Day: Thursday 27 April **Session: 7**
Time: 1:25pm

Constructing Neogene Palaeogeographical Maps for the Sunda Region

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Introduction

The palaeogeography of the Sunda region has been subject to dramatic change during the Cenozoic. These changes have been driven by tectonic events and by fluctuations in sea level and climate. After the Mesozoic assembly of the broad area from microplates derived from Gondwana, widespread rifting took place across the region following the initial collision of the Indian Plate with Asia. Further dramatic palaeogeographic changes relate to the opening of the South China Sea and the closure of the Proto-South China Sea, coupled closely with the Sabah Orogeny, which resulted in widespread uplift in Borneo. The collision of the Australian Plate with the region during the Neogene also resulted in major changes with further uplift, as well as modifying marine currents, and causing changes in regional climate.

Generalised palaeogeographic maps for the region based on tectonic reconstructions and published palaeoenvironmental data have been prepared by Hall (2002, 2009, 2012) at 5 m.y. time intervals. Major questions remain however, especially with respect to the tectonics and palaeogeography of the heart of Sundaland itself, and particularly in explaining the timing and significance of the numerous unconformities that can be followed across the region, the timing and extent of mountain building, the nature of palaeo-drainage basins and the courses of the river systems which created the region's deltas.

This paper attempts to answer some of these questions through the sequence biostratigraphic and palynological evaluation of the region. The position of deltas can be suggested from regional changes in sedimentation rates, and the altitude of former uplands can be suggested from the record of montane pollen.

Sequence biostratigraphy provides a tool which allows sedimentation rates to be determined from distal to proximal facies through the differentiation of regional transgressive-regressive cycles, that can be differentiated from temporal changes in benthonic foraminiferal and palynomorph assemblages, and dated in fully marine settings where marine index fossils are present (Fig 1, 2). Correlations always need to be cross-checked against seismic to avoid mis-matching depositional cycles. This paper utilizes detailed evaluations of such measurements from approximately 170 wells from across the region.

Methods

Sedimentation rates were calculated for each cycle using the time framework of the current International Commission on Stratigraphy (ICS) chart (Gradstein & Ogg, 2012) and were calculated in terms of uncorrected sedimentation rates per 100ka. The cycles are termed VIM (Vietnam, Indonesia, Malaysia) transgressive-regressive cycles (Fig 1), (Morley et al. 2011, 2014, 2016). Sedimentation rate maps were initially prepared for each VIM depositional cycle. Maps that showed similar trends were then merged resulting in a total of ten maps to show the main palaeogeographical changes from the basal Miocene to Pleistocene.

Palaeogeographic map construction

The positions of trenches, shelf edges and carbonates in areas without unpublished well or seismic control follow Hall (2012). The positions of the lakes and inland seas of the Sunda Shelf follow de Bruyn et al. (2014), Shoup et al. (2013) and Morley and Morley (2013). The palaeoenvironmental reconstructions of Lunt (2013) have been used for Java. The reconstructions for Sumatra are much less precise than for the rest of the region due to lack of data.

What to map?

Making palaeogeographic maps on a regional scale is fraught with interpretation difficulties. Different interpreters may place a generalised palaeocoastline differently based on their source of reference, and whether maps are based on mainly on marine microfossils or the occurrence and character of sands, or from seismic. This issue is illustrated by showing three maps for the last glacial-interglacial cycle of the Late Quaternary. Depending on whether sea levels were high (present day), 'medial' or low, at least three maps can be generated (Fig 3).

Here mapping has followed a modal perspective, and thus is nearest to the medial reconstruction 'b' for the Late Quaternary, reflecting the setting for the bulk of deposition. Former deltas and fans are identified in areas with very high sedimentation rates, and to locate and compare palaeodeltas sedimentation rates are divided into five divisions as follows:

1. Sedimentation rates more than 80m/100 ka = 'Mega' deltas/fans
2. Sedimentation rates between 40 and 79 m/100 ka = 'Super' deltas/fans
3. Sedimentation rates between 20 and 39 m/100 ka = deltas/fans (present day Mahakam falls in this group)
4. Sedimentation rates between 1 and 19 m/100 ka = non-deltaic
5. No or minimal sedimentation, shown for marine facies only, condensed deposition.

Location of rivers

River systems are positioned using sedimentological data, the position of present day river systems, and topography to identify possible 'misfit' rivers that might infer earlier river capture. For older periods, rivers are located based on the position of former deltas, using indicators of provenance, and the probable location of uplands which would have provided the sediment source.

Location of uplands and extent of uplift

In addition to well established geological criteria summarised by Hall and Nichols (2002) and Hall (2009, 2012), three additional data types, erosion rates derived from sedimentation rates, pollen records of plants restricted to montane environments in the tropics, and plant phylogeographical studies based on molecular analyses of montane biota help locate and date former uplands. The presence of Laurasian conifer pollen indicates the former presence within catchment areas of uplands above 1500m, and probably over 2000m in altitude, since the plants which produced this pollen are found nowhere in the tropics below 2000m today (Morley 2017). These pollen types indicate the presence of frost-tolerant trees in upper catchments.

Maps

In the early Miocene, (Figs 4 and 5) upland areas established during the Palaeogene were eroded and a weakly radial river system was established, with moderate-sized deltas building out around the Sunda region. During the earlier Middle Miocene (Fig. 6) the Sabah Orogeny resulted in the uplift of the Central Kalimantan Ranges and Meratus, and with inversion across much of the Sunda Shelf, most sediment transport was directed into the Proto-Mahakam catchment, resulting in a centripetal drainage pattern, and the formation of a massive Middle Miocene 'mega' delta four times larger than the present-day Mahakam. With continued inversion across the Sunda Shelf during the later part of the Middle Miocene (Fig. 7), local erosion but minimal deposition by major rivers resulted in the Middle Miocene unconformity (MMU). This was the time of greatest development of the Proto-Mahakam.

