Structural characteristics of northern Houtman sub-basin, Perth Basin

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SUMMARY

The northern Houtman Sub-basin is an under-explored region of Australia's western continental margin. It is located at the transition between the non-volcanic margin of the northern Perth Basin and the volcanic province of the Wallaby Plateau and lies adjacent to the Wallaby-Zenith Transform Margin. In 2014, Geoscience Australia acquired new 2D seismic data (GA-349, 3455 km) across the northern Houtman Sub-basin to assess its hydrocarbon prospectivity. Previous studies of the Houtman Sub-basin indicated that en-echelon basin bounding N-NW trending faults are associated with the Permian half graben complex, however, it was not known if this structural style continued into the northern area of the Houtman Sub-basin.

This study integrated interpretation of the recently acquired survey, with regional interpretation of the Houtman Sub-basin. This was further supported by well data and geophysical modelling and a regional 2D structural and stratigraphic interpretation developed. Structural mapping was done for the basement, Early Triassic (Woodada Formation) and Early Jurassic (Eneabba Formation).

The basement structure of the northern Houtman Sub-basin is controlled by a series of large en-echelon NW-SE trending SW dipping faults, some of which have a throw of more than 10 km. These basement-involved faults control a series of Permian half graben separated by transfer zones and fault ramps. This basement architecture is similar to the inboard part of the southern Houtman Sub-basin, however the structures are larger. The Early Triassic and Early Jurassic faults trend NW-SE similar to the basement-involved faults, however major faults within the Jurassic succession lie about 50 km to the west of the Permian faults.

Interpretation of the northern Houtman Sub-basin reveals a structurally complex basin containing a wide range of structural and stratigraphic traps at several stratigraphic levels. Potential plays have been identified in the upper Permian, Triassic and Jurassic successions. They include large stratigraphic plays in the Upper Permian/Lower Triassic, rollover anticlines within the Lower Triassic and Jurassic, and fault propagation folds and fault block plays in the Jurassic.

Key words: Houtman Sub-basin, Permian syn-rift, Structural mapping, Petroleum prospectivity.

INTRODUCTION

Introduction

The Houtman Sub-basin is the largest structural element in the Perth Basin, covering an area of 52,900 km^2 (Figure 1; Copp, 1994; Jones et al., 2011; Totterdell et al., 2014). It is an elongate, NW-SE trending depocentre, extending approximately 700 km along-strike. Sediment thickness is variable but is interpreted to reach up to 19 km in the northern sub-basin (Borissova et al., 2017). Prior to Geoscience Australia's (GA) acquisition of new 2D seismic data in 2014-15, data coverage in the northern Houtman Sub-basin was sparse. Available data included only several regional 2D seismic lines acquired by GA in 1999 (GA-135) and 2008 (GA-310). These data suggested that most of the northern Houtman Sub-basin contained only a relatively thin (5–6 km) Paleozoic section. New seismic data acquired by GA over the northern Houtman Sub-basin (GA-349) clearly images a much thicker basin and allows mapping of the Moho, basement, pre-rift sequence and major syn-rift sequences (Figure 2). Integration of the new seismic data with the regional interpretation of the Houtman and Abrolhos sub-basins allowed assigning of ages and lithological characteristics to the mapped seismic sequences and developing a tectonostratigraphic framework for the study area (Owens et al. 2017 in prep).

Perth Basin depocentres have formed through two separate phases of extension and rifting, one during the early to mid-Permian and another during the Early Jurassic to Early Cretaceous and resulted in the existing NW-SE trending architecture of the Houtman Sub-basin. Permian rifting led to the development of NNW-oriented half graben across the northern Perth Basin, including the northern Houtman Sub-basin (Norvick, 2004; Jones et al., 2011; Rollet et al., 2013). The Jurassic-Early Cretaceous rifting led to accumulation of thick successions in the outboard part of the central Houtman Sub-basin and in the adjacent Zeewyck Sub-basin. This second episode of rifting culminated in the Early Cretaceous with the breakup of Australia and Greater India (Gibbons et al., 2012; Hall et al., 2013).

