Day: Thursday 27 April **Session: 7**
Time: 3:05pm

A New Plate Model for South East Asia Aimed at Understanding Basin Evolution

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Introduction

South East Asia is the most geologically complex region on Earth due to the three-way convergence of the Indo-Australian, Eurasian and Pacific plates. Many attempts have been made to unravel its tectonic history with varying levels of success, but most are limited by the lack of integration of offshore geological data, hence their utility as basin exploration tools is limited.

We have gone back to first-principals, by interpreting basement terranes and major structures across the region, both onshore and offshore, to provide a spatially consistent and continuous view of its geological fabric. We then worked back in time to undo deformation patterns on major shear zones, basins and subduction zones. A detailed understanding of the basins of the region helped us to unravel this history.

The resulting animated plate model provides a kinematically and geologically constrained view of the tectonic evolution of South East Asia. It is consistent with the evolution of basins and petroleum systems across the region, and can be used as a predictive tool for hydrocarbon exploration.

Model boundary conditions

The starting point our model is a spatially consistent interpretation of the present-day crustal framework of South East Asia, comprising basement terranes and major structures. Plate tectonic analysis is somewhat futile without a good definition of these building blocks, both onshore and offshore. We used published geological maps, digital elevation data, gravity and magnetics to map basement terranes and structures focussing on spatial continuity, especially offshore.

The complex collage of basement terranes in South East Asia comprises three broad terrane groupings:

1. Precambrian ‘Cratons’ including Greater India, Australia and South China-Indochina. At first approximation these continents have behaved rigidly since the early Paleozoic.
2. Proterozoic-Paleozoic, Gondwana-derived continental terranes that crossed the Tethyan oceans and progressively amalgamated with Eurasia in the Mesozoic.
3. Mesozoic-Tertiary arc-related terranes that have amalgamated to South East Asia or formed in situ at its margins since the Cretaceous.

We have interpreted the regional structures that bound and deform these basement terranes, from subduction zones and orogenic thrusts, to strike-slip faults and basin-bounding normal faults. These structures have been attributed by age and plate code so that they appear and disappear appropriately when reconstructed.

In order to understand the temporal evolution of the geology of South East Asia, a detailed

tectonostratigraphic event chart was constructed by analyzing more than 300 publications for relevant observations. These data were divided by basement terrane and basin, and then used to define a series of key events and corresponding basin phases. Petroleum systems have been characterized in this 4D framework, and most South East Asian megasequences coincide with these time steps. Key time steps and tectonic events in our model include:

5.5 Ma	• Complex tectonics in Eastern Indonesia as ongoing 'salami-slicer' tectonic shears fragments of Australian plate off and transports them westward. • Slab rollback drives formation of Banda Orocline.
10.8 Ma	• Onset of extrusion of North China Block. • Ongoing sinistral transpression in East Indonesia propagates through to NW Philippines.
15.5 Ma	• Cessation of extrusion of Indochina, likely caused by the onset of sinistral 'salami-slicer' tectonics in Eastern Indonesia, driving sinistral transpression through to NW Borneo. • Onset of extrusion of South China causes vergence reversal on Red River Fault Zone.
21 Ma	• Onset of growth of the Tibetan Plateau causes major change in stress patterns and crustal thickness in the Himalaya. • Onset of collision of the northernmost terranes of the Australian Plate with the Sunda Arc.
32 Ma	• India moves further north, continuing Himalayan growth. Indochina begins to extrude, again rotationally about an Euler pole in the Bay of Bengal, accommodated by the Red River Fault Zone. • A second phase of rifting occurs in the South China Sea, leading to sea floor spreading.
42.5 Ma	• Onset of continent-continent collision in the Himalaya causes major global plate reorganization, changing movement direction of Pacific plate. • Collision of India causes onset of rotational extrusion of Sundaland, accommodated by major sinistral shear zones through the Gulf of Thailand, 'horse-tailing' into the South China Sea normal rift system. • Margin-perpendicular back-arc extension on Pacific margin of SE Asia opens basins from Makassar Straits to Taiwan.
55 Ma	• Onset of collision of India with Tethyan arcs. • Change in movement direction of Pacific plate causes dextral transtension on West Pacific margin, opening proto-South China Sea, East Sea, Bohai Basin as dextral back-arc basins. • Dextral back-arc shear causes collision of proto-South China Sea terranes with SE Sundaland, driving the Rajang Orogeny

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Plate reconstruction methodology

Our plate modelling was undertaken using Rothwell's *PaleoGIS* software in *ArcGIS*. Starting in the present-day, we worked back in time to undo deformation patterns on major shear zones, basins and subduction zones, using the time steps outlined above. The resulting plate model was animated in Microsoft PowerPoint to enable controlled viewing both forwards and backwards in time. Animation is a key step in plate modelling as it highlights inconsistencies in plate rotation poles.

