CHAPTER IV

PETROGRAPHY

The following discussion is focussing upon detailed petrographic study of representative rock samples collected from numerous measured rock sections under the present investigation. The petrographic work is almost exclusively undertaken for carbonate rocks on three important aspects, notably, the mineralogical composition; texture; and characteristics of allochems, matrix as well as cement. The mineralogical composition is carried out using both the X-ray diffractrometry (XRD) investigations and thin-section, whereas the exmination of texture and characteristics of allochems, matrix, and cement are carried out by thin-section methods.

Mineral Composition

Totally forty-one carbonate rock samples have been analysed using the XRD technique for the determination of mainly calcite, dolomite, and quartz, etc. Additional attempt has been made to determine the calcite and dolomite ratio by measuring the intensity of strongest peaks (Tennant and Berger, 1957). This method is most useful for the application of the compositional terminology of carbonate rock by Leighton and Pendexter (1962) or Pettijohn (1962) to the carbonate rocks under the present study.

Carbonate minerals

Calcite

The calcite is present in almost all carbonate rocks under this study. However, the content of calcite varies greatly in the carbonate sequences. This mineral occurs in several forms, namely, allochems, micrite (microcrystalline matrix), and cement.

Petrographically, microcrystalline calcite (micrite), sparry calcite, skeletal and non-skeletal calcite varieties are recognized. The microcrystalline calcite (<4 microns) with or without sparry calcite is almost entirely present in the intergranular pore spaces. The microcrystalline calcite is mainly formed by the mechanical break-down of both skeletal and non-skeletal grains, or direct precipitation from sea water, and also the micrite envelope of allochems by diagenetic alteration. The sparry calcite is most abundant as cementing material, and as calcite veinlets of fracture-filling origin which are most apparent, particularly in the Ban Nong Hin and the Tham Suae Mop Members. Besides, the calcite is most abundant in the allochems of both skeletal and non-skeletal origins. The microstructure of the allochems is most useful in the identification of types of allochems and their origins.

Dolomite

The Nam Maholan Formation in the study area has been extensively dolomitized, particularly in the Phu Pha Khao and the Ban Nong Hin Members, as revealed by the XRD analysis. Based on staining of thin-sections and rock-slab samples, the dolomite can be easily recognized and differentiated from calcite.

Petrographically, the two characteristics of dolomite are recognized based solely on crystal sizes. They are finer-and coarser-grained crystalline textures of anhedral and/or euhedral dolomite crystals (Figs. 4.1 to 4.4). Both finer-and coarser-grained dolomites are believed to be of replacement after calcite in origin.

The finer-grained dolomite commonly demonstrates a pervasive replacement with xenomorphic and equigranular fabrics. The strongly dolomitized carbonate rocks usually exhibit the mosaic texture (Figs. 4.1, 4.2). The outlines of original skeletal grains of allochem are recognized as dark track relics, or "ghost structure" (Fig. 4.2), possibly indicating the replacement of dolomite after original calcite.

The coarser-grained dolomite shows rhom-shaped, subhedral to euhedral crystals exhibiting idiomorphic and inequigranular fabrics of poikilotopic texture (Fig. 4.3). The poikilotopic texture is generally implied finer dolomite crystals embedded in coarser crystals of dolomite. The finer dolomite crystals were formed first, and coarser dolomite crystals were formed later on. This texture also involves two different Mg-rich fluids forming dolomite at different intervals of time.

Non-carbonate minerals

The XRD results and thin-section observation reveal that the non-carbonate components are detrital quartz (Fig. 4.4) and chert. However, the dark tracks of carbonaceous matter are probably derived from algal decay. In addition, the terrigenous clay is sometimes present as impurities in the carbonate rocks.