Methods

This study integrated interpretation of the recently acquired survey (GA-349), with regional interpretation of the Houtman Sub-basin, underpinned by ties to well data, potential field data (Figure1), and geophysical modelling to develop a regional 2D structural and stratigraphic interpretation. Geological and geophysical modelling (Sanchez et al., 2016) integrated gravity magnetic and velocity data, as well as the initial interpretation of the GA-349 seismic data to improve the understanding of the crustal architecture and distribution and thickness of magmatic rocks in the Houtman Sub-basin. The results from the geophysical modelling were then used to further constrain the seismic interpretation in areas of poor quality data.

Thirteen seismic sequences were interpreted for this study, from the Valanginian break-up unconformity (NH-K2) to the Moho (Table 1). Structural fault mapping was undertaken on three of these sequences (NH-Pz, NH-TR2 and NH-TR/J1) to further understand the architecture of the basement and its control on Early Triassic and Early Jurassic deposition across the northern and central Houtman Sub-basin.

Table 1: Mapped seismic sequence boundaries and interpreted lithostratigraphic equivalents (Borissova et al., 2017)

Seismic Sequence Boundary	Tectonic Event/ Basin Phase	Lithostratigraphic equivalent
NH-K2	End of Jurassic-Early Cretaceous syn-rift - Valanginian unconformity	Base post-rift
NH-J4		Base Yarragadee formation equivalent
NH-J3		Base Cadda Fm equivalent
NH-J2	Onset Jurassic Syn-rift	Base Cattamarra CM equivalent
NH-TR/J1		Base Eneabba Fm equivalent
NH-TR3		Base Lesueur Sst equivalent
NH-TR2		Base Woodada Fm equivalent
NH-TR1		Base Kockatea Shale equivalent
NH-P3	Onset Permo-Triassic post-rift	Base Dongara Sandstone equivalent
NH-P2	Onset Permian syn-rift II	Base Caryngginia Formation
NH-P1	Onset Permian syn-rift I	Base Permian (base Nangetty Fm equivalent)
NH-Pz		Base Pre-rift sediments (?Cambro-Ordovician?)/Top Proterozoic Basement
Moho		

Results

Crustal structure

In the central part of the Houtman Sub-basin, top Proterozoic basement lies between 12 and 19 km deep (Figure 2a), resulting in a total sediment thickness of approximately 8 to 18 km (Figure 2b). The model currently shows basement shallowing to less than 2 km on the Bernier Platform, however integrated interpretation of the seismic and potential field data suggests that a thicker (5 – 6 km) pre-rift sedimentary succession may be present. This result, however is not taken into account in this study (Figures 3a and 3b) Sanchez et al., 2016; Borissova et al., 2017).
New seismic data clearly images the Moho which is mapped between 30 and 35 km depth beneath the Bernier Platform and shallows to about 12 km on the western border of the Houtman Sub-basin (Figure 2c). Moho depth from seismic interpretation was independently confirmed using potential field modelling results (Figure 3b, Sanchez et al., 2016). Crustal thickness varies considerably across the study area from over 30 km to less than 5 km (Figure 2d).

Structural domains

The Houtman sub-basin has experienced several phases of rifting, first in the early to mid-Permian and then again in the Jurassic- Lower Cretaceous which has resulted in highly extended to hyperextended crust (Sanchez et al., 2016; Borissova et al., 2017). The necking domain is characterised by a narrow zone of hyper extended crust (less than 5 km thick) at the eastern boundary of the Houtman Sub-basin where crustal thinning was focused during these successive extensional events (Figure3b). The highly extended to hyperextended domain (distal and outer domains on Figures 3b and 4d) refers to the zone where the crust is less than 10 km thick. In the hyperextended domain (less than 5 km of crust) serpentinisation at the top of mantle may have occurred (Sanchez et al., 2016).

