of Proterozoic basement underneath the Hodgkinson Province). Our findings suggest that the Palmerville Fault was a first-order normal fault that controlled Early-Middle Palaeozoic basin development in the Hodgkinson Province. Subsequently, the fault acted as a (mid-crustal) décollement zone accommodating basin inversion in the Hodgkinson Province during the Late Palaeozoic. These results provide important constraints on the tectonic evolution of the Hodgkinson Province in northeastern Australia, and, importantly, demonstrate the strength of combining geological observations with geophysical analysis, in particular multi-scale wavelet edge analysis, in resolving the surface geometry and evolution of major fault systems, especially in areas of low-data density.

Keywords: Multi-scale wavelet edge analysis; Forward modelling; Palmerville Fault; Hodgkinson Province

1. Introduction

Understanding the nature and subsurface expression of major fault systems is fundamental to understanding the role of fault systems in basin inversion processes (e.g. Hills et al., 2003; Betts et al., 2004). Combination of structural geology and interpretation of regional geophysical datasets has successfully been applied to determine the geometry of major fault systems (e.g. Grauch et al., 2003; Betts et al., 2004; Bierlein and Betts, 2004). We apply a multi-disciplinary approach to determine the geometry of the Palmerville Fault and its role in the evolution of the Hodgkinson Province in northeastern Queensland, Australia (Fig. 1).

The Palmerville Fault has previously been described as a steeply dipping normal fault (e.g. De Keyser, 1963) as

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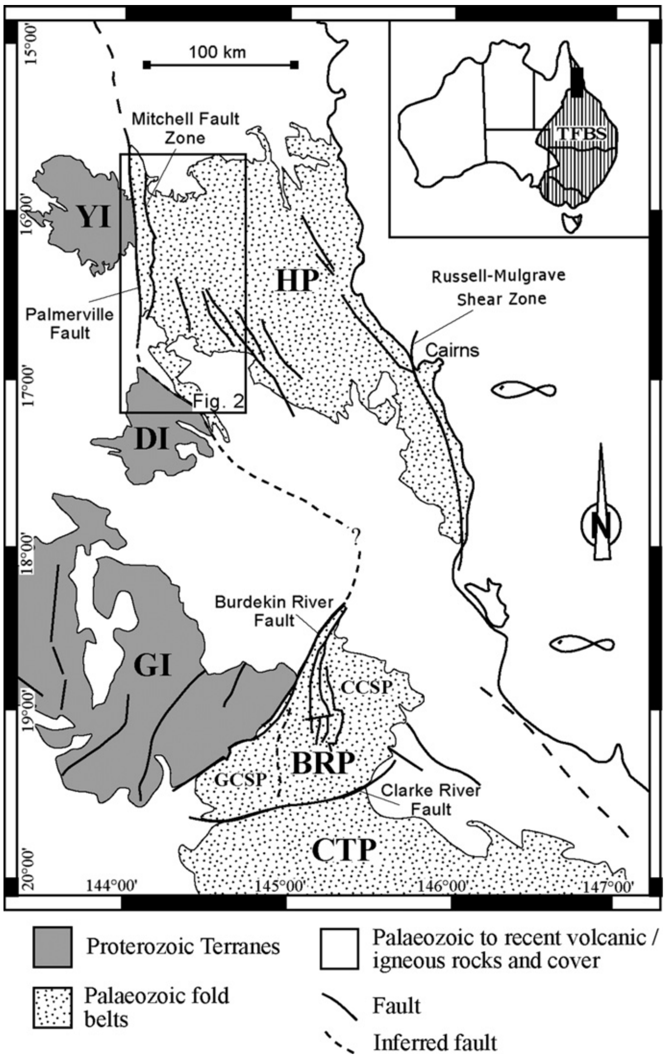

Fig. 1. General geology and major faults of northeastern Australia; inset indicates the area covered in the Tasman Fold Belt System (TFBS) of eastern Australia. YI, Yambo Inlier; DI, Dargalong Inlier; GI, Georgetown Inlier; HP, Hodgkinson Province; BRP, Broken River Province; CTP, Charters Towers Province; GCSP, Graveyard Creek Subprovince; CCSP, Camel Creek Subprovince.

well as a west-dipping thrust fault steepened and overturned during later phases of shortening (Shaw et al., 1987). To date no seismic reflection data have been collected across the Hodgkinson Province and only regional geophysical datasets are available. The latter include aeromagnetic data (400 m line spacing) and gravity data (generally 10 km station spacing) generated by the Geological Survey of Queensland and Geoscience Australia. Based on the limited availability of high-resolution datasets together with a general scarcity of outcrop, we classify the Hodgkinson Province and areas to the west of the Palmerville Fault as low-data density.

In this paper we present structural observations from two study areas in the Palmerville Fault region. Study areas were selected based on accessibility and (minor) presence of outcrop along two differently striking segments of the fault. Multi-scale wavelet edge analysis ('worming') was conducted across the western portion of the Hodgkinson Province to complement field observations. This analysis involves the 3-D spatial representation of gravity and magnetic gradients, through a mathematical process of wavelet-based transformation of gridded data at successive upward continued (i.e. above ground) heights (e.g. Hornby et al., 1999). Furthermore, forward modelling of magnetic and gravity data was carried out over the western portion of the Hodgkinson Province and finally these were integrated with our field observations and results from 'worming' as well as available geochemical data sets.

Our findings favour a model in which the Palmerville Fault forms a steeply eastward-dipping fault structure and challenge the validity of a westward-dipping fault model. In our model, the Palmerville Fault represents a first-order feature controlling Palaeozoic basin development and inversion that played an important role in the evolution of the epicratonic Hodgkinson Province. This paper illustrates the strength of combining structural field mapping with geophysical analysis and interpretation, in particular 'worming', to constrain the evolution and subsurface geometry of major structures in low-data density areas. Our approach and findings can greatly contribute to insights into the role and geometry of large-scale faults during basin inversion and can be applied in similar areas elsewhere.

2. Geological setting

The Palmerville Fault marks the boundary between Proterozoic terranes to the west and the Palaeozoic Hodgkinson Province to the east (Figs. 1 and 2). The Hodgkinson Province forms the northernmost part of the dominantly Palaeozoic Tasman Fold Belt System in northeastern Australia (inset in Fig. 1). The fault strikes to the north and defines the westernmost extent of the Hodgkinson Province. The Palmerville Fault is interpreted to extend northward beneath the Mesozoic Laura Basin (Doutch, 1976). In the southern portion of the Hodgkinson Province, the continuation of the fault is obscured by Carboniferous and Permian igneous rocks (De Keyser, 1963), but is generally considered to change to a southeastern trend (Fig. 2) and most probably continues further south, possibly linking with a major terrane-bounding fault in the adjacent Broken River Province (Fig. 1). The Palmerville Fault has been considered to represent a relatively shallow-dipping feature based on the negligible difference in regional gravity across the fault (Fraser et al., 1977).

