Geol. Soc. Malaysia, Bulletin, 7, June 1974; pp. 89–138.

Malaya and Southeast Asia in the pattern of continental drift

P.H. STAUFFER[1]

(Sixth Presidential Address of the Geological Society of Malaysia, delivered to a meeting of the Society on the evening of Friday, the 16th of February, 1973, in the Lecture Room of the Department of Geology, University of Malaya, Kuala Lumpur)

To the horizon that lifts before us,
To the horizon that ever recedes,
To the horizon that ever draws near,
To the horizon that causes doubt,
To the horizon that instills dread,
To the horizon with unknown power,
To the horizon not hitherto pierced,
—from a Polynesian sea-chant

At a specified time the earth can have had just one configuration. But the earth supplies no direct information about this. We are like a judge confronted by a defendant who declines to answer, and we must determine the truth from circumstantial evidence. All the proofs we can muster have the deceptive character of this type of evidence. How would we assess a judge who based his decision on part of the available data only?

It is only by combining the information furnished by all the earth sciences that we can hope to determine "truth" here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability.

—Alfred Wegener, 1929

On this occasion each year, by one of our Society's most ancient traditions, the retiring President is allowed to unburden himself of any thoughts he may wish to express without the chastening prospect of searching questions to follow. In spite of the grievous temptation involved in this situation, our previous Presidents have given us thoughtful, cogent, and even philosophical discourses. Every tradition must, however, have its lapse, and this evening I plan to take advantage of the freedom from criticism to lead you on what many sober earth scientists would regard as a journey through fantasy. Nonetheless, it is a journey I have much enjoyed reconnoitering, and even if you do not share with me a feeling that it may be instructive as well, I hope at least that you will enjoy the ride.

It is also traditional that these addresses start with a suitable quotation. Tonight I give you two. The first expresses a little of the spirit of my inquiry. The second is from that pioneer of continental drift, Alfred Wegener, a level-headed thinker if there ever was one, and makes a point too little taken to heart in the literature of continental drift—both pro and con.

Let me make it clear at the outset that I do not intend tonight to discuss the merits and demerits of either the theory of 'continental drift' as expounded by

[1] Department of Geology, University of Malaya, Kuala Lumpur.

Wegener (1929), du Toit (1937) and others, or the hypotheses of 'sea-floor spreading' and 'plate tectonics' as they have evolved from especially the work of Dietz (1961), Hess (1962), Vine and Matthews (1963), Wilson (1965a), Morgan (1968), and Le Pichon (1968) and effectively summarized by Isacks, *et al.* (1968), Dickinson (1971), and McKenzie (1972). The evidence in favor of the reality of continental displacements seems to me now so varied and so strong that it requires a powerful faith to believe still in the fixity of position of continents and oceans. And the set of hypotheses known as plate tectonics, while far from explaining everything, do outline a kinematic pattern (of still unknown ultimate cause) which fits the geological and geophysical data far better than any previous attempt and which makes sense for the first time of many old geological puzzles. I therefore accept these ideas as the best available working hypotheses, and it is within this framework that I wish to examine the history of Malaya and Southeast Asia.

Acknowledgements

A synthetic study such as this one is built from the work of many people. I would like to acknowledge my debt to those who have provided the material to which, like a tailor, I have merely done some stitching. For helping me obtain relevant information I am grateful to Dr. Wayne Fry of the University of California (Berkeley), Dr. D.J. Gobbett of Cambridge University, Prof. T. Kobayashi of Tokyo University, Mr. R.W. Murphy of Esso Exploration (Malaysia), and Dr. (Madam) Nguyen Lan Tu of the University of Saigon. Prof. N.S. Haile and Dr. C.S. Hutchison of the University of Malaya kindly allowed me to refer to material not yet published.

To the authors and publishers who gave permission to reproduce copyrighted illustrations I express my thanks. Draughting work for the other figures was done by Mr. Ching Yu Hay and Mr. S. Srinivass and the photography by Mr. Jaafar bin Haji Abdullah.

Many useful ideas and critical comments came out of discussion with various people, especially Mr. R.W. Murphy, Dr. B.C. Stone of the University of Malaya School of Biological Sciences, and Dr. C.S. Hutchison and Dr. K.R. Chakraborty of the University of Malaya Geology Department. Dr. C.K. Burton of Cities Service International (Kuala Lumpur) read through a draft of the manuscript and made numerous useful suggestions and criticisms.

The ideas expressed here, however, and any errors or misinterpretations, remain the responsibility of the author.

HISTORICAL REVIEW

Recent explicit attempts to fit Malaya and Southeast Asia into the pattern of continental drift, such as those of Burton (1970) and Ridd (1971), make us realize how this region has been generally left out of past reconstructions. This being 'left out of the action' has taken two forms. One is simple amputation of the region as in Dietz and Holden (1970), leaving a dashed-line scar on the underbelly of Asia (Fig. 1). The other is to leave the present arrangement of Southeast Asian lands (with or without the islands) to be dragged along wherever the rest of Asia goes. This approach was recently seen in a popularized version of continental drift presented in a Kuala Lumpur newspaper (Fig. 2). Here the Malay Peninsula dangles into the lonely ocean like the tail of Asia. This map was actually derived from an earlier paper by Tuzo Wilson, a semi-popular account now a decade old (Wilson, 1963).

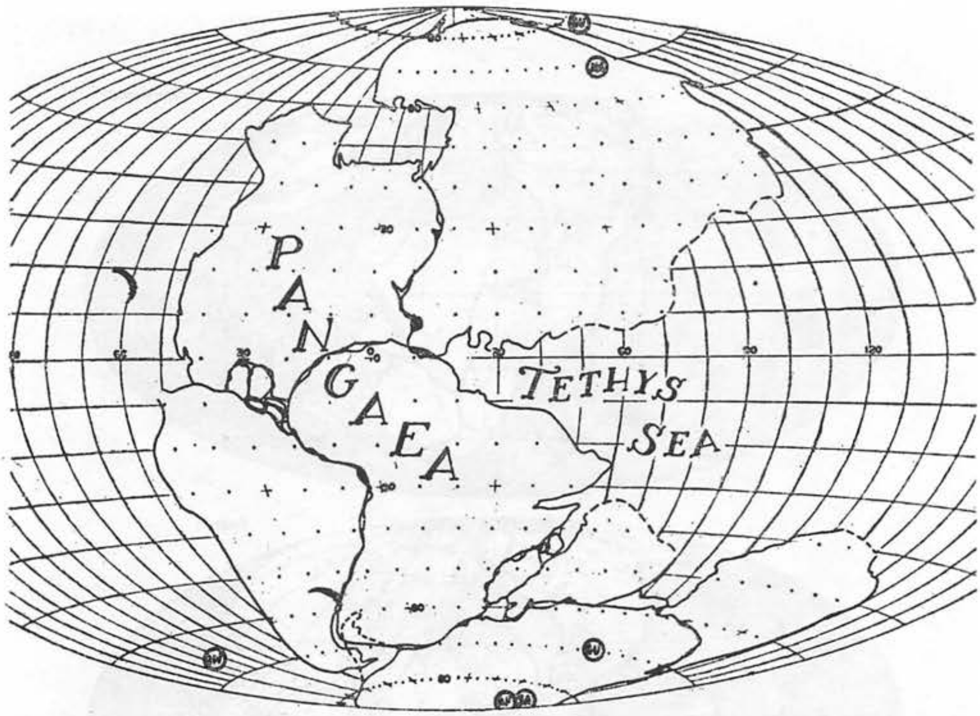

Fig. 1. Reconstruction of Pangaea (at end of Permian) according to Dietz and Holden (1970, figure 2). Copyright by American Geophysical Union. Reproduced by permission.

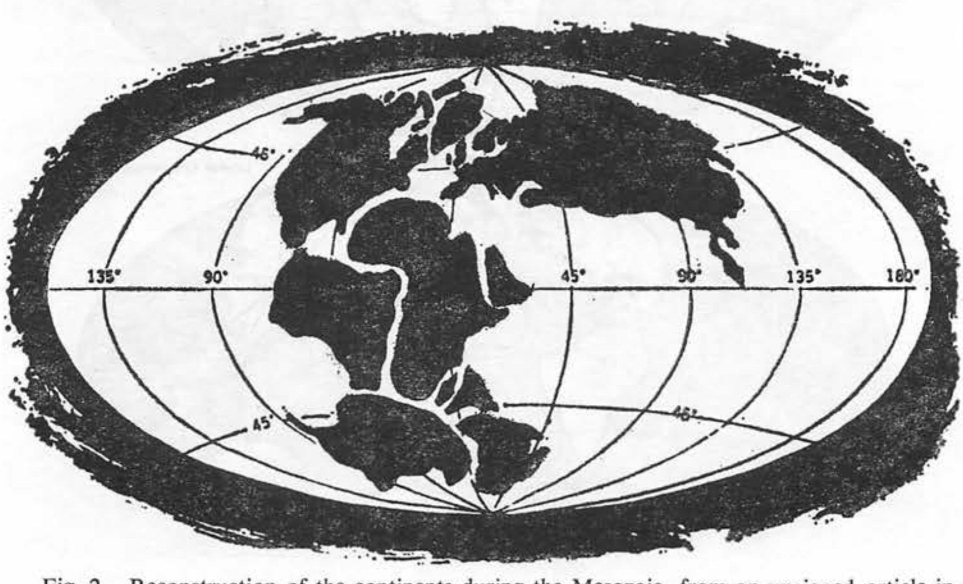

Fig. 2. Reconstruction of the continents during the Mesozoic, from an unsigned article involving continental drift in *The Malay Mail* for October 4, 1972, page 9. Obviously based on the map of Wilson (1963).

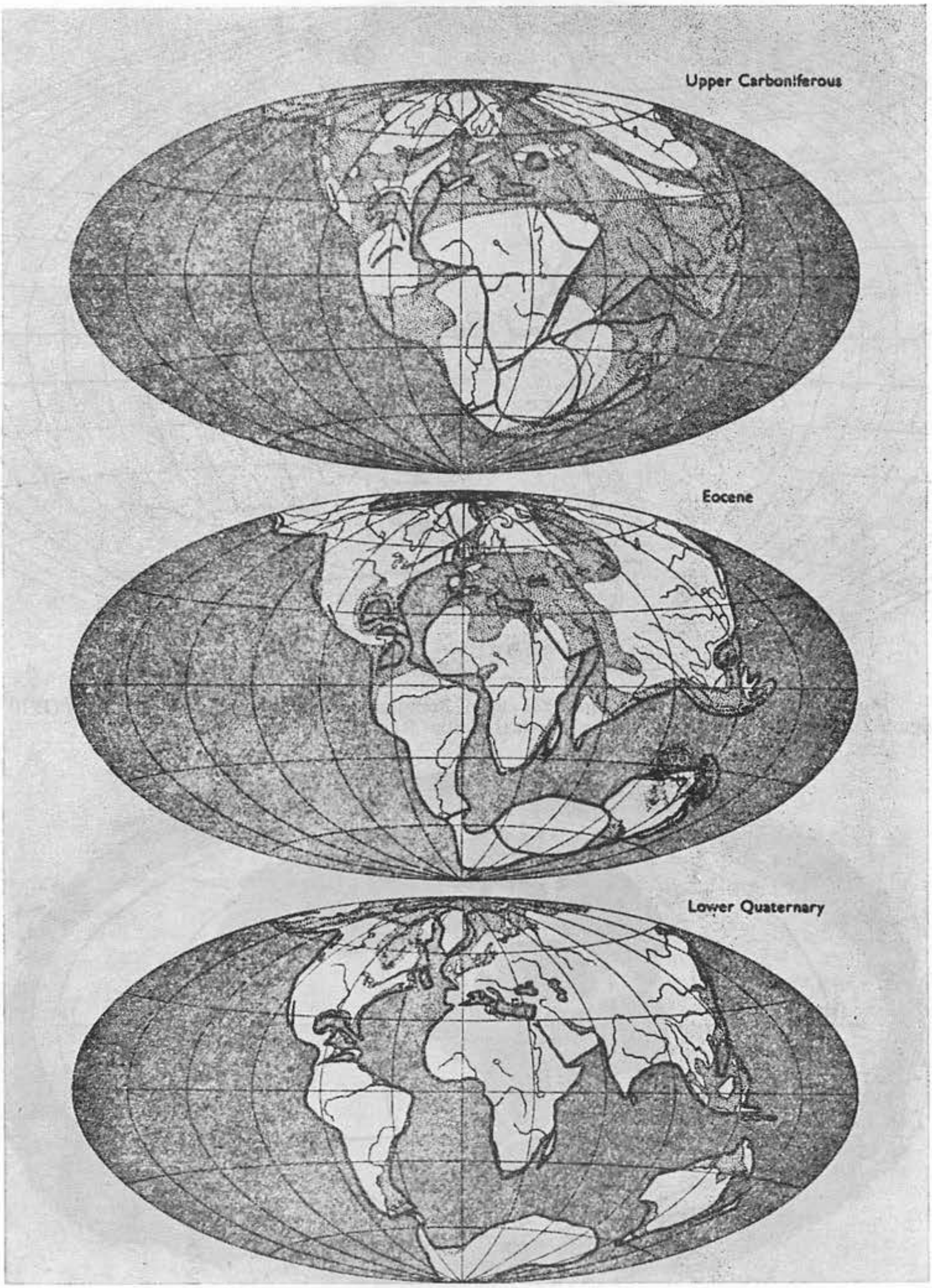

Fig. 3. Wegener's classic reconstruction of the pattern of drift since the Carboniferous. Reproduced from Wegener (1929, figure 4, in reprint) by permission of Dover Publications.

Not all the earlier reconstructions, of course, ignored Southeast Asia. Wegener himself included it, as indeed he included everything in his famous version of Pangaea (Fig. 3). It is included as an unchanged portion of a giant unitary block of Eurasia, and even the young island arcs are shown in embryonic form in the Carboniferous. Wegener, you will note, does not really put Southeast Asia into the Gondwanaland portion of Pangaea, but leaves a narrow gap of ocean.

In 1921, however, Wing Easton suggested that the basement of the Sunda region had been derived from Antarctica west of Wilkes Land, starting a trend which can be seen continuing down to this day—a tendency to look always southward to Gondwanaland to find Southeast Asia's original home. One sees it even in du Toit's remarkable 1937 book *Our Wandering Continents*, so much of which is turning out to be prophetically accurate (for instance, the computer best-fit reassembly of Gondwanaland of Smith and Hallam, 1970, is almost an exact copy of du Tiot's inductive reconstruction of a third of a century earlier). In writing about Southeast Asia, du Toit clearly presents floral and faunal evidence that it is related to China and Laurasia and very distinct from the classical Gondwana areas, yet is able to make this strange comment: "the evidence suggests that a wedge-shaped fragment that fitted between India and Western Australia has become involved in the Tertiary crumplings of Burma, Siam and Malay States . . . though the details have admittedly still to be worked out." (du Toit, 1937, p. 126). He then quotes Wing Easton's suggestion of an Antarctic origin.

In a sketch map of probable geography in Viséan times, Fitch (1952, fig. 7) shows "Gondwanaland" to the west of the Malay Peninsula, with another landmass, "Cathaysia", occupying the present South China Sea area. A map presented by Klompé (1955) shows "Gondwana Foreland" adjoining Sumatra and Java on the west and south. Other examples could be given. This tendency to look to the Gondwana areas to find Southeast Asia's place was maintained in the face of much contrary evidence, yet it is turning out—rather ironically—that it may have been at least technically correct.

The more recent attempts to fit Southeast Asia into the picture began, I believe, with two papers by Melville (1966, 1967). Melville considered most of Southeast Asia a fragment of Gondwanaland, partly on the basis of a single and apparently erroneous report of *Glossopteris* from Borneo. Therefore he let the Sunda area ride with India during the latter's migrations (Fig. 4), and in his reconstruction of Gondwanaland (Fig. 5) nestled it between India, Australia, and Antarctica. Melville is a distinguished botanist and these interpretations were based on biogeographic arguments (much altered by more recent discoveries) and generally uninhibited by geologic considerations. This is, I am convinced, not altogether a bad thing, as such a person may be able to come to the bold conclusion that we, immersed in our knowledge of the difficulties, would shy away from. Melville will provide us with an illustration of this later.

Smith and Hallam (1970) in their computer reassembly of the southern continents suggested that those portions of the original border of Gondwanaland not marked by later orogenic zones may have had microcontinents attached to them. As an example they propose that Southeast Asia may have been attached to northwest Australia.

A very explicit proposal was made by Burton (1970) who matched the Malay Peninsula against the east coast of India and suggested that the Bay of Bengal was

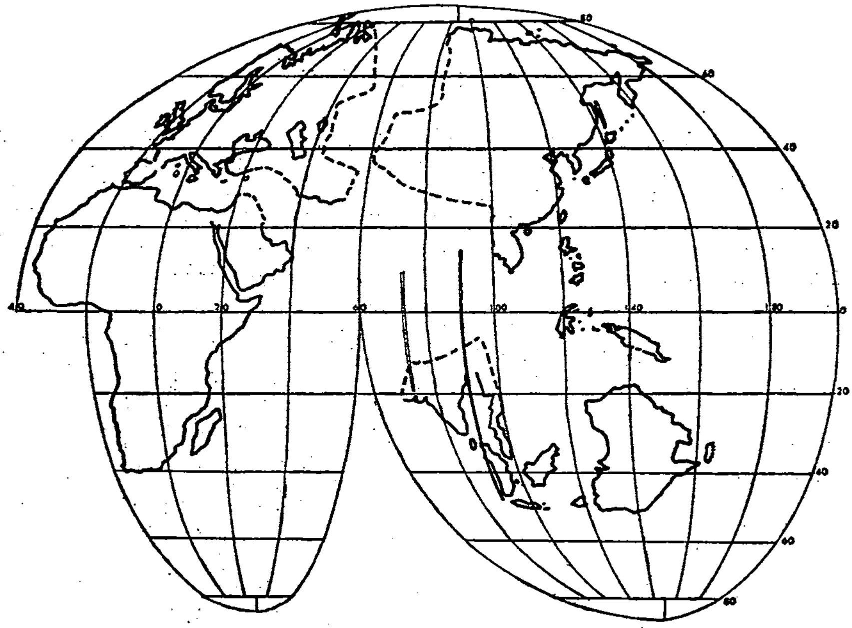

Fig. 4. Melville's reconstruction of the Tethyan region about mid-Cretaceous, showing much of Southeast Asia drifting northward with India. Reproduced by permission from Melville (1967, figure 2).

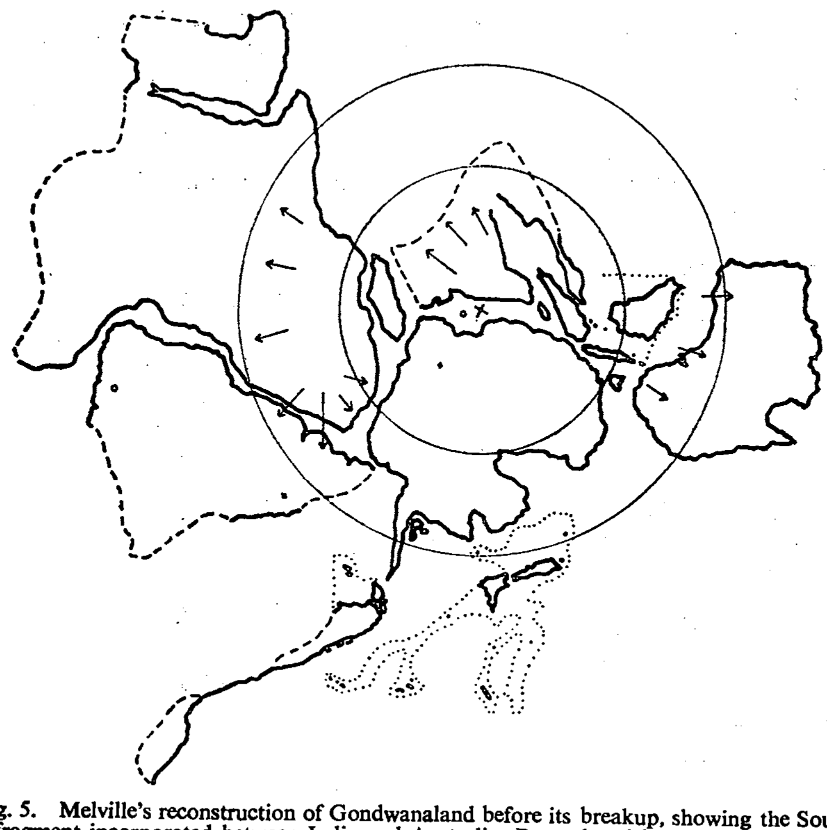

Fig. 5. Melville's reconstruction of Gondwanaland before its breakup, showing the Southeast Asian fragment incorporated between India and Australia. Reproduced by permission from Melville (1966, figure 2).

a sphenochasm formed as the Peninsula rotated away from India. Burton's arguments in favor of this proposal were: (1) the need for a Precambrian cratonic area to the west of Malaya in the Paleozoic; (2) the presence of India as the closest available craton; (3) the apparent fit of the two opposing coastlines; and (4) the presence of detrital diamonds in the late Paleozoic sediments of the Malay Peninsula and the occurrence of diamonds in Peninsular India.

