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Does the Caribbean hold lessons for SE Asia? Part 2

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Abstract: This note builds on an earlier Warta note (Doust, 2022) that summarised the geological development of the island of Trinidad and the margins of the Caribbean Sea. Parts of Southeast Asia can be readily compared to these areas and, I believe, the two provinces can provide valuable analogues for each other. I illustrate this by considering examples of tectonic style taken from transpressional fold belts in Trinidad and eastern Java, from the evolution of foreland and wrench basin stratigraphy and from striking similarities between the stratigraphy and structure of Borneo and Trinidad's Tertiary continent margin deltas.

Keywords: Geological evolution, Trinidad, Java, transpression, Borneo, deltas

INTRODUCTION

In this and a previous note I ask whether the overall geologic similarities between Southeast Asia and the Caribbean (Figure 1) are such that we can make use of aspects of their sedimentary and tectonic evolution to help mutual interpretation efforts. Accordingly, in part 1 (Warta Geologi, December 2022) I examined some of the geological characteristics of the Caribbean, as exemplified in the island of Trinidad and in this second note I have selected a few situations where I believe the geology there carries useful lessons for interpreting the geology in parts of SE Asia.

Rift sequences, characteristic of many Tertiary basins in SE Asia, are rare and scattered in the Caribbean and may not be present at all in Trinidad. However, many aspects of post-rift sag and collision cycles are very comparable, in particular where they record the impact of transpressional shear associated with young plate movements. Below I review a few striking examples.

TRANSPRESSIONAL FOLD AND THRUST BELTS

Figure 2 shows a cross-section through the Tertiary fold and thrust belt in Trinidad based on recent seismic data. The fold belt is oblique and adjacent to the Northern Range dextral wrench uplift zone and is sliced by WNW-ESE directed faults (such as the Los Bajos Fault). This transpressional style has contributed to the formation of stacked imbricated thrust culminations, possibly related to shear faults in both basement and overburden (e.g. Pindell & Kennan, 2002), separated by synclinal troughs. In both Trinidad and eastern Venezuela this results in the formation of disharmonic folds and out-of-sequence thrusts.

A similar transpressional situation is seen in the Tertiary fold belt of eastern Java (Figure 3), where a northward-directed Plio-Pleistocene thrust belt lies adjacent to a major Late Miocene east-west wrench zone, resulting in the development of opposing thrust belts. Subduction driven thrusts of the Kendeng zone border a developing foreland trough (the Randublatung zone), the northern part of which (the Rembang zone) forms a left-lateral wrench flower structure resembling the Northern Range of Trinidad (Figures 3,4). It is interesting to note that in both Trinidad and Java the wrench zones are aligned along crustal hinge lines and are often associated with important facies boundaries.

Much of the East Java fold belt lies below an active volcanic arc but recent interpretations (e.g. Clements *et al*., 2009) have emphasised its extent along the trend of the Java subduction zone. In Sumatra, where the fold belt corresponds with the Barisan wrench zone (Figure 1), we could expect that the Trinidad model could provide valuable analogues.

Oil fields in Trinidad, charged from rich Late Cretaceous source rocks, are abundant in stacked thrust zones in the fold belt. Their structure is complicated by under-compaction driven by clay diapirism in the rapidly deposited foreland cycle sediments (as seen in eastern Java). A characteristic example is the SW-NE trending Penal/Barrackpore oilfield in the Central Ranges of Trinidad (Figure 5), which comprises multiple oil accumulations in isolated thrust blocks. Notably, sandy

