

Integrating structural interpretation and supersequence correlation in the South Nicholson Basin

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Introduction

The South Nicholson Basin is one of several important Palaeo–Mesoproterozoic sedimentary depocenters over the North Australian Craton, alongside the McArthur and Birrindudu basins and the Tomkinson and Davenport provinces (Ahmad and Munson 2013; Carr *et al* 2020). Geographically, it is bounded by the McArthur Basin at the northwest and the Isa Inlier to the west and southwest, covering an area of approximately 20 000 km² (Henson *et al* 2018; Carson *et al* 2023; **Figure 1a**).

The South Nicholson Basin has recently been the focus of the *Exploring for the Future* program (Henson *et al* 2018; Carr *et al* 2019; Grosjean *et al* 2023). This program was designed to reveal the stratigraphic sequences beneath the Georgina Basin and above the Palaeo–Mesoproterozoic Lawn Hill Platform. It included the acquisition of 2D seismic surveys (L210 and L212), and new geochemical, geochronological, and hydrological analyses (Jackson *et al* 1999, Ahmad and Munson 2013). As part of the *Exploring*

for the Future program, several stratigraphic boreholes were drilled, including Carrara 1 where analysis of core samples and geophysical logs (Gamma-Ray, Sonic and Density) identified thick black shales rich in organic material from the Lawn Hill Formation (Ahmad and Munson 2013, Bailey *et al* 2022). Other boreholes, such as 23BNM001, 23BNM002 and 23BNM003 from the Benmara Copper Project (Lawley 2023), and BRKDD001, BRKDD002 and BRKDD004 from the Barkly Project (Reed 2019), suggest minor iron ore concentrations at the Crow Formation and Caulfield Beds (Carson *et al* 2023; Munson 2023).

Despite these advances, significant uncertainties remain about the evolution of the South Nicholson Basin, particularly how multiple tectonic events have shaped its present-day structural architecture and controlled the deposition, erosion and preservation of multiple Proterozoic sequences in the study area. This study provides a basin-scale structural synthesis integrating the interpretation of multiple 2D seismic surveys across the South Nicholson Basin (**Figure 1a**). Our results give insights into the tectonic events that have controlled the deposition including multiple extension events that influenced primary basin architecture for deposition and shaped local palaeo-topography which were later inverted during multiple compression events.