Major rivers subsequently developed across Sarawak during the earlier part of the Late Miocene (Figs 8 and 9), and during this time it is thought that one or more of these captured the main tributaries of the Proto Mahakam, diverting the bulk of sediment eroded from the Central ranges away from Kutai and into Sarawak deltas (Fig. 10). With uplift of the Barisan, Java and Sulawesi and the final stage of uplift of Kinabalu (Figs 11-13), coupled with increased amplitude of sea level changes during the Quaternary, river systems were further disrupted, resulting in the present deranged drainage pattern.

Conclusions

Sequence biostratigraphy has a critical role to play in unravelling the geological development of the Southeast Asian region. It is hoped that this study will encourage the generation of high quality biostratigraphic datasets to further help clarify the remarkable story unfolding of the geological development of Southeast Asia.

References

Blow, W.H., 1979, Cainozoic Globigerinida: A Study of the Morphology, Taxonomy, Evolutionary Relationships and Stratigraphical Distribution of some Globigerinida (mainly Globigerinacea): E.J. Brill, Leiden, 3 volumes, 1413p.

Bruyn, M, de, Stelbrink, B., Morley, R.J., Hall, R., Carvalho, G.R., Cannon, C.H., Van Den Bergh, G., Meijaard, E., Metcalfe, I., Boitani, L.,Maiorano, L., Shoup, R. & Von Rintelen, T. 2014 Borneo and Indochina are Major Evolutionary Hotspots for Southeast Asian Biodiversity. Systematic Biology 63, 879–901

Gradstein F., J. Ogg, et al., 2012, The Geologic Time Scale 2012: Elsevier, 2 volumes, 1176 p.

Hall, R. 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. Journal of Asian Earth Sciences 20, 353–431

Hall, R. 2009. Southeast Asia’s changing palaeogeography. Blumea 54, 2009: 148–161.

Hall, R, 2012. Sundaland and Wallacea, geology, plate tectonics and palaeogeography. In Biotic evolution and environmental change in Southeast Asia, eds Gower, D et al. Cambridge University Press 32-78

Hall, R. & Nichols, G., 2002. Cenozoic sedimentation and tectonics in Borneo: climate influences on orogenesis. In: Jones, S., and Frostick, L., (eds) Sediment flux to basins: causes, controls and consequences. Geological Society of London Special Publication 191, 5-22

Lunt, P., 2013. The sedimentary geology of Java. Indonesian Petroleum Association, Jakarta 346pp.

Martini, E., 1971, Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation, in A. Farinacci, editor, Proceedings of the II Planktonic Conference, Roma, 1970: Tecnoscienza, p. 739 - 785

Morley, R.J. 2014. Rifting and mountain building across Sundaland, a palynological and sequence biostratigraphic perspective. Proceedings, Indonesian Petroleum Association Thirty-Eighth Annual Convention & Exhibition IPA14-G-011M

Morley, R.J. 2017 The complex history of mountain building and the establishment of mountain floras in Southeast Asia and Eastern Indonesia. In Hoorn, C. and Antonelli, A. Mountains, climate and biodiversity. Wiley

Morley, R.J. & Morley, H.P. 2013. Mid Cenozoic freshwater wetlands of the Sunda region. Journal of Limnology 72, 18-35.

Morley, R.J., Swiecicki, T. & Pham, D.T.T. 2011, A sequence stratigraphic framework for the

Sunda Region, based on integration of biostratigraphic, lithological and seismic data from Nam Con Son Basin: Vietnam Proceedings, Indonesian Petroleum Association 35th Annual Convention & Exhibition, May 2011, IPA11-G-002, 22p.

Morley, R.J. Swiecicki, T & Restrepo Pace, P. 2015. Correlation across the Sunda Shelf using VIM transgressive-regressive cycles. AAPG Search and Discovery Article 51109.

Morley R.J. Morley, H P. & Swiecicki, T., 2016. Mio-Pliocene palaeogeography, uplands and river systems of the Sunda region based on mapping within a framework of VIM depositional cycles. Proceedings, Indonesian Petroleum Association 39th Annual Convention & Exhibition, May 2016.

Sathiamurthy, E. & Voris, H.K. 2006. Maps of Holocene sea level transgression and submerged lakes on the Sunda Shelf. The Natural History Journal of Chulalongkorn University, Supplement 2, 1-41.

Shoup, R.C, Morley, R. J, Swiecicki, T. & Clark, S. 2012.Tectono-stratigraphic Framework and Tertiary Paleogeography of Southeast Asia: Gulf of Thailand to South Vietnam Shelf. Search and Discovery Article #30246 Posted September 24, 2012

Yakzan, A.M., A. Harun, B. M. Nasib, & R.J. Morley, 1996, Integrated biostratigraphic zonation for the Malay Basin: Bulletin of the Geological Society of Malaysia, v. 39, p. 157-184

Speaker Biography

After 16 years with a UK based international geological consultancy (Robertson Research), and a short stint with British Geological Survey (Overseas), on a training program with Lemigas in Jakarta, Dr Robert (Bob) Morley and his wife Santi set up the 'Palynova' consultancy in 1992.

Palynova UK Ltd aim is to provide state of the art advice and assistance to the petroleum industry, geological surveys and other institutions with respect to the application of biostratigraphy to the resolution of stratigraphic and palaeo-environmental problems. Palynova mission - ‘Toward improvement in stratigraphic correlation and sequence biostratigraphy’. Palynova is currently involved with various petroleum exploration companies in Thailand, Vietnam, Malaysia and Indonesia.

