CHAPTER I

INTRODUCTION

Mesozoic rocks of Thailand consist of both marine and non marine deposits (Chonglakmani, 1983; Meesook et al., 2002). Marine Triassic rocks of Thailand are distributed in three sedimentary basins, namely the Lampang-Phrae, Mae Sariang-Kanchanaburi, and Songkhla Basins (Chonglakmani and Grant-Mackie, 1993). These rocks can be indicated due to the occurrence of index bivalve fossils as *Daonella* and *Halobia*. The study of stratigraphy of marine Triassic sedimentary rocks was mostly conducted in the central north of Thailand, especially in the area of Lampang-Phrae Basin whereas the ones in the western region, located in Mae Sot-Phop Phra District, Tak Province has been rarely studied in detail in term of its geological age. The marine Triassic rock distributed in the west contains chert yielding abundant radiolarian. Recently, the detailed age determination, based mainly on the radiolarian biostratigraphical data of pelagic sediments, has been used for terrane analysis and to understand the timing of terrance collisions (e.g. Sashida et al., 1993; Sashida and Igo, 1999).

Radiolarians are most useful for biostratigraphy of Mesozoic and Cenozoic deep sea sediments. They have great potential as paleoenvironmental indicators. The distribution of the pelagic sediments and their geological ages indicates the spatial extent of the Paleotethys, its processes of development, and its times of opening and/or closing (Kamata et al., 2002). However, the timing of these events is still debatable. Thus, the Mae Sot–Phop Phra area in Tak Province is selected for this detailed study.

1.1 Study area and Geography

1.1.1 Location

The study area is located in Mae Sot District and Phop Phra Districts, Tak Province on the northwestern part of Thailand (Figure 1.1). The study area is located between Latitude 16° 15′-16° 50′ N and Longitude 98° 30′ -98° 50′ E. The area appears in the reference topographic map, scale 1:50,000, edition 1,2-RTSD, Series L 7017, map sheets Amphoe Mae Sot (4742III), Amphoe Phop Phra (4741IV), Amphoe Mae Ramat (4742IV), Ban Pang Sang (4742I), Ban Mae Lamao (4742II), and Ban Pa Di (4741I) (Figure 1.2). Moreover, the geologic maps scale 1:50,000 of Amphoe Mae Sot and Amphoe Phop Phra, Tak Province have been used in this study (Saengsrichan, 2006 unpublished data).

1.1.2 Accessibility

The travelling to the area is starting from Bangkok to Tak Province along the highway no. 1 with a total distance of 426 km, and then turn left to highway no. 105 about 80 km to Mae Sot District. The main transportation routes within the study area comprise (Figure 1.3):

1) Highway no. 105 is from Tak Province to Mae Sot District.

2) Highway no. 1090 is between Mae Sot and Umphang Districts.

3) Highway no. 1206 is connecting between Mae Sot and Phop Phra Districts. It is ended at Ban Wa Lay, near the border between Thailand and Myanmar.

1.1.3 Physiography and Climate

The topography of the area is characterized by high mountain ranges in the middle part and Mae Sot Basin in the western part (Figure 1.4). The Mae Sot Basin covers the areas of Phop Phra and Mae Ramat Districts, with a total area of about 700 km^2. The high mountain in the middle part, lying approximately N-S direction, 60 km long, with an elevation of 1,400 m, is called Thanon Thong Chai. The Thanon Thongchai mountain range extends to the south strating from Chiang Mai, Tak Provinces to Thong Pha Phum District in Kanchanaburi Province.

The climate around the study area is a tropical savanna. According to the climate classification of Koppen, there are 3 seasons: rainy, winter and summer. Rainy season starts in May and lasts until the middle of September or the beginning of October. Totally, it lasts approximately 4-5 months. Cold season (winter) usually starts in the middle of October and lasts until the middle of February. The duration of the season is around 3-4 months. The coldest period is in December until January. Summer takes around 3 months which starts from the mid-February until mid–May. Usually, the highest temperature is in April. The average highest temperature is 36.50° C – 40.40° C and the lowest temperature is 9.70° C – 13.90° C.

1.2 Purposes of the study

1. To define lithostratigraphy of marine Triassic sedimentary rocks in Mae Sot and Phop Phra Districts, Tak Province, northwestern part of Thailand.

2. To systematically describe Triassic radiolarian species.

3. To clarify the details of the geological age and discuss the depositional environment.

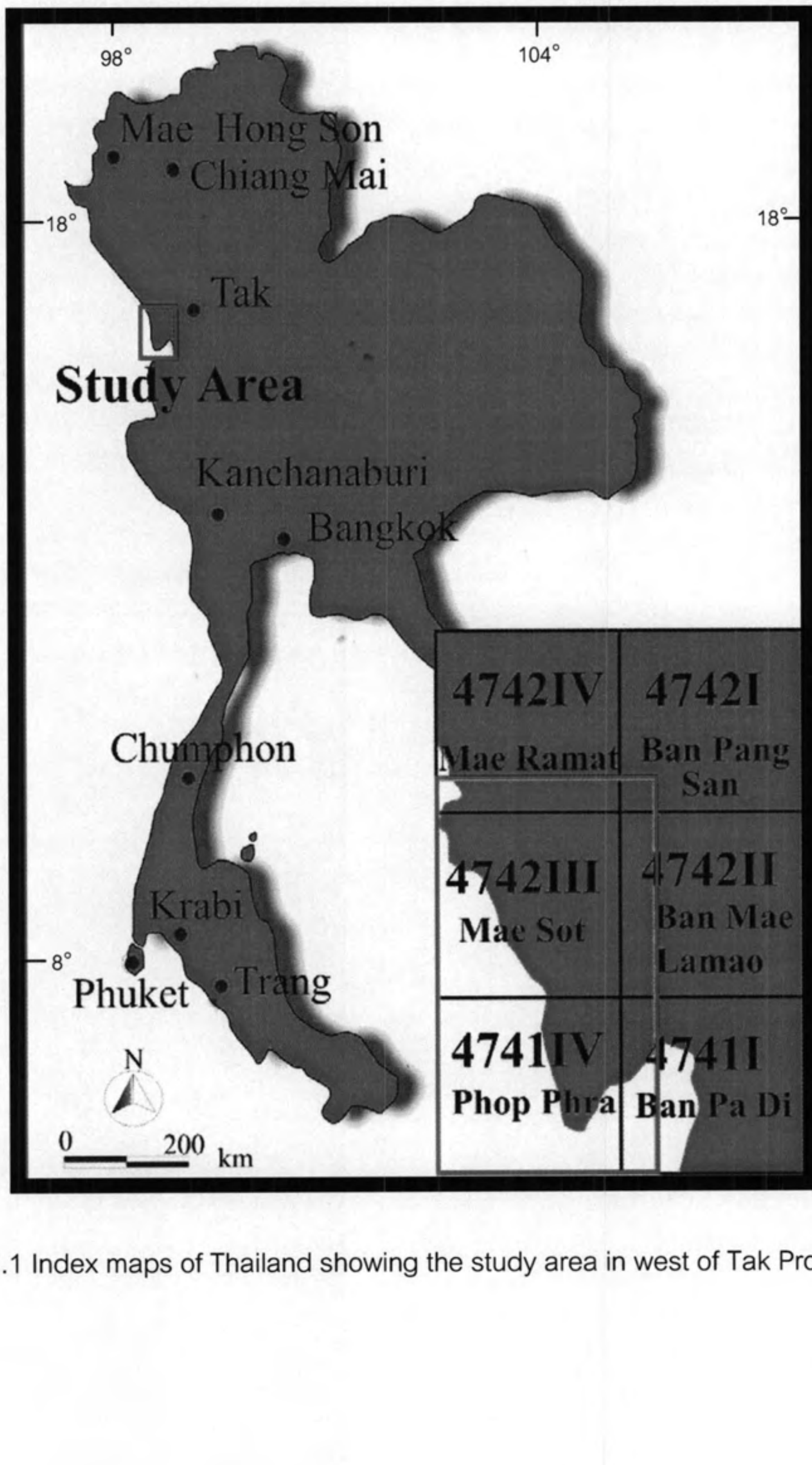


Figure 1.1 Index maps of Thailand showing the study area in west of Tak Province.

