Exploring for the Future: South Nicholson Basin region project outcomes and sequence stratigraphy

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Introduction

Exploring for the Future (EFTF) is a four year $100.5 million initiative by the Australian Government conducted in partnership with state and territory government agencies, Geoscience Australia, CSIRO, and universities. The EFTF initiative aims to boost northern Australia's attractiveness as a destination for resource exploration investment. As part of this program, Geoscience Australia's researchers have gathered, on an unprecedented scale, new pre-competitive data and information about the energy, mineral, and groundwater resource potential concealed beneath the surface in northern Australia.

A major EFTF deliverable, the acquisition of crustal seismic reflection data in the region between the southern McArthur Basin and the Mount Isa western succession, crossing the South Nicholson Basin and Murphy Province, was completed in August 2017 (**Figure 1**). Prior to this survey, the region contained no seismic data, minimal well data and minor subsurface geological data (Carr *et al* 2016). Five seismic lines were acquired in an orientation to best image geological features as identified in outcrop, and subsurface geophysical anomalies as identified in gravity and magnetics data (**Figure 1**). The acquisition was designed to explore both exposed and undercover sedimentary basins to better understand the location and scale of the region's potential resources and crustal architecture. The seismic program was undertaken in tandem with regional groundwater (Wallace *et al* 2018), surface geochemistry (Bastrakov *et al* 2018), and petroleum and mineral systems geochemistry (Jarrett *et al* 2018a; 2018a,b) studies.

The primary aim of the survey was to investigate prominent areas with a low measured gravity response ('gravity lows') in the region to determine if they represent thick basin sequences similar to the nearby Beetaloo Sub-basin, a highly prospective petroleum province (Cote *et al* 2018, Close *et al* 2016) . The gravity low that straddles the Northern Territory–Queensland border to the north of Camooweal (**Figure 1**), which is entirely overlain by the Georgina Basin, was a primary target of the survey. This new dataset has greatly improved our understanding of the geology and resources of the region. It was initially released in Alice Springs at the 2018 Annual Geoscience Exploration Seminar (Henson *et al* 2018). This paper provides an update

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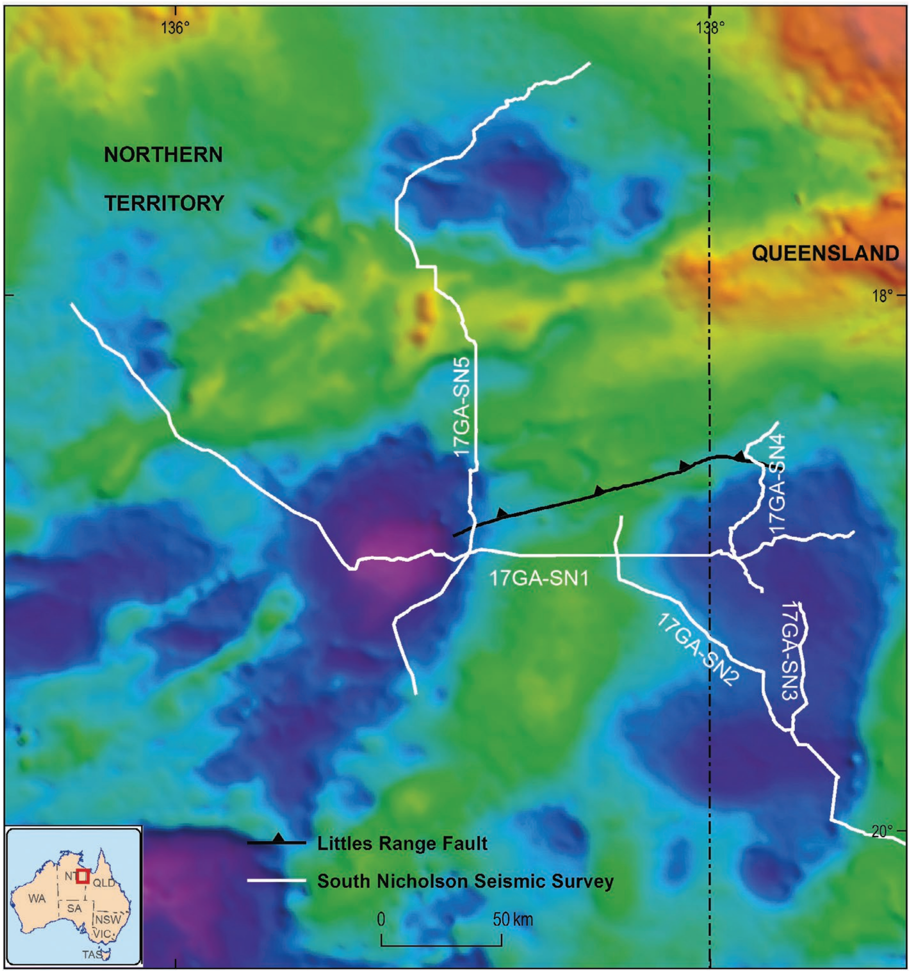

