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GLIMPSES INTO FOSSIL ASSEMBLAGES OF THAILAND: CORAL PERSPECTIVES

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ABSTRACT

Fossil corals are widespread in Thailand. They belong to many geological intervals, from Ordovician to Quaternary. They have been studied actively during the last 20 years. They are better known, even though some research still needs to be carried out; for instance, Triassic corals, which occur in abundance at many localities of Thailand, remain inadequately known. Carboniferous, Permian and Triassic corals are widespread in Thailand. Devonian and Jurassic corals are in abundance in restricted areas. Ordovician and Silurian corals are rare and remain poorly known. Cretaceous corals are completely absent. In Thailand, the study of corals is the study of a long history. One can observe living corals as well as many groups of fossil corals. Corals provide important information on past environments and help to reconstruct paleogeography; they also provide information on the ages of the rocks in which they are included. In this paper, two Devonian localities are mentioned for the first time; they were discovered in January 2002.

Key words: Tabulata, Rugosa, Stromatoporoids, Scleractinia, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Quaternary.

INTRODUCTION

In Thailand, corals are widespread both in the sea and on the land. In the sea they thrive in warm water and offer diverse and remarkable shapes. They build up fascinating landscapes. Coral reefs, the "rainforests of the sea" for some authors, are well developed in Thailand. They form very complex and very diverse ecosystems. Their biological diversity includes commercially important species, such as fishes, providing livelihood to many people in Thailand. On land, corals are distributed all over the country. They are fossils included in rocks and are commonly easy of access to everybody, but they are not prominent and do not attract immediate attention. They are also associated with diverse other fossil species of plants and animals.

Limestone rich in corals, especially Permian limestone widespread in Thailand, has been used to produce wonderful marble. Corals are visible on many walls of Bangkok, along several streets. However, because of the tropical climate, the good polish of the marble slowly disappears and the details of the coral structure become obliterated. Nowadays, many people prefer granite which is more resistant to weathering. Inside houses and hotels,

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marble is well protected. Beautiful corals are splendidly preserved and adorn many kinds of marble pieces (see Figs. 1A–B).

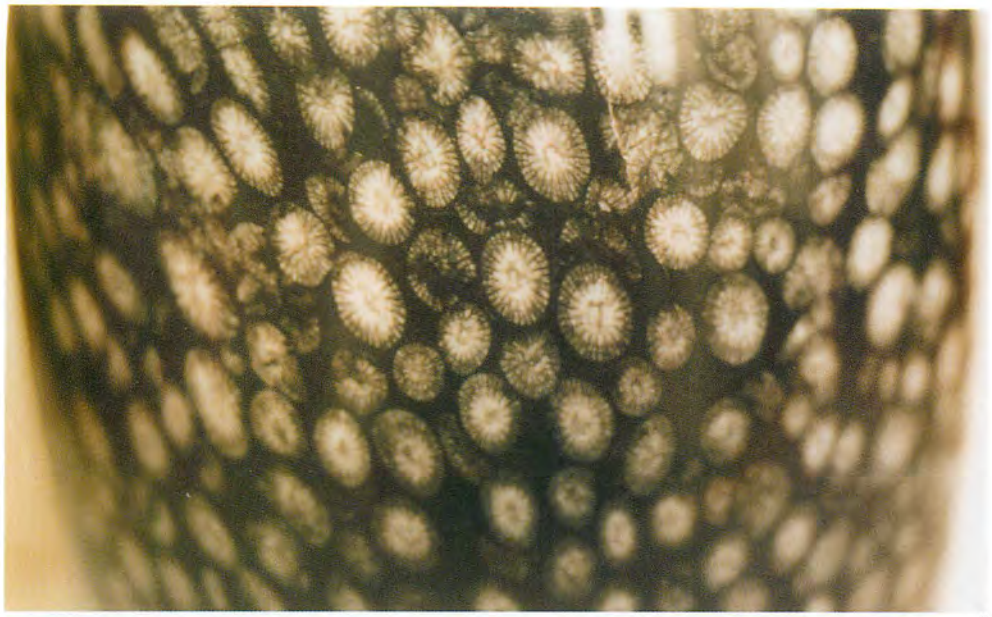
Before travelling about and visiting the coral rock exposures, one should know some characteristics of the corals. The primary purpose of this paper is to provide general information on the fossil corals of Thailand.

ENVIRONMENT

Corals are exclusively marine, sessile organisms which grow as solitary individuals or exhibit a colonial mode of growth. Most of the colonial corals are restricted to warm, shallow and clear sea water. They are sensitive to temperature, depth, salinity, nutrient supply and illumination. Locally, they build up reefs. They are generally found at depths of less than 50 m, and may be exposed to routine wave energy. Although well adapted to environments, they can be severely damaged by cyclones. A small climatic change may result in heavy losses. Many corals are characterized by narrow thermal tolerances, and are not cosmopolitan in distribution. They have limited ability to acclimatize or adapt to the effects of climate change. Hence they are a growing concern of scientists studying present coral reefs, afraid that coral adaptation cannot keep pace with increasing sea temperatures. Mortality of reefs has been suggested recently in some areas of the world because of bleaching outbreak, possibly due to global warming (for instance, see DENNIS, 2002). Coral bleaching occurs when coral expels from its body the symbiotic zooxanthellae so important to its life, probably because these algae become toxic to the coral at higher temperatures. Mass coral bleaching has been estimated to have destroyed about one-sixth of the world's coral colonies during the last major occurrence in 1998; 18 percent of reefs were damaged in Southeast Asia. Despite this severe event, recovery is occuring. It is difficult to predict what proportion of bleached coral will die. There is much debate over whether coral can adapt to increasing temperature, but so far, there is little evidence of thermal adaptation. Such adaptation may be too slow to be noticed by observers. In Thailand in the Phuket area, sea temperatures increased at a rate of more than 2° per 100 years between 1981 and 1999 (BURKE *ET AL.*, 2002).

The corals of the past lived in similar conditions as today. Where they are abundant and highly diverse in rocks, they are often associated with many other thermophilic benthic organisms. A warm climate during the Permian is evidenced in West Cambodia near the Thai border by the accumulation of bauxite. Green algae occur with the corals and indicate shallow sea depth. Using geochemistry, it is possible to get some information on the temperatures of the seas of the past and to confirm that corals are commonly good indicators of warm climates (YASAMANOV, 1980). Corals are useful in deciphering paleoclimates because of their environmental sensitivity; they can constrain paleogeographic reconstructions. For instance, fossil corals of Peninsular Thailand are different from those of Central and East Thailand; they show a lower diversity, especially during the Carboniferous and the Permian. These differences fit with the proposal, by geologists (BUNOPAS, 1981), that Thailand occupies and straddles two different continental blocks

Over the past 530 million years (Ma), the seas have invaded parts of Thailand many times. Environments were not at all times and places favourable to corals. For instance, when sea water was loaded with sand in some areas, corals were killed by the sand moving



a

b

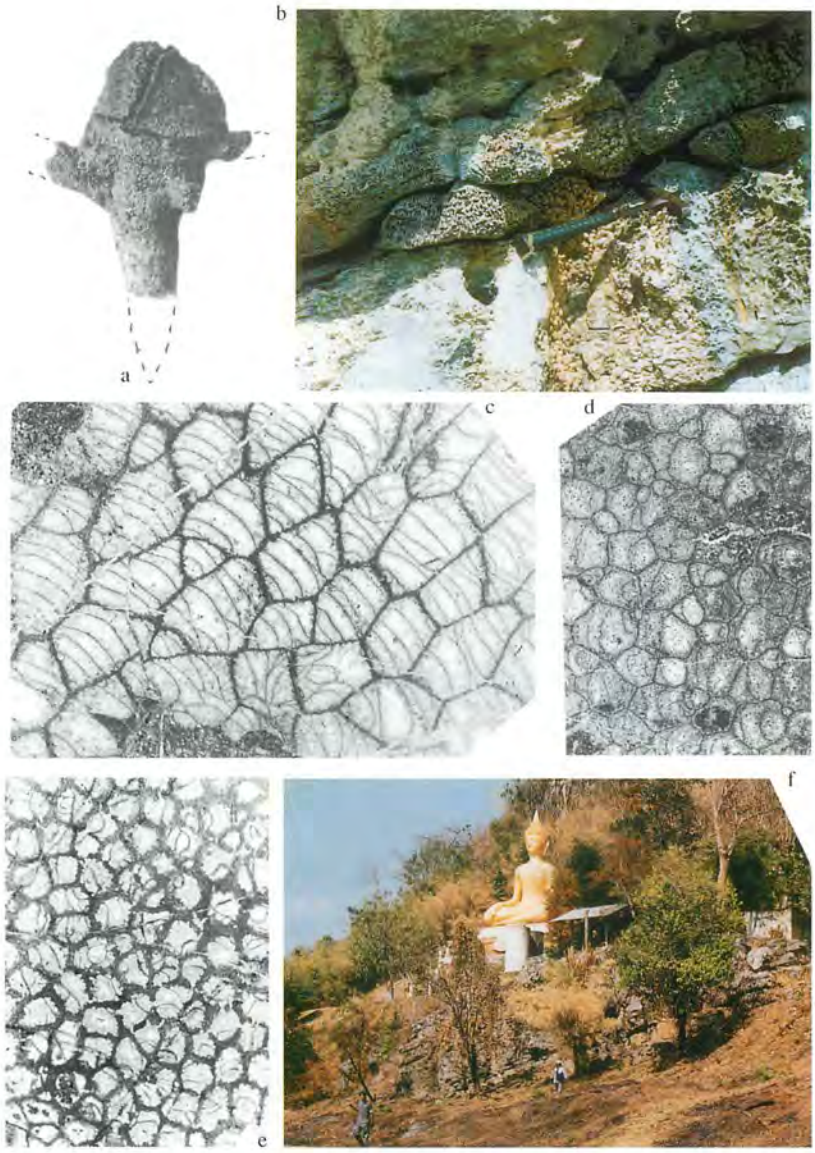
Figure 1. A, B. Vase (12.5 cm high) made of Permian limestone containing a fasciculate coral (*Pseudohuangia*). On one side, corallites are perpendicular to the surface of the pot. On the other side, the corallites are oblique to almost parallel to this surface. The septa are of two orders, long and short. The columella is visible in the center of the corallite.