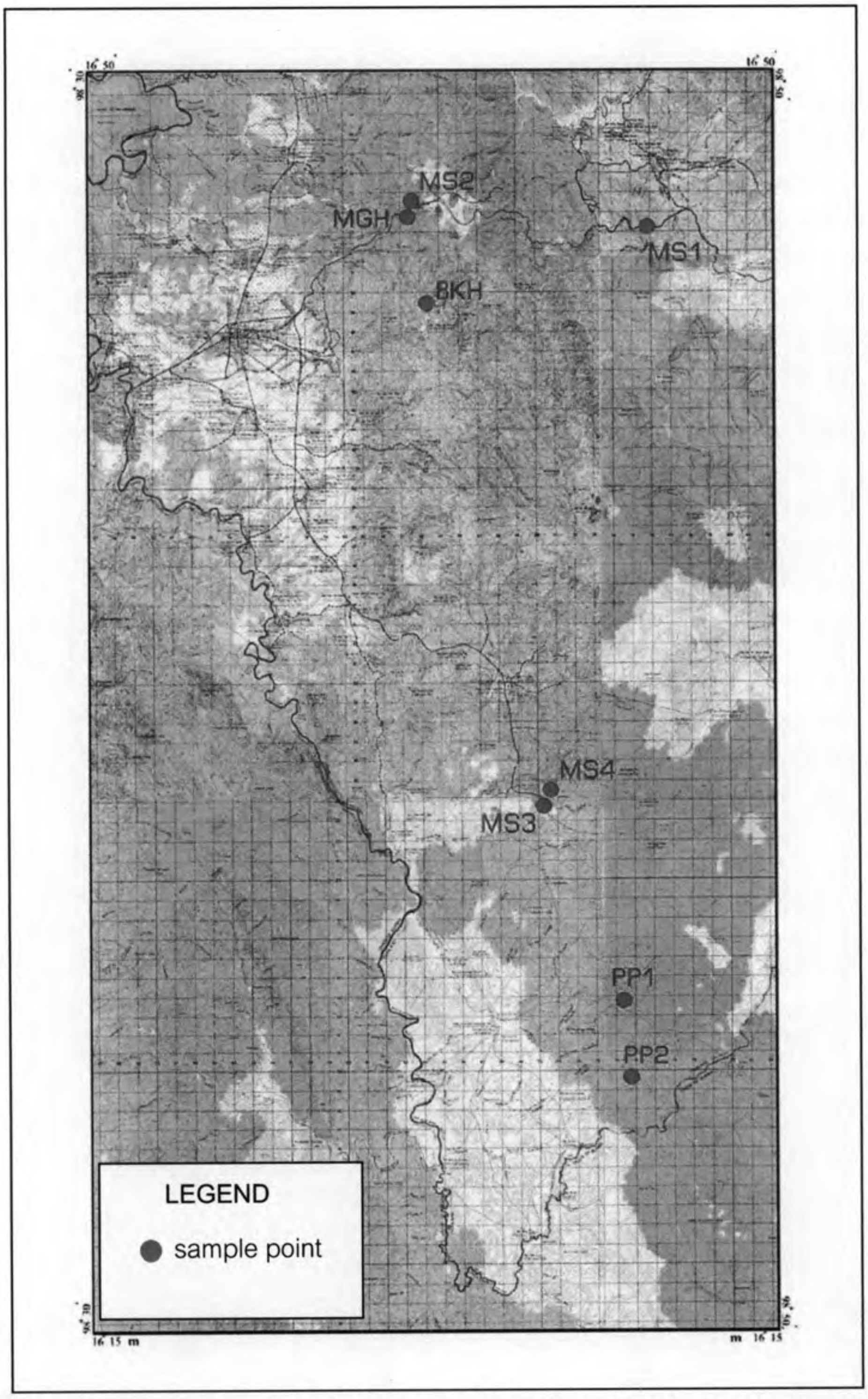


Figure 1.2 Topographic maps of the investigated areas. Map sheets Amphoe Mae Sot (4742III) and Amphoe Phop Phra (4741IV) and part of topographic map sheets Amphoe Mae Ramat (4742IV), Ban Pang Sang (4742I), Ban Mae Lamao (4742II), and Ban Pa Di (4741I) (after Royal Thai Survey Department, 1979).

