

Final separation of Eastern Gondwana - Plate kinematics and their implications for frontier exploration.

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Frontier Exploration Potential Down Under

The offshore regions south and east of Australia and the continental fragments containing New Zealand and the Lord Howe Rise (Zealandia) comprise over 10 million km² of submerged continental crust that has yet to be properly explored for hydrocarbons. This vast area holds promise, as there are plenty of producing fields on the shallow-water fringes of the Otway, Gippsland, and Taranaki basins, which prove the presence of regional petroleum systems (Figure 1).

All proven and potential plays in the region are tied to the protracted separation of Australia, Antarctica, and Zealandia, which began in the Middle Jurassic and was not complete until the Early Eocene. This period was punctuated by a complicated series of extensional events that have influenced prospective petroleum systems from the Bight Basin of Australia to the Great South Basin of New Zealand.

The revised Neftex[®] Plate Model can be used to assess frontier petroleum prospectivity and help explain potential source rock and reservoir distribution, by thinking within a palinspastic context. This article looks at how the regional kinematic evolution may have influenced potential source rock development and preservation in the Bight Basin, southern Australia, as well as the transient development of a hinterland source area for potential reservoir units in the Great South Basin of New Zealand.

Revised Kinematic Model

The re-evaluation of continent-ocean boundary (COB) locations across the Antarctica–Australia–Zealandia conjugate margins provided a framework to remodel the pre-rift fit of the East Gondwana continental blocks. For example, some of the oldest magnetic anomalies, previously regarded as ocean floor isochrons on the southern Australia–Antarctic conjugate, are now interpreted as crests of exhumed continental lithospheric mantle. These form linear peridotite ridges discernible on seismic lines (Figure 2b) and sampled by dredging (Direen et al., 2012; White et al., 2013). The oldest true oceanic isochrons on this margin are now interpreted as C34n, which correlates well with the break-up unconformity below the base Campanian Hammerhead Formation clastics, in the Bight Basin.

There are several possible models already proposed for the Australia–Antarctic fit (White et al., 2013), many tying various combinations of fracture zones that may or may not have been active in the final stages of break-up. The most robust geological tie across the Australia–Antarctic margin is the correlative early Paleozoic Grampian-Steveley Arc Complex, which can be traced through the western South Tasman Rise and into the Bowers Terrane of Antarctica. Any robust plate model requires restoration of the whole system, including Australia–Antarctica, and must account for significant mid-Cretaceous extension, in both the West Antarctic Rift (Siddoway, 2008) and basins across Zealandia, to get a sensible palinspastic fit.