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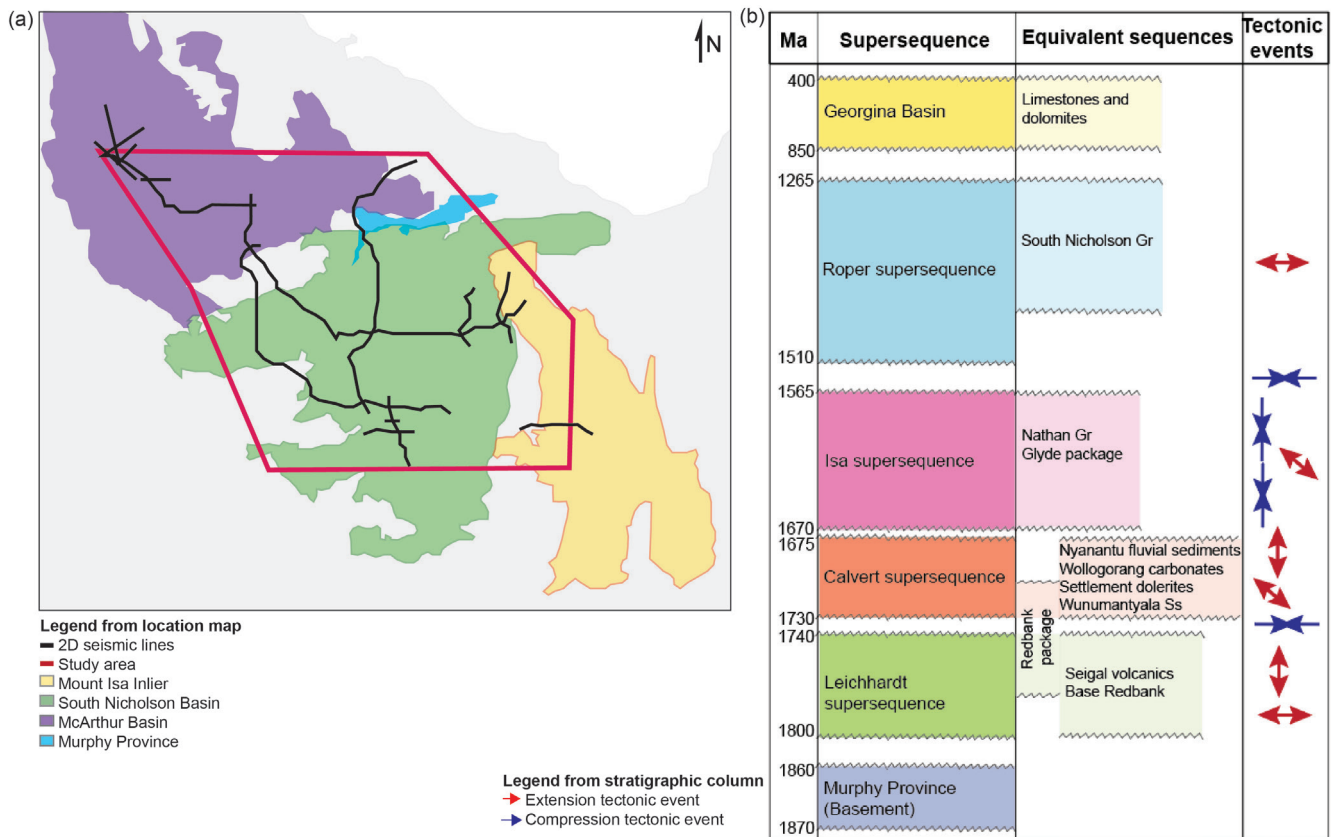


Figure 1. (a) Location map of the study area and the 2D seismic interpreted in this study. Red line corresponds to the extent of the available 2D seismic surveys within the South Nicholson Basin, the southwestern McArthur Basin, and the western Isa Inlier. Modified from Carson *et al* (2023), Blaikie and Kunzmann (2020). (b) Stratigraphic column showing the interpreted supersequences and a summary of the tectonic events proposed in the literature. The stratigraphic column summarises information from Ahmad and Munson (2013), Jackson *et al* (1999), Rawlings (1999), Blaikie and Kunzmann (2020), Gibson and Edwards (2020), Carr *et al* (2020), Munson (2023).

These compression events led to the inversion of some of the normal faults and restricted the accumulation of syn-kinematic and younger supersequences into smaller depocentres.

Geological settings

The South Nicholson Basin comprises stratigraphic sequences deposited between 1800 and 1270 Ma below the limestone and dolomite sequence of the Georgina Basin (850–400 Ma; Smith 1972, Ahmad and Munson 2013). Regionally, several episodes of deposition and volcanism are separated by regional unconformities associated with extensional and compressional tectonic events (Ahmad and Munson 2013, Blaikie and Kunzmann 2020, Gibson and Edwards 2020). Each depositional episode (defined as superbasins), consists of several stratigraphic sequences equivalent in age and composition to formations and groups recognised in the McArthur Basin, Isa Province and Lawn Hill Platform (Jackson *et al* 1999, Carson *et al* 2023). The Murphy Province (>1860 Ma) represents the oldest unit and characterises the top of the basement underlying the South Nicholson Basin (Ahmad and Munson 2013, Carr *et al* 2020, Verdel and Munson 2025).

