PALEOCEANOGRAPHIC MAPPING PROJECT
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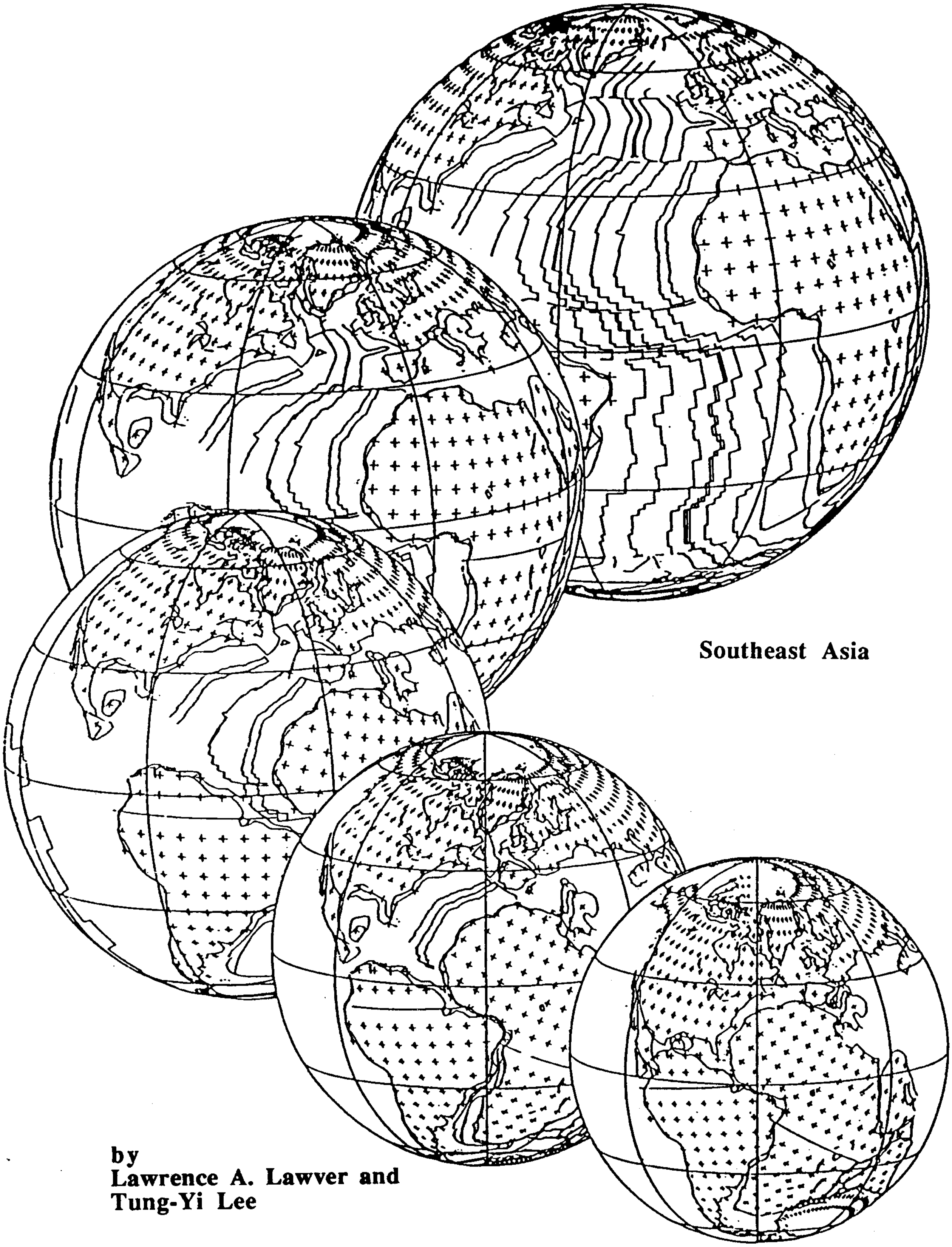

Southeast Asia

by
Lawrence A. Lawver and
Tung-Yi Lee

Contents

I. Introduction

by Lawrence A. Lawver

During the last six months we have had four people working on the Southeast Asia Project. Lila Beckley, a University of Texas undergraduate has digitized the Indonesian region of Southeast Asia. She has finished the coastlines, plate boundaries, and identified marine magnetic anomalies, see figure 1. She used the following charts:

Mammerickx, J. Fisher, R.L., Emmel, K.J., and Smith, S.M., 1976. Bathymetry of the East and Southeast Asian seas, GSA Map and Chart Series MC-17, Washington, D.C.