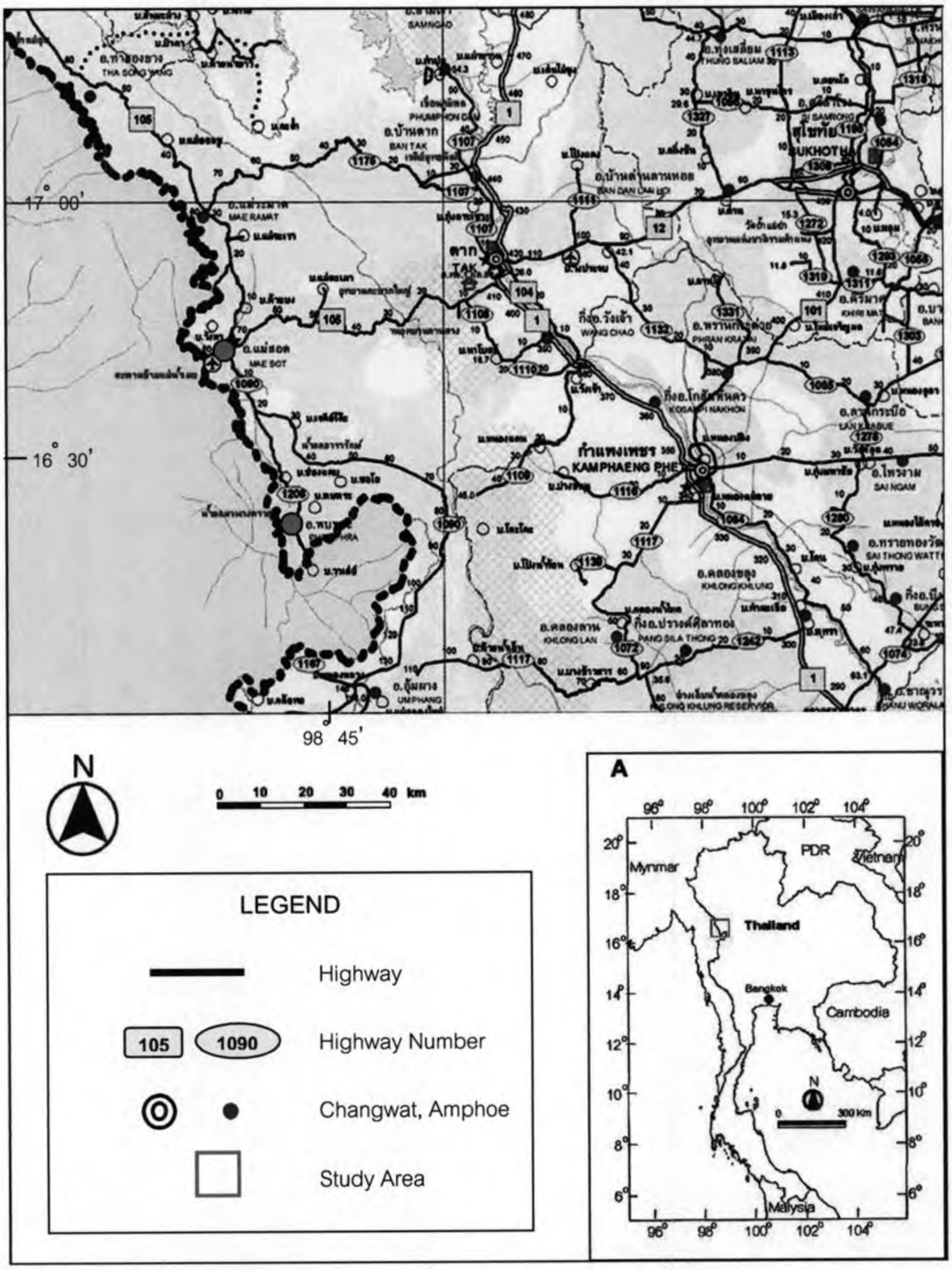


Figure 1.3 Index map of Thailand (A) showing the accessibility to the study area in Mae Sot-Phop Phra District, Tak Province (after Department of Highways, 2006).

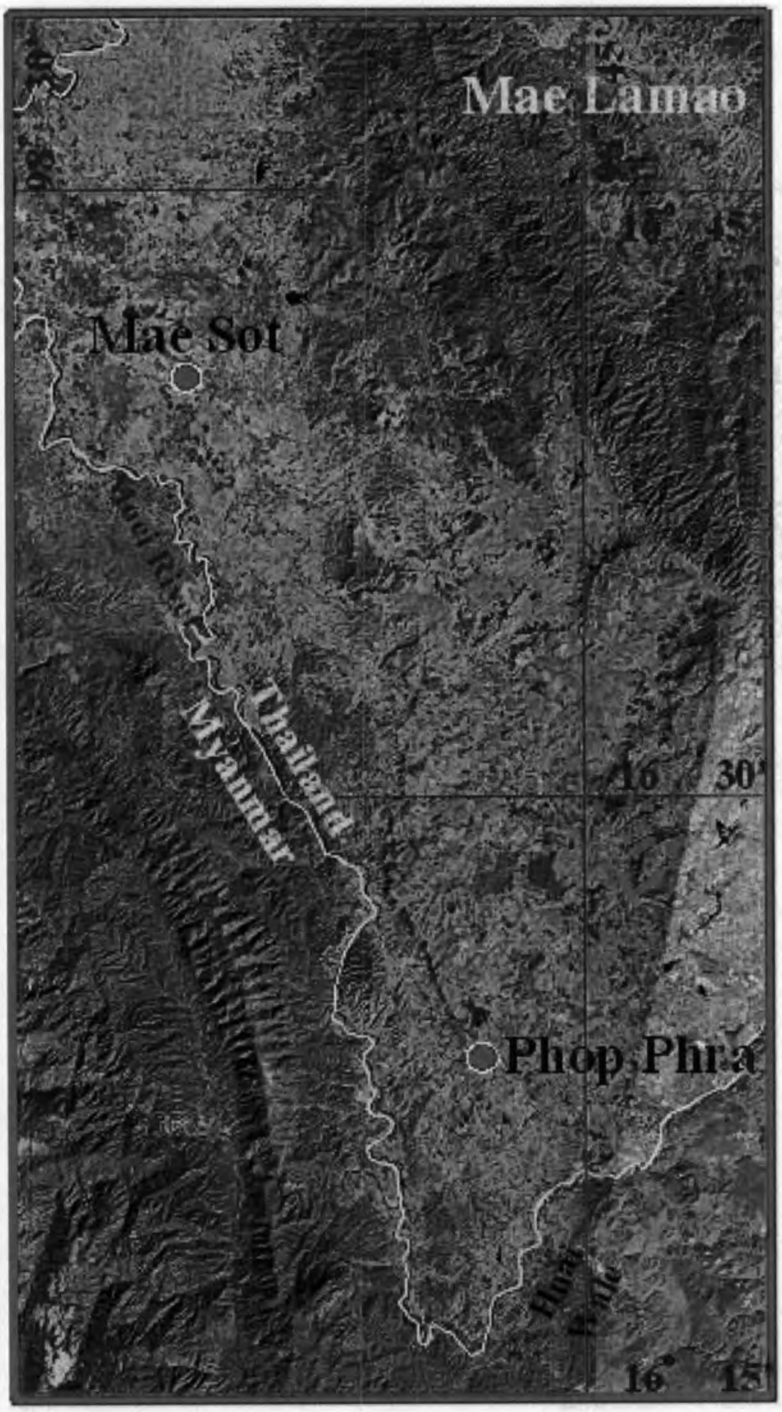


Figure 1.4 Satellite image from LANDSAT 5-TM showing topography of study area (after Saengsrichan, 2006 unpublished data).

1.3 Methodology

Methodology contains 3 parts: office, field and laboratory works. The summarized flow chart showing methods of the study is illustrated in Figure 1.5.

1.3.1 Office work

The office work includes the review on previous work on stratigraphy, sedimentology, radiolarian fauna and preparation of topographic and geologic maps of the study area and adjacent regions.

1.3.2 Field work

Field surveys were undertaken in April of 2005 and August 2006. The field investigation is divided into 2 parts: the measurement and study the stratigraphic sections of marine Triassic sedimentary rocks in Amphoe Mae Sot; section MS1 (UTM 475958 E, 1853149 N), section MS2 (UTM 463394 E, 1854470 N), section section MGH (UTM 463122 E, 1853971 N) and section BKH (UTM 464362 E, 1849404 N) and Amphoe Phop Phra; section MS3 (UTM 704470 E, 1824118 N), section MS4 (UTM 707470 E, 1824401 N), section PP1 (UTM 474451 E, 1813698 N) and section PP2 (UTM 474941 E, 1809655 N) and sample collection for paleontologic and petrologic studies.

1.3.3 Laboratory work

1.3.3.1 Paleontologic study

The rock samples were extracted for radiolarian study by using hydrofluoric acid (HF). The rock samples prepared for hydrofluoric acid (HF) treatment were crushed into small pieces approximately into 2-3 cm chips or crushed rocks several centimeters in size and soaked in a dilute hydrofluoric acid (HF) solution (5-10%) for about 24 hours in the plastic beaker. This etch radiolaria from cherts using hydrofluoric acid is extremely dangerous and must only be carried out in a fume cupboard with full protective clothing and as such should be left to trained personel only. After that, the samples have been washed and sieved through 270# nylon mesh. Residues were dried in an oven. Well-preserved radiolarian specimens were taken and placed on a SEM plug and then coated with gold in a vacum evaporator for taking the photo and radiolarian identification.

1.3.3.2 Petrologic study

Thin sections of rock samples have been prepared for petrologic study under microscope. Petrology of sedimentary rock in this study is based on Selly's classification (1996).

