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One Basin with Several Sediment Sources: Stratigraphic Records of the Bunguran Trough, Central South China Sea

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Abstract

The Bunguran Trough (BT) is an intra-continental deepwater basin located in the West Luconia Province, offshore Sarawak at the centre of the South China Sea. It evolved as a tectonically induced sag basin, where two major lineaments appear to have crossed. Its oldest known stratigraphy is formed by shelfal clastics of the equivalent lower Miocene Cycles I/II Nyalau Formation, now buried beyond a depth of 6000m. The Neogene clastics deposited above are of neritic and bathyal characters. The upper Miocene Cycle V Upper Arang Formation equivalent consists of some 3000m of slope and toe-of-slope deposits, overlain by very distal and muddy sediments of the equivalent Muda Formation. All sedimentary units, apart from the youngest post-Pleistocene section underwent a variety of deformations during distinct intervals.

A study of Plio-Pleistocene deformation history and the corresponding sedimentation rates of the BT recognised the following sediment-source patterns:

- The Natuna High (in geographic terminology: the Riau Archipelago) contributed medium- to fine-grained feldspathic quartz-rich turbidite deposits.
- Fine sand and silt-rich deposits reached the BT from the fringes of the Rajang Delta (synonym: West Luconia Delta). The advancing delta front spawned turbidite currents flowing north to northeast. These clastics can be characterized as mud-rich, with channelized (shoestring geometry) and lobate turbidite deposits of increased sand potential.
- A minor amount of sediment might have originated from localized sources in the Dangerous Grounds area to the north.

Overall during the Neogene, predominance of sediment supply shifted from the Natuna High area to the Rajang Delta. In the Pliocene, the sediment source appeared to have shifted back to the Natuna area, as demonstrated by mineralogical composition data. In addition, a semiquantitative analysis of the sedimentation rates show that sedimentation rates were low before 3Ma, increasing in the late Pliocene, and peaking in the Pleistocene. Physical compaction is thought to have played a key role in this trend, with possible increased sediment supply from the Natuna High.

Introduction

The South China Sea corresponds to an area of Cenozoic crustal extension, flanked by the Asian continent (Vietnam, China), the Philippines, and the Sundaland continent (areas of Java, Borneo, and Peninsular Malaysia). The area saw periods of compression, manifested in strike-slip (and occasional thrust) movements along major lineaments. Underlying the different sedimentary fills of variable thicknesses, the basement is formed predominantly by strongly to moderately attenuated continental crust. Tectonic processes affected the BT spanning at least the entire Tertiary; these have been summarized recently by Jong et al. (2014). The BT with its deepwater sedimentation equivalent of the Rajang Delta and the Bunguran Fold Belt (BFB) is located in the centre of the South China Sea and can be described as a roughly triangular crustal depression. It is wedged between the Terumbu Platform in the West, Central Luconia Platform to the East both sites of major Miocene to Pliocene platforms and pinnacle reefs) and the Dangerous Ground Massif to the North and Northeast (Figure 1). Sediments in the BFB are late Miocene through Pleistocene, and consist of mainly slope facies of the Rajang Delta system (Kessler and Jong, 2014). There is, however, a marked sedimentary input originating from the Natuna High, both in the very early history of the basin, and likely again later during the Neogene.

Structural Development and Estimation of Sedimentation Rate

A good understanding of the timing of the structure development in the BFB is paramount in the analyses for sedimentary fairways and depositional patterns of the study area, which in turn will assist in the trap assessment of various thrust-cored anticlinal features. For further reference, the methodology and fundamental assumptions employed to unravel the deformation history of the BFB are summarised in Jong et al. (2014).

Concurrently with the study of deformation profiles of the structures, the sedimentation rates from the Pliocene to Recent were also analysed. The maximum sedimentation rates were calculated by measuring the true stratigraphic thickness of the sedimentary sequence for each time period; i.e., Max Sedimentation Rate (m/Ka) = True Stratigraphic Thickness (m) / Time period (Ka). The maximum rate was reached by sampling in the frontal syncline of the growing structures where the accommodation space was greatest.