Figure 1. Bouguer gravity image of the South Nicholson region showing seismic lines collected for the study the South Nicholson Seismic Survey (after Carr *et al* in press). Dark blue indicates low gravity response.

of project results and presents an initial interpretation of the sequence stratigraphy.

Seismic interpretation

Acquisition of new 2D seismic data over the South Nicholson Basin region as part of the EFTF program has delivered new scientific insights that will progress understanding of regional energy and mineral resource potential. The South Nicholson seismic survey has revealed a previously unknown new sedimentary basin that straddles the Northern Territory–Queensland border and coincides with a large gravity low northwest of Mount Isa (**Figure 1**). This basin is ~120 km wide as imaged by the seismic data, ~190 km long as defined from regional gravity data (**Figure 1**) and up to ~8 km deep. Our interpretation suggests that the new basin contains a thick McNamara Group or Isa Superbasin age sedimentary succession overlain by a relatively thin succession of the South Nicholson Group; these are for the most part unconstrained (Carr *et al* in press). As outlined by Henson *et al* (2018), the sequences imaged on the seismic data are mostly unknown due to the lack of well data; however, existing seismic data interpretations in the Century Mine area (ie lines 06GA-M1 and 06GA-M2) and correlations with surface mapping suggest that the McNamara Group units and overlying Mesoproterozoic units (which have proven gas discoveries and host major Cu, Pb, and Zn resources elsewhere) may extend undercover to the west of their current outcropping locations in Queensland and into the new basin (Henson *et al* 2018).

The seismic data on lines 17GA-SN1 and 17GA-SN2 images basin-bounding faults and hence, also the basin architecture. This includes the Isa Superbasin horizon and overlying sequences, which have a sag-type geometry. Below the Isa Superbasin horizon, the geometry of the lower sequence suggests an extensional phase followed by contraction, which occurred before deposition of the overlying units. These units are flat-lying with some contractional features suggesting reactivation of early structures. While we have interpreted this lower horizon as base Calvert/Leichhardt Superbasin, the authors would like to emphasise that this is based on its stratigraphic position, rather than any direct control on the stratigraphy. **Figure 2** shows the base Isa Superbasin horizon's interpolated surface intersecting the four seismic lines 17GA-SN1, 17GA-SN2, 17GA-SN3 and 17GA-SN4 in the new basin. More work is required to further constrain the southern and southwestern extent of this basin.

A second gravity low observed further west in the Northern Territory, imaged on both 17GA-SN1 and 17GA-SN5 (**Figure 1**), is not interpreted as a basin. The cause of the gravity low is not clear, but we interpret this feature as a felsic igneous complex. Further, there are examples of felsic volcanic units in the CALVERT HILLS map area and further north (Roberts *et al* 1962). This igneous complex occurs adjacent to the Littles Range Fault (**Figure 1**), suggesting that this major structural trend has acted as a conduit for this intrusion and may have also provided pathways to focus mineral bearing fluids (Carr *et al* in press).

The generally north–south-trending 17GA-SN5 seismic line (**Figure 3**) is oriented largely orthogonal to the southern outcropping boundary of the South Nicholson Basin, broadly defined by the Littles Range Fault. A series of parallel east–west striking structures are clearly defined in geological

