Correlation across the South China Sea Using VIM Transgressive-Regressive Cycles*

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Search and Discovery Article #51109 (2015)
Posted June 30, 2015

*Adapted from extended abstract prepared for the presentation at AAPG Asia Pacific Region Geosciences Technology Workshop, "Tectonic Evolution and Sedimentation of South China Sea Region," Kota Kinabalu, Sabah, Malaysia, May 26-27, 2015. AAPG © 2015

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Introduction

The Cenozoic sedimentary successions of the interconnected basins which stretch from the Gulf of Thailand to Nam Con Son and the successions of Sarawak and Sabah present major problems with respect to the determination of age and environments of deposition due to the sporadic occurrence of marine index microfossils, seemingly anomalous assemblages, and common reworking.

The basins formed during the late Eocene, followed by late Oligocene and early Miocene sag, phases of inversion in some basins and renewed rifting in others, and late Miocene and Plio- Pleistocene regional subsidence. During much of the Miocene the interconnected basins formed a long, narrow, mostly shallow elbow-shaped arm of the sea, extending over 1500 km, with sedimentation mostly taking place near sea level. Short-lived, presumed glacio-eustatic marine incursions intermittently brought marine or brackish conditions, sometimes with distinct age-diagnostic fauna, even into the more proximal basins (Restrepo Pace et al., 2014). To make sense of these occurrences, an independent framework is required. Linked trends in palynomorph and benthonic foraminiferal abundance suggest repeated transgressive-regressive cycles can provide such a framework. The packages can be 'fingerprinted' with microfossils and dated from the rare records of index fossils. The regional continuity of the packages has been cross-checked against seismic and correlated across the area. In this way the age of the least marine-influenced basins as well as the distal and peripheral successions can be determined.

The thick successions in Sarawak and Sabah also present major issues with respect to dating, due on the one hand to common reworking in gravity-flow deposits resulting in misplaced index fossils and, on the other, to the occurrence of carbonate dissolution, which may result in calcareous microfossils (including all the index fossils) being absent. These deposits also display a cyclicity, which can be identified from patterns of downslope transportation and carbonate dissolution, and again thought to be driven by glacio-eustacy.

Biostratigraphy and Depositional Cyclicity

Examination of the occurrence of index fossils in relation to the response of foraminifera and palynomorphs to transgressive-regressive cycles often allows conflicting microfossil associations to be recognised. The position of index fossils in relation to systems tracts often allows identification of reworking (Figure 1) and the occurrence of marker taxa in relation to package-stacking patterns helps to determine whether taxon 'tops' reflect the top of biostratigraphic zones or are depressed due to facies or water chemistry issues (Figure 2). In addition to the presence of sporadic index fossils, individual depositional packages may be 'fingerprinted' from characteristic foraminiferal assemblages and from palynomorphs, the latter reflecting regional patterns of changing mangrove development and also changing palaeoclimate. Such fingerprinting is most important in proximal settings where index fossils may be absent.

Some workers have used graphic correlation methods to help understand the stratigraphy of South China Sea wells, but graphic correlation often fails to place highstands in their correct sequence, and it may also fail in recognising reworking and where tops are depressed due to facies. In the current scheme depositional cycles from shelf to bathyal have been placed into a numeric chronostratigraphic framework with individual cycles attributed the suffix VIM (Vietnam, Indonesia, Malaysia), building on the initial framework of Morley et al. (2011). Many of these cycles show approximate 400 ka cyclicity, testifying to glacio-eustacy as the probable driving mechanism (Figure 3).

The VIM cycles are particularly valuable in allowing the age of successions to be clarified from the most proximal to the most distal facies, and also in dating the onset of sedimentation as late Eocene, from the determination of palynological zone E9 of Morley (2014) in the oldest marine-influenced sediments from Sarawak wells. The VIM packages also permit clarification of unconformities across the region (Figure 4), many of which have previously been confused as a single middle Miocene unconformity (MMU). Six main unconformities are recognised; a mid Oligocene unconformity (MOU) relating to the onset of South China Sea spreading; a basal Miocene unconformity (BMU) thought to reflect the end of Proto-South China Sea subduction; an early Miocene unconformity (EMU) at about 18 Ma, coinciding with the onset of the second rifting phase in areas such as the Nam Con Son Basin and offshore Sarawak; a middle Miocene unconformity (MMU) showing a maximum extent at about 11 - 12 Ma and associated with the end of Nam Con Son and offshore Sarawak rifting; one or more late Miocene unconformities (LMU), with time gaps at ~9, 7.2 and 5.5 Ma; and an early Pliocene unconformity (EPU) at about 3.5 Ma. There is also a well developed unconformity near the base of the Quaternary. The VIM super-cycles relate to the packages between these unconformities.