If we look at Burton's reconstruction (Fig. 6) we note there is indeed a reasonable match. But this has been made on the present actual shorelines and takes no account of the broad continental shelf—up to 250 km wide—along the west side of the Malay Peninsula. Nor, as Burton points out, does it take account of the intervening basement rocks—partly Paleozoic—of Sumatra. The reconstruction leaves the structural trends in the Paleozoic and Mesozoic rocks of southern Malaya bumping straight into the supposedly Precambrian gneisses of Ceylon. Finally, the diamonds of Phuket in south Thailand are distinctive and different from the Indian diamonds (Grantham, in Mitchell, *et al.*, 1970), which in any case occur in southwest Mysore

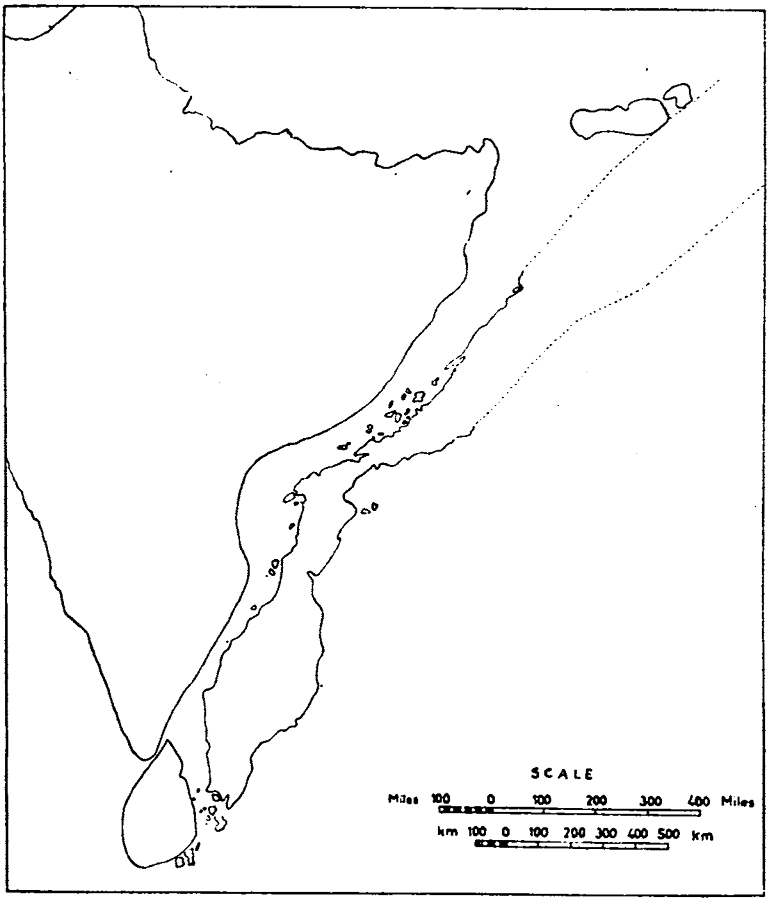

Fig. 6. Burton's proposed configuration of the Malay Peninsula, India, and Ceylon in the Jurassic. Reproduced by permission from Burton (1970, figure 2).

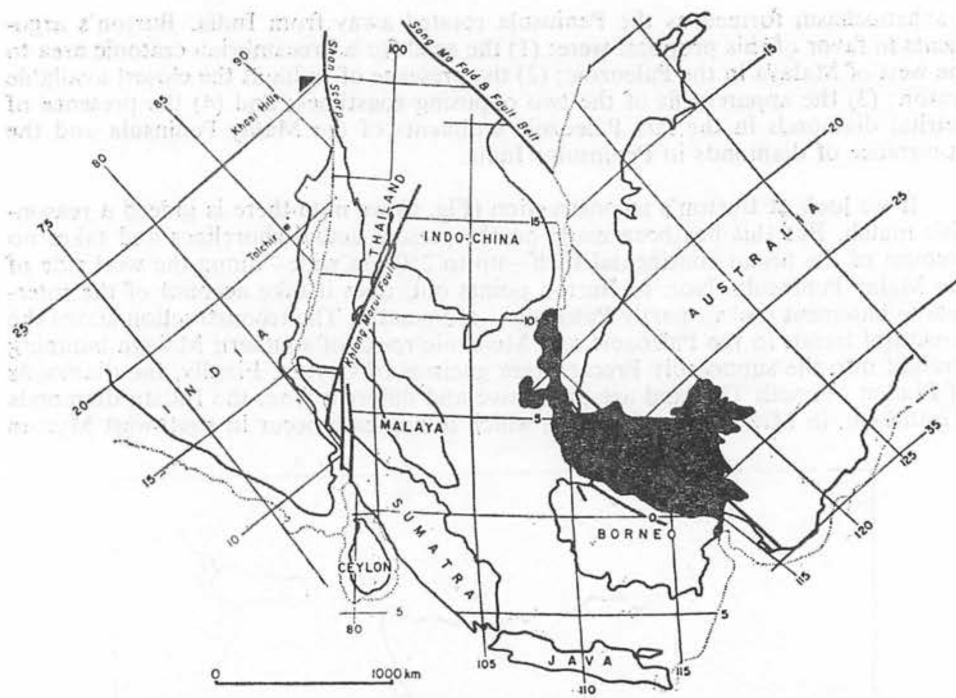

Fig. 7. Ridd's proposed fit of Southeast Asia into Gondwanaland before the latter's breakup. Boundary of stippled areas is the continental slope. Black area is overlap between Australia and northern (mostly Cenozoic) part of Borneo. Reproduced by permission from Ridd (1971, figure 2).

State, hundreds of kilometers from the portion which was supposed to have formerly adjoined Phuket (Crawford, 1973).

Ridd (1971, 1972) has made a more comprehensive proposal, fitting mainland Southeast Asia and the Sunda shelf region as a single block into Gondwanaland. In Ridd's reconstruction this block fits between India on the west (in much the same position as Burton suggested, but here retaining Sumatra and the continental shelf) and western Australia on the east. The fit (Fig. 7) is admittedly rather good, and even the large overlap in north Borneo is occupied by younger accretions and quite rightly disregarded. The fault displacements by which Sumatra has been made to fit the Indian margin are also quite possible, though certainly not established. This compelling reconstruction nonetheless meets, like Burton's, with serious difficulties (Stauffer and Gobbett, 1972).

The principal one is the incompatibility of late Paleozoic conditions in these juxtaposed areas. During the Permian both India and Australia suffered cool temperate to glacial climates in high southern latitudes, while all the evidence, as we shall see, points to Southeast Asia's being at that time in the tropics or sub-tropics and probably north of the equator. Ridd's reconstruction also makes it difficult to make sense out of former plate boundaries in the region. Several inferred sutures, marked by ophiolite belts of late Paleozoic and early Mesozoic age, cross portions of Southeast Asia, and these seem to imply the former existence of ocean basins which have closed by relative movement of parts of Southeast Asia. But in Ridd's reconstruction there is no room for such an ocean basin; rather the region is treated as a single rigid block unchanged in shape since early Paleozoic.

Apart from the geometric fit, and the need for a craton to the west of Malaya in the Paleozoic, Ridd's evidences for his reconstruction include the same diamonds mentioned by Burton, and some "Gondwana" floral elements in Thailand. The bulk of the floral evidence, as will be detailed below, is however heavily against this reconstruction.

Ridd's reconstruction has already been accepted and reproduced by Audley-Charles, *et al.* (1972), who incorporated it in their hypothesis of the development of eastern Indonesia.

Recently Tarling (1972) has given us another reconstruction of Gondwanaland (Fig. 8) in which again it is suggested that Southeast Asia occupied a position somewhere between Australia and India. Although no supporting evidence is given, Tarling's view was based on various published and unpublished opinions that this region has ties to Gondwanaland (D.H. Tarling, personal communication). So the tradition of looking always toward the classic Gondwana areas of the southern continents to find Southeast Asia's former relationships continues.

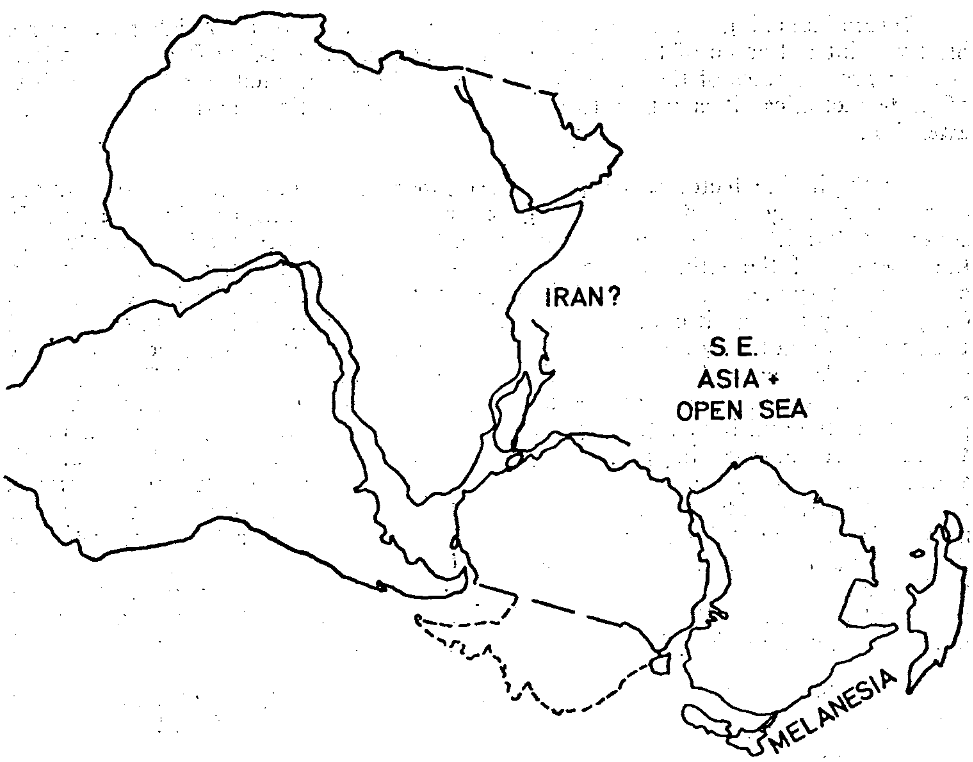

Fig. 8. Tarling's reconstruction of Gondwanaland, with Southeast Asia suggested to be somewhere near Australia. Reproduced by permission from Tarling (1972, figure 1).

Crawford (1973) has given a refreshing variation by suggesting that the Tibetan massif was the source of the geosynclinal sediments of Malaya, having been formerly adjacent to the latter and pushed to its present position by India. But even if correct, this hypothesis does not fully solve our problem, because the Tibetan massif by itself is far too small to have adjoined the whole length of the geosynclinal belt.

If, as I think can be shown, both Australia and India can be virtually ruled out as the craton formerly adjacent to Malaya, which craton was it then? What has been the history of Southeast Asia, what were its relationships to other areas, its travels over the globe?

Here you must not expect too much in the way of definite answers. It may be easier to cast doubts on previous proposals than to actually construct a more viable alternative. Nothing makes one appreciate the courage of people like Burton and Ridd better than getting immersed waist-deep in the same quicksand!

But I do feel that if we keep a balanced view of all the evidence and try to work backwards step by step towards earlier geologic times, we can at least identify some likely possibilities and label others as unlikely.

SOME GROUND RULES

Before launching into my own attempt to sort out Southeast Asia's past, let me briefly point out some of the principles of modern continental drift reconstructions —some ground rules of the game, if you like. I take for granted here the main ideas of plate tectonics; it is rather to some of their implications that I wish to draw attention.

Firstly, if plate tectonics ideas are correct, we may expect to find both separations of areas formerly united, and convergence, collision and merger of areas formerly separated. Traditionally, interest was concentrated on the separations involved in the opening of the Atlantic and the break-up of Gondwanaland, and the other, complementary phenomenon was ignored, except for the collision of India with Asia. Only a few years ago it could be suggested as a daring possibility "that continental drift produces not only the break-up of continents, which is the conspicuous feature of Wegener's theory, but also continental welding after collisions" (Irving, 1967, p. 73). In unravelling past movements, then, we must be prepared to take apart some present continental blocks (and lose their familiar shapes thereby) as well as to try to match broken edges in jig-saw puzzle fashion. Let me illustrate what I mean with another diagram by the botanist Melville (1966) in which he proposes a Jurassic continent in the middle of the present Pacific (Fig. 9). This proposed continent is made of snippets cut from various of the present-day continents. The geological evidence seems to be against this particular reconstruction, but the principle is valid and we should keep it in mind. In particular, Eurasia appears to be a composite continent (Hamilton, 1970; Kropotkin, 1971), and especially its eastern and south-eastern portions consist of many small fragments rafted together and amalgamated.

Secondly, in undoing plate motions by sea-floor spreading, we cannot always be sure whether two areas will have moved closer together, moved farther apart, or kept the same spacing. We can see why on a simple diagram (Fig. 10). Here we consider three possible situations. In the first the two areas A and B—micro-continents, perhaps—are on adjoining plates which meet along a rift or spreading line; here

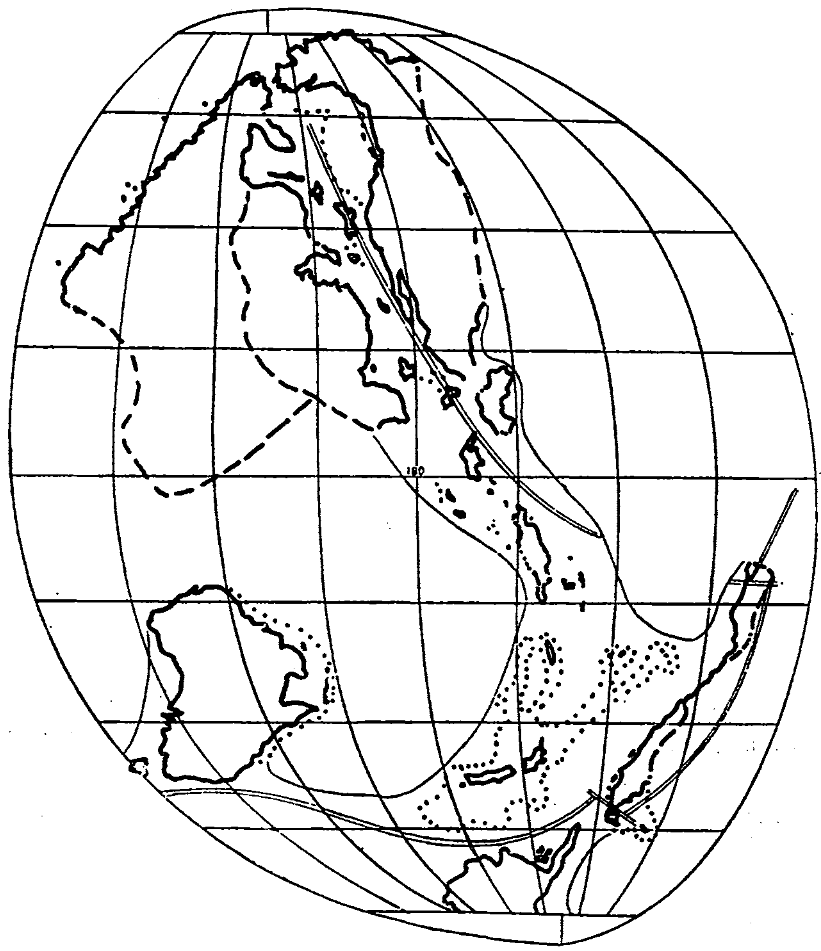

Fig. 9. Melville's proposed Jurassic continent of 'Pacifica', comprising fragments of Asia, North and Central America, and joined by an isthmus (whose edges are marked with a thin line) to the Antarctic and Australian portions of Gondwanaland. Reproduced by permission from Melville (1966, figure 3).

clearly A and B will move progressively farther apart. In the second case, A and B are on adjoining plates connected along a subduction zone; here just as clearly A and B will progressively converge. In the third case, however, where A and B are on non-adjoining plates and both kinds of boundaries occur between them, the situation is ambiguous: depending on the comparative rates of subduction and spreading, areas A and B might be converging, diverging, or—perhaps most likely in the situation as sketched—maintaining approximately the same spacing. It is important to remember these differences when postulating past movements of continents and continental fragments.

Thirdly, the movement of lithosphere plates on the spherical earth is in the form of rotations about axes which pass through the center of the earth. This means that

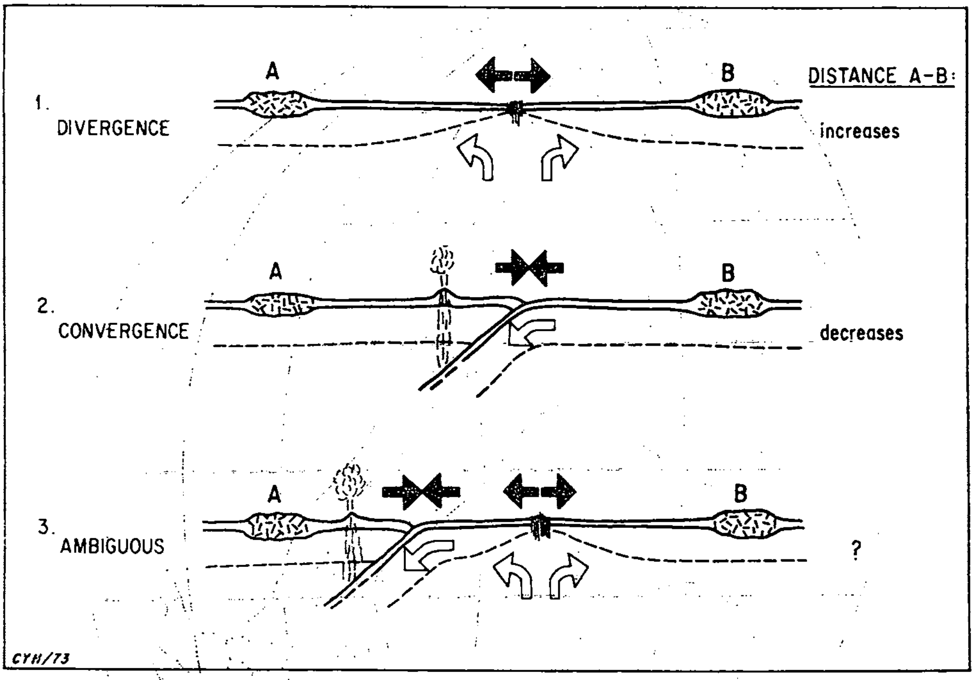

Fig. 10. Diagram illustrating the relationship of two areas ("A" and "B") separated by (1) divergent plate boundary, (2) convergent plate boundary, and (3) both kinds, showing that in the last case the change with time in their separation is ambiguous.

the rate of spreading or convergence (in cm/year) will vary along a plate boundary, and also that plates may undergo rotation relative to other areas of lithosphere. However, except perhaps for small areas caught along complex plate boundaries, this rotation will be slow and generally relatively minor. Complete turning around by 180° would require a very long time (save for apparent rotations produced by areas drifting over the pole). Something approaching a complete turn-around not in polar latitudes has been claimed for the Siberian platform (Kropotkin, 1971), and that is supposed to have occurred over more than 150 million years (from Middle Cambrian to Middle Devonian). For areas in high latitudes, the apparent rotation caused by polar wandering or drift over the pole may, of course, be more rapid and severe. But for areas in low latitudes this limitation on rotation is important in helping us to assign an area to the northern or southern hemisphere on the basis of paleomagnetic data.

Fourthly, we may keep in mind the distinction proposed by Wilson and Burke (1972) between the kinds of orogenies produced at a continent-ocean convergent plate boundary depending on which plate is more actively advancing relative to the deep mantle. To take the two extreme cases, if the continent is pushing forward and the oceanic plate is fixed, the result would be a Cordilleran-type orogeny within the continent, in which the shelf sediments become highly deformed; if the continental plate is fixed, the advancing oceanic plate would produce separate island arcs away from the continental edge, with commonly small ocean basins on their inland sides. As a corollary, a continent can have a Cordilleran orogeny on only one side at a time, but may have island arcs on two or more sides—as indeed we see in Southeast Asia today. It is interesting to note that today's distribution of orogenic zones of these two types suggests a general tendency of plates to move actively westward relative to the deep mantle, as already suggested (in fact considered to be obvious!) by Wegener and other early workers.

Lastly I would like to reiterate the admonition of Alfred Wegener which I quoted at the beginning. Each individual line of evidence which we may try to use to reconstruct past configurations carries its own limitation or ambiguity. The "fit" of continental edges is seldom so perfect that alternatives can be ruled out—this is seen in the continuing arguments over the placing of Madagascar, India, and Antarctica in Gondwanaland—and such broken edges may also be modified and distorted to unrecognizability by later tectonic activity. Paleoclimatic and paleontological evidence of former latitudes is very imprecise, because the distribution of deserts, glaciers, evaporites, and of the fauna and flora is influenced not only by latitude but also by the arrangement of lands and seas and the resulting patterns of water and air circulation; climatic zones have not always been positioned just as at present; and the paleoecology of fossil organisms is generally only poorly known. Paleomagnetism can provide values for paleolatitude, but by itself gives absolutely no information on paleolongitude, and the accuracy of its latitude estimates is admitted by its more honest practitioners to be only to within five or ten degrees at best. Even undoing sea-floor spreading gives unambiguous results only, as just pointed out, for areas on immediately adjoining plates.

It is therefore imperative, I feel, that any efforts to unravel the past movements and relationships of crustal plates, particularly in an area as complex as Southeast Asia, must make use of all lines of evidence which are available, balancing and integrating these to yield the most probable solution.

I want now to look at the different lines of evidence on the geologic history of Southeast Asia.

THE EVIDENCE I: GENERAL GEOLOGY

That Malaya and Southeast Asia may have a history related to the major continental blocks is most clearly suggested by the Lower Paleozoic rocks of this region. Although sedimentary rocks of that age have long been known from Burma and southwestern China, only through the work of the Malaysian Geological Survey over the past two decades have we come to realize that these Lower Paleozoic rocks form a long and coherent belt stretching from Yunnan and Szechuan Provinces of China, through northeast Burma and northwest Thailand, and down the Malay Peninsula at least as far as Kuala Lumpur. This hall is within a few kilometers of the southernmost known Lower Paleozoic fossil locality in Asia (Gobbett, 1964).