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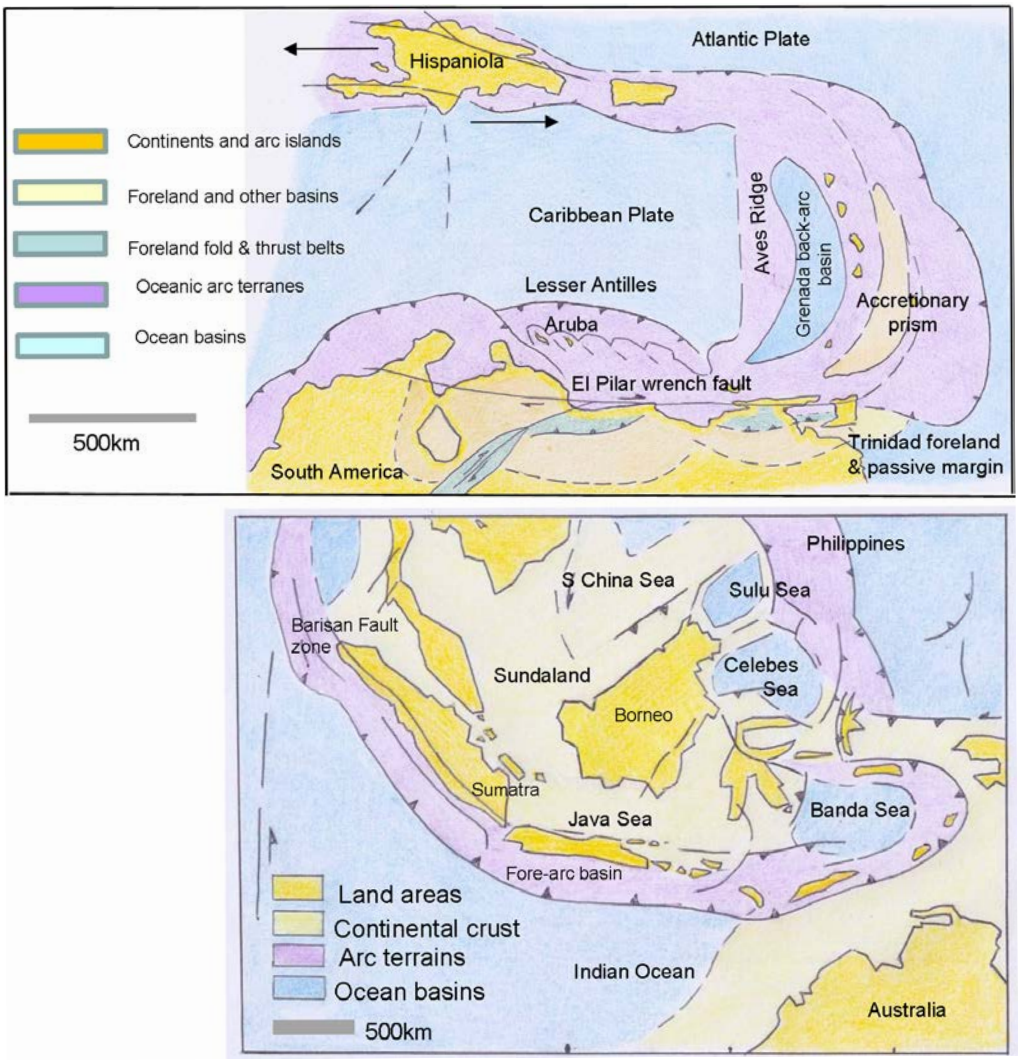


Figure 1: Simplified sketch maps of the eastern Caribbean Sea and SE Asia, highlighting the overall geodynamic similarity, whereby transpressional collisions of continental and oceanic crustal elements have resulted in arcuate deformation zones and the formation of small ocean basins. Note the arc-parallel extension along the Lesser Antilles deformed zone.

turbidite accumulations in depressions on continental slopes up-slope of developing syn-sedimentary thrusts had been recognised in Trinidad purely based on well penetrations, long before 3D seismic data over deep-water fold belts became available (Figure 5B). Similar geologic features form the focus of recent exploration in the deeper water areas of SE Asian Tertiary deltas (e.g. in western offshore Sabah, Grecula *et al*., 2018).

FORELAND BASIN SEDIMENTARY EVOLUTION

As the transpressional zone between the South American continent and the oceanic domain of the Caribbean reached Trinidad in the late Tertiary (Figure 1), the developing fold belt migrated southwards, gradually incorporating foreland cycle deposits into the thrusts and shifting the focus of foreland sedimentation southwards. This trend is seen in many fold belts, but thanks to the precision of age-dating it was already possible in the 1950's to map the displacement of the fold belt through the Oligocene to Pliocene in Trinidad with great accuracy (Figure 6) and to understand the local facies developments. Models like this may help interpretation of developing foreland sequences in, for instance, Java and Sumatra. Possible evidence for such foreland migration has been hinted at in eastern Sabah (Baluguru & Nichols, 2004).