A major aim is to provide higher resolution stratigraphic interpretations for the Southeast Asia area using the approach of Sequence Biostratigraphy

Figures

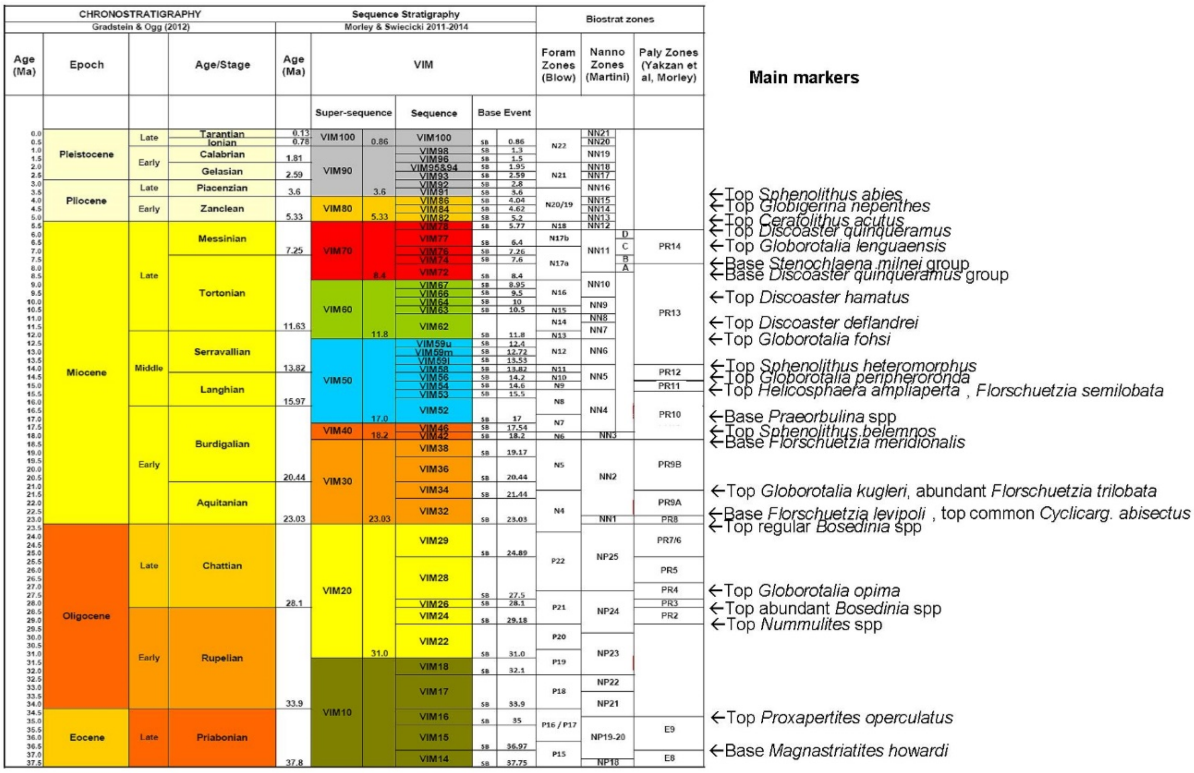

Figure 1: VIM transgressive-regressive cycles. The relationship to foraminiferal, nannofossil and palynological zones and some important markers are shown. Foraminiferal zones follow Blow (1979), nannofossils Martini (1971) and palynomorphs Yakzan et al. (1996) and Morley (2014), age framework recalibrated to Gradstein & Ogg (2012).

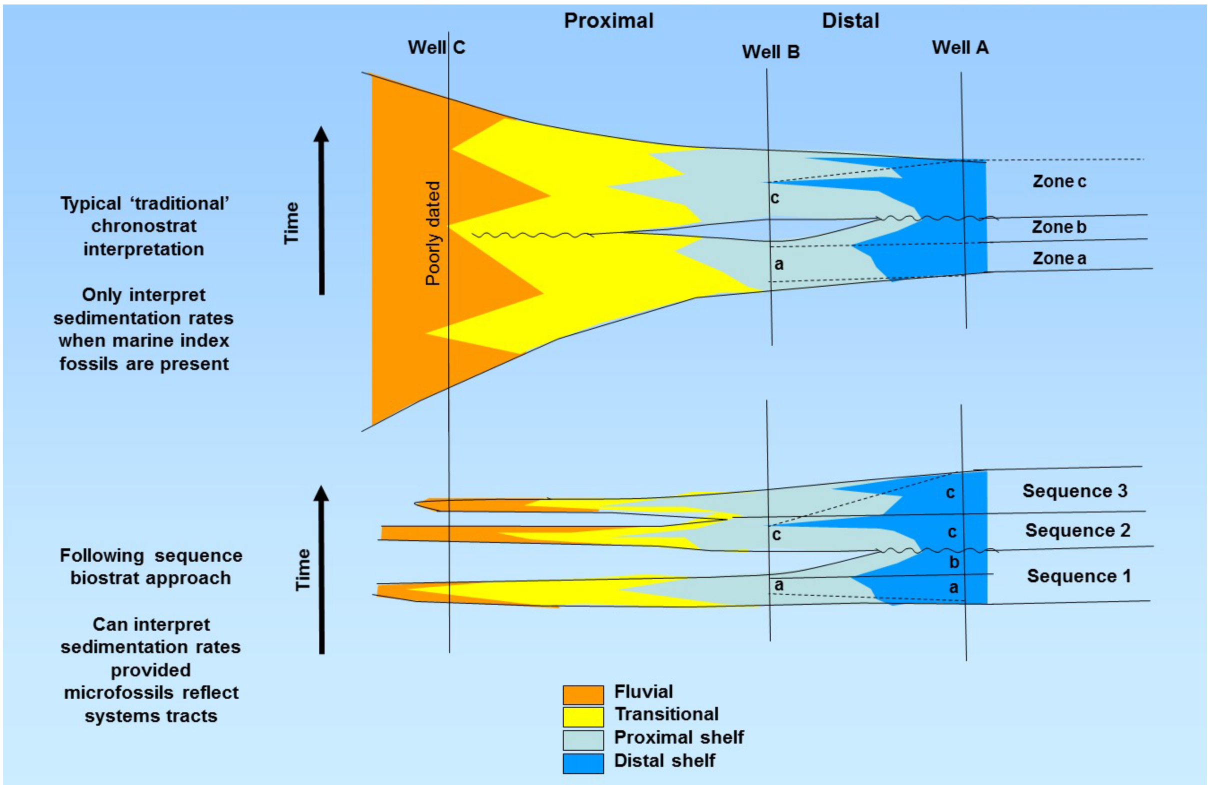

Figure 2: Comparison of chronostratigraphies based on (upper) a 'traditional' approach with ages based only on the presence of marine index fossils, and (lower) sequence biostratigraphy where systems tract identification allows depositional packages to be carried proximally into a basin into areas where age-restricted microfossils may be missing, but where the highest sedimentation rates are likely to occur.