De Keyser (1963) first recognised the complex movement history of the Palmerville Fault, which has been supported by several more recent studies (e.g. Shaw et al., 1987; Bultitude et al., 1993, 1997). A detailed summary of the geological history of the Hodgkinson Province is given in Bultitude et al. (1997), Vos and Bierlein, 2006 and Vos et al., 2006. The Palaeozoic evolution of the Hodgkinson Province can be summarised as Late Silurian to Middle Devonian basin development during which the volcanic and sedimentary successions of the

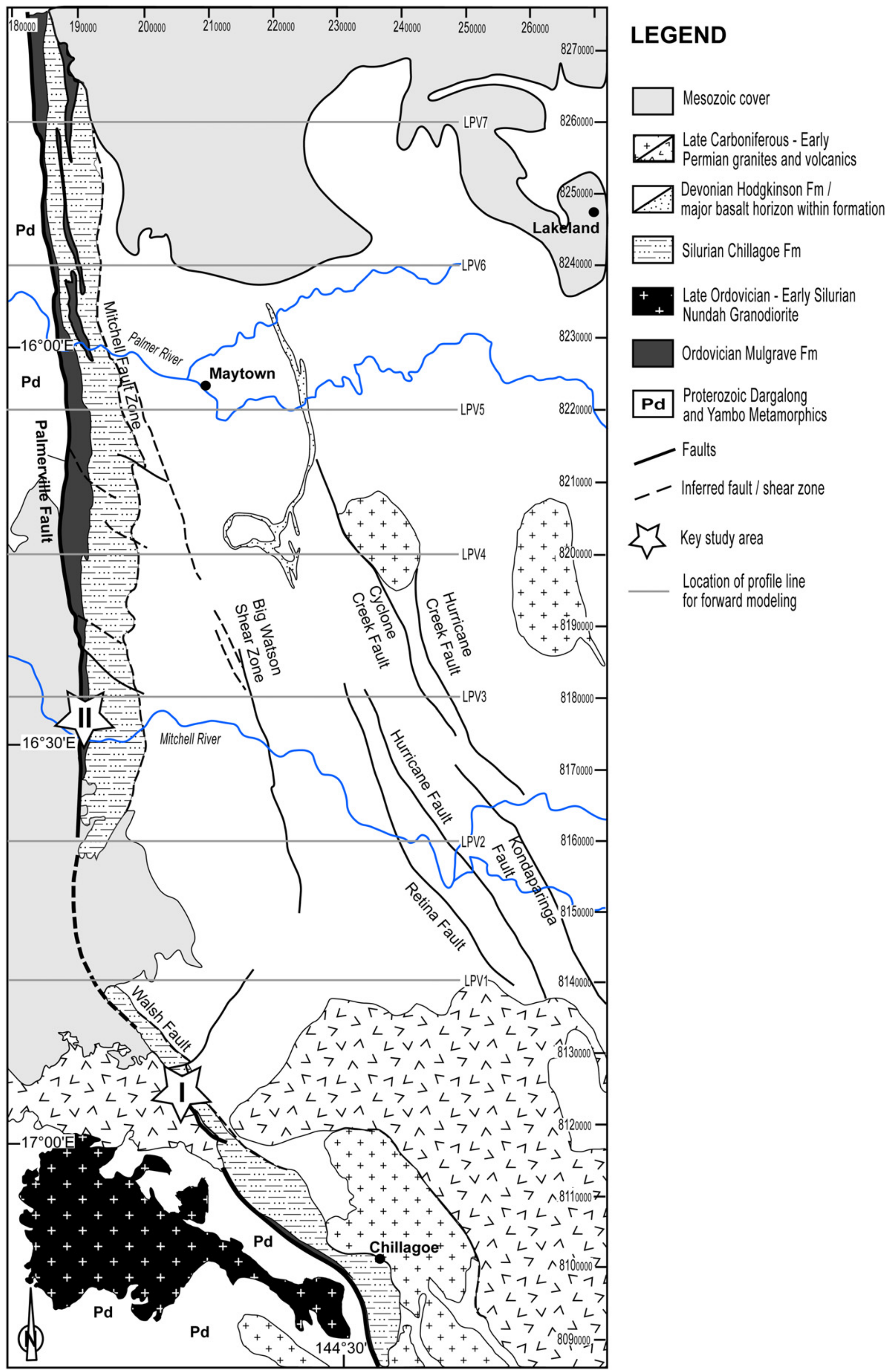

Fig. 2. Detailed geology of the western part of the Hodgkinson Province (inset in Fig.1) outlining the Palmerville and adjacent faults as well as the locations of profiles across the fault and locations of study areas.

Chillagoe and Hodgkinson Formations were deposited (Fig. 3). This was followed by basin inversion during repeated episodes of Late Devonian to Carboniferous deformation that resulted in localized high strain zones and steeply-dipping fault parallel cleavage and intense folds (e.g. Bultitude et al., 1997; Vos and Bierlein, 2006).

The Palmerville Fault is considered to represent a reactivated Precambrian basement structure as inferred from basement schistosity attributed to post-1580 Ma deformation and prograde amphibolite/granulite facies metamorphism (Bultitude et al., 1993; Bultitude et al., 1996). This basement schistosity is represented by high strain mylonite zones in the Proterozoic Yambo and Dargalong inliers directly adjacent to the Palmerville Fault. Bultitude et al. (1996) recognized a protracted movement history along the Palmerville Fault between the Neoproterozoic and the Tertiary, with the main movement along the fault occurring pre-Late Carboniferous, since neither the Palmerville Fault nor adjacent faults significantly displace Late Carboniferous and Permian granites and volcanics in the area.