Methodology

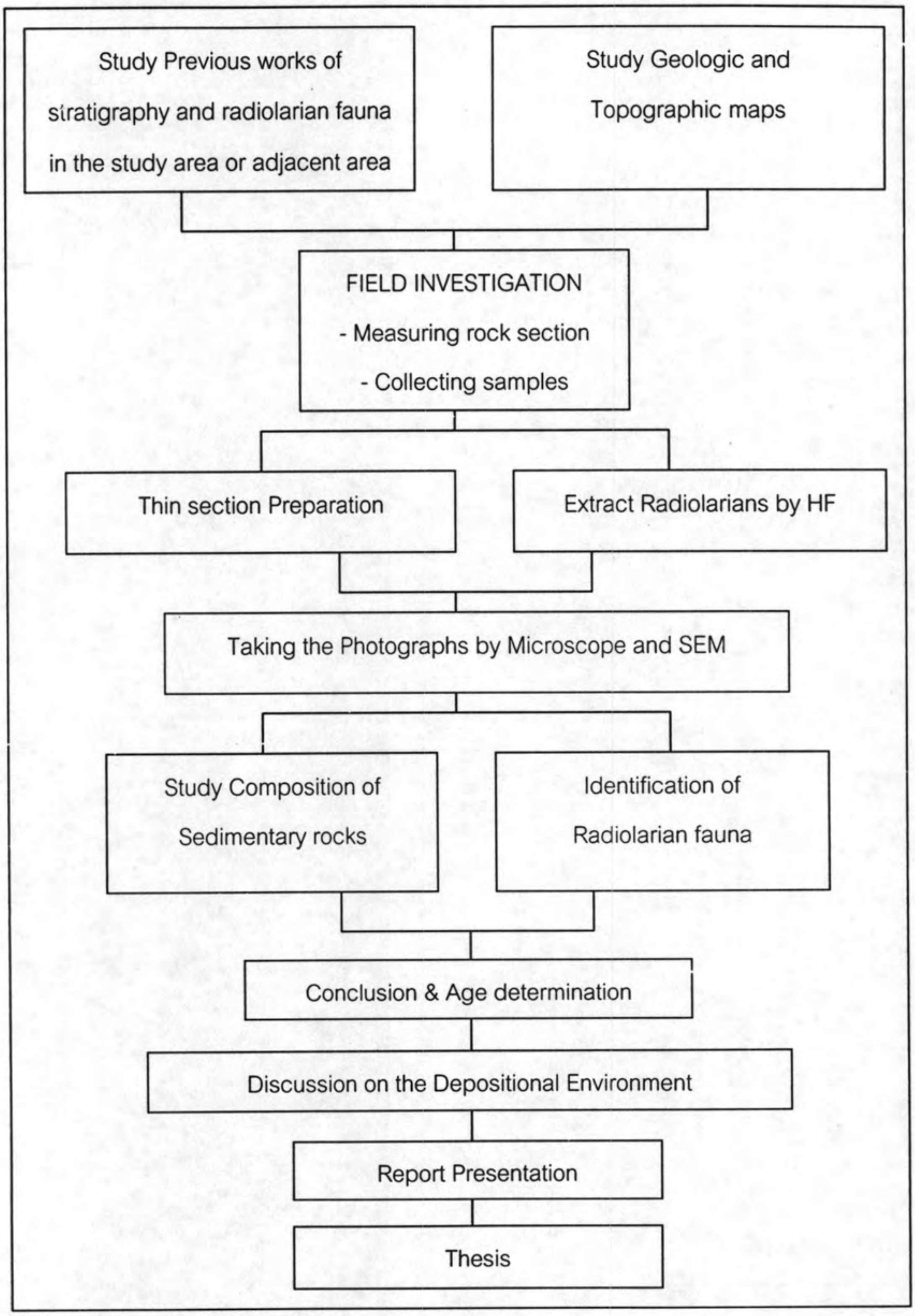


Figure 1.5 The summarized flow chart of methodology.

1.4 Previous investigations

A. Geology

Braun and Jordan (1976) proposed "Mae Moei Group" for the Mesozoic sedimentary sequence exposed in the Mae Moei and Mae Sot areas of western Thailand and sedimentary sequence consisting mainly of sandstones, shale and limestone with Triassic and Jurassic macrofossils on both east and west margins of the Mae Sot basin. The Mae Moei Group consists of two major units-the Lower and the Upper Units. The Triassic lower Mae Moei Group strats with basal redbeds overlain by a thick marine shale and sandstone sequence with limestone intercalations in the upper part. The bulk of the Kamawkala limestone belongs to this unit. Its uppermost portion is suspected to be Lower Jurassic. Two sections were stratigraphically studied, one a section through the Kamawkala ridge of the Mae Moei River (Kamawkala section) and the along the Asian Highway east of Mae Sot (Mae Sot section).

Bunopas (1981) first proposed the name Mae Sariang Group and the type section of the Mae Sariang Group is at the western part of the road between km 5 to km 10 from Mae Hong Son city to Mae Sariang District. The Mae Sariang Group consists of 50 m-thick conglomerate unit in the lower part, 700 m-thick interbedded gray shale/siltstone and sandstone, and 100 m-thick sandy shale. Parts of the shale contain chert and limestone bands with the bivalves *Daonella* and *Halobia* but the thickness and stratigraphic position of this calcareous sequence are not well defined.

Chonglakmani and Grant-Mackie (1993) studied biostratigraphy and facies variation of the marine Triassic sequences in Thailand. They are generally fossiliferous, ranging in age from Early to Late Triassic. The proposed biostratigraphic division based on stratigraphic sequences in the Lampang-Phare Basin comprises 12 faunal assemblages. They are the *Claraia-Ophiceras zone* (Late Griesbachian); *Hollandites-Leiophllites*, *Hollandites-Balatonites*, and *Costatoria* zones (Anisian); *Daonella indica* zone (Ladinian); *Parathrachyceras* zone (Early Carnian); *Halobia styriaca*, *H. charlyana*, *H. parallela*, and *Trigonodus* zones (Middle-Late Carnian); and the *Halobia distincta* and

Indopecten zone (Early Norian). The marine Triassic sediments can be classified into four distinct facies: the near-shore neritic, off-shore neritic, slope and basin, and deep marine facies. The first three are sediments deposited extensively from Late Griesbachian to Early Norian in the intracontinental basins, and the last one represents the true oceanic sediments of Carnian age distributed in the northwest region.

Tofke et al. (1993) studied the detailed Triassic sedimentary sequence of typical pre-orogenic and syn-orogenic strata in the region of Mae Sariang. They reported that the Triassic sedimentary sequence shows ture ribbon-chert which contains abundant radiolarian, true pelagic limestones, which contain radiolarian and thin-shell pelagic bivalves, and a thick turbidite sequence of siliciclastics, which contains *Posidonia* and *Halobia* intercalated shales. These fossils indicate Middle to Late Triassic age.

Sashida et al. (1999) summarized the sedimentary facies and fossil occurrence of the Triassic sediments in mainland Thailand and northwestern peninsular Malaysia. They clarified the sub-parallel arrangement of three rock units, from west to east: shallow to slope limestone, clastic, and chert sequences, which extend from the areas of Mae Sariang, Kanchanaburi, southern peninsular Thailand, and northwestern peninsular Malaysia during Middle Triassic time.

Chonglakmani (1999) proposed the Triassic sedimentary belt exposed in the Mae Sariang area as the Mae Sariang Group. It extends southward to Tak, Mae Sot, Kanchanaburi, and to Songkhla in peninsular Thailand where the sequence is known as the Na Thawi Formation. He considered that this belt is deep marine and oceanic facies.