a

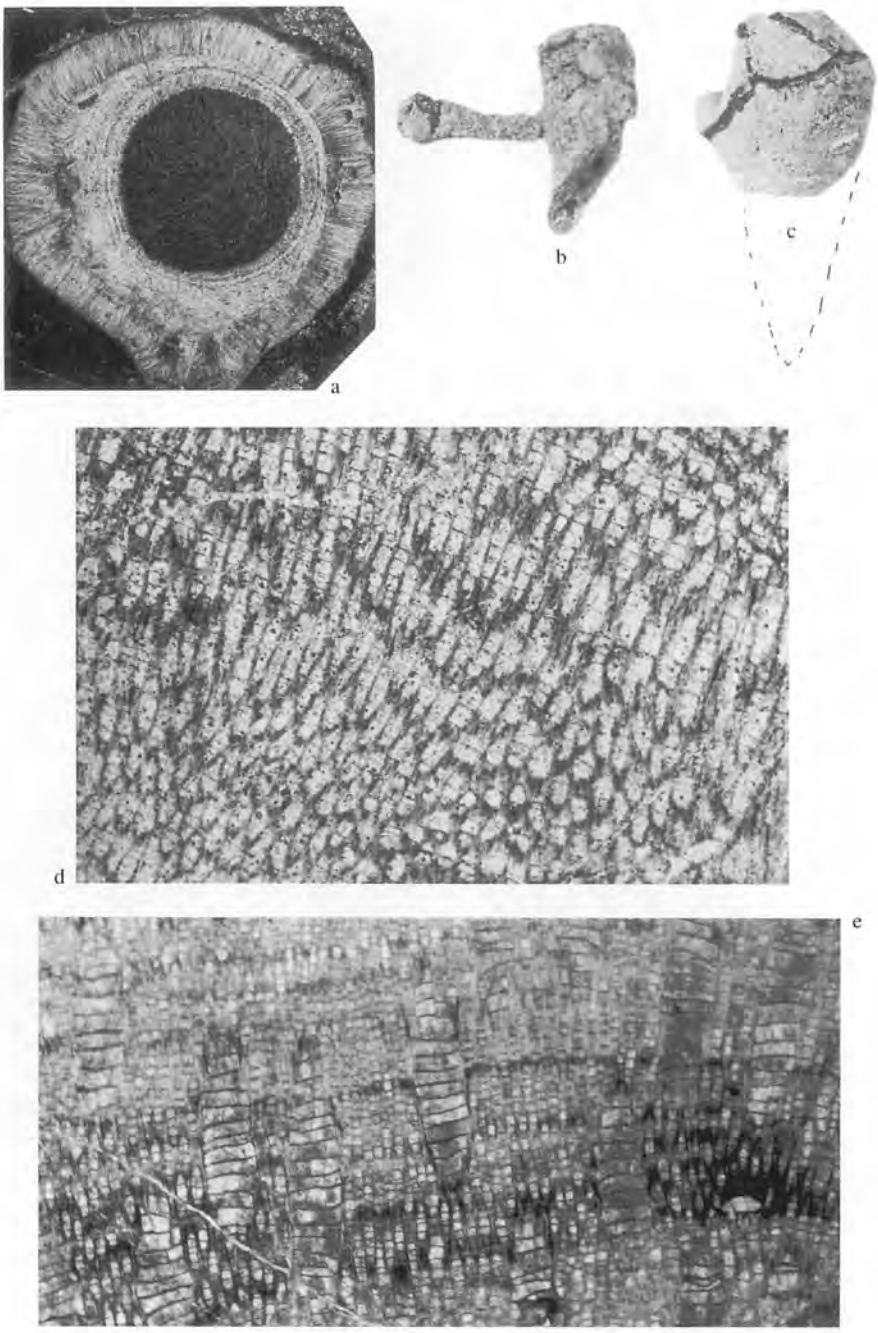
Figure 2A. Triassic fasciculate coral in the field at Khao Pathawi north of Uthai Thani.

b

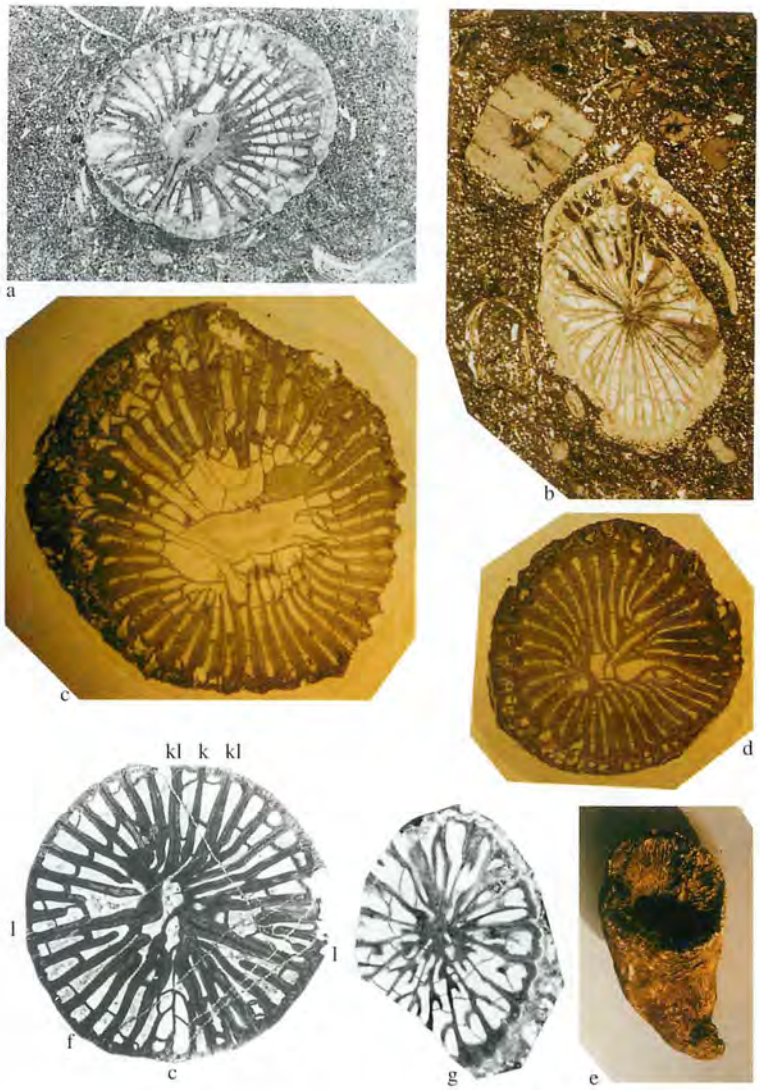
Figure 2B. Jurassic fasciculate corals in the field in Ban Huai Ya-u area east of Mae Sot. The corals of figures 2A and 2B cannot be identified in the field with certainty; their age is difficult to ascertain in this state.



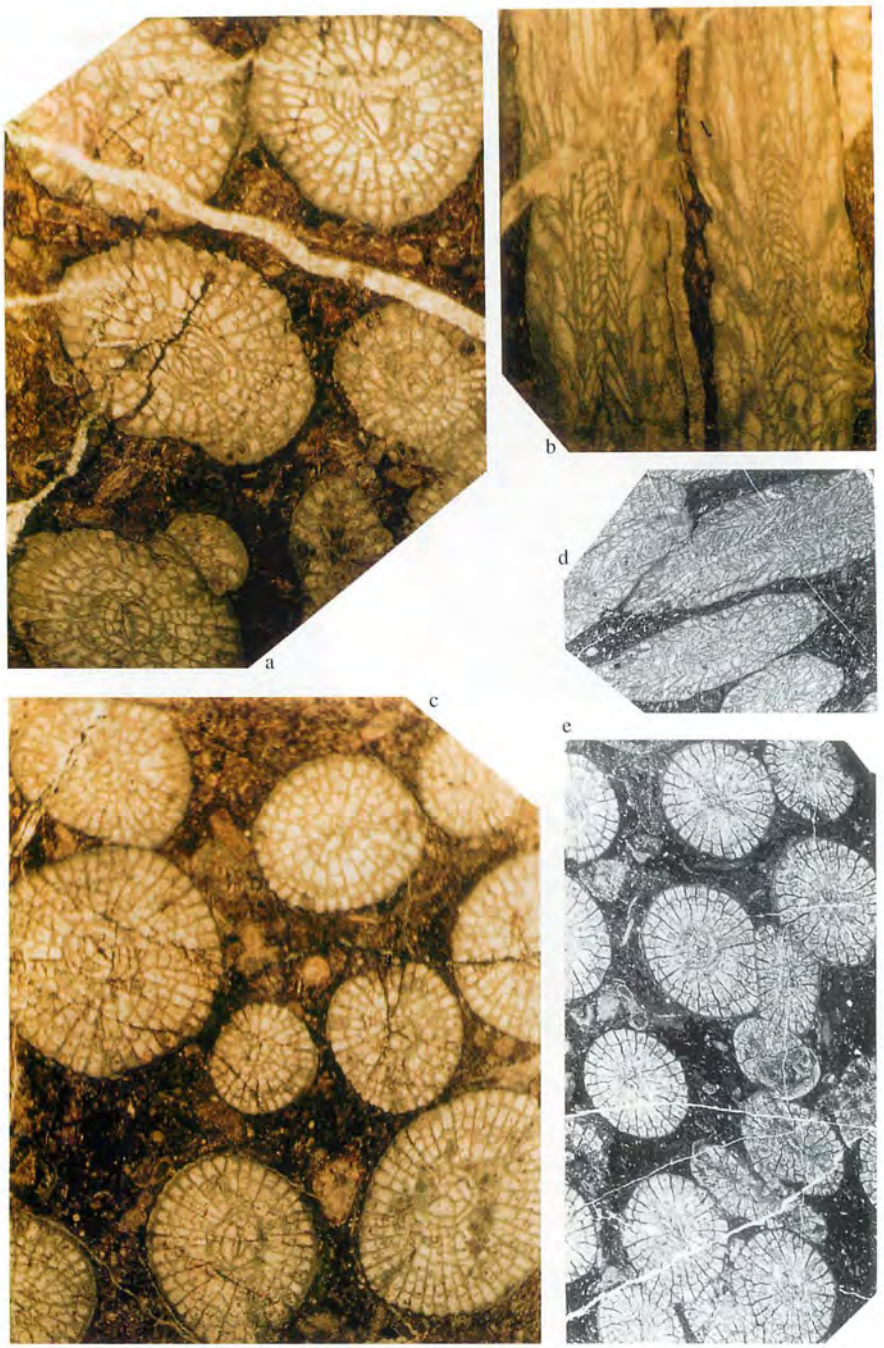
Figures 3A–F. Tabulata in the field and in thin sections. A: *Khmeria problematica* Mansuy. Very peculiar coral with an operculum of one to three convex plates (see Fontaine et al. 1994, p. 49–50). Sample T3352 from Ban Na Chaliang along the road from Lam Narai to Phetchabun. This type of coral is rare in Thailand. It apparently occurs at two other localities: near Wat Tham Wua Daeng (16°04'24"N, 101°26'00"E) and at Khao Tham Yai between Lomsak and Nam Nao. B: Bedded limestone of Laem Phap Pha in Surat Thani Province, rich in *Sinopora*, a branching Tabulata C: *Protomichelinia* aff. *multitabulata* Yabe & Hayasaka; sample T519 from Khao Tham Nam Bang, 20 km south of Phetchabun. D: *Protomichelinia simplex* Zhao & Chen; sample T3728 from Khao Chak Chan along the road from Khok Samrong to Takfa. E: *Protomichelinia crassitheca* Zhao & Chen; sample T2531 from Phu Pha Khao east of Ban Phia, Loei Province. F: Bedded limestone at the foot of Phu Pha Wang along the road from Wang Saphung to Udon Thani. This limestone is rich in *Protomichelinia*.



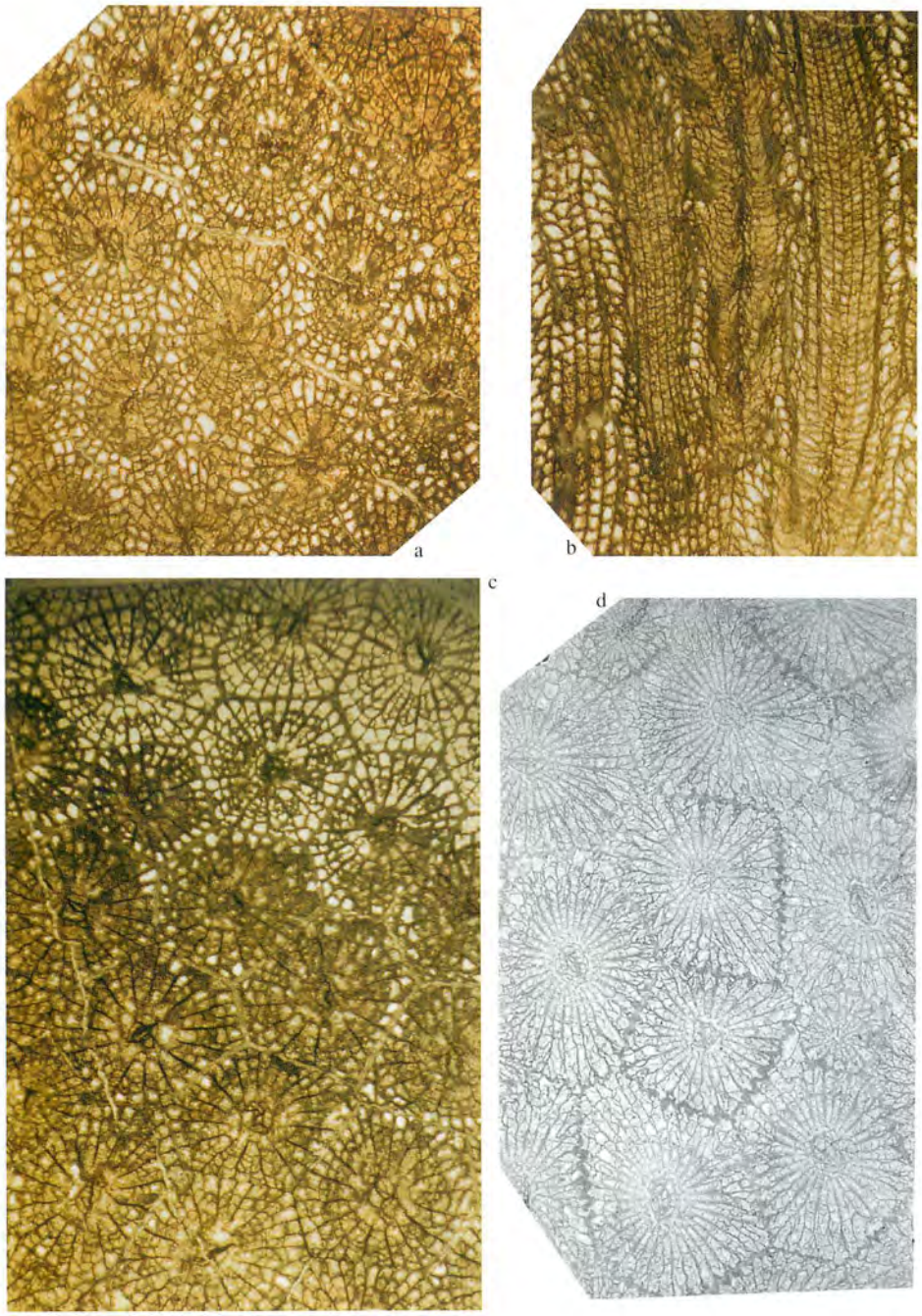
Figures 4A–E. Tabulata. A, *Sinopora asiatica*. Transverse section of a corallite, showing the microstructure of the skeleton. Microstructure is important to differentiate some corals. B, C, *Khmeria problematica* from Ban Na Chaliang. D, *Chaetetes*. Oblique section. Sample T3851 from Middle Carboniferous limestone in a pond near Ban Na Duang. E, *Heliolites*. Longitudinal section. Sample T4315 from the Devonian limestone of Phu Nam Khoi in Northeast Thailand.



