

PS Tectonophysical Processes and Their Surface Feedback in the Ashmore Platform Region, Timor Sea: A Combined 2D and 3D Seismic-Reflection Analysis*

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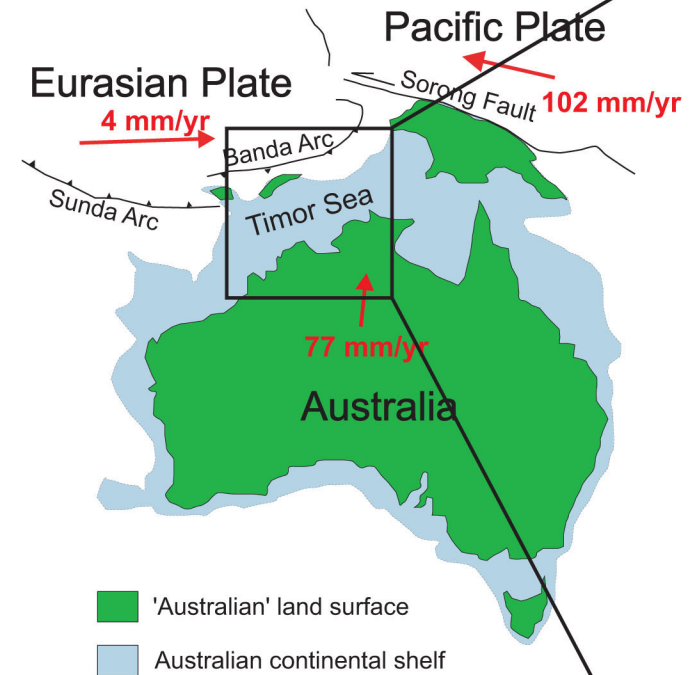
Abstract

A 2D and 3D seismic-based structural analysis of the Ashmore Platform in NW Australia is aiming to unravel the tectonophysical processes resulting from an early-stage foreland basin deformation in the Timor Sea region. A re-evaluation of lithospheric flexural models proposed for this region and a comparison against the observed fault pattern reveal various differences. The study area provides an exceptional opportunity to examine the early-stage development of the foreland basin between the colliding Australian continental margin and the Banda arc. The Timor region's abundant normal faulting within a remotely convergent plate-margin setting has been a debated subject with numerous studies devoted to explain this issue. 2D elastic half-beam models of and simple bending elastic beam models from evidence that bending of the Australian lithosphere is a key mechanism responsible for the current tectonic development of the Timor Sea. This seismic-based tectonic study constrains these numerical models inferring a combination of mechanisms to explain the modern extensional faulting of the study area. This study integrates interpretations from 2D and 3D seismic-reflection data with standard wireline logs of two wells to subdivide the subsurface of the study area into five seismic units, corresponding to a Paleozoic basement, thick Mesozoic clastic and carbonate sequences and a topmost Cenozoic succession of predominantly carbonate rocks. This sedimentary succession is deformed by numerous normal faults, of which 165 were mapped in 3D, particularly focusing on the displacement of the recent to sub-recent sedimentary cover. The modern structural styles encountered in the study area resulted in the differentiation of three normal-fault sets. This seismic-based tectonic analysis ultimately ground truths theoretical models of lithospheric flexure, highlighting the importance of combining modelling studies with observational field-based constraints.

1 INTRODUCTION

A 2D and 3D seismic-based structural analysis of the Ashmore Platform in NW Australia is aiming to unravel the tectonophysical processes resulting from an early-stage foreland basin deformation in the Timor Sea region.

A re-evaluation of lithospheric flexural models proposed for this region (i.e. Londoño and Lorenzo 2004; Langhi et al. 2011) and a comparison against the observed fault pattern reveal various differences.



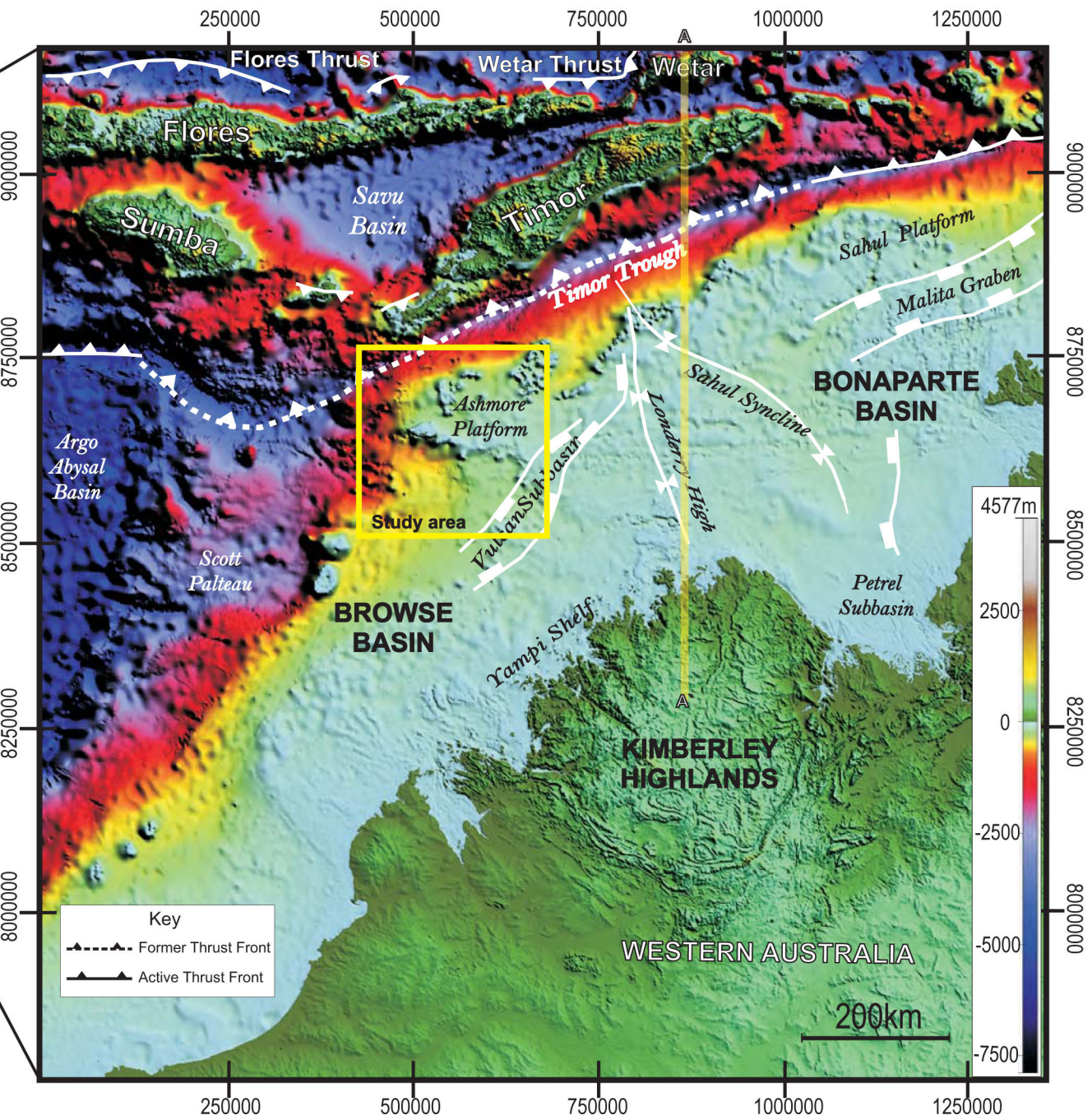
Tectonic setting of North-West Australia
(after Harrowfield and Keep, 2005).

