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On Pleistocene Migration Routes of Vertebrate Fauna In Southeast Asia

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Abstract: Geological and paleontological studies as well as our knowledge of Pleistocene vertebrates in Southeast Asia indicate that they originated in the Asian continent and migrated during the Pleistocene period into the island archipelago of Southeast Asia. It seemed that their migration followed two different routes, i.e. a western route which crossed the Sunda Land area, and an eastern route via Taiwan (Formosa) and the Philippines toward the Sunda Land area and Sulawesi (Celebes). In this last island both of those migration routes eventually met sometime in the Upper Pleistocene period.

From the Sunda Land area, the western migration route continued along the geanticlinal ridge of the Lesser Sunda island chain into Flores and from there it went on to arrive eventually in Timor. On the other hand, it seemed that there was no direct link between Sulawesi (Celebes) and the Lesser Sunda island chain; in other words the eastern migration route did not connect with the western one in the Lesser Sunda island chain.

So far, it seemed that the Pleistocene vertebrates had not reached Australia during the time when the Post-glacial sea submerged the areas of the Timor sea and the Sahul shelf. This is substantiated by the fact that up to now there have been no reports made of their discovery on that continent. However, the recent discoveries of *Pithecanthropus*-like hominids in Victoria (Australia) may suggest that a part of the Pleistocene vertebrate fauna actually did reach the Australian continent (Thorne 1971). The most obvious landbridge connecting Timor with Australia could be via the Timor sea and the Sahul shelf.

There are no reports of Pleistocene vertebrate fossils from West Irian-Papua, Halmahera and Talaud islands, nor does our relatively little paleogeographic knowledge of those areas gives much idea as to whether there was a land-connection between Mindanau (Philippines) and West Irian-Papua via Talaud and Halmahera islands. The same is also true for the deep Banda sea, which is encircled by Sulawesi (Celebes), the Lesser Sunda islands, Sahul shelf, West Irian-Papua, and the Halmahera islands.

The migration of the Pleistocene vertebrates from the Asian continent to Southeast Asia was made possible by the interaction between orogenetic movements affecting many parts of Southeast Asia and the worldwide lowering of the sea-level during the Pleistocene period. As a result of this interaction many areas of this region emerged above sea-level to become dry land acting as land-bridges through which the above fauna could migrate from Asia toward Australia during the Pleistocene. The orogenetic movements caused block faulting and gave rise to graben and horst-like features.

During the Post-glacial period, the sea submerged the low-lying subsiding grabens. Consequently deep submarine basins and trenches as well as deep sea straits came into being between the numerous islands of Southeast Asia. These deep marine waters prevented the further migration of the Pleistocene vertebrates. Groups of this last fauna isolated on the numerous islands by the submergence of the Post-glacial sea afterward pursued an independent evolutionary trend, which resulted in specific differences among them until they became extinct after the Pleistocene period.

INTRODUCTION

In most discussions on the distribution and migratory movements of a fauna, considerable emphasis is placed on comparison of the fossil forms themselves and of their respective ages. Equal ages of two different fossil sites and similar faunal assemblage may suggest that they are contemporaneous and that there exist an intermingling among them if no physical barriers separate those fauna from each other.