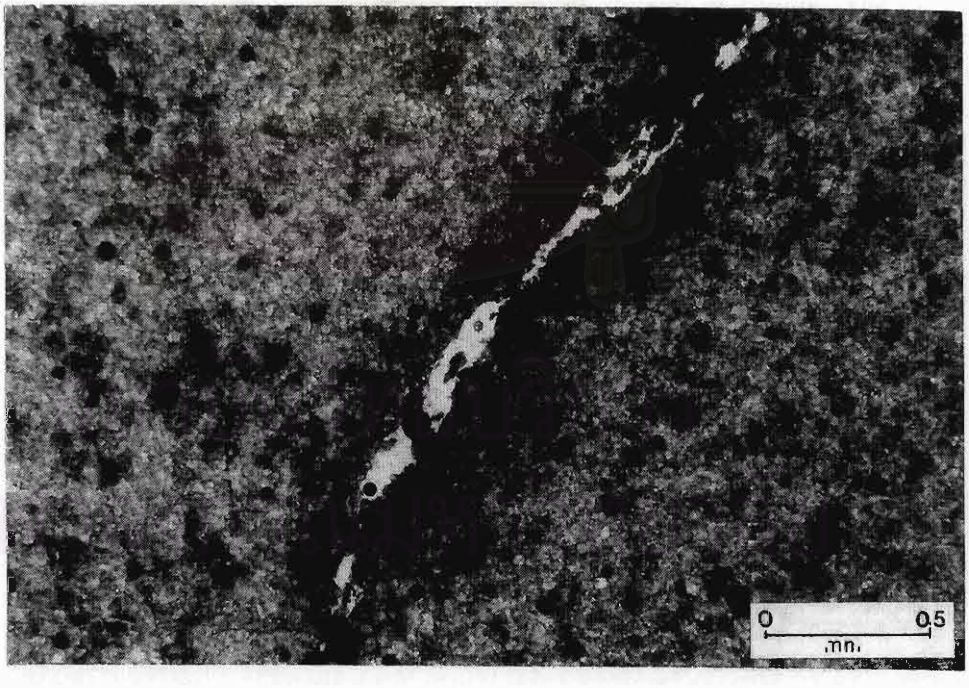

Fig. 4.1 Photomicrograph of finer crystalline dolomite illustrating pervasive replacementof xenomorphic equigranular fabric. Light colour indicates chert infilled cavity during late diagenesis (sample no. 48). The XRD reveals entirely dolomite. The chemical composition contains MgO 18. 34 wt %.