PULL-APART AND "PERCHED" BASINS

These basin types are common in the wrenched tectonic zones of the southern Caribbean and Trinidad and in eastern SE Asia.

Classic examples of pull-apart basins occur in the Caribbean deformed zone north of the El Pilar wrench fault offshore eastern Venezuela, where fault-bounded basins

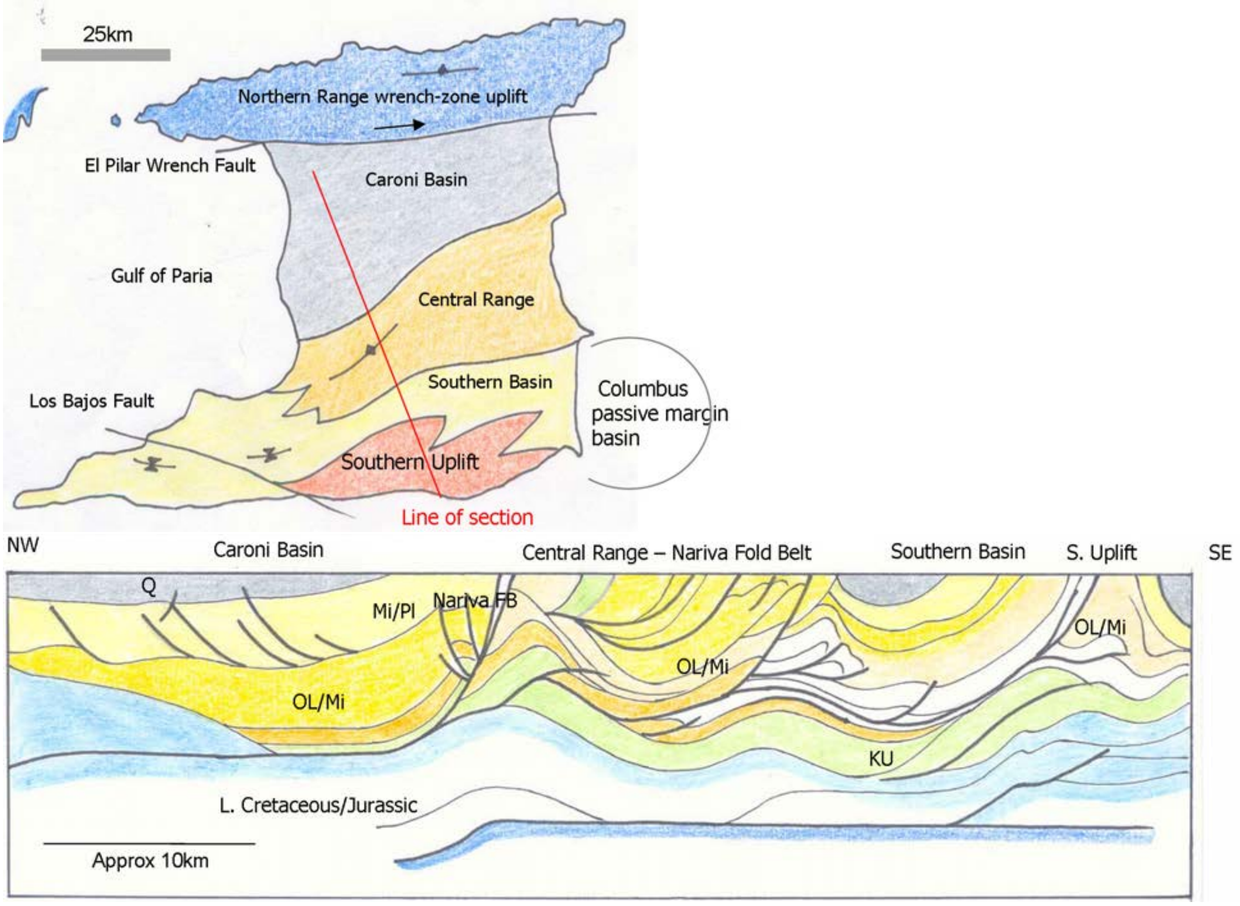


Figure 2: Simplified geologic map of Trinidad and a NW – SE seismic-based geologic section across the Trinidad fold belt (red line), redrawn and simplified from Osman & Moonan, 2019. Stacked imbricated fold trends are separated by synclinal troughs. Note the discordance between surface and subsurface structure. KU = Upper Cretaceous, OL/Mi = Oligo-Miocene, Mi-Pl = Mio-Pliocene, Q = Quaternary

filled mainly with deep marine Tertiary shales separate high blocks upon which the Lesser Antilles islands like Aruba are situated (Figure 1). These basins resulted from "arc-parallel extension" and are related to shear along the Caribbean and South American plate margins as the latter moved westwards.