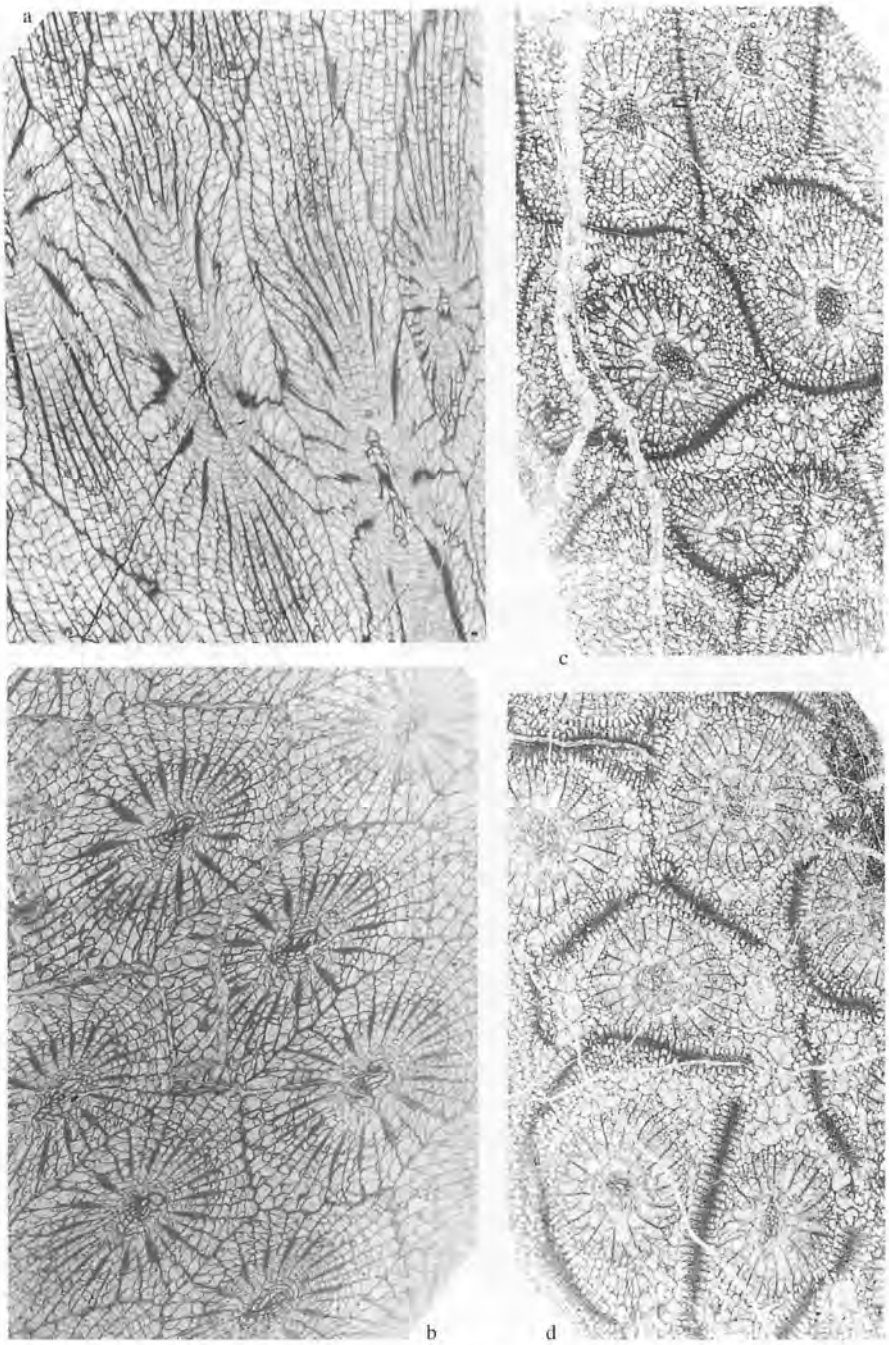
Figures 5A–G. Solitary Rugosa. These corals were able to live in diverse environments. They are known at many localities of Thailand. A, *Lophophyllidium pendulum* Grabau. Transverse section showing the septa and a solid columella. Sample T856 from Ban Phu Plu along the road from Kanchanaburi to Thong Pha Phum. A horizon of the Middle Permian section exposed at Ban Phu Plu is rather rich in solitary corals. B, Coral known by a single section, a transverse section. Sample T6292 from Phahong Cave, a limestone hill 500 m far from the road from Lomsak to Chumphae. The limestone is rich in crinoids, but poor in corals. C, D, *Caninophyllum* sp. Transverse sections near the base (4d) and near the top (4c) of the coral. Middle Carboniferous sample T6350 from Huai Nam Suai, north of Ban Na Duang, Loei Province. This sample is eroded at its periphery. E, Solitary Rugosa collected from a weathered shale of Loei Province. F, *Ufimia* sp. Transverse section showing a clear bilateral symmetry: c = cardinal septum, k = counterseptum, l = alar septa, kl = counter lateral septa. Middle Permian sample T2286 from Ko To Ngai north of Pak Meng beach in Peninsular Thailand. G, *Paraduplophyllum* sp. Transverse section. Lower Permian sample T3835 from Ban Na Din Dam area in Loei Province.



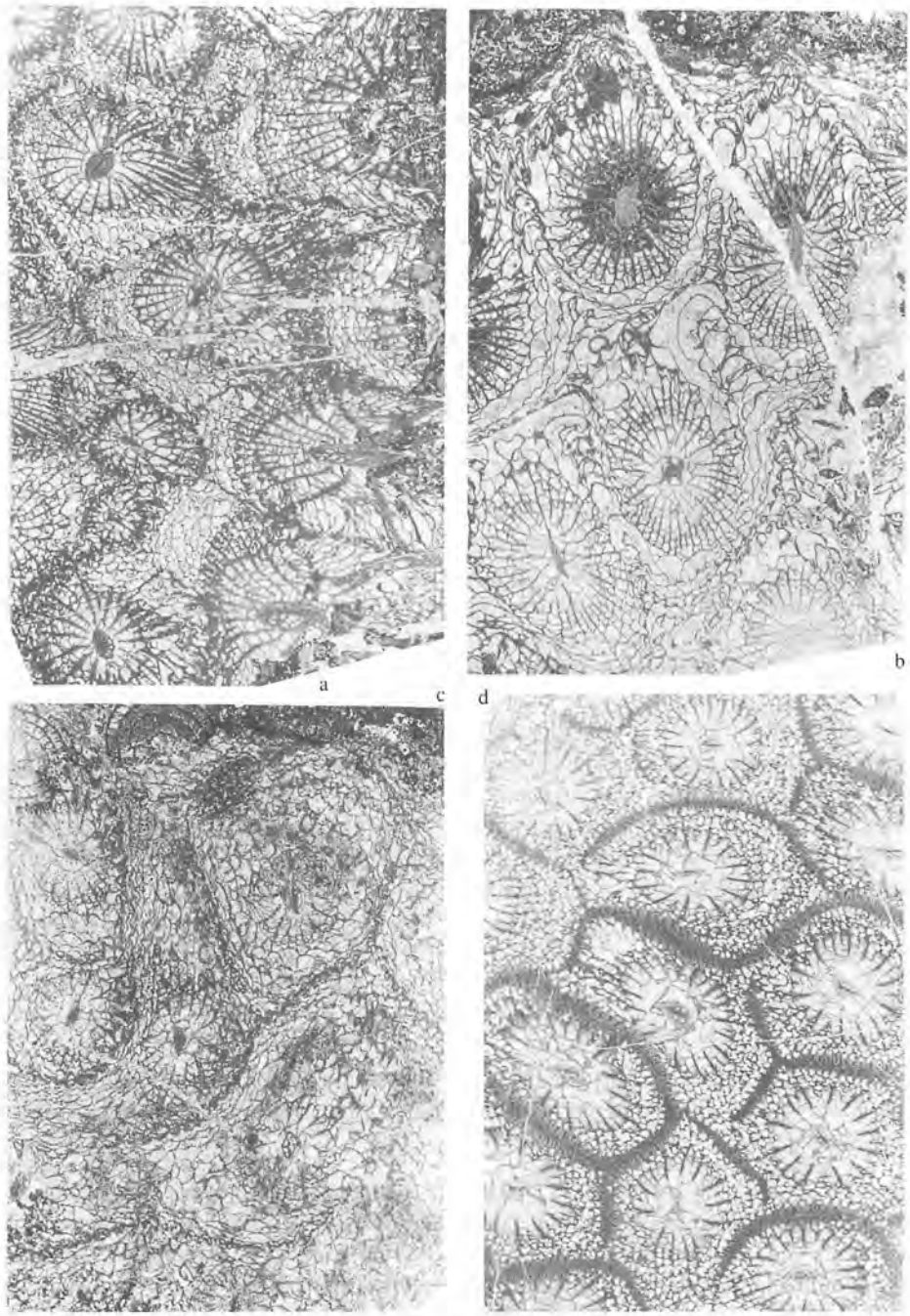
Figures 6A–E. Fasciculate Rugosa. A, B, *Waagenophyllum*. Transverse section (6a) and longitudinal section (6b). Sample T5354 from the Permian limestone of Khao Phai, Sakaeo Province. C, *Waagenophyllum*. Transverse section. Sample T5351 from the Permian limestone of Khao Phai, Sakaeo Province. D, E, *Chihiaphyllum*. Longitudinal section (6d, sample T80) and transverse section (6e, sample T59). Samples from Khao Khao between Saraburi and Lopburi.



Figures 7A–D. Massive Rugosa. A, B, *Ipciphyllum*. Transverse (7a) and longitudinal (7b) sections. Sample T5675 from Khao Tham Yai. C, *Ipciphyllum*. Transverse section. Sample T5672 from Khao Tham Yai. D, *Paraipciphyllum*. Transverse section. Sample T903 from Khao Tham Sua in Peninsular Thailand.