The distribution of Lower Paleozoic rocks in this region is shown in Figure 11. I have left off the map numerous occurrences of undated "crystalline schist", for instance on a number of the Indonesian islands, as most of these are likely to prove much younger than previously thought. I should mention, however, that there is one such area, of considerable size, at the southern end of Sumatra, which, if only because of its position, might well prove to be pre-Devonian.

On this map the belt of Lower Paleozoic rocks in the Malay Peninsula stands out very clearly, and its continuity northward into China is evident. This great belt

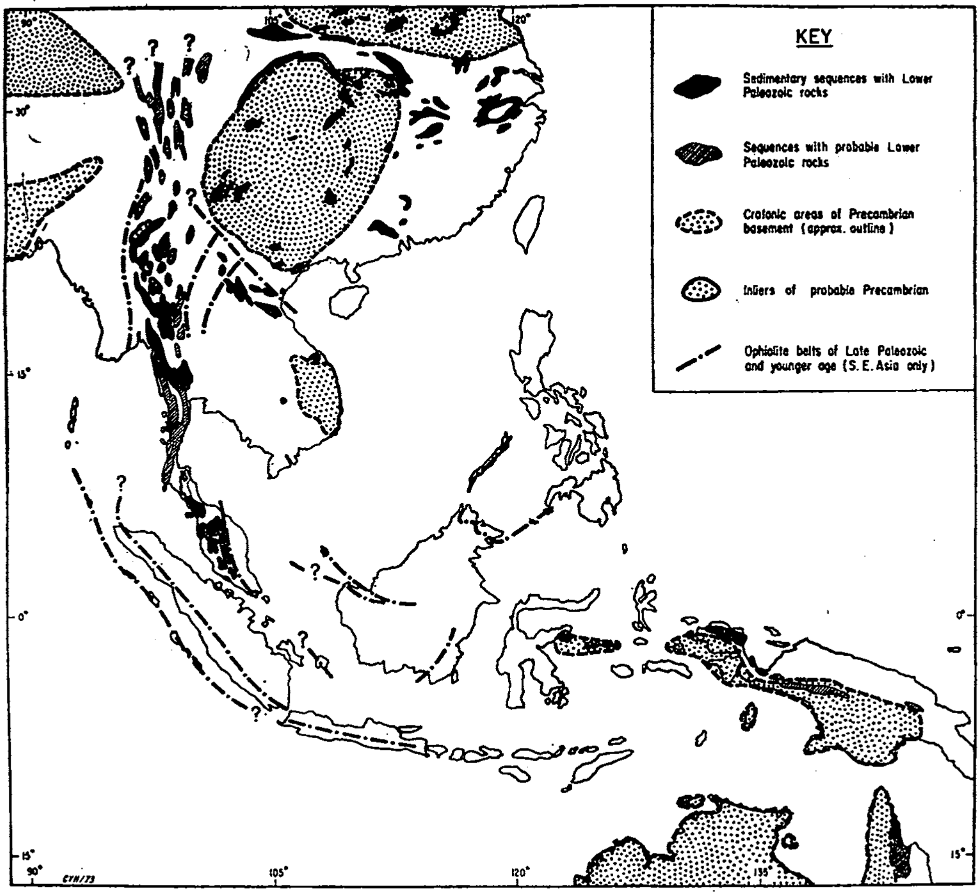

Fig. 11. Pre-Devonian rocks of Southeast Asia and adjacent regions. Data compiled from Audley-Charles (1968), Aung and Kyaw (1969), Baum, *et al.* (1970), Berry and Boucot (1973), Chang (1953), Fromaget, *et al.* (1971), Gobbett (1972a), Hamilton (1972), Javanaphet (1969), Klompé (1965), Saurin (1956), and United Nations (1959). Sizes of smaller areas exaggerated.
Also shown are the later ophiolite belts in Southeast Asia (after Hutchison, MS).

has been termed the Yunnan–Malaya Geosyncline by Burton (1967a), while the stratigraphy and facies of its Malayan portion have been interpreted by Jones (1968). It was Jones who pointed out that the rocks fall into north–south facies belts, ranging from "miogeosynclinal" shelf or platform facies in the west (characterized by Cambrian quartzose sandstones and richly fossiliferous Ordovician limestone) to "eugeosynclinal" facies in central Malaya (containing radiolarian cherts, basic igneous rocks, and thick sections of possibly deep water clastics), with a "geanticlinal" zone in between (including rhyolitic volcanics). To complete the pattern Jones postulated the former presence of a large continental landmass adjoining on the west, since rifted off and carried away—who knows where?

This deduction of a former western craton, which has been challenged by Mitchell, *et al.* (1970), is clearly crucial to interpretation of the region's past history, and if correct would make the Yunnan–Malaya belt possibly the largest "detached orogen" known. Hence I feel obliged to say a few words in justification of this idea, with which I agree. Jones (1968) felt the craton was necessary as a source for the quartzose sediments, and that it must be on the west because of the evidence of deep water "eugeosynclinal" facies to the east. To these reasons I might add a few more: In the northern portions of the belt there are some exposures of probable to nearly certain Precambrian gneisses, and these are concentrated toward the western edge of the belt (Fig. 11), suggesting the rise of the basement in that direction. Acid to intermediate volcanic rocks of Lower Paleozoic age are now known to be sporadically present in Malaya near the eastern edge of the belt, from northern Perak (Jones, 1970) south to central Selangor (Yew, 1971). Similar rocks of mainly Ordovician age are reported from the Bawdwin area of northeast Burma (Pascoe, 1959), and also (with age given as "Sil./Dev.") from southwestern China (Ch'ang, 1959). If this belt of volcanics is interpreted now as related to a past Benioff zone, it must have been a west-dipping one surfacing in the "eugeosynclinal" facies belt to the east, the only known likely site for an oceanic trench at the time.

Diamonds thought to be derived from mid-Paleozoic sediments in southern Thailand (Mitchell, *et al.*, 1970) and pebbles and boulders of granite from the same sediments there (Klompé, 1962) and in northern Malaya (Jones, MS) further suggest derivation from an area of Precambrian crystalline basement. Mitchell, *et al.* (1970) concluded from indirect evidence that these Paleozoic sediments in southern Thailand had an eastern source, but recent sedimentological studies in northwest Malaya (Ahmad Jantan, personal communication) indicate a western derivation.

Finally, last year's President of this Society, Dennis Taylor, pointed out in his Presidential Address (Taylor, 1974) that it probably requires many cycles of burial and partial melting to achieve ore concentrations of tin, which is therefore characteristically an economic mineral of old continental areas. This again implies the association of this region, so rich in tin deposits, with an ancient craton.

Accepting that the Yunnan–Malaya belt was rifted off a continent formerly to the west side of it, what can we say about that continent? Firstly, it was a large mass. The Lower Paleozoic belt stretches at least 3000 km and may have been greater originally. Secondly, because the stratigraphy in the belt starts with Cambrian quartzose sandstones of platform type, it must have been an area of primarily Precambrian crust. Finally, there must have been some diamond-bearing rocks. From these considerations we may conclude that the area we seek was one of the great Precambrian "shields"—either one still existing, or perhaps one now broken into fragments and scattered.

To the east of the portion of the Yunnan–Malaya belt containing Lower Paleozoic rocks is a zone lacking Lower Paleozoic rocks (Fig. 11). If Jones' interpretation is correct this should have been an area of oceanic crust in Lower Paleozoic time. The area is now more or less continental and is characterized by abundant Upper Paleozoic rocks (Fig. 12). The boundary with the Lower Paleozoic belt is marked by considerable tectonic deformation and by weakly developed ophiolite belts of Late Paleozoic age (Haile, in press; Hutchison, MS—see also Burton, 1967b; Gobbett and Tjia, 1973). The Lower Paleozoic Yunnan–Malaya belt forms one coherent block which I will call the West Malaya Block (including, rather doubtfully, all of Sumatra). The zone to the east, which is characterized by abundant volcanics, slope-deposited clastics, and scattered shallow-water limestone, I interpret as a possible island arc formed in Late Paleozoic times and welded onto the block to the

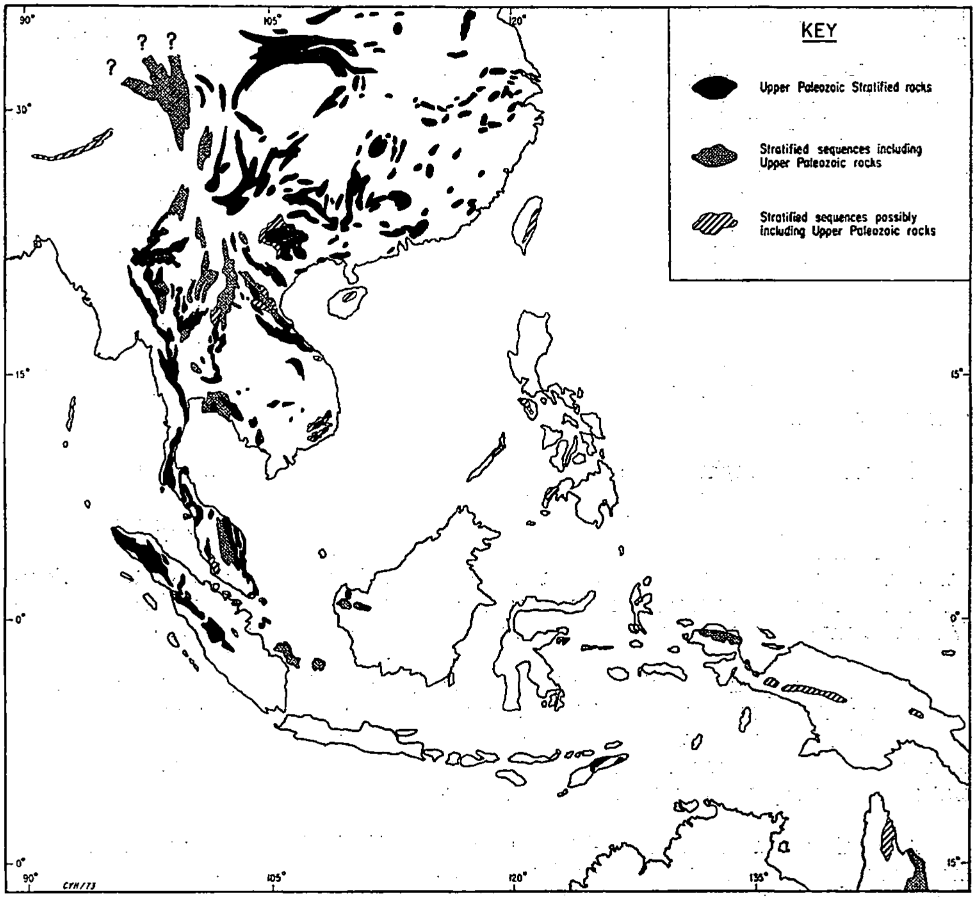

Fig. 12. Upper Paleozoic (Devonian-Permian) stratified rocks of Southeast Asia and adjacent regions. Data compiled from Audley-Charles (1968), Aung and Kyaw (1969), Chang (1953), Fromaget, *et al.* (1971), Gobbett (1972a), Hamilton (1972), Javanaphet (1969), Klompé (1965), Saurin (1956), and United Nations (1959). Sizes of smaller areas exaggerated.

west. This former island arc I shall call the East Malaya Block (including, again rather doubtfully, the western portion of Borneo).

To the east of the East Malaya Block in its northern portion is a long-stable micro-continent I will call the Indochina Block. It incorporates the 'Indosinia' of Fromaget (1941) but is here extended out to bordering ophiolite belts. This block has a crystalline basement (in the "massif du Kontum", see Saurin, 1956) for which there is now radiometric evidence of a basically Precambrian age (Hurley and Fairbairn, 1972). Associated with this basement are a number of occurrences of Lower Paleozoic sediments (Fig. 11). The boundary with the East Malaya Block is marked by an ophiolite belt of Permo-Triassic age (Hutchison, MS).

To the northeast, this Southeast Asian cluster of micro-continents is bounded by a major suture marked by abundant ophiolites (the Song Ma—Black River line-see Fromaget, *et al.*, 1971), on the other side of which is the much broken and disturbed but basically Precambrian South China platform, with its covering and fringing sediments including Lower Paleozoic. The Song Ma suture is Permo-Triassic in age. Thus Permo-Triassic represents the time when the conjoined West Malaya and East Malaya Blocks collided with Indochina and with South China. Since then these four units have behaved essentially as one block, though some internal displacements by strike-slip faulting have undoubtedly occurred.

On their other margins the Southeast Asian blocks are clearly truncated and show no continuation. To the west and south are oceanic crust, of Cretaceous to Tertiary age (von der Borch, *et al.*, 1972), and a major active plate boundary marked by subduction and transform faulting.

To the southeast and east we have the archipelagoes of eastern Indonesia and the Philippines. Within this vast area, composed of island arcs and intervening small oceanic basins, we find no Lower Paleozoic rocks until we reach New Guinea, where a considerable section of Lower Paleozoic represents a 'geosynclinal' zone marginal to the old Australian continent (see compilations of Visser and Hermes, 1962, and Purbo-Hadiwidjojo, 1963). This Paleozoic belt includes rocks as old as Ordovician (Kobayashi and Burton, 1971), but no Cambrian is yet known from New Guinea.

It is at first sight tempting to regard the truncated western end of the New Guinea Paleozoic belt as the displaced continuation of the West Malaya Block, and therefore to suggest that Australia was the formerly adjoining craton. But there are a number of strong reasons against this identification, some of them already mentioned. Even the general similarity of the Paleozoic history of eastern Australia (Brown, *et al.*, 1968) to that of Malaya is no strong argument, since under the plate tectonics theory some degree of regional or even worldwide synchronism of tectonic "pulses" is to be expected. One could show equally striking similarities of history between Malaya and the Appalachians of North America.

There are a few more occurrences of Upper Paleozoic rocks known in the Philippines and eastern Indonesia (Fig. 12). Those in the southwestern Philippines may in part represent actual fragments of old continent rafted out from mainland Asia to their present position, perhaps as part of the process of formation of the marginal basins such as the South China Sea (Karig, 1971). Those in eastern Indonesia represent very old island arc remnants or the marginal facies of the Australian continent (Audley-Charles, 1968). There is again no real continuation of the older geology of Southeast Asia. Klompé (1961) some years ago already pointed out the fundamental geologic difference between 'old' western Indonesia, here included in the Southeast Asian cluster, and 'young' eastern Indonesia, the two approximately separated, perhaps not so coincidentally, along the famous zoogeographical boundary of Wallace's Line (Wallace, 1869), though the geologic line is probably better taken through the 'neck' of central Sulawesi, rather than to the west of that island (C.K. Burton, personal communication). It is now generally agreed that these two halves of Indonesia have quite separate geologic histories (Audley-Charles, *et al.*, 1972).

I might note here that the better-known Upper Paleozoic occurrences in Sumatra, in the Djambi area (see van Bemmelen, 1970) and other parts of central Sumatra (Katili, 1968), have a character very similar to the East Malaya belt, although they now lie to the west of it, possibly as a result of strike-slip faulting. The "hammerhead" shape of the southern end of the Malayan blocks may be the result of considerable slicing and strike-slip movement in response to north–south plate convergence (as, indeed, such faulting is currently active in Sumatra today—see Katili, 1970, Posavec, *et al.*, 1972).

Ignoring such complications, we see that Southeast Asia and western Indonesia comprise a cluster of three blocks (Fig. 13): (1) the West Malaya Block, which represents an old continental margin underlain by Precambrian basement; (2) the East Malaya Block, which formed in Late Paleozoic times, probably as an island arc never far removed from the continental edge and welded to it by the end of the Paleozoic; and (3) the Indochina Block, an independent Precambrian-floored micro-continent which collided with the other two in Permian or Triassic.

These then are the pieces of the puzzle whose past movements and histories we must try to elucidate and whose origin we wish to learn.

Some clues to past movements can be derived from the evidence of past plate-boundary activity contained in the rocks of these areas. I have already mentioned

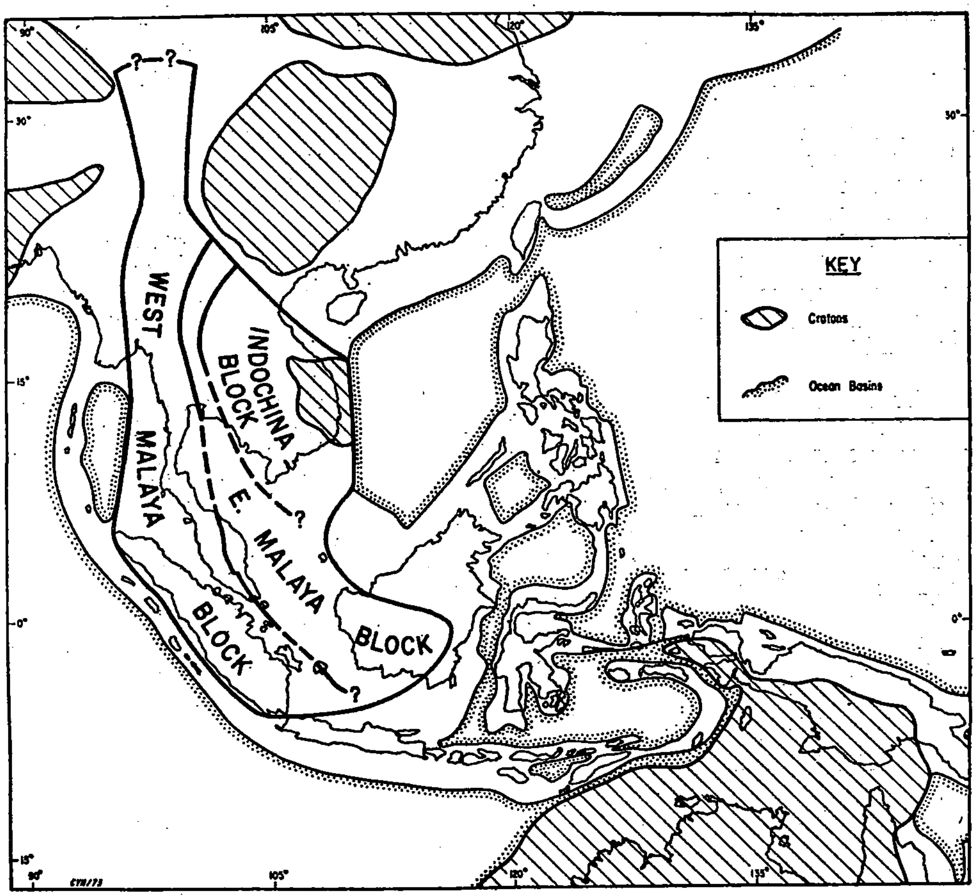

Fig. 13. Outline structure of the Southeast Asian region showing the three smaller blocks which make up Sundaland and mainland Southeast Asia. Also shown are the present ocean basins and cratonic (essentially Precambrian) areas, based on Figure 15.

the Lower Paleozoic volcanism which argues for westward (relative to present north) subduction of oceanic crust under the West Malaya Block in that time. The Carboniferous seems to have been a time of active orogenic movements in the West Malaya Block, giving rise to a widespread unconformity (Koopmans, 1965; Burton, 1966; Yeap, 1969; Wong, 1970) which now seems to be most likely early Carboniferous in age (Sarkar, 1972; Yancey, 1972); to the formation of terrestrial red bed sequences, commonly conglomeratic (Haile and Stauffer, 1973); and to considerable granitic magmatism (Bignell and Snelling, 1972; Baum, *et al.*, 1970; Hutchison, 1973b).

The Permian is marked by andesitic to rhyolitic volcanism in the East Malaya Block, representing what may have been an offshore island arc formed in relation to continuing westward subduction underneath the edge of the continent, though with the site of subduction migrating to the east. The abundance of relatively acid volcanic and intrusive igneous rocks within this belt does suggest, however, that some old silicic crust may have been present in the area. Permian andesitic volcanism in central Sumatra, in an association of rocks very similar to eastern Malaya (Katili, 1968) may perhaps be interpreted as an offset southern continuation of this possible island arc; in its present position it is anomalous, as Katili points out. It should be noted that some rhyolites in the Main Range (Haile, 1970) and some granites at scattered sites in western Malaya (Hutchison, 1973b) may also be of Permian age.

Applying the hypothesis of Wilson and Burke (1972), we may surmise that during late Paleozoic time the craton was comparatively fixed relative to the deep mantle, while the oceanic plate to its east was actively advancing, causing the formation of an offshore island arc. By contrast, in the earlier Paleozoic the volcanic belt was apparently within the continental plate, and in Triassic time widespread and intense tectonic deformation and acid igneous activity spread across the breadth of Malaya, these conditions possibly indicating active advance of the continental plate at those times. The extent and intensity of Triassic orogenic events may alternatively, however, be a consequence of the postulated series of collisions between micro-continents.

Probably in Permian time, the island arc of the East Malaya Block collapsed or was compressed against the West Malaya Block. Orogenic activity continued into the Triassic, with a culmination of granitic magmatism indicated in the middle Triassic (Bignell and Snelling, 1972). All of this activity, from early Paleozoic through Triassic time, may be related to a single westward-dipping subduction system, essentially continuous during this period, though sporadic in activity, and generally migrating eastwards. I do not see any good evidence for the existence of simultaneous or alternating Benioff zones of opposed dips in the later Paleozoic and Triassic, as postulated by Hutchison (1972).

By the end of Triassic, the Indochina Block had collided with the East Malaya Block, and the South China platform had collided with the whole Southeast Asian cluster. These collisions appear to have caused a cessation of subduction within the region, leading to widespread uplift, formation of extensive continental deposits (Koopmans, 1968; Smiley, 1970; Borax and Stewart, 1965), and amalgamation of the entire region from Sumatra to South China into a single block which has remained relatively stable ever since.