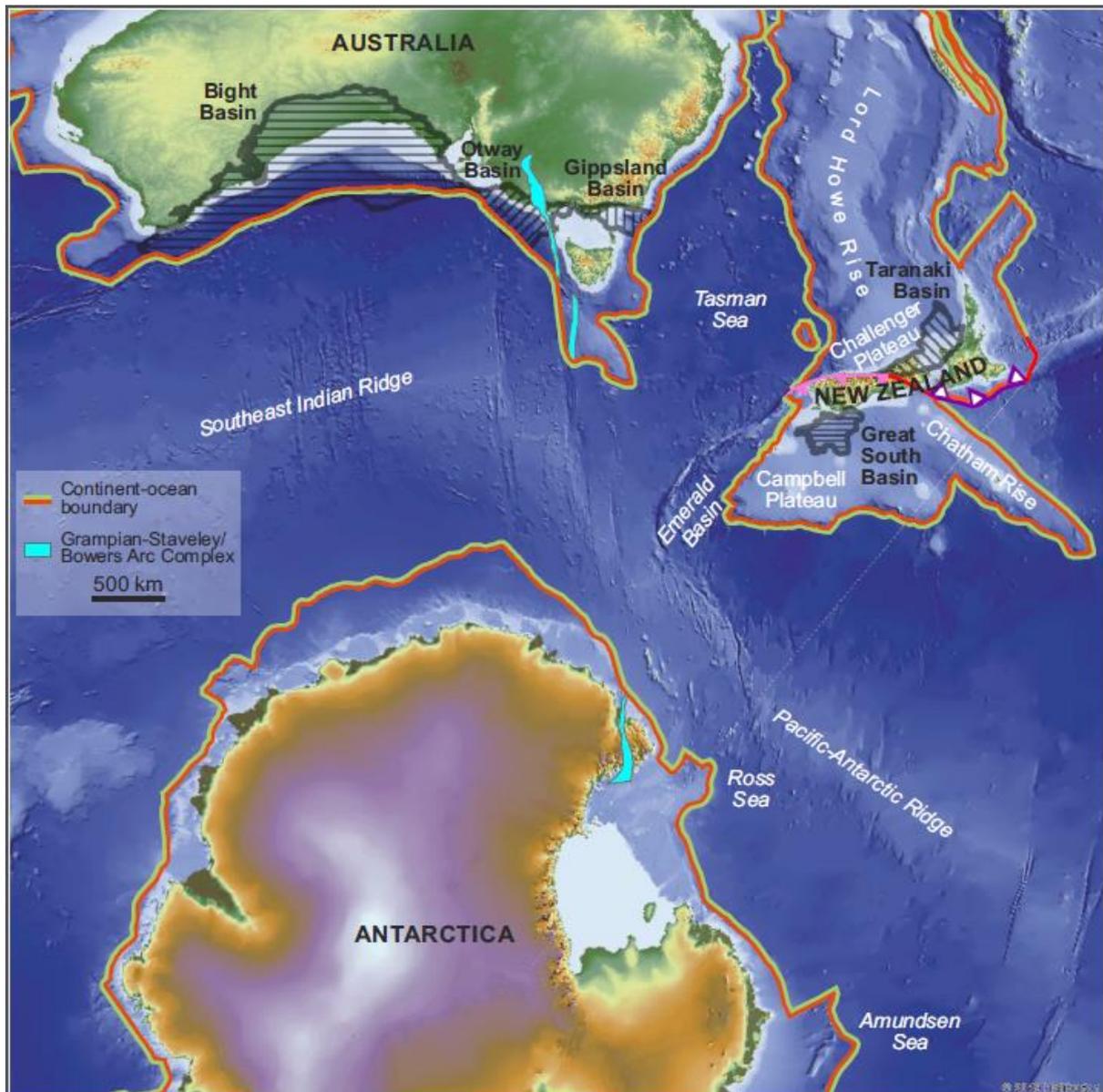


Figure 1. Location map highlighting the basins and features mentioned in the article.

The rift to drift transition across the Zealandia and Antarctic conjugate margins resulted in the opening of the southern Tasman Sea and the Amundsen and Ross Seas, from the Late Cretaceous to Eocene. The opening of these respective oceans displaced northern Zealandia (including the Challenger Plateau) and southern Zealandia (including the Campbell Plateau/Chatham Rise) along slightly different trajectories (figures 1 and 5). The initiation of oceanic spreading in both of these domains can be constrained to the base Campanian by the abrupt changes from syn-rift to post-rift strata in most basins offshore New Zealand, as well as by the oldest ocean floor isochrons on the passive margins.

The two case studies below highlight the important link between the revised regional tectonic evolution, evolving paleogeography, and play potential.

Protracted Break-up and Source Rocks in the Bight Basin

Regionally, the stratigraphy of basins along the southern margin of Australia records two classic syn-rift packages: an earlier Callovian–Barremian phase observed, at least in part, along the entire margin; and a Late Cretaceous phase, which is restricted to the Otway Basin margin, where divergence was more transtensional. In the Ceduna Sub-basin (Bight Basin), deep seismic profiles confirm that a thick, early syn-rift section is present, controlled by basement faulting. However, the succeeding late syn-rift succession, below the base Hammerhead Formation break-up unconformity, appears more akin to a sag phase, with gravity-driven delta tectonics clearly visible (Figure 2c). This architecture is unique among syn-rift passive margin successions, where deltaic gravity-driven successions are exclusively found in the post-rift, and thus implies the Bight Basin requires a different syn-rift extension model from those of typical passive margins.

A two-stage rift extension model proposed by Espurt et al., (2012) explains the discrepancy in extensional style and locus between the two phases, using asymmetry and non-uniform lithospheric thinning across the conjugate margins (Figure 3a). During the early phase, the majority of extension on both the Australian and Antarctic margins was taken up by classical crustal block faulting. In the later phase, the Australian margin was subjected to rapid thinning of the lithospheric mantle, but little extensional expression in the crust, thus allowing the apparent ‘sag’ and gravity-driven morphologies to develop.