Hayes, D.E. and Taylor,B., 1978. A geographical atlas of the East and Southeast Asian seas, GSA Map and Chart Series MC-25, Washington, D.C.

Hamilton, W., 1978. Tectonic map of the Indonesian region, USGS Survey, Map I-875-D, Reston, VA.

Tung-Yi Lee is a Ph.D. student working on a thesis on using seismic stratigraphic methods to carry out a quantitative basin analysis on a basin in the northern South China Sea. He has compiled the reference list included in part three of this report. Since he reads and speaks Chinese, he has been able to access literature that has not been translated. He will be studying the sedimentary basins of the region and trying to determine their ages, stretching histories, and tectonic settings.

Lila placed the digitized Southeast Asia data on the Evans and Sutherland PS300 computer system and ran through some preliminary reconstructions but we judged it premature to send them out. We need to first resolve the dispute as to what it was that rifted off of Northwest Australia during the Middle Jurassic. I have been putting together the preliminary work discussed in Part B of this report.

During the next six months we hope to put together the major tectonic evolution of Southeast Asia. This will require merging the work concerning the early tectonic framework, the impact of the collisions of India and Australia, and the evolution of the eastern margin of Southeast Asia. We hope to be well along on the dating of the sedimentary basins and starting on determining the stretching factors involved in the basins. Our first model for the region will consist of the major blocks, terranes, and plates and their motion with respect to one another. Our final model will incorporate the sedimentary basin evolution and entail designating numerous platelets.

II. Tectonic setting for Cenozoic evolution of Southeast Asia

by Lawrence A. Lawver

In order to undertake a study of the tectonic evolution of Southeast Asia, we must understand the tectonic framework in which it evolved. Southeast Asia as we now know it, originally consisted of numerous separate blocks (figure 2). A simplified Mainland China consists of at least six separate pieces including the Sino-Korean craton (or North China Block, NCB) in the northeast; the Yangtze craton (or South China Block, SCB) to the southeast; the North Tibet Block and South Tibet Block to the southwest, the Tarim craton including the Qaidam (or Chaidam) Basin to the west, and finally, the Altai-Sayan or Dzungaria block to the northwest. In their paper on the plate tectonics of China, Zhang, Liou and Coleman (1984) subdivide China into three cratons, nine foldbelts, sixteen microcontinents, one back-arc basin and one inland basin. Other pieces crucial to our understanding of the tectonics of southeast Asia include: the Indian plate on the west and south; the Australian plate on the south; the Burma plate of Curray et al., 1978; the Shan-Thai craton of Barr and Macdonald, 1987, which may include Malaya, Sumatra, Sulawesi and Banda according to Audley-Charles et al. (in press); Indochina or the Indosinian craton; and various bits of the Philippine archipelago and Taiwan that need to be sorted out. The South China block (SCB) includes not only the Yangtze paraplatform but the South China fold system of Huang (1978), and as defined by Lin et al. (1985) also includes the continental shelf of the South China Sea, the southern part of the East China Sea, northern Viet Nam and possibly the southern part of the Korean Peninsula.

During Permian time the Altai-Sayan foldbelt was attached to Siberia and had drifted with Siberia during the Phanerozoic, according to Khramov et al. (1985). The Tarim craton had drifted northwards during the Late Paleozoic and collided with the Kazakhstanian/Tianshan block by Late Carboniferous time (Bai et al., 1987). Since the Tianshan foldbelt separates the Tarim craton from the Altai-Sayan, it is assumed that the Tarim craton was therefore connected with Siberia by Permian time. Li et al. (1988) have measured a Late Permian paleomagnetic pole for dikes from the Tarim craton which indicate that the Tarim craton must have moved with respect to Siberia after its collision with the Altai-Sayan block. The Late Permian paleolatitude of the Tarim craton was 30.4° N versus its present day paleolatitude of 37.5° N. Li et al. (1988) suggest that the Tarim craton moved northward and eastward as a result of the collision of India with Eurasia.