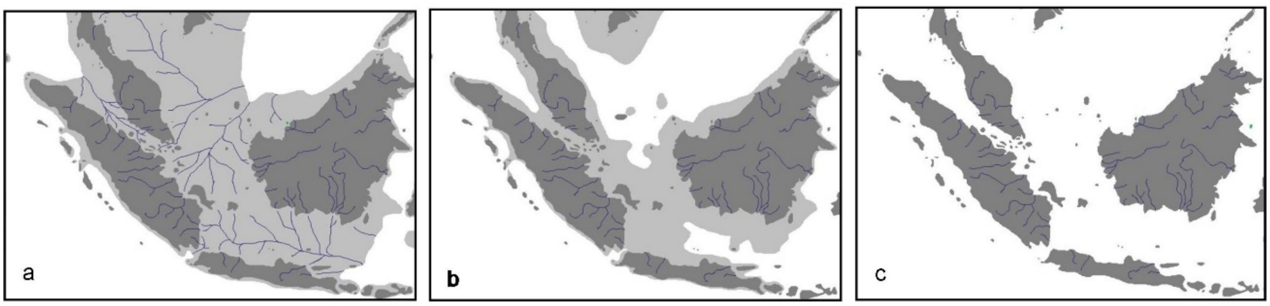

Figure 3: Map reconstructions for the Late Quaternary by Sathiamurthy & Voris (2006) and Morley (2012). a) 20 ka, b) 12 ka, c) present day. Which reconstruction for the last 120 ka is most meaningful from a deep time geological perspective?

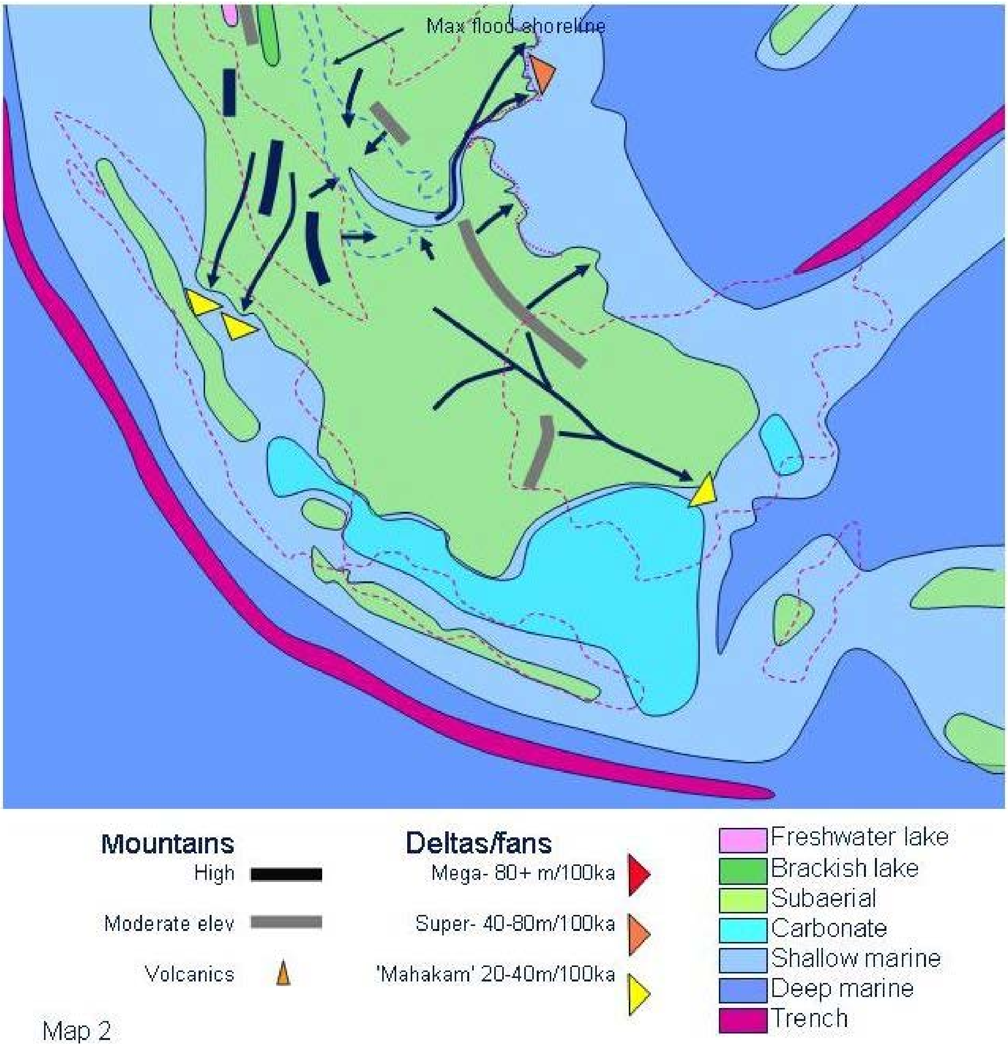

Figure 4: Map 1; 'early' Early Miocene palaeogeography (VIM32-34), 23.1–20.5 Ma. Present day land areas shown by dashed pink lines