Unconformably overlying this basement, the Leichhardt supersequence (1800–1745 Ma) correlates with the Seigal and base Redback formations. Above this, the Calvert supersequence (1740–1680 Ma) represents sequences equivalent to the Nyanantu fluvial sequence, Wollogorang carbonates, Settlement Creek Dolorite and Wunumantyal sandstones (Jackson *et al* 1999, Rawlings 1999, Ahmad and Munson 2013, Blaikie and Kunzmann 2020, Carr *et al* 2020). Unconformably above, the Isa supersequence (1670–1570 Ma) corresponds to sequences equivalent to the Nathan and Glyde shales, tuff, sandstones and carbonates, McNamarra and Flickling groups (Andrews 1998, Ahmad and Munson 2013, Blaikie and Kunzmann 2020, Verdel and Munson 2025). On top, the Roper supersequence (1500–1270 Ma) corresponds to sequences equivalent to the South Nicholson group (Jackson *et al* 1999, Ahmad and Munson 2013, Spinks *et al* 2016, Carr *et al* 2020) (**Figure 1b**).

Multiple authors have proposed that several tectonic events resulted in erosion and uplift of the Proterozoic supersequences. These include extensional events with easterly (1800–1780 Ma) and northerly (1760–1740 Ma, 1680–1660 Ma and 1640–1630 Ma) strikes (Blaikie and Kunzmann 2020), as well as compressional events with northwestern (1850–1870 Ma) (Ahmad and Munson 2013), eastern (1730–1720 Ma and 1560–1540 Ma), northern (1630–1620 Ma, 1600–1570 Ma) (Gibson and Edwards 2020) and north northeastern (1640–1580 Ma) orientations (Ahmad and Munson 2013, Blaikie and Kunzmann 2020) (**Figure 1b**).

Methodology

We use multiple 2D seismic lines including: L210 South Nicholson (2017) and L212-Barkly (2019) surveys from the *Exploring for the Future* program, Beetaloo (2012), L180-Isa Deep (2006) and Barkly 2D from Teck (2020), and

L179-Camooweal (2019) (**Figure 1a**). Our interpretation focuses on: 1) identifying the characteristics of multiple fault systems including strike, dip direction and along-strike length, and 2) mapping the lateral extent of supersequences, such as changes in thickness and continuity.

We use formation tops from Wang *et al* (2023) to tie the Carrara 1 well to the 17GANS1 2D seismic line. We map nearby formation tops from the Roper (equivalent to the unconformity that marks the base of Georgina sequence) and the Isa supersequences. These tops correspond to strong changes in amplitude that can be traced regionally along the South Nicholson basin. As Carrara 1 only reached the middle of Isa supersequence, we use the interpretation of the 17GANS1 from Carr *et al* (2020) to infer the tops of older sequence such as the Calvert and Leichhardt supersequences, as well as the basement. We include an additional horizon within the Roper supersequence to highlight a strong change in seismic amplitude. These horizons highlight lateral variations in thickness within the shallower supersequences.

Results and interpretation

Fault systems

We identify two different fault systems (normal and inverted faults) that displaced the mapped supersequences (Georgina, Roper, Isa, Calvert and Leichhardt) and the basement.

Normal faults typically form horst and graben structures characteristic of extensional events. These faults exhibit north, north-northeast and north-northwest strikes. They generally displace either a single or multiple supersequences between the middle Roper supersequence and the basement, particularly in the south and east study areas. Conversely, in the centre's north and northwest regions, normal faults are concentrated in the basement. Throughout the study area, no normal fault reaches the Georgina Basin or the surface (**Figure 2b, c**).

These normal faults align with the eastern extensional event during the deposition of the Leichhardt supersequence (1800–1780 Ma). Similarly, faults displacing the Leichhardt and middle Roper supersequences could stem from more recent extension events like the eastward extension during the Roper supersequence deposition (1700–1660 Ma and 1640–1630 Ma).