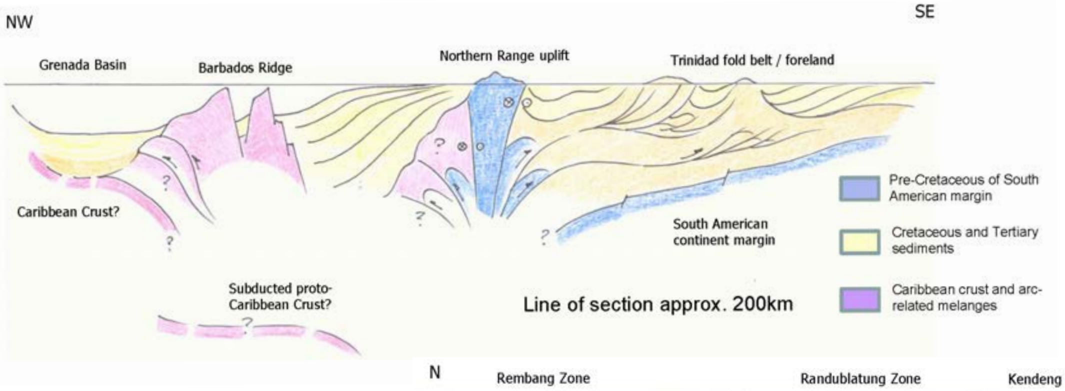
Similar pull-apart basins occur in the Sumatra and Java forearc zone (Berglar *et al*., 2008) and may characterise many of the Tertiary basins in eastern Indonesia and the eastern Philippines whose development has been affected by transcurrent movements (CCOP, 2002). Most of these basins contain gradually shallowing Neogene sequences starting with mainly deep water clastics lying on volcanic and melange basement, often with local carbonate reef developments. As they originated from young shear movements that are still in many cases active, many of them are subject to recent transpression and inversion or, as in the case of Java, volcanic arc migration.

Although "Perched" or "wedge-top basins" vary in structure and stratigraphy, Caribbean candidates include undeformed Plio-Pleistocene supra-fold belt synclines like the Caroni Basin, Gulf of Paria and Southern Basin in Trinidad (Figure 2). They may be tilted or faulted, but often comprise relatively undeformed sequences situated above active fold belts. Identification of these basin types in complex wrench SE Asian fold belts such as in Sabah (Balaguru & Nichols, 2004; Figure 7) and their relationships to underlying and adjacent cycles may help to clarify the structural history.

TERTIARY DELTAS

Growth-faulted SE Asian Tertiary deltas like the Mahakam and Baram deltas are characteristic of the continental margins in Borneo, where they form important petroleum provinces. Their basic structure and stratigraphy, including their petroleum system development, show striking similarities to those of Caribbean deltas such as the Plio-Pleistocene Columbus Basin of offshore Trinidad (Figure 8), also an important petroleum-producing province.

The Columbus Basin developed on an older Tertiary and Cretaceous sequence that lies on Atlantic Ocean crust