Basement Structure

The basement of the northern Houtman Sub-basin is characterised by three large NW to SE trending, SW dipping en-echelon faults which mark the north-eastern margin of the sub-basin. These faults have a throw of more than 10 km and control a series of Permian half graben linked by fault ramps and transfer zones (Figure 4a). Basement along the western margin of the sub-basin is shallower and is defined by N-S to NNW-SSE to trending, east dipping antithetic faults. These are much smaller than the northeastern border faults with throws of up to 2-3 km.

A N-S trending transfer zone separates the northern and central depocentres of the sub-basin, and is approximately 80 km long by 50 km wide (Figure 4a). The basement shallows over the transfer zone to approximately 10 km deep, in contrast to the northern and central depocentres where it is up to 19 km deep (Borissova et al 2017). The faults across the transfer zone trend NNW to SSE and have a maximum throw of approximately 2-3 km. This transfer zone defines a region where there is little or no Permian syn-rift (Figure 4d) suggesting that this region was topographically high during the Permian.

In the central part of the Houtman Sub-basin two large border fault systems controlled the location of the Permian depocentres. These are not as large as in the northern part having a maximum throw of approximately 4-5 km. Most of the faulting in both the northern and central depocentres is focused in the necking structural domain identified by the geophysical modelling (Sanchez et al 2016, Figure 4d).

The thickest part of the Permian syn-rift also corresponds to the necking domain (Figure 4d) indicating that much of the extension resulting in crustal thinning occurred during the deposition of these sediments. The Permian syn-rift sediments in the northern depocentre are 7-10 km thick (Borissova et al 2017, Figures 4a and 4d) thinning westwards to a hinge zone which marks the westward extent of the Permian depocentre. In the central depocentre (Figures 4a and 4d) Permian syn-rift sediments are 2-3 km thick with the upper part of the succession likely to have been eroded at the end of the Permian rifting.

Early Triassic

The Early Triassic succession contains an array of NW to SE trending, SW dipping faults similar in orientation to the underlying basement involved faults (Figure 4b). The faults typically are closely spaced and have maximum throw of about 2 km. Faults over the eastern part of the Permian depocentre are often listric and typically sole out in sequence TR-1 (interpreted to be equivalent to the Kockatea Shale). Towards the basement hinge zone the faults cut through Jurassic – Early Cretaceous succession and extend down into the Permian (Figure 3a). These large faults are likely to have formed during the Jurassic extension with some of them reactivating pre-existing Permian faults (Figure 3a). Above the basement transfer zone described above, Early Triassic faults change to N-S in orientation, suggesting that basement structure has controlled the distribution and orientation of subsequent faulting (Figure 4b).

Early Jurassic

The faults in the Early Jurassic succession trend NW-SE and dip towards the SW. They are closely spaced and have a maximum throw of 3 km. Some faults are listric, while others are interpreted to extend to, and link with the older basement-involved faults that control the geometry of the Permian syn-rift (Figure 3a and Figure 4c). Unlike the Early Triassic, the basement transfer zone does not appear to have any influence on fault orientation in the Early Jurassic succession. In the early Jurassic succession maximum fault throws are observed in the centre of the sub-basin over the basement hinge zone. This suggests that the focus of extension has shifted 50 km further westward from that in the Permian and the Triassic.

Petroleum Prospectivity

The multiple phases of rifting of the northern Houtman Sub-basin and the resulting structural complexity led to the formation of a wide range of structural and stratigraphic traps at several stratigraphic levels these include:

1. Stratigraphic pinch-out of the upper Permian/Lower Triassic sandstones (NH-P3, Dongara Sandstone equivalent) against the major Permian basin bounding faults. The overlying marine shales of NH-TR1 (Kockatea Shale equivalent) potentially acting both as a source and the top seal;

1. Triassic fault block plays and rollover anticlines bounded by listric faults in the fluvio-deltaic sandstones of the NH-TR2 sequence (Woodada Formation equivalent). These plays could be charged by the underlying source rock intervals in NH-TR1 (Kockatea Shale equivalent) and sealed by intraformational shales; and
2. Jurassic fault block plays and fault propagation folds within sequence NH-TR/J1 (Eneabba Formation equivalent), fault block plays within fluvio-deltaic sandstones of sequence NH-J2 (Cattamarra Coal Measures equivalent) with top seal provided by marine shale within sequence NH-J3 (Cadda Formation equivalent) and potential stratigraphic plays beneath the Valanginian unconformity.