Figures 8A–D. Massive Rugosa. A, *Ipciphyllum laosense*. Longitudinal section. Sample T1139 from Khao Khi Nok in Wichianburi area of Central Thailand. B, *Ipciphyllum laosense*. Transverse section. Sample T3133 from Khao Phoem north of Chon Daen. C, D, *Multimurinus suteethorni*. Transverse sections. Samples T3701 C and T3698 D from Wat Tham Sua Khuha at Khao Wong Chan Daeng.



Figures 9A–D. A–C, Kepingophylliade. Transverse sections. A, Sample T3994 from Ban Na Duang area, Loei Province. B, Sample T4008 from the eastern foot of Phu Khao northwest of Ban Na Duang. C, Sample T4010 from the eastern foot of Phu Khao northwest of Ban Na Duang. D, *Multimurinus*. Transverse section. Sample T484 from the northern end of Khao Somphot in Lam Narai area.

with the water. They generally do not occur in sandstone. Muddy environments also were usually not favourable to corals, with rare exceptions of some small simple corals. In shale and mudstone, corals are absent or represented only by scattered solitary corals, in their living positions or transported before burial. In limestone deposited in warm, clear and shallow water, corals are in great abundance and high diversity, and are predominantly large compound corals. They secreted skeletons of calcium carbonate, reaching up to more than 1 m in diameter. In some locations they have even built up reefs.

With their very small soft bodies or polyps, commonly one to a few mm in diameter, the corals secrete skeletons of highly diverse shapes and sizes; they have produced a very great quantity of calcium carbonate on the earth since the Ordovician, that is to say during the last 500 My. All over the world, they presently produce about one billion tons of calcium carbonate per year. Limestone is widely distributed in the stratigraphy of Thailand, especially in the Ordovician, Devonian, Carboniferous, Permian, Triassic and Jurassic sequences.

CLASSIFICATION AND BIOSTRATIGRAPHY

The corals belong to Phylum Cnidaria, Class Anthozoa. Our knowledge about them has grown considerably during the last 50 years and the number of described families, genera and species has greatly increased.

In the field, corals are very difficult to study (see photographs of Triassic and Jurassic corals in Figs. 2A–B). For precise microscopic observation, corals must be cut into thin longitudinal and transverse sections 0.03 mm or less thick (Figs. 3–9). Then their characteristics appear clearly if the coral is well preserved (see a complete solitary Rugosa, about 310 Ma old, in Fig. 5E, coral impossible to identify without thin sections).

In addition to giving information on past environments, many corals are useful for determining the ages of the rocks in which they are imbedded. Some corals display a short stratigraphical range and hence can document the age of a rock. Corals can be used for international correlations, but they are limited to warm climate areas covered by shallow and clear sea water.

1. Paleozoic Corals

Paleozoic corals consist of two classes: Tabulata and Rugosa (or Tetracorallia). They became widespread during the Ordovician Period and remained important fossils until the end of the Permian.

Tabulata: The hard parts of the Tabulata are slender polygonal or circular tubes (the corallites) with perforate (with mural pores) or imperforate walls, divided by horizontal diaphragms (the tabulae). The tabulae are easy to see only in longitudinal sections; they suggested the name of the class. Small radial elements may be present; they are commonly reduced to short septa, spines or squamulae, visible in transverse sections. The coral tubes may grow in approximately parallel position or they may be partly or entirely welded laterally to their neighbours. Tabulata are divided into about 60 families and 330 genera. The stratigraphic distribution of these families and genera is variable, as indicated by Hill (1981, table 3, p. 496–505).

The Tabulata are characterized by their exclusively colonial mode of growth. They are fasciculate (shrubby, with corallites not laterally contiguous) or massive (with contiguous corallites). They are commonly a few cm to 50 cm in diameter. The mineral present in the skeletons of Tabulata is calcite. The microstructure of these skeletons is important for the determination of phylogenetic relationship between taxa, but other features of secondary origin may cause confusion (OEKENTORP, 2001). In Thailand, the Tabulata are in abundance and very diverse in Devonian rocks. In Loei Province, massive corals are common and include genera such as *Favosites* and *Heliolites*. Branching corals are also in abundance, for instance *Thamnopora*. The Tabulata also occur with moderate diversity in Carboniferous and Permian sediments.

Rugosa: The hard parts of the Rugosa are much more complicated than the skeletons of Tabulata. In the skeleton of Rugosa are prominent radial plates called septa (Fig. 5A–D and F–G, 6A–D, 7A–D, 8B–D, and 9A–D). They are of two orders (major and minor septa) in many corals, but in others there are three or, more rarely, four orders. They commonly show a clear bilateral symmetry. The first septum appearing in the youngest part of the coral establishes the bilateral symmetry. At first, the cardinal (C) and the counter (K) major septa appear in opposite position; then, the two alar (L) septa appear, followed by the two counter lateral (KL) septa (Fig. 5F). This plan of septal insertion is sporadically associated with a differentiation in size. For instance, the cardinal septum is shorter than the other major septa and the major septa of the cardinal quadrants may be thicker. In longitudinal sections, small arched plates are visible at the periphery of the corallite (for instance, see fig. 8A); they are the dissepiments. Tabulae occupy the rest of the corallite cavity. In the axial part of the corallite, a columella is present in some genera. The Rugosa consist of about 80 families and 700 genera. The stratigraphic distribution of these families and genera has been indicated by Hill (1981:74–94, table 1).

The skeletons of fossil Rugosa are of calcite, but was it the primary mineral in the living corals? Opinions about this differ (OEKENTORP, 2001).

The Rugosa may consist of a single corallite of conical to cylindrical shape (a trochoid shape is shown in Fig. 5E). Some were deprived of dissepiments and simple, and were able to live in diverse environments. Those with dissepiments were more complex, and apparently needed slightly better environments. Many other Rugosa are compound. These indicate very favourable environments. Some types are fasciculate with ramose corallites or massive with contiguous corallites.

Studies of stratigraphy reveal that several crises occurred in the history of the Rugosa. For instance, seven different crises occurred during the upper part of the Paleozoic, at the end of the Lochkovian 400 Ma (million years ago), with a strong decline of the Silurian taxa; at the Frasnian–Famennian boundary (365 Ma, Kellwasser event with the disappearance of the massive Devonian corals); at the Serpukhovian–Bashkirian boundary (350 Ma, minor extinction with renewal of the coral faunas); at the Moscovian–Kasimovian boundary (305 Ma, decrease of the coral community); at the end of the Lower Permian (270 Ma, for instance disappearance of the Kepingophyllidae); at the end of the Middle Permian (250 Ma, disappearance of all the massive Rugosa); and at the end of the Permian (245 Ma, complete extinction of the Rugosa).

The Heterocorallia differ from the common Rugosa and form their own small order. They are good markers of the age of the rocks because they appeared during the Devonian

and disappeared during the Carboniferous. They are fragile, elongate corals consisting of a single corallite of small diameter. They are easy to recognize. In Thailand, they are abundant in some Lower Carboniferous limestones; two genera (*Hexaphyllia* and *Heterophyllia*) have been found. In China during the last 20 years, diverse Heterocorallia have been described with the creation of new families, genera and species. The validity of many of these taxa remains questionable, as comparable variability among *Hexaphyllia* specimens from England has been considered to represent only intraspecific variation.

Stromatoporoids: A group of fossils related to Porifera (sponges) must be mentioned because they are associated with the corals in many places and sometimes played a great role in the building of reefs. The stromatoporoids originated at the beginning of Middle Ordovician and were widely distributed until the end of the Devonian. They then disappeared, and reappeared from Middle Jurassic to Cretaceous. They are very important in Thailand, especially because they are major frame builders of the Devonian reefs found in Loei Province.

2. Post-Paleozoic Corals or Scleractinia

The mass extinction that ended the Permian Period saw the end of the Rugosa, trilobites, and fusulinaceans. Other organisms declined markedly. Corals are almost absent from the Lower Triassic. A large break seems to separate the Paleozoic corals from the post-Paleozoic corals or Scleractinia. At the beginning of Middle Triassic (Anisian), Scleractinia appeared and started to show a great variety of forms belonging to solitary, fasciculate, or massive corals. At the end of Middle Triassic (Ladinian), they started to build reefs. The early phylogeny of the Scleractinia is poorly known because of poor fossil records during the Early Triassic. EZAKI (2000), after describing Permian corals with a putative aragonitic skeleton in Tunisia in 1997, discovered solitary "scleractiniamorphs" in the Middle Permian of China (*Yabeina* zone). The mode of septal insertion of these corals was impossible to study, but six orders of septa are distinctly present. "Septa are seemingly arranged radially in circular corallites whereas those in elongate and elliptical corallites may show a bilateral symmetry" (EZAKI, 2000). Ezaki suggested that an initial radiation of Scleractinia-like corals occurred during the Permian. This radiation might have been terminated by the mass extinction of the end of the Permian, or it might have survived in a few refuges with relatively good environments.

Scleractinia are an extant class known from the Triassic to the present. They are the most important constituents of modern coral reefs. They far surpass the older corals in diversity, and comprise a great number of orders, families, genera and species. They are characterized by prominent cyclic insertion of the septa. The first-formed septa are 6 in number. A bilateral skeletal structure is very rare and underlines a phylogenetic relationship between the Sceractinia and the Rugosa. The skeleton is of aragonite. Through diagenesis, aragonite is easily replaced by coarse calcite and the microstructure of the coral is lost forever. Scleractinia are solitary or compound corals (fasciculate and massive).

In Thailand, Scleractinia date to different periods from Triassic to the present; they are observable in sea and on land.

CORALS OF THAILAND

In 1920, a Carboniferous Tabulata was found at Khuan Din So in the Phatthalung area of Peninsular Thailand (REED, 1920). In 1944, a Permian Rugosa species was reported in Northwest Thailand (MINATO, 1944). Later on, other species were discovered and their number reached 25 in 1969 (PITAKPAIVAN *ET AL.*, 1969); they were assigned mainly to Permian, subordinately to Triassic (5 species) and to Carboniferous (3 species). Since then, diverse fossil corals have been noticed at many localities of Thailand; they are locally in great abundance and indicate favourable environments in the past. They belong to many time intervals, from Ordovician to Quaternary. From Ordovician to Jurassic, more than 250 species have been mentioned in Thailand, belonging to about 150 genera. Additional studies should multiply the numbers of genera and species. Even if it were possible to find corals in the Cambrian (540–500 Ma), the environment was not favourable to corals in the Cambrian areas of Thailand.

The fossil coral faunas of Thailand are largely not endemic, but exhibit similarities with other faunas of the world. Detailed studies show that, even within Thailand, endemicity and the predominance of some taxa may vary geographically and according to the period, under global and regional controls.

Corals are widespread in Thailand, but their importance in the sediment varies according to the environments in which they lived. They predominated in local areas and bound together with other organisms (stromatoporoids in the Devonian in the Loei area), they built up rigid frameworks having wave resistance, forming reefs. In other places, they appear only in relatively thin horizons, for instance the Carboniferous *Lublinophyllum* bed (1 m thick) of Ban Na Charoen in Northeast Thailand, or in some Permian limestone beds north of Saraburi along the road to Lam Narai, where they form biostromes. In other areas they are more scattered, especially in the Permian limestone of Peninsular Thailand where they contribute a small fraction of the sediment. At some localities, they show evidence of being transported by currents from their original place of attachment.

Ordovician (500–435 Ma)

The oldest coral-bearing strata in Thailand are Ordovician in age, but the corals are very rare and remain poorly known. HAHN & SIEBENHUNER (1982: 38) mentioned Middle-to-Late Ordovician solitary Rugosa at a locality of Northwest Thailand, west of Chiang Mai and northeast of Ban Mae La Noi. These corals were considered belonging to "Metriophyllidae? or Streptelasmatinae indet". This identification did not indicate a precise Paleozoic age, but the corals were associated with trilobites (*Trinucleina*), bivalves and gastropods.

Silurian (435–410 Ma)

Silurian corals also remain poorly known and appear to be uncommon in Thailand. This paucity is partly explained by poor environments. A few Tabulata (*Favosites, Heliolites*) and a Rugosa (*Rhizophyllum*) found in the Nam Som area of Northeast Thailand have been assigned a Silurian age (SAKAGAMI & NAKORNSRI, 1987). *Rhizophyllum*, commonly considered to be a typical Silurian coral, actually ranges from Early Silurian to the end of Early Devonian.