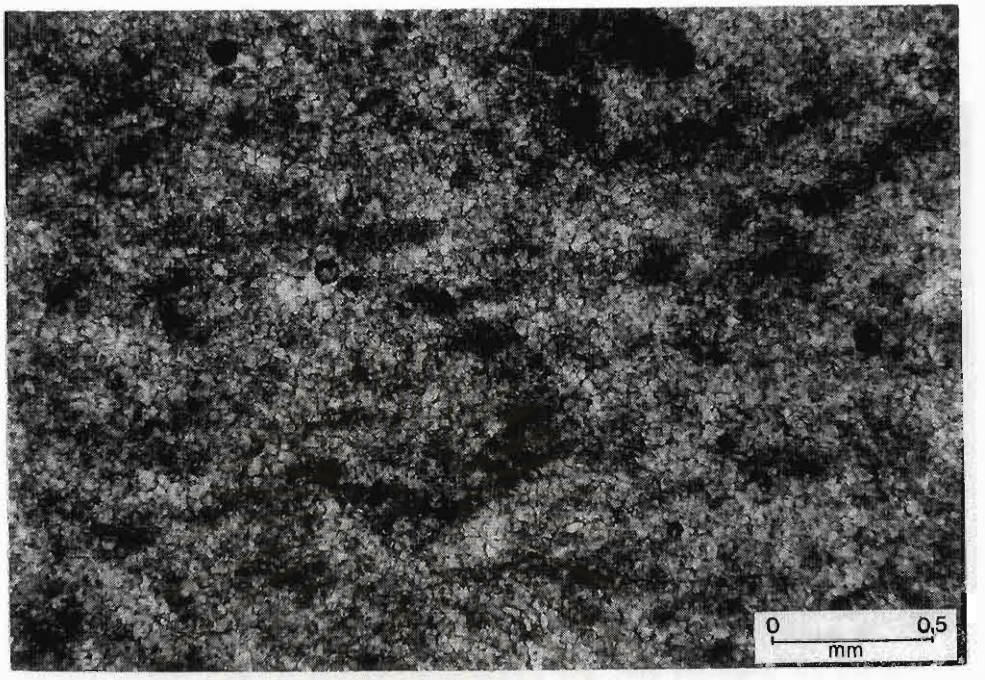

Fig. 4.2 Photomicrograph of a replacement finer-grained dolomite showing compromise boundary of xenomorphic equigranular fabric. Dark tracks are probably organic matter originally outlined the structure of brachiopod shell. The XRD reveals mainly dolomite with small amount of calcite. The chemical composition indicates MgO contents is 19. 9 wt %. (sample no. 54).

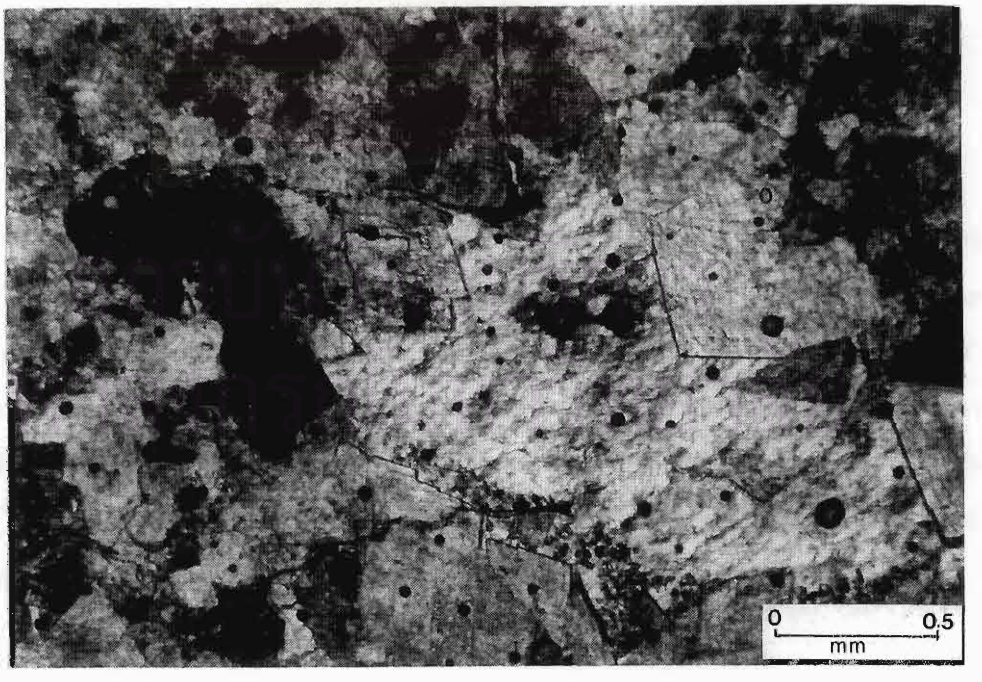

Fig. 4.3 Photomicrograph of dolomite showing rhomb-shaped subhedral to euhedral crystals with poikilotopic texture indicating two generations of dolomites (sample no. 46).