3. Nature and subsurface expression of the Palmerville Fault

3.1. Field and microstructural investigations

Structural datasets have been collected from two study areas in the Palmerville Fault region (Fig. 2), which are likely to preserve structures that may be associated with different parts of the structural history as they are situated along different strike segments of the fault. Study area I is situated on the contact between Early Palaeozoic basin assemblages with Proterozoic basement rocks and Late Palaeozoic granites where the fault strikes northwest. Study area II is positioned at the contact between Palaeozoic basin assemblages and Proterozoic basement rocks along the north-striking part of the fault. Outcrops of the Palmerville Fault are only sporadically exposed, since the contact is commonly obscured by Mesozoic cover sequences and/or igneous intrusions that presumably utilised the fault as a conduit for magma flux. Where exposed, the extent of deformation in the vicinity of the Palmerville Fault is intense and decreases away from the fault (Fig. 4a–d). In places, the Palmerville Fault

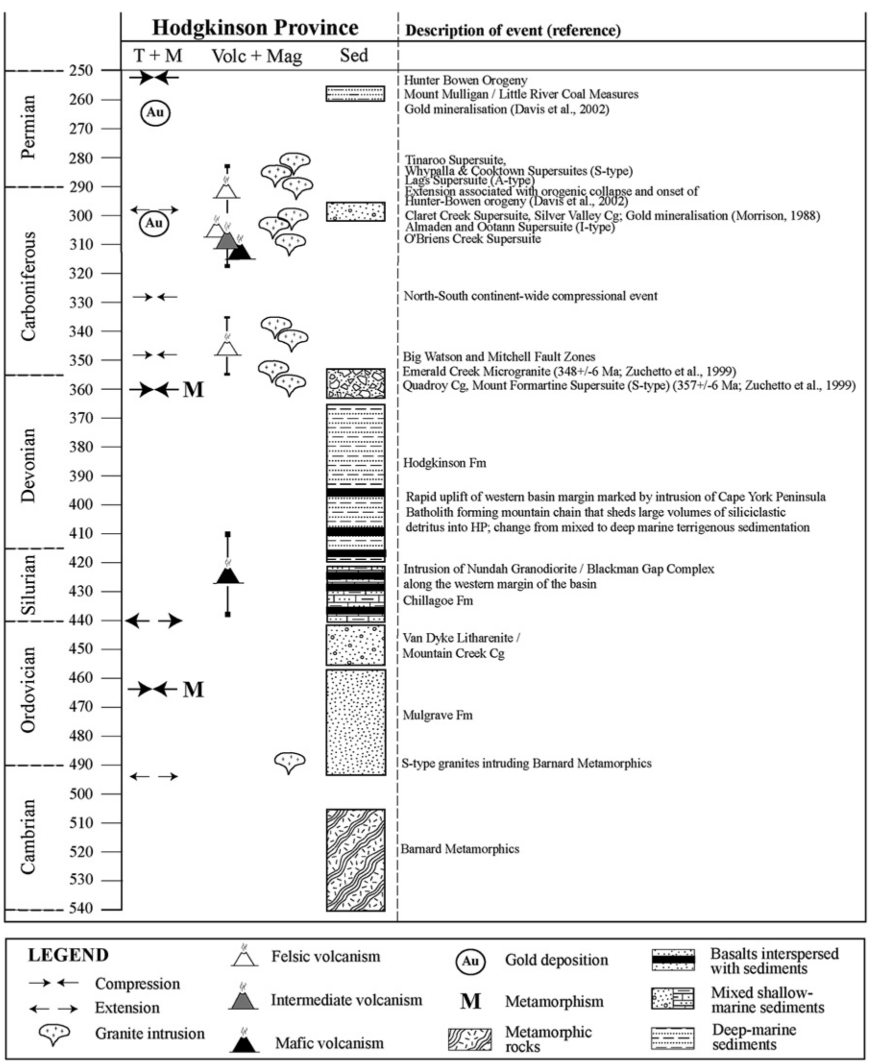

Fig. 3. Time-space diagram of Palaeozoic geological events across the Hodgkinson Province (compiled from Morrison, 1988; Bultitude et al., 1997; Zucchetto et al., 1999; Davis et al., 2002). Abbreviations: T + M, Tectonic framework and mineralisation, Volc + Mag, volcanism and magmatism; Sed, sedimentation.