The Timor region's abundant normal faulting within a remotely convergent plate-margin setting has been a debated subject with numerous studies devoted to explain this issue. Therefore the study area provides an exceptional opportunity to examine the early-stage development of the foreland basin between the colliding Australian continental margin and the Banda arc.

This seismic-based tectonic study constrains some of the proposed numerical models inferring a combination of mechanisms to explain the modern extensional faulting of the study area.

2 GEOLOGICAL SETTING

The study area is situated offshore on the Timor Sea region of the Australian North West Shelf. The Timor Sea region has a complex evolution history, involving the interaction of the Banda Arc, a volcanic and non-volcanic arc of islands (Hall and Wilson, 2000); a network of long-lived sedimentary basins, such as the Browse and Bonaparte Basin (Harrowfield and Keep, 2005); as well as highly structured blocks: Ashmore and Sahul platforms (Geoscience Australia, 2011).



Geological elements of North West Shelf Australia (after AGSO, 1994; Londoño and Lorenzo, 2005; Hall and Wilson, 2000) overlain on Gebco bathymetry. Inset shows location of the study area.

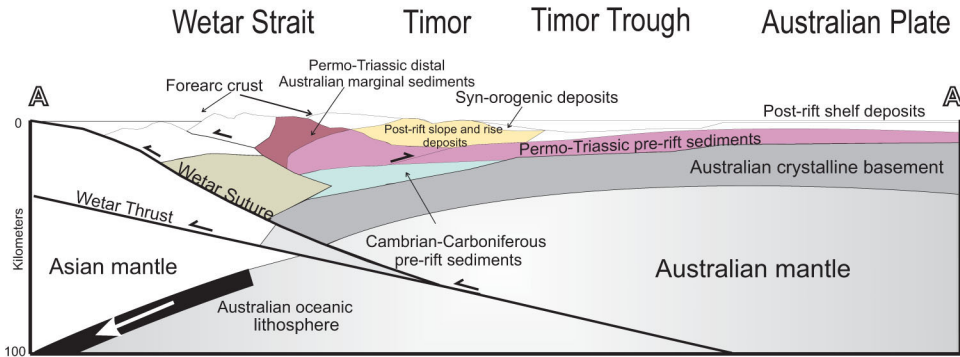
Key events in the evolution of North West Shelf Australia (NWS)

- Extension on NW Australia began in the Late Devonian in response to the break-up of Gondwana (Baillie et al., 1994). During the early Permian, extension led to the creation of a wide intracontinental rift. A thick Triassic-Jurassic sedimentary sequence was accommodated by this wide depocenter (Etheridge and O'Brien, 1994).

- During the Jurassic-Early Cretaceous, seafloor spreading at the rift axis started and the present-day passive margin of NW Australia developed (Baillie et al., 1994; Longeley et al., 2002). Tectonism had ceased by the Aptian, after which time the NWS was blanketed by a thick passive margin succession comprising siliciclastic and carbonate units (Harrowfield and Keep, 2005).

- During the Oligocene, the collision of the northern margin of Australia with the Banda Arc influenced the NWS (Baillie et al., 1994); this collision reached the Timor region around 2.5 Ma (Keep et al., 1998). Thinned crust of the Australian continental margin was subducted beneath the Banda Arc, the attached oceanic crust was broken off during late Neogene (Hall and Wilson, 2000). Buoyant Australian continental crust jammed the subduction zone in the Timor region around 2 Ma (Keep et al., 1998), causing a reversal of the subduction polarity (Johnston and Bowin, 1981; McCaffrey, 1998).

- At the present time, subduction in the Timor region has ceased (Hughes et al., 1996); the Timor Trough as well as the others troughs fringing the Banda Arc have evolved from subduction trenches to a collisional flexural (deepwater) foreland basin (Carter et al., 1976; Audley-Charles, 1986; Ziegler et al., 1998).



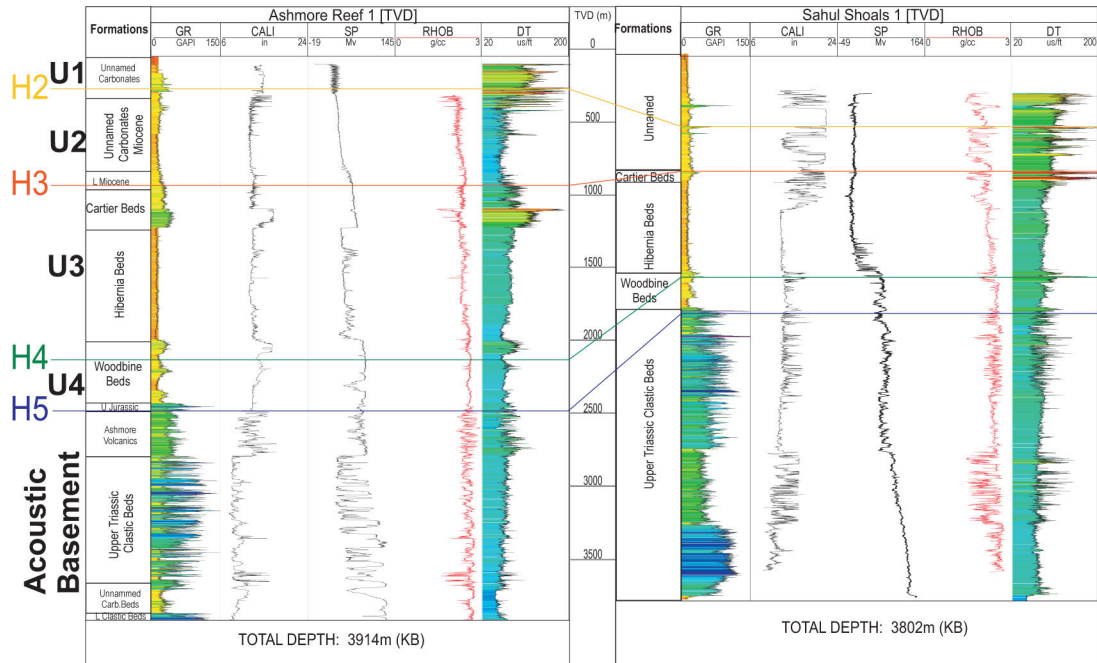
Regional crustal-scale transect illustrating the early-stage collision of the Australian Plate with the Banda Arc (after Hall and Wilson, 2000; Moreley et al., 2001).