Model highlights

Some significant outcomes of our new plate model include:

- The recognition that SW Borneo and Peninsular Malaysia are part of the same rigid Sundaland basement terrane linked by mappable basement structures and compositional domains, discounting independent rotation of Borneo.
- 'Progressive rotational extrusion' of Sundaland then Indochina was accommodated by a series of major strike-slip bounding shear zones, first the greater Wing Chao Shear Zones in Thailand, then the greater Red River Shear Zone in SW China and Northern Vietnam. A series of syn-extrusion, strike-slip basins opened during this strike-slip tectonics, most spectacularly in the Gulf of Thailand. The accommodating shear zones 'horse-tailed' into the South China Sea, and caused clockwise rotation of Sundaland + Borneo in two phases in the Late Eocene and Oligocene, consistent with observed basin evolution.
- The opening of the South China Sea is a logical consequence of our rotational extrusion model, which is consistent with published data on the timing and kinematics of sea floor spreading, as well as rift ages for extension on its margins.
- A detailed analysis of the 'train wreck' of terranes in East Indonesia, consistent with the onshore geology, basin evolution, paleogeography and petroleum systems. This domain is dominated by westward movement of the Pacific Plate coupled with northward movement of Australia. We have analysed the complex counter-clockwise rotation of the Bird's Head in this context, explaining its surrounding basins and fold belts.
- A series of NW-trending sinistral strike slip shear zones linked the 'salami-slicer' tectonics of East Indonesia with NW Borneo, driving the Sabah Orogeny in the mid-Miocene. Unravelling these shear zones clarifies the geology of Northern Indonesia and the Philippines, and a series of linear island arcs and back-arc basins emerge that significantly simplify the geology of this highly complex region.

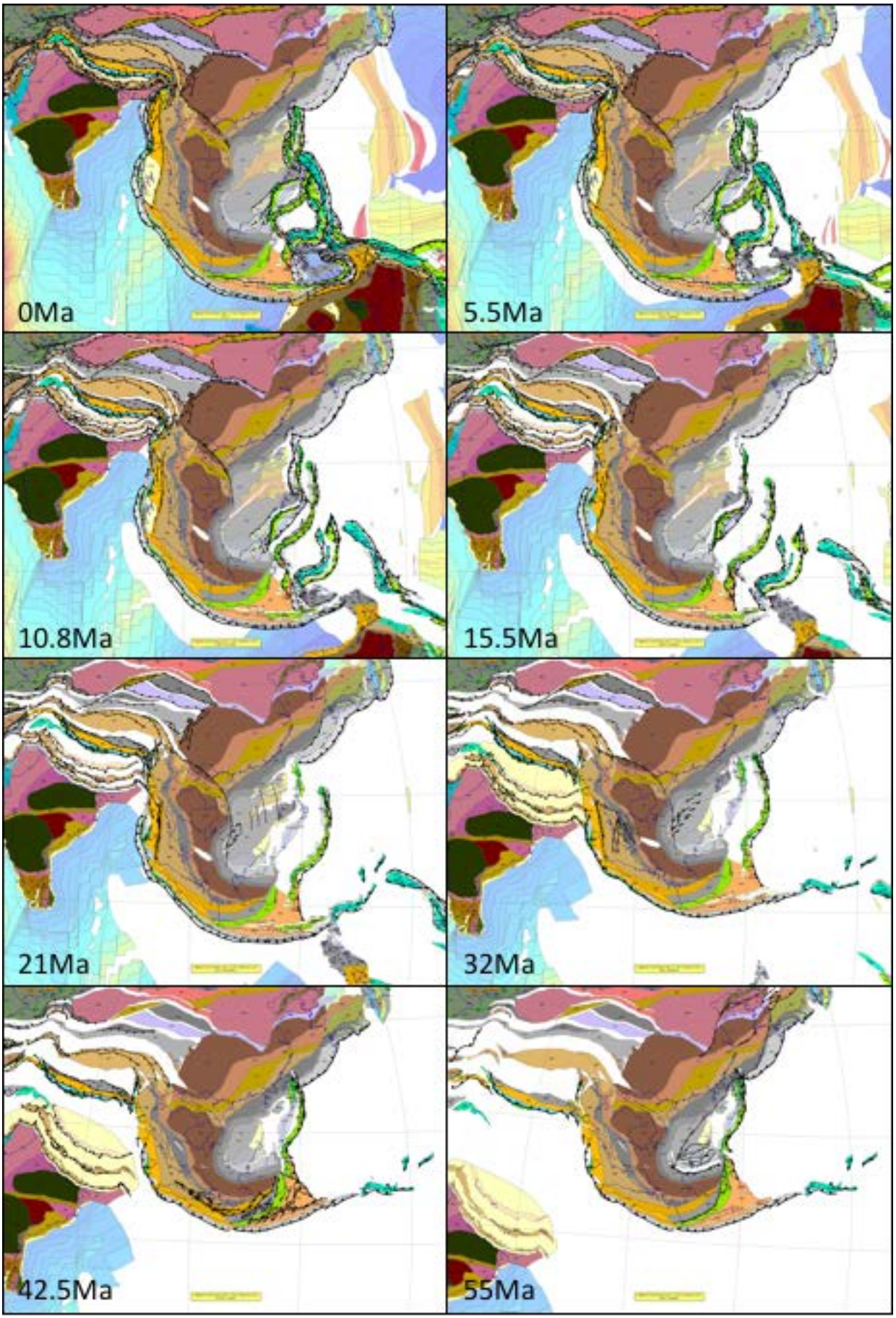

Figure 1: Snapshots from plate tectonic animation showing basement terranes and regional structures at key time slices.