The Jurassic was a quiet period for Southeast Asia. There is no evidence of any kind of plate boundary activity in this region. Jurassic rocks of Southeast Asia are either continental sediments (e.g. the Khorat Group, Tembeling Formation, Gagau

Group, Upper Indosinias) or shallow marine sediments such as the Bau Limestone in Sarawak and Jurassic limestones in Sumatra, these marine sediments occurring only on the edges of the consolidated block of Southeast Asia. Yet the Jurassic is the key period, as it was probably during this time that Southeast Asia rifted off from its craton and drifted unknown distances on a moving plate of lithosphere. This I conclude because until some time in the Triassic the region was the site of converging plate boundaries, and from Cretaceous on we have good evidence that the region no longer adjoined a craton on its western side.

In the late Cretaceous we find again evidence of convergent plate boundaries, but now on more than one side of the Southeast Asian block. A Cretaceous subduction and volcanic-magmatic arc occurs along the entire southern boundary from Sumatra to Kalimantan (Katili, 1972). Southward subduction is indicated at this time in west Borneo (Haile, in press). A late Cretaceous to early Tertiary thermal event, probably including scattered granitic magmatism, is recognized down the west side of the West Malaya Block from North Thailand (Baum, *et al.*, 1970), through South Thailand (Burton and Bignell, 1969), and then along western Malaya adjoining the Malacca Straits (Hutchison, 1973b). This last section is anomalous in being so far back from the contemporaneous magmatic arc in Sumatra and hence very far from the inferred trench and subduction zone. But if we postulate large right-lateral strike-slip along the line of the Malacca Straits or within Sumatra (such as would appear necessary to place the Permian volcanics in their present position), one can imagine this section also to have formed near the western edge of the continental block.

During Tertiary times, subduction has continued on the southern edge of Southeast Asia, and on the east and northeast it has stepped back and produced the complicated arc structures of eastern Indonesia and the Philippines, while convergent activity seems to have been generally absent on the western side. Here instead we had the late Tertiary rifting off of the Andaman-Nicobar Islands, which had formed as sedimentary wedges along the edge of the continental crust of Southeast Asia (Rodolfo, 1969). The oldest known sediments in the islands are Cretaceous, again indicating that by that time the old craton was no longer adjacent to Southeast Asia. This rifting off of the continental edge, which opened out the Andaman Sea oceanic basin as a small rhombochasm (Rodolfo, 1969), may have been related to changes in the direction of movement of plates in the Indian Ocean region occasioned by the major collision of the Indian shield with mainland Asia. That collision was apparently a Middle Miocene event (Gansser, 1964), using the recently revised ages of the Miocene (Couvering and Miller, 1971; Gill and McDougall, 1973).

Possibly associated with these movements was the extensive strike-slip faulting in the Malay Peninsula (Tjia, 1972), where most of it is left-lateral (Shu, 1969) and some movement probably has occurred in very late Tertiary or even Quaternary time (Stauffer, 1968), and in Sumatra, where right-lateral movement continues today (Katili, 1970; Posavec, *et al.*, 1972).

This geologic evidence, summarized so briefly here, serves to outline Southeast Asia's tectonic position in past times, and also tells us something about the craton from which this region was rifted off, probably in Jurassic time. Let us now turn to other lines of evidence which might indicate directly the former latitudes and positions of Southeast Asia and throw light on its relationships with other regions.

THE EVIDENCE II: PALEONTOLOGY AND SEDIMENTARY FACIES

Indirect evidence of paleolatitudes and of former geographic arrangements can be obtained from the character of fossil faunas and floras, and from the facies of ancient sediments. This evidence is of several kinds:

(1) Plants and animals are dependent on climate in their distribution, and the primary control of climate is latitude—the major climatic zones are essentially latitude belts. Not only are different organisms adapted to different conditions of temperature and (for land organisms) humidity, but warmer areas also show a richer assemblage, that is, a greater diversity of types (witness the hundreds of species of 'common' trees in the Malaysian rain forest in contrast to the few types which comprise the great cool-temperate forests).

(2) Fossil assemblages also are indicative of connections between areas. Very similar marine assemblages imply a sea connection; dissimilar contemporaneous ones suggest an intervening land barrier. Terrestrial assemblages give similar indications about land connections and sea barriers. Such interpretations must, of course, take account of the paleoclimates of the areas compared and the varying capabilities of migration possessed by different organisms.

(3) Certain kinds of sediments—particularly certain chemical and organic deposits—form preferentially under limited ranges of temperature and humidity, and hence in approximate terms, of latitude. Interpretations of paleolatitude based on sediments fell into disrepute because of much oversimplification and consequent error in the past. But recent work (Briden and Irving, 1964; Briden, 1970b) tends to verify the basic principle. In general one can say that thick carbonate deposits formed mainly in latitudes of less than 45°, dolomites, organic reefs, and desert sandstones in latitudes less than 30°, and Paleozoic evaporites also within 30° of the equator. There are complications: Carboniferous coals formed generally within 20° of the equator, while Permian (Angara and Gondwana) and later coals formed mainly in high latitudes, greater than 50°. Permian desert dunes occur in paleolatitudes mainly less than 10°, indicating an equatorial arid belt at that time. Mesozoic evaporites formed in latitudes of 10°–30° in the main, while Cenozoic ones formed mainly in 20°–50° of latitude. Finally, redbeds, formerly thought to be mainly the product of low latitudes, have been shown to have formed over a wide range of climate and latitude and to be in themselves useless as paleolatitude indicators (Briden, 1970b).

Allowing for such complexities, the occurrence of these sediment types can be used as very rough guides to probable paleolatitudes.

(4) The work of Seibold (1970) indicates that marginal seas around continents in humid and arid climatic belts will have markedly different water circulation patterns, the former highly conducive to the production of an euxinic bottom environment and hence to the deposition of carbonaceous sediments of the 'black shale' type. By contrast, circulation in arid areas will tend to keep the bottom environment oxidizing and hence lead to deposition of 'clean', non-carbonaceous sediments. Allowing again for various complicating factors, one can take a great abundance of euxinic-type sediments as a strong suggestion of humid climate, while their marked absence over a variety of marine facies suggests an arid one.

Using these admittedly imprecise criteria, let us see what the record from Malaya and adjacent areas can tell us about past climates and past latitudes.

Cenozoic

Cenozoic sedimentary rocks in the Malay Peninsula are limited to the Neogene and Quaternary and their character generally indicates conditions similar to present. The Neogene lignite-bearing basins of Malaya, probably late Miocene or Pliocene in age (see Stauffer, 1973), have yielded an assemblage of plants characterized by modern types but which has been interpreted to indicate possibly a somewhat drier climatic regime than at present (H.N. Ridley, quoted in Scrivenor, 1931, p. 115). The presence of significant numbers of relatively fresh feldspar grains in the early Quaternary(?) "Older Alluvium" of Singapore (Burton, 1964) has also been interpreted as suggesting a somewhat drier climate (Tai, 1972). This change in climate, if real, might relate to global changes in climatic distribution in the late Cenozoic, to possible changes in the latitude of Malaya, or to some combination of these causes, I have not studied the Cenozoic deposits of other parts of Southeast Asia, which might reveal better evidence of paleoclimates.

Mesozoic

Continental deposits of later Mesozoic (Jurassic and Cretaceous) age form extensive cappings in eastern Malaya (Burton, 1973), eastern Thailand (Borax and Stewart, 1965; Javanaphet, 1969), and parts of Indochina (Fromaget, *et al.*, 1971). Fossil plant assemblages from these rocks in Malaya have been interpreted to indicate a warm climate with a prolonged dry season, such as is found today in parts of Indochina and Thailand some 10° of latitude to the north (Smiley, 1970). Eastern Thailand appears to have had a fully arid climate, for here we have thick salt deposits (probably formed in inland lakes) in the Jurassic (Jacobson and Japakasetr. 1965) and desert dune sands in the Cretaceous (Borax and Stewart, 1965). Such desert deposits in the Mesozoic suggest a probable paleolatitude of 10°–30° (Briden and Irving, 1964); their present latitude is 17°–18°N. Thus there is a suggestion that Southeast Asia in the later Mesozoic was either somewhat farther from the equator than at present, or was turned so that both Malaya and Thailand could be simultaneously in relatively arid climatic regimes.

Late Paleozoic (Carbo-Permian)

For the Carboniferous and Permian periods there is an abundance of sedimentologic and paleontologic evidence on former climates and latitudes, both for the Southeast Asian region and for the major continents throughout the world. The evidence falls into definite patterns, indicating a grouping of areas into the supercontinent of Gondwanaland, and the arrangement of these and other areas into climatic zones.

Let us first look at the late Carboniferous and Permian floras. In contrast to earlier times, we see in these periods distinctly differentiated floral provinces (Seward, 1933). The most famous of these is the "Gondwana" flora characterized by *Glossopteris*, which occurred in South America, Africa, India, Australia, and Antarctica, the land masses which are thought to have been then joined together to form Gondwanaland. Other major floras of these periods (particularly the Permian) were the Euramerican (western Europe, Greenland, eastern North America), the Angaran (western Siberia and parts of central Asia), and the Cathaysian (Korea, China, Japan, Southeast Asia). In southwestern North America occurred a group of floras sometimes included with the Cathaysian, or alternatively regarded as constituting a separate North American province. These floral provinces are shown in Figure 14.

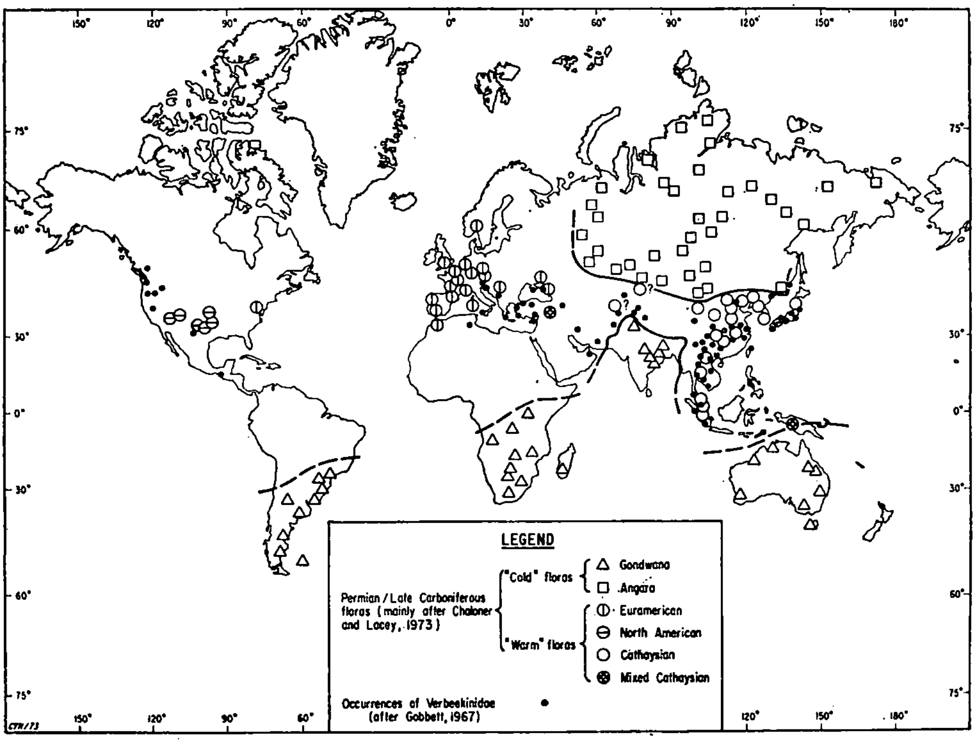

Fig. 14. Early Permian/Late Carboniferous floras (after Chaloner and Lacey, 1973), with the Late Permian Cathaysian floras of Malaya and Thailand added. The sites of some mixed floras mentioned in the text are shown. Also indicated is the distribution of the Verbeekinidae (after Gobbett, 1967), a Permian foraminifer group serving to show the approximate extent of the Tethyan marine faunal province.

Because the occurrence of *Glossopteris* has been one of the lines of evidence used to reconstruct the fragments of Gondwanaland, there has sometimes been a tendency to think of each of these floras as simply characterizing one separate landmass or former continent: Gondwanaland, Cathaysia, Angaraland. This tendency is shown by Melville (1967) who, because no *Glossopteris* is known from the northern part of South America, suggested that the area north of the Amazon River had not been part of Gondwanaland.

But I think the evidence is strong that the distribution of these floras was controlled by climate as well as land connections. The Gondwana and Angara floras appear to have been cool temperate ones, characterized by paucity of taxa and by strongly marked growth rings in woody stems; the Cathaysian, Euramerican, and North American floras appear to have been tropical or subtropical ones showing greater diversity of taxa and whose trunks and woody stems lack the growth rings evidencing seasons (Seward, 1933; Kobayashi and Shikama, 1961). As will be seen later, the cool temperate nature of the Angara and Gondwana floras is quite consistent with paleomagnetic and other evidence indicating the proximity of the land areas involved to, respectively, the north and south polar regions. The interesting question is the relationships of the Euramerican, North American, and Cathaysian floras, which all appear to represent similar warm climatic conditions and yet which are taxonomically distinct. It may be that they represent different portions of the warm belt—equatorial versus subtropical, perhaps. But more probably their differences may be due to separation by physical barriers, in much the same way as the present tropical forests of South America and Asia are very largely distinct at the generic level and almost completely so at the specific level.

Plotting the distribution of these Permian floras on the present geography gives a pattern (Fig. 14) which makes little sense. Considerable movement of continents and parts of continents is evidently required to bring the plants into a coherent and reasonable pattern.

A number of later Paleozoic floras are known from Southeast Asia. The known Carboniferous floras are no help to us because they are mainly Lower Carboniferous and no clear floral provinces appear to have existed in that time. But the Permian ones, including several very recently described, add much to our evidence. Permian floras from Sumatra (Posthumus, 1927; Jongmans and Gothan, 1935), Malaya (Kon'no and Asama, 1970; Kon'no, *et al.*, 1971), and Thailand (Kon'no, 1963; Asama, 1966) all belong quite clearly to the Cathaysian floral province, though the Sumatran Djambi flora, which is early Permian, shows affinities with the Euramerican Carboniferous flora, while the Malayan floras, which are late Permian, show close relationships to the typical northern Cathaysian floras of China.

In a basically Cathaysian flora of probable late Permian age in Thailand, Kon'no (1963) identified *Glossopteris* and another typical "Gondwana" genus, each from a single fragmentary and poorly preserved specimen. Kon'no thought these must be stray migrants from Gondwanaland. Asama (1966), who recollected the site, was unable to find any more of these forms, but his work did confirm the Cathaysian character of this Thai flora. Asama suggested that the "Gondwana" forms might have resulted from parallel evolution of leaf shapes. The two rather rich late Permian floras described recently from Malaya (Kon'no and Asama, 1970; Kon'no, *et al.*, 1971) contain not a single form suggesting any ties with the Gondwana flora. In spite of all this, the two fragmentary Thai fossils assume great importance in Ridd's (1971) argument that Southeast Asia was part of Gondwanaland.

Melville (1966) also placed Southeast Asia into Gondwanaland, mainly on the basis of a single old report of *Glossopteris* from Borneo, presumably the same one which van Bemmelen (1970) dismisses as an early erroneous report.

Thus the Permian floras of Southeast Asia show affinities with eastern Asia and in spite of (present) close proximity to India, no forms, other than two fragmentary and doubtful specimens, suggest any relationship to the Gondwana flora.

Elsewhere, mixtures of the Carbo-Permian floras have been reported. In New Guinea, a basically Cathaysian flora of late Carboniferous age is associated with a few Gondwana elements (Jongmans, 1940). Admixtures of Euramerican elements have been reported from the Gondwana floras (generally Carboniferous) of South America (Lundquist, 1919) and southern Africa (Walton, 1929). These floras are Carboniferous or early Permian, and their Euramerican elements may represent survivors from the more cosmopolitan earlier Carboniferous floras.

Most interesting is a flora reported from the Hazro area of southeastern Anatolia (Wagner, 1958). This flora, which is Middle to Upper Permian in age (i.e. approximately contemporaneous with the Malayan Permian floras) is basically a Cathaysian flora, including the forms *Gigantopteris nicotianaefolia*, *Lobatannularia*, *Taeniopteris*, *Pecopteris*, and others. The flora also contains fossil leaves which Wagner identified as *Glossopteris* and one or two other elements of the Gondwana flora, as well as one form typical of the Euramerican flora, and one possible specimen of a typical member of the Angara flora. Though the identification of the "Gondwana" forms in the Hazro flora is not fully certain (see discussion at the end of Wagner, 1958), the basically Cathaysian character of the flora is not in doubt. Equally important is the fact that the site, at about 38°N, 41°E, is on the edge of the Arabian–African craton, south of the major suture which arcs across Anatolia (Yanshin, 1966) and which forms the actual boundary of the craton. This suture seems to have an age of early Tertiary, judging from the rocks reported from it (Brinkmann, 1972). From Anatolia down to South Africa there is no sign of collision sutures of Phanerozoic age, and hence this has been one block all during that time. Therefore the Hazro flora grew on what was physically part of the continent of Gondwanaland, even though the flora itself belongs to the Cathaysian floral province. This again emphasizes the fundamental control of climate, rather than merely land connections, in the distribution of Permian floras.

It might be noted here that by the Triassic, more extensive migrations and mixings had occurred in the floras, elements of the Gondwana flora spreading to Indochina (Gothan and Weyland, 1954) and Siberia (Seward, 1933), areas previously in the Cathaysian and Angaran provinces. While these floral migrations may have required some changes in climates, the occurrence of *Lystrosaurus*, a typical Gondwana reptile, in the Triassic deposits of Singkiang argues for definite land connections between Gondwanaland and more northerly areas (Simpson, 1970). As will be shown later, these land connections could have come about as a result of the series of collisions involving Southeast Asia.

Upper Paleozoic marine invertebrates tend to affirm the tropical or subtropical position of Southeast Asia at that time. The Permian faunas of the region belong to the Tethyan province (Gobbett, 1972b), generally regarded as a warm-water region. Distribution of the Verbeekinidae, a group of Permian fusulinacean foraminifera (Gobbett, 1967) also defines the Tethyan region, or at least a warm-water belt around the earth, conspicuously *not* including the major components of Gondwanaland known or thought to have been cold (Fig. 14).

The abundance of calcareous sediments in the Upper Paleozoic of Malaya (Gobbett, 1973) and Southeast Asia in general argues for a position of these areas in low latitudes. In particular the richly fossiliferous and generally quite clean Permian carbonates (Suntharalingam, 1968; Gobbett, 1968; Rajah, 1970) indicate warm-water conditions and possibly an arid climate, which could have been in equatorial latitudes, judging from the distribution of Permian desert sandstones (Briden and Irving, 1964).

This evidence for warm conditions and low, possibly equatorial latitudes for Southeast Asia in the Upper Paleozoic, especially Permian, is a strong argument against placing the region into Gondwanaland in a position such as suggested by Melville (1966), Burton (1970), or Ridd (1971). Any of these suggested positions would put Southeast Asia in very close proximity to the evidences of Permian glaciation in India (Ahmad and Khan, 1964), Australia (Crowell and Frakes, 1971), or both.

Earlier Paleozoic

For the earlier periods of the Paleozoic there is less decisive evidence on the paleoclimates and paleolatitudes of the Southeast Asian areas. The Devonian, at least in Malaya, is not well documented, but includes apparently mainly clastic sequences, often thin and locally replaced by unconformities, but does include some poorly fossiliferous carbonates (Gobbett, 1973).

The Silurian and Ordovician, on the other hand, are represented commonly by carbonate sequences, sometimes richly fossiliferous (Jones, 1973). In particular the Ordovician limestones of the Malay Peninsula (the Setul Formation and correlatives) show a rich and diverse fossil assemblage. The Setul Formation is also black and highly carbonaceous, and some of the contemporaneous sediments in Malaya, Thailand, and Burma are graptolitic black shales. If the rich diversity of fossils can be taken to indicate warm-water conditions, and the abundance of carbonaceous sediments a humid climate, then in the Ordovician we again have a hint of low to equatorial latitudes.

The known Cambrian rocks, mainly quartz sandstones and finer clastics, merely indicate supracratonic "platform" conditions and have so far given no real evidence of climate or latitude.

Thus we see that the paleontological and sedimentary evidence suggests that Malaya (and for at least the latter part of its history also the rest of Southeast Asia) has occupied relatively low latitudes repeatedly and possibly more or less continuously during the Phanerozoic.

Independent and perhaps more definite and precise indications of paleolatitudes can be obtained from paleomagnetic studies of Southeast Asian rocks, a line of evidence I want to look at next.

THE EVIDENCE III: PALEOMAGNETISM

Southeast Asia is a region where until recently there was a total absence of any paleomagnetic determinations to help in unravelling past movements of lithosphere plates. Some preliminary results were reported from Malaya last year (Haile and McElhinny, 1972), which have since been strengthened by further work (N.S. Haile, personal communication). These results fall into two rather clear groups, of different ages, giving two different sets of virtual poles.

The younger group, considered Mesozoic by Haile and McElhinny, gives a mean virtual pole at 48°N, 32°E, and thus a paleolatitude for Kuala Lumpur of about 20°. The older group, considered late Paleozoic (Carbo-Permian), gives a mean virtual pole at 54°N, 158°E, with a paleolatitude for Kuala Lumpur of about 21°. Both of these pole positions indicate rotation of the Malay Peninsula (one clockwise, the other counterclockwise), and if one assumes the minimum rotation, the paleolatitudes indicated would be in the northern hemisphere.