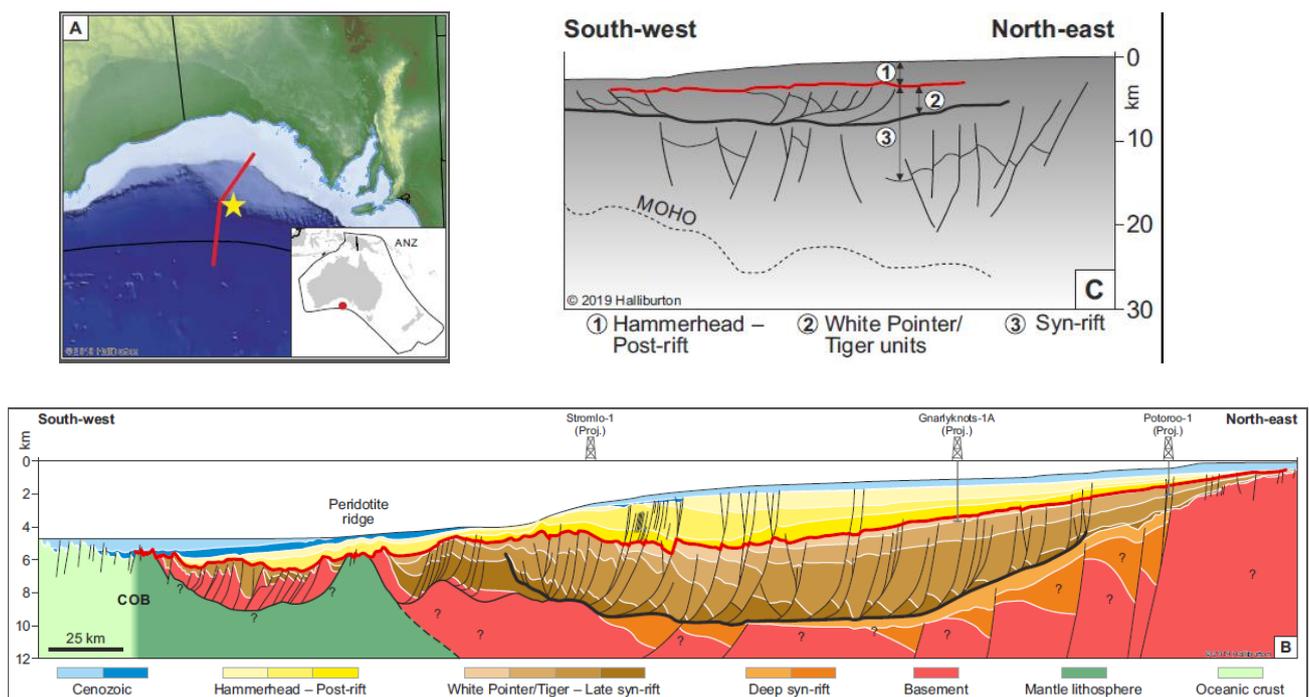


Figure 2. The overall structure and tectonic style of the Bight Basin. (A) Locations of the cross section in Figure 2B (red line) and the proposed Stromlo-1 well (yellow star). (B) Interpreted cross section (modified from Espurt et al., 2009), highlighting the structure of stratigraphic mega-sequences and exhumed continental mantle on the hyper-extended margin. (C) Simple interpretation of a deep seismic profile (ION Geophysical, 2015), highlighting a thick, early syn-rift package controlled by basement faulting. Exact line location and horizontal scale are not known.

This break-up model has important implications for the deposition and preservation of the proposed main source rock interval in the deep-water Bight Basin. Cenomanian–Santonian organic-rich marine shales, sampled by dredging, provide the best opportunity for a mature, oil-prone source and were deposited during the later ‘syn-rift’ phase. As there was little, if any, active tectonism (e.g. crustal faulting, uplift, and erosion on footwalls), units of this age could have accumulated and been preserved across a wide area (Figure 3b). The revised plate model, incorporating a longer-lived and more quiescent separation, maximises the time over which a narrow, restricted seaway existed, favourable for source intervals to accumulate. Source rock presence is likely to be one of the key exploration risks for the upcoming Stromlo-1 commitment well (location shown in Figure 2a; Equinor, 2018), highlighting the importance of plate model assessment in frontier play-based understanding.