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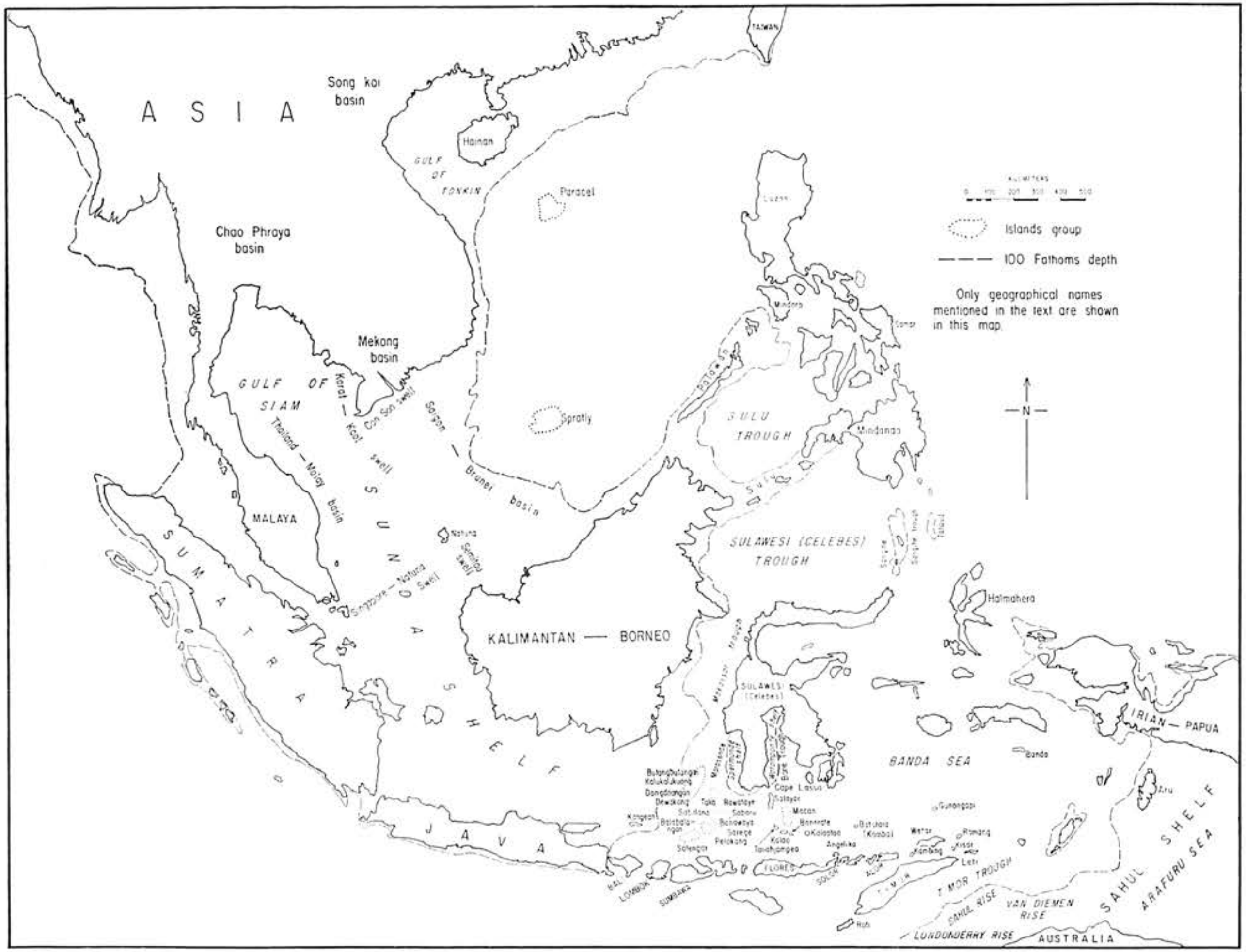

Fig. 1. Sketch map of Southeast Asia.

Without the existence of physical barriers separating different fauna it is assumed that they have, one way or the other, contact with each other and an ability to intermingle and even to interbreed. This, for one region, has been proposed for the Pleistocene vertebrates of South and Southeast Asia, notably from India, Burma, Malay Peninsula, China, Java and Borneo (Hooijer 1952, Andrews 1905, Koenigswald 1953, Colbert 1943). Migration routes of those vertebrates have been postulated by Koenigswald (1940) and Weidenreich (1945). In this case the Java Sea and the southern part of the South China Sea have not been assumed to be of significant importance as a physical barrier to the Pleistocene migratory movements, because these were land areas during the Pleistocene linking Asia with the Larger Sunda islands of Sumatra, Java, and Borneo (Molengraaff 1922).

After the last World War, Pleistocene vertebrate fossils have been discovered on several islands in Southeast Asia which are separated from each other by straits hundreds and even of thousand of meters deep. These islands are Mindanau, Celebes, Flores and Timor (see fig. 1). Difficulties arise as to how to interpret these fossil sites in terms of faunal migrations, since those deep channels and sea straits obviously were physical barriers to the migratory movements of the Pleistocene vertebrates and could not be crossed by a land fauna. Notwithstanding these difficulties, attempts have been made to draw migration routes based on these fossil sites (Terra 1943, Sartono 1969). These attempts show a too simplified picture of these events, geological interpretations of the region being neglected.

The purpose of this paper is to suggest the existence of Pleistocene landbridges in Southeast Asia which made possible the migratory movements of the vertebrate fauna in this region from the Asian continent into the Sunda shelf and across the deep sea straits and channels toward the Australian mainland. In this connection the Pleistocene history of the region concerned will be briefly discussed.

STATEMENT OF THE PROBLEM

From the viewpoint of the present faunal distribution Indonesia shows remarkable aspects. The western part possesses a faunal association which is Indo-Malayan in appearance, while its eastern part is mainly Australo-Papuan. The central part is the most interesting in that it has a mixed fauna of both Indo-Malayan and Australo-Papuan elements, i.e. Indo-Malayan if we go to the direction of the Sunda shelf and more of an Australo-Papuan appearance if we approach the Sahul shelf. The most pronounced faunal difference can be found between Sulawesi (Celebes) and Kalimantan (Borneo) in the north and between Bali and Lombok in the south. Based on this fundamental feature Wallace (1860) drew his "Wallace's line" between those islands as a zoogeographic boundary between the Indo-Malayan and Australo-Papuan fauna which almost coincides with the eastern edge of the Sunda shelf.