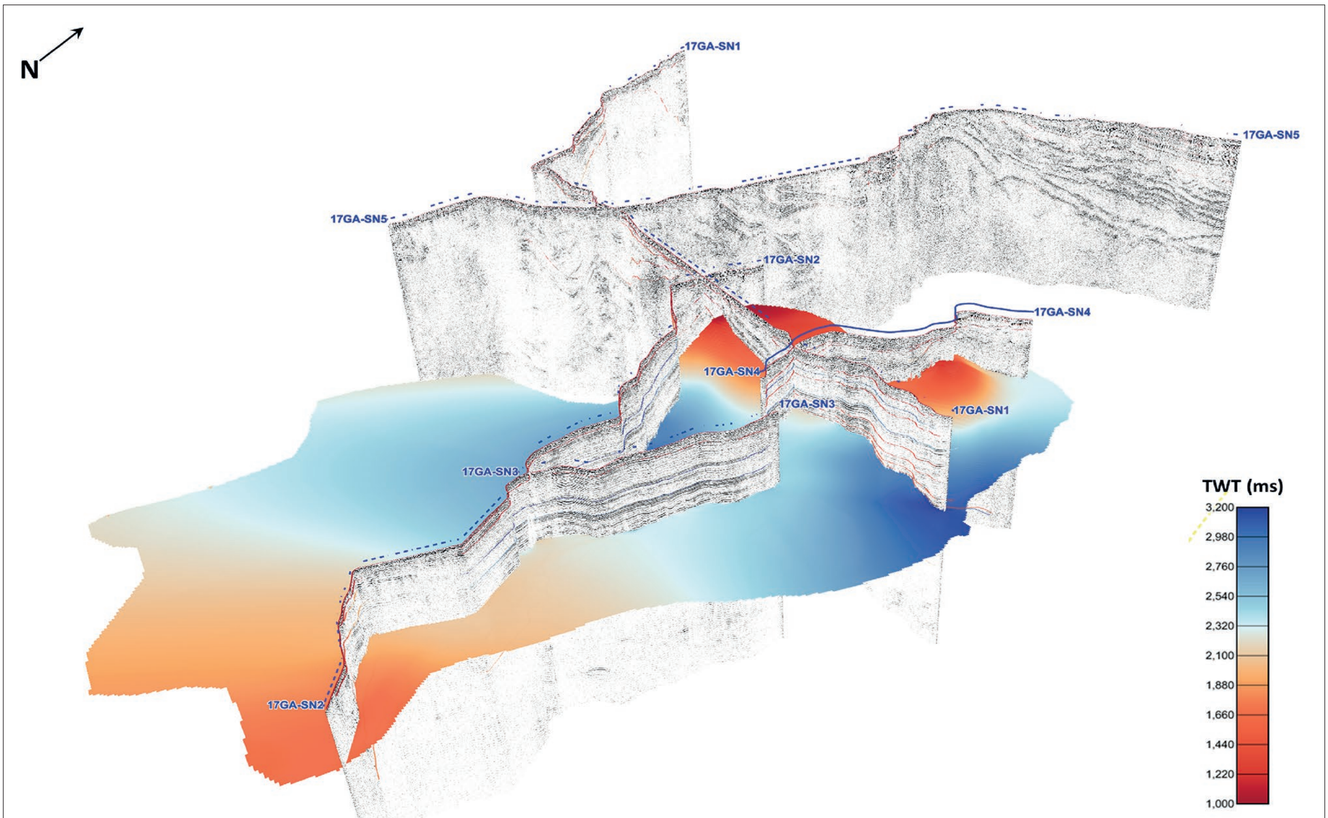

Figure 2. Geological model used as basis for seismic modelling. The vertical extent is 150 m. The velocity (v) and density (d) are shown for each layer (see **Figure 1** for location).

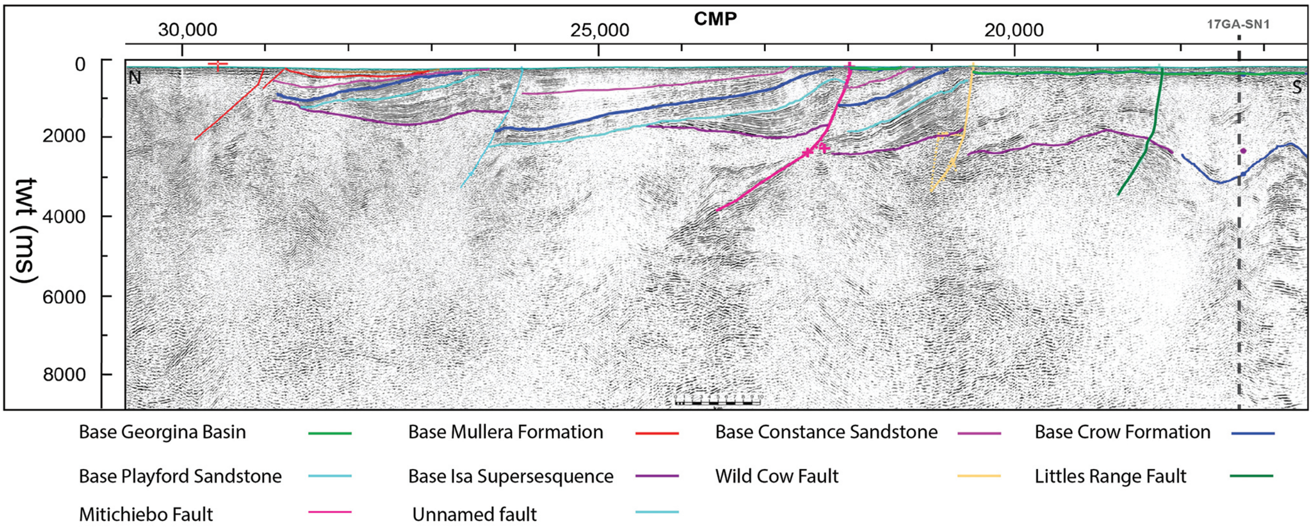

Figure 3. Seismic line 17GASN5 showing north (left) over south (right) thin skinned deformation.