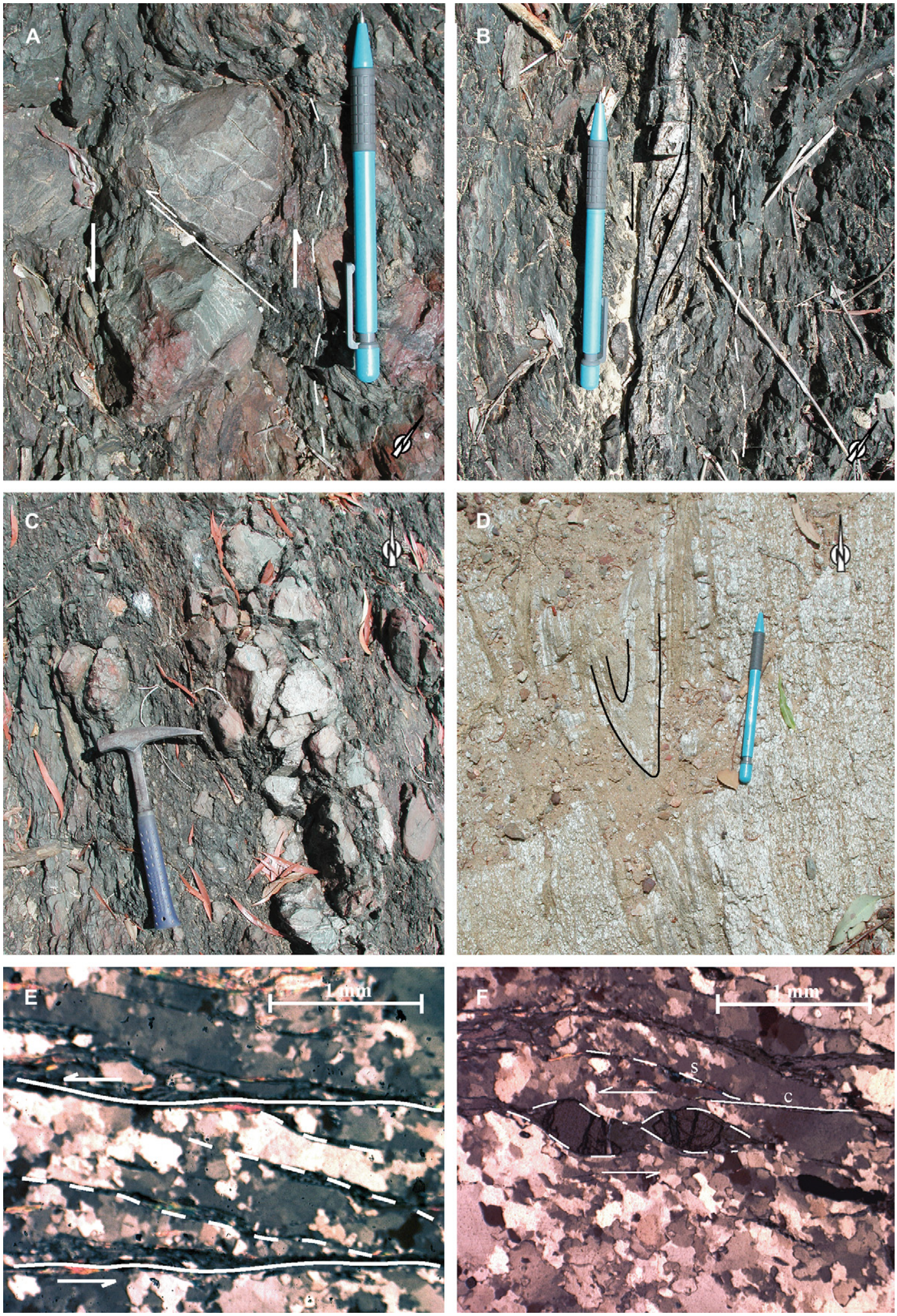

Fig. 4. (a) Close-up of shear band boudins in strongly sheared shales in NW-striking section of the Palmerville Fault (study area I) indicating sinistral shear movement (cf. Goscombe and Passchier, 2003). (b) Close-up of shear bands in quartz vein hosted by sheared shales and arenites in the NW-striking section of the Palmerville Fault (study area I) indicating sinistral sense of shear. (c) Chaotic disarray of shale, chert and arenite beds (melange) as generally observed in the vicinity of the Palmerville Fault (study area II). (d) Isoclinal folding of Proterozoic micaceous schists to the west of the Palmerville Fault (study area II). (e) Photomicrograph (XPL, thin section cut perpendicular to steep lineation on fault plane) of a section of the Palmerville Fault (study area I, Fig. 2) showing s-c fabrics depicted by mica-rich bands in a matrix of strongly recrystallised quartz indicating a sinistral sense of shear. (f) Photomicrograph (XPL, thin section cut perpendicular to steep lineation on fault plane) of a section of the Palmerville Fault (study area I, Fig. 2) showing σ-clasts of garnet as well as s-c fabrics indicating a sinistral sense of shear.

can be identified as a 30–100 m wide fault zone that represents the transition from strongly deformed Palaeozoic shales and arenite beds in the east (Fig. 4c) to Proterozoic micaceous schist in the west (Fig. 4d).

3.1.1. Shear sense indicators

As previously noted by other authors (e.g. Shaw et al., 1987; Bultitude et al., 1997), Palaeozoic rock assemblages to the east of the Palmerville Fault generally parallel the strike of the Palmerville Fault (Fig. 5a) and have a dominantly steep eastward dip. These rock assemblages are characterised by upright folding, intense cleavage fabrics, and fault-mélange and breccias that surround and incorporate low strain lenses and pods. Shear band boudins, S-C fabrics and rotated porphyroclasts in these assemblages in study area I record a component of sinistral shear (Fig. 4a,b).

3.1.2. Stretching lineations

Steep- as well as shallow-plunging stretching lineations were recorded in both study areas (Fig. 5b). In study area I, both steep- and shallow-plunging lineations were observed in the Proterozoic rocks adjacent to the Palmerville Fault. In study area II, only steep lineations were recorded in both Proterozoic and Palaeozoic rocks.

3.1.3. Shear sense indicators in Proterozoic basement rocks

Microstructural investigations of Proterozoic basement rocks from the Palmerville Fault indicate that in the study areas the Palmerville Fault can be characterised as a proto-mylonite zone based on the presence of (folded) micaceous shear bands and elongated garnet crystals within strongly recrystallised quartz matrix on sections cut perpendicular to steep lineations on the fault plane (Fig. 4e,f). Micaceous shear bands and deformed and rotated quartz crystals indicate a sinistral sense of shear (Fig. 4e,f). Micaceous shear bands defining S-C fabrics in sections parallel to the steep lineations on the fault plane indicated normal movement. This indicates that the Proterozoic basement rocks record normal movement with a sinistral sense of (i.e. transtension) that may be considered to reflect the earliest movements along the Palmerville Fault in the Early Palaeozoic.

3.2. Geophysical modelling

To better understand the subsurface geometry and architecture of the Palmerville Fault and to extrapolate the structural relationships observed in the study areas we have undertaken interpretation and forward modelling of magnetic and gravity data (e.g. Betts et al., 2003). Importantly, this includes the interpretation of multiscale wavelet edges to constrain the nature of lithological and fault contacts and forward modelling to constrain the 3-D subsurface geology of the Palmerville Fault region.

3.2.1. Worming

Multiscale wavelet edges or 'worms' are vectorised points of maximum gradient derived through a process of wavelet transformation and upward continuation of potential field data (Archibald et al., 1999; Hornby et al., 1999). An array of upward continuation levels ('worm sheets') provides insight into the behaviour of potential field gradients at different scales and depths (i.e. small upward continuations reflect gradients near surface and large upward continuations map gradients at depth). Depending on the potential field and transformation employed, the strongest gradients relate to contacts of rock-property contrasts (i.e. susceptibility for magnetic fields and density for gravity). Contacts without rock property contrast cannot be imaged, but may be inferred through linear truncations and offsets in overlapping worm sets. Synthetic models indicate that the dip direction of a worm sheet can

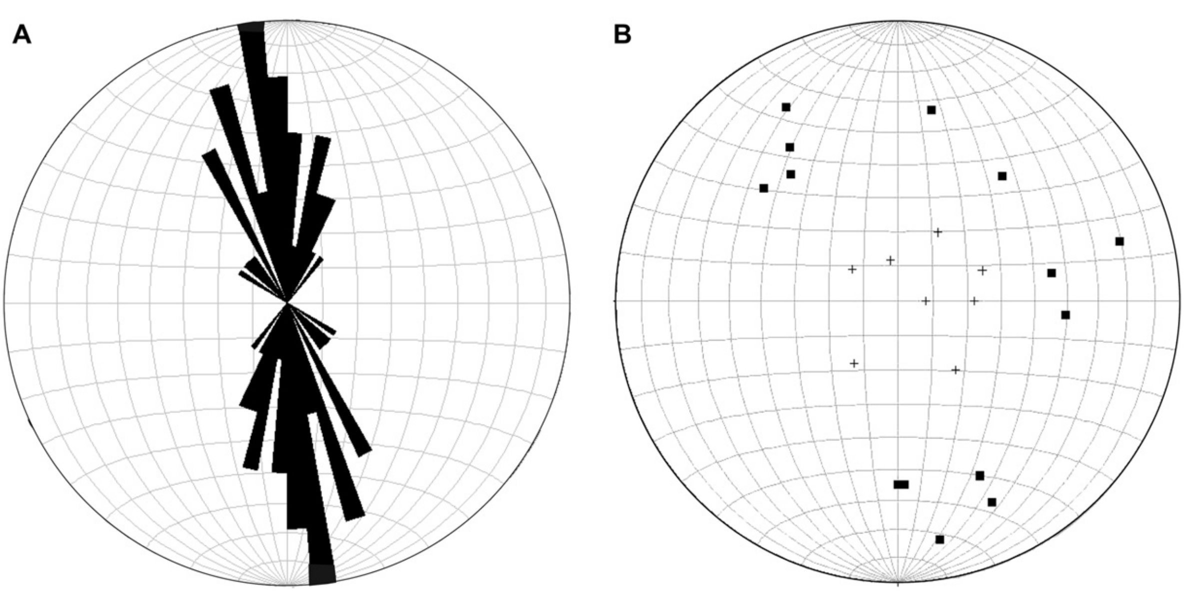

Fig. 5. (a) Rose diagram ($n = 35$) indicating dominant north to northwest strike of rock assemblages adjacent to the Palmerville Fault (collected from key study areas). (b) Lower hemisphere projection of steep (crosses) and shallow (squares) lineations recorded in key study areas.