The application of VIM cycles clarifies the geology and tectonics of the region from the Gulf of Thailand to the Philippines. Only by applying such a cyclical approach can we define plays at the scales required for exploration in mature areas and to extend successful plays into still poorly calibrated frontier basins.

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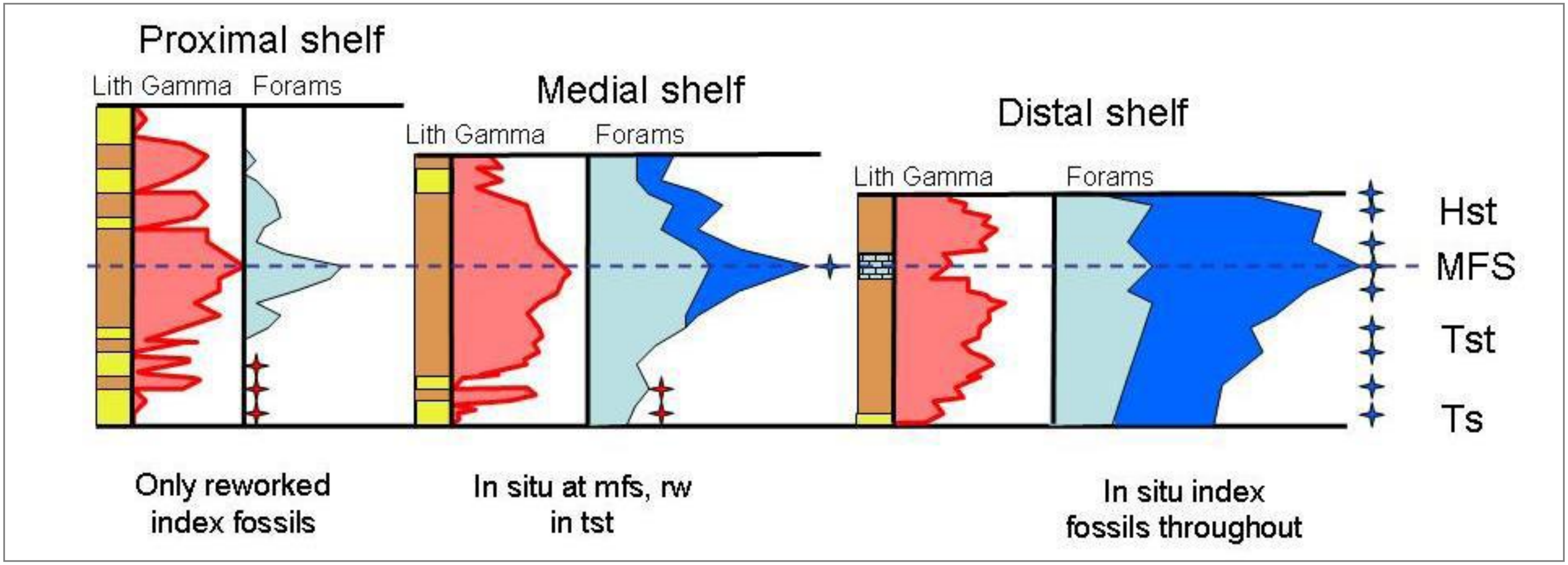

Figure 1. Foraminiferal trends in transgressive-regressive packages from proximal to distal. In distal shelf/slope settings, index fossils are likely to be present to the top of a package; in a mid-shelf setting, index fossils may occur only at the maximum flooding surface (mfs or MFS), sometimes with reworking of older index taxa in the transgressive systems tract (tst or Tst). In a proximal setting, water depths may be too shallow for index fossils, but reworked index spp. may occur in a basal lag deposit. Hst- highstand systems tract; Ts- Transgressive surface.