The actual age ranges covered by these two sets of determinations are open to some doubt. The younger set includes the basalt flows at Segamat and basic dykes near the similar flows at Kuantan, both of which occurrences of lavas have generally been thought to be Cenozoic in age, possibly even Quaternary (Stauffer, 1973). This set also includes other rocks which are certainly older. The older set includes some rocks definitely Carboniferous or Permian in age, but also others which may be

Permo-Triassic. In general, age control for these Malayan specimens is not very good.

It is interesting to compare these determinations with those from southern and southwestern China listed by McElhinny (1969). If, as inferred earlier, South China and the Southeast Asian cluster have been united and have behaved as a single block since the Triassic, paleomagnetic determinations on Mesozoic and Cenozoic rocks from anywhere with this block might be expected to be consistent and to apply to the entire block. Three poles (McElhinny's numbers 36, 37, 38) from Tertiary redbeds ("Oligocene-Miocene?") in Hunan, southern China, would give Malaya a paleolatitude very similar to that indicated by Haile and McElhinny's "Mesozoic" pole set, but with somewhat less rotation out of present orientation. On the other hand, McElhinny's (1969) poles from southern China for the Cretaceous (numbers 57 to 61) and Jurassic (numbers 72 to 76) give positions for the Southeast Asian blocks within 10° of paleolatitude (one on either side) of Haile and McElhinny's (1972) "Carbo-Permian" determination, and almost identical in orientation, i.e. rotated the opposite way from either the Chinese Tertiary poles or Haile and McElhinny's "Mesozoic" determination. In view of these facts, I tend to regard Haile and McElhinny's younger set of determinations as more probably representing mainly Cenozoic conditions, and the Chinese Jurassic and Cretaceous data as indicating the Mesozoic picture. For at least the Malayan portion of Southeast Asia, this Mesozoic situation may extend with only minor changes back into the Upper Paleozoic, as suggested by Haile and McElhinny's older set of determinations.

The paleomagnetic determinations on Southeast Asian and South Chinese rocks thus indicate that during Cenozoic the area has moved southward and rotated counterclockwise (consistent with the paleobotanical hints of former drier climates); that during very late Mesozoic or early Cenozoic the region suffered considerable (not much less than 90°) clockwise rotation with little change in latitude; and that previous to the late Mesozoic, as far back probably as the late Paleozoic, it suffered very little of either rotation or change in latitude, though it could have undergone any amount of movement parallel to lines of latitude during that time.

For other areas of the world there is now a wealth of paleomagnetic information on paleolatitudes and orientations. And, though paleomagnetism by itself gives no information on paleolongitude, some constraints on this are in fact provided by simple space requirements and possibly by volcanic ridges such as the Hawaiian, on the assumption that these represent the traces of deep mantle plumes of "fixed" position (Wilson, 1965b; Morgan, 1971).

In my attempt to unravel the past relationships of Southeast Asia with other areas (Fig.'s 17–25) I have drawn freely on this body of data, using mainly the recent compilation of Tarling (1971), supplemented by Briden (1970a), Hamilton (1970), Irving(1967), McElhinny (1969), McElhinny and Wellman (1969), and Wensink (1972) In a few cases where the data for the same continent in the same period do not agree, I have arbitrarily taken what seemed to be the more sensible of the indicated positions.

UNRAVELLING THE TALE

Let me now attempt to put this varied evidence together in order to reconstruct the past movements and history of the Southeast Asian region. In doing so I think it best to start with the present, in which at least we know where things are, and to work step by step backwards in time, unravelling the tale back toward the mistier reaches of the early Phanerozoic, where we know so much less and where some areas will be totally lost from view.

The present gross structure of Southeast Asia and surrounding regions is shown in Figure 15. In eastern Indonesia is the complicated triple junction between the Pacific plate (moving westward), the India–Australia plate (moving northward), and eastern and Southeast Asia in what I cannot resist calling the China plate (it is uncertain whether this plate extends westward all the way to the Mid-Atlantic Ridge or is terminated along the Baikal structure). Plate boundaries near this triple junction are mainly convergent, with well-developed subduction-volcanic arcs along Sumatra, Java, the Philippines, and the east Indonesian arcs. But some portions of the boundaries are transcurrent, as along the north side of New Guinea, or highly oblique, as the Andaman Sea section north of Sumatra.

Farther west the northern boundary of the India–Australia plate is involved in the tremendous compressional structures of the Himalayas, where continents have been in collision since Middle Miocene, the actual line of collision probably represented by the Indus Suture Zone and its lateral equivalents (Gansser, 1966). This compressional suture is continued down through the ranges of western Pakistan, and similar structures extend westward across Iran as the Zagros Thrust Belt, carrying on through Anatolia, where collision appears to have taken place in early Tertiary (Brinkmann, 1972).

The western boundary of the India–Australia plate may be marked by a large transform just east of Arabia, or possibly that plate now includes Arabia. To the south and west of the India–Australia plate lie the Antarctic and African plates, the boundary marked by a series of spreading axes and connecting transforms crossing the Indian Ocean and extending up through the Red Sea. There has apparently been little or no relative movement between Africa and Antarctica in more recent geologic time, and the boundary between them is a dormant one.

The crust in the Indian Ocean is mainly late Cretaceous and Cenozoic in age and apparently records the rather rapid northward movement of India during this time. India's path is marked by two probable nemataths (volcanic tracks left on moving lithosphere plates by the activity of 'fixed' deep mantle plumes)—the Laccadive-Chagos Ridge (Dietz and Holden, 1970) and the Ninety-East Ridge (Anon., 1972). Northward-younging sea floor (Cretaceous-Tertiary) in the Wharton Basin (von der Borch, *et al.*, 1972) northwest of Australia shows that there was formerly a spreading center here, which became inactive in later Tertiary and was replaced by the new spreading axis farther south, separating Australia from Antarctica and initiating the former's rather rapid northward movement.

A note on the maps

In the series of maps which now follow (Fig.'s 15–25), as indeed in the earlier ones (Fig.'s 11–14), I have used always the Mercator projection. Despite the rather extreme scale distortion in high latitudes, this projection is very convenient to use because the lines of latitude and longitude form an orthogonal grid, areas can be shifted in longitude without change in shape (very handy when dealing with positions determined by paleomagnetism), and compass directions are correctly indicated by orientations on any part of the map.

The maps showing inferred former positions and arrangements of areas (Fig.'s 17–25) have been constructed largely on the basis of paleomagnetic data, with longi-

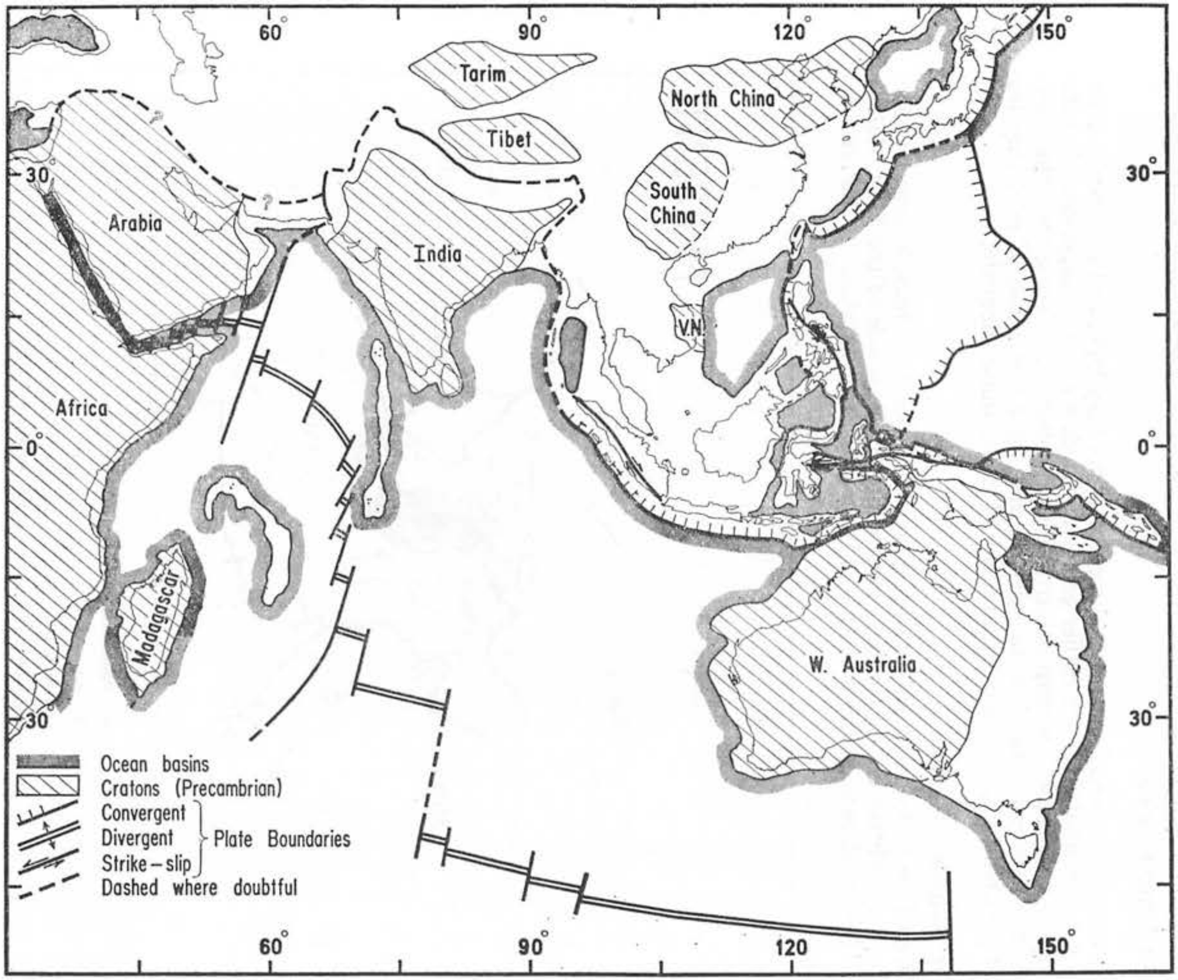

Fig. 15. Present gross structure of Southeast Asia and surrounding regions, showing active and possibly active plate boundaries, cratonic (essentially Precambrian) areas of the continents, and ocean basins. Continental edge based on 1000 fathom line as shown by U.S. Navy Hydrographic Office (1961), modified at major deltas and somewhat simplified. Cratonic areas based on Brown, *et al.* (1968), Chang (1959), Gansser (1964), Hamilton (1972), and Yanshin (1966). Plate boundaries based on Gansser (1964), Hamilton (1972), Isacks, *et al.* (1968), Katili (1971), and Yanshin (1966). 'V.N.' indicates the Viet-Nam microcraton ("massif du Kontum").

tudinal adjustments taking account of other kinds of evidence, and sometimes making use of arbitrary assumptions. The actual mechanics involved shifting transparent cut-outs of the areas concerned on a globe, tracing off the revised latitude and longitude grid, and transferring the outlines freehand onto a Mercator grid. Outlines of different areas were then compiled onto the final maps in what were considered the most logical relative longitudes.

Obviously the precision of such a method is not very high, and the proposed relatives paleolongitudes for the earlier geologic periods are merely suggestive. But the accuracy of this method of map construction is probably not worse than the accuracy of the paleomagnetic data themselves, and for my purpose of exploring the general possibilities in past configurations is, I think, quite adequate.

Present positions of cratons

One of the main questions we wish to answer as we work back in time is: what was the Precambrian craton formerly attached to the west side of the West Malaya Block? I have shown on the map (Fig. 15) the possible candidates in the area co-

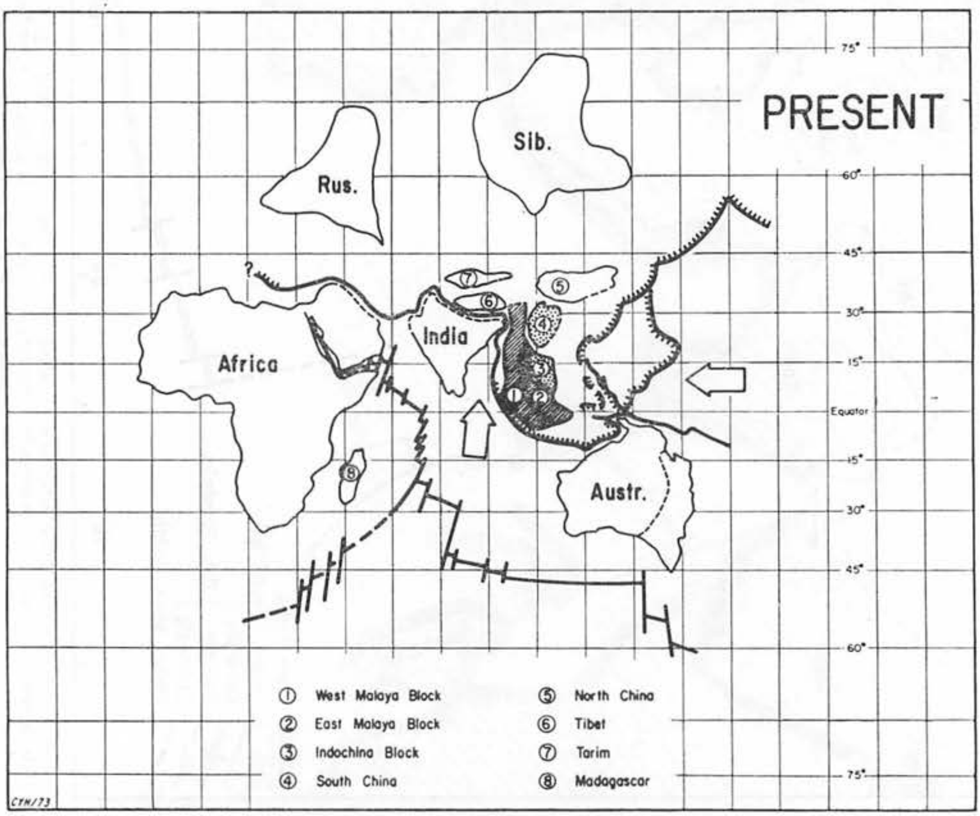

Fig. 16 Present position of the Southeast Asian blocks, as defined in Figure 13, in relation to the present plate boundaries and cratonic areas, as in Figure 15. Two additional cratonic areas, the Russian and Siberian platforms, have been added, following Hamilton (1970). Large arrows show general movement directions of the Pacific and India–Australia plates.

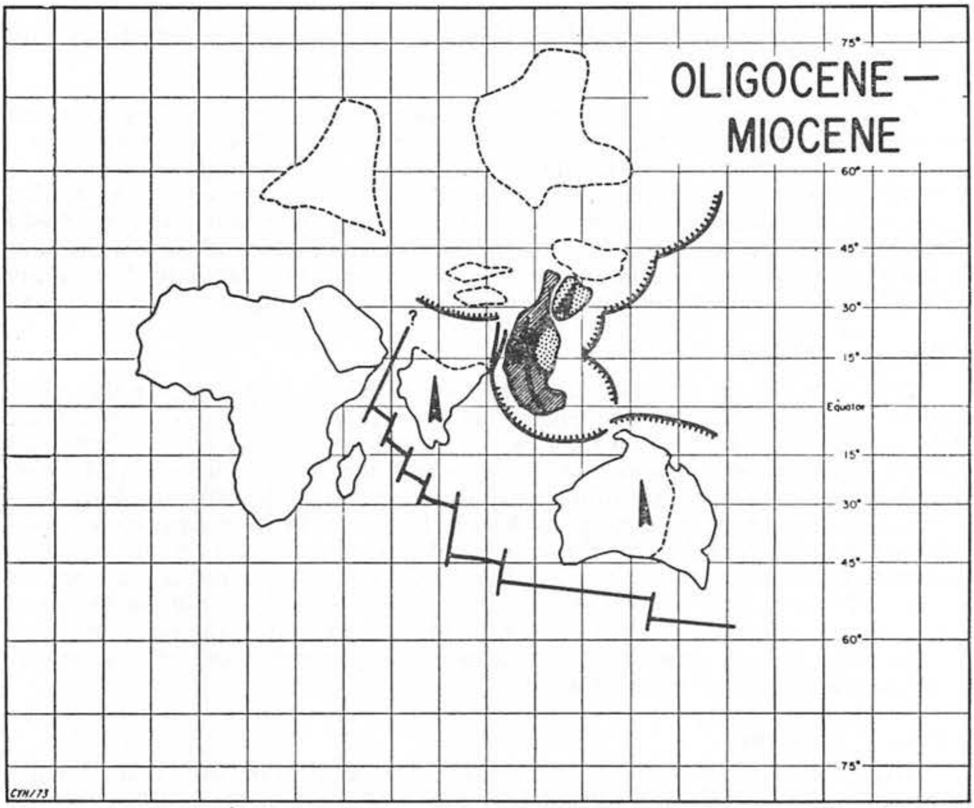

Fig. 17. Positions in mid-Tertiary (Oligocene-Miocene). Selected inferred plate boundaries (symbols as in Figure 15) sketched in. Small arrows indicate present north for reference (also on all subsequent maps). Paleomagnetic data from McElhinny (1969): South China with Southeast Asia attached; Wensink (1972): India; Tarling (1971): Australia. North China has been arbitrarily shifted to fit South China. Other areas are left in their present positions. Data for Africa (Briden, 1970a) indicate little change from present for that continent.

vered. The various 'cratons' shown are known with highly varied degrees of accuracy, ranging from very good (e.g. India, Australia) to quite poor (e.g. Tibet). From even a quick look at this map we can see that some 'candidates' are easily ruled out: Indochina forms part of the Southeast Asian cluster, on the opposite side from West Malaya, and has been there since Triassic; the Tarim and Tibetan areas are too small to have, by themselves, formed the craton adjoining the West Malaya Block along its entire length. It is not impossible that Tibet and/or Tarim may represent part of that craton as suggested by Crawford (1973), perhaps rifted off together with Southeast Asia and never detached from the latter. But I know of no good evidence on this. A few paleomagnetic determinations from these areas might quickly settle the question.

Most of the remainder of the map area in Figure 15 is covered by younger continental accretions and by ocean basins, themselves representing Mesozoic and Cenozoic lithosphere. Hence in order to see clearly the actors in our drama, I have in the next map (Fig. 16) stripped away all but the Precambrian 'cratons' and the Southeast Asian blocks as previously defined (Fig. 13). The present plate boundaries have been left on for reference.

As a single exception I have shown the orogenic terrain of eastern Australia because of the interest in the question of whether it is related to the Malayan orogenic terrain, so that we can see their spatial relationships through geologic time. The removal of other Phanerozoic continental areas does not, of course, imply that these areas have not in part been continental for a long time (some parts no doubt since Precambrian), but since the actual history and past status of these areas have in most cases not been worked out, it is simpler to omit them entirely. In this way at least we will not be misled by any present continental outlines.

Oligocene — Miocene

If we now roll the film backwards and look at the situation in mid-Tertiary (Fig. 17), we see India straddling the equator in its northward flight, passing Southeast Asia on the east and Africa on the west, probably by means of two transform fault systems. India is about to come into collision with the Asian mainland in Miocene. Arabia is just about to begin rifting away from the rest of the African block. Australia, also drifting rather rapidly northward, is not yet in its present close proximity to Southeast Asia. The Southeast Asian blocks are moving southward or southeastward, and are yet to make a small counterclockwise rotation to their present position. Possibly connected with this rotation was the opening out of the Andaman sphenochasm in late Tertiary, shown here as already beginning. The position shown for Southeast Asia is consistent with the several vague indications of a somewhat drier climate in Malaya in late Tertiary.

Paleocene — Eocene

When we step back to early Tertiary (Fig. 18) we see some of the same trends at an earlier stage. India and Australia are both well south of the equator, more or less "out of the way" of Southeast Asia. Australia is here just about to break off from Antarctica and begin its northward flight. At this time a spreading axis existed to the northwest of Australia, probably serving or helping to propel India northward. Subduction arcs should have existed along the south side of Tibet and of Southeast Asia to take up crust as India converged with them, but evidence for these is minimal. Possibly this was a period of very slow or even dormant plate activity. As Africa seems to have been almost stable in latitude, a large transform is required between it and India. Madagascar, whose position is controversial, has been dropped from the cast. The Southeast Asian blocks were in almost exactly the latitude and orientation they hold today.