3 INPUT DATA

The tectonophysical processes and their surface feedback in the Ashmore Platform were analyzed using open-file seismic reflection data: 68 MCS 2D lines from the Browse-98 2D offshore seismic survey (BR98) and 9,467 km² from the North Browse TQ3D seismic survey. The wireline information of two wells: Ashmore Reef No.1 (AR) and Sahul Shoals No.1 (SH) was available for this study; the wells were drilled in 1968 and 1970, respectively. The well information was obtained from WAPIMS database; which is provided by the Department of Mines and Petroleum from the Government of Western Australia.

4 INTEGRATION OF SEISMIC AND WELL INTERPRETATIONS

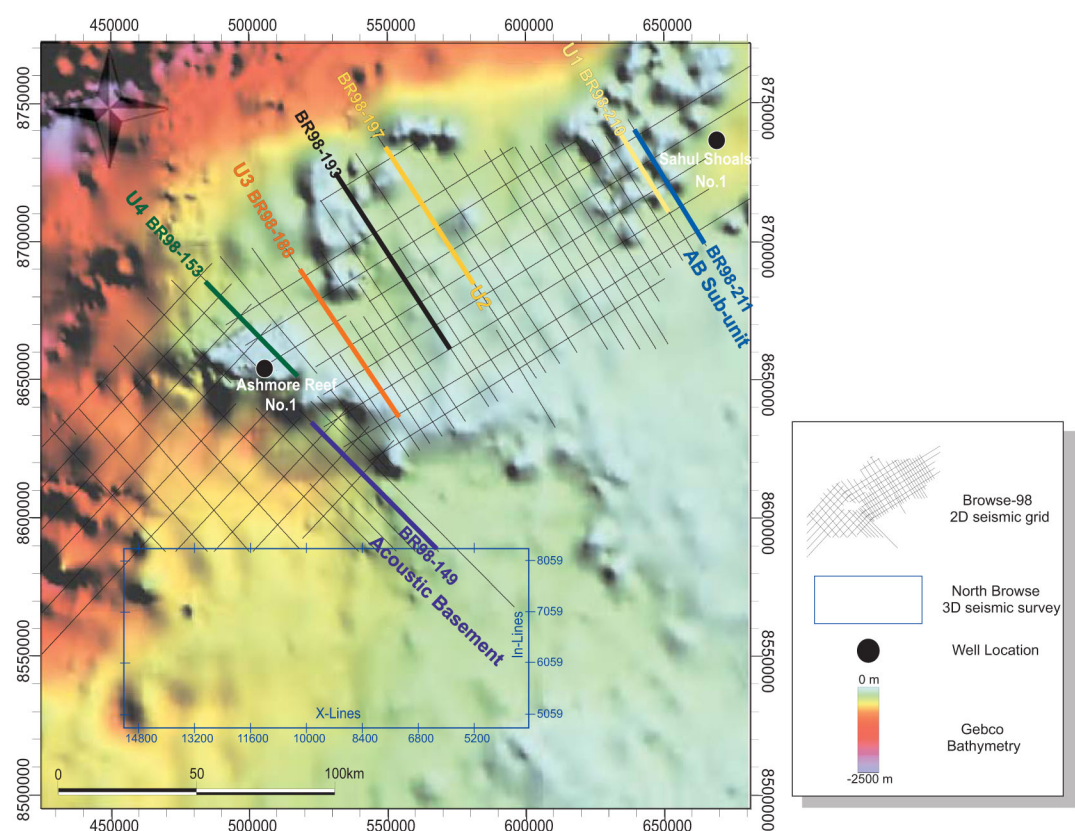
Wireline-log interpretations were carried out to gain lithological information about the subsurface. From the seismic data interpretation the seafloor (H1) and five horizons (H2, H3, H4, H5 and H6) were mapped along the entire area. Based on the horizon interpretation the subsurface is subdivided into five seismic units: U1, U2, U3, U4 and acoustic basement; which correspond to a Paleozoic basement, thick Mesozoic clastic and carbonate sequences and a topmost Cenozoic succession of predominantly carbonate rocks.



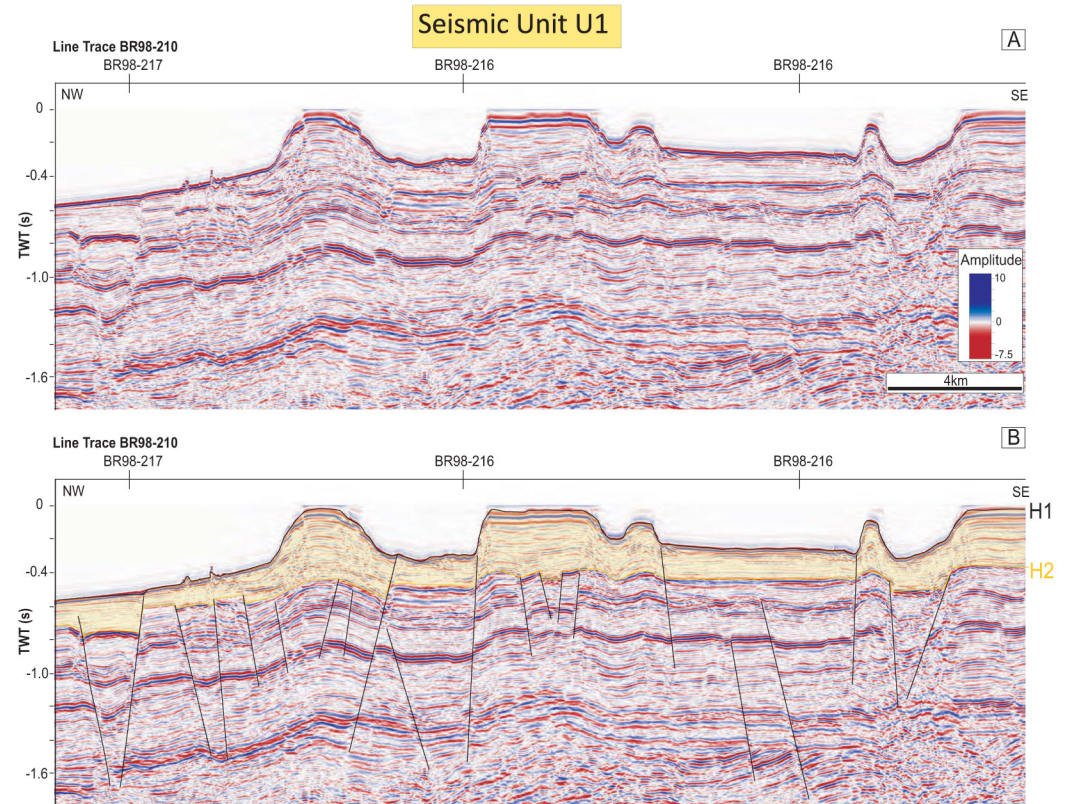
Correlation of wells Ashmore Reef No.1 and Sahul Shoals No. 1, including the intersection with the interpreted seismic horizons H2, H3, H4 and H5. The top well formations were obtained from the well completion reports.