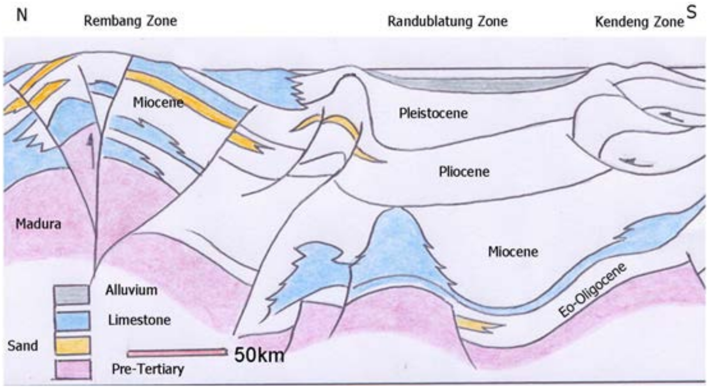
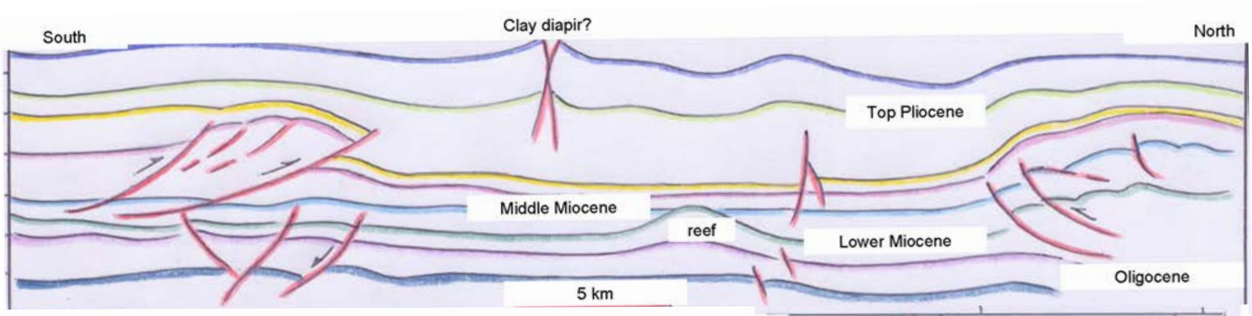
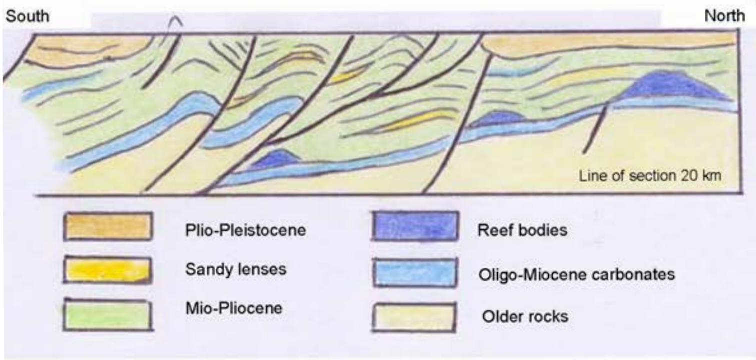


Figure 3: Top: Sketched interpretation of structural provinces in the Trinidad area, compiled and interpreted from various sources (see Doust, 2022). Below: N – S structural cross section through East Java and Madura Island redrawn from Sharaf *et al*., 2005.





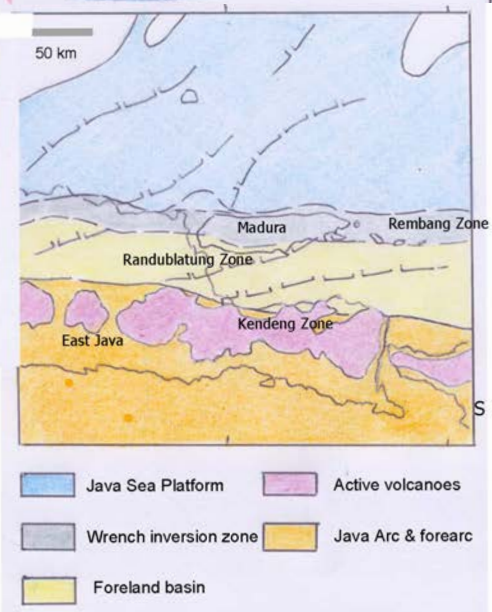


Figure 4: East Java fold belt and wrenched foreland. Top: Interpretation of the Radublatung foreland zone showing opposing thrusts originating from the Kendeng (left) and Rembang (right) trends (From Ran Weimin *et al*., 2019). Below: Detailed structural cross section through the Liman area, Kendeng thrust belt, highlighting the Plio-Pleistocene foreland cycle (ochre colour). Redrawn from Indonesia 2021 bidding round brochure (www.scribd.com). Right: Structural provinces of East Java. Note the oblique fault zones in the Randublatung zone.