Recent zoogeographic studies in Indonesia indicate that Wallace's line does not seem to form an insurmountable barrier for the faunal migration of the present time. This is substantiated by the fact that mixing between fauna of Indo-Malayan and Australo-Papuan origin actually does occur in East Indonesia. Many investigations had been done on the faunal distribution in Indonesia since Wallace's studies. Works of Beaufort (1926), Rensch (1936), Scrivenor et al. (1943), Zeuner (1942, 1943) and Mayer (1944) give accounts on the migration of the present fauna in this part of Asia and on events which promoted this migration. Their results can be summarized as follows:

1. Wallace's line is not a zoogeographic boundary between Indo-Malayan and Australo-Papuan fauna.
2. Weber's line is the boundary of two regions with a predominant Indo-Malayan and one in which the Australo-Papuan elements prevail.
3. Wallace's line indicates the eastern edge of the Sunda shelf.

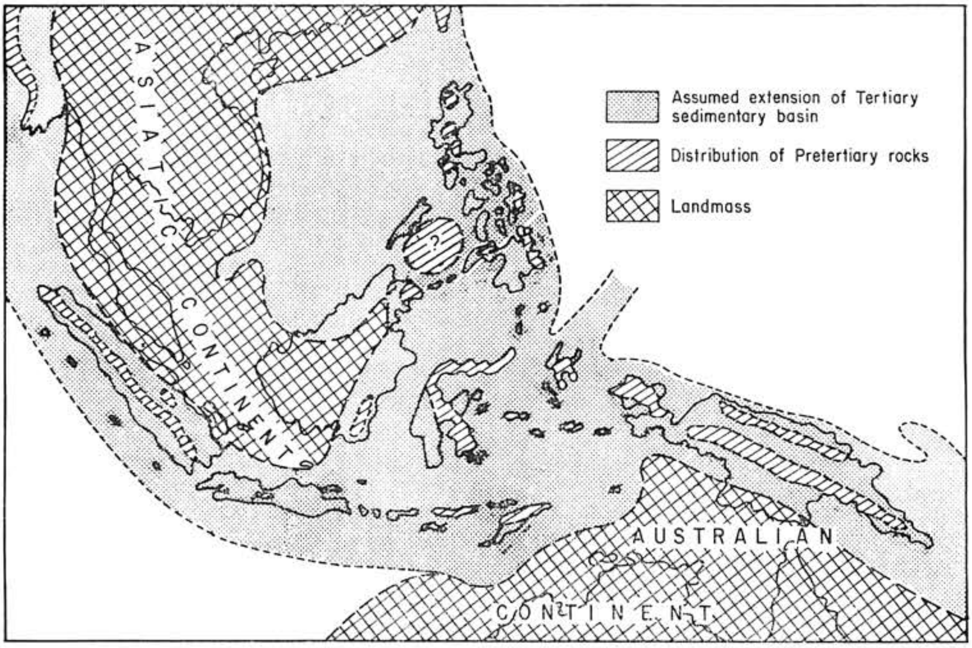

Fig. 2. Marine basins during Tertiary in Southeast Asia.

In the last twenty years discoveries have been made of vertebrate fossils east of Wallace's line. These were found in the Philippines on the island of Mindanau (Koenigswald 1956) and in Indonesia in Celebes (Hooijer 1957), Flores (Hooijer 1964), and in Timor (Sartono 1969). Since then more vertebrate fossil sites have been reported in Indonesia (Hooijer 1961 a, b, 1972; Sartono 1972) and determination of these specimens is still going on.

The above discoveries of vertebrate fossils and our increased knowledge of Pleistocene geology of East Indonesia make a revision of the existing theory of Pleistocene vertebrate migration routes in this region necessary. So far, the problem of this faunal migration is not yet solved, especially as to the conditions which have promoted the migratory movements. There is an assumption that vertebrates were able to migrate from Asia towards Australia along the present island chains, which acted as land-bridges, by way of moving from one island to the other (Koenigswald 1939, Terra 1943, Weidenreich 1945). This special mode of migration has been called "island hopping". But a satisfactory explanation as to how the Pleistocene fauna were able to cross the deep sea straits in the island chains has not been given. The discoveries of *Stegodon trigonocephalus florensis* (Hooijer 1964) in Flores, *Stegodon timorensis* (Sartono 1969) and *Geochelone atlas* (Hooijer 1971) in Timor and *Stegodon*