CONCLUSIONS

The Houtman Sub-basin has undergone multiple phases of rifting, first in the early to mid-Permian and again in the Early Jurassic/Early Cretaceous resulting in highly extended (10 km thick) to hyper-extended crust (less than 5 km thick) where crustal thinning/extension was focused during these successive extensional events.

The basement structure of the northern Houtman Sub-basin is controlled by a series of large en-echelon NW-SE trending southwest dipping faults, some of which have a throw of more than 10 km. They control a series of Permian half graben separated by transfer zones and fault ramps. The Permian syn-rift sediments are up to10 km thick in the northern depocentre and 3 km in the central depocentre. Despite this significant difference in the thickness of the Permian section and fault throws the basement architecture imaged by the GA-349 data in the northern part of the Houtman Sub-basin is similar to the inboard part of the southern Houtman Sub-basin described by Jones et al. (2011) and Rollet et al. (2013), however the structures are larger in the north. Geophysical modelling undertaken by Sanchez et al. (2016) suggests that a strong rheological contact between the basement terranes underlying the proximal and necking domains may have played an important role in localising deformation during the Permian extension event.

The faulting in the Lower Triassic succession occurred during the Jurassic extension and appears to be influenced by the underlying basement structure. Early Jurassic faults trend NW-SE similar to the basement-involved faults, however the focus of faulting and extension shifts approximately 50 km westwards from the necking domain to the distal and outer domains (Figures 4c and 4d).

The northern Houtman Sub-basin has a several different trap types at multiple stratigraphic levels, however there are overarching risks to the validity of the potential plays, including: i) the absence of well data to provide lithological control on characteristics of the identified reservoirs and seals; ii) uncertainties in the relative timing of hydrocarbon generation and trap formation; and iii) reactivation of some major basement-involved faults in the Jurassic and in the Valanginian potentially resulting in a trap breach.