In the past, Helmcke (1985) has argued that the NCB and the SCB originated in the northern hemisphere and did not originate from Gondwanaland. There are now better paleomagnetic data (Li et al., 1988; Opdyke, 1986; and Lin et al., 1985) that support a Gondwana origin for both the NCB and the SCB. Combined with paleobotanical evidence, Lin et al. (1985) place the SCB adjacent to North Australia between 800 and 460 Ma and the NCB at 35°S close to Iran, Tibet and northern India during the same time. Since Bai et al. (1987) indicate that the Tarim craton and the NCB occurred as a single unit during the Caledonian orogeny, the Tarim craton can be assumed to have also originated from Gondwanaland. It separated from the NCB prior to the Late Carboniferous since both the NCB and the SCB were far south during the Permian (Zhao and Coe, 1987) [McElhinny (1985) places them near the equator (3.2°) in the Permian]. The NCB began to collide with Siberia in the Triassic (Sengor, 1986) and was sutured by the Early Cretaceous. Zhao and Coe's (1987) paleomagnetic work indicates that SCB may have collided on its northeastern margin during Permo-Triassic time and then rotated 067° counterclockwise with respect to the NCB. By Late Cretaceous the paleomagnetic poles for the two blocks are indistinguishable, so collision between the NCB and the SCB was complete before Late Cretaceous. Unfortunately the Late Cretaceous event overprinted much of eastern China so there are presently no data for the Late Triassic and Early Jurassic (Zhao and Coe, 1987).

Achache and Courtillot (1985) state that the synthesis of paleomagnetic and paleontological data from the Khorat Group of central Thailand indicates that Indochina was welded to Eurasia by the upper Middle Jurassic. The initial contact between the two continental domains occurred prior to the Late Triassic and resulted in partial closing of the intervening Paleotethys Ocean. Achache et al. (1983) state that there is clear evidence for continental connections between Indochina, South China and central Asia as early as Late Triassic. Barr and Macdonald (1987) discuss the Nan River suture zone of northern Thailand, and suggest that amalgamation of the Shan-Thai block and the Indochina block occurred in the Permian or Triassic (Hutchison, 1983; Bunopas and Vella, 1983). Barr and Macdonald (1987) have the Shan-Thai/Indochina/SCB amalgamation occurring in Late Permian prior to the collision of the SCB with the NCB. Finally North Tibet was sutured to Eurasia during the Late Triassic, according to Achache et al. (1984) and South Tibet was added by 110 Ma (Achache et al., 1984).

With the exception of India, South Tibet and the Australian block, most of the major pieces of China, North Tibet and Southeast Asia were assembled by Late Triassic. It is probable though that few of the blocks had undergone solid collisions since even though Zhao and Coe (1987) favor initiation of collision between the NCB and the SCB in the Early Triassic they suggest that completion of the 067° rotation of the SCB with respect to the NCB did not occur until the Jurassic. Obviously the Cenozoic collision of India with Eurasia has moved many of these blocks with respect to one another along the Permian to Late Cretaceous sutures.

The probable origination, timing, and placement of the main blocks of China and Southeast Asia put considerable constraints on the prior locations of all the pieces of Southeast Asia. The reconstruction of Gondwanaland (Lawver and Scotese, 1987) just prior to break-up (~170 Ma) places additionally constraints on the sequence of events affecting the tectonics of Southeast Asia. Their reconstruction based on marine magnetics and geological constraints, places Greater India along the East Antarctic craton west of Australia. Lawver et al. (in press) suggest that the northern part of Greater India rifted off the west coast of Australia at M10 (130 Ma) time prior to when Peninsular India rifted off East Antarctica at about M4 (~125 Ma) time. Northern Greater India moved a few hundred kilometers along a left-lateral transform fault with respect to Peninsular India. The strike-slip fault is presently obscured by the Yarlung-Zangbo-Indus accretionary fold belt or is lost in the folding of the Himalayas.