Cretaceous

When we go back to the Cretaceous (Fig. 19) we find some interesting changes. This was a period of rapid developments and one really should have a whole series of maps to cover different stages in the Cretaceous, but here one map will have to do. Australia and India are, as they were in the early Tertiary, in moderate to high southern latitudes, but must have been closer together in view of the early Tertiary and late Cretaceous spreading between them. Their resulting positions seem very consistent with the suggested matching of the two continents by Veevers, *et al.* (1971). Africa is here rotated clockwise out of its present position. The actual counterclockwise rotation implied by this may have been related to the existence of a very active spreading axis to the east and northeast of that continent, possibly part of the system

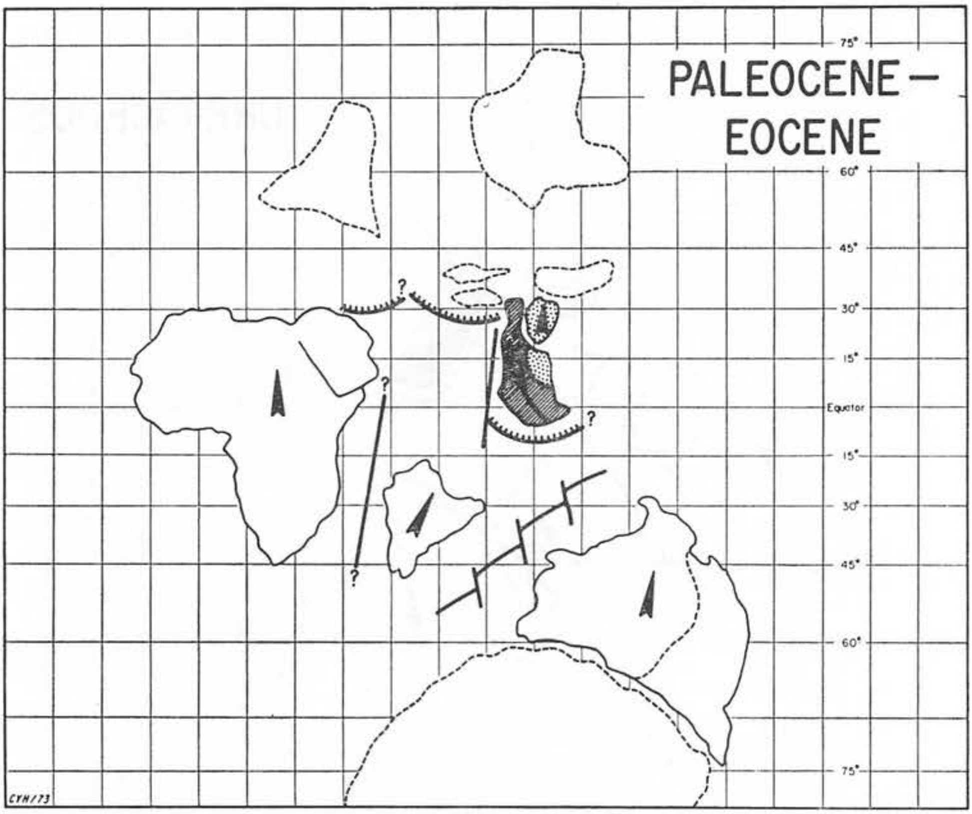

Fig. 18. Positions in the early Tertiary (Paleocene-Eocene). Paleomagnetic data from McElhinny (1969): South China with Southeast Asia attached; Tarling (1971): India, Africa; McElhinny and Wellman (1969): Australia. Antarctica is shown as attached to Australia, other areas in their present positions. Madagascar has been dropped.

that separated western from eastern Gondwanaland. The possibility that this involved separation also of India from Africa emphasizes the uncertainties about India's role and position.

The Southeast Asian blocks in the Cretaceous were rotated rather sharply counterclockwise from their early Tertiary (and present) position, but remain in approximately the same latitudes, shifted only slightly northward. This is consistent with the evidence for active but relatively narrow volcanic-magmatic arcs of Cretaceous age along the southern, eastern, part of the northern and possibly the western sides of the Southeast Asian cluster, implying (Wilson and Burke, 1972) a relatively static position for this continental fragment. Similarly, there is good evidence in the Karakorum Mountains (Gansser, 1964) for subduction and volcanic-magmatic zones along the southern edge of Tibet, possibly serving to hold that area in a relatively fixed position also. The inferred position of Southeast Asia fits the evidence of desert conditions in northeast Thailand. For the remaining areas shown on the map (and for Tibet) either I had no information or what I had indicated little change from

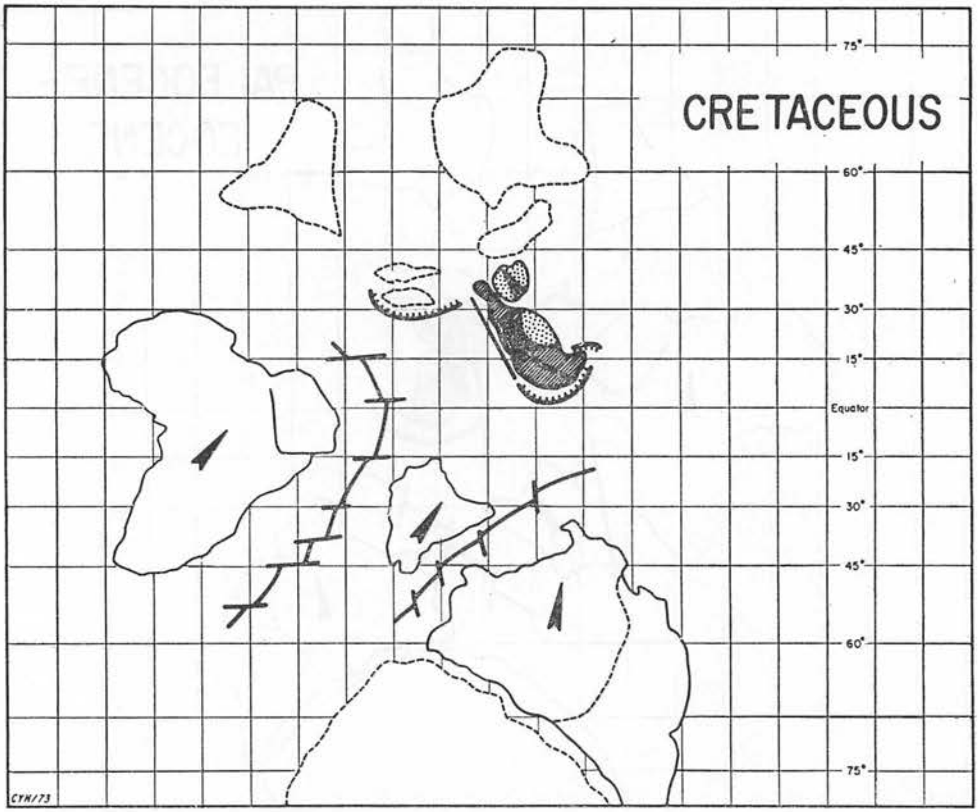

Fig. 19. Positions in the Cretaceous. Paleomagnetic data from McElhinny (1969): South China with Southeast Asia attached; Tarling (1971): India, Africa; McElhinny and Wellman (1969): Australia with Antarctica attached. Other areas are shown in present positions, except that North China has been turned slightly to fit South China, and the other northern areas shifted a bit westward.

present, so I have used their present positions, except for North China which has been moved somewhat to accomodate the shift in South China.

Jurassic

Now we come to the Jurassic (Fig. 20), which I regard as the critical period because it seems likely, for reasons presented earlier, to be the time when the West Malaya Block (with the other Southeast Asian blocks and South China attached to it) rifted off from a Precambrian craton. The arrangement of continents indicated by paleomagnetism for the Jurassic is markedly different from that of the present. We see Gondwanaland largely united into one giant block (South America is not shown, but would have been separated from Africa by only a narrow Atlantic Ocean). India is shown in the more conventional position against Africa (though south of that favored by du Toit, 1937, and Smith and Hallam, 1970), but I have indicated an alternative position, equally consistent with the paleomagnetic evidence, which accords well with the position advocated by Ahmad (1961) and Veevers, *et al.* (1971). Africa straddles the equator in much the same orientation as in the Cretaceous.

The main mass of Eurasia, containing the Russian and Siberian platforms in rigid connection, is rotated markedly counterclockwise, making room for a great wedge-shaped Tethyan Ocean, opening eastwards. Within this Tethyan wedge, however, there may have been various fragments and microcontinents later swept together into the composite continent of Eurasia, including the present Southeast Asia.

The Southeast Asian cluster was in Jurassic time in moderate northern latitudes, slightly farther from the equator than in the Cretaceous (it could hardly have been then attached to Eurasia in the present relationship), and was rather more rotated counterclockwise, about 45° from its present orientation. If during this time it was rifted off a craton along the present west side of the West Malaya Block, that craton's corresponding broken edge (a minimum of 3000 km long) should appear on the Jurassic map with a trend roughly parallel to it, i.e. about northwest-southeast, and should be in similar or slightly more southerly latitudes, so that a northeast–southwest spreading could account for their separation.

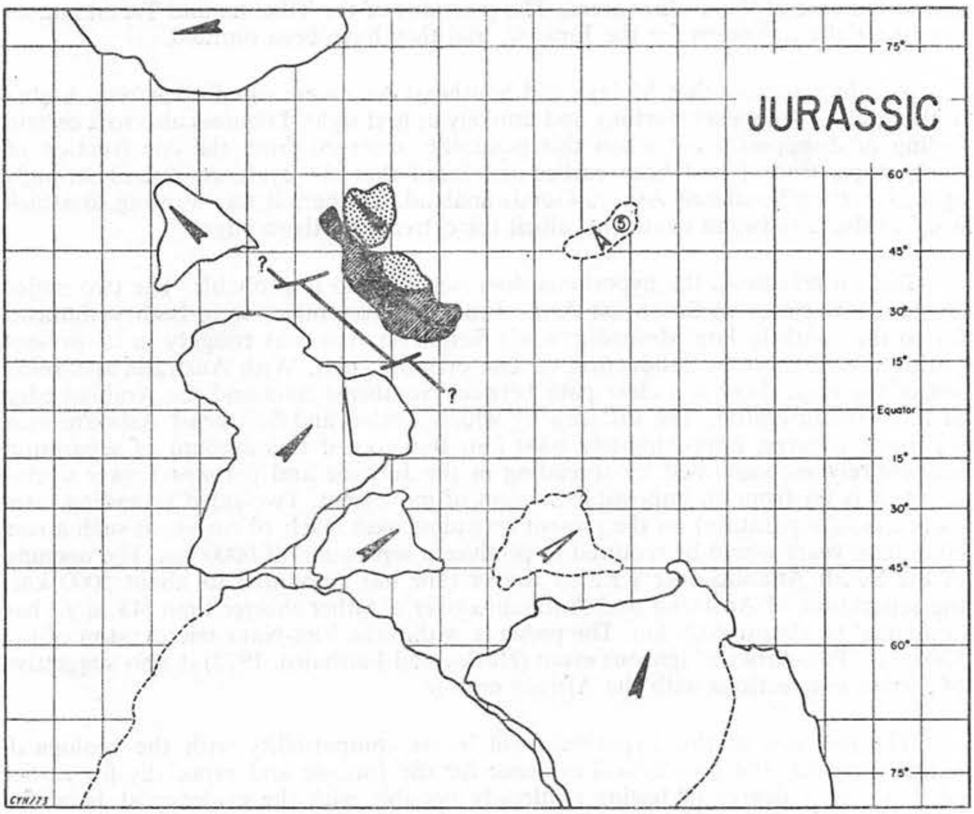

Fig. 20. Positions in the Jurassic. Paleomagnetic data from McElhinny (1969): South China with Southeast Asia attached; Tarling (1971): India (for which two alternate paleolongitudes are shown), Australia with Antarctica attached, Africa; Hamilton (1970): Russia/Siberia (common pole). North China has been left in its Cretaceous position for reasons explained in the text; Tibet and Tarim have been dropped. Note that the orientation and paleolatitude of the Southeast Asian blocks at this time, when they are inferred to have rifted off a large craton, strongly suggest Africa was that craton.

A glance at the map (Fig. 20) reveals with startling simplicity that under the assumptions made there is really only one likely candidate for this craton and that is Africa (including Arabia). The Russian platform is ruled out by being too far north and somewhat too small, and the only edge of proper orientation is not available for matching, being joined by rigid intervening connections to the Siberian platform. Similarly, the American continents are ruled out because the path to them is effectively blocked by the Eurasian mass. All other cratonic masses are in unsuitable latitudes.

In view of these rather persuasive considerations, I have moved the Southeast Asian cluster westward in paleolongitude to a position closer to Africa, and have sketched in a spreading axis separating them.

North China, for which I have no Jurassic data, has been left in its Cretaceous position. It has not been shifted west with Southeast Asia and South China because paleomagnetic data for the Triassic seem to require its having been separated from and to the east of these other areas. The positions of the Tibetian and Tarim masses are essentially unknown for the Jurassic, and they have been omitted.

This hypothesis—that Malaya and Southeast Asia were rifted off Africa–Arabia in the Jurassic—appears startling and unlikely at first sight. I confess also to a certain feeling of disappointment when this possibility emerged from the construction of these maps, since I had been earlier convinced that the evidence argued strongly against putting Southeast Asia in Gondwanaland. Yet here it was wanting to attach itself to the Gondwana continent, albeit the extreme northern edge!

But on reflection, the hypothesis does not seem so improbable. The two major cratons now closer to Southeast Asia—India and Australia—were both withdrawn far to the south in late Mesozoic, while Southeast Asia was roughly in its present position, held there by subduction on one or more sides. With Australia and India out of the way, there is a clear path between Southeast Asia and the Arabian edge of the African craton. The distance by which Arabia and Southeast Asia are now separated is large, approximately 6000 km. But even if this amount of separation was entirely accomplished by spreading in the Jurassic and perhaps Lower Cretaceous, it is far from an impossible amount of movement. Two-sided spreading rates (i.e. rates of separation) on the present spreading axes reach 10 cm/yr; at such a rate 60 million years would be required to produce a separation of 6000 km. The opening of the South Atlantic over a rather longer time has amounted to about 5000 km; the separation of Australia and Antarctica over a rather shorter time (43 m.y.) has amounted to almost 4000 km. The presence within the Viet-Nam microcraton of the 530 m.y. "Pan-African" igneous event (Hurley and Fairbairn, 1972) is also suggestive of former connections with the African craton.

The real test of this hypothesis will be its compatibility with the geological, paleontological, and geophysical evidence for the Jurassic and especially for earlier periods. Some degree of testing is already possible with the evidence at hand for earlier periods. Let us then continue our backward progress.

Triassic

In the Triassic (Fig. 21) we see Gondwanaland in approximately the same position as during the Jurassic, but somewhat turned, so that Australia is not so far south and northwest Africa not quite so far north. The Eurasian mass remains turned

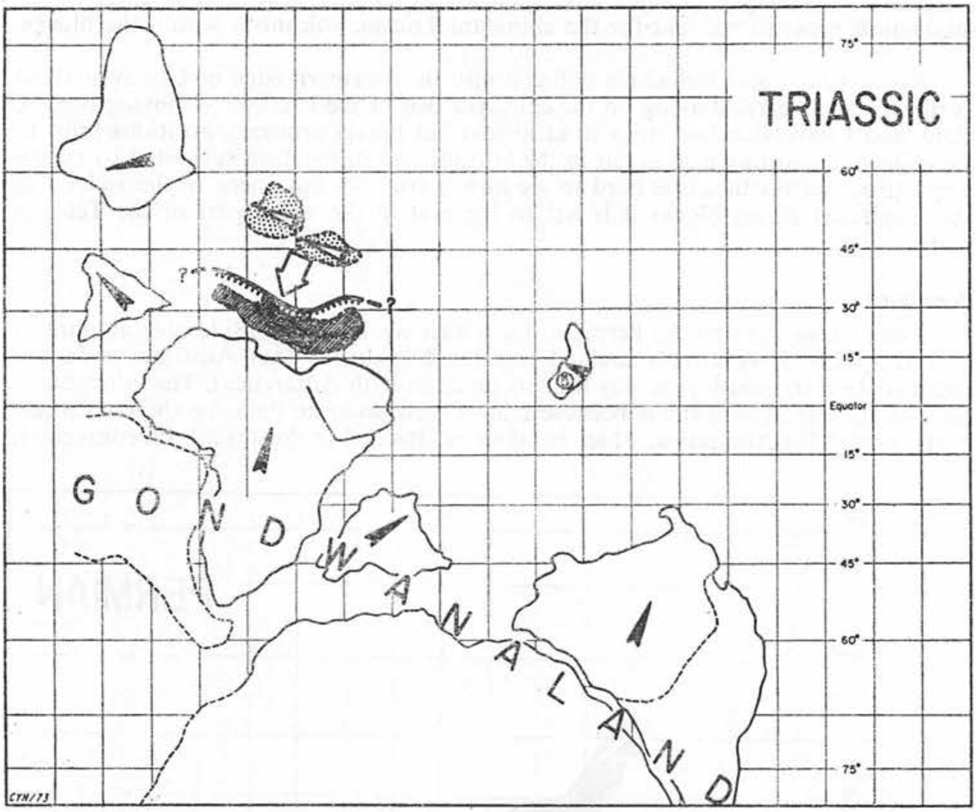

Fig. 21. Positions in the Triassic. Paleomagnetic data from Wensink (1972): India; Tarling (1971): Australia with Antarctica attached; Briden (1970a): Africa; Irving (1967): North China; Hamilton (1970): Russia/Siberia (common pole). The West Malaya and East Malaya Blocks are shown in their postulated position attached to the African craton; Indochina and South China in arbitrary hypothetical positions prior to their collisions with the Malayan blocks. Russia and Siberia have been moved westward to avoid overlap with Africa.

on end, but is somewhat farther south, so much so that in order not to overlap Africa it must be shifted rather to the west to a position which would seem to preclude any joining of North America against northwest Africa at this time. Such a more westerly position of Laurasia relative to Gondwanaland has been proposed more than once (van Hilten, 1964; Irving, 1967); it is favored here not only because it solves problems of space but also because it would seem to make certain patterns of Permian biogeography more understandable, as we shall see.

The West Malaya and East Malaya Blocks are here shown nestled against northern Africa and Arabia in a presumed position while still attached to that great craton. Although their position here (Fig. 21) is purely determined by the position of Africa, it might be noted that the older set of paleomagnetic determinations of Haile and McElhinny (1972), regarded by them as Carbo-Permian but possibly including Triassic rocks, is really quite compatible with this position. Along the outer margin of the Malayan Blocks I have sketched in a convergent plate boundary with subduction zone, to account for the abundant Triassic volcanism within the blocks.

South China and Indochina collided into this northern edge of Gondwanaland during Triassic, carried along on the conveyor belt of the southward-moving oceanic plate, and I have sketched them in at logical but purely arbitrary positions prior to the collisions. North China is put in the latitude and orientation suggested by paleomagnetism, but because it is hard to see how it could fit anywhere in the vicinity of the Southeast Asian blocks it is left to the east in the wider part of the Tethyan wedge.

Permian

Let us now turn to the Permian, for which we have a considerable amount of data (Fig. 22). Here Gondwanaland is rotated again, so that Australia is farther south (indeed the south pole was near its junction with Antarctica). The "disrupted" look of the supercontinent is because I have used separate data for the constituent parts (except for Antarctica, which is taken as attached to Australia). Paleomagnetic

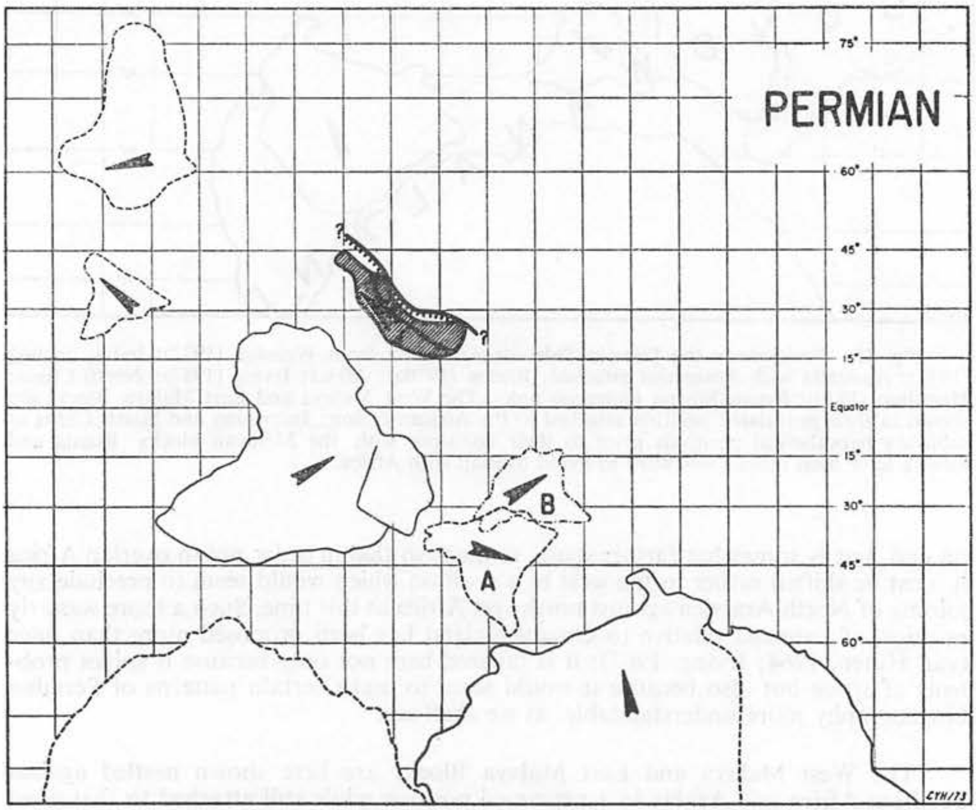

Fig. 22. Positions in the Permian. Paleomagnetic data from Haile and McElhinny (1972): West Malaya/East Malaya; Tarling (1971): India (both the irreconcilable positions given by his poles 'A' and 'B'), Australia with Antarctica attached. Africa, Russia and Siberia have been left in their Triassic positions; North China, South China, and Indochina have been dropped.

data for India give two rather irreconcilable positions, and both are shown. With a slight shift in latitude, the 'A' position could be fit against Africa in the common way, but neither position seems compatible with a fit against Australia at this time.

The Malayan blocks are shown in the position indicated by Haile and McElhinny's (1972) "Carbo-Permian" determinations, with paleolongitude chosen in light of the hypothesis that they were attached to Africa at the time. There is a moderate gap between the two, but it seems not excessive in view of the accuracy of paleomagnetic data and the uncertainty about the ages being dealt with. The position of the Southeast Asian block as shown is consistent with the geologic and biotic evidence, but a slightly more southerly position, nestled against northern Africa, would accord better with the hints of an equatorial latitude for Malaya at this time. Along the outer margin of the Malayan blocks I have shown again the convergent plate boundary, causing the Permian volcanism. The South China, Indochina, and North China blocks are now lost to our view and I have omitted them.