The inverted faults displace the sequences between the Georgina sequence and the basement, locally reaching the surface at the centre and north regions of the study area. They display east–west to northeast strikes and folding in the hanging walls. These examples are more noticeable in the north and northwest parts of the study area. To the east and south regions, inverted faults are less common and mainly displace the supersequences between the Leichhardt supersequence and the Georgina sequence. In contrast to the centre, north and northwest, they appear more frequently reaching the basement and forming flower-like structures. These structures strongly fold and tilt the Georgina sequence and the Isa, Roper, Calvert and Leichhardt supersequences (**Figure 2b, c**).

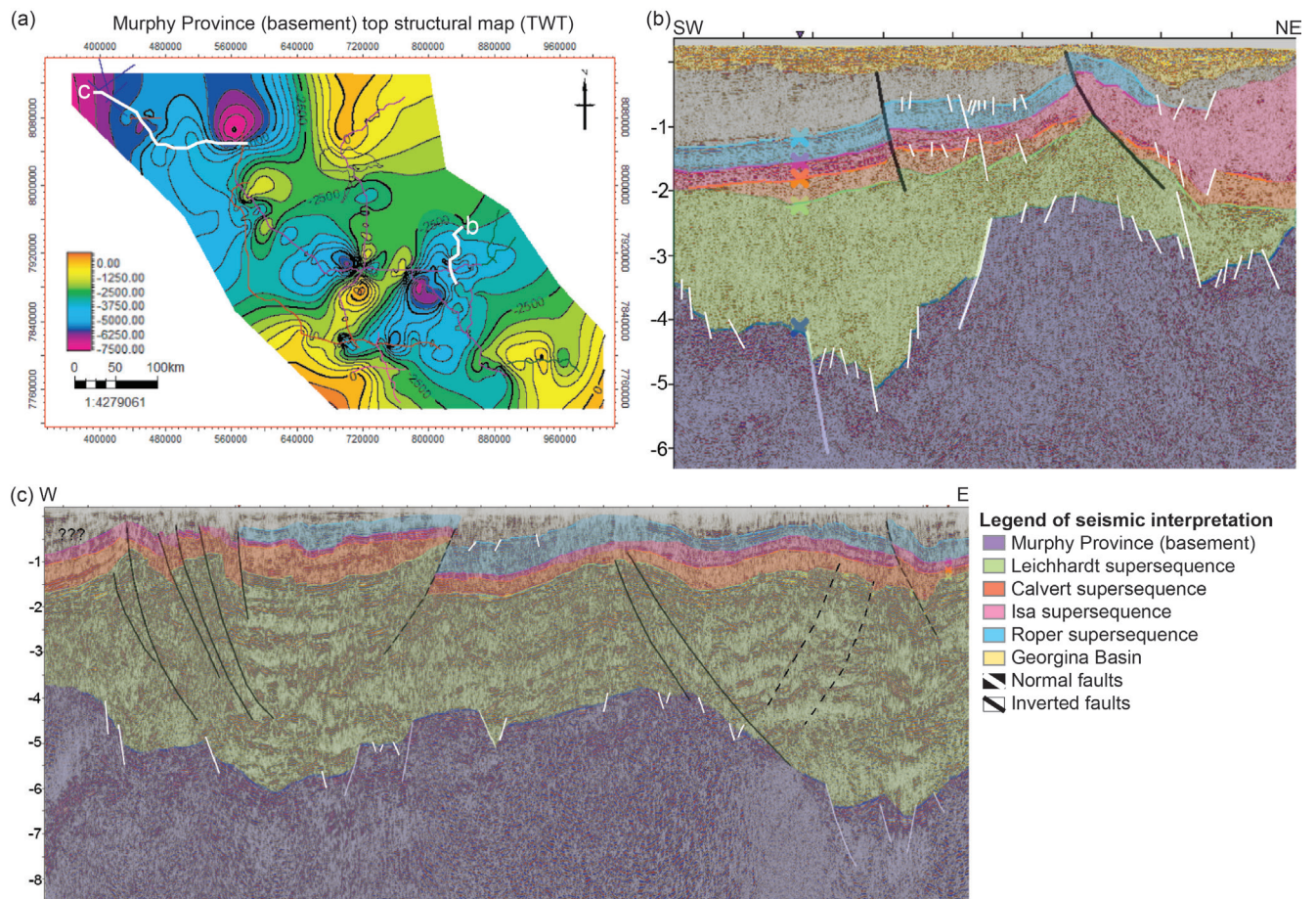


Figure 2. (a) Location of some of the interpreted 2D seismic lines in the South Nicholson Basin. (b) 19GAB4 in the east. (c) 17GASN4 in the northwest. These 2D seismic lines are part of the *Exploring for the Future* program.

These inverted faults suggest initial eastern and northeastern striking normal faults that might have formed during the deposition of the Leichhardt supersequence (1800–1780 Ma) and they were likely inverted during the Isa Orogeny (1630–1540 Ma; Blaikie and Kunzmann 2020). However, the contrast within the northerly striking normal faults suggests that not all the faults were inverted during the different orogenic events such as the Isa Orogeny and the Riversleigh tectonic event (1650–1640 Ma; Gibson and Edwards 2020).

Structural maps

We generate structural maps of each of the supersequences using the interpretation of the available 2D seismic lines. These maps allow us to: 1) identify changes in depth and thickness of the different supersequences, and 2) verify the strike and lateral extent of faults in the subsurface.