mirror its related geological contact (e.g. folds, faults, intrusive bodies; Holden et al., 2000). Using the height and length persistence of near-surface worm sheets, inferences can be made about the relative depth of penetration of a geological edge. To investigate the geometry of the Palmerville Fault, worming has been applied to gravity and magnetic datasets for the western portion of the Hodgkinson Province.

Detailed analysis of worms in the Palmerville Fault area was undertaken to investigate the fault dip (Fig. 6). In Fig. 6, the worm sheet associated with the Palmerville Fault consists of very tightly spaced worms, which suggests a very steeply dipping worm array and hence may be interpreted to mirror the steep dip of the Palmerville Fault. To the east of the Palmerville Fault, the worm sheet associated with the Mitchell Fault Zone (Fig. 6) displays an increasing upward continuation level from west to east. This indicates an easterly dip for this worm array and can be considered to reflect an easterly dip for the Mitchell Fault Zone. Regional results of worming of data covering the area of Fig. 2 are presented in Fig. 7a and b for aeromagnetic and Bouguer gravity data, respectively. Magnetic worms predominantly outline the edges of magnetic rock bodies (i.e. Siluro-Devonian basalts of the Chillagoe Formation) that are considered to parallel fault structures. Gravity data across the Hodgkinson Province is sparse and unevenly distributed. Combined with relatively minor density contrasts, this limits the capacity of (gravity) worming to pick up contacts other than those with the lowest density members (i.e. Carboniferous to Permian granites). The gravity worms mainly depict edges of granitic bodies where there is a major density contrast with the country rock. However, despite the minor density contrast between rock assemblages across the Palmerville Fault, results from gravity worming indicate the presence of a worm sheet associated with the Palmerville Fault (inset in Fig. 7b) that suggests a steep eastward dip for this structure.

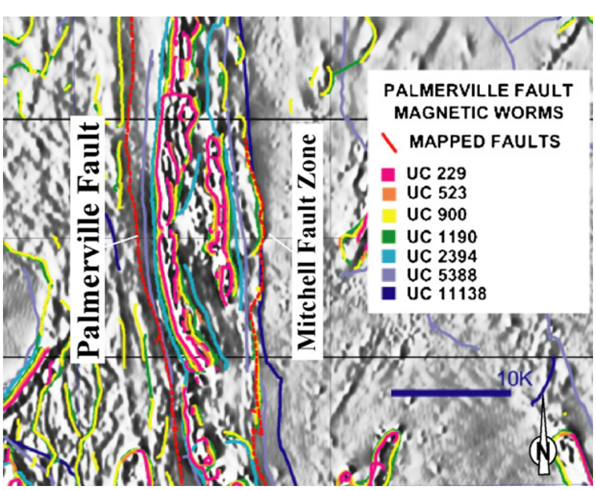

Fig. 6. Detailed worming over a section of the Palmerville Fault (location indicated by red dashed line on figure) indicating a steeply dipping fault geometry. Worm sheets associated with the Mitchell Fault Zone suggests a steep eastward-dipping geometry for this structure.

3.2.2. Forward modelling

Gravity and magnetic data was forward modelled for seven regional cross-sections across the Palmerville Fault to further constrain the geometry and depth extent of the fault. Our modelling methodology is based on the following: (1) worming results have been used to constrain block boundaries; (2) representative density and susceptibility values from the region have been used to define the contrasts; (3), the simplest and most conformable model between slices has been developed; and (4) the constructed block model has been tied to surface geology. Modelling was performed with Encom's ModelVision™ software as a series of 2-D slices at 20 km intervals along the entire length of the fault (Fig. 2). A representative profile is given in Fig. 8 indicating (a) observed (black) and modelled (blue) Bouguer gravity response; (b) topography; (c) residual magnetics with field response (nT) in black and modelled response in pink; (d) surface geology; and (e) block geology model. The Palmerville Fault is interpreted to represent the boundary between lithologies with contrasting rock properties. Directly east of the fault, the Palaeozoic rocks have been assigned 0.005–0.02 SI and 2.62–2.65 g/cm^3 for magnetic susceptibility and density respectively based on the average values obtained from the dominantly basaltic and sedimentary rocks in this region. To the west of the fault, Proterozoic rocks have been assigned 0.0–0.02 SI and 2.70–2.72 g/cm^3 for magnetic susceptibility and density respectively based on the average values obtained from metamorphic rocks (gneiss / schist) in this region. A decreasing observed gravity gradient is apparent across the fault (Fig. 8), indicating less mass to the east of the fault compared to the west of the fault as expected from density differences in the Proterozoic and Palaeozoic rock assemblages. Previously, Champion and Bultitude (1994) and Bultitude et al. (1996) suggested that regional Bouguer anomalies indicate that continental crust with similar characteristics to the metamorphic basement west of the Palmerville Fault extends east of the Palmerville Fault underneath the Hodgkinson Province. To achieve 'best fit' in our modelling results, the presence of Proterozoic basement underneath the Palaeozoic assemblages is required. If this model is correct, it would also lend support to the interpretations by Champion and Bultitude (1994) and Bultitude et al. (1996). A magnetic gradient is observed across the Palmerville Fault (Fig. 8) from −140 nT in the west to +340 nT in the east (maximum values). The magnetic response to the east of the Palmerville Fault is controlled by the presence of basaltic units within the Chillagoe Formation. Although variable in distribution along the length of the fault, their magnetic response suggests the presence of steeply eastward-dipping magnetic bodies to the east of the Palmerville Fault, which can be interpreted to parallel the fault and therefore support a model of a steeply eastward-dipping regional fault structure. All constructed model sections across the Palmerville Fault are given in Fig. 9. In this figure, the modelled sections are combined to generate a permissive 3-D block model of the western part of the Hodgkinson Province. Overall, results from potential field modelling over the western portion of the Hodgkinson Province closely match the observed