Srinak (2002) studied stratigraphy of the marine Triassic rocks in the Mae Hong Son-Mae Sariang area in Northwestern Thailand which have long been known as Mae Sariang Group. He proposed the lithostratigraphy subdivided into 3 formations in ascending order: Kong Sum formation consisting of 2 lithofacies - the lower conglomerate and the lithic sandstone ; Pra Trumuang formation consisting mainly of 4 lithofacies - the dark gray mudstone and sandstone, the chert interbeded mudstone, the conglomerate interbedded sandstone, and the sandstone and shale, and Mae Leab formations predominantly consisting of the calcareous mudstone and sandstone, the siliceous shale interbedded mudstone, and the medium sandstone. The calcareous mudstone with abundant *Halobia* sp. was deposited during the Triassic. Based upon stratigraphic and paleontological points of view, the age of the Mae Sariang Group is assigned as Middle to Late Triassic. The overall lithology, stratigraphy, sedimentary structure, geometry and fossil assemblages reflect the deep-water submarine fan environment.

Meesook et al. (2002) studied Triassic strata in the Mae Saring area, Changwat Mae Hong Son. The strata is unconformably underlain and overlain by Paleozoic and Jurassic, respectively. It can be divided into 2 informal formations as upper and lower formations with total thickness of 220 meters, consisting of (from bottom to top) greenish red, thin-bedded (< 10 cm) cherts intercalated with thin-bedded claystones and partly with limestones. Besides, reddish brown to gray conglomerates, sandstones and mudstones are also present. The sedimentary characteristics show the Bouma sequence with graded beds, and fining upward sequence. Clasts of conglomerate and sandstone consist of chert, metamorphic rock, and granite. Based on the radiolarian and bivalves *Halobia comata*, *Posidonia*, *Halobia styriaca* Mojs, *Daonella* cf. *sumatrensis* Volz found in this sequence, they indicate Middle Triassic age.

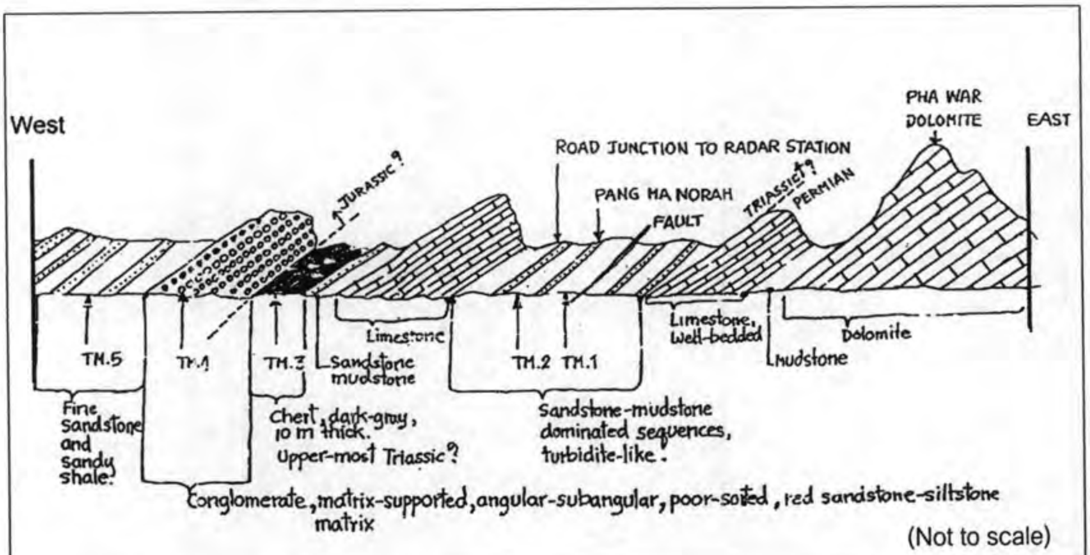


Figure 1.6 Sketching stratigraphy of the marine Triassic rocks exposed along the road highway no.105 from Pha War to Mae Sot, Tak Province, Northwestern Thailand (A. Meesook, personal communication).

B. Radiolarian fauna

Sashida et al. (1993) studied Paleozoic and Mesozoic radiolaria obtained from bedded chert and fine-grained clastic rocks of Thailand. This study has clarified details of the geologic ages of these radiolarian-bearing rocks from northeastern, northern and southern Thailand. Devonian, Early Carboniferous and Permian radiolarians were found in the "Fang Chert" which crops out along the Chiang Mai-Fang Road, upper north Thailand, Early Carboniferous radiolarians were recovered from a sequence of tuffaceous shale and chert exposed in the Pak Chom area along the Mekong River, and well-preserved Late Devonian and Early Carboniferous radiolarians were also recovered from cherts exposed along the Pak Chom-Loei Road in northeast Thailand. These Devonian to Carboniferous radiolarian faunas are apparently identical with those reported from eastern and western Australia. Well-preserved Early Triassic conodonts and radiolarians were obtained from a limestone exposed near Patthalung, southern Thailand. Most of the radiolarian species of this fauna show close affinity with those reported from the Upper Paleozoic rocks. Based on the micropaleontological evidence, the geotectonic significance of these radiolarian rocks are briefly discussed in relation to the paleography of the Palaeo-Tethys Ocean, Sibumasu and Indochina Terranes, and Australia during the Late Devonian to Middle Permian time.

Sashida and Igo (1999) studied radiolaria from bedded chert and fine-grained clastic rocks of Thailand and Peninsular Malaysia. The radiolarian faunas indicate Upper Devonian to Middle Triassic ages. This study has clarified details of the geologic ages of these radiolarian-bearing rocks and summarized the stratigraphic occurrences of radiolarian. The following 13 radiolarian assemblages are discriminated in these rocks; *Helenifure laticlavium*, *Entactinia variospina*, *Pseudoalbaillella bulbosa*, *Pseudoalbaillella elegans*, *Pseudoalbaillella lomentaria*, *Pseudoalbaillella scalpra-ta*, *Follicucullus monacanthus*, *Follicucullus scholasticus*, *Neoalbaillella optima*, *Neoalbaillella ornithoformis*, *Entactinia nikorai*, *Parentactinia nakatsugawaensis*, and *Eptingium manfredi* assemblages in stratigraphic order. Based on radiolarian studies and accumulated paleobiogeographical data, the timing of collision of Shan-Thai with East Malaya, and of Shan-Thai with Indochina are respectively assigned to the Early Triassic and Late Triassic.

Kamata et al. (2002) studied Triassic radiolarian fauna obtained from bedded chert sequence in the Mae Sariang area, northern Thailand. Based on the similarity of radiolarian fauna and petrographical characteristics, it is inferred that fine grained siliceous and calcareous sediments of the Mae Sariang Group are equivalent to those belonging to the eastern marginal facies of the Sibumasu Blocks. The occurrence of early (?) Carnian radiolarian assemblage from bedded chert shows that the closure of the Paleotethys Ocean between the Sibumasu and Indochina Blocks in northern Thailand occurred after the early Carnian.

Feng et al. (2005) studied well-preserved Permian and Triassic Radiolaria from 7 sections in the Mae Hong Son-Mae Sariang area, northwestern Thailand. Fifty-five species assigned to 34 genera have been identified. One new species (*Triassospongosphaera erici* Feng sp. nov.) and 19 unidentified species were reported. They belong to Late Permian, late Ladinian and middle Carnian radiolarian assemblages. Newly identified radiolarian assemblages, together with the published radiolarian biostratigraphic data from this region, indicate that there was a pelagic basin during the Late Paleozoic and Triassic.