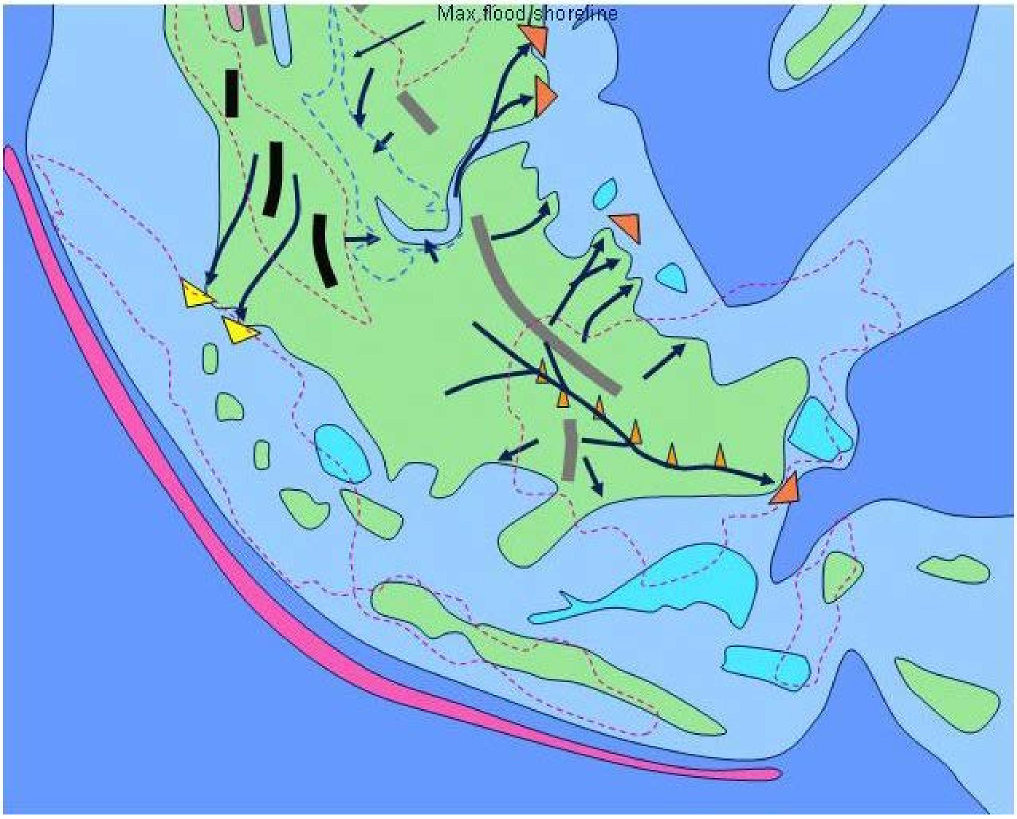

Figure 5: Map 2; ‘later’ Early Miocene palaeogeography (VIM 36-42), 20.5–17.0 Ma.
For legend refer to Fig. 4

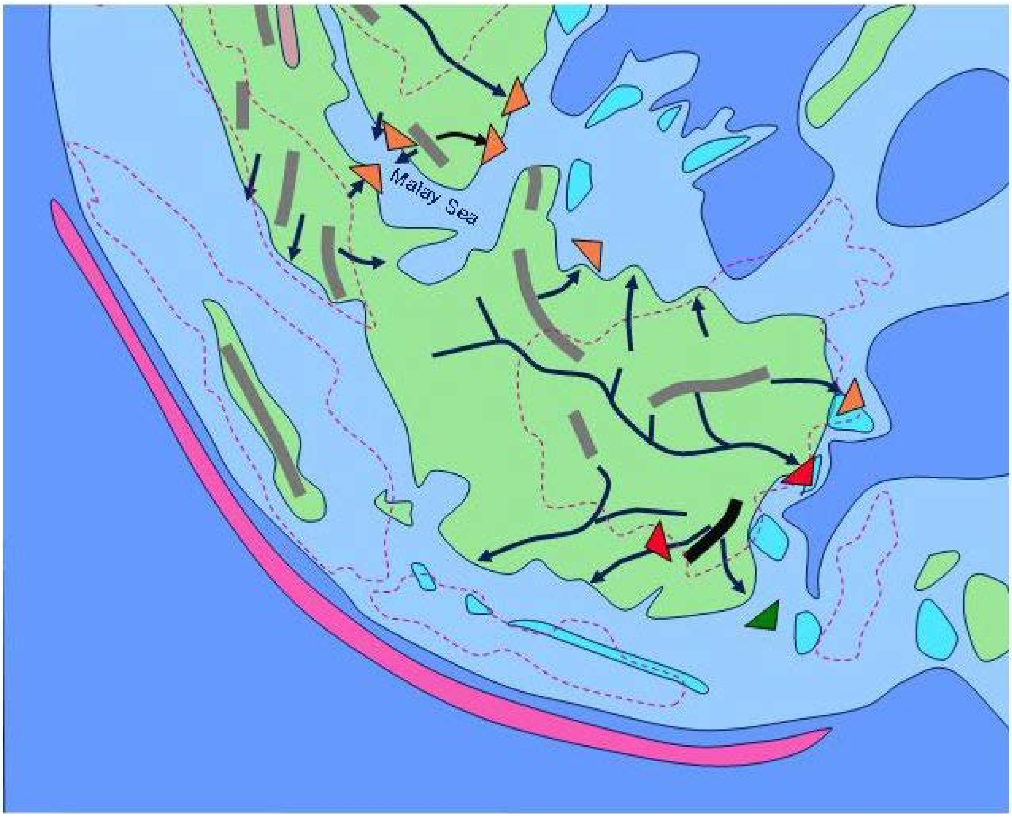

Figure. 6: Map 3; Middle Miocene palaeogeography (VIM52-58), 17.0–13.5 Ma.
For legend refer to Fig. 4.