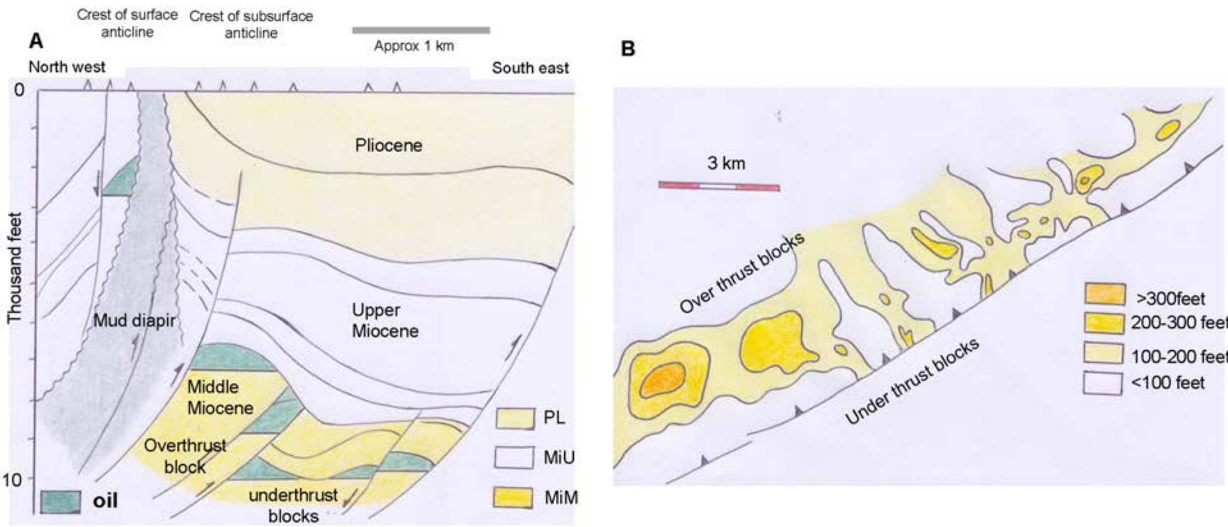


Figure 5: Penal/Barrackpore Field, southern Trinidad. A: NW-SE cross section showing crestal clay diapir and structural offset of surface and subsurface structure. B; Map showing thickness of porous Herrera turbidite sand (middle Miocene) in the overthrust block from well control, showing feeder channels ponded behind and in places breaking through the syn-depositional thrust anticline. From Dyer & Cosgrove, 1992.