The structural map of the top basement confirms that the normal faults predominantly strike north, north-northeast and north-northwest. These maps also show significant deformation from compression events. This results in substantial changes to basement depth and uplift at the study area’s centre. For example, the basement is shallower in the north and south, indicating the South Nicholson Basin’s closure as a depocenter (**Figure 3a**).

The Leichhardt, Calvert, Isa and middle Roper supersequences show significant deformation, particularly

towards the central, north and northwest regions of the study area. In the subsurface, we identify folding, pinch-outs and erosion associated with outcrops of older sequences such as the Isa, Calvert and Leichhardt supersequences (**Figure 2b, c**). Similarly, the Isa Orogeny may have caused local uplift and erosion of the Roper supersequence in addition to folding and shallowing of the Leichhardt supersequence to base of the Isa supersequences, reducing the accommodation space for the Roper supersequence to be deposited (**Figure 3b, c**).

The structural maps show that all the supersequences are shallower in the north, northeast, centre and southwest regions of the study area. Combining these results with seismic interpretation reveals that the uplift in the north, northeast and southwest regions marks the boundaries of the South Nicholson Basin. In contrast, the central region of the study area corresponds to an elevated palaeo-topography that subdivides the South Nicholson Basin into three smaller depocenters where the Roper supersequence was deposited (**Figure 3a, b, c, d, e**).

Conclusions

This study provides a regional basin-scale structural synthesis integrating available 2D seismic datasets and demonstrates that fault inversion during the deposition of the Leichhardt, Calvert and Isa supersequences fundamentally controlled the available accommodation space, basement