Devonian (410–360 Ma)

Devonian rocks are widely exposed in Northeast and West Thailand, but with different lithologies.

1. *Northeast Thailand*

Devonian sediments are known only in Loei Province and Nong Bua Lamphu Province. They locally display thick limestone bodies. They are very rich in diverse fossils and corals are in abundance at many localities (FONTAINE *ET AL.*, 1981 AND 1990; FONTAINE & TANTIWANIT, 1987; FONTAINE, 1990; FONTAINE & SUTEETHORN, 2000), which may be divided into three areas, as follows.

Area 1a: The area extending in a N-S direction around longitude 101°55'E from the Mekong River in the vicinity of Pak Chom to the road from Wang Saphung to Udon Thani exhibits many Devonian limestone outcrops and appears to be the richest in corals. From north to south, the main localities are: near Ban Khok Phai (Pha Tok and Phu Khong), in Phu Laem area (Phu Laem Huai Na Phung, Phu Yot Huai Thian, at and near Phu Laem), in Ban Chiang Klom area (Phu Yai east of Ban Chiang Klom, Phu Wang Pha, Wat Tham Saeng Tham Phromawat at Phu Foi Lom), east of Ban Chom Noi (6 localities from Ban Huai Bo Sun to the north to Khao Sam Yot to the south; at an old quarry, a good section, 83 m thick, has been observed), and south of Ban Chom Noi (Phu Thanon and Huai Nam Suai). Corals are in great abundance and high diversity. Tabulata are common and consist of: Chaetetidae: *Chaetetes yunnanensis, Chaetetipora;* Favositidae: *Squameopora, Emmonsia, Squameofavosites;* Pachyporidae: *Cladopora, Gracilopora, Striatopora, Thamnopora nicholsoni, T. polygonalis, T.* sp, *T. tumefacta?;* Alveolitidae: *Alveolites* cf. *admirabilis, A. smithi, A.* sp., *A.* cf. *taenioformis, Crassialveolites crassiformis, C. crassus, C.* sp., *Caliapora battersbyi, Scoliopora;* Coenitidae: *Coenites, Planocoenites;* Heliolitidae: *Heliolites porosus, H.* sp.; Syringoporidae: *Syringopora.* Rugosa are scattered and include: Cystiphyllidae: *Cystiphyllum vesiculosum;* Stauriidae: *Dendrostella;* Ptenophyllidae: *Dohmophyllum involutum* and other taxa; Endophyllidae: *Endophyllum abditum, Sinospongophyllum tabulatum, S.* sp.; Phillipsastraeidae: *Scruttonia, Pterorrhiza, Thamnophyllum stachei, T.* sp.; Stringophyllidae: *Solipetra.* The Tabulata and Rugosa are associated with stromatoporoids: *Actinostroma devonense, A.* sp., *Amphipora angusta, A. insignis, A. perforata, A. ramosa, A. rudis, A.* sp., *Clathrodictyon, Hermatostroma beuthii, H. pustulosum, Stachyodes, Stromatopora, Trupetostroma.* All the fossils show affinities with the Devonian faunas of Viet Nam and South China; they focus mainly on a Givetian–Lower Frasnian age. The corals build reefs in association with stromatoporoids. Devonian reef building peaked during the Givetian in many parts of the world, including Thailand. This Devonian area of Thailand extends to Ban Vang, a Laotian village on the northern bank of Mekong River. Near this village, a limestone hill contains Tabulata (*Favosites styriacus, Thamnopora* cf. *polygonalis, Syringopora schulzei Heliolites porosus*) and Rugosa (*Xystriphyllum laosense, Breviphrentis yunnanense, Microplasma ronensis*). These fossils have been described by FONTAINE (1961). Fossils other than corals and stromatoporoids have rarely been studied. At Phu Koi (CHAIRANGSEE *ET AL.*, 1990), a small limestone hill northwest of Ban Chiang Klom, conodonts have been isolated and belong to the genera *Belodella* and *Neoprionodus*; they are associated with tentaculitids (*Styliolina*). Cherts near

and south of Pak Chom contain radiolarians indicating a Frasnian to Tournaisian age (SASHIDA *ET AL.*, 1998). Sandstone near Ban Pak Niem has yielded a palynological material indicating an Uppermost Devonian to Lower Carboniferous age (FONTAINE *ET AL.*, 1981).

Area 1b: Devonian rocks are exposed in a second area extending in a N-S direction around longitude 102°10'E from the Mekong River (near Ban Muang: 18°10'14"N, 102°09'30"E) to Ban Chok Chai (17°35'22"N, 102°11'27"E) southwest of Nam Som. Limestone is less prominent; shale, marl and sandstone are more widespread. These sedimentary rocks are older than the limestone of the first area; they belong to Lower Devonian, maybe down to Upper Silurian. At Ban Muang and Ban Noi, Tabulata are in abundance. They include *Favosites goldfussi* and *Heliolites* sp. At Ban Muang, they are associated with *Lancicula*, an alga common in Lower Devonian. Near Ban Na Ngiu, a village S-SW of Ban Muang, a limestone has yielded a fragment of *Favosites* associated with *Renalcis*, an algo-microbial structure. Further south at Ban Na Khae (17°54'25"N, 102°04'58"E), Tabulata (*Favosites* cf. *styriacus, F.* cf. *ottiliae*) and solitary Rugosa are associated with brachiopods (Spiriferacea and others) in argillaceous limestone and shale. At Ban Yuak (17°40'48"N, 102°09'58"E), shale with black limestone lenses contains Tabulata (*Emmonsia* in abundance, *Squameofavosites*), solitary Rugosa (*Cystiphylloides fongi*), brachiopods (*Atrypa* and others). At the bottom of a pond near Ban Chok Chai, a limestone is rich in fossils: *Renalcis*, Tabulata (*Favosites nitidus* or *alpina*?, *Squameofavosites, Heliolites*), solitary Rugosa, stromatoporoids. At the wat of Ban Chok Chai, limestone is again rich in corals.

Two new discoveries of January 2002 have extended this Devonian area towards the south. Phu Pha Duang (17°26'54"N, 102°16'36"E), south of Ban Chok Chai and 1 km north of Ban Wichit Patthana, is a limestone hill with a large cave. The limestone is gray and thickly bedded. It is partly recrystallized and fossils appear to be uncommon. However, some scattered fossils have been noticed at the western side of the hill; they consist of Tabulata, solitary Rugosa, and Stromatoporoidea. They have not been studied yet. Another limestone hill (17°26'45"N, 102°16'49"E), about 800 m east of Phu Pha Duang, exhibits similar fossils.

Area 1c: South of the road from Wang Saphung to Udon Thani, Devonian limestone is exposed in an area elongated in a NW-SE direction (FONTAINE & SUTEETHORN, 2000). From northwest to southeast, it builds up a few hills: Phu Lao (17°15'24"N, 102°03'20"E), Khao Pha Cham Nam, Phu Khrao and Phu Khao (17°13'50"N, 102°03'55"E). It crops out at the bottom of a pond near Wat Pakittisophanaram (17°14'48"N, 102°02'40"E). Fossils consist of Tabulata (*Heliolites, Alveolites, Thamnopora* and other genera), Rugosa and Stromatoporoidea.

2. *West Thailand*

This area includes the Peninsula, and areas from Kanchanaburi to Mae Hong Son and Fang. Devonian seas were widespread, but not favourable to corals. Environments were muddy and sandy, with rare deposition of limestone containing conodonts and tentaculites; corals have not been found so far (JAEGER *ET AL.*, 1969; HAHN & SIEBENHUNER, 1982; LONG & INGAVAT, 1989; WONGWANICH *ET AL.*, 1990).

Carboniferous (360–295 Ma)

Thailand was mostly covered by seas during the whole Carboniferous, with local and temporary emergences. For instance, a marine regression occurred in Northeast Thailand at the end of the Lower Carboniferous; it allowed the deposition of coal (anthracite) in Ban Na Duang area and gypsum in Loei–Wang Saphung area. A shale exposed west of Ban Loeng, 38 km northeast of Loei as the crow flies, is rich in continental plant imprints. These fossils have not been studied yet. They apparently belong to the Carboniferous (new data). After this regression, the sea came back and corals reappeared.

The corals of Thailand belong to several areas and to different time intervals. They are most prolific in central and northeastern Thailand. They are the richest coral faunas so far known in the Carboniferous of Southeast Asia. They were particularly abundant during the younger part of the Lower Carboniferous (Visean to Early Serpukhovian). After decimation at the end of the Lower Carboniferous, new coral faunas replaced the old ones during Middle and Upper Carboniferous; they were less widespread.

In Peninsular Thailand, environments were not favourable to corals during the Carboniferous; only tiny Rugosa without dissepiments are expected there. A Tabulata (*Cladochonus* cf. *michelini* EDWARDS & HAIME) has been reported in Phatthalung area (REED, 1920).

The Carboniferous is divided into two parts as follows.

1. *Lower Carboniferous*

Corals are abundant at several Lower Carboniferous localities of East, Central, Northeast and Northwest Thailand.

Area 1a: In eastern Thailand, Lower Carboniferous limestone is known in two areas: north of Klaeng, and in the Kabinburi area. North of Klaeng or east of Si Racha, a diverse assemblage of corals belonging to the end of Lower Carboniferous has been found recently east of Khao Yai Mo Noi (13°22'30"N, 101°41'15"E; FONTAINE & SALYAPONGSE, 1997). It consists of a few tubular Tabulata, large solitary Rugosa (apparently *Kueichouphyllum*), common fasciculate Rugosa (*Siphonodendron* cf. *irregulare* and *Solenodendron* cf. *furcatum*) and, in abundance, Heterocorallia (*Hexaphyllia*). The corals are associated with algae and diverse faunas. Near Kabinburi, only a solitary Rugosa has been collected from a limestone quarry; it has been described as belonging to *Koninckophyllum* (SUGIYAMA & TORIYAMA, 1981).

Area 1b: In Central Thailand between Pichit and Phetchabun, several limestone exposures containing Lower Carboniferous corals are distributed from Noen Maprang to Chon Daen over a distance of more than 50 km (FONTAINE *ET AL.*, 1991). At Khao Hin Pun in Chon Daen area (16°07'30"N, 100°42'40"E), limestone is bedded and contains scattered Tabulata (*Syringopora*) and solitary Rugosa (*Koninckophyllum*), associated with foraminifera, brachiopods and crinoids. It belongs to Lower-Middle Visean and is a little older than the limestone of many other localities. At Khao Pha Thap Pon south of Noen Maprang (16°29'59"N, 100°40'20"E), a section of limestone overlying shale and sandstone is easy to observe. The corals are well preserved and belong to Tabulata (*Syringopora*, Chaetetidae), diverse solitary Rugosa (Cyathaxoniidae: *Cyathaxonia*; Laccophyllidae: *Syringaxon*,

Amplexocarinia; Antiphyllidae: *Rotiphyllum*; Hapsiphyllidae: *Hapsiphyllum, Zaphrentites, Allotropiophyllum;* Cyathopsidae: *Caninia, Melanophyllum;* Aulophyllidae: *Arachnolasma cylindricum, A. equiseptatum, A.* sp., *Kueichouphyllum sinense*), fasciculate Rugosa (Lithostrotionidae: *Siphonodendron irregulare, S. chonglomense, S.* cf. *petalaxoidea, Solenodendron furcatum;* Axophyllidae: *Lonsdaleia congjiangensis, L.* cf. *duplicata*), massive Rugosa (Lithostrotionidae: *Lithostrotion decipiens;* Axophyllidae: *Actinocyathus floriformis, A.* sp.) and Heterocorallia (*Hexaphyllia*). They are associated with algae (common *Koninckopora*), foraminifera, bryozoans and diverse brachiopods. They show more similarities with the Chinese and European forms than with the Australian counterparts; for instance, *Lithostrotion* is not known with certainty in Australia (Webb 1994). The fossils of Khao Pha Thap Pon are also present at other localities of Noen Maprang area, locally with other corals: *Kizilia, Siphonodendron junceum, S. pauciradiale, Axophyllum Vaughani* and *Dorlodotia* cf. *mengi*.