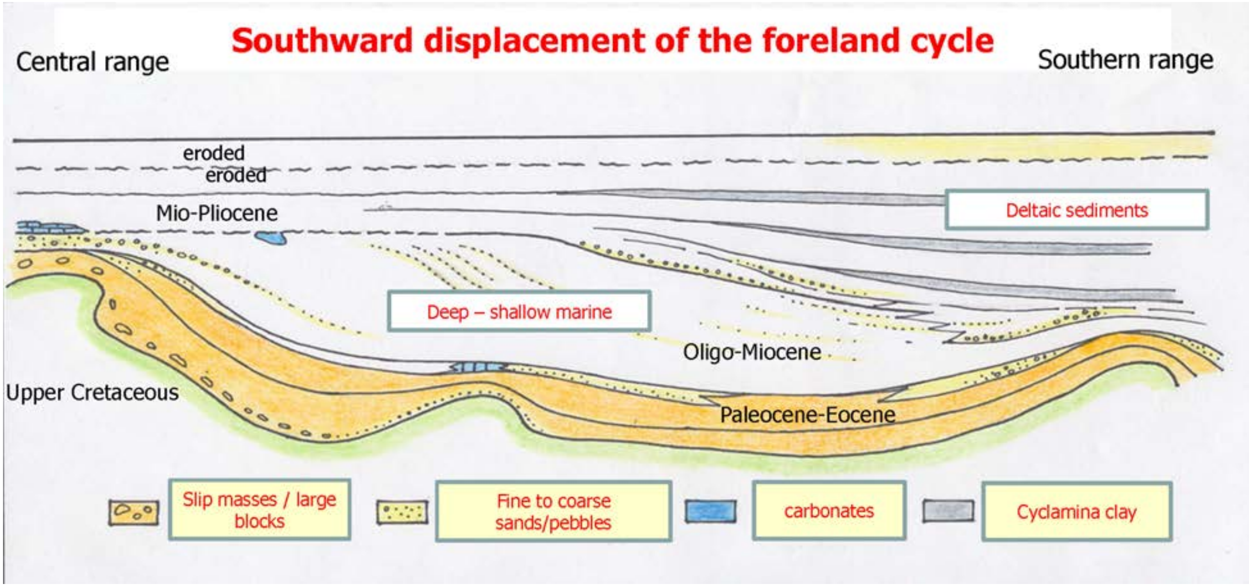


Figure 6: Southward movement of the foreland cycle deltaic sequences during the development of the transpressive collision cycle through the Oligo-Miocene and Mio-Pliocene. Follows the line of section on Figure 2. Redrawn from Kugler & Saunders, 1967 (in Kugler, 1996).

east of the Trinidad fold-belt, outside the zone of Caribbean deformation. It contains a thick sequence of fluvial to deep marine clastics derived from the Orinoco River and forms a classic prograding passive margin delta, in which a full range of depositional environments is developed throughout its Late Pliocene to Pleistocene evolution. As a result of the time-transgressive progradation, the sequence becomes successively more proximal (indicated by upward coarsening trends) through time (Figure 8a). As in other continental margin deltas, the north-eastward prograding delta sequence is cut by a series of down-to-the-basin syn-sedimentary growth faults, here trending NNW-SSE. Movement along a series of NE-SW directed wrench faults in the pre-deltaic (?Cretaceous) basement has resulted in local uplifts that form subtle structural culminations that intersect with the growth fault trends. The main gas fields in this province are situated in these culminations.

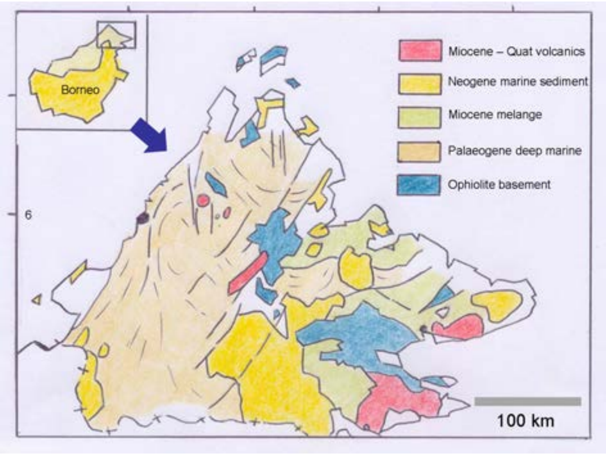


Figure 7: Geological map of Sabah showing the complex relationships of the tectonic units. Uplifted ocean basement, forearc Palaeogene formations and Neogene melange are in places overlain by Neogene shallow marine sediments and volcanics belonging to a foreland cycle. From Balaguru & Nichols, 2004.