Audley-Charles et al. (in press) argue that South Tibet, Burma, Malaya, West Kalimantan (Borneo), Sumatra, East Kalimantan, West Sulawesi and Banda did not rift off northern Australia until M25 (160 Ma) time. They base the timing of the rift on the magnetic anomalies observed in the North Australian Basin (Heirtzler et al., 1978). Clearly some fragment rifted off the northwest corner of Australia in the Late Jurassic, but we have no evidence that that piece was very big or even continental. The orientation of the observed anomalies would suggest that the fragment probably headed northwest with respect to Australia. According to Allegré et al. (1984) South Tibet has abundant Late Triassic palynomorphs that suggest an equatorial or tropical latitude. The Triassic flora lack any significant Indian taxa and most of the taxa are commonly found in Europe or the Caucasas and most recently in Szechuan Province. It is possible that South Tibet was part of Eurasia during the Triassic, drifted southeastward and then careened off the northwest corner of Australia during the Middle Jurassic. South Tibet is the only piece of 'older' Southeast Asia that did not suture to Eurasia until Early Cretaceous. Another possibility is that an island arc, possibly the Sunda Arc, left the Northwest Australian margin during the Middle Jurassic and accounts for the observed Mesozoic magnetic anomalies seen in the

Northwest Australian Basin.

If China and Southeast Asia can be envisioned as a loose amalgamation of cratons, microcontinents, foldbelts and collapsing oceans from the Late Permian to the Early Cretaceous, it then underwent major changes as India began to collide with it in the Cenozoic (Tapponier et al., 1982, 1986). As mentioned above, the Tarim craton was shoved northward and translated eastward with respect to Siberia. Indochina underwent a large clockwise rotation with respect to Eurasia with no resolvable latitudinal motion since 50 Ma, according to Achache and Courtillot (1985). The South China Sea opened starting about 30 Ma ago. Major strike-slip faults developed along the margins of the separate blocks such as the Altyn Tagh fault (Molnar et al.; 1987b) separating the Tarin craton from North Tibet and the Red River fault separating the Indochina block and the SCB (Achache et al., 1983). Figure 1 of Molnar et al. (1987b) summarizes the recent motion of India and its distribution in the deformation of Eurasia. The direction of motion on the Red River Fault as shown in this figure was drafted incorrectly and should be shown as left-lateral.

We feel that the impact of India on Eurasia is undoubtedly the major driving force causing the present-day deformation of Southeast Asia. Tapponier et al. (1982) popularized the idea of a rigid indenture to explain the deformation of Southeast Asia. Conceptually it is a good model but it does not explain the timing or sequence of some of the events observed. We hope to put ages on the sedimentary basins of Southeast Asia and determine if there is systematic growth.

III. Tectonic setting for South China Sea: Problems and solutions

by Tung-Yi Lee

In the late 60's, Wageman et al. (1970) recognized an extensive angular unconformity that separates the Neogene from the Paleogene strata beneath Yellow Sea, East China Sea, and the continental shelf of East Asia. The sediments underlying the unconformity shows evidence of structural deformation followed by erosion, and the sediments above the unconformity generally consist of horizontal layers. Therefore, Wageman et al. (1970) proposed the "pre-deformation" and "post-deformation" sedimentary facies for the sediments above and below the unconformity.

Recently, more data have been collected from both geophysical investigations and drilling activities (e.g.. Taylor and Hayes, 1980 and 1983; Holloway, 1982; Feng and Zhang, 1982; Chen and Dickison, 1986) which enable us to appreciate a widespread angular unconformity that extends from South China Sea, North Philippines, eastern China mainland, to Taiwan. This angular unconformity occurs in numerous basins, ranging from the size of Bohai and South China Sea basins to small half-grabens, and was suggested by Holloway (1982) as the "breakup" (rift-drift transition) unconformity of the South China Sea. The age of the unconformity is thought to be of early Late Oligocene from the drilling information (Holloway, 1982).

The prominent and almost synchronous angular unconformity would suggest a similar tectonic evolution history of the East Asian continental margin during the mid-Tertiary. This would mean a large area along East Asia had been uplifted, stretched, and subsided in a similar way. There was also some oceanic crust formation in the same time (e.g.. South China Sea basin). Tapponnier et al. (1982) used plane indentation experiments to explain the opening of the South China Sea basin as the result of the collision between the Indian and Eurasia plates, which in part can explain the observed angular unconformity in the regions around the South China Sea. Still, no satisfactory explanation has been given as to why the unconformity extends from Taiwan to most part of eastern China.