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Figures

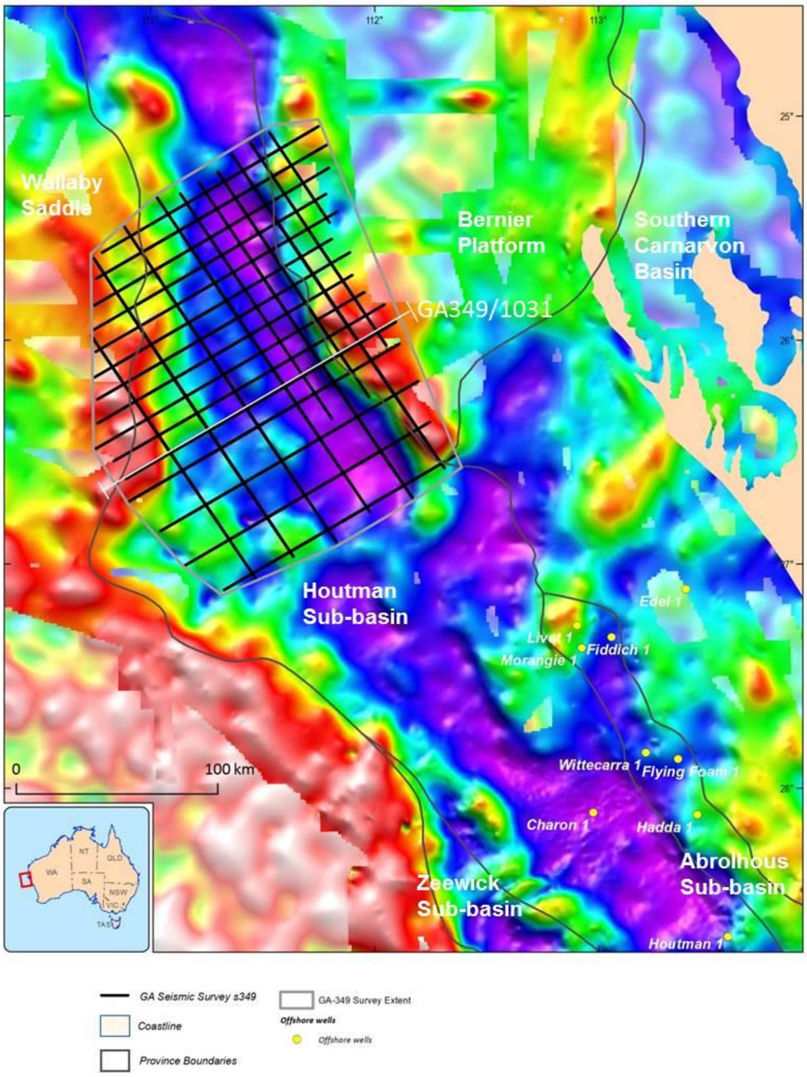


Figure 1: a) Location map showing structural elements of the Houtman Sub-basin with underlying bouger gravity anomaly from Hackney 2012 and the location of seismic line GA349/1031.