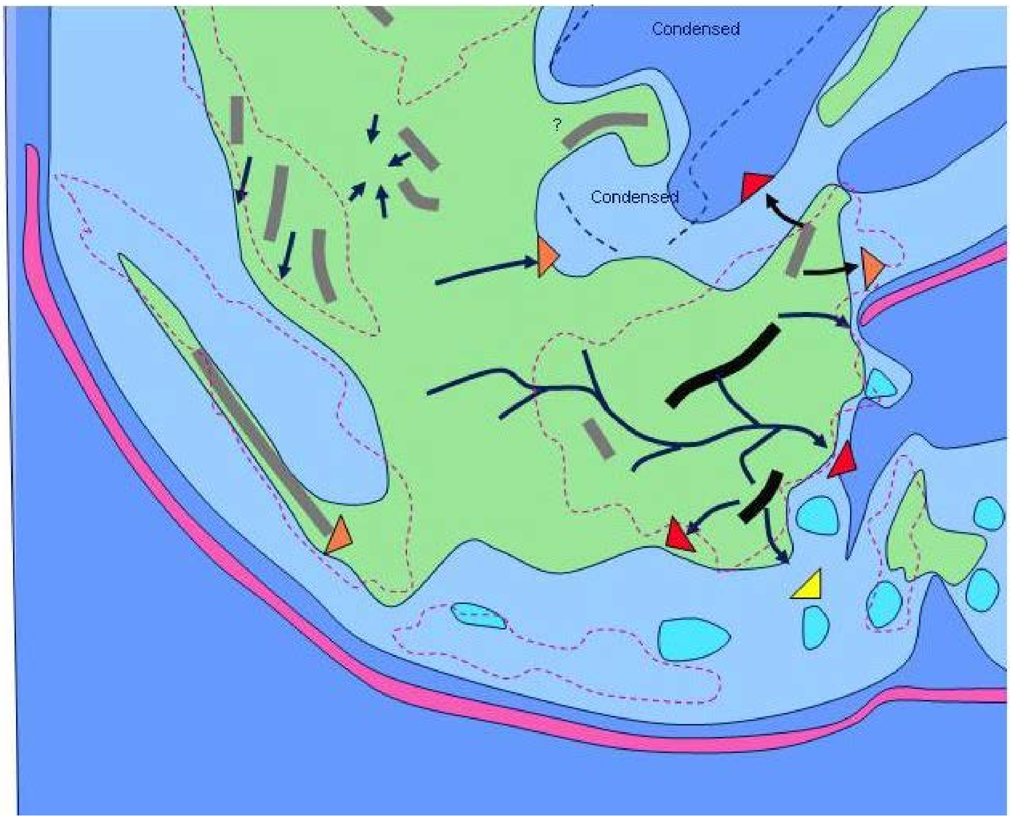

Figure 7: Map 4; latest Middle to earliest Late Miocene palaeogeography (VIM59-62), 13.5 – 10.5 Ma. For legend refer to Fig. 4

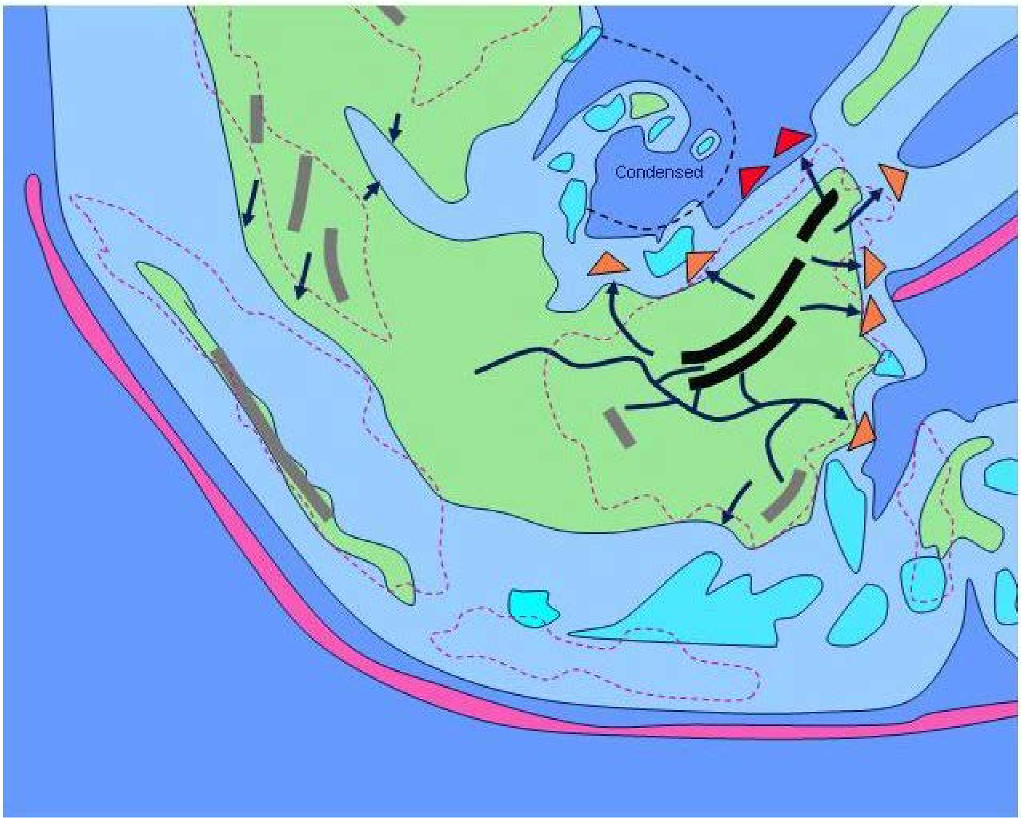

Figure 8: Map 5; 'mid' Late Miocene palaeogeography (VIM63-67), 10.5–8.4 Ma.
For legend refer to Fig. 4