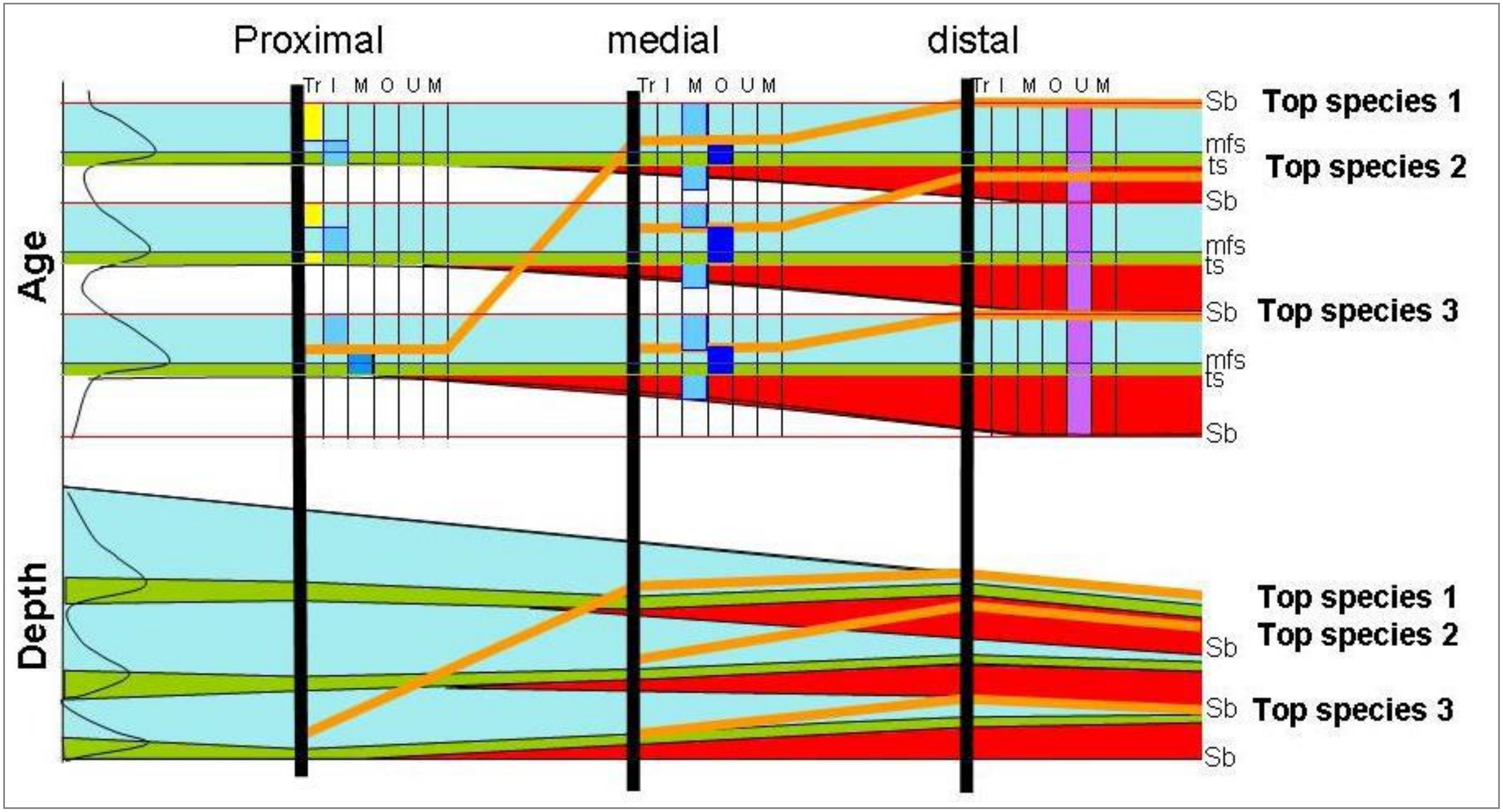

Figure 2. Diachronous occurrence of index fossil 'tops' from proximal to distal setting in area characterised by transgressive-regressive depositional packages. red = lst (lowstand systems tract) , green = tst (transgressive systems tract), blue = hst (highstand systems tract). Water depth from left to right: tr- transitional; I- inner neritic; M- middle neritic; O- outer neritic; U- upper bathyal; M- middle bathyal; Sb- sequence boundary.