Seismic Unit	Boundaries	Geological characterization
U1	Top: Seafloor (H1) Base: H2	It records the most recent carbonate sedimentation, with a widespread development of carbonate builds and atolls as depicted by the present-day seafloor morphology.
U2	Top: H2 Base: H3	It is mainly composed of Miocene carbonates and calcarenites as interpreted from the wireline logs signature. This sequence was presumably deposited during a shallow marine environment, slightly influenced by currents from the coast transporting terrigenous material, as proposed by B.O.C. (1979). Relatively thin (400 ms) unit; an abrupt change in the sedimentation thickness is recorded in the southern area, possibly due to the reef growth.
U3	Top: H3 Base: H4	Lithologically subdivided into a lower and an upper part: lower part, Hibernia Beds formation, consists of a thick and fairly uniform Paleocene to possibly Eocene succession of carbonates, evidencing an open marine deposition; whereas the upper portion, Cartier Beds formation, indicates shaly and sandy sediments probably deposited during the Oligocene under shallow marine conditions.
U4	Top: H4 Base: H5	It is composed of an alternation of carbonates and shales, as deciphered by the logs signature, Upper Cretaceous in age. Gorter et al. (2002) propose that the Cretaceous depositional interval, in the Timor Sea region, initiated with a transgressive environment with shallow marine deposition, followed by a thermal subsidence phase that last throughout the rest of the Cretaceous.
Acoustic Basement	Top: H5 Base: H6 (only in N and central area)	The acoustic basement sub-unit comprises a thick Triassic succession of mainly sandstones and siltstones, carbonates also occur as thin bands, deposited presumably in a shallow marine to fluvio-deltaic environment. It is tectonically characterized by a series of horst and graben structures as well as tilted fault blocks formed during late Middle Jurassic contemporaneous to intracratonic rifting. The acoustic basement is bounded at its top by a prominent regional unconformity (horizon H5), according to Gorter et al. (2002) is Callovian age. This unconformity has been interpreted to indicate the beginning of the continental breakup (Longley et al., 2002).