maps in this area; significant displacement is interpreted across faults. The new seismic data has imaged structures in the area consistent with a structural architecture of thin-skinned, north over south, low angle thrusting (**Figure 3**); the timing of this deformation is yet to be determined. These structures are in contrast to the relatively undeformed basin to the south, indicating that there is a sharp transition in structural character south of the Littles Range Fault.

The northern extent of the 17GA-SN5 seismic line traverses a large gravity low to the north of the Murphy Province, over an area of outcropping McArthur Basin units. From the northern boundary of the Murphy Province where lower Tawallah Group units outcrop, to the northern extent of the seismic line where the McArthur Group units outcrop, the new seismic data images an unexpectedly deep basin sequence of semi-continuous, northward dipping reflectors that reach a total depth of 5500 ms twt or ~15 km. This basin sequence hosts the Redbank copper mine; hence, these new findings are likely to have implications for understanding the genesis of this mineral system. The newly identified deep section of stratigraphy is also encouraging for energy prospectivity as it remains relatively undeformed and may be thick enough for hydrocarbon generation (Carr *et al* in press).

Seismic sequence stratigraphy

The eastern end of seismic line 17GA-SN1 from Common Mid Point (CMP) 11 000 to 2000 appears to be orientated close to the dip direction of the new basin. This allows the geometries of the depositional sequences to be determined; however, the vertical resolution of the seismic data, being ~50 ms (~130 m) at 1000 ms TWT deep and 70 ms (~200 m) at 2800 ms TWT depth, limits the detail to which the sequences can be interpreted.

The seismic data in the South Nicholson Group succession occurs between 600 ms and 1600 ms depth; it appears washed out and difficult to interpret, possibly due to the presence of carbonate rocks in the overlying Georgina Basin. The Isa Superbasin succession is better imaged and interpretation of a basic sequence stratigraphic framework has been attempted (**Figure 4**). Due to the low vertical resolution of the seismic data, the sequences interpreted within the Isa Superbasin succession have been divided into two para sequences: 1) lowstand, and 2) combined transgression and highstand parasequences. Three sequences have been interpreted (**Figure 4**) and are described below.

The initial phase (Sequence 1) of deposition at the base of the Isa Superbasin succession shows discontinuous and chaotic seismic reflectors with medium to low amplitudes typical of sediments accumulating in the footwall of normal fault blocks. These are interpreted to be proximal debris and talus slopes or alluvial fans. Overlying these basal sediments is a package of discontinuous to semi-continuous medium amplitude reflectors. These onlap onto the talus/debris sediments below and are interpreted to be a combined transgressive and highstand sequence.

The overlying Sequence 2 begins with a lowstand regressive parasequence. The seismic character of this parasequence shows discontinuous to continuous medium amplitude reflectors with down lapping and prograde geometries. There also appear to be channels (**Figure 4**: blue line) present within this lowstand package. The overlying combined transgression/highstand parasequence extends to the basin bounding fault at the western extent of the new basin; the seismic character of this package is interpreted as continuous medium to high amplitude reflectors. These onlap onto the underlying Calvert/Leichardt sequence in the proximal (western) part of the basin and also onto the lowstand in the distal part of the basin. The proximal part of the parasequence appears aggradational with vertical stacking of reflectors; however, the distal part thickens towards the basin deep indicating deposition during an active extensional phase.