1.5 Basic knowledges

1.5.1 Basic knowledge radiolarian fauna

Radiolaria are single-celled planktonic marine organisms. Formally they belong to the Phylum Protozoa, Class Actinopoda, and Subclass Radiolaria. Radiolarians are distingished from other protists by diversion of the cell contents into an inner zone separated by a membrane from the remaining outer zone. Characteristics of the membrane are in turn used to separate the major subgroups of radiolarians. Geologists are concerned almost exclusively with one major radiolarian group, the polycystina which form skeletons of pure opal and are therefore more resistant to dissolution in seawater and hence more commonly preserved in the fossil record. The polycystines divided into two suborders the radially symmetrical spumellarians and the helmet-shaped nassellarians. One other important group the tripyleans, are generally larger forms that are so common in the plankton but rarely preserved in sediments. The Acantharians, a group closely related to radiolarians, bear skeletons composed of celestite (strontium sulfate) which are never preserved in sediments. Heliozoans, a group of fresh-water protozoans with radial symmetry, resemble radiolarians but also do not produce a preservable skeleton (Brasier, 1980).

The living radiolarian

The single-cell radiolarians average between 100-2000 µm in diamenter, although cononial association up to 250 mm long is reported. The protoplasm of each cell is divided into an outer ectoplasm and an inner endoplasm, separated by a perforate organic membrane called the central capsule (Figure 1.7). Radiating outwards from this central capsule are the pseudopodia, either as thread-like filopodia or as axopodia, which have a central rod of fibers for rigidity. Near the centre of the dense endoplasm occurs a large nucleus or several nuclei. The ectoplasm typically contains a zone of frothy, gelatinous bubbles, collectively termed the calymma and a swarm of yellow symbiotic algae call zooxanthellae.

As far as is known, reproduction is entirely asexual, by division of the cell into two daughter cells, with either one daughter keeping the old skeleton or with both evacuating it and secreting new ones. In the Family Colloshaeridae (Spumellaria), the cells remain attached to form colonies. Individual radiolarians are though to live no longer than one month.

Radiolarians are marine zooplankton, using their sticky radiating axopodia to trap and paralyse passing organisms (e.g. phytoplankton and bacteria). Food particles are digested in vacuoles within the calymma and nutrients are passed through the perforate central capsule to the endoplasm. Those living in the photic zone may also contain zooxanthellae and can survive by symbiosis with these alone (Brasier, 1980).

The skeleton

Only a very few species of radiolarians lack hard parts. The radiolarian skeleton is encased in the soft cytoplasm. The bulk of the test usually lies in the ectoplasm, with pseudopodia extending outward to encase any protruding spines. Thus, the hard parts are never in direct contact with sea water, so that the skeleton of living organisms is never subject to dissolution in the aqueous environment. Innermost portions of the test may lie within the endoplasm in the central capsule.

Skeletons of the major fossil radiolarian group, the polycystines, are composed exclusively of amorphous silica (SiO_2. nH_2O). In living and well-preserved fossil material the siliceous substance is clear, transparent and isotropic with a glassy appearance in transmitted light. Internal structures of well-preserved material can be observed by focusing at various levels while viewing though the outer layers.

The skeleton is typically constructed of a network of siliceous elements, of which there are two fundamental types. Elongate elements connected at both ends to other elements are known as bar, whereas elongate element attached at one end only are spines. There are groups of polycystines whose skeleton consists solely of a simple association of spines known as a spicule. The majority of species though, have a more complex skeleton in which a definite enclosing wall can be recognized (Figure. 1.8 and 1.9).

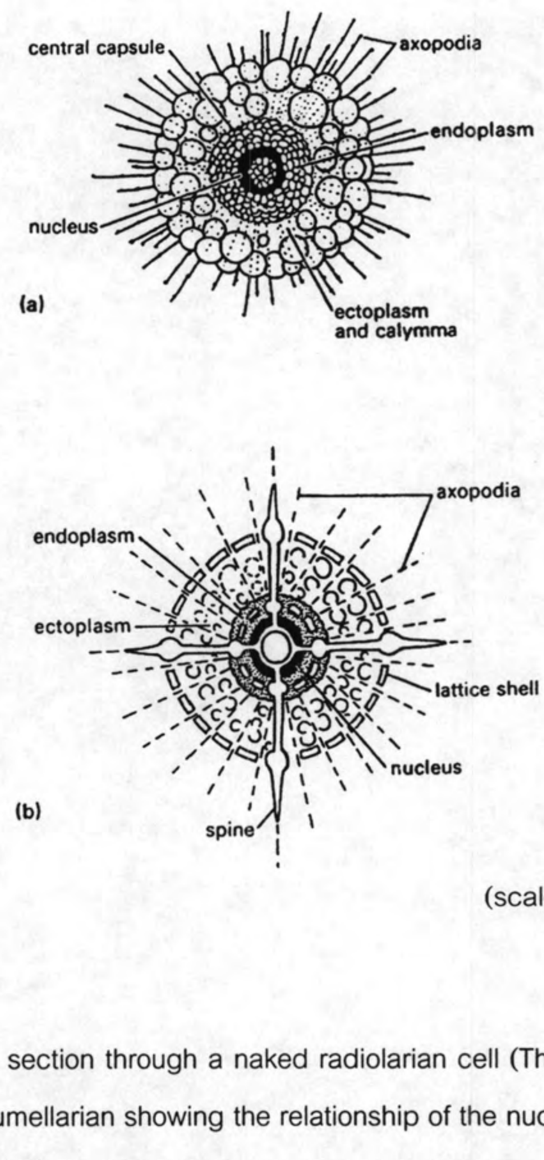
Wall structure

The basic kinds of radiolarian wall structure are also illustrated in Figure. 1.10. The latticed wall consists of a network of bars forming closely spaced pores. The basic shape of the pores is usually hexagonal but deposition of silica inside pores produces rounded outlines. Shapes of pores and their distribution are generally consistent in a species and can often be used for taxonomic purposes. The spongy wall is an intricate interlacing of relatively thin bars in a thick, usually irrgular, and three dimensional networks. Clearly defined pore patterns cannot be reconized. A third wall structure, the perforate plate wall, is a solid, unifomly thin wall penetrated by pores that are relatively widely spaced.

Skeletal shapes

The two major polycytine groups, the Nassellaria and the Spumellaria, are charecterized by different skeletal shapes. Spheres are the commonest shape among spumellarians and radial spines usually extend from the surfaces of the spheres. A skeleton often consists of two or more nested spheres, which are, with very few exceptions concentric and are connected by radial bars. The main, external shell is referred to as a cortical shell and the inner ones as medullary shells. Although the innermost spherical shell may be extremetry small, it is characteristic of radiolarians that radial elements never actually meet at the center. Paleozoic spumellians typically bear an internal spicule of converging radial bars, and similar structures are present in some living forms but these structures also are characteristically excentric. Other spumellarian shells are ellipsoidal (one axis elongated) discoidal (one axis shortened) coiled, or based on a series of concentric bands. These, too may display multiple concentric shells and radial spines.

Nassellarians are characterized by axial symmetry although various modifications of this fundamental pattern can be seen in the multitude of individual forms. The walls of nassellarian tests are usually latticed although spongy structure appears in some species and in some forms the wall is a perforate plate.



(scale unknown)

Figure 1.7 (a) Cross section through a naked radiolarian cell (Thalassicola); (b) cross section through a spumellarian showing the relationship of the nucleus, endoplasm and ectoplasm to three concentric lattice shells and radial spines (after Brasier,1980).