Area 1c: In Northeast Thailand in the Loei region, marine sediments belonging to Lower Carboniferous are exposed in three areas: in Pak Chom area at Ban Sa Ngao and Ban Pak Niem, at Pha Chom Nang along the road from Chiang Khan to Pak Chom, and in Ban Na Klang area at a few localities. Near Ban Sa Ngao (18°04'N, 101°57'30"E), limestone is exposed along Huai Sa Ngao and extends to the west at ground surface south of Ban Pak Niem (FONTAINE *ET AL.*, 1982). It contains solitary Rugosa (*Kueichouphyllum sinense, Arachnolasma equiseptatum, Yuanophyllum*), Rugosa (*Solenodendron furcatum, Siphonodendron petalaxoidea, Hexaphyllia* and *Heterophyllia*). These corals are associated with calcispheres and foraminifera. The Ban Sa Ngao–Ban Pak Niem limestone is well dated and belongs to the Upper Visean. At Pha Chom Nang, limestone contains scarce solitary corals (*Gangamophyllum*) associated with a poor assemblage of foraminifera belonging to a Visean age. Near Ban Na Klang, 15 localities have yielded Lower Carboniferous corals (FONTAINE & SUTEETHORN, 2000). Near Phu Pha Wiang north of Ban Na Klang (17°25'05"N, 102°05'00"E), solitary Rugosa (*Arachnolasma* and *Kueichouphyllum*) have been found and indicate a Late Visean age. At Ban Non Thawon east of Ban Na Klang, corals are more diverse and consist of Tabulata (*Syringopora*) and Rugosa (*Lithostrotion, Solenodendron, Hexaphyllia, Heterophyllia*). At Khao Pha Sean 6 km south of Ban Na Klang, corals are few; they belong to Tabulata (*Chaetetipora*) and Rugosa (*Rotiphyllum, Lonsdaleia* cf. *congjiangensis*). Other localities of Ban Na Klang area contain rare corals.

Area 1d: In Northwest Thailand, Carboniferous limestones are exposed at some localities between Phrao (Chiang Dao area) and Mae Hong Son. Corals have been found in Visean limestones exposed between Ban Mae Lana and the Burmese border (CARIDROIT *ET AL.*, 1987; FONTAINE *ET AL.*, 1993). They consist of *Clisiophyllum* near the Burmese border (19°41'N, 98°13'40"E), of *Arachnolasma* and *Hexaphyllia* associated with *Koninckopora* (an alga) northeast of Ban Mae Lana (19°35'N, 98°13'35"E). These localities have been assigned to an Upper Visean–Serpukhovian age.

2. *Middle-Upper Carboniferous*

Corals have been found in Middle-Upper Carboniferous sediments in Central, Northeast and Northwest Thailand.

Area 2a: In Central Thailand between Lam Narai and Thep Sathit, Middle–Upper Carboniferous corals have been found in a small area near Ban Bo Nam (15°17'40"N, 101°17'15"E; FONTAINE *ET AL.*, 1999). They are few, scattered in the rock. They consist of Tabulata (*Multithecopora*), solitary (*Caninia, Bothrophyllum, Amygdalophylloides*), fasciculate (not identified) and massive (*Petalaxis siamensis*) Rugosa. They are Moscovian–Kasimovian in age. At Wat Khao Takaeng south of Ban Bo Nam (15°04'20"N, 101°19'40"E; FONTAINE *ET AL.*, 1996), a Gshelian limestone has yielded a solitary Rugosa (*Sestrophyllum*).

Area 2b: In northeast Thailand, Middle–Upper Carboniferous corals occur at many localities belonging to five areas.

2b1: An important area is elongated in a N–S direction along longitude 101°45'E from the Mekhong River to Khao Tham Nam Maholan south of Wang Saphung. The localities will be mentioned from north to south. East-southeast of Phu Pha Maen (17°54'06"N, 101°48'12"E), a limestone contains a few solitary Rugosa (*Arachnolasma*) and a few foraminifera including *Eblanaia*. An Upper Tournaisian-Lower Visean age has been suggested because of the occurrence of *Eblanaia*. During a recent fieldwork (January 2002), a few solitary Rugosa have been found at the top of Phu Pha Maen (17°54'58"N, 101°45'49"E), solitary and fasciculate Rugosa at other localities to the south (17°49'56"N, 101°47'48"E; 17°49'03"N, 101°48'36"E; 17°48'56"N, 101°48'43"E); these fossils have not been studied yet. Tabulata (*Multithecopora, Chaetetes*) and fasciculate corals (*Paralytvophyllum?, Opiphyllum* cf. *intermedium*) occur in Upper Bashkirian limestone exposed in a small valley (Huai Nam) 3 km east of Ban Tat So. At km 13 of the road from Ban That to Pak Chom, Tabulata (*Chaetetes nagaiwaensis, Donetzites, Multithecopora* cf. *choiana*), solitary Rugosa (*Sestrophyllum*) and massive Rugosa (*Petalaxis kitakamiensis*) have been discovered in another Upper Bashkirian limestone. Near Nam Thao reservoir (17°35'N, 101°52'30"E; FONTAINE *ET AL.*, 1994), Moscovian limestone contains Tabulata (*Chaetetes nagaiwaensis, Multithecopora*), solitary Rugosa (*Lophophyllidium, Caninia lipoensis*) and massive Rugosa (*Petalaxis siamensis*). At Pha Tha, corals are represented by common *Chaetetes* and *Kionophyllum* in a Bashkirian limestone. At Phu Bo Bit near and east of Loei (17°29'00"N, 101°47'00"E), *Multithecopora* and *Koninckocarinia* have been mentioned also in a Bashkirian limestone. At Ban Pha Noi, a section is visible along Huai Nam Puan and ranges from Upper Moscovian to Permian. A few Tabulata (*Multithecopora*) and solitary corals (*Caninia lipoensis, Amygdalophylloides, Rotiphyllum* and others) have been collected from this section. East of Wang Saphung along the road to Udon Thani, a few Tabulata (*Multithecopora*) and solitary corals (*Caninia* cf. *tieni*) have been noticed in Moscovian beds. In a probably Upper Moscovian limestone at the northern side of Phu Ki Kai, Tabulata (*Multithecopora*), solitary (*Lophophyllidium, Amygdalophylloides, Sestrophyllum*) and fasciculate (*Lublinophyllum*?) Rugosa have been found (FONTAINE *ET AL.*, 1991). West of Khao Tham Nam Maholan at the wat, rare solitary Rugosa occur in a Gshelian limestone. South of Khao Tham Nam Maholan between Ban Pha Khao and Ban Somsak Phatthana (17°01'57"N, 101°58'45"E; FONTAINE *ET AL.*, 1995), shale and limestone beds exposed at the bottom of a pond contain solitary (*Pseudotimania, Caninia* cf. *tieni, Caninophyllum indosinense, C. somtaiense*) and fasciculate (*Lublinophyllum*) Rugosa; they belong to Upper Moscovian.

2b2: In Ban Huai Som Tai area east of Phu Kradung, Middle–Upper Carboniferous sediments

occur widely, but are not easy to observe because they are commonly covered by alluvium (FONTAINE *ET AL.*, 1995). At the bottom of a pond 1 km east of Ban Huai Som Tai (16°53'00"N, 101°59'55"E), fossils are in abundance in interbedded shale and limestone; they belong to foraminifera, corals, bryozoans, brachiopods, echinids (spines) and crinoids. Corals are diverse and belong to Tabulata (*Multithecopora* cf. *yohi*), solitary Rugosa (*Caninophyllum indosinense, C. somtaiense*) and massive Rugosa (*Ivanovia sigillata*). The age of this locality is Early Kasimovian. At another Middle Carboniferous locality near Ban Wang Lan (16°52'30"N, 102°01'20"E), limestone blocks in a pond contain rare small solitary Rugosa (*Amygdalophylloides*). Northwest of Ban Wang Lan (16°53'00"N, 102°00'30"E), limestone lenses in shale belong to Lower Moscovian and contain solitary Rugosa (*Caninophyllum*).

2b3: In Ban Na Duang area (17°30'N, 101°58'E), Moscovian to Gshelian sediments have been observed in a river (Huai Nam Suai) and in more than 10 ponds (FONTAINE *ET AL.*, 1991; FONTAINE & SUTEETHORN, 2000); they consist of shale and limestone, locally with a minor interbed of volcanic rock. Corals have been found in Moscovian limestone beds; they belong to Tabulata (*Chaetetes, Multithecopora*), solitary Rugosa (Cyathaxoniidae: *Cyathaxonia;* Cyathopsidae: *Caninia simpliseptata;* Bothrophyllidae: *Caninophyllum domheri, Pseudotimania* aff. *mosquensis;* Aulophyllidae: *Sestrophyllum carinatum*), fasciculate Rugosa (*Lublinophyllum thailandicum*) and massive Rugosa (*Ivanovia rareseptata*).

2b4: Phu Tham Pha Thang is an isolated Upper Bashkirian limestone hill 10 km southeast of Pak Chom (FONTAINE & SUTEETHORN, 1988). It is surrounded by spilitic basalt and is supposed to overlay this basalt. The limestone is rich in fossils including Tabulata (*Chaetetes lungtanensis*).

2b5: In Ban Na Charoen area south of the road from Wang Saphung to Udon Thani, several localities have been found (FONTAINE *ET AL.*, 1982, 1991, 1994). At the foot of a small hill 1 km south Ban Na Charoen (102°01'30"N, 17°11'30"E), a limestone bed contains, in abundance, very large Moscovian fasciculate corals (*Lublinophyllum thailandicum*), up to 1 m in diameter; it was discovered during a road construction in 1980. In a pond 2 km east of Ban Na Charoen, Tabulata (*Multithecopora*) and solitary Rugosa (*Caninophyllum indosinense*) occur in an argillaceous limestone. At a small hill south of the pond, an Upper Carboniferous limestone contains massive Rugosa (*Ivanovia sigillata*). Near Ban Sam Luang 6 km southeast of Ban Na Charoen, an Upper Kasimovian-Lower Gshelian limestone is rich in *Lublinophyllum thailandicum*. A Moscovian limestone near Tham Pha Noi, 3 km northeast of Ban Na Charoen, contains *Caninophyllum* and *Lublinophyllum thailandicum*. At Ban Samboon, 5 km south-southwest of Ban Na Charoen, solitary corals are common in an Upper Moscovian limestone.

Area 2c: In Northwest Thailand north of Chiang Dao, only a few Tabulata and solitary Rugosa have been noticed in Late Kasimovian-Early Gshelian limestone 2 km north of Ban Na Wai (CARIDROIT *ET AL.*, 1987).

Permian (295–245 Ma)

Permian Limestone is widespread in Thailand and its castellated topography adorns many areas. Not too far from Bangkok, it is well known near Ratburi and in the Saraburi and Lopburi areas. Between Chiang Mai and Mae Hong Son, it displays typical karst topography with sinkholes, caves, underground rivers, rivers disappearing and reappearing. It is an enchantment for the visitor. All over Thailand, many names of limestone hills indicate karst topography: Khao Lak (hill with a milestone shape), Khao Tham or Khao Khuha (hill with cave), Khao Tham Nam Lot (hill with underground river), Khao Wong (hill with sinkhole), Khao Laem (pointed hill) and so on.

The limestone exposures of Thailand range from the base to the top of the Permian if we consider the country in general. As a matter of fact, their distribution is heterogeneous stratigraphically as well as geographically (FONTAINE *ET AL.*, 1994). At the end of the Permian, the Rugosa became extinct along with the trilobites and fusulinids in a very important mass extinction event. The disappearance of the Rugosa is easy to observe in Thailand. These corals died out after several million years of decline. This crisis was marked by a decrease in diversity in two main events: first, the disappearance of all the massive Rugosa at the end of the Midian (the upper part of Middle Permian); and second, the disappearance of all the other Rugosa at the end of the Upper Permian.

Lower Permian

In Thailand, Lower Permian limestone is not very common. Limestone belonging to the lower part of Lower Permian (Asselian and Sakmarian) is particularly rare, but it is in evidence in a few areas. Corals have been found in three areas of Northeast Thailand. They are also present in Central Thailand in at least one locality.