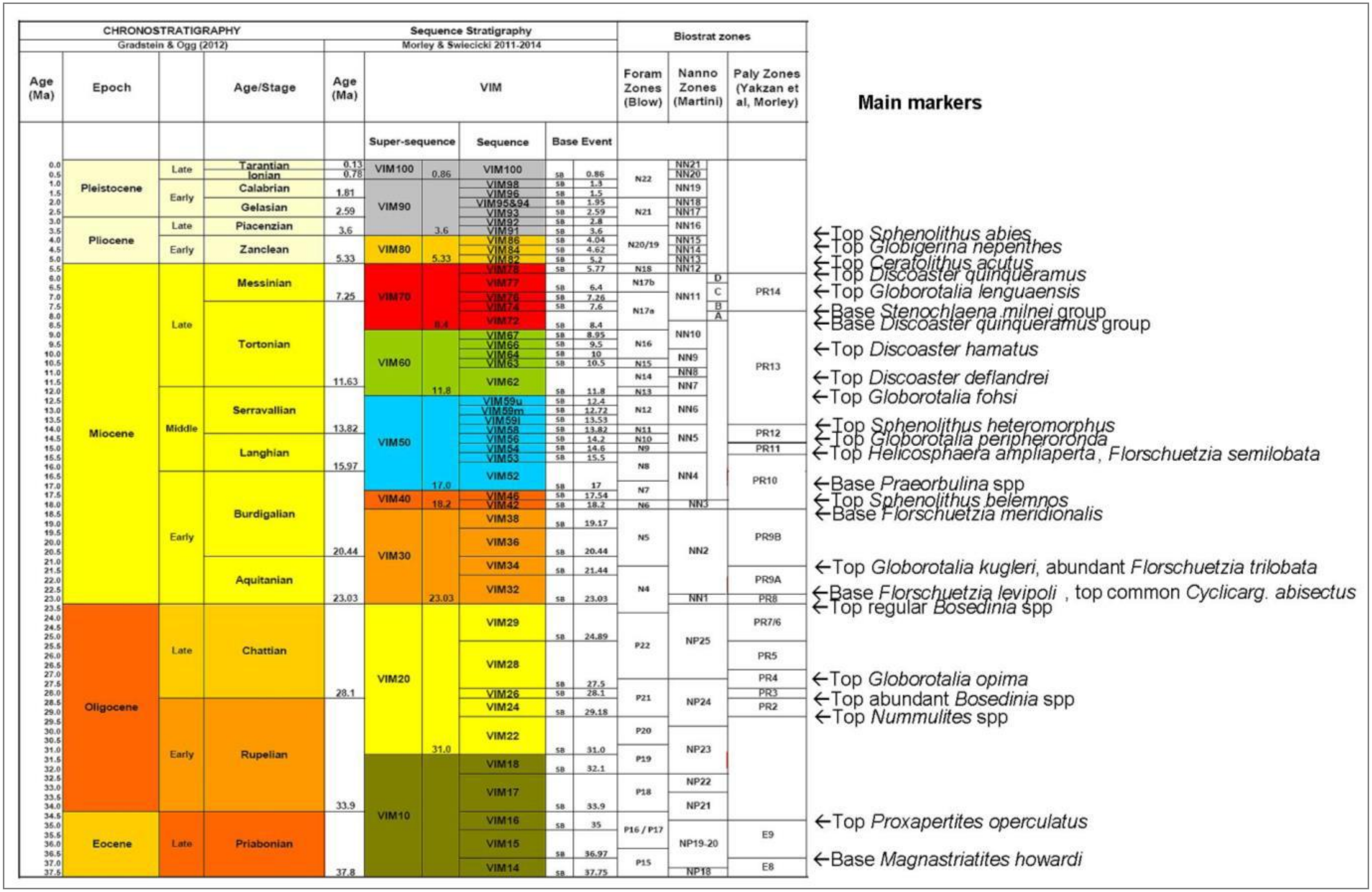

Figure 3. VIM transgressive cycles as applied to South China Sea stratigraphy. The relationship to foraminiferal, nannofossil and palynological zones and some important markers are shown. Foraminiferal zones follow Blow (1979); nannofossils, Martini (1971); and palynomorphs, Yakzan et al. (1996) and Morley (2014); age framework is from Gradstein, Ogg, et al. (2012).