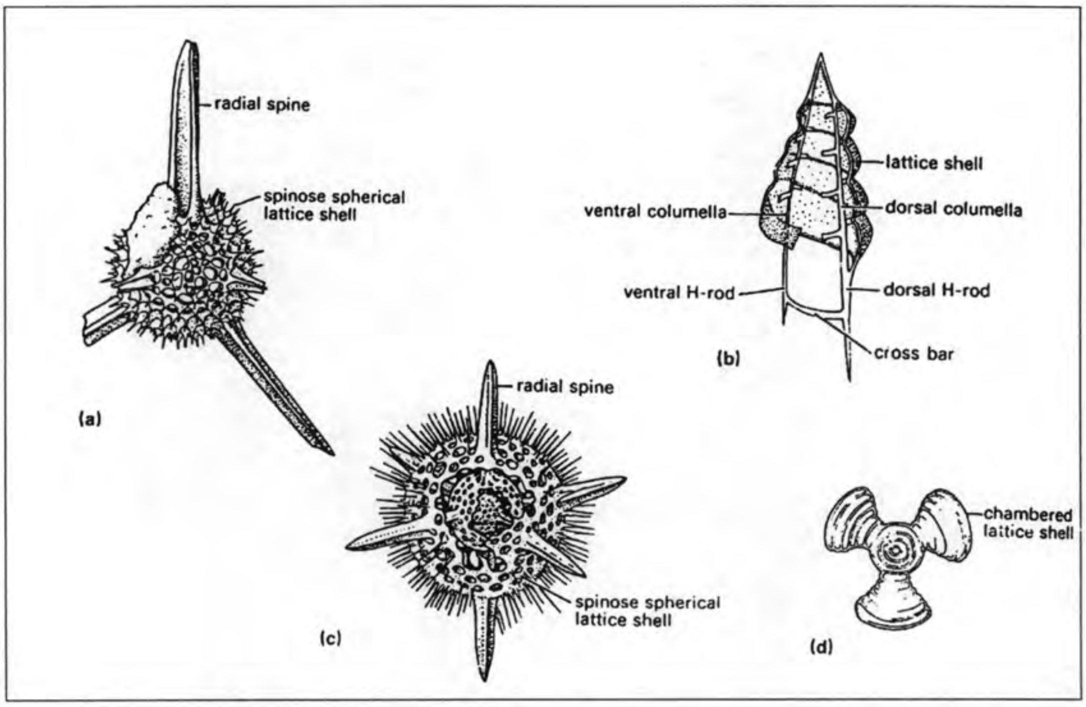


Figure 1.8 Polycytine Radiolaria. (a) *Entiactinosphaera* x 195; (b) *Albaillella* (scale unknown); (c) *Actinomma* (scale unknown); (d) *Dictyastrum* x 66 (after Brasier, 1980).

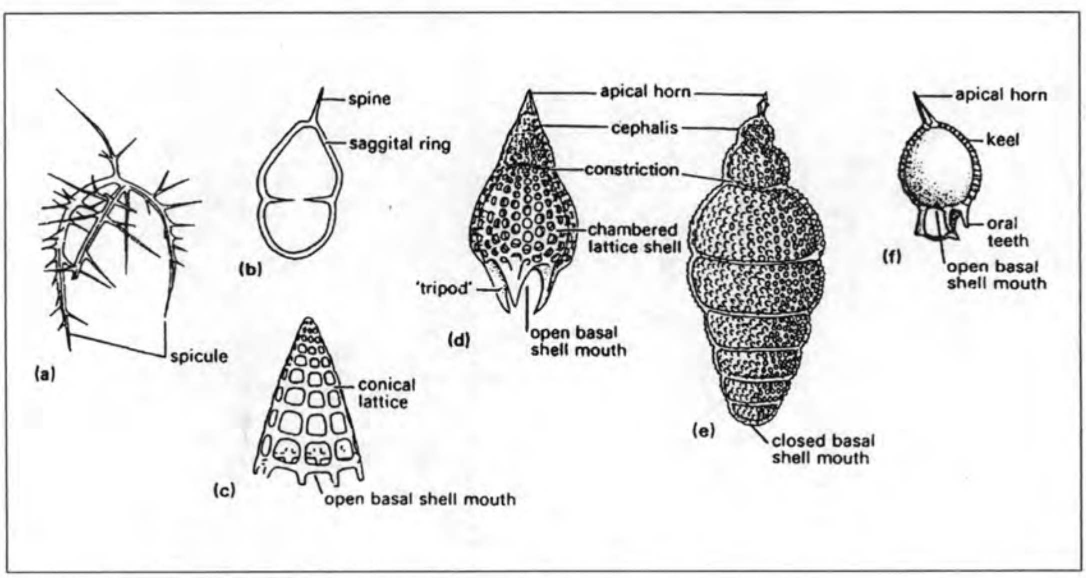


Figure 1.9 Nasellarian and phaeodarian Radiolaria. (a) *Campylacantha* x 200; (b) *Acanthocirus* x40; (c) *Bathropyramis* x 133; (d) *Podocyrtis* x 100; (e) *Cyrtocapsa* x 200; (f) *Challengerianum* x 187 (after Brasier, 1980).