In Northeast Thailand, solitary corals and massive corals (Kepingophyllidae) have been collected from a few localities (FONTAINE *ET AL.*, 1991). At the eastern foot of Phu Khao 6 km northwest of Ban Na Duang, an important assemblage of corals occurs in an Asselian–Sakmarian limestone. The corals consist of solitary Rugosa (Cyathopsidae: *Caninia lingwuensis, Pseudozaphrentoides mapingense;* Bothrophyllidae: *Bothrophyllum*?, *Caninophyllum;* Geyerophyllidae: *Amygdalophylloides*) and massive Rugosa (Kepingophyllidae: *Antheria* cf. *polygonalis, Nephelophyllum*). In the Ban Na Din Dam area, another Asselian–Sakmarian limestone contains solitary Rugosa (*Cyathaxonia, Paraduplophyllum, Amplexocarinia, Calophyllum, Lophophyllidium pendulum, Pseudozaphrentoides*), fasciculate Rugosa (*Densicolumnophyllum thailandicum*) and massive Rugosa (*Anfractophyllum*). West of Chumphae, Kepingophyllidae (*Anfractophyllum, Antheria*) have been found 2 km southeast of Wat Samakki Tham along the road to the Center for Wildlife Conservation. Kepingophyllidae are a coral family previously described in China from the Maping Limestone (Upper Carboniferous–Lower Permian).

In central Thailand, the red limestone of Khao Tham Rusi Laat northwest of Ban Bung Samphan contains poorly preserved solitary and massive Rugosa. At Khao Chon Tho north-northwest of Ban Na Chaliang, solitary corals (*Pavastehphyllum*) occur in an Asselian–Sakmarian limestone.

In the upper part of the Lower Permian of Loei region, Tabulata (*Protomichelinia*) are relatively widespread and in abundance at several localities. Phu Pha Wang (17°19'01"N,

102°01'40"E) along the road from Wang Saphung to Udon Thani is a good example; this hill contains *Protomichelinia laosensis* and *P. simplex*. South of Wang Saphung at Khao Pha Fai (17°02'30"N, 101°44'38"E), very rare massive Rugosa are present in an Artinskian limestone; they appear to belong to *Wentzellophyllum*.

Middle Permian

Corals are known in Middle Permian limestones, which are distributed all over Thailand. They are in abundance and great diversity in East, Central, Northeast and North Thailand. They are associated with large assemblages of fusulinaceans; these faunas are completely different from those in Australia. Fusulinaceans are unknown in the Permian of Australia. In Peninsular Thailand, corals are different from those of the rest of Thailand; they are less diverse.

Peninsular Thailand: Limestone ranges from the end of Lower Permian to Middle Permian and the beginning of Upper Permian. The extreme top of the Permian has not been evidenced paleontologically yet, seemingly because of dolomitisation. The limestone contains particular and moderately diverse faunas. Corals occur at many localities of Kanchanaburi, Ratburi, Phetburi, Prachuab Khirikhan, Chumphon, Surat Thani, Phang Nga, Phatthalung and Trang areas (FONTAINE & SALYAPONGSE, 2001). They are rarely diverse and not usually abundant. Their age is Murgabian to Midian. Phissadarn Cave (10°45'27"N, 99°13'57"E) is a limestone hill north of Chumphon; it contains a quite rich coral assemblage consisting of Tabulata (*Sinopora*) up to 30 cm in diameter, rare solitary and common massive Rugosa (*Paraipciphyllum thailandicum, P. kulvanichi*). In fact, corals are scattered in the limestone. They did not appear as important builders. In Peninsular Thailand, Tabulata are represented by widespread *Sinopora*. Solitary Rugosa without dissepiments (*Lophophyllidium, Amplexocarinia, Ufimia*) have been found in the Trang area; *Lophophyllidium pendulum, Amplexocarinia*, and *Paracaninia* occur at Ban Phu Plu (14°05'45"N, 99°16'05"E), *Lophophyllidium* at Khao Laem Dam. Solitary Rugosa with dissepiments (*Pavastehphyllum* and *Iranophyllum*) are present at several localities: Khao Laem Dam (14°48'07"N, 98°35'19"E), Khao Lan (13°33'44"N, 99°36'12"E), 3 localities in Prachuab Khirikhan, and a few localities in the Chumphon, Surat Thani, Phang Nga and Phatthalung areas. Colonial corals exhibit a geographic distribution similar to that of the solitary corals with dissepiments. They belong to massive corals (mainly *Paraipciphyllum*, locally *Wentzelella* or *Chombungia*) and rarely fasciculate corals (Khao Yoi). *Wentzelella* has been found at a single locality: Ko Ma (6°45'34"N, 99°45'22"E), an island of Satun area; it has been identified as *Wentzelella megastoma* (FONTAINE *ET AL.*, 1979). The corals of Peninsular Thailand do not include genera such as *Ipciphyllum* and *Pseudohuangia* which are so common in Central Thailand. The environment was not favourable to the development of many organisms. At Khao Lan (13°33'44"N, 99°36'12"E) near Chom Bung, massive corals are rare and display growth bands at the foot of the hill; higher up, they are common without showing growth bands (FONTAINE & JUNGYUSUK, 1997). This fact has been interpreted as indicating a climate change, from a seasonal climate at the foot of the hill with different growth rates during the seasons to a continuous warm climate at the top of the hill with a more regular growth. The base of the Lower Permian of Peninsular Thailand contains pebbly mudstone which has been interpreted by several geologists as a glacial deposit. Corals are completely unknown in this part of the Permian. Other faunas also underline the peculiarities of the

Permian of Peninsular Thailand (FONTAINE *ET AL.*, 1994).

East Thailand: Many limestones have yielded fossils ranging from Kubergandian to Midian, it is to say belonging to the whole Middle Permian (FONTAINE & SALYAPONGSE, 1997). Corals have been found at several localities between the road from Sa Kaeo to Chanthaburi and the Cambodian border. At Khao Chakan (13°39'50"N, 102°05'E), there are only a few solitary corals: *Khmerophyllum* cf. *cambodgense* (SUGIYAMA & TORIYAMA, 1981) as well as at Khao Bang Phrik (13°15'30"N, 102°18'E; *Tachylasma, Lophocarinophyllum*; FONTAINE & SALYAPONGSE, 1997). At other localities belonging mainly to Midian, corals are somewhat more diverse. They consist of a few Tabulata (*Sinopora*), fasciculate Rugosa (*Waagenophyllum*) and massive Rugosa (*Parawentzelella, Multimurinus*). *Parawentzelella*, a genus previously described in the Midian limestone of the Sisophon area in West Cambodia, has been found again at some localities of East Thailand: Khao Phai (13°40'20"N, 101°57'55"E), Khao Sung–Khao Ta Ngok at the Cambodian border, Khao Chongkhaeb north of Khao Ta Ngok.

Central Thailand: Middle Permian limestone is widespread and is rich in many kinds of fossils. It had been deposited in shallow and warm water; changes in sea level even led to the temporary deposition of clastic beds containing continental plants around Saraburi and Phetchabun. Corals are prolific and diverse at a very great number of localities near Muak Lek, Saraburi, Lopburi, Lam Narai (in particular Khao Somphot and Khao Wong), Khok Samrong, Tak Fa, Wichianburi (Khao Khi Nok), Nong Phai and Phetchabun. They are especially abundant in the Murgabian. They consist of Tabulata (*Protomichelinia, Sinopora*), solitary Rugosa (*Lophophyllidium pendulum, L. zaphrentoidea, Pseudozaphrentoides mapingense, Verbeekiella*?, *Pavastehphyllum, Laophyllum, Iranophyllum splendens*), fasciculate Rugosa (*Yatsengia asiatica, Waagenophyllum kueichowense, Chaophyllum, Pseudohuangia chiuyaoshanensis, P. counilloni, P. thailandica, P.* cf. *aberrans, Chihsiaphyllum kanmerai*) and massive Rugosa (*Ipciphyllum laosense, I. elegans, I. subelegans, I. irregulare, I. phadaengense, I. saraburiense, Paraipciphyllum magnificum, Crassiparietiphyllum sattayaraki, C. tenue, Multimurinus regularis, M. khmerianus, M. fontainei, M. frechi, M. suteethorni, Wentzelophyllum thailandicum*). A very peculiar coral (*Khmeria problematica* Mansuy), previously described in West Cambodia, has been found south of Phetchabun in Ban Na Chaliang area (FONTAINE *ET AL.*, 1994); it is associated with *Codonofusiella*, a fusulinacean indicating a Murgabian to Late Permian age. Between Central and Northeast Thailand, Khao Tham Yai is a very large limestone hill with an important cave (16°56'40"N, 101°30'35"E), well visited by tourists. It displays a section 700 m thick ranging from Murgabian to Midian, very easy to observe (FONTAINE & SALYAPONGSE, 2001). The lower part of the section is rich in massive Rugosa (*Ipciphyllum, Multimurinus*).

Northeast Thailand: Permian corals are known in a large area west of Chumphae and in Loei region (FONTAINE *ET AL.*, 1994; FONTAINE *ET AL.*, 1995). West of Chumphae, corals are common in Murgabian limestone along the road from Lomsak to Chumphae: at the northern end of Khao Ruak 33.7 km from Chumphae (*Sinopora, Lophophyllidium, Ipciphyllum subelegans, Multimurinus fontainei*), at Phu Sam Phak Nam 28 km from Chumphae (*Sinopora, Lophophyllidium, Ipciphyllum, Multimurinus frechi*) and at Sak Chay quarry 25 km from Chumphae (*Protomichelinia laosensis, P. globosa, P. simplex*). At the

southeastern foot of Khao Hin King 35.5 km from Chumphae, solitary Rugosa (*Lophophyllidium*) have been found in a Kubergandian limestone. Along the road from Khon San to Chulabhorn Dam, at Khao Dat Fa 22 km from Khon San, *Sinopora* occurs in small numbers. At Wat Samakki Tham 23 km from Khon San, corals are more diverse and consist of rare Tabulata (*Protomichelinia, Sinopora*), solitary Rugosa (*Lophophyllidium*) and fasciculate Rugosa reaching 1 m in diameter (*Pseudohuangia* cf. *chiuyaoshanensis*). At Khao Pha Phung 7 km north of Wat Samakki Tham, a new genus of colonial Rugosa (*Phaphungia*) has been found; it is associated with Tabulata (*Sinopora*), solitary corals and other massive Rugosa (*Paraipciphyllum magnificum*). In the Loei–Wang Saphung region, Middle Permian limestone is exposed east of Loei and northwest of Wang Saphung. East of Loei, Tabulata (*Sinopora*) and massive Rugosa (*Ipciphyllum laosense* and 2 other species of *Ipciphyllum*) have been found at Ban Sam Yaek; Tabulata (*Sinopora*), solitary Rugosa (*Pavastehphyllum*), fasciculate Rugosa (*Pseudohuangia chiuyashanensis*) and massive Rugosa (*Crassiparietiphyllum sattayaraki*) at Ban Nam Suai Tha Saat; Tabulata (*Sinopora*), solitary Rugosa (*Lophophyllidium*), fasciculate Rugosa (*Chihsiaphyllum vacuum, Pseudohuangia*) and massive Rugosa (*Crassiparietiphyllum sattayaraki*) at Ban Nam Suai Tha Sawan. Farther to the east around Nam Som, Tabulata (*Sinopora*), solitary Rugosa (*Pavastehphyllum*) and rare massive Rugosa probably belonging to *Ipciphyllum* have been observed at Phu Pha Kup and at a neighbouring small hill, Tham Suwana Khuha. Northwest of Wang Saphung, corals are rare at Khao Pha Phung and Khao Pha Bao Pha Sao. They are associated with *Codonofusiella*, a fusulinacean unknown so far east of Loei; they belong to Upper Murgabian or Midian.

North Thailand: Permian corals have not been found in great abundance; they are widely scattered in the rock (YANAGIDA *ET AL.*, 1988; FONTAINE ET AL., 1994; new data). They have been collected mainly in Nan area from a Late Kubergandian-Early Murgabian limestone at Khao Pha Toob and Khao Pha Sing. In Lampang area, they are poorly known. At Khao Pha Sing 12 km north of Nan, corals are rare; they are solitary Rugosa (*Laophyllum*) and fasciculate Rugosa (*Chihsiaphyllum* cf. *kanmerai*). At Khao Pha Toob 9 km north of Nan, corals are more common, especially fasciculate corals (*Pseudohuangia* cf. *aberrans, Chihsiaphyllum* cf. *kanmerai*). They include also some solitary (*Laophyllum*) and massive (*Wentzelella*) Rugosa.