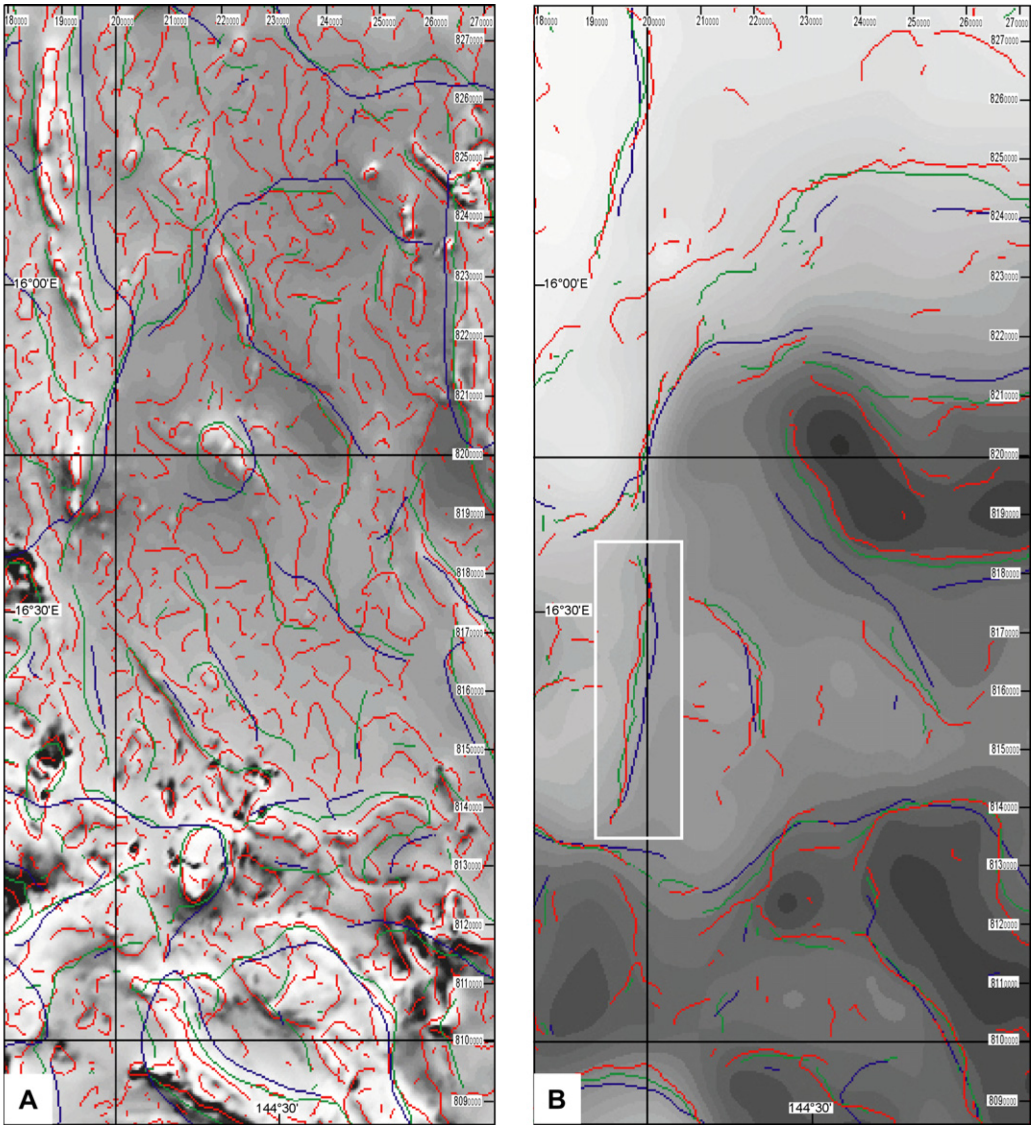

Fig. 7. (a) Magnetic worms over greyscale total magnetic intensity image. Worm colours correspond to upward continued layers: red, 1096 m; green, 5269 m; blue, 11553 m. (b) Gravity worms over greyscale Bouguer gravity image. Worm colours correspond to upward continued layers: red, 1190 m; green, 5388 m; blue, 11,138 m. Inset encloses worm sheet that is directly associated with the Palmerville Fault.

gravity and magnetic response (Fig. 9). A best fit between the observed and calculated geophysical response is achieved when the Palmerville Fault is modelled as a steeply eastward-dipping fault that soles out at a depth of approx. 6 km. The fault is modelled as a detachment/décollement, where it ramps to a depth of approximately 7.5 km around 40 km east of the Palmerville Fault. Nonetheless, the depth extent of the fault (i.e. the depth to which the fault penetrates into the basement) remains an issue that could not be resolved satisfactorily. Due to the relatively subtle susceptibility and density contrasts within rock assemblages adjacent to the fault, the overall model is relatively insensitive to the total depth of rock displaced by the Palmerville Fault. Although the modelling demonstrates a depth to basement of around 6–7.5 km, the actual depth extent of the Palmerville Fault and consequently the depth of Proterozoic basement may be several kilometres deeper or shallower than our modelling suggests.

4. Discussion

4.1. Kinematics of the Palmerville Fault

De Keyser (1963) suggested the occurrence of at least four phases of movement along the Palmerville Fault. These include: (1) normal movement initiating subsidence in the Hodgkinson Province during the Silurian; (2) reverse displacement causing folding and uplift of the Hodgkinson Province during the Carboniferous; (3) normal movement during the Late Permian; and (4) reverse displacement that may have continued until the Quaternary. More recent work has indicated that the first two episodes of deformation are dominantly recorded in the western part of the Hodgkinson Province, where the latter two stages are generally preserved in the eastern portion of the Hodgkinson Province (Bultitude et al., 1997; Vos et al., 2006). Therefore, we interpret that our field and