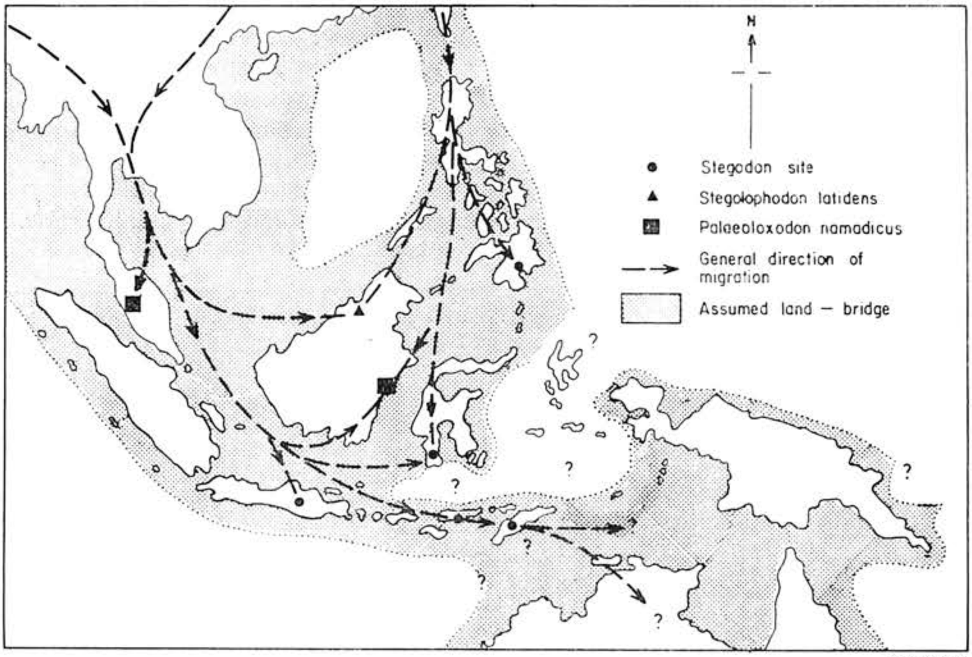

Fig. 3. Paleogeography of Southeast Asia during Pleistocene.

mindanensis in Mindanau (Koenigswald 1956) as well as vertebrate fossils in South Celebes (Hooijer 1957), conclusively prove that Pleistocene Indo-Malayan elements are also found east of the present "Wallace's line". This means:

a. that these vertebrates were able to cross even the thousands of meters deep straits and channels.

b. or that the deep sea straits and channels did not exist during Pleistocene time; in other words they were landbridges connecting the various islands during that period.

It is hard to imagine how a vertebrate land fauna could possibly cross the deep sea straits between the islands of Southeast Asia during Pleistocene time. However, the fact that at the present time Indo-Malayan and Australo-Papuan elements are found mixed in the same region suggests the possibility that in Pleistocene time they too were able to move freely from the Asian mainland towards Australia and vice-versa, and to intermingle in an area which is now East Indonesia. This suggests also that Asia and Australia may have been connected with each other by dry land enabling the migratory movements of this fauna from Asia toward Australia during that period.

LANDBRIDGES

The map of the island archipelago between the Asian and Australian mainland shows three distinct physiographic units. These are (Bemmelen 1949, vol. IA, Chapter 1):

1. Sunda area: this includes Sunda shelf, the Larger Sunda islands of Kalimantan (Borneo), Sumatra, Java and the seas in between. This part is connected with the Asian mainland by the Malay peninsula.
2. Sahul area: this includes the Sahul shelf, Irian (New Guinea) and Aru. These islands are connected with the Australian mainland by the Arafura sea.
3. Submerged borderland: this includes Sulawesi (Celebes), the northern and southern Moluccas, the Lesser Sunda island chain, and the Philippine archipelago. This submerged region lies between the above two shelves (see fig. 4).

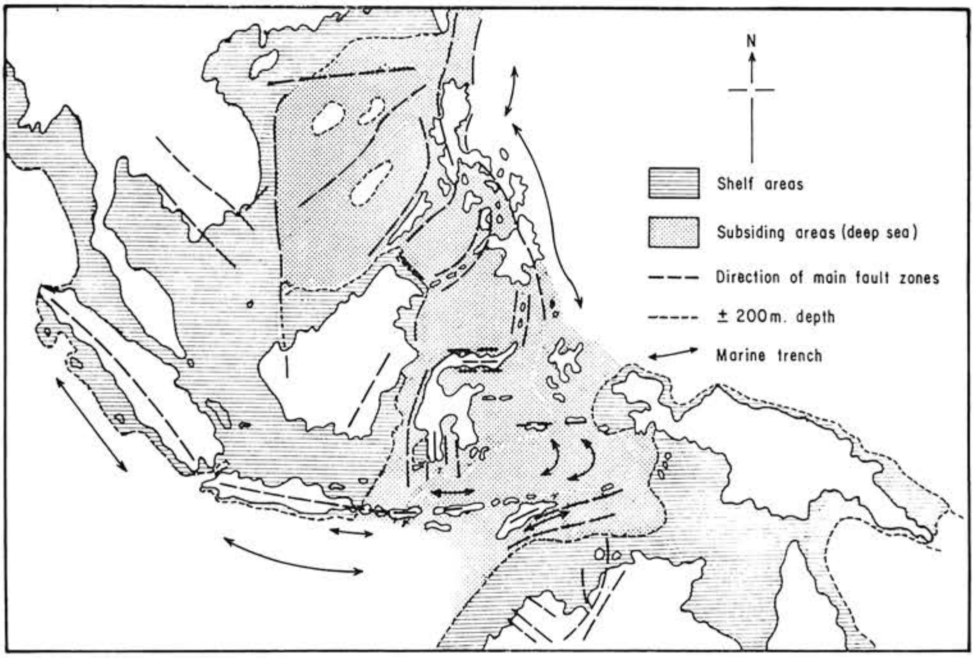

Fig. 4. Distribution of shelves and deep seas during Postglacial period in Southeast Asia.