Northwest Thailand: Corals are not widespread. They are known: in the Fang area, between Chiang Dao and Mae Hong Son (at Sop Pong, Ban Mae Lana and Ban Mae Suya) and in the Mae Sariang area (MINATO, 1944; FONTAINE & SUTEETHORN, 1993; FLUGEL, 1997; HAHN & SIEBENHUNER, 1982). The coral identified by MINATO (1944) as a specimen of *Wentzelella subtimorica* belongs actually to *Ipciphyllum laosense* (MINATO & KATO, 1965). It had been collected from Fang area between Ban Doi Hua and Ban Ai about 80 km north-northeast of Chiang Mai. Fasciculate Rugosa (*Waagenophyllum*) and Tabulata (*Sinopora*) have been found north of Sop Pong. South of Ban Mae Lana, fragments of *Waagenophyllum* have been collected from a dolomitic limestone. At Ban Mae Suya, massive colonies of *Multimurinus* are common; they are associated with fusulinaceans indicating a Late Murgabian age. HAHN & SIEBENHUNER (1982) have cursorily mentioned *Verbeekiella, Yatsengia* and *Waagenophyllum* at two localities between Mae Sariang and Tha Song Yang.

Upper Permian

Upper Permian limestone has been evidenced in East and North Thailand. It has yielded very few corals.

East Thailand: at Wat Khao Kaew (13°06'N, 102°24'20"E), solitary corals (*Paracaninia*) occur in a limestone containing *Colaniella* and probably belonging to Wuchiapingian. Northeast of Klaeng, *Palaeofusulina*, a Changshingian fusulinacean, has been found at two small limestone hills near Wat Khao Hin (12°52'30"N, 101°48'45"E; FONTAINE *ET AL.*, 1999); no coral was observed.

North Thailand: solitary Rugosa (*Lophophyllidium*) and fasciculate Rugosa (*Liangshanophyllum*) have been collected from limestone at Ban Cham Ka northeast of Lampang and at Phra That Muang Kham southeast of Lampang; they are associated with a Wuchiapingian microfauna (FONTAINE & VACHARD, 1988). At Huai Thak west of Ban Pang Kho along the road from Lampang to Ngao, an Upper Permian sequence of shale, calcareous shale and argillaceous limestone contains rare small solitary Rugosa (*Asserculinia*) associated with abundant *Leptodus* (brachiopods). North of this locality at Doi Pha Phlung, *Waagenophyllum* aff. *virgalense* has been reported in Changshingian limestone (YANAGIDA *ET AL.*, 1988; ISHIBASHI *ET AL.*, 1998).

Triassic (245–205 Ma)

Triassic limestones have been evidenced recently at many localities of Thailand. In the past, they were considered Permian in age because they are similar to Permian limestones if fossils are not taken into account. They range from Lower Triassic to the lower part of Upper Triassic (Carnian); the lower part of the Norian may be locally present. Triassic Corals have been found at several limestone exposures in Peninsular, East, North, and West Thailand. They have never been collected from Lower Triassic rocks. A little more than 20 species have been mentioned. Solitary forms (*Montlivaltia, Distichophyllia, Conophyllia, Margarophyllia*), fasciculate and massive colonies (*Thecosmilia, Volzeia, Cyathocoenia, Elysastraea, Margarosmilia, Thamnasteria*) have been identified mainly from reports on regional geology (PITAKPAIVAN *ET AL.*, 1969; YANAGIDA *ET AL.*, 1988; ADACHI *ET AL.*, 1993; FONTAINE *ET AL.*, 1993). They have not been studied in detail. They need to be revised. Some identifications are actually debatable.

Peninsular Thailand: Solitary, fasciculate and massive corals have been observed at Khao Phanom Wang, a hill 9 km northwest of Phatthalung, where they are in abundance (ADACHI *ET AL.*, 1993; FONTAINE *ET AL.*, 1993). Solitary corals have been found at Khao Khuha south of Phatthalung where they are associated with *Aulotortus* (FONTAINE *ET AL.*, 1993). A Carnian age has been proposed for the two localities. The Triassic limestones of Phatthalung range from late Early Triassic to early Late Triassic (AMPORNMAHA, 1995).

East Thailand: Solitary and fasciculate corals have been noticed at three Triassic limestone exposures: the first at Khao Cha-ang On north of Klaeng (13°12'30"N, 101°39'30"E); the second at Khao Thep Nimit Banphot south of Aranyapathet (13°37'30"N, 102°27'30"E); and the third at Khao Noi Si Chomphu near the Cambodian border (13°34'40"N, 102°32'E; FONTAINE & SALYAPONGSE, 1997).

North Thailand: PITAKPAIVAN *ET AL.* (1969) mentioned solitary and fasciculate Scleractinia in Phrae Province at the antimony mine at Pha Khan, Amphoe Long. *Thecosmilia* was reported at Huai Rong Sak north of Ngao (YANAGIDA *ET AL.*, 1988). In Nan Province, Triassic limestone is exposed in several areas (FONTAINE *ET AL.*, 2001). Solitary, fasciculate and massive corals have been found in Ban Huai Kaet area; YANAGIDA *ET AL.*, (1988) mentioned *Elysastraea, Montlivaltia* and *Thecosmilia* at this locality. Solitary and a few fasciculate corals have been noticed in Na Noi area and between Pong and Santisuk (FONTAINE *ET AL.*, 2001).

West Thailand: Triassic limestone is widespread and builds up two north-trending series of hills in Uthai Thani area (FONTAINE *ET AL.*, 2000). Hills of the western series display well-preserved fossils and corals have been observed at five hills. They contain Upper Triassic microfossils. At Khao Pathawi (15°28'20"N, 99°45'40"E), solitary, fasciculate and massive corals have been found. Large solitary corals reaching 6 cm in diameter and 20 cm in length are common in the middle part of the hill; fasciculate corals up to 1 m in diameter are in abundance at the northern end of the hill. North of Khao Pathawi, solitary and fasciculate corals have been observed at Khao Hin Thoen and Khao Phra North; at Khao Kachi, corals are very rare. South of Khao Pathawi at Khao Pun, a single fasciculate coral has been noticed. At the eastern series of hills along longitude 99°58'E, limestone is recrystallized. Nevertheless, corals are still visible at the surface of the rock at a few hills: Khao Ngo, Khao Rum, Khao Lai, Khao Pun (same name as another hill of the western series), small hill northeast of Khao Hin Phloeng, and Khao Kaeo. They are poorly preserved; to the naked eye, they appear similar to those in the hills of the western series.

Jurassic (205–135 Ma)

Marine sediments of Jurassic age are known only in West Thailand. They are exposed in several areas from Peninsular Thailand to Mae Hong Son. They have been the subject of a recent PhD thesis (MEESOOK, 1994). Shallow marine conditions existed over most of West Thailand. Mudstones, siltstones and sandstones are widespread. Limestone is prominent only in Mae Sot, Umphang and Kanchanaburi areas. Fossils are abundant and diverse; they consist of algae, foraminifera, corals, sponges, bryozoans, brachiopods, bivalves, gastropods and ammonites (FONTAINE & SUTEETHORN, 1988; BEAUVAIS & FONTAINE, 1993; MEESOOK, 1994). They indicate mainly Toarcian, Aalenian and Lower Bajocian ages. However at Pa La Tha south of Umphang, corals are associated with two Late Jurassic fossils: *Cladocoropsis mirabilis*, a calcisponge, and *Salpingoporella pygmaea*, an alga. The marine Jurassic strata of West Thailand can be correlated with the non-marine Jurassic of Northeast Thailand, belonging to the "Khorat Group" and extending from Chiang Rai to Nakhon Phanom and Prachinburi.

Corals are sporadically present from Kanchanaburi to Mae Sot. They may be only a few scattered fragments of corals as in Kanchanaburi area (at Huai Si Sa Ho) or they may be rich assemblages as in some areas of Umphang and Mae Sot where they consist of solitary, fasciculate and massive specimens. About 50 species have been recognized in Thailand [FONTAINE & SUTEETHORN (1988) with a chapter written by Beauvais; BEAUVAIS & FONTAINE (1993)].

In the area of Klo Tho west of Umphang, corals are in abundance and they constitute the richest Jurassic coral fauna known in Thailand. They do not form true reefs. Although they are in a tremendous number, they do not join one another and hence do not build up a rigid framework. They consist of: *Epistreptophyllum giganteum, Montlivaltia numismalis, M. tenuiradiata, M. fragilis, M.* cf. *caryophyllata, Calamophylliopsis flabellum, C. flabellum* var. *compacta, C. klothoensis, C. etalloni, C.* sp., *Stylosmilia tenuis, S. michelini, S. corallina, Stylina girodi, S. deluci, Cladophyllia thailandica, C. dichotoma, Lochmaeosmilia radiata, Latomeandra ramosa, L.* sp., *Dermosmilia laxata, D. crassa, D.* sp., *Fungiastraea pseudoarachnoides, Microsolena exigua, M.* sp., *Litharaeopsis fontainei, Thamnasteria* sp., *Actinaraea granulata, Kobyastraea subagaricites, K. bourgeati, K. haradai, Thamnoseris frotei, Haplaraea* sp., *Intersmilia exigua, Allocoeniopsis bernensis, Latiphyllia langi, Clausastraea edwardsi, Andemanastraea densisepta, Araiophyllum* sp.

Near Ban U The Khi south of Umphang and Ban Pa La Tha, solitary corals (*Cyathophyllopsis, Epismilia*) have been collected from a single locality. *Calamophylliopsis* has been found northwest of Ban Pa La Tha.

In the Mae Sot area, corals are rare at Doi Din Chi northwest of Mae Sot; they are solitary. Five to 10 km east of Mae Sot, there are also small numbers at a few localities near Ban Pha De, along Huai Pha Yo and along Huai Hin Fon.

Near Ban Huai Ya-u 25 km east of Mae Sot (as the crow flies), many Jurassic corals have been found recently but have not been studied yet. They are mainly fasciculate and massive colonies. The fasciculate corals are in abundance; they are 30 to 50 cm in diameter. The massive corals are smaller and less common; they reach a maximum diameter of only 15 cm .

The Jurassic corals of Thailand display some similarities with Jurassic corals throughout Asia (Indonesia, Japan, Philippines, Sarawak), western Europe (England, France, Switzerland), Morocco, Madagascar, and the Middle East. However, they show peculiarities and Thailand can be considered a distinct subprovince within Asia.

Cretaceous (135–65 Ma)

There is no marine Cretaceous in Thailand or in Cambodia, Laos and Vietnam. In Southeast Asia, marine Cretaceous is known only in the Philippines, East Malaysia, and Indonesia. Accordingly, there is no Cretaceous coral at all in Thailand.

Tertiary and Quaternary (65 Ma to present)

On land far from sea, Tertiary sediments fill small to moderately large basins; they are non-marine. Even at the bottom of the Gulf of Thailand, Tertiary–Quaternary sediments are fluvio-lacustrine at their base and become marine only at the top (ALDERSON *ET AL.*, 1994). During the Quaternary, sea level changes were important and sedimentation was non-marine to marine in the coastal zones. The latest Pleistocene-to-Middle-Holocene marine sediments have been described (for instance) in the Songkhla area (CHAIMANEE, 1987) or in the Bangkok plain with the occurrence of a 1-m thick oyster bank (5,500 years old) at Wat Hoi in Amphoe Lat Lum Kaeo, 40 km north of Bangkok (CHONGLAKMANI *ET AL.*, 1983, DHEERADILOK, 1987). Accordingly, corals sporadically occur in varying numbers.

Coral fragments form up to 30 percent of the beach sand of Samui and Phangan Islands (KOHPINA & CHIEMCHINDARATANA, 1997).

In the Gulf of Thailand and the Andaman Sea, coral reefs occupy about 1,800 km^2.

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