The Russian and Siberian blocks are shown in their Triassic positions which were probably similar to the Permian ones. In Permian these areas were colliding with one another, their earlier histories being different (Hamilton, 1970), and the Russian block was also in collision with North America. It seems not unreasonable to suggest that this series of major collisions in the northern hemisphere, plus the lesser ones involving the Chinese and Southeast Asian blocks, forced the abandonment of the previous pattern of plate motions, and led to the initiation of a radically different system of plate boundaries in the Mesozoic, this new system involving the fragmentation of Gondwanaland, with Southeast Asia as one of the resulting fragments. The convergent plate boundary adjoining the Malayan blocks, which had been active throughout much of the Paleozoic, appears to have ended activity in the Triassic.

If we look at the positions of India and Australia in the Permian (Fig. 22), and remembering that both those continents experienced glaciations during that time, we can see that it would be very difficult to reconcile the evidence with a position for Southeast Asia either against the present east coast of India (Burton, 1970) or between India and Australia (Ridd, 1971).

The impossibility of such a position becomes even clearer when we consider the distribution of Permian floras and faunas on this reconstructed geography (Fig. 23). The Tethyan marine province as defined, for example, by the Verbeekinidae, is seen to occupy low latitudes and to stretch possibly most of the way aroud the globe. The latitudinal control of the Permian floras emerges clearly. The Angara flora is sited in moderate to high northern latitudes; the Gondwana flora mainly in moderate to high southern latitudes; and the Euramerican, North American, and Cathaysian floras divide the zone of low latitudes between them. Note that the Cathaysian admixture in the flora of New Guinea dates from the late Carboniferous, when Australia was considerably farther north, and the site of this flora would have been at a paleolatitude of about 20°S (Embleton, 1973). The evidence in hand would seem consistent with the view that these major floras were essentially controlled by latitude and climate with the very important exception of the distinction between the three floras of the warm zones.

Since these three floras appear to have thrived in essentially the same latitudes (Fig. 23), the differences between them must have been the result of separation by physical barriers. Most plausibly these barriers could have been marine embayments

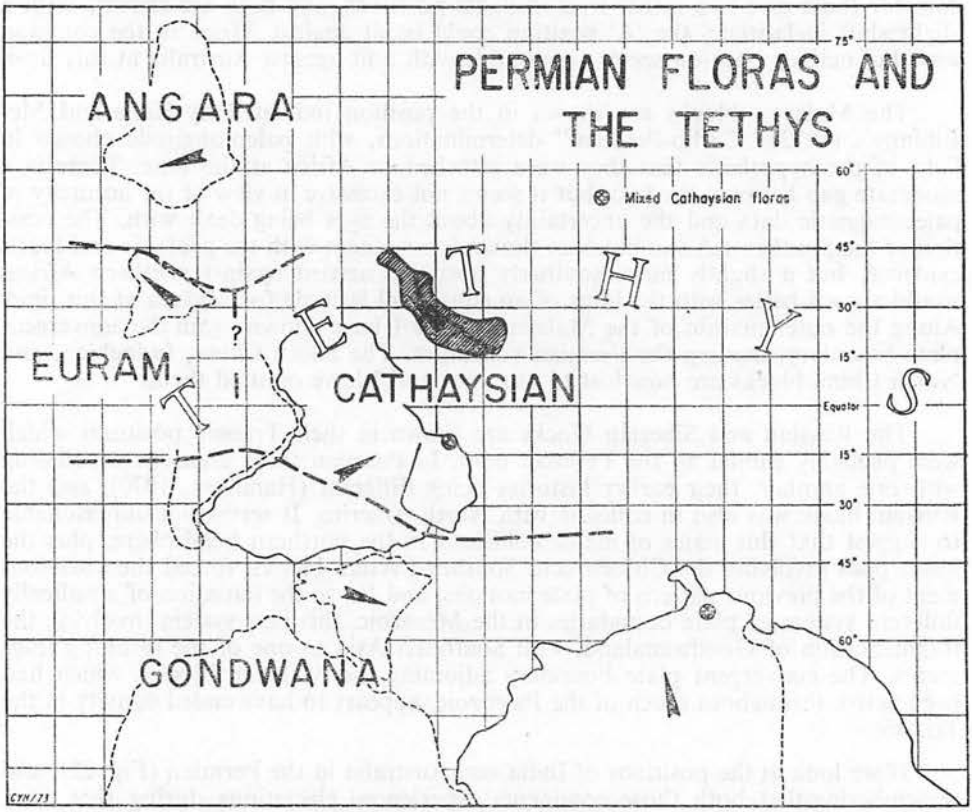

Fig. 23. Permian/Late Carboniferous floral provinces and the Permian Tethys (data derived from Figure 14) plotted on reconstructed Permian positions (as on Figure 22).

(whether deep ocean or epicontinental) that precluded land migration continuously within the warm belt (as the tropical floras of Africa and Southeast Asia are today quite distinct, though land connection through Eurasia exists). Since the Cathaysian flora appears definitely to have been established on the landmass of Africa–Arabia (at Hazro, even without the postulated attachment of Southeast Asia), then it seems less likely that Europe (with eastern North America attached?) was touching or even very close to Africa. These areas may instead have been off to the west, allowing room for a marine barrier. One might therefore expect that other finds of Cathaysian floras may be made in northern Africa, and that the Euramerican flora should be absent from those areas which were attached physically to this portion of the African craton. It is of interest to note that the northwest corner of Africa, where an Euramerican flora is recorded (Fig. 14), is now considered by some to be a fragment of Europe affixed to Africa comparatively recently (K.J. Hsu, personal communication).

If a marine barrier is invoked to explain the differences between the Cathaysian and Euramerican floras, what can we say about their relations to the North American flora, similar enough to the Cathaysian to be classed with it by some workers? It is hard to believe that a great Pacific Ocean could have existed and yet not served as a very effective barrier to the migration of tropical floras. Yet it is perhaps equally difficult to imagine a fragment of North America shifted westward so far that it was in contact with the Cathaysian areas of the Permian. These are intriguing problems and worth some attention.

Carboniferous

Although our data become quite spotty and incomplete in the pre-Permian, let us take at least a brief look into these earlier periods, mainly to see whether the hypothesis that the Malayan blocks were attached to Africa–Arabia is consistent with the evidence.

In the Carboniferous (Fig. 24) Africa was rather farther south than in the Permian. This was the time of glaciation in southern Africa, the Dwyka tillite apparently spanning the entirety of the period (Crowell and Frakes, 1972). India was also in moderate southern latitudes. The West Malaya Block is shown adjoining Africa, the East Malaya Block as a then-active island arc, with the convergent plate boundary on its outer margin. The resultant position of these areas is in low latitudes south

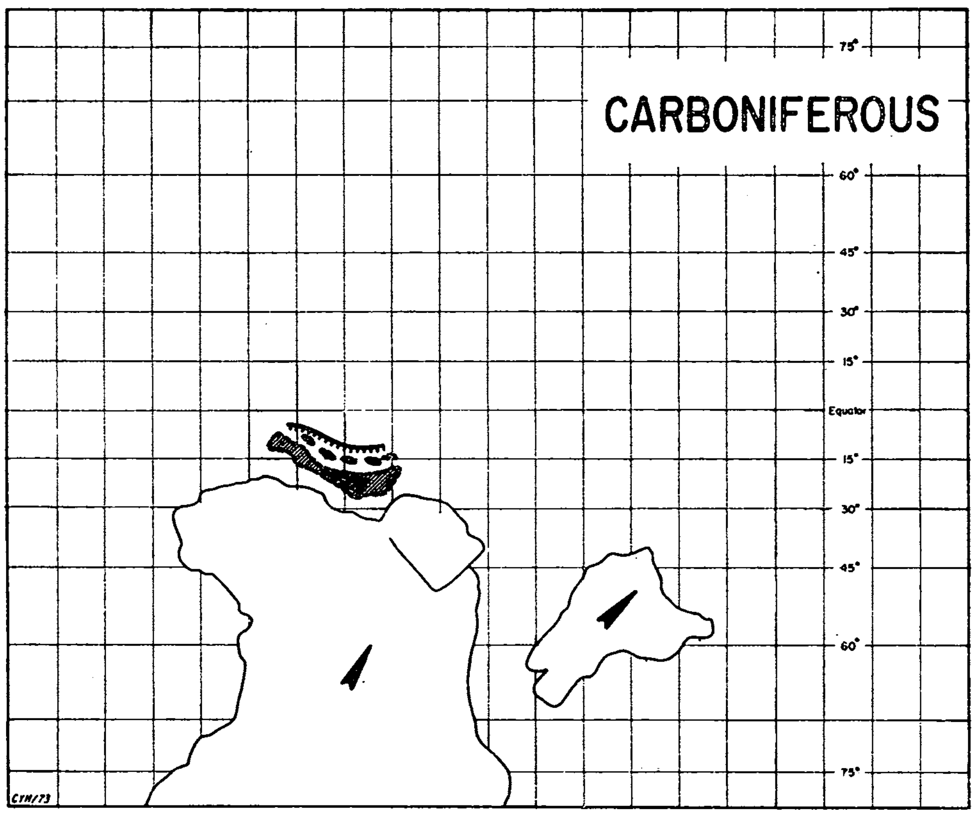

Fig. 24. Positions of selected areas in the Carboniferous. Paleomagnetic data from Tarling (1971). For India his Upper Carboniferous 'B' pole has been used; the African pole (Dwyka) probably is early Carboniferous. The West Malaya Block is shown in a postulated position attached to Africa, with the East Malaya Block in process of formation as an island arc.

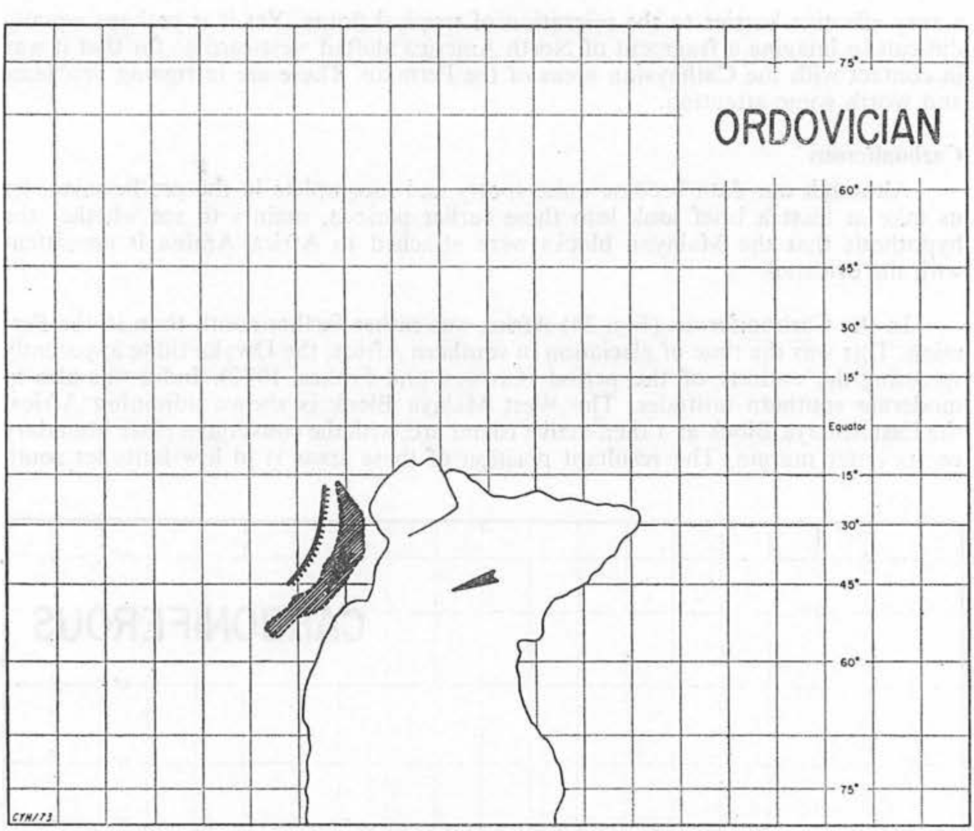

Fig. 25. Position of Africa in the Ordovician, based on paleomagnetic data from Tarling (1971). The West Malaya Block is shown in a hypothetical position attached to northern Africa.

of the equator, consistent with the geologic and paleontologic evidence in Malaya, but not very consistent with Haile and McElhinny's "Carbo-Permian" paleomagnetic determinations. The position implied by these paleomagnetic data is also consistent with the geologic and biotic evidence. A position for Malaya adjoining India's present east coast, however, is strongly conflicting with all these lines of evidence.

Ordovician

As a final check I have plotted Africa in the Ordovician (Fig. 25). The West Malaya Block is shown in the position postulated earlier, the convergent plate boundary again at its outer margin. Because of much movement of the pole from the Carboniferous position, Malaya now appears rotated nearly 180° from its present orientation. In the position assumed, it would occupy moderate latitudes south of the equator. Such a position is not inconsistent with the character of the Ordovician rocks here, though an alternative position more against Arabia would give equatorial latitudes more congenial to the evidence.

It is interesting to note that Africa is so large that even though the Ordovician south pole was near its present western margin, the Arabian corner of the continent still almost reached the equator. Thus in spite of the glaciation in Ordovician-Silurian in Saharan Africa (Fairbridge, 1970), a warm water carbonate environment is still quite possible for Malaya if attached near the Arabian corner of the continent.

Let me point out that this "upside down" position of Malaya is not easy to test by paleomagnetism, as might be thought at first sight. With the ambiguity given by polarity reversals, this position is paleomagnetically indistinguishable from a "right side up" position in comparable northern latitudes!

There is no point in looking farther back at this stage. The Cambrian of the West Malaya Block gives us too little information, the Precambrian is too poorly known, and paleomagnetic data for even the major continents in these periods do not yet allow very confident reconstructions.

CONCLUDING REMARKS

In this necessarily brief foray into the role of Malaya and Southeast Asia in global tectonic evolution, we have seen that in most previous syntheses this region was generally omitted or ignored. We have also seen that with those authors who have dealt with the region's past relationships there has been a tendency to try to fit Southeast Asia into Gondwanaland, in spite of much contrary evidence. Ironically it would seem that this tendency may prove to have been at least technically on the right track.

In recent years a considerable amount of geologic data about Southeast Asia has become available, and new data are coming with increasing rapidity. From this new evidence, some things can be said with reasonable assurance about the region's history:

(1) Mainland Southeast Asia, including Sundaland, is a cluster of at least three smaller blocks, here called the West Malaya, East Malaya, and Indochina Blocks. These blocks are joined to each other, and to South China, by sutures marked by ophiolite belts, the sutures having ages of Late Paleozoic to Triassic, representing the times of collision. Before the Late Paleozoic the blocks have separate histories; since Triassic they have behaved as a single unit, together with at least South China.

(2) The West Malaya Block represents the former edge of a large Precambrian continental craton and includes both a slice of the Precambrian basement and the sedimentary wedge which formed at the edge of that continent from Cambrian or earlier times to at least the end of the Paleozoic. The craton was on the west side of the present West Malaya Block.

(3) The East Malaya Block formed in close association with the West Malaya Block during late Paleozoic times, possibly in the main as an offshore island arc system, and was compressed against the West Malaya Block and its continent by the end of Permian or early Triassic.

(4) The Indochina Block is a small Precambrian-floored microcontinent which accidentally impinged on the other blocks in the Triassic (as did South China).

(5) The cluster of Southeast Asian blocks (including South China) probably rifted off from the adjoining craton in Jurassic time. This is inferred from the evidence that the region was involved with convergent plate boundaries throughout the Paleozoic and Triassic, while by Cretaceous there was clearly oceanic crust to the west.

(6) Evidence from sedimentary facies and paleontology indicate that the West Malaya Block has occupied a warm climate and low to moderate latitudes through most, if not all of the Paleozoic, with suggestions of an equatorial position in the Ordovician and again in the Permian. Similar evidence from several parts of Southeast Asia, united since Triassic, indicate low latitudes in the later Mesozoic and later Cenozoic, but suggests for both periods a position slightly farther from the equator than at present.

(7) Limited paleomagnetic evidence available from Southeast Asia and South China support the inferences from geology and paleontology, yielding positions in low (less than 30° for Kuala Lumpur) latitudes back through the Mesozoic and into the late Paleozoic. The paleomagnetic positions of this and other areas in the Jurassic make it highly probable that if Southeast Asia was rifted off a continent at that time, that continent was Africa–Arabia.

The hypothesis that Southeast Asia was formerly attached to Africa–Arabia, and that the West Malaya Block formed as the continental margin of that craton, though far-fetched at first sight, is not in fact unreasonable: the mechanics, distance, and geometry of separation seem acceptable in the framework of plate tectonics; certain facts of plant and animal distribution would be more easily explained (particularly the Permian Cathaysian flora of Anatolia and the migration of *Lystrosaurus* from Gondwanaland to Singkiang in the Triassic); and an attachment to Africa–Arabia seems to be at least consistent with the bulk of the evidence for pre-Jurassic times.

Clearly, however, this hypothesis needs more critical testing before it can be accepted. Paleomagnetic researches in Southeast Asia must be continued to give us more data, and particularly should be extended into the earlier Paleozoic. The geology of Africa–Arabia must be compared with that of Southeast Asia, and previous paleogeographic and paleontologic interpretations should be reexamined in the light of the hypothesis. The northward extension of the West Malaya Block in China, and its relationships to the Tibetan and Tarim massifs, should be studied in detail.

None of these tasks is a small one, and each will take much effort over a period of years. It may therefore be some time yet before we can say whether this hypothesis is a useful inference or turns out to be indeed merely a flight of fantasy.

REFERENCES

AHMAD, F., 1961. Paleogeography of the Gondwana Period in Gondwanaland, with special reference to India and Australia, and its bearing on the theory of continental drift. *Geol. Surv. India Mem. 90,* 142 p.

AHMAD, F., and KHAN, A.M., 1964. The pre-Pleistocene glacial deposits of India. *Report XXIInd Int. geol. Congr., 16,* 112–139.

ANONYMOUS, 1972. One microcontinent turns out not to be. *New Scientist, 56* (No. 822), 494 only.

ASAMA, K., 1966. Permian plants from Phetchabun, Thailand and problems of floral migration from Gondwanaland. *Geol. and Paleont. S.E. Asia, 2,* 197–235.

AUDLEY-CHARLES, M.G., 1968. The geology of Portuguese Timor. *Geol. Soc. London Mem. 4,* 76 p.

AUDLEY-CHARLES, M.G., CARTER, D.J., and MILSOM, J.S., 1972. Tectonic development of eastern Indonesia in relation to Gondwanaland dispersal. *Nature phys. Sci., 239,* 35–39.

AUNG KHIN and KYAW WIN, 1969. Geology and hydrocarbon prospects of the Burma Tertiary geosyncline. *Union of Burma Jour. of Sci. and Technology, 2,* 53–73.

BAUM, F., BRAUN, E.V., HAHN, L., HESS, A., KOCH, K-E., KRUSE, G., QUARCH, H., and SIEBENHÜNER, M., 1970. On the geology of Northern Thailand. *Beih. geol. Jb.* (*Hannover*) *102*, 24 p.

BEMMELEN, R.W. VAN, 1970. *The Geology of Indonesia*, 2nd Ed. Vol. 1A: *General geology of Indonesia and adjacent archipelagoes*, 732 p.

BERRY, W.B.N., and BOUCOT, A.J., 1973. Correlation of the Southeast Asian and Near Eastern Silurian rocks. *Geol. Soc. America Spec. Pap. 137*, 65 p.

BIGNELL, J.D., and SNELLING, N.J., 1972. The geochronology of the Thai-Malay Peninsula. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers*, 62 only

BORAX, E., and STEWART, R.D., 1965. Notes on the Khorat Series of northeastern Thailand. ECAFE 3rd Symp. on Devel. of Petroleum Resour. Asia and Far East, Tokyo, Nov. 1965, 25 p.

BORCH, C.C. VON DER, SCLATER, J.G., *et al.*, 1972. Deep sea drilling project, Leg 22. *Geotimes*, *17*, No. 6, 15–17.

BRIDEN, J.C., 1970a. Paleomagnetic polar wander curve for Africa. *in* Runcorn, S.K. (ed.) *Palaeogeophysics* (Academic Press), 277–289.

BRIDEN, J.C., 1970b. Palaeolatitude distribution of precipitated sediments. *in* Runcorn, S.K. (ed.), *Palaeogeophysics* (Academic Press), 437–444.

BRIDEN, J.C., and IRVING, E., 1964. Palaeolatitude spectra of sedimentary palaeoclimatic indicators. *in* Nairn, A.E.M. (ed.), *Problems in Palaeoclimatology* (Interscience), 199–224.

BRINKMANN, R., 1972. Mesozoic troughs and crustal structure in Anatolia. *Geol. Soc. America Bull.*, *83*, 819–826.

BROWN, D.A., CAMPBELL, K.S.W., and CROOK, K.A.W., 1968. *The Geological evolution of Australia and New Zealand.* Pergamon, 409 p.

BURTON, C.K., 1964. The Older Alluvium of Johore and Singapore. *J. trop. Geogr.*, *18*, 30–42.

BURTON, C.K., 1966. Palaeozoic orogeny in north-west Malaya. *Geol. Mag.*, *103*, 364–365.

BURTON, C.K., 1967a. Graptolite and tentaculite correlations and palaeogeography of the Silurian and Devonian in the Yunnan-Malay Geosyncline. *Trans. Proc. paleon. Soc. Japan* (*n.s.*), *65*, 27–46.

BURTON, C.K., 1967b. The Mahang Formation: a mid-Palaeozoic euxinic facies from Malaya—with notes on its conditions of deposition and palaeogeography. *Geol. en Mijnb.*, *46*, 167–187.