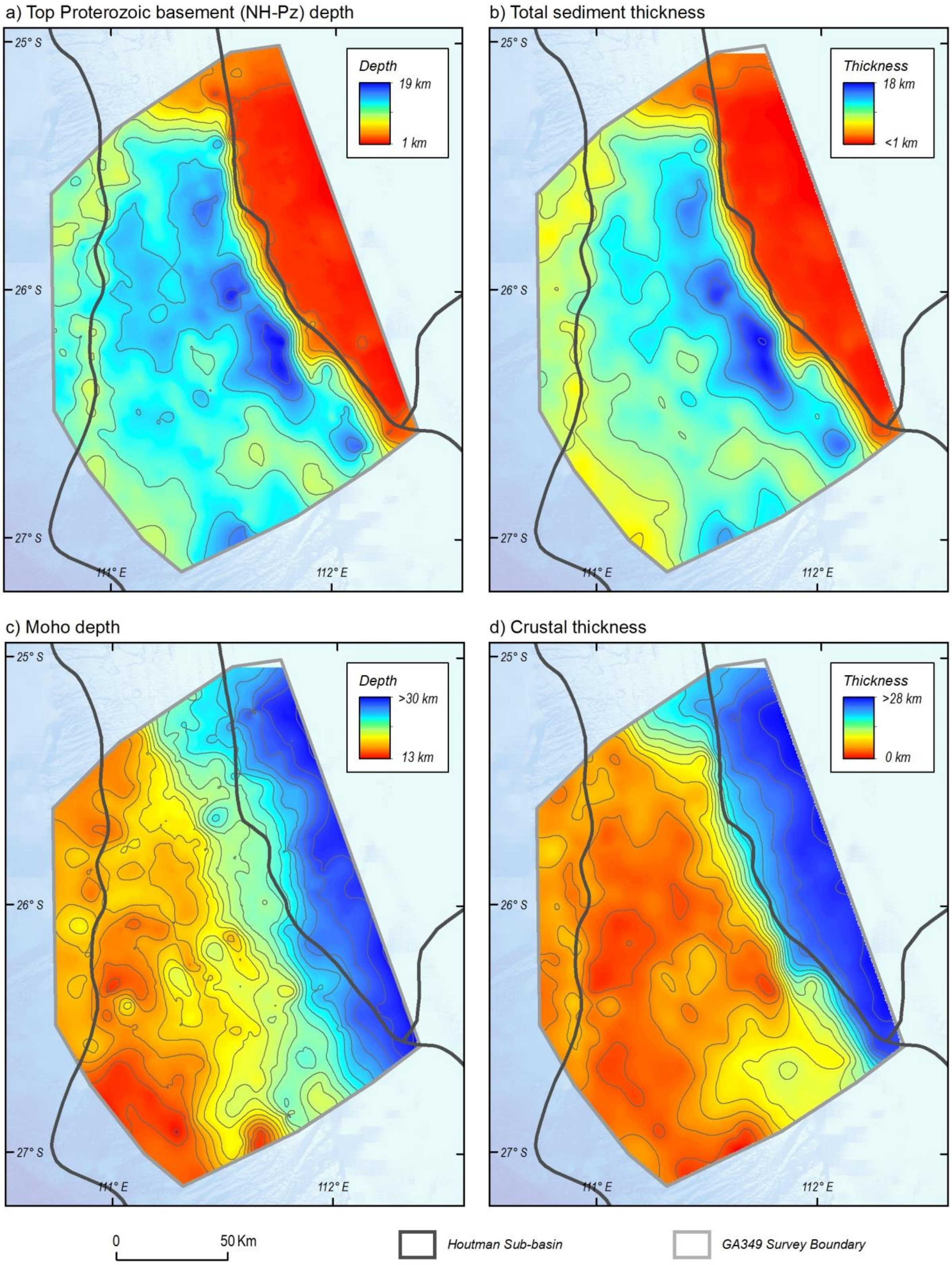
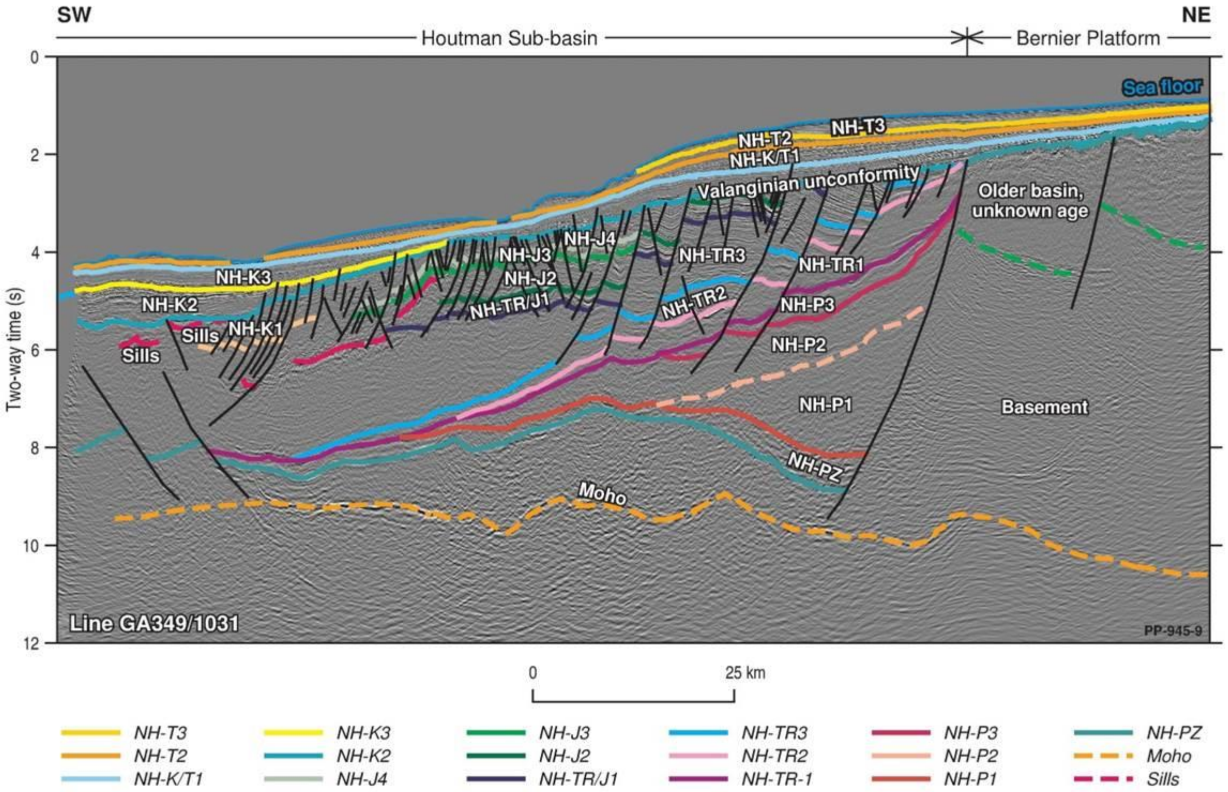