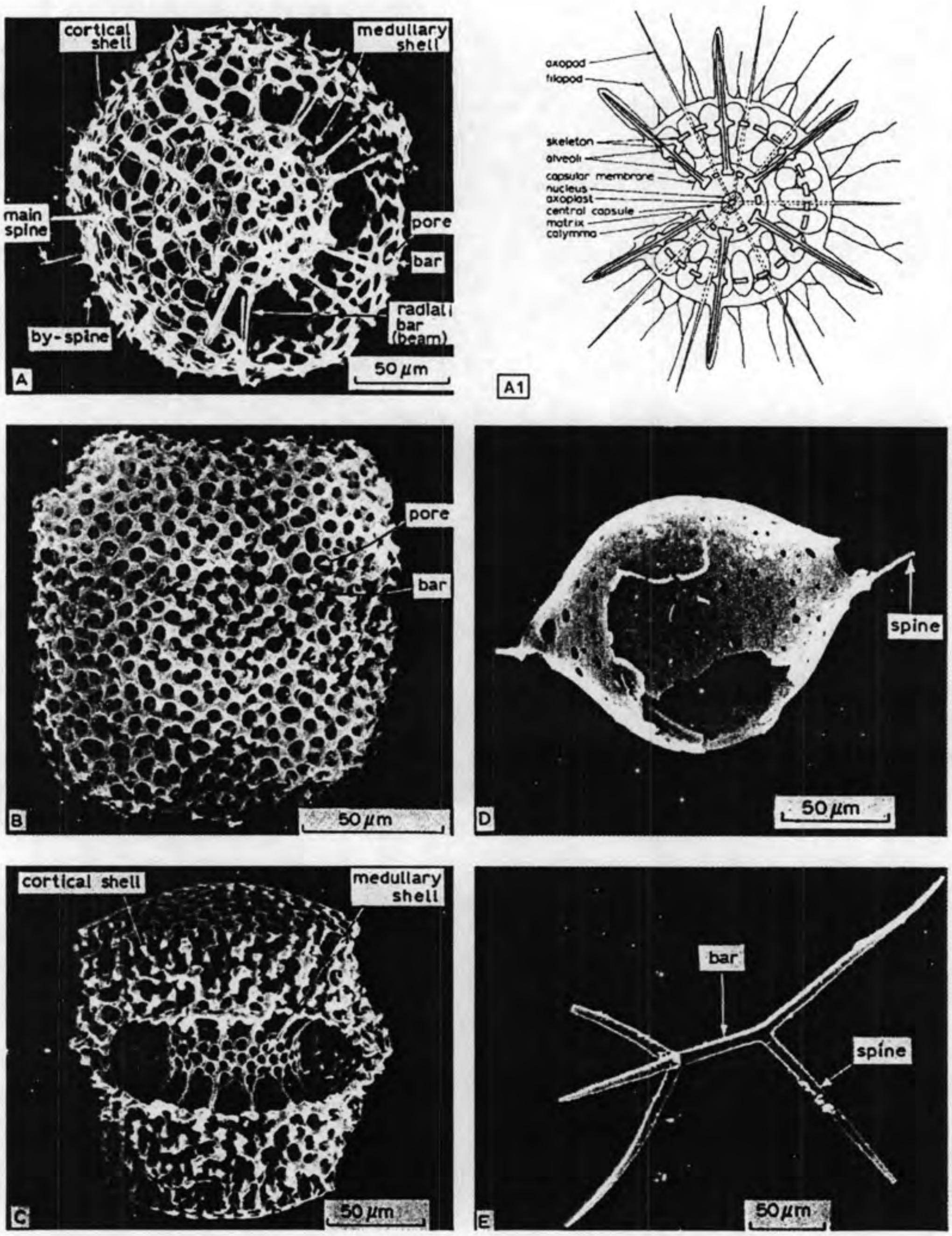


Figure 1.10 Terminology of basis radiolarian skeletal element of wall type. A. latticed wall. B. Spongy wall. C. Spong shell with latticed medullary shell. D. Perforate plate wall. E. Spicule. A1.Diagram of major features of radiolarian soft anatomy (after Kling, 1980).

Ecology

Radiolarians are charactertically open ocean organisms and distinctive coastal forms are not generally recognized. They apparently live all depths in the oceans and are restricted to discrete depth zones as indicated by changing species. The bulk of species and individuals are found in the upper few hundred meters with a rapid decline in abundance in deeper waters, although deep opening-and-closing net tows do contain specimens with soft part, showing that they actually can live at great depths. (Kling, 1980).

Different species may occur in assemblages at distinct water depths, each approximately corresponding to discrete water masses with certain physical and chemical characteristics. Assemblage boundaries at 50, 200, 400, 1000, and 4000 m are reported, with Acantharia and Spumellaria generally dominating the photic zone (‹ 200 m) and Nassellaria and Phaeodaria dominating depth below 2000 m. understandably, these Phaeodaria lack symbiotic algae. Some radiolarian species have very great depth ranges, though, with juveniles and small adults thriving at the shallower end of the range and the larger adults living in the deeper waters (Brasier, 1980).

1.5.2 Basic knowledge on turbidite features

Immediately after introduction of the turbidity current concept in 1950, studies emphasized a vast array of new sedimentary structures and their use in determining paleoflow directions. In the absence of a turbidite facies model, there was no norm with which to compare new examples, no framework for organizing observation, no logical basis for prediction, and no unified basis for hydrodynamic interpretation. As a result of continued work during the 1950's, a small but consistent set of feature began to be associated with beds here termed classical turbidites (Figure. 1.11):

1) Sandstones and shales are monotonously interbedded through tens or hundreds of metres of section.

2) Beds tend to have sharp, flat bases, with no indicatations of erosion of the seafloor on a scale exceeding a few tens of centimeters

3) The shape bases (soles) of the beds have abundant markings, now classified into three types; tool mark, which are carved into the underlying mud by rigid objects (strick, stones, shells); scour mark, which are cut into the underlying mud by fluid scour; and organic marks, which represent trails and burrows made by organisms and filled in by the turbidity current. Tool and scour marks give accurate indications of local flow directions.

4) Within the sandstone beds the grain sized commonly decreases upward (graded bedding); the basal division A of the bed is commonly structureless, and grades up into a sandy, pararallel-laminated division B—this in turn grades into a current-rippled division C. Both divisions B and C can also contain convolute lamination. The rippled division C is overlain by parallel-laminated silt and mud (division D)—this division is difficult to see in weathered and/or tectonized outcrops. The uppermost division E is pelitic, and mostly deposited by the turbidity current. Only the uppermost part of the pelitic division represents the slow accumulation of mud deposited directly from the ocean after the passage of the turbidity current (hemipelagic deposition). This grouping of sedimentary structures and lithologies was first published by Bouma (1962), and is now known as the "Bouma sequence" (Walker and James, 1992).

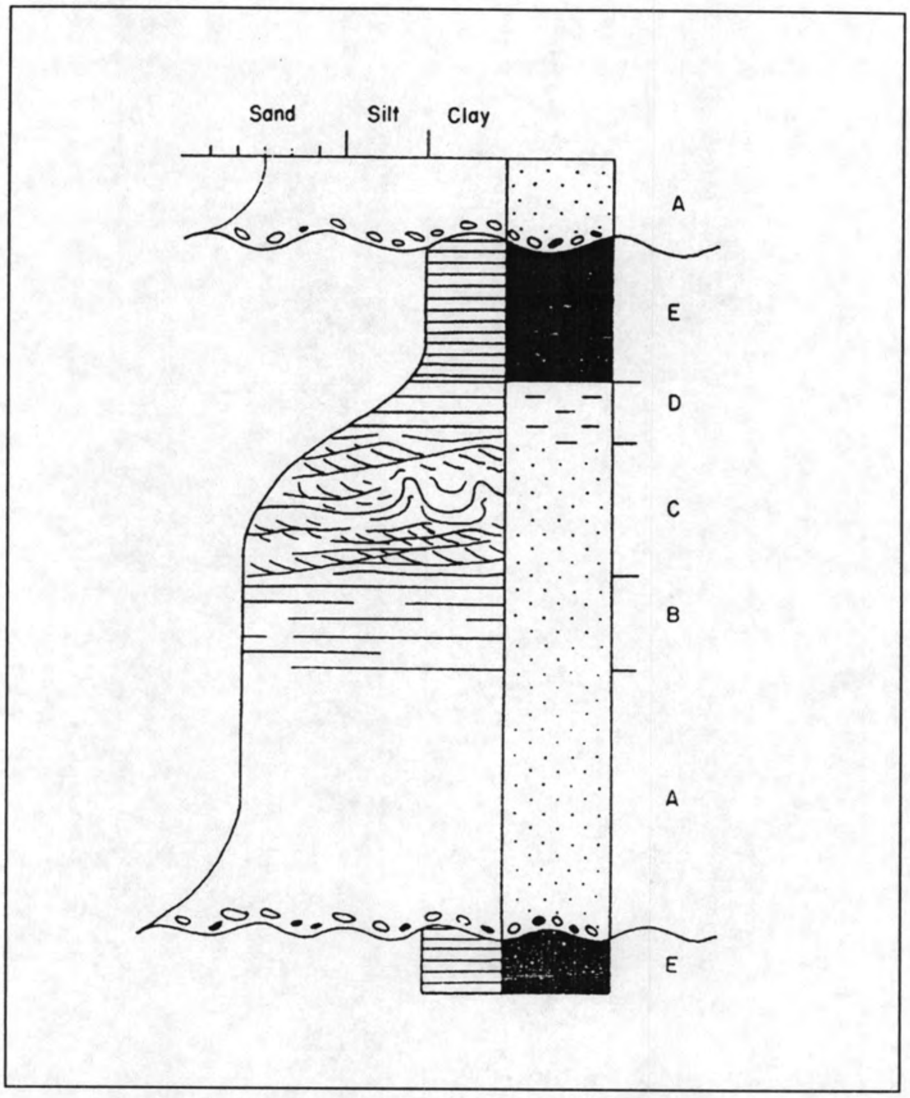


Figure 1.11 Generalized sequences through a turbidite unit (after Selly, 1996).