Sequence 3 comprises an initial lowstand parasequence with high amplitude, continuous reflectors in the proximal part. These reflectors then become discontinuous and low to medium amplitude in the central basin, with some possible progrades in the central part; they are chaotic in the distal part of the basin. The overlying transgression/highstand parasequence has low amplitude, semi-continuous to discontinuous reflectors in the lower two thirds and high

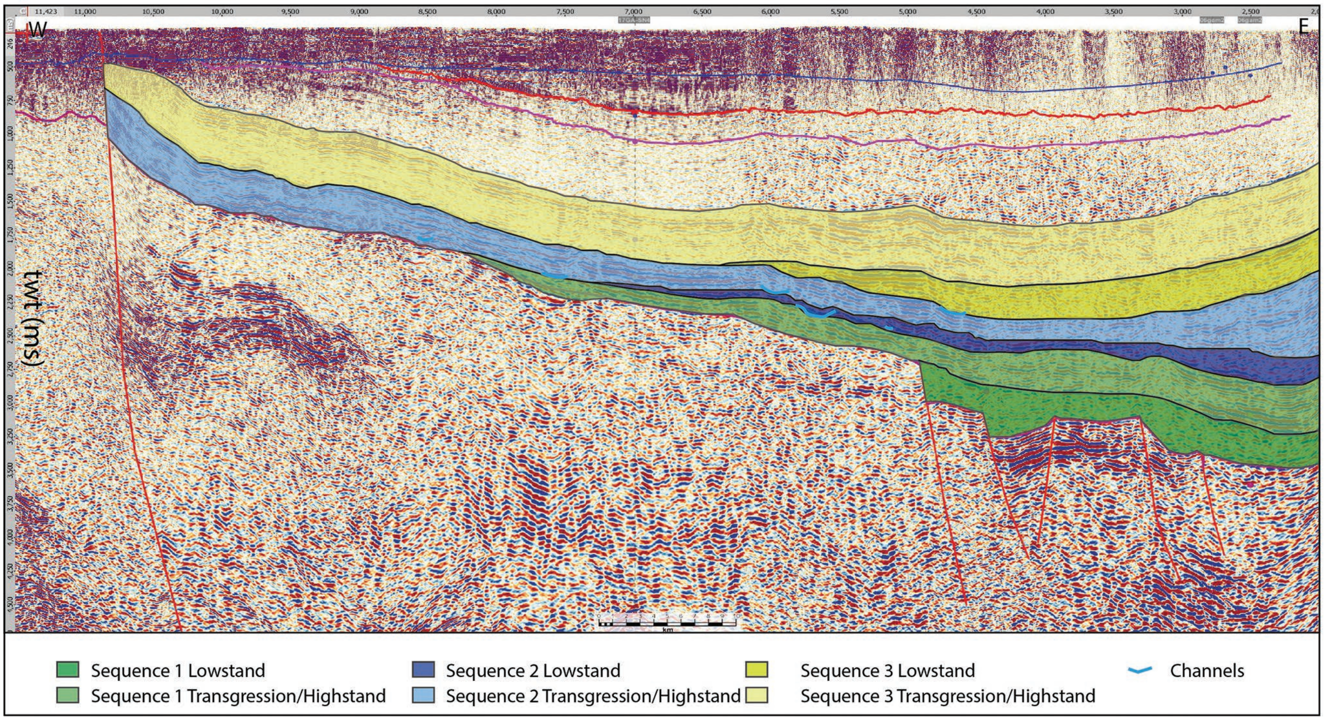

Figure 4. Sequence stratigraphic interpretation of the Isa Superbasin succession of seismic line 17GA-SN1 (see **Figure 1**) showing three interpreted sequences and para sequences. Horizontal scale is Common Mid Point **(**CMP); vertical scale is two way time (ms).

amplitude, continuous reflectors in the upper third. This change in seismic character may represent a change in depositional environment from shallow water, high energy chaotic deposition in the lower portion to deeper water, low energy deposition of more continuous sheet sandstones or mudstones in a shelf environment (Kirk 2013, 2014). This transgressive highstand package has a relatively constant thickness across the basin, indicating that it was deposited during a thermal sag phase.

A sequence stratigraphic interpretation on the overlying South Nicholson Group has not been attempted due to the low data resolution as described above; however, the overall seismic character is described as comprising low amplitude, discontinuous to chaotic reflectors. The overall geometry is subparallel to parallel and conformable within the package. This indicates that it was deposited during a thermal sag phase and may represent deepening basin conditions.

Conclusion

The new South Nicholson Basin seismic survey is a foundational dataset acquired as part of the EFTF program. This survey links the highly prospective resource rich areas of the McArthur Basin and Mount Isa Province via a continuous seismic traverse. Decades of scientific research undertaken in both regions provides a framework to interpret the new data in the South Nicholson Basin region and will act as a catalyst for scientific knowledge transfer across the border. The seismic data will be combined with additional EFTF data collected over the region (ie magnetotelluric surveys, airborne electromagnetic surveys and passive seismic surveys) to greatly improve resource evaluations in northern Australia. The *Exploring for the Future* program aims to further de-risk exploration within greenfield regions and position northern Australia for future exploration investment.

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