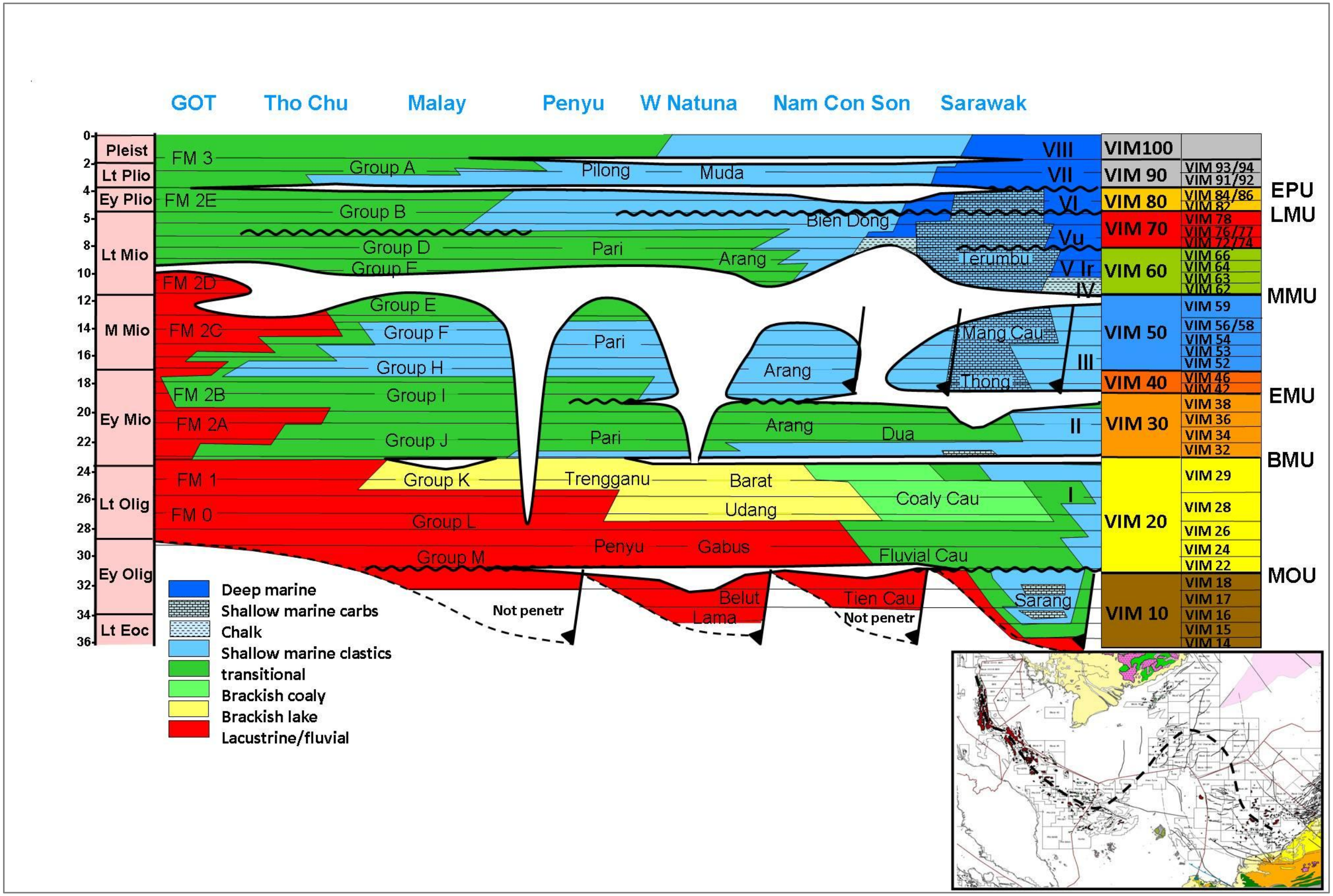

Figure 4. VIM depositional cycles interpreted from proximal to distal from Gulf of Thailand to Sarawak, highlighting the manner in which VIM cycles help to clarify stratigraphic relationships and the nature of unconformities across the region.