The calculated sedimentation rates (Figure 2) show a clear declining trend from very high sedimentation rates more recent than 600Ka to low rates up to 3Ma. This trend is expected for numerous reasons; one of the key reasons is the resultant compaction that sediments undergo during burial and thus the apparent systematic decrease in sedimentation rate through time. A high rate of sedimentation for 600K yr of ~1.5m/1 K yr, which falls over time to <0.5m/1K yr along a power function trend, is observed. The deposition during the Lower Cycle VIII shows a potential increase in rate away from the trend, which corresponds to a period of high deformation and thus accommodation space in the frontal syncline where the sedimentation rate is measured. This observation potentially also implies that a secondary source from the nearby Natuna High might have contributed to the sediment supply of the BT during this period.

Discussion

The deepwater sediments of the BT are thought to be mud-prone. However, whole rock bulk mineralogical composition analysis of ditched cuttings from Jelawat-1 well intervals 2330-3421m (Late Miocene – Early Pliocene) suggests there is potentially far more sand in the Miocene, compared to the mudlog indications (Figure 3). Whether clay is distributed within the sand matrix, or alternatively layered in thin-bedded sequences, cannot be answered at this point, in absence of core and/or image-logging analysis. Whilst the majority of grains consist of quartz, there is also a considerable element of plagioclase and orthoclase. The latter may have biased the wireline interpretation in suggesting the higher clay content. *More importantly, the presence of feldspar indicates a proximate sand source, given that feldspars weather quickly and do not survive multiple phases of reworking*. In addition, all sandy intervals contain carbonate, probably cement, and fossil fragments; which are indicative (i) of the proximity of nearby carbonate platforms and, (ii) water depth – carbonate is present, hence the point of sedimentation was above the CCD, which corresponds to *ca.* 800m of water depth. A recent study of tectono-stratigraphic framework and Tertiary paleogeography of Southeast Asia by Shoup et al. (2012; Figure 3 inset) indicate that during late Miocene – early Pliocene, Natuna High was an exposed area connected to Borneo landmass and, therefore, a likely potential sediment source area for the deepwater BT. According to Kessler and Jong (2014), the facies environment of the Pliocene is very similar to the Miocene section, only that sand is deviated increasingly into elongated depocentres parallel to thrust-cored anticlines, as a consequence of active deformation. During the Pleistocene, the facies remains the same as Pliocene; however, material again reached the BT from the West and Southwest, with indications of channelized features, turbidites, and mass-flow complexes on seismic, observable particularly well on the recently PETRONAS-acquired 2D/3D seismic in Block SK301A area (Syamir Osman, personal communication).

Conclusions

The central part of the BT is filled with particularly young sediments of late Pliocene, Pleistocene age, and even the Holocene layer is several hundreds of meters thick. By its relative distance from continental shorelines, it is logical to expect a clay-dominated environment, with limited amounts of sand only and with the perceived mud-proneness of the Rajang Delta. However, study of the sedimentation rate and mineralogical composition of the BT sediments suggests more sand content than thought possible and likely additional sediment inputs from the nearby Natuna High, which peaked as recent as 600 Ka. Additional feeders from now submerged areas of the Dangerous Grounds and Central Luconia areas could have existed, but these remain speculative. Overall delivery systems may have changed in transport direction over time, from southwest to northeast during Oligocene time to southeast to northwest during Miocene time, and reverting back to southwest to northeast during Pliocene time.

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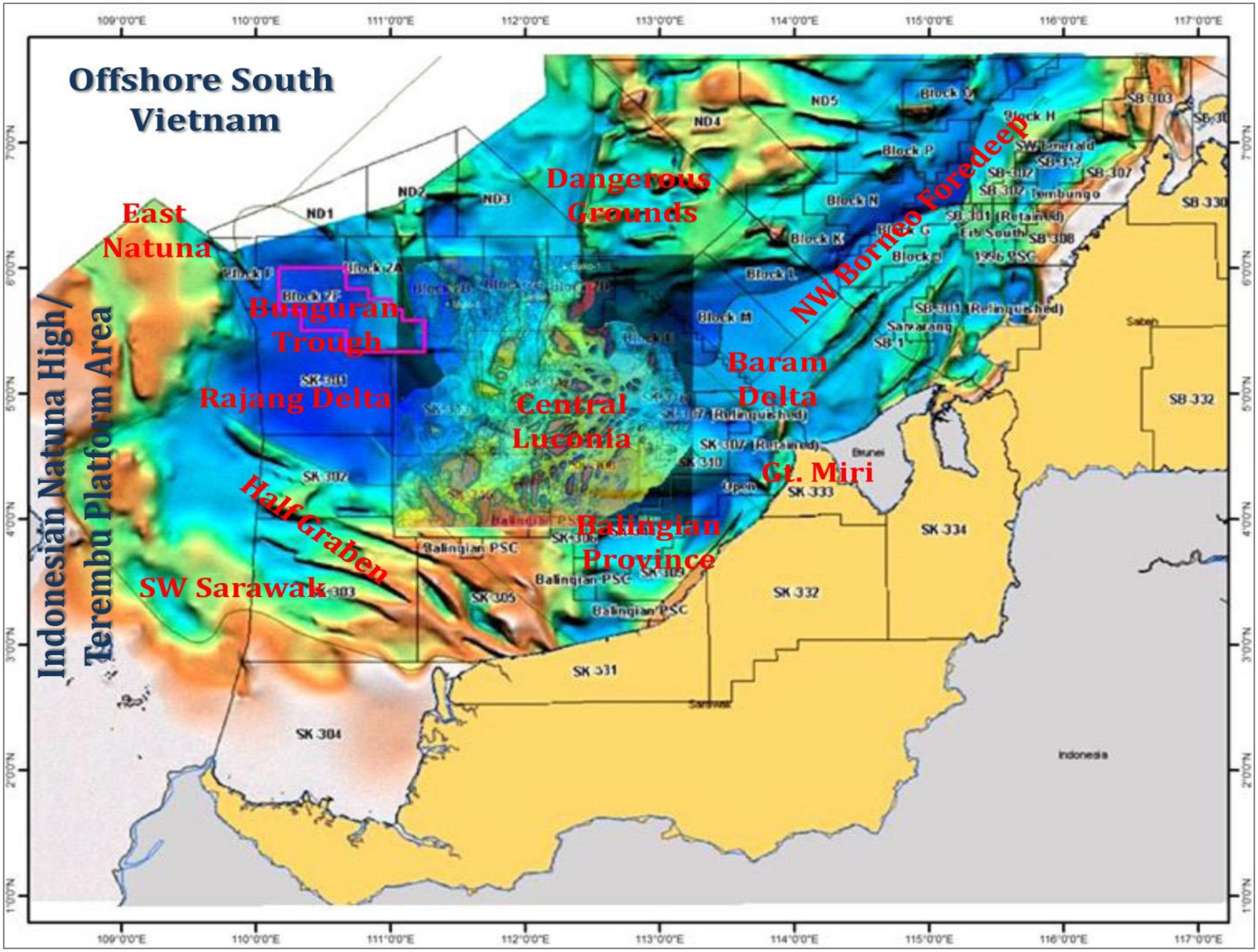

Figure 1: Location of Bunguran Trough and adjacent structural domains of NW Borneo.

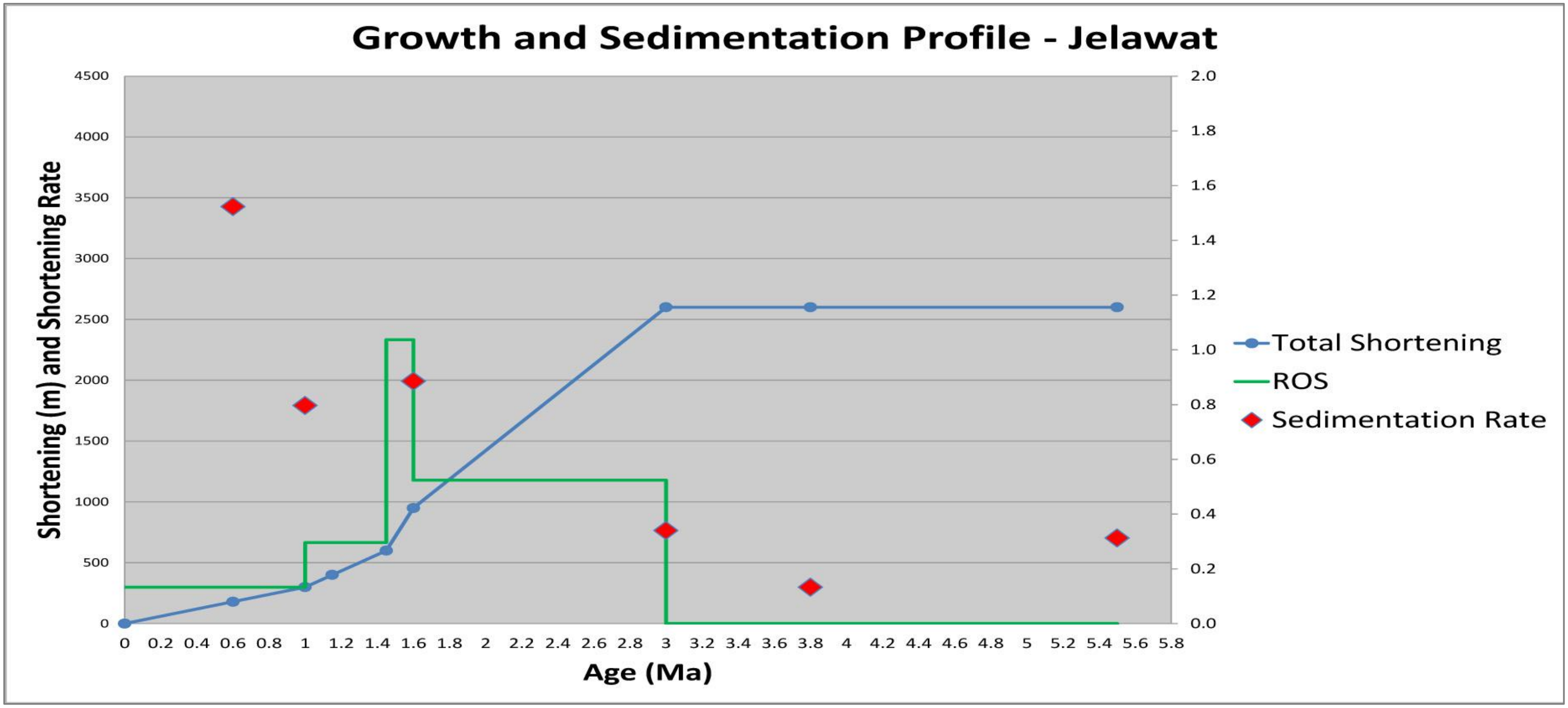

Figure 2: Summary of structural growth and sedimentation profile of the BT.

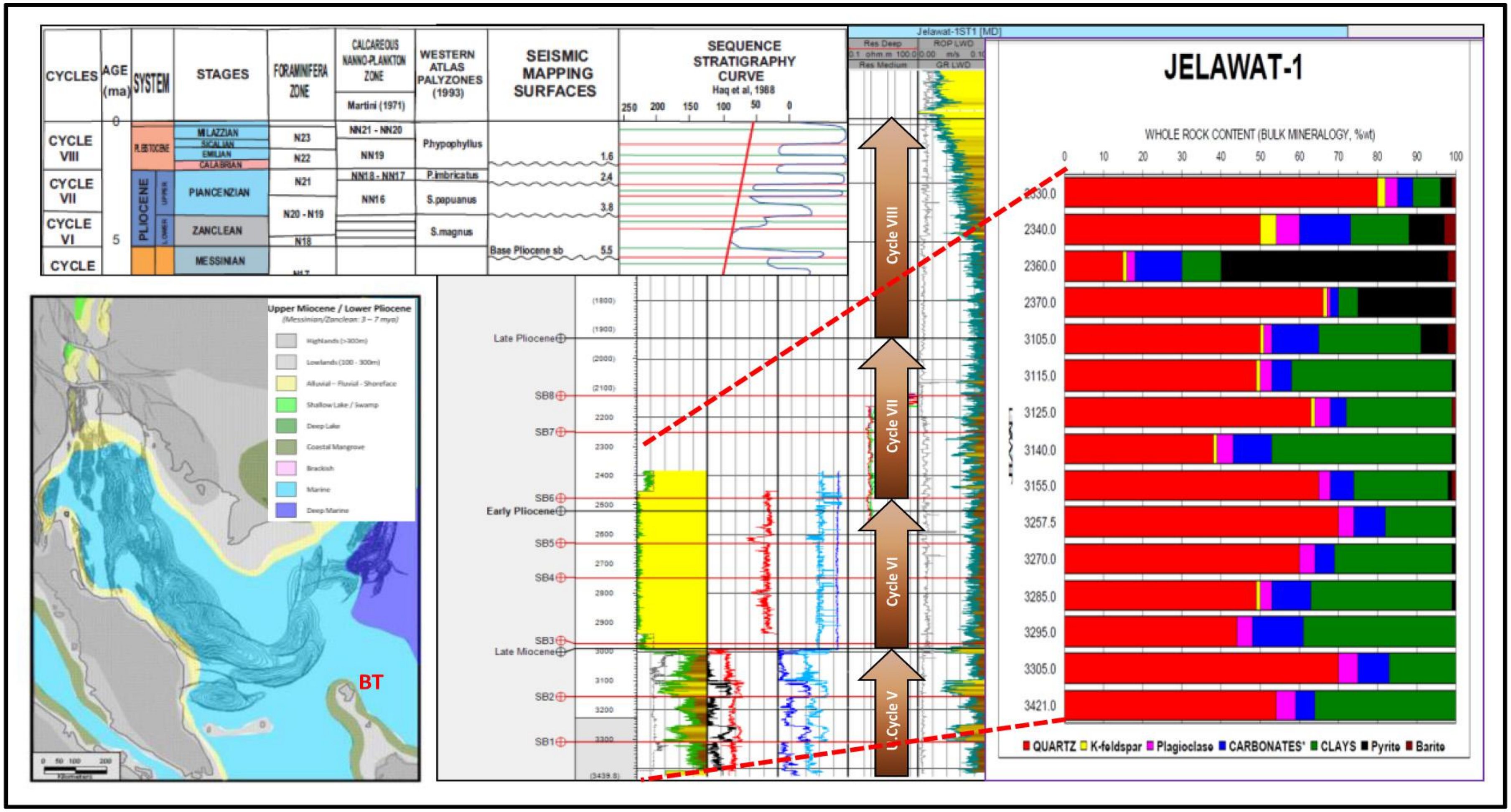

Figure 3: Right: Bulk mineralogical composition of ditch cuttings from Jelawat-1 well intervals 2330-3421m (late Miocene – early Pliocene in age). Lower left: Late Miocene to early Pliocene palaeogeographic map by Shoup et al. (2012).