The present Sunda and Sahul area are submerged by relatively shallow seas of almost even depths mostly less than 100 meters, while the submerged borderland has deep seas hundreds and even thousands of meters deep. The eastern edge of the Sunda shelf coincides approximately with Wallace's line, while an equivalent shelf edge exists in the east separating the Sahul shelf from the submerged borderland. Both the Sunda and the Sahul shelves are assumed to be dry land during the Pleistocene glaciation (Molengraaff and Weber 1919, Molengraaff 1922) while the submerged region was still inundated by the Pleistocene sea. It seems that the supposedly deep seas in the submerged borderland did not form an unsurmountable physical barrier for the migration of vertebrate fauna from the Asian mainland toward Australia during the Pleistocene time. Even if the shelf areas became dry land during the Pleistocene as a result of the lowering of the Pleistocene sea level, the depth of the seas of the submerged borderland would still attain hundreds and even thousands of meters, which obviously could not be crossed by vertebrate land animals. Their migration could only be made possible if there were no seas between the Sunda and Sahul shelves during the Pleistocene period; in other words the submerged borderland or part of it would have to be a land area during the Pleistocene over which those vertebrates were able to cross and to migrate from Sunda Land across the submerged borderland toward the Sahul shelf.

Geologically speaking, the Pre-Tertiary central part of the Sunda Land is surrounded by Tertiary mountain systems in which downwarps as well as upheavals still play an important role until today. Rocks of these mountain systems were deposited in geosynclinal basins, which occupied the area of the present Southeast Asia and separated the Asian from the Australian continent (see fig. 2). This condition prevailed throughout the Tertiary period, with alteration of the paleogeographic picture from one period into the other (Sartono 1970).

The Tertiary basins were uplifted at the end of the Tertiary period, which occurred in two phases, i.e. an early phase during Plio-Pleistocene time and a late phase marking the end of the Pleistocene (Umbgrove 1949, Gervasio 1968, Sartono 1972). This Pleistocene uplift was accompanied by the regression of the glacial sea which terminated at the end of the Pleistocene as a result of the Postglacial transgression. These geologic processes which in fact still persist until today were accompanied by tectonic earthquakes, volcanic activities, isostatic anomalies, block faulting and uplift, resulting in the formation of island arcs and island chains, deep trenches, deep sea straits, and deep marine basins, all with great differences in depths and altitudes.

These geological events brought about changes in the distribution of land and sea in Southeast Asia during the Pleistocene and Holocene time. In attempting to synthesize this change of the paleogeography of this region, it is necessary to consider the geology of this area as a whole briefly.

Kalimantan (Borneo)

During Plio-Pleistocene time the central part of Kalimantan (Borneo) was subjected to an upheaval giving rise to a central ridge, which extended in a northeast to southwest direction (Zeylmans van Emmichoven 1938). This uplift seemed to cause a regression of the sea from Central Borneo and adjacent areas, i.e. in North Borneo (Schuppli 1946), and also from East and Southeast Borneo and South Celebes. Both of these last areas were once occupied by a Neogene basin, and the Plio-Pleistocene uplift left the intervening Makassar Strait as a low land connecting both of them (Bemmelen 1949, Vol. IA, p. 358). This low land later on became a landbridge between Kalimantan (Borneo) and Sulawesi (Celebes) as a result of the subsequent subsiding Pleistocene sea level. It is assumed that the Pleistocene vertebrate fauna as well as Pleistocene hominids were able to migrate across this landbridge from the Sunda shelf to Celebes (Hooijer 1970, Bemmelen 1949, Vol. I p. 435).

In Kalimantan (Borneo) itself Pleistocene *Stegolophodon latidens* and *Palaeoloxodon namadicus* had been discovered from the areas of Brunei and Samarinda respectively (Hooijer 1955). The discovery of the latter species in the Malay peninsula (Andrews 1905) may indicate the existence of a landbridge between this region and Kalimantan (Borneo) across the Sunda shelf in Pleistocene time.

Sulawesi (Celebes)

The uplift which occurred in Southeast Borneo during Plio-Pleistocene time also affected South Celebes. During this period this area had been subjected by an uplift accompanied by block faulting which divided the upheaved north to south trending geanticline crest into a western and eastern part, respectively the socalled Western Divide Mountain and Bone Mountain (Hoen and Ziegler 1917). The interjacent subsiding longitudinal block is called Walanae trough. In this Pleistocene subsiding trough coral reefs have been found in the southern part, in the area of Batuku, and in its northern tip marine claystone can be found in the Tempe plain.