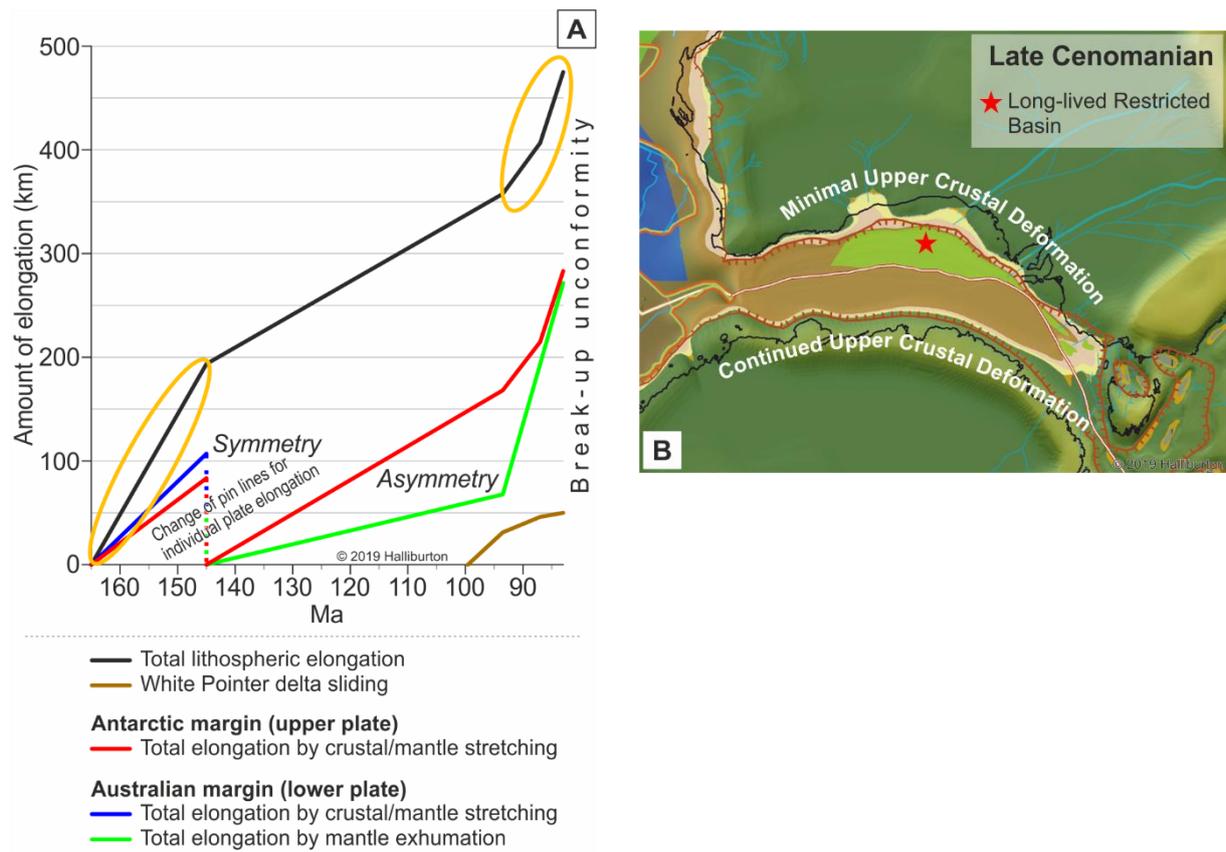


Figure 3. (A) Graph detailing the extensional history of the Australia-Antarctic conjugate (after Espurt et al., 2012). The two periods of extension are highlighted by yellow ellipses. In the later extensional phase, the Bight Basin margin elongation is accommodated by lithospheric mantle exhumation, in contrast to the Antarctic margin, where crustal extension is still prevalent. (B) Later extensional phase — late Cenomanian Neftex® Palinspastic Gross Depositional Environment map showing a possible restricted source rock model, where preservation is favoured along the more tectonically quiescent Bight Basin margin.

Paleo-hinterlands of the Great South Basin

The Great South Basin (GSB), offshore south-eastern New Zealand, is a vast frontier province of 100,000 km² with only approximately 12 wells drilled. The syn-rift Hoiho Group likely contains the most prospective source rocks, whilst the post-rift succession may contain some of the highest quality clastic reservoir targets. A series of large, stacked delta-top lobes have been mapped on seismic (Uruski, 2017) and show significant clastic input from the west, particularly during the Campanian to Early Eocene (Figure 4). Thereafter, the clastic supply appears to have reduced dramatically, and the delta systems seem to have shut down throughout the later Paleogene.