Figure 2: a) Basement depth; b) total sediment thickness; c) Moho depth; and d) crustal thickness.

a) Interpreted seismic line GA-349-1031



b) Gravity modelling results

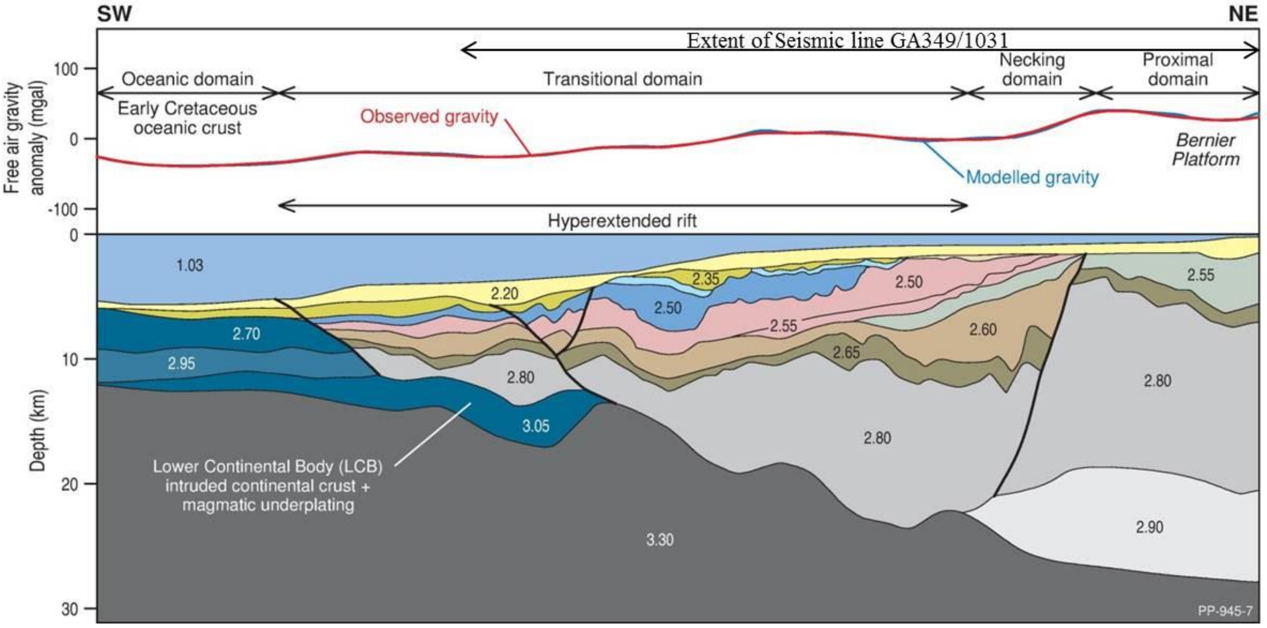


Figure 3: a) Interpreted GA-349-1031 seismic line showing sequences listed in Table 1; b, Gravity modelling results for the same line showing crustal architecture and modelled densities of all sequences (modified from Sanchez et al., 2016).