In the Walanae trough, in Sopeng district near the village of Tjabenge, a Pleistocene vertebrate fauna has been found including among others *Archidiskodon celebensis*, *Celebochoerus heekerini*, *Testudo margae* later on renamed *Geochelone atlas* (Hooijer 1971), *Anoa depressiocornis* (Smith) subsp., *Babirusa beruensis* nov. subsp., *Stegodon sompoensis* (Hooijer 1948) and stone implements. Although there are in general no distinct affinities with the Javanese Pleistocene vertebrate fauna, *Testudo margae* (Hooijer 1971) resembles the giant tortoise of Kaliglagah fauna of Bumiaju (Java) and of Siwalik (India). The stone implements resemble the Upper Paleolithic flakes from the Pleistocene Kabuh beds of Sangiran in Central Java (Heekeren 1958), which contain the famous Trinil fauna as well as *Pithecanthropus*. As mentioned previously, it has been assumed that during Pleistocene time the Javanese vertebrate fauna, and very likely also Pleistocene *hominids*, could arrive in South Sulawesi (Celebes) across the Makassar trough which was then a low land. Two islands chains may give indications of the existence of this low land. The northern one runs along the row of islands beginning from Spermonde shelf trough Kalukalukuang, Butongbutongan, Dongdoangan, Marasende, and Dewakang, into the Sunda shelf. The southern one could have followed along the submarine ridge beginning from the southern tip of Western Divide Mountain through Taka Rawatjae (De Brill), Sabaru, Sabalana (Postiljon), Banawaja, Sarege, Pelokang, Balabalangan (Paternoster), Satengar (Zandbuis), and Kangean, into Sunda shelf (Bemmelen 1949, vol. IA, p. 436–437). As discussed above, both these island chains and the area between them were broken by block faulting at the end of Pleistocene time and submerged by the Postglacial sea resulting in the formation of the deep Makassar trough.

To the west and to the east of South Celebes, i.e. west and east of Western Divide Mountain respectively, Bone Mountain, the geanticline of South Celebes is cut off by fault zones which slope down in terraces toward the Makassar trough in the west and Bone trough in the east, as is indicated for instance by the parallel north to south trending rows of coral reefs in Spermonde shelf west of Western Divide Mountain and reefs in Watampone shelf east of Bone Mountain range (Molengraaff 1922). The seacoves and notches in Miocene limestone found on a 30 meters high coastal plain of Makasar give indications of the former relative sea level. The uplift of this plain occurred till very recent times (Umbgrove 1947, p. 760), very likely as an adjustment to the downward movements of Makasar as well as of Bone trough.

Philippines

As in Indonesia, the Pleistocene orogenesis in the Philippines occurred in two phases, i.e. an early phase in Plio-Pleistocene time and a late phase at the end of the Pleistocene (Gervasio 1968).

During the early phase in Plio-Pleistocene time, the Luzon and Samar Arch were upheaved into a broad geanticlinal ridge which extended toward Kalimantan (Borneo) and Sulawesi (Celebes) to the south, as well as to the north toward Taiwan (Smith 1910, 1924; Willis 1937). As a result of this uplift the top of this geanticline broke down along transversal and longitudinal faults causing block faulting and the formation of the median depression zones, i.e. the Manila and Ragay zones, including Sulu trough within the Manila zone as well as Sulawesi (Celebes) and Sangihe trough within the Ragay zone (Bemmelen 1949, vol. IA, p. 374).

During the second phase of uplift at the end of the Pleistocene, the subsiding movements of the geanticlinal ridge continued. On the subsiding blocks alluvial silts, coral reefs, and volcanic products can be found, while on the elevated ones river terraces and upheaved coral reefs as well as raised beach deposits can be observed.

The Pleistocene history of the Sulu basin can be inferred from the geology of the surrounding islands; these are Palawan, Sulu, Mindoro, and Zamboanga. The Sulu basin together with these islands are assumed to have formed a landmass during Pre-Cretaceous time. This landmass was not entirely submerged by the Tertiary sea as can be inferred from the coarse-grained Tertiary sediments observed in the eastern part of Palawan and reef limestones more to the west (Gervasio 1968).

The Neogene sedimentation cycle ceased during Plio-Pleistocene time by an uplift accompanied by block faulting and gave rise to the formation of horst and graben-like features. The Pleistocene sedimentation was confined to the subsiding rift valleys with deposition of coarse-grained sediments as molasse and also reef limestones in places. As a consequence of the regression of the glacial sea, many parts of the landmass which occupied the Sulu basin became dry land.