BURTON, C.K., 1970. The palaeotectonic status of the Malay Peninsula. *Palaeogeog., Palaeoclimatol., Palaeoecol.*, *7*, 51–60.

BURTON, C.K., 1973. Mesozoic. Chap. 5 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula* (*West Malaysia and Singapore*). New York: Wiley-Interscience, 97–141.

BURTON, C.K., and BIGNELL, J.D., 1969. Cretaceous-Tertiary events in Southeast Asia. *Geol. Soc. America Bull.*, *80*, 681–687.

CHALONER, W.G., and LACEY, W.S., 1973. The distribution of Late Paleozoic floras. *in* Hughes, N.F. (ed.), *Organisms and continents through time.* London: The Palaeont. Assoc., Spec. Pap. in Palaeont. 12, 271–289.

CHANG LI-SHO, 1953. (MAP) Geological map of Taiwan (1:300,000). Geol. Surv. Taiwan.

CHANG WEN-YOU, 1959. Grundzüge der geologischen Struktur und Entwicklung Chinas. *Geologie*, *8*, 471–488.

CH'ANG, T., 1959. *The geology of China.* United States Government Joint Publications Research Service, 623 p. (translation of *Chung-kuo Ti-chih Hsueh*, Peking, 344 p.)

COUVERING, J.A. VAN, and MILLER, J.A., 1971. Late Miocene marine and non-marine time scale in Europe. *Nature*, *230*, 559–563.

CRAWFORD, A.R., 1973. A displaced Tibetan massif as a possible source of some Malayan rocks. *Geol. Mag.*, *109*, 483–489.

CROWELL, J.C., and FRAKES, L.A., 1971. Late Paleozoic glaciation: part IV, Australia. *Geol. Soc. America Bull., 82,* 2515–2540.

CROWELL, J.C., and FRAKES, L.A., 1972. Late Paleozoic glaciation: part V, Karroo Basin, South Africa. *Geol. Soc. America Bull., 83,* 2887–2912.

DICKINSON, W.R., 1971. Plate tectonics in geologic history. *Science, 174,* 107–113.

DIETZ, R.S., 1961. Continent and ocean basin evolution by spreading of the sea floor. *Nature, 190,* 854–857.

DIETZ, R.S., and HOLDEN, J.C., 1970. Reconstruction of Pangaea: breakup and dispersion of the continents, Permian to present. *J. geophys. Res., 75,* 4939–4956.

EMBLETON, B.J.J., 1973. The palaeolatitude of Australia through Phanerozoic time. *J. geol. Soc. Austr., 19,* 475–482.

FAIRBRIDGE, R.W., 1970. An Ice Age in the Sahara. *Geotimes, 15,* No. 6, 18–20.

FITCH, F.H., 1952. The geology and mineral resources of the neighbourhood of Kuantan, Pahang. *Geol. Surv. Dep. Fed. Malaya Mem. 6,* 143 p.

FROMAGET, J., 1941. L'Indochine francaise. Sa structure géologique, ses roches, ses mines et leurs relations possible avec la tectonique. *Serv. géol. Indochine Bull., 26, fasc. 2.* Hanoi.

FROMAGET, J., SAURIN, E., and FONTAINE, H., 1971. (MAP) Carte géologique de Viet-nam, Kampuchia, et Lao (1:2,000,000) 3rd Ed.

GANSSER, A., 1964. *Geology of the Himalayas.* London: Interscience, 289 p.

GANSSER, A., 1966. The Indian Ocean and the Himalayas. *Eclog. geol. Helv., 59,* 831–848.

GILL, J.B., and MCDOUGALL, I., 1973. Biostratigraphic and geological significance of Miocene-Pliocene volcanism in Fiji. *Nature, 241,* 176–180.

GOBBETT, D.J., 1964. The Lower Palaeozoic rocks of Kuala Lumpur, Malaysia. *Federation Museums J., 9,* 67–79.

GOBBETT, D.J., 1967. Palaeozoogeography of the Verbeekinidae (Permian foraminifera). *in* Adams, C.G., and Ager, D.V. (eds.), *Aspects of Tethyan biogeography.* Systematics Assoc. Publ. 7, 77–91.

GOBBETT, D.J., 1968. The Permian System in Malaya. *Geol. Soc. Malaysia Bull., 1,* 17–22.

GOBBETT, D.J., 1972a. (MAP) Geological map of the Malay Peninsula (1:1,000,000). Geol. Soc. Malaysia, Kuala Lumpur.

GOBBETT, D.J., 1972b. Carboniferous and Permian stratigraphic correlation in Southeast Asia. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers,* 13 only.

GOBBETT, D.J., 1973. Upper Paleozoic. Chap. 4 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula (West Malaysia and Singapore).* New York: Wiley-Interscience, 61–95.

GOBBETT, D.J., and TJIA, H.D., 1973. Tectonic history. Chap. 10 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula (West Malaysia and Singapore).* New York: Wiley-Interscience, 305–334.

GOTHAN, W., and WEYLAND, H., 1954. *Lehrbuch der Palaeobotanik.* Akademie-Verlag, Berlin.

HAILE, N.S., 1970. Rhyolitic and granitic rocks around Genting Sempah, Selangor and Pahang, Malaysia, with a definition of a proposed new formation, the Sempah Conglomerate. *Geol. Soc. Malaysia Ipoh Discussion Meeting Abstracts,* 1–4.

HAILE, N.S., in press. The recognition of former subduction zones in Southeast Asia. *in* Tarling, D.H., and Runcorn, S.K. (eds.), *Continental drift, seafloor spreading and plate tectonics: implications for the earth sciences.* Academic Press, London.

HAILE, N.S., and MCELHINNY, M.W., 1972. The potential value of paleomagnetic studies in restraining romantic speculation about the geological history of Southeast Asia. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers,* 16 only.

HAILE, N.S., and STAUFFER, P.H., 1973. Redbeds and radiolarian chert: uneasy bedfellows of the 'Bentong Group'. *Geol. Soc. Malaysia A.G.M. Discussion Meeting Abstracts.*

HAMILTON, W., 1970. The Uralides and the motion of the Russian and Siberian platforms. *Geol. Soc. America Bull., 81,* 2553–2576.

HAMILTON, W., 1972. (MAP) Tectonic map of Indonesia (draft). U.S. Geological Survey.

HESS, H.H., 1962. History of the ocean basins. *in* Engel, A.E.J., *et al.* (eds.) *Petrographic studies: a volume in honor of A.F. Buddington.* Geol. Soc. America, 599–620.

HILTEN, D. VAN, 1964. Evaluation of some geotectonic hypotheses by paleomagnetism. *Tectonophysics, 1,* 3-71.

HURLEY, P.M., and FAIRBAIRN, H.W., 1972. Rb-Sr ages in Vietnam: 530 m.y. event. *Geol. Soc. America Bull., 83,* 3525–3528.

HUTCHISON, C.S., 1972. Tectonic evolution of the Malay Peninsula and Sumatra—a personal view. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers,* 29–32.

HUTCHISON, C.S., 1973a. Volcanic activity. Chap. 7 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula (West Malaysia and Singapore).* New York: Wiley-Interscience, 177–214.

HUTCHISON, C.S., 1973b. Plutonic activity. Chap. 8 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula (West Malaysia and Singapore).* New York: Wiley-Interscience, 215–252.

HUTCHISON, C.S., MS. Ophiolites of the Southeast Asian region. (presented at a symposium on "Ophiolites in the earth's crust", Moscow, 1973)

IRVING, E., 1967. Palaeomagnetic evidence for shear along the Tethys. *in* Adams, C.G., and Ager, D.V. (eds.), *Aspects of Tethyan biogeography.* Systematics Assoc. Publ. 7, 59–76.

ISACKS, B., OLIVER, J., and SYKES, L.R., 1968. Seismology and the new global tectonics. *J. geophys. Res., 73,* 5855–5899.

JACOBSON, H.S., and JAPAKASETR, T., 1965. Salt at Chaiyaphum, Thailand. United Nations Special Fund—Mekong Committee Minerals Survey, northeast Thailand, Progress Report 5. Bangkok, 21 p.

JAVANAPHET, J.C., 1969. (MAP) Geological map of Thailand (1:1,000,000). Bangkok, Department of Mineral Resources.

JONES, C.R., 1968. Lower Paleozoic rocks of Malay Peninsula. *Amer. Assoc. Petrol. Geol. Bull., 52,* 1259–1278.

JONES, C.R., 1970. The geology and mineral resources of the Grik area, Upper Perak. *Geol. Surv. Dep. West Malaysia Mem. 11,* 144 p.

JONES, C.R., 1973. Lower Paleozoic. Chap. 3 *in* Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula (West Malaysia and Singapore).* New York: Wiley-Interscience, 25–60.

JONES, C.R. MS. Geology and mineral resources of Perlis, north Kedah and the Langkawi Islands, Malaya. To be published as a Memoir of the Geol. Surv. Dep. West Malaysia.

JONGMANS, W.J., 1940. Beiträge zur Kenntnis der Karbonflora von Niederländisch Neu-Guinea-*Geol. Stichting Nederland Medd. Jaarverslag. 1938–39,* 263–274.

JONGMANS, W.J., and GOTHAN, W., 1935. Die paläobotanischen Ergebnisse der Djambi-Expedi. tion 1925. *Jaarb. Mijnwezen in Nedr. Indie 1930, Verhandl.,* 71–201.

KARIG, D.E., 1971. Origin and development of marginal basins in the western Pacific. *J. geophys. Res., 76,* 2542–2561.

KATILI, J.A., 1968. Permian volcanism and its relation to the tectonic development of Sumatra. *Nat. Inst. Geol. Min. Bandung Bull., 1,* 3–13.

KATILI, J.A., 1970. Large transcurrent faults in Southeast Asia with special reference to Indonesia *Geol. Rundschau, 59,* 581–600.

KATILI, J.A., 1971. A review of the geotectonic theories and tectonic maps of Indonesia. *Earth Sci. Rev.*, *7*, 143–163.

KATILI, J.A., 1972. Geochronology of West Indonesia and its implications on plate tectonics. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers*, 33 only.

KLOMPÉ, TH.H.F., 1955. On the supposed Upper Paleozoic unconformity in North Sumatra. *Leidse geol. Med.*, *20*, 120–134.

KLOMPÉ, TH.H.F., 1961. Pacific and Variscan orogeny in Indonesia: a structural synthesis. *Proc. 9th Pac. Sci. Congr.*, *12*, 76–115.

KLOMPÉ, TH.H.F., 1962. Igneous and structural features of Thailand. *Geol. en Mijnb.*, *41*, 290–302.

KLOMPÉ, TH.H.F., 1965. (MAP) Geologic map of Indonesia. U.S. Geol. Surv.

KOBAYASHI, T., and BURTON, C.K., 1971. Discovery of Ellesmereoceroid cephalopods in West Irian, New Guinea. *Japan Acad. Proc.*, *47*, 625–630.

KOBAYASHI, T., and SHIKAMA, T., 1961. The climatic history of the Far East. *in* Nairn, A.E.M. (ed.), *Descriptive Palaeoclimatology* (Interscience), 292–306.

KON'NO, E., 1963. Some Permian plants from Thailand. *Jap. J. Geol. Geogr.*, *34*, 139–159.

KON'NO, E., and ASAMA, K., 1970. Some Permian plants from the Jengka Pass, Pahang, West Malaysia. *Geol. and Paleont. S.E. Asia*, *8*, 97–132.

KON'NO, E., ASAMA, K., and RAJAH, S.S., 1971. The Late Permian Linggiu Flora from the Gunong Blumut area, Johore, Malaysia. *Geol. and Paleont. S.E. Asia*, *9*, 1–85.

KOOPMANS, B.N., 1965. Structural evidence for a Palaeozoic orogeny in north-west Malaya. *Geol. Mag.*, *102*, 501–520.

KOOPMANS, B.N., 1968. The Tembeling Formation—a lithostratigraphic description (West Malaysia). *Geol. Soc. Malaysia Bull.*, *1*, 23–43.

KROPOTKIN, P.N., 1971. Eurasia as a composite continent. *Tectonophysics*, *12*, 261–266.

LEE, J.S., 1939. *The geology of China*. London: Thomas Murby, 528 p.

LE PICHON, X., 1968. Sea-floor spreading and continental drift. *J. geophys. Res.*, *73*, 3661–3697.

LUNDQUIST, G., 1919. Fossile Pflanzen der *Glossopteris-Flora* aus Brasilien. *Kgl. Svenska Vet Akad. Handl.*, *60*, 3.

MCELHINNY, M.W., 1969. Notes on progress in geophysics: palaeomagnetic directions and pole positions—X. *Roy. astron. Soc. geophys. J.*, *19*, 305–327.

MCELHINNY, M.W., and WELLMAN, P., 1969. Polar wandering and sea-floor spreading in the southern Indian Ocean. *Earth and planet. Sci. Lett.*, *6*, 198–204.

MCKENZIE, D.P., 1972. Plate tectonics and sea-floor spreading. *American Scientist*, *60*, 425–435.

MELVILLE, R., 1966. Continental drift, Mesozoic continents and the migrations of the angiosperms. *Nature*, *211*, 116–120.

MELVILLE, R., 1967. The distribution of land around the Tethys Sea and its bearing on modern plant distribution. *in* Adams, C.G., and Ager, D.V. (eds.), *Aspects of Tethyan biogeography*. Systematics Assoc. Publ. 7, 291–312.

MITCHELL, A.H.G., YOUNG, B., and JANTARANIPA, W., 1970. The Phuket Group, Peninsular Thailand: a Paleozoic ?geosynclinal deposit. *Geol. Mag.*, *107*, 411–428.

MORGAN, W.J., 1968. Rises, trenches, great faults, and crustal blocks. *J. geophys. Res.*, *73*, 1959–1982.

MORGAN, W.J., 1971. Convection plumes in the lower mantle. *Nature*, *230*, 42–43.

PASCOE, E.H., 1959. *A manual of the geology of India and Burma* (4 vols.). Calcutta: Government of India Press.

POSAVEC, M.M., TAYLOR, D., VAN LEEUWEN, T., and SPECTOR, A., 1972. Tectonic controls of volcanism and complex movements along the Sumatran Fault System. *Geol. Soc. Malaysia Reg. Conf. Geol. Southeast Asia: Abstracts of Papers*, 47–48.

POSTHUMUS, O., 1927. Some remarks concerning the Palaeozoic flora of Djambi. *Kon. Akad. Wetenschappen, Amsterdam, Proc., 30*, 628–634.

PURBO-HADIWIDJOJO, M.M., 1963. Geology and mineral wealth of West Irian. *Contr. Dept. Geol. Inst. Techn. Bandung, 53*, 33–47.

RAJAH, S.S., 1970. Limestone occurrences in Johore. *Geol. Soc. Malaysia Bull., 3*, 131–133.

RIDD, M.F., 1971. South-East Asia as a part of Gondwanaland. *Nature, 234*, 531–533.

RIDD, M.F., 1972. Southeast Asia a part of Gondwanaland?: reply. *Nature phys. Sci., 240*, 140–141.

RODOLFO, K.S., 1969. Bathymetry and marine geology of the Andaman Basin, and tectonic implications for Southeast Asia. *Geol. Soc. America Bull., 80*, 1203–1230.

SARKAR, S.S., 1972. On the *Posidonia* from Rebak Islands, Langkawi, West Malaysia. *Geol. Soc. Malaysia Newsletter, 37*, 5–9.

SAURIN, E., 1956. Indochine. *Lexique Stratigraphique International, III, 6a*. Comm. de Strat., 20em Congrès Geol. Int., 1956. Centre Nat. de la Recherche Scientifique, Paris.

SCRIVENOR, J.B., 1931. *The geology of Malaya*. London: MacMillan, 217 p.

SEIBOLD, E., 1970. The geology of adjacent seas in arid and humid climates. *Geol. Soc. Malaysia Newsletter, 26*, 8–13, (brief English summary of work reported in Seibold, E., 1970. Nebenmeere im humiden und ariden Klimabereich. *Geol. Rundschau, 60*, 73–105).

SEWARD, A.C., 1933. *Plant life through the ages*. 2nd Ed. (reprinted 1959). New York: Hafner, 603 p.

SHU, Y.K., 1969. Some NW trending faults in the Kuala Lumpur and other areas. *Geol. Soc. Malaysia Newsletter, 17*, 1–5.

SIMPSON, G.G., 1970. Drift theory: Antarctica and Central Asia. *Science, 170*, 678 only.

SMILEY, C.J., 1970. Later Mesozoic flora from Maran, Pahang, West Malaysia. Part 1: geologic considerations. *Geol. Soc. Malaysia Bull., 3*, 77–88.

SMITH, A.G., and HALLAM, A., 1970. The fit of the southern continents. *Nature, 225*, 139–144.

STAUFFER, P.H., 1968. The Kuala Lumpur fault zone: a proposed major strike-slip fault across Malaya. *Geol. Soc. Malaysia Newsletter, 15*, 2–4.

STAUFFER, P.H., 1973. Cenozoic. Chap. 6 in Gobbett, D.J., and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula* (*West Malaysia and Singapore*). New York: Wiley-Interscience, 143–176.

STAUFFER, P.H., and GOBBETT, D.J., 1972. Southeast Asia a part of Gondwanaland? *Nature phys. Sci., 240*, 139–140.

SUNTHARALINGAM, T., 1968. Upper Palaeozoic stratigraphy of the area west of Kampar, Perak *Geol. Soc. Malaysia Bull., 1*, 1–15.

TAI, S.A., 1972. Geology of eastern Singapore Island with special emphasis on the Old Alluvium. Unpubl. B.Sc.(Hons.) thesis, Department of Geology, Univ. Malaya, 71 p.

TARLING, D.H., 1971. Gondwanaland, palaeomagnetism and continental drift. *Nature, 229*, 17–21.

TARLING, D.H., 1972. Another Gondwanaland. *Nature, 238*, 92–93.

TAYLOR, D., 1974. The liberation of minor elements from rocks during plutonic igneous cycles and their subsequent concentration to form workable ores, with particular reference to copper and tin. Fifth Pres. Address, Geol. Soc. Malaysia. *Geol. Soc. Malaysia Bull., 7*. 1–16.

TJIA, H.D., 1972. Strike-slip faults in West Malaysia. *24th Sess. int. geol. Congr., Canada, Sect. 3*, 255–262.

TOIT, A.L. DU, 1937. *Our wandering continents—an hypothesis of continental drifting*. Edinburgh: Oliver and Boyd, 366 p.

UNITED NATIONS, 1959. (MAP) Geological map of Asia and the far east (1:5,000,000). Econ. Comm. for Asia and the Far East.

UNITED STATES NAVY HYDROGRAPHIC OFFICE, 1961. (MAP) Map of the world, Mercator projection (1:12,233,000 at equator), 2nd Ed.

VEEVERS, J.J., JONES, J.G., and TALENT, J.A., 1971. Indo-Australian stratigraphy and the configuration and dispersal of Gondwanaland. *Nature, 229*, 383–388.

VINE, F.J., and MATTHEWS, D.H., 1963. Magnetic anomalies over oceanic ridge. *Nature, 199*, 947–949.

VISSER, W.A., and HERMES, J.J., 1962. Geological results of the exploration for oil in Netherlands New Guinea. *Kon. Ned. geol. mijnb. gen., Verh., geol. Ser., 20*, 265 p.

WAGNER, R.H., 1958. On a mixed Cathaysian and Gondwana flora from SE Anatolia (Turkey). *Congrés Strat. Géol. Carboniférе, 4me Heerlen 1958, Compte Rendu, 3, 745–752.*

WALLACE, A.R., 1869. *The Malay Archipelago*. (reprinted 1962). New York: Dover, 515 p.

WALTON, J., 1929. The fossil flora of the Karroo System in the Wankie—District, Southern Rhodesia. *Geol. Surv. S. Rhod. Bull., 15*, 2.

WEGENER, A., 1929. *Die Entstehung der Kontinente und Ozeane*. Braunschweig: Friedr. Vieweg und Sohn. (English translation by John Biram, 1966, *The origin of continents and oceans*. New York: Dover, 246 p.)

WENSINK, H., 1972. The paleomagnetism of the Salt Pseudomorph Beds of Middle Cambrian age from the Salt Range, West Pakistan. *Earth and planet. Sci. Lett., 16*, 189–194.

WILSON, J.T., 1963. Continental drift. *Sci. Amer., 208*, No. 4, 86–100.

WILSON, J.T., 1965a. A new class of faults and their bearing on continental drift. *Nature, 207*, 343–347.

WILSON, J.T., 1965b. Evidence from ocean islands suggesting movement in the earth. *Phil. Trans. Roy. Soc., A 258*, 145–167.

WILSON, J.T., and BURKE, K., 1972. Two types of mountain building. *Nature, 239*, 448–449.

WONG, T.W., 1970. Geology of the Rawang area, Selangor, West Malaysia. Unpubl. B.Sc. (Hons.) thesis, Department of Geology, Univ. Malaya.

YANCEY, T.E., 1972. Devonian fossils from Pulau Rebak Besar, Langkawi Island, West Malaysia. *Geol. Soc. Malaysia Newsletter, 37*, 10–12.

YANSHIN, A.L., 1966. (MAP) Tektonischeskaya Karta Eurazii (1:5,000,000). Geol. Inst. Nauk-SSR and Minist. Geol. SSR, Moscow.

YEAP, E.B., 1969. Geology of the Petaling Jaya—Salak South area, Selangor, West Malaysia. Unpubl. B.Sc. (Hons.) thesis, Department of Geology, Univ. Malaya.

YEW, C.C., 1971. The geology and mineralization of the eastern Kuala Lumpur area, West Malaysia. Unpubl. B.Sc. (Hons.) thesis, Department of Geology, Univ. Malaya.