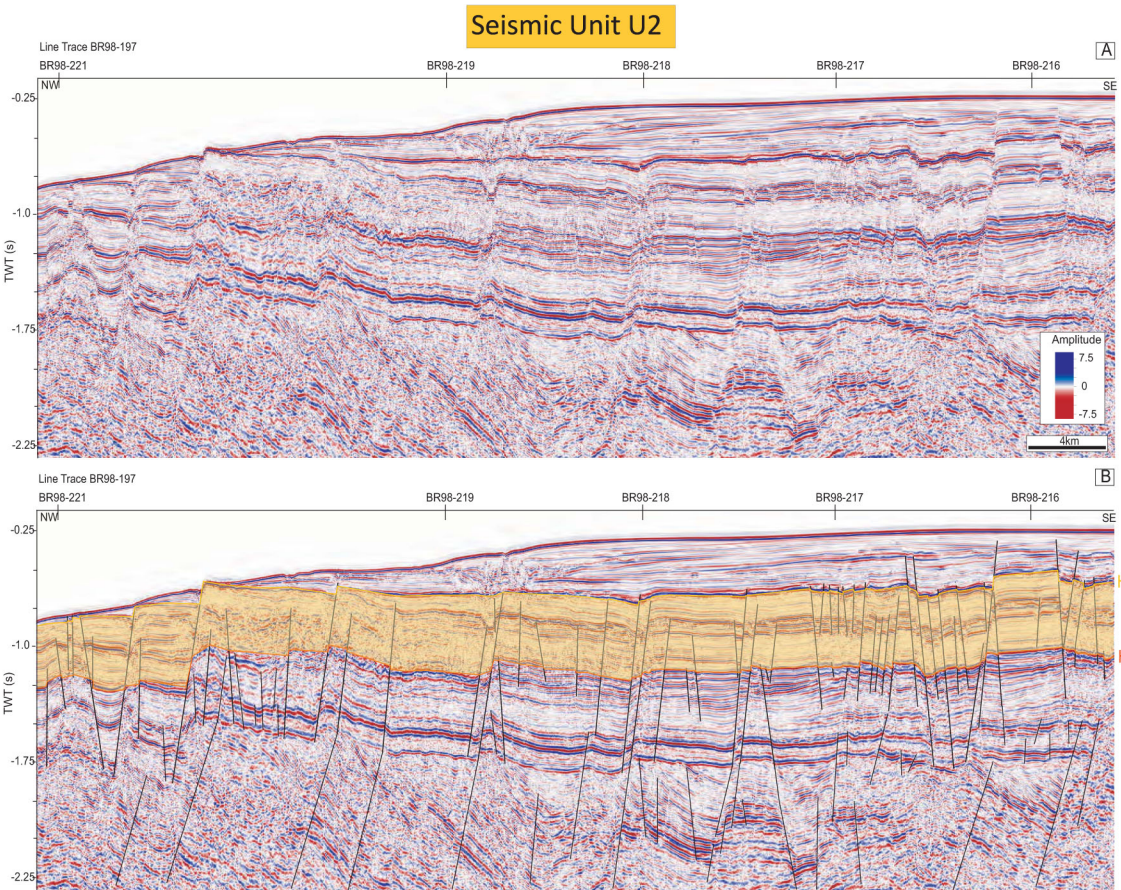
4 INTEGRATION OF SEISMIC AND WELL INTERPRETATIONS



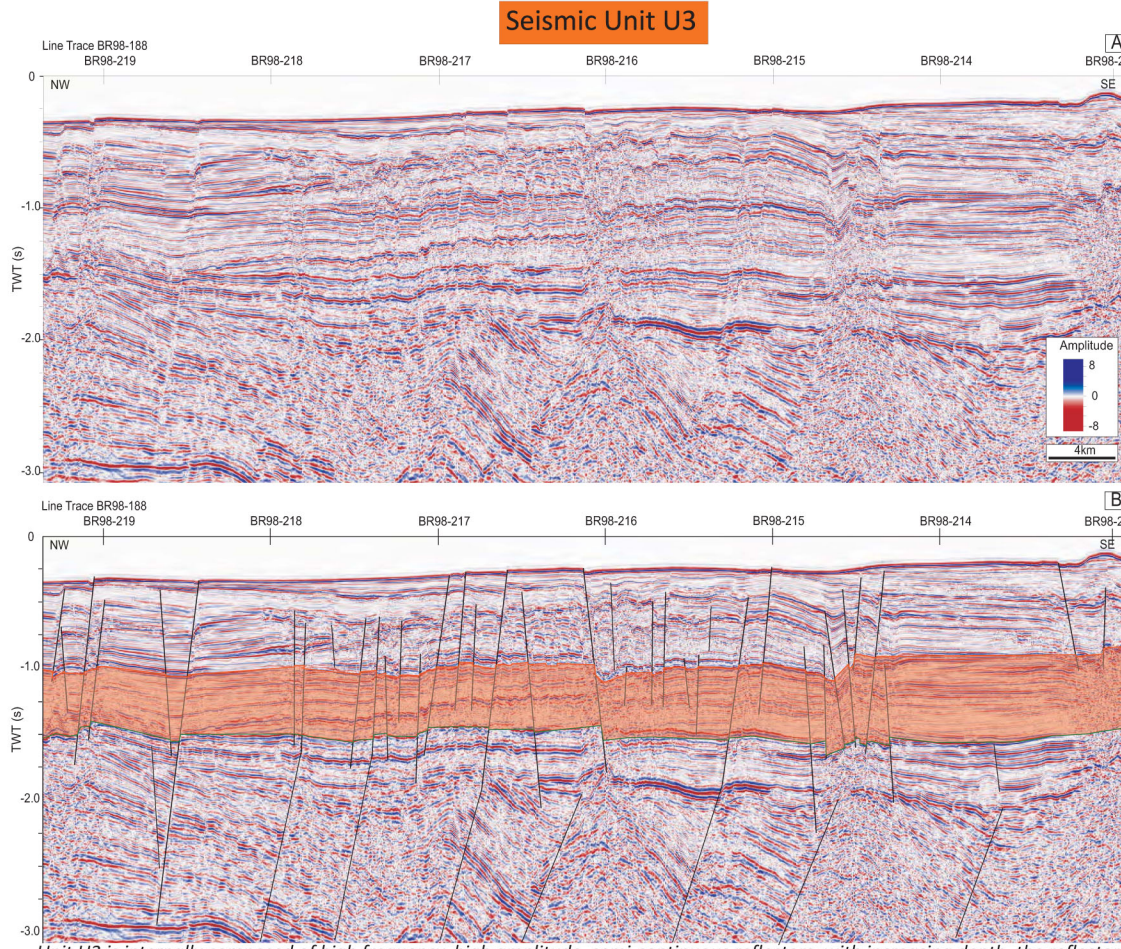
Study area map illustrating the data used in this study, the 68 MCS 2D seismic traces from the BR98 survey, the 3D seismic volume from the NB-3D survey and the Ashmore Reef No.1 and Sahul Shoals No.1 well locations overlain on Gebco bathymetry.



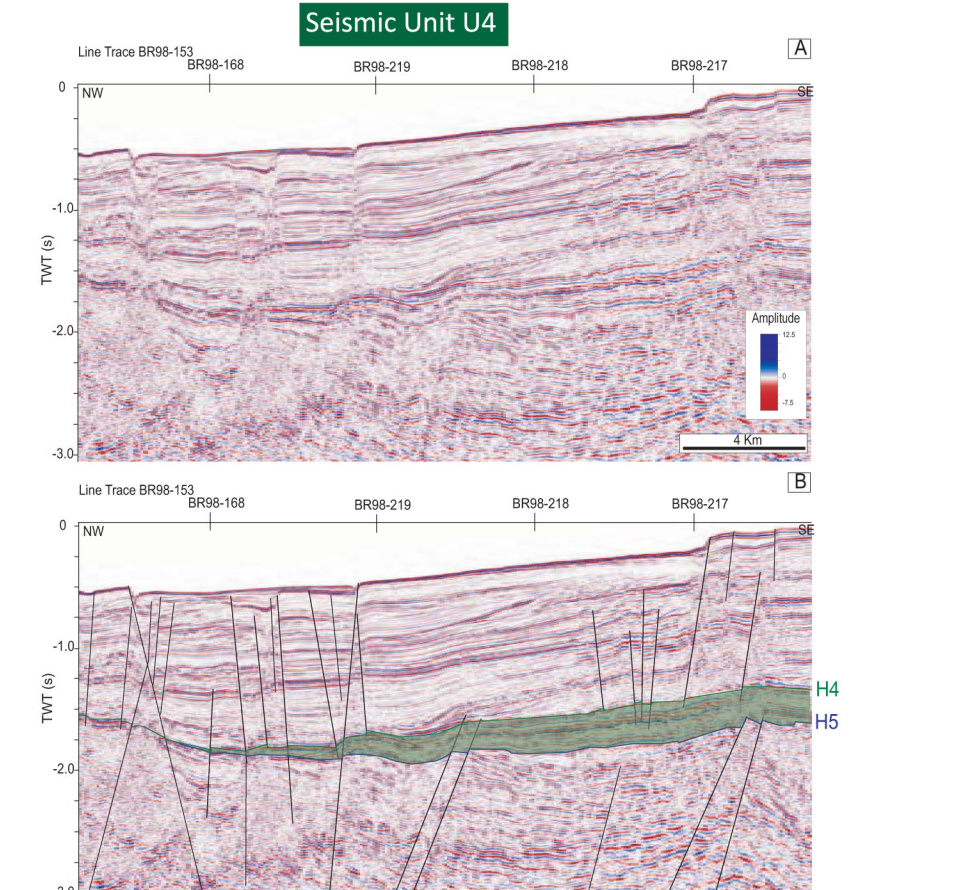
Horizon H1 (seafloor) forms the top of unit U1. The internal configuration of unit U1 is characterized by low frequency reflectors, chaotic reflectors predominate around reef-buildups.