During the Postglacial period the sea submerged the low lying grabens of the Sulu basin area, while only the horst-like features stayed above sea level as a relatively uplifted rim readjusted to the downwarp movements of its central part. This rim had been subjected afterwards to transverse faults so that an island chain came into being on both flanks of the Sulu basin, i.e. the Palawan and Sulu archipelago respectively on the west and east side (Gervasio 1968).

South China Sea

The submarine geology of the southern part of the South China sea is not much known. From the collected data from this area it is inferred that during the Cenozoic the largest portion of it was submerged by sea and that the islands within it were formed only in subrecent time, very likely by orogenetic movements at the end of the Pleistocene. The Tertiary basin in this area is bounded to the west by the east coast of the Malay peninsula, and to the north is partly enclosed by the Mui Bat Song swell and to the south by the Singapore-Natuna structural swell. To the east, between the Natuna and Khorat-Kcol-Con So swells, this basin extends into the Tertiary basin of northwest Borneo. In a northern direction its boundary approaches very near the east coast of Viet-Nam and further northward in the Gulf of Tonkin it deflects to the east toward south of Hainan (Meng 1968).

There is also a possibility that the delta area of the Song Koi (Red River), Mekong and Chao Phraya basins, as well as the lacustrine sediments of the coastal plain of the east coast of the Malay Peninsula and on the west coast of the Gulf of Siam may contain late Tertiary (?Pliocene) and Quaternary sediments and may form an extension of the Tertiary basins (CCOP., Tech. Bull., 1968, vol. I, p. 129–142; see also fig. 2).

In this part of the South China sea two island groups can be found, namely the Spratley and Paracel islands. The first island group is situated north of Brunei between Viet-Nam and the island of Palawan on the western flank of Sulu basin, while the second can be found southeast of the island of Hainan (China) in front of the Gulf of Tonkin. On both island groups marine Pleistocene and recent coral limestones are found which have been uplifted, faulted, and even folded into broad anticlines by recent orogenic movements. Very likely, the area occupied by these islands were below sea level during the Pleistocene and became islands as a result of block-faulting into horst and graben-like features just in subrecent time (CCOP, Technical Bulletin, 1968, vol. 1, p. 135).

The Lesser Sunda islands

The Sumatra-Java geanticline which borders the southern and south-western edge of the Sunda shelf extends further to the east and, crossing the eastern limit of this shelf, into the Lesser Sunda islands chain. This island chain consists of two almost parallel geanticlines, i.e. the Timor-Leti and Bali-Romang geanticlines, occupying respectively the present non-volcanic Outer Banda Arc and the volcanic Inner Banda Arc. These two geanticlines had been elevated at the end of Neogene time, coinciding with the uplift which also affected most parts of the archipelago of Southeast Asia (Umbgrove 1949). Simultaneously to this Plio-Pleistocene uplift, a median trough came into being on the crest of the Timor-Leti geanticline which is known as the Central Basin of Timor filled with Pleistocene deposits (Brouwer 1940, 1941, 1942; Bemmelen 1949, vol. IA, p. 541). In Bali-Romang geanticline the same tectonic events took place which resulted in longitudinal faulting of this geanticlinal belt and the formation of the subsiding volcanic zones of Bali, Lombok, Sumbawa, Flores, Solor, Alor and extend westward into the volcanic zones of Java, Strait Sunda, and Sumatra, while to the east they can be traced further on in Banda and Gunung-api in the Banda sea.

The Pleistocene glacial sea still inundated partly the above subsiding volcanic zones resulting in deposition of mixed shallow marine and volcanic facies containing a rich vertebrate fauna at certain places, for instance the famous Sangiran (Es 1931) and Trinil (Duyfjes 1938) sites of Java. In fact, a subdivision of the Pleistocene epoch of Indonesia has been based exclusively on the vertebrate fauna of this island. In Central Flores, in the area of Soa plain, the *Stegodon*-bearing Pleistocene deposits also show a mixed marine and volcanic facies (Hartono 1961).

Toward the end of Pleistocene time an uplift affected the area of the Lesser Sunda islands. This resulted in the formation of transversal faulting of both geanticlinal belts and gave rise to a large number of horsts and grabens (Bemmelen 1949, vol. IA, b. 536–544). The isolated blocks became the numerous islands of the Lesser Sunda islands while the subsiding grabens are the rift zones representing the sea straits between the present numerous islands. These sea straits are deep ones, ranging from hundreds of meters, as for instance in the case of Strait Bali about 400 meters deep, to at least 3000 meters in Strait Wetar between Wetar, Kisar, and Romang. It is likely that as an adjustment to the subsiding grabens, upward movements of the horst-like islands have been accentuated. This can be deduced from the existence of coast terraces, upheaved reef limestones, and "hanging" valleys which have different altitudes ranging from several meters to about 700 meters, as can be observed at the highest terraces in Kambing and Alor, and even more in Wetar where reef limestone is found at about 820 meters.