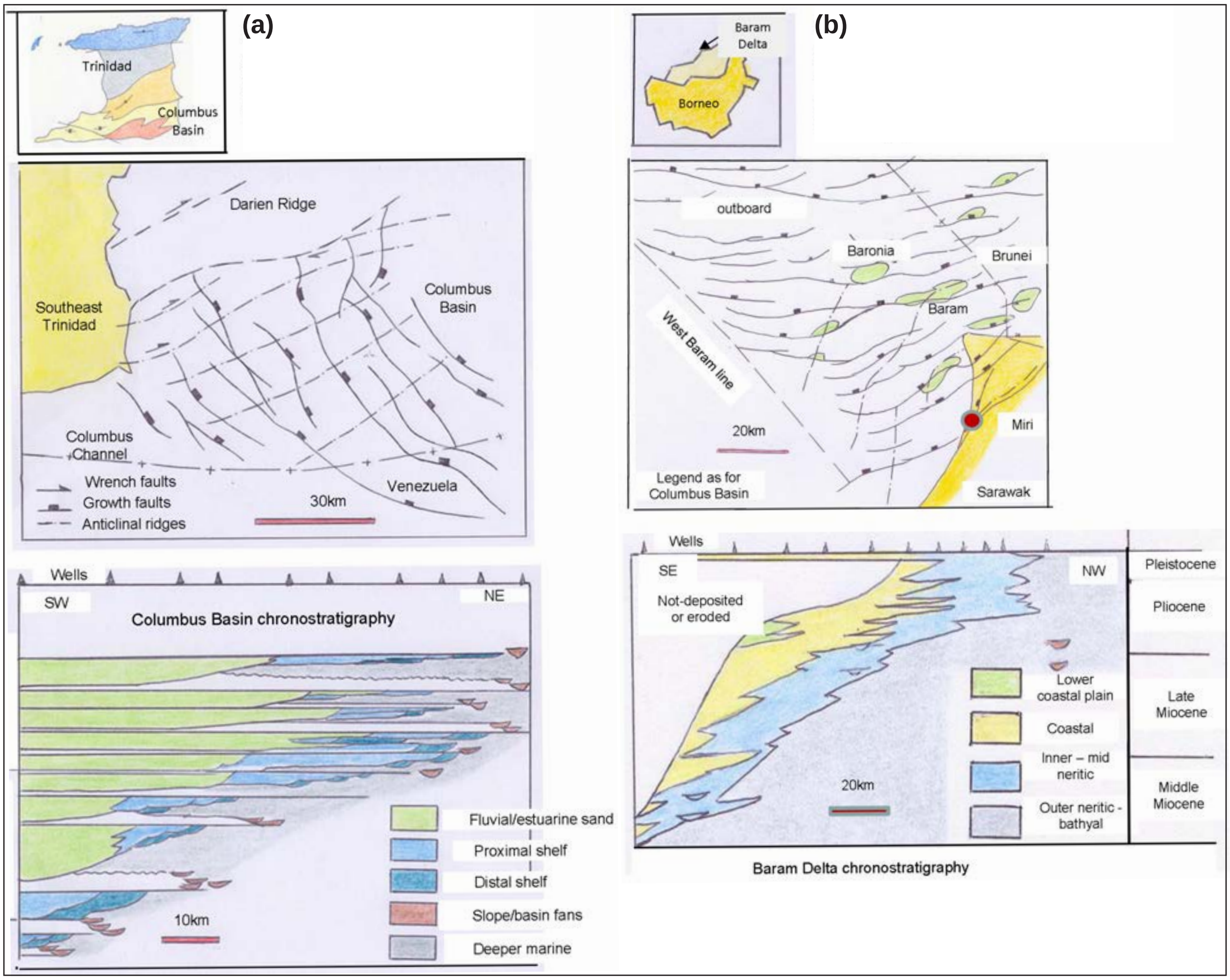


Figure 8: (a) Structure and chrono-stratigraphy of the Columbus Basin, southeast offshore Trinidad. From Wood, 2000. (b) Structure and chronostratigraphy of the Baram Delta, offshore Sarawak and Brunei with some larger oil fields. Modified from Sandal, 1996 and Petronas, 1999.

The Baram Delta (Sandal, 1996; Petronas, 1999) is also characterised by a succession of prograding offlap sequences of Late Tertiary shallow to deep marine clastics cut by trains of E – W trending growth faults in much the same manner as in the Columbus Basin (Figure 8b). As in the latter, the growth faults are intersected by subtle anticlinal culminations that define the locations of the main oil and gas fields. These culminations are related to a north-westward prograding front of inversion, which according to Tingay *et al*. (2005) is related to 'basement-associated' tectonics, probably associated with transpression along the northwest Borneo continental margin. A notable difference between the Baram and Columbus deltas is the almost complete absence of coastal plain (fluvial) facies in the former due to erosion as a consequence of harsher inversion.

FINAL WORDS

In these two notes (this and previous Warta article), I make a plea for a super-regional approach to sedimentary basin evaluation. I hope I have shown that parts of these two provinces have much in common and that they lend themselves to sharing experiences. Differences do, of course exist, both in style and in detail, but I believe that incorporating data and interpretations of the common issues [in analogue basins] can contribute to new insights, especially when we struggle with limited data and, as in these areas, complex tectono-stratigraphic histories.

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CONFLICT OF INTEREST

I declare that there is no conflict of interest in this note.

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