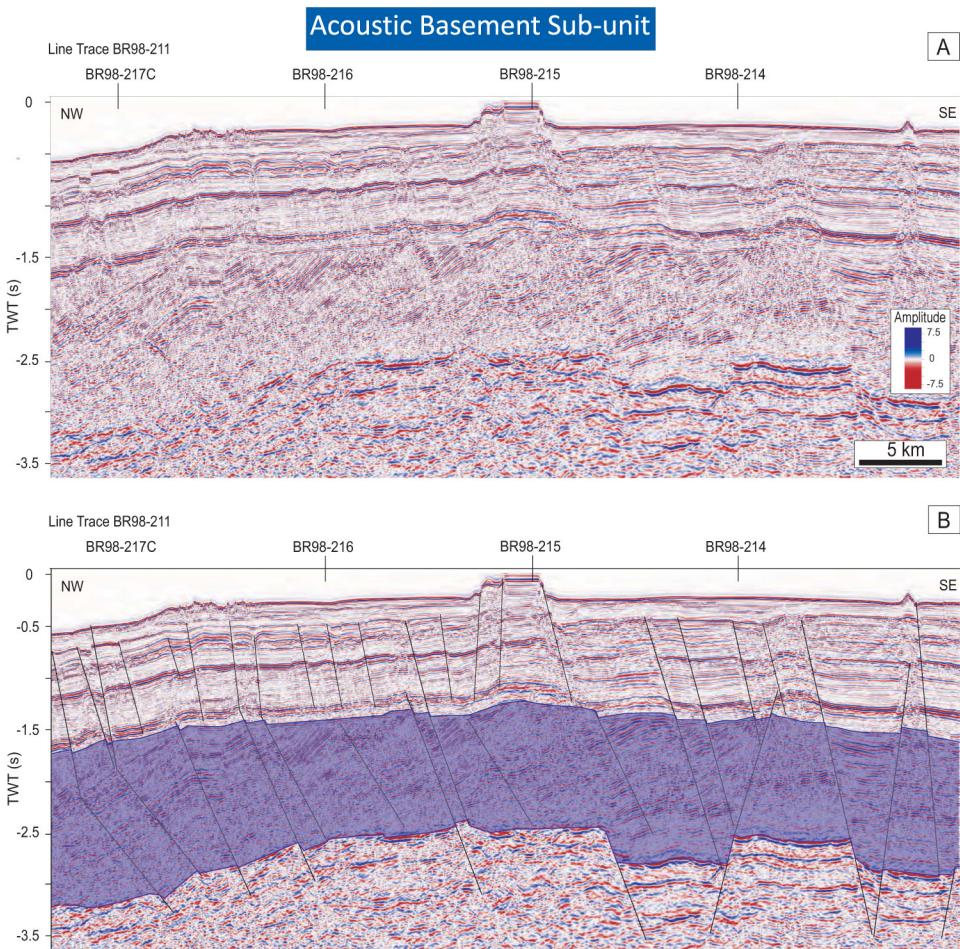
Horizon H2 forms the top of unit U2; it is frequently displaced by normal faults and interrupted by structural highs. Unit U2 is internally characterized by low-frequency, semi-continuous to discontinuous reflectors.



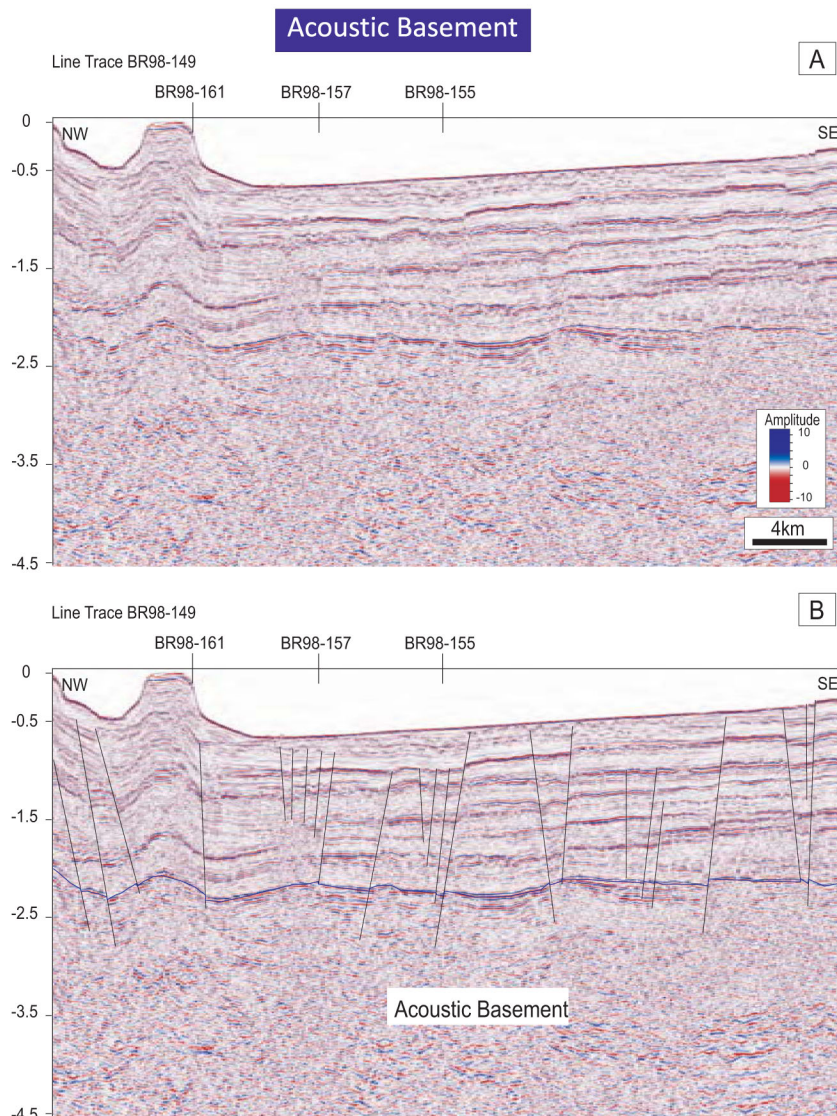
Unit U3 is internally composed of high frequency, high amplitude, semi-continuous reflectors; with increasing depth, the reflectors decrease in amplitude as well as in continuity.



Unit U4 is internally characterized by discontinuous reflectors oriented at varying angles. In the West, it is truncated by horizon H5, producing a remarkable erosional unconformity.



The acoustic basement sub-unit extends across the northern and central area.



Across the southern study area the acoustic basement is characterized by unclear chaotic and discontinuous, low frequency reflectors.