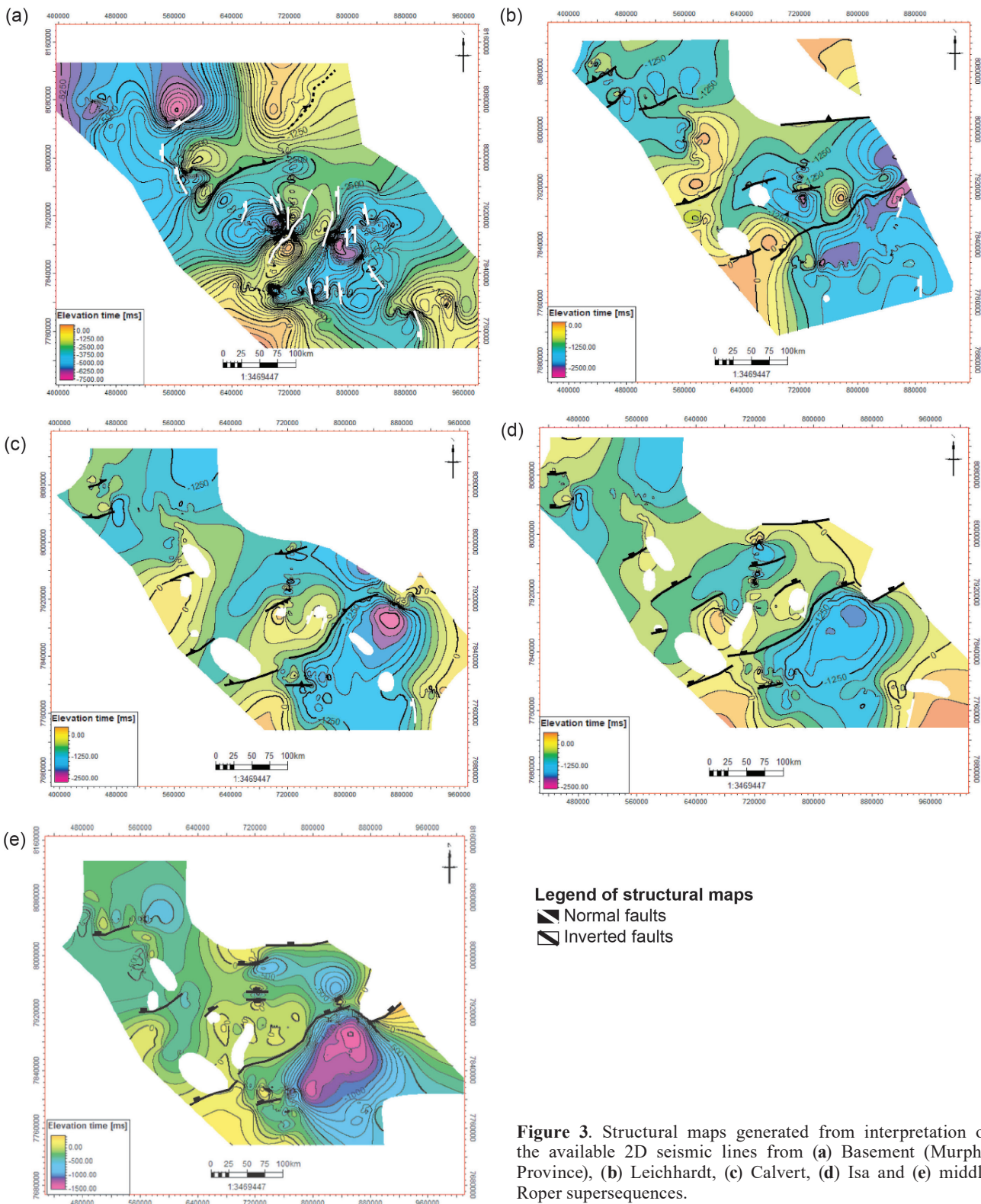


Figure 3. Structural maps generated from interpretation of the available 2D seismic lines from (a) Basement (Murphy Province), (b) Leichhardt, (c) Calvert, (d) Isa and (e) middle Roper supersequences.

architecture, and the distribution of these supersequences along the South Nicholson Basin.

We identify two distinct fault systems in the South Nicholson basin with different strikes that confirm dynamic tectonic events that influenced the evolution of the South Nicholson Basin. The normal faults with north, north-northeast and north-northwest strikes contrast with the inverted faults that have mostly east and northeast strikes. These differences in strike highlight changes in the orientation of the maximum horizontal stress in the area and

explain why the extensional faults were not inverted during the north-orientated stress during the Isa orogeny.

The structural maps reveal variations in supersequence thickness that are strongly controlled by the relative timing of extension, inversion and deposition. For example, the inverted faults in the central and northern regions produced significant uplift and supersequence erosion, resulting in a shallower basement, whereas preserved normal faults in the eastern and southern regions at the basement form horst and graben extensional structures.

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