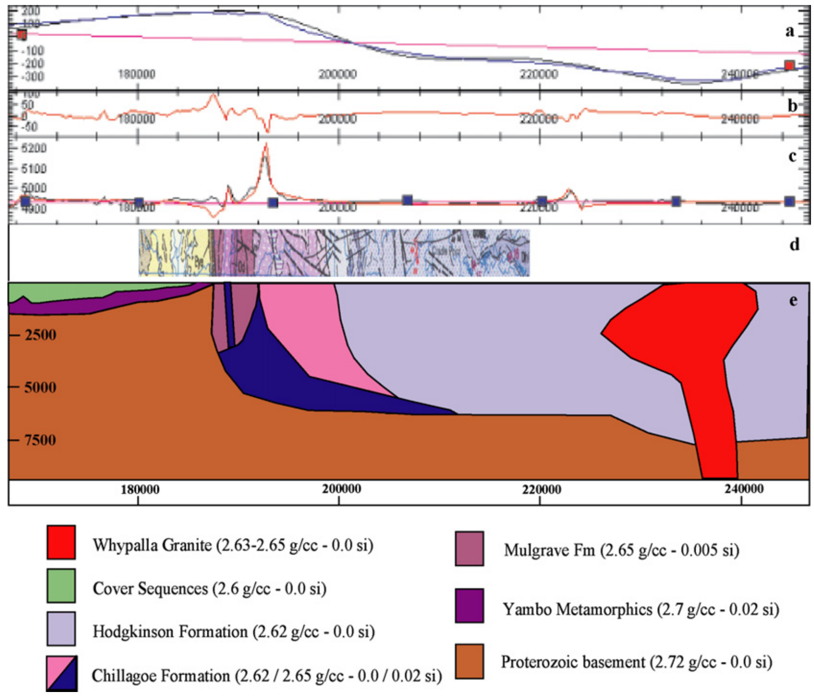

Fig. 8. Modelled profile at 8220000N across the Palmerville Fault (LPV5). From top window down: (a) Bouguer gravity response (gu) in black and modelled in blue; (b) topography; (c) residual magnetics with field response (nT) in black and modelled response in pink; (d) surface geology slice from 1:250,0000 Mossman Map Sheet (Bultitude et al., 1996); and (e) proposed block geology model with density and magnetic properties outlined in legend.

microstructural observations are associated with the first two phases of movement along the fault. In this case, stretching lineations along segments of the fault record Early Palaeozoic extension/transtension that is followed by Middle-Late Palaeozoic compression/transpression as illustrated by the presence of shear sense indicators in Palaeozoic rocks. Proterozoic basement rocks immediately to the west of the fault only recorded the initial phase of fault movement. Microstructural investigations from these rocks indicated that normal movement with a component of sinistral shear represents this initial phase of fault movement. The absence of kinematic indicators in Proterozoic basement rocks to the west of the Palmerville Fault indicates that the basement rocks have not been substantially deformed. We extrapolate that the juxtapisition of strongly deformed Palacozoic basin rock assemblages against the Proterozoic basement rocks indicates a process of basin inversion associated with west-directed thrusting. The strongly deformed Palaeozoic basin rock assemblages characterised by mélange zones and fault-breccias most probably accommodated the bulk of west-directed, basin inversion during the Middle-Late Palaeozoic. On the basis of (1) the presence of preserved lineations and kinematic indicators that point to normal movement during the initial phase of movement along the Palmerville Fault, (2) the east to west increase of strain in Palaeozoic basin rocks towards the fault and (3) the overall deformation focus on the hanging wall of the fault (i.e. the Palaeozoic rock assemblages) as compared to the footwall of the fault (i.e. the Proterozoic basement rocks), we suggest that the Proterozoic basement rocks and by inference the Palmerville Fault acted like a buttress during Late Palaeozoic basin inversion. Hanging wall buttressing is considered a common characteristic of inverted normal faults (e.g. Butler, 1989; Betts, 2001; Betts et al., 2004). The presence of steep and shallow lineations as well as sinistral shear sense indicators in deformed Palaeozoic rock assemblages along the south-west striking section of the Palmerville Fault in study area I suggests that a component of strike-slip may have been associated with inversion along this portion of the fault.

4.2. Implications for the tectonic evolution of the Hodgkinson Province

Our structural observations and modelling results suggest that the Palmerville Fault forms a steeply eastward-dipping structure that becomes listric at depth. This is in contrast with results from Shaw et al. (1987), who interpreted the Palmerville Fault as an integral part of a major reverse west-dipping thrust system.

A westward-dipping model cannot be ruled out on the basis of geophysical analyses as conducted as part of this study. However, we strongly favour an eastward-dipping model for the Palmerville Fault, as it is not only geologically more straightforward, but also complimentary to interpretations of the tectonic evolution of the Hodgkinson Province. The evolution of the Hodgkinson Province is interpreted to reflect inversion of an extensional back-arc basin controlled by episodes of subduction rollback intermittent with microcontinent/ridge subduction outboard of the Palaeozoic Australian Craton (e.g. Bultitude et al., 1997; Vos et al., 2006). Importantly, our modelling results imply the presence of Proterozoic basement underneath the Hodgkinson Province. This is in agreement with an eastward-dipping fault model and is in turn

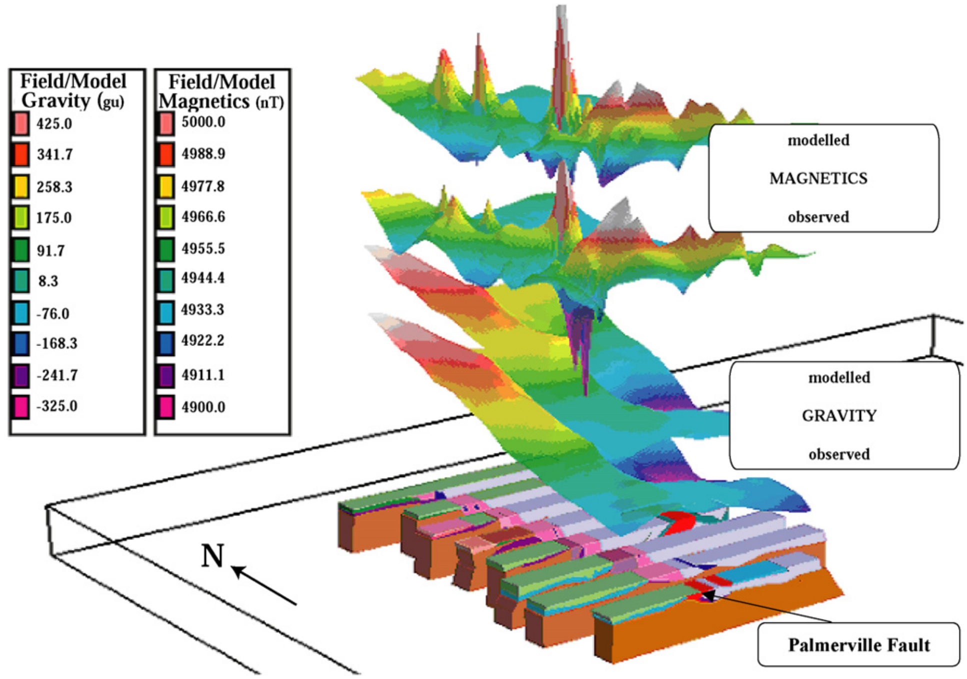

Fig. 9. All constructed model sections across the Palmerville Fault created by forward modelling and based on integration of field observations, 'worming' and geochemical datasets illustrating a steeply eastward-dipping Palmerville Fault. Together these sections combine to generate a permissive 3-D block model of the geometry of the western part of the Hodgkinson Province. Modelled and observed magnetic and gravity response are given. Note the close match between observed and modelled magnetics and gravity.