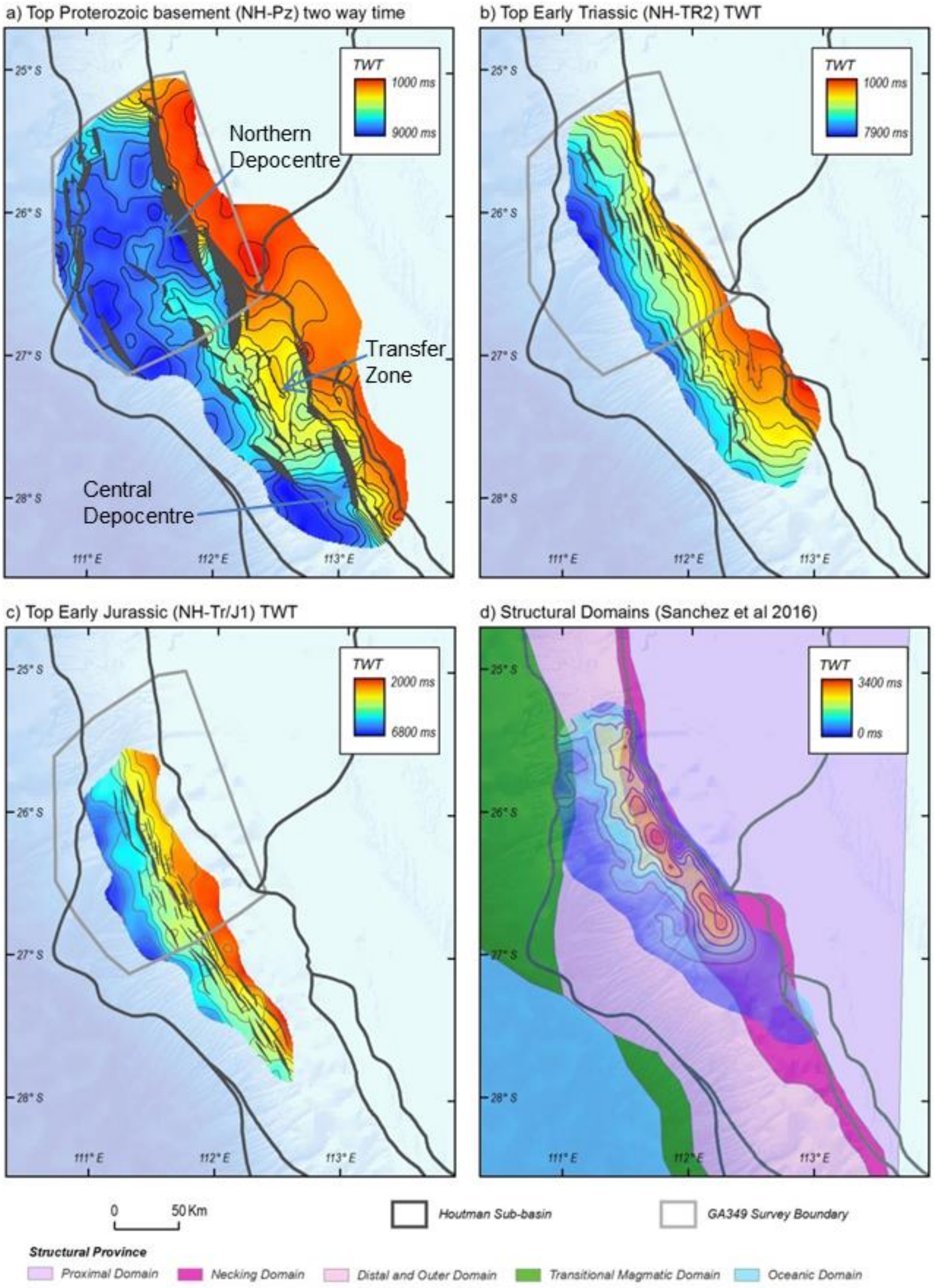


Figure 4: a) Top Basement structure map; b) Early Triassic structure map; c) Early Jurassic structure map; d) Two way time isochron map of Permian Syn-rift sediments overlying structural domains of the northern Houtman Sub-basin based on integrated interpretation of potential field and seismic data from Sanchez et al. (2016).