Talk organized by Total E&P, Malaysia
Continental deformation and large-scale evolution of basins in Eastern Asia: An update

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Paul Tapponier gave a second talk on the 27th, sponsored by TOTAL E&P Malaysia. This talk was by invitation only, and most of the attendees were from oil and gas companies. Five academic staff from University of Malaya were also invited.

The question on everyones' mind had to do with Tapponnier's extrusion tectonics theory. Many Malaysian geologists have read, or are aware of, the original paper (Tapponnier et al., 1982), but are not aware of subsequent work on the theory. In the meantime, the theory has come under criticism by other researchers (see Hall et al., 2008). Is this theory still relevant? How well has it stood up over time? Does Tapponnier still subscribe to it in its original form? Has new data caused it to be modified, or altered in any way?

He began by showing us a movie of the original experiment. A block made up of contrasting bands of plasticine, representing the Eurasian plate, held rigidly on the left side but unbound on the right, was indented by a block of rigid PVC, representing the Indian subcontinent. On the left side, the plasticine was moved upwards and out of the way, however, on the right side, the plasticine was shoved to the right, with major strike-slip "faults" developing to accommodate the movement. In addition, blocks, bounded by faults, were seen to rotate clockwise by various amounts. Voids also appeared in between some of the blocks. The plasticine approximates the behavior of the crust at depth, where rock is plastic, rather than at the surface. Strike-slip faults generated in this manner will extend to very great depths, the entire thickness of continental crust will be involved.

Rates of continental movement can be derived from the study of ocean floor and spreading centers. In the present, the Indian subcontinent is moving north at about 5cm/yr. 50 million years ago, the rate was 14 cm/yr. The collision was initiated at about 50-55 m.a., causing a sudden slowdown in the rate. At this time, the fossil record shows that India, heretofore joined to Australia and populated by marsupials, was invaded by placental mammals. These estimates have not changed much over the last 20 years.

The degree of continental shortening due to the collision is, based on these rates, 3000-3500 kilometers, and the area of displaced material is about six million square kilometers. Can this amount be accommodated entirely by vertical movement? No, argues Tapponnier, even if the crust thickness has been doubled, vertical movement in the Himalayas and Tibet can only account for 1000 kilometers of shortening. The current outline of the Indian subcontinent that has been moved or deformed can also be derived from the position of its ophiolitic rim, which can be observed in the current Himalaya.

Given that vertical movement alone cannot accommodate this amount of continental shortening, it follows that something else must have occurred to do so, and Tapponnier stated that this was the sideways extrusion of South East Asia predicted by the plasticine model of 1982. He then went on to demonstrate that not only was this the case, but that the plasticine model also predicted many features we observe today in the structural geology and physical geography of region in question.

One of the major strike-slip faults in the region is the Red River Fault, which extends from Yunnan in China to the point defined by the south boundary of the Gulf of Tonkin in Vietnam. The shear zone is marked, in Yunnan, by the Ailao Shan, a prominent ridge of mylonite, several kilometers in width. The last movement along this fault has been dated to the Oligo-Miocene, which means this fault was active for 15 million years. Displacement along this fault was left lateral, and estimated at 500-700 kilometers, based on rates of movement, and displaced geology, such as sutures. Tapponnier also mentioned that the rich Tin Belt of China only extends south to the Ailao Shan, and then disappears. It reappears again as the Tin Belt of South East Asia, displaced to the east by 700 km.

A strike-slip fault with this much displacement cannot just end abruptly. According to the extrusion model, at the end of the Ailao Shan-Red River Fault is the South China Sea, which opened, due to movement along the fault, between 32 and 16 m.a. The latest data on magnetic anomalies of the South China Sea shows that spreading actually occurred on more than one, parallel, spreading centers (Briais et al., 1993; Leloup et al., 1995) Such an arrangement would be difficult to explain by normal, mantle plume driven rifting models, or by slab-pull models, but could be explained if the South China Sea were being pulled apart by the shearing of a continent. If the shear zone is propagating faster than can be accommodated by sea-floor spreading, stresses at its tip will cause subsequent spreading centers to open parallel to the first. This view of the South China Sea would be incompatible with the

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idea that the Dangerous Grounds has drifted southeast from off Vietnam due to the subduction of a proto South China Sea under Borneo, as has been proposed by Taylor and Hayes (1983) and others. The best estimate of the amount of extension in the South China Sea is 540 +/- 50km. Added to the extension of the Dangerous Grounds, and this increases to 700km, which is consistent with estimates of movement along the Ailao Shan, as well as the displacement of the Tin Belt. Such a shear zone has all the properties of a plate boundary – the fault zone extends down into the deep lithosphere.

The Ailao Shan shows compression to the north, where rock that was originally 20-30 km deep is now on the surface, and extension to the south. Aside from the strike-slip movement of the fault, the block to the south-west has rotated clockwise in comparison with the block to the northeast, resulting in "zipper tectonics". Cooling ages are younger to the north, where rocks which were hotter at depth have more recently been brought to the surface and were therefore at temperatures of closure more recently than those to the south.

Before the collision between India and the Eurasian Plate, the South Asian continental margin was much further south than it is now, extending as a line between the present day Gulf of Oman and Sumatra, shown by the detection by seismic tomography of a cold slab in the mantle at 1100km depth in this position (Replumaz et al., 2004). Since the collision, the plate margin has been pushed northward, and the Sunda Trench is now oriented north-south, west of the Andaman Islands and Sumatra. Subduction is now oblique to the shelf edge, resulting in lateral stresses which cause the right lateral movement along the Sumatra, Seuliman and West Andaman Faults, as well as the Sagaing Fault, which passes northwards through Myanmar. The Andaman Sea represents a pull-apart basin between the southern end of the Sagaing fault and the northern end of the West Andaman Fault (Curray, 2005).

Movement along the faults commenced at the beginning of the India-Asia collision during the Paleocene. The plasticine model accounts for the presence of not only the north-south trending faults such as the Sagaing and West Andaman Faults, but also northeast-southwest trending faults such as the Ranong, which passes through southern Thailand.

The model also explains the formation of the Malay Basin, caused by pull-apart tectonics at the end of the Three Pagodas Fault. Movement along this fault is estimated at 200 km, and the Wang Chao shear zone in Thailand is analogous to the Ailao Shan. In the plasticine model, voids appear between rotated blocks – and the Malay Basin is, indeed, a deep hole in the fabric of the Sunda platform.

So - how well does Tapponnier's extrusion tectonics model fare in the present day? Observations of the geology of Borneo, and elsewhere (compiled in Hall et al., 2008) would seem to contradict aspects of the model, particularly those which pertain to the extension of major strike-slip faults to the offshore area northwest of Borneo, and the movement and clockwise rotation of Borneo and other blocks in South East Asia. Yet, the data compiled by Tapponnier and his coworkers on the movement of faults in China and the Himalaya support his contention that large-scale movements have occurred, and distal motions in Borneo probably in part reflect counterclockwise rotations predicted by the model . The activities of Tapponnier and his coworkers since the 1982 publication have centered on the Himalaya, southern China, Vietnam and Myanmar, where active fault movements can be studied, and for this reason, are unfamiliar to many of us who study the tectonics of this part of South East Asia. Yet this work has great relevance to our region, and deserves to be considered whenever we interpret local geology.

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Report by Nur Iskandar Taib

Note: This second talk by Prof. Dr. Tapponnier in Kuala Lumpur was inadvertently left out in the previous issue of Warta Geologi.