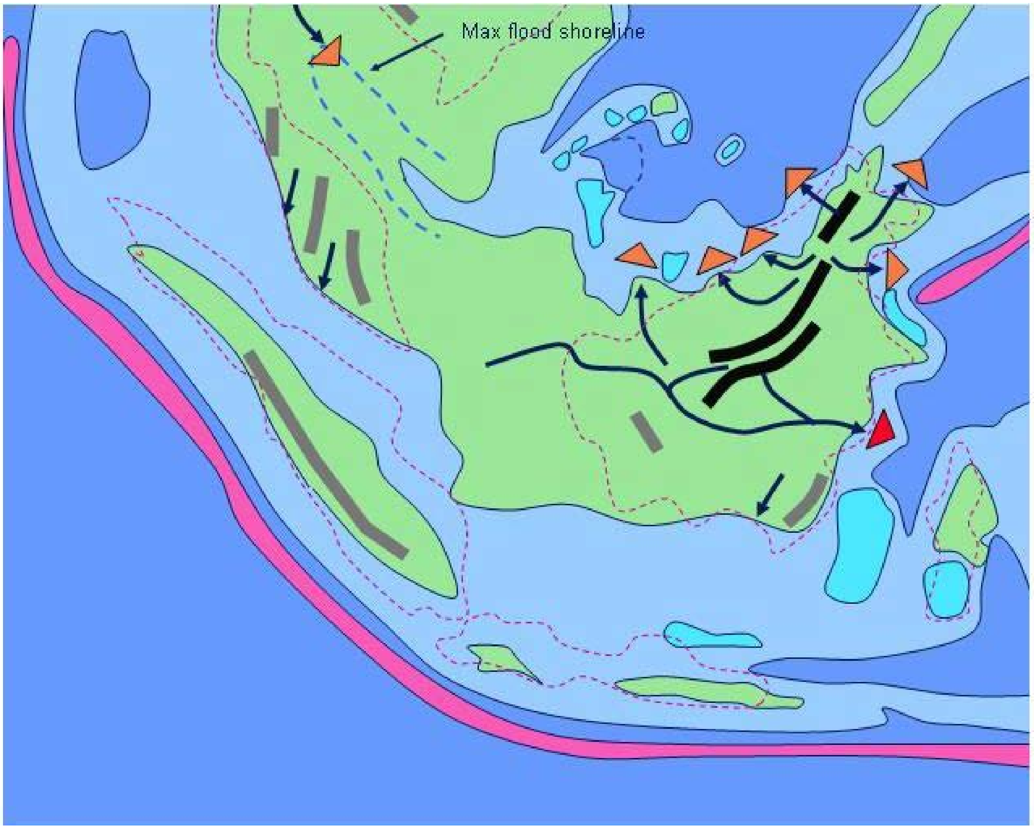

Figure 9: Map 6; Palaeogeography map 6, 'mid' Late Miocene (VIM72-74), 8.4 – 7.2 Ma. For legend refer to Fig. 4.

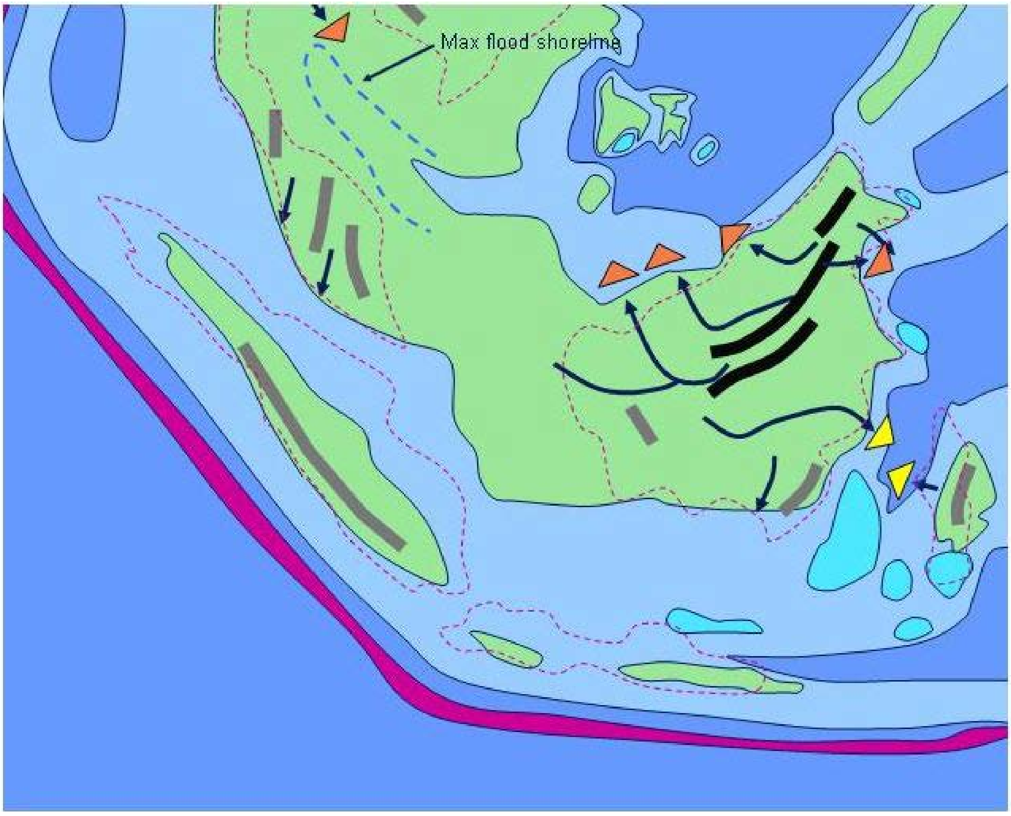

Figure 10: Map 7; 'latest' Late Miocene palaeogeography (VIM76-78), 7.2 – 5.2 Ma. For legend refer to Fig. 4.