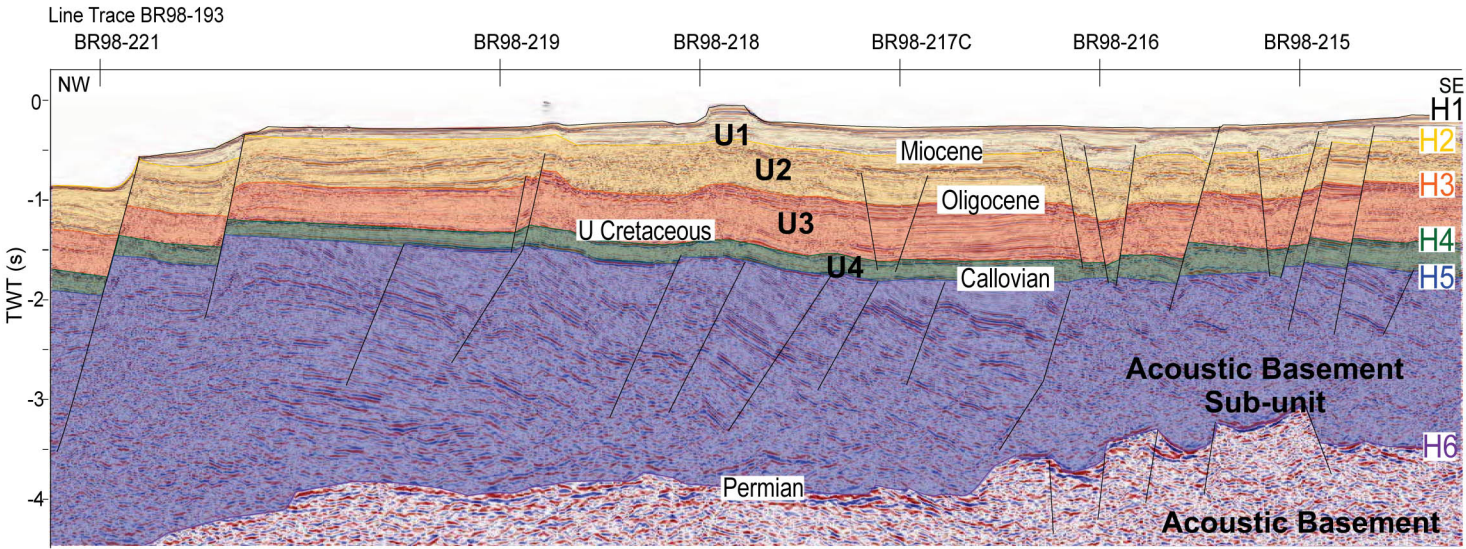
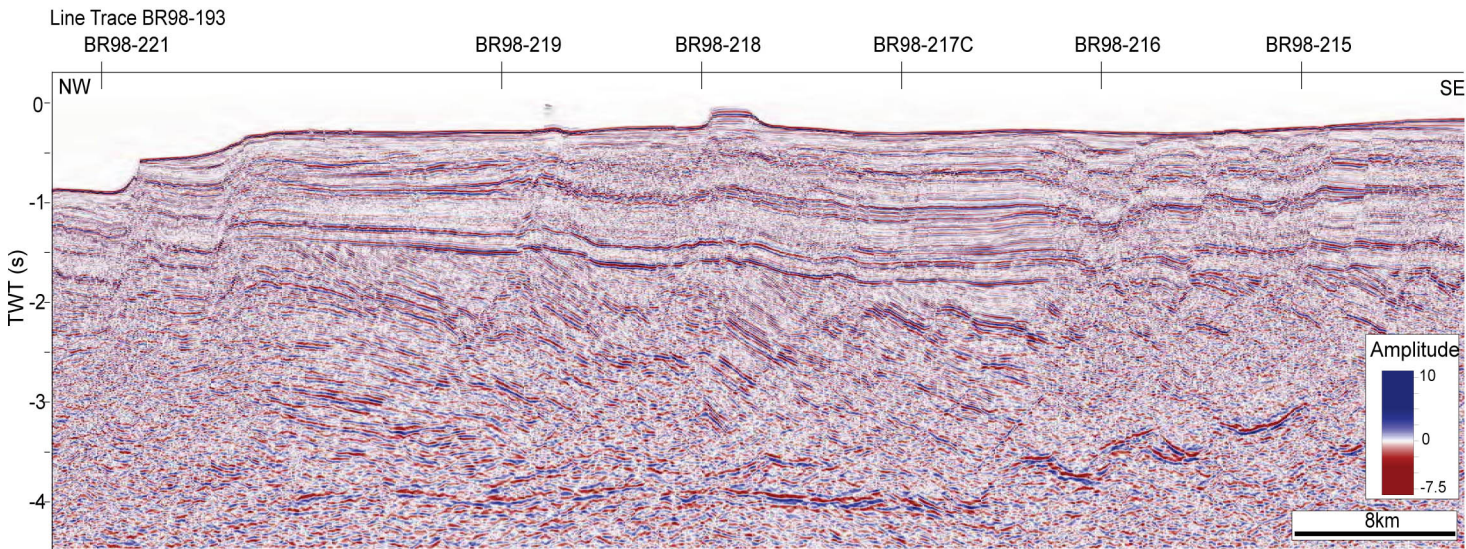
Seismic Unit	Boundaries	Seismic character
U1	Top: Seafloor (H1) Base: H2	Low-frequency, semi-continuous to discontinuous reflectors of low amplitude.
U2	Top: H2 Base: H3	A set of reflectors with low-frequency, semi-continuous to discontinuous and low amplitude alternating with infrequent, high-amplitude reflectors
U3	Top: H3 Base: H4	High frequency, high amplitude, semi-continuous reflectors with increasing depth the reflectors decrease in amplitude as well as in continuity.
U4	Top: H4 Base: H5	Sub-parallel reflectors, strong amplitude and high frequency reflectors are alternating with weak amplitude and low frequency zones.
Acoustic Basement	Top: H5 Base: H6 (only in N and central area)	Chaotic, discontinuous reflectors of variable amplitude; in the northern and central area, a sub-unit extends above H6, which is characterized by tilted, high to medium reflectors with varying dips.

5 LITHOSPHERIC FLEXURE MODELS

Different models have been proposed to justify the abundant normal faulting within a remotely convergent plate-margin setting.

Londoño and Lorenzo (2004) used simple bending elastic beam models and proposed that extensional stresses, created during the bending of the north-western edge of the Australian plate under the load of the Banda orogeny accretionary prism, could have triggered the Neogene reactivation and/or the new growth of normal faulting in the Timor region.