Hooijer (1970) has assumed the existence of a land connection between Flores and Timor on grounds that the Flores and Timor *Stegodon* are similar to each other.

In this case both of those islands may have not been sufficiently isolated from each other during the Pleistocene period (see fig. 3). The southern tip of the southern arm of Sulawesi is connected by two almost parallel rows of ridges, one a submarine ridge and the other consisting of a row of islands (Hetzel 1930, Kuenen 1933, 1935). The submarine ridge extends from Watampone shelf on the eastern coast of the Bone Mountain to a south-southeast direction toward Macan islands, and deflects to east-southeast toward Kalaotoa islands. From here on this submarine ridge bifurcates, one branch extends toward Angelika flat and the other runs to the east joining the submarine rise carrying the submarine Batu Tara volcano (or called Komba island) in the southern part of the deep Banda basin (Hartmann 1935, Brouwer 1940). This last island lies within the volcanic Banda Inner Arc. The second ridge extends southwards from Cape Lassa on the southeastern tip of Bone Mountain to Salayar island and from here on it turns in east-southeast direction into Tanah Jampea, Kalao, Bonerate, and Marianne as well as Kayupanggang reefs. Both of these submarine ridges are separated from each other by Salayar trough. The Flores trough then occupies a position between the southern arm of Sulawesi in the north and Flores island in the south, Doangdoangan-Kangean in the west, and the abovementioned row of ridges in the east (Bemmelen 1949 vol. IA, fig. 182). So far, the geological relationship between this Flores trough and its surrounding areas is not much known. There is a general assumption that structurally there is no direct link between the Lesser Sunda islands chain and Sulawesi (Celebes).

The Sahul Shelf

It seems that the area between Timor and Australia, i.e. the present Timor trough and the Sahul shelf, has been subjected to the same tectonic events which affected the Lesser Sunda island chain during the Pleistocene. The reports of van Andel and Veevers (1965) on these areas give very interesting results. According to both authors the deep Timor trough and the differences in relief of the basins and the rises on the Sahul shelf as well as on the associated Sahul shelf edge give evidences of regional epeirogenic deformation and of slow downwarping. They assumed that as a result of an uplift and the regression of the sea sometime during the Late Tertiary the Sahul shelf and the areas of Timor and Roti as well as the present Timor trough were above sea level. In the early stage of the orogenetic movements those areas had a low relief and were partly still submerged by the Early Pleistocene sea. Then they were subjected to a slow uplift accompanied by a regression of the glacial sea and the formation of a series of steep erosional surfaces such as the Timor trough, Van Diemen rise, Sahul rise, and Londonderry rise. The Timor trough and the pronounced edge of the Sahul shelf are assumed to have been formed in relatively recent time, i.e. in the younger part of the Pleistocene. The edge shelf itself was submerged by the Post-glacial sea at approximately 19.000 years B.C. (Andel and Veevers 1967 fig. 11. 1. A.). It is inferred from this that the edge of the Sahul shelf which attained its present form in sub-recent time is merely a morphological phenomenon rather than the limit of the Australian continent (Sartono, Kusumadinata, Pulunggono 1972).

CONCLUSIONS

Several inferences can be made from the previous chapters discussed in this paper. These are:

1. The Pleistocene orogenic movements in most parts of Southeast Asia can be subdivided into two phases:
   a) An early phase during Plio-Pleistocene.
   b) A late phase at the end of the Pleistocene time.

2. As a result of the interaction between the early phase of the Pleistocene uplift and the lowering of the glacial sea in the Pleistocene period, many regions of Southeast Asia became dry land forming land-bridges, a.o. the area of Sulu sea, Celebes sea, Makasar trough, the sea straits interjacent the islands of the Lesser Sunda islands, Timor trench, the Sunda and Sahul shelf, and the inland seas of the Philippine archipelago.

3. The above dry lands not only served as a link between the Asian and the Australian continent, but also faciliated the migration of the Pleistocene vertebrate land fauna from Asia across Southeast Asia toward Australia (see fig. 3).

4. The northern part of the South China sea was still inundated by the sea during Pleistocene time which hampered the migratory movements of the vertebrates across this particular area. Consequently, the migration took a western route from South Asia into the Sunda shelf, and an eastern route from East Asia across Taiwan and the Philippines into Celebes. Both of these routes met in South Celebes and possibly also in Borneo.

   From Java the western route continued in an eastern direction along the region of the Lesser Sunda islands to Timor and there is a possibility that it eventually reached the Australian continent too (see fig. 3).

5. The early phase of the Pleistocene uplift was reactivated during the late phase at the end of the Pleistocene period, which caused the formation of horst and graben-like features on the Pleistocene Southeast Asian continent with large differences in altitudes.

6. The above features were inundated by the Postglacial sea giving rise to the isolated islands and the intervening deep sea straits, forming together the typical intricate pattern of present Southeast Asia (see fig. 4).

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