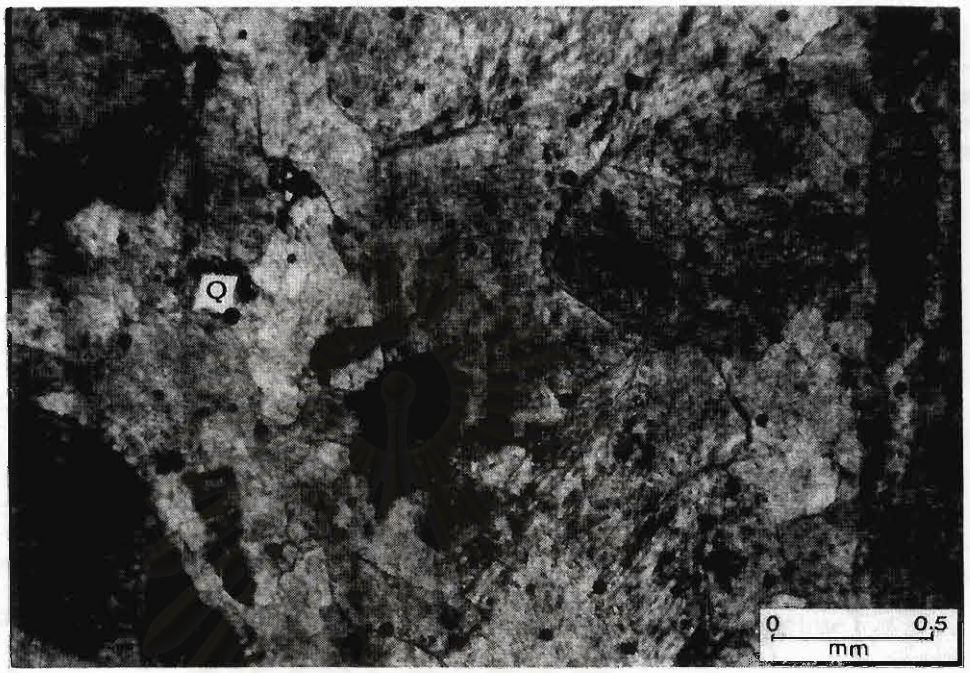

Fig. 4.4 Photomicrograph of crystalline limestone illustrating coarse calcite crystals with crystalline calcite matrix and quartz (Q). (sample no. 18). Outcrop is illustrated in Fig.3. 25. XRD result reveals entirely calcite with small amount quartz. Geochemically, the rock contains 53.07 wt % CaO.

Selective microfacies recognition and interpretation

Thin-section observtion are served as the basis for describing carbonate texture, and identifying allochemical constituents. The facies are defined on the bases of lithology, allochemical constituents, texture, and fossil associations in order to reconstruct their depositional environments. The carbonate facies are named following the carbonate rock classification either developed by Folk (1959, 1962) or Dunham (1962) and also Embry and Klovan (1971). Additionally, the fabric characteristics are complementary. These selective microfacies are summarized in Table 4.1.

Table 4.1 Summary the microfacies types identified in the study area.

Microfacies	Lithological characteristic	Deg	Depostional environments
I Oosparu dite	Normal, superficial, and compound ooids, pisolite, algae, sparry cement, dasycladaceans, foraminifers	R	Intertidal to subtidal, tropical near shore.
II Algal lamination	Very thin-laminae, algal decayed, detrital quart grains	R	Shallow subtidal.
III Pelmicrite	Decret peloids, fine fossil fragments	R	Subtidal zone of inner shelf, low-water energy.
IV Sparse biomicrite	Poorly sorted, floating grain, micrite matrix	R	Subtidal and/or subwave base of the shelf sea close to the shore
V Packed biomicrite	In-situ deposition of unfragment fossils, micrite matrix, fragmental fossils, intraclasts, cabonaceous matter	A	Subtidal zone below the active wave base.
VI Biosparite	Intraclasts, fragmentals and unfragment fossils, lumped pellets, poorly to moderately sorted	C	Intertidal to near shore subtidal above the wave base
VII Crystalline	Calcite and fine to coarse grain pervasive dolomite	R	-No interpretation

A= abundant, C= common, R= rare Deg=degree of abundant

Microfacies I Oosparudite

Oolite and pisolite are confined in thick- to very thick- bedded limestone in the lower part of the Phu Pha Khao Member at the Tham Sue Mop area. The oolites and larger ooids or pisolites characteristics can be observed either microscopically or megascopically (Fig. 4.5).