It is not clear what events drove this sediment supply pattern, nor where the hinterland was that derived the material. The modern hinterland topography and drainage of New Zealand's South Island is a result of Neogene transpressional convergence along the Alpine Fault system and is not valid as a guide for assessing Late Cretaceous sediment pathways.

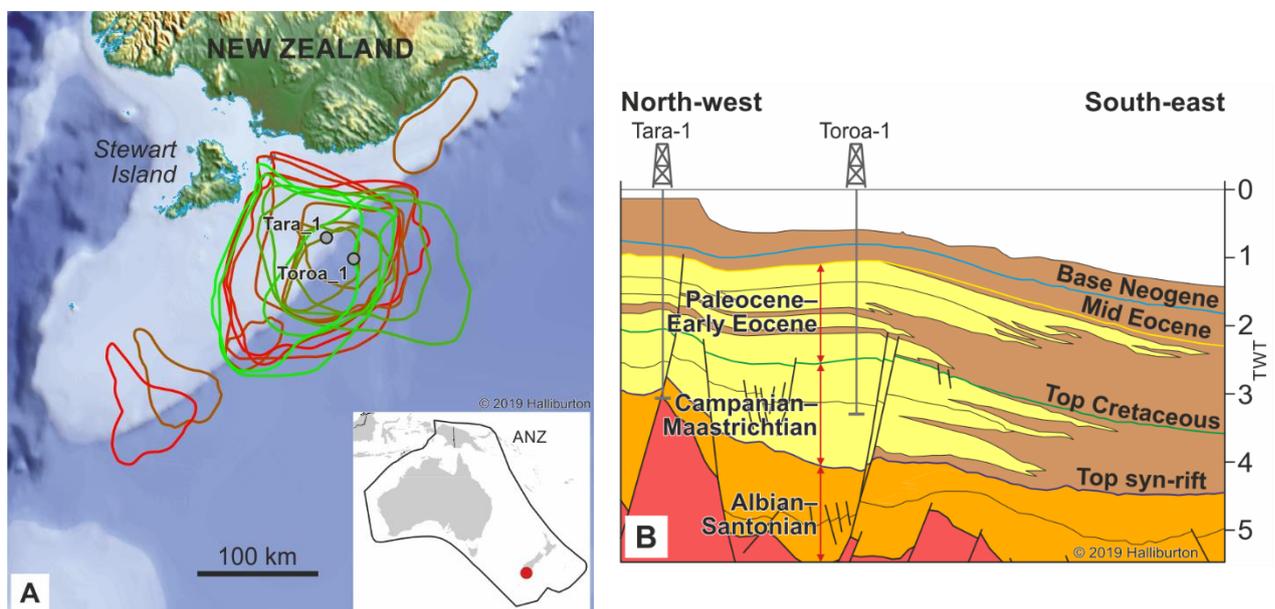


Figure 4. A distinct period of high clastic supply to the Great South Basin took place in the Late Cretaceous–Eocene, producing stacked delta-top lobes in (A) map view, and (B) interpreted cross section view (after Uruski, 2017). The major progradational clastic systems sit within the Campanian to Early Eocene section, prior to eventual shut-down in the Middle or Late Eocene.

The Neflex Plate Model trajectories of the northern and southern (present-day coordinates) Zealandia continental blocks, during the early drift phase, provide insight into the possible tectonic driving mechanisms for hinterland evolution (Figure 5). From break-up (base Campanian) through the latest Cretaceous and into the Early Paleogene, the spreading at the Tasman Sea and Pacific-Antarctic ridges displaced the two Zealandia continental blocks in a manner that necessitated some convergence between them, in the region of the present-day western Challenger Plateau and the eastern Campbell Plateau. Convergence across this zone could be responsible for the significant clastic supply into parts of the GSB during this time interval.

Following the cessation of spreading in the Tasman Sea and then, more significantly, the Eocene (approximately 47 Ma) change in the rotation of the Pacific Plate, southern Zealandia began to rotate counter-clockwise (Figure 5). This created a new extensional regime, which led to opening of the Southeast Tasman/Emerald Basin (Lebrun et al., 2003), in the region that was previously the potential hinterland supplying the earlier delta systems in the GSB. It is possible this older hinterland was dismembered, then subsided, and was drowned during the Middle to Late Eocene, thus explaining the drastic reduction in clastic supply observed in the GSB and the drowning of the delta-top system. The basement lithologies in this lost hinterland region likely determined the reservoir quality of targets in prograding delta sequences.