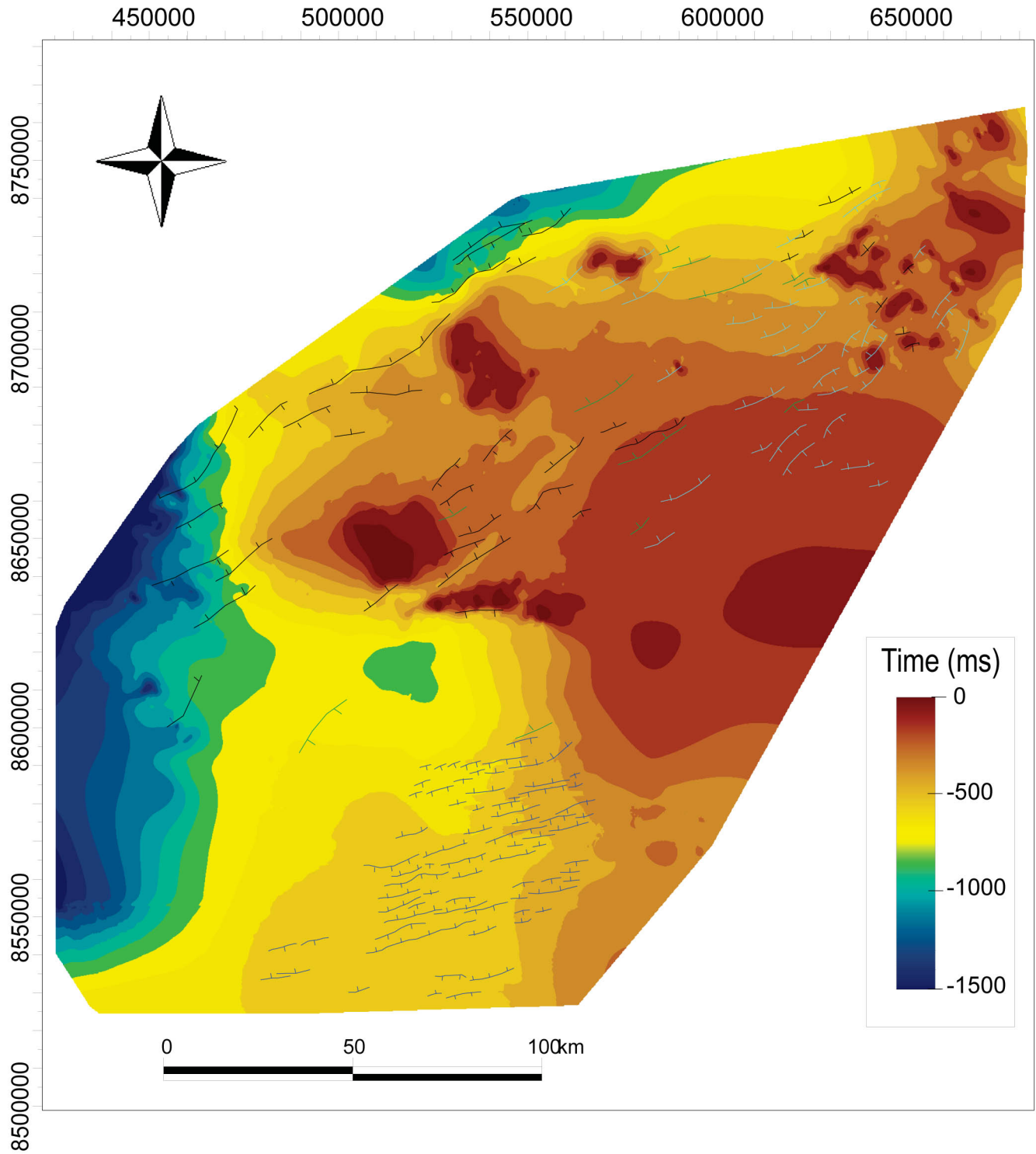
By integrating the structural analysis with 2D elastic half-beam models and regional schematic plate reconstructions, Langhi et al. (2011) argued that lithospheric flexure of the Australian plate margin, due to thrust loading around the Timor Island, could explain the Neogene structural style in the Timor region.



Seismic reflection profile of line BR98-193. After the well to seismic tie and the integration of well completion reports with literature, the following horizon ages are proposed: H2 Miocene age, H3 Oligocene age, H4 Upper Cretaceous, H5 Callovian age and H6 is interpreted as Permian age. These key reflectors (horizons) are the boundaries of the five depicted seismic units, corresponding to a Paleozoic basement with a Triassic upper acoustic basement sub-unit, overlain by a Cretaceous carbonate sequence (U4), followed by a Paleogene succession of carbonates and a topmost shaly and sandy sequence (U3), overlain by Miocene carbonates and calcarenites (U2) and a topmost succession of predominantly Quaternary carbonates (U1).

6 OBSERVED FAULT PATTERN

The topmost recent sedimentary cover is deformed by numerous normal faults, of which 165 were mapped in 3D. A detailed structural analysis of the recent to sub-recent fault development in the study area resulted in the differentiation of three normal-fault sets:



✂ Fault Sub-set 1a ✂ Fault Sub-set 1b ✂ Fault Set 2 ✂ Fault Set 3

Summary fault map constructed by overlay of the fault maps interpreted on the sea-floor (fault sub-sets 1a and 1b), -100ms below sea-floor (fault set 2) and Horizon H2 (fault set 3). The basemap is the study area seafloor mapped from the seismic reflection data.

• **FAULT SET 1** cut the seafloor, indicating that this fault population has been recently active and thus reflect the recent stress state. Two sub-sets of currently active faults are identified:

• Faults from **sub-set 1a** are NE striking and their location coincides with the Australian present-day shelf-slope break; this fault sub-set is interpreted to have developed due to the gravitational collapse of the present-day upper continental slope.

• Faults of **sub-set 1b** are ENE striking; these faults are interpreted as flexure-induced normal faults that represent the structural response to bending at the current location of the modern forebulge hinge. According to the structural interpretations, this study evidences a different present-day forebulge hinge location than Langhi et al. (2011).

• **FAULT SET 2** trends NE-SW with shallow to moderate dips. These faults terminate with their upper tip between the seafloor (horizon H1) and the underlying horizon H2, they can be observed in the central part of the study area. This fault set is most likely associated to the flexure of the Australian plate, and their subsurface location at distance to fault set 1 evidences a landward migration of the flexural forebulge zone.

• **FAULT SET 3** the oldest faults interpreted in this study are restricted to the northeastern area. These are extensional, NE striking faults that dip shallowly towards the NW and SE. These faults terminate downwards within the acoustic basement, and upward within horizon H2. This fault set can be interpreted to have formed in response to the Australian lithospheric flexure. Their location, in the northern study area, confirms that the normal faulting front moved southwards across the Australian plate.

7 CONCLUSIONS

♦ This seismic-based tectonic analysis constraints theoretical models of lithospheric flexure, highlighting the importance of combining modelling studies with field-based observations.

♦ 2D elastic half-beam models of Londoño and Lorenzo (2004) and simple bending elastic beam models from Langhi et. al. (2011) evidence that bending of the Australian lithosphere is a key mechanism responsible for the current tectonic development of the Timor Sea.

♦ Based on structural interpretations, this study evidences that flexure-induced normal faulting began to affect the Australian plate in the northeast and propagated southwestward trough time, contrasting with the eastward stress propagation proposed by Londoño and Lorenzo (2004); as well as a different present-day forebulge hinge location than Langhi et. al. (2011).

ACKNOWLEDGMENTS

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