The oosparudite (Folk, 1959; 1962) is recognized corresponding to consists allochem of over twenty-five per cent ooids with size range from 2 to 4 millimetres embedded in sparite cement. This is equivalent to oolithicpack/grainstone (Dunham, 1962) according to contains more than ten per cent of ooid grains, mud-free, and grain-supported. The rudstone (Embry and Klovan, 1971) is also recognized for the microfacies due to includes more than ten per cent of grains that larger than 2 millimetres and self supported.

Petrographically, allochems exhibit discret grains of abundant normal ooids (Figs. 4.6 to 4.8) and superficial ooids (Fugel, 1982) of which are moderately well sorted and occasionally distorted. Pseudo-ooids (Fig. 4.9) are observed by their cortex contains less than two cocentric rings (Rao, 1997). Micrite ooids (Flugel, 1982) is occasionally present. In addition, algal-coated composite grains of different components or origins are also present (Fig. 4.10). It is noted that, the different morphology of oncoinds or algal-coated grain are influenced by the type and shape of the nuclei or core materials. Besides, the other surface of numerous oncoids or algal-coated grains show various features of alteration from diagenetic process to mechanical break down due to compaction. Algae, fusulinaceans, smaller forraminifers, curved shells and peloids are generally served as nuclei of ooids and oncoids. Fusulinacean *Pseudofusulina* sp., smaller foraminifers *Tetrataxis* sp., *Schubertalla* sp., indicating Sakmarian-Yahtashian age (Early Permian), are identified.

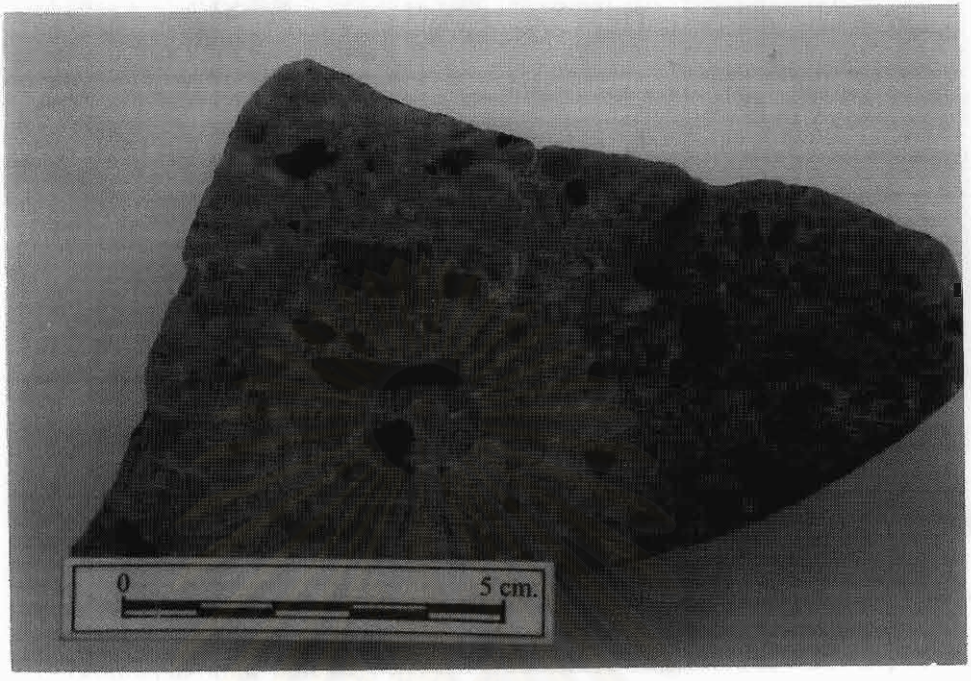

Fig. 4.5 Polished slab illustrating oosparudite microfacies consisting of discrete fusulinaceans (light) and algal clasts (dark) in sparry calcite cement at the Tham Suae Mop area (sample no.7, section-1).