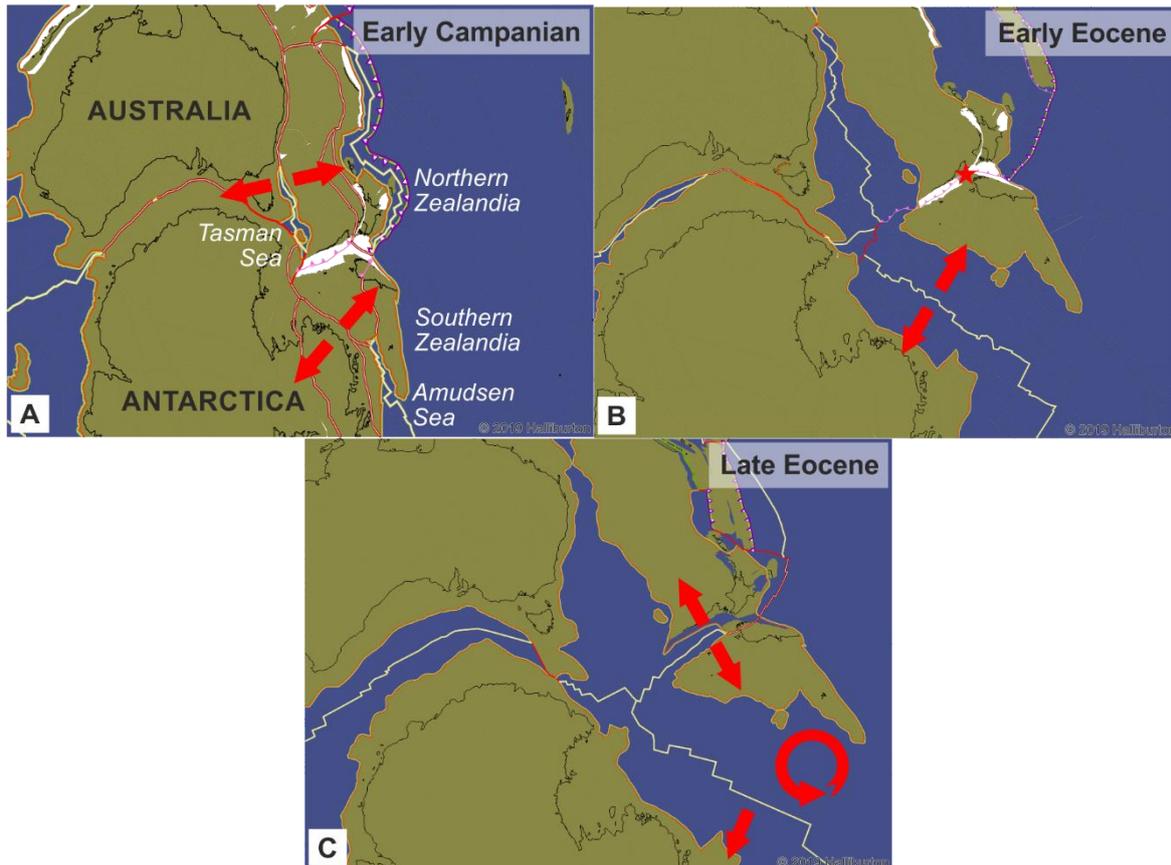


Figure 5. Plate reconstructions displaying relative trajectories of the Zealandia continental blocks during the latest Cretaceous to Eocene. Between the Campanian and Early Eocene, the locus of convergence is highlighted by the red star. This area was the site of rapid extension by the later Eocene.

Conclusion

The final break-up of eastern Gondwana during the late Mesozoic and early Cenozoic created a series of basins along the margins of Australia and New Zealand, which remain underexplored. Such frontier areas are plagued by significant exploration risks. Key exploration risks in this region include the presence and preservation of source rock in the Bight Basin, and the hinterland location and clastic supply to the GSB.

Utilizing plate models and palinspastic gross depositional environment (GDE) maps can better inform explorationists about regional basin evolution, by highlighting critical deposition periods, as well as helping to identify and reduce uncertainty.

In the Bight Basin, timing and duration of rift events and their tectonic style may be key factors in supporting widespread Late Cretaceous organic-rich facies models. In the GSB, relative plate motions through time (localized convergence/divergence) could help explain paleo-hinterland evolution and its effect on supply and shut-down of prospective clastic systems. These case studies highlight how evolving plate models are useful tools in the early-stage process of exploring prospective plays and opening up future potential.

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