To make things a little bit more complicated, Pautot et al. (1986) based on coupled seabeam mapping and single channel seismic reflection profiling, suggest that the E-W trending magnetic anomalies in the South China Sea as observed by Taylor and Hayes (1980 and 1983) are actually aligned NE-SW. The magnetic anomalies have been generated by NW-SE extension, but the closely spaced transform faults may have rearranged the anomalies such that sampling by the rather few marine transverses available to date has given a false impression of their azimuth. Other studies in this region, such as the one by Ru and Pigott (1986) suggest that South China Sea experienced at least three stages of rifting and two stages of sea-floor spreading since the Early Cretaceous. The episodic rift system corresponding to the first episode trends NE-SW, whereas those of the second and third trend E-W. Liu and Chen (1987), based on heat flow data, conclude that the formation of the Central basin in the South China Sea is a result of polystage and polyaxes sea-floor spreading under the control of faults.

Several studies in the sedimentary basins on the continental margin north to the South China Sea also indicate that a NE-SW fault trend in the pre-Oligocene acoustic basement and an E-W fault trend in the post-Oligocene strata (Jin et al., 1984; and Feng and Zheng, 1982). Besides, a recent study by Stephan et al. (1986) suggests that subduction of an oceanic capped lithosphere extended from the present-day location of western East China Sea to the South China Sea along the proto-Malina Trench from Late Oligocene to Middle Miocene, and the consumption of this oceanic lithosphere was completed during Late Miocene to Early Pliocene. If this is the case, then the spreading of South China Sea should not be recognized as the simple passive-margin-type spreading. Its spreading history may have been controlled by the interactions between Eurasia, India, and Pacific plates and the paleo-flaws within the eastern China continental margin.

To obtain a better understanding of the Cenozoic evolution of the Southeast Asia, the South China Sea is a good starting place. Not only because the South China Sea is located in such a critical position between the Eurasia, Pacific, and India plates, but also because there are so many sedimentary basins around and within the South China Sea region. From recent exploration activities, sedimentary facies maps and strata columns have been generated (e.g.. Wu, 1988; and Beddoes, 1981), which can enable us to set certain constraints as to the relative positions of the tectonic blocks and to examine the paleogeographic reconstructions through time.

Our future research will concentrate on building up a time frame for the various tectonic events in the Southeast Asia region, and by coupling these events to the sedimentary records we can get a better timing of the individual event. All in all, we are dealing with a highly integrated study using every piece information which is available to us.

IV. Bibliography

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VI. Abstract

submitted by Tung-Yi Lee for Master's thesis at The University of Texas at Austin

SEISMIC STRATIGRAPHY AND TECTONIC EVOLUTION OF TUNGYINTAO BASIN, OFFSHORE NORTHERN TAIWAN

The Tungyintao Basin, offshore northern Taiwan, is part of the East China Sea rift system. The basin is a half-graben, filled with lower Tertiary sediments derived principally from the Chinese mainland. This research used 1,840 kilometers of industrial seismic reflection sections and 2 exploration wells to investigate an area of about 10,000 square kilometers.

Three syn-rift and two post-rift sequences are separated by an angular break-up unconformity. The Early Paleocene initial rift phase was characterized by deposition of fan-delta systems in shallow structural lakes. During Late Paleocene, with gradually rising sea-level and subsidence, deep water sedimentary facies were deposited. At the very end of the Paleocene, thin limestone was deposited on the ridges surrounding the basin, marking the first marine influence of this area. The final stage of the syn-rift basin was marked by deposition of Eocene and Early Oligocene (?) delta systems. After the Early Oligocene breakup, the basin became stabilized, with only gentle tilting toward the southeast. The principal depocenters shifted far to east, where Miocene fluvial and delta systems were deposited in the Okinawa Trough. During Late Miocene to Quaternary, fluvial systems originating in East China continued to transport sediment to the Okinawa Trough.

This study also concludes that infill deposition was associated with listric normal faulting during the initial rift phase, and that syn-tectonic deposition was accompanied by planar normal faulting during the major rift phase. The rift basin is asymmetric not only in the transverse direction but also in the longitudinal cross section. An oceanic lithosphere, associated with the spreading of South China Sea, that extended from the East China Sea to the South China Sea, was consumed along the Malina Trench from Late Oligocene to Early Pliocene.

Inferred reservoir and source-rock conditions in Tungyintao Basin indicate very favorable hydrocarbon potential.

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