supported by geochemical datasets from mafic volcanic rocks and granite intrusions in the Hodgkinson Province (Champion and Bultitude, 1994; Vos et al., 2006) . These datasets point to the presence of Proterozoic basement at depth. The presence of Proterozoic basement underneath the Hodgkinson province and the character and intensity of deformation in Palaeozoic basin rocks in the province implies a mechanism of thin-skinned thrusting during Late Palaeozoic basin inversion. In this scenario, the intensity of the deformation in the Palaeozoic rock assemblages in the hanging-wall of the Palmerville Fault is controlled by their competency contrast with the more competent Proterozoic rocks in the footwall of the fault (e.g. Betts, 2001; Betts et al., 2004). By inference, the Palmerville Fault would have acted not only as a buttress along the western margin of the Hodgkinson Province but also as a low-angle décollement zone between the Palaeozoic basin assemblages and the underlying Proterozoic basement.

The presence of a proto-Palmerville Fault in the Proterozoic (e.g. Bultitude et al., 1993) most probably controlled the location and development of the Palmerville Fault during Early Palaeozoic extension along the proto-Pacific margin of northeastern Australia. We therefore suggest that during Silurian to Late Devonian extension in the Hodgkinson Province the Palmerville Fault developed as a (mid-crustal) detachment fault along the margin of Proterozoic Australia. During subsequent basin inversion, the Palmerville Fault acted as a mid-crustal décollement zone and Palaeozoic basin assemblages were strongly disrupted in response to thin-skinned thrusting. The kinematics of the Palmerville Fault as described above and the general evolution of the Hodgkinson Province have been illustrated in Fig. 10.

Although our modelling did not resolve the character of intra-basinal second-order thrust faults in detail, we suggest that these further accommodated shortening in the province and could have been oversteepened in the western part of the province as a result of more intense deformation. Alternatively, intra-basinal west-dipping structures could be explained by backthrusting adjacent to the Precambrian buttress. Such a scenario is reminiscent of interpretations of the Moyston Fault in the Lachlan Fold Belt in southeastern Australia (Cayley and Taylor, 1998; Taylor and Cayley, 2000). These authors argued that a doubly-vergent pop-up structure could develop during convergence towards a buttress where a zone of high deformation will be spatially concentrated along the controlling fault. As such, the Palmerville Fault can be regarded as being analogous to the Moyston Fault, where zones of tectonic melange can be found directly adjacent to the major faults.

5. Concluding remarks

Results from integrated worming, forward modelling and field studies combined with available geochemical datasets indicate that the Palmerville Fault, which forms the boundary between Proterozoic and Palaeozoic rock assemblages in northeastern Australia, represents a steeply eastward-dipping inverted normal fault. The eastward-dipping nature of the Palmerville Fault that is juxtaposed against Proterozoic basement implies that the fault probably developed as a basin- and terrane-bounding mid-crustal detachment fault during Early to Middle Palaeozoic extension on the margin of Proterozoic Australia. During subsequent inversion and deformation of the basin in the Late Palaeozoic, the Palmerville Fault acted

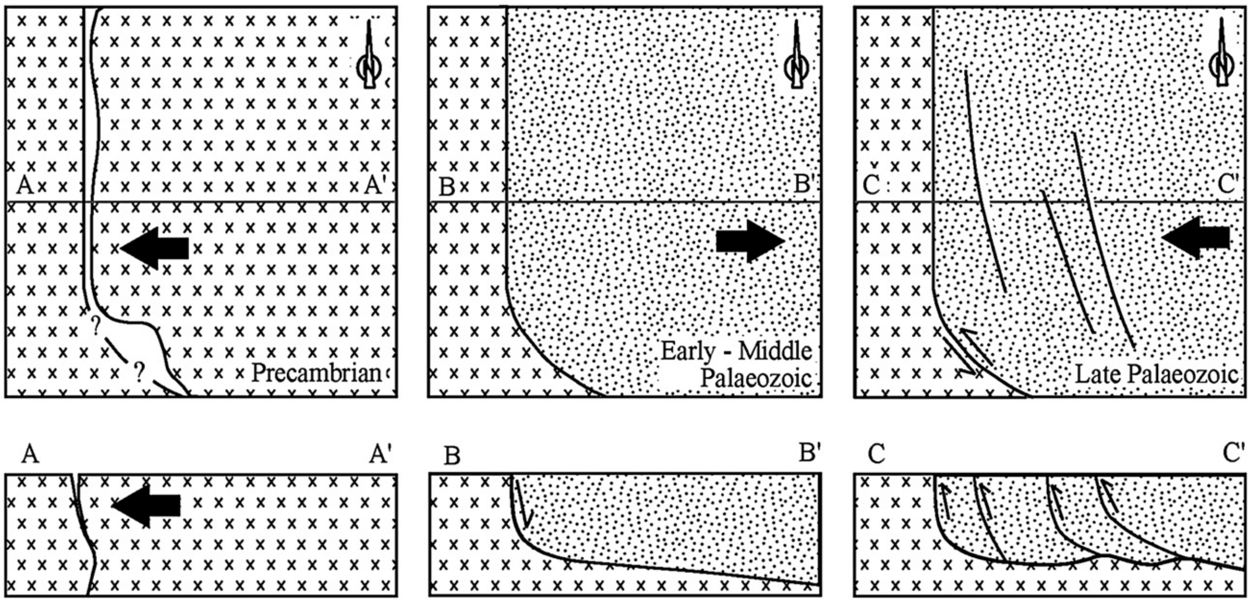

Fig. 10. Schematic plan views and cross sections illustrating the role of the Palmerville Fault in the tectonic evolution of the Hodgkinson Province.

as a décollement zone that accommodated thin-skinned, west-directed thrusting during a number of episodes of contraction in the Hodgkinson Province.

The nature of the subsurface structure of major faults is an important problem (e.g. Lynch and Richards, 2001) and commonly integral to understanding the role of large-scale faults in the tectonic evolution of an area (e.g. Betts et al., 2004). Especially where faults have undergone multiple reactivations and data density remains low, determinations regarding their subsurface nature and structural evolution are rendered difficult. The approach of combining geological, geophysical and geochemical datasets has proven particularly useful in determining the nature and character of a major fault system in a low-data density area in northeastern Australia and could be applied successfully in similar regions elsewhere. In particular, the application of multi-scale wavelet edge analysis has been illustrated to be a powerful tool for providing insights into the nature and geometry of large-scale structures.

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