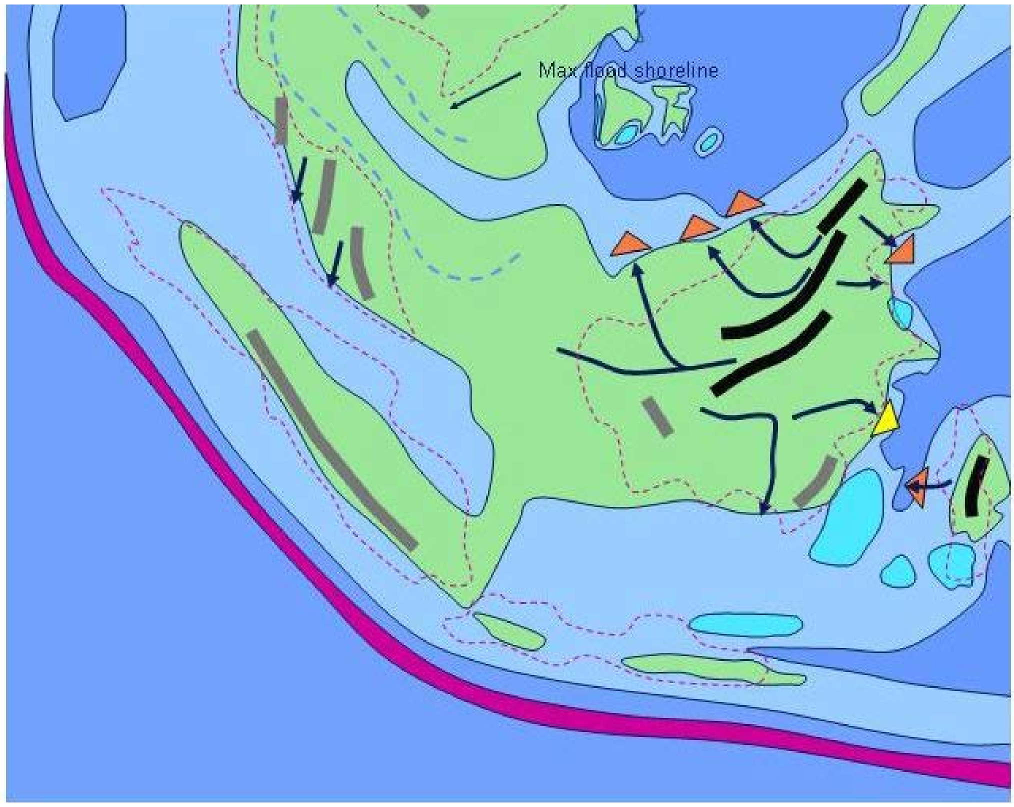

Figure 11: Map 8; Early Pliocene palaeogeography 5.2–3.4 Ma (VIM82-86),
For legend refer to Fig. 4.

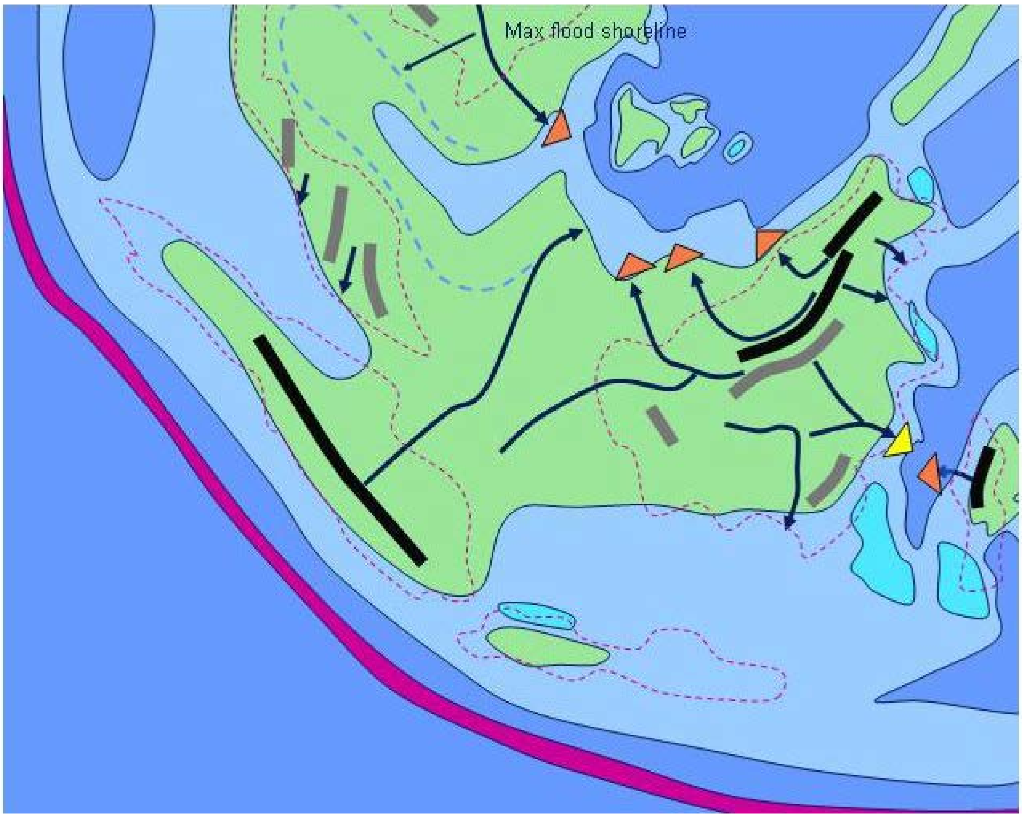

Figure 12: Map 9; Late Pliocene palaeogeography 3.4–1.95 Ma (VIM 91-93),
For legend refer to Fig. 4.

Figure 13: Map 10; Pleistocene palaeogeography 1.95–0.01 Ma (VIM 95-100), based on Late Quaternary maps by Sathiamurthy & Voris (2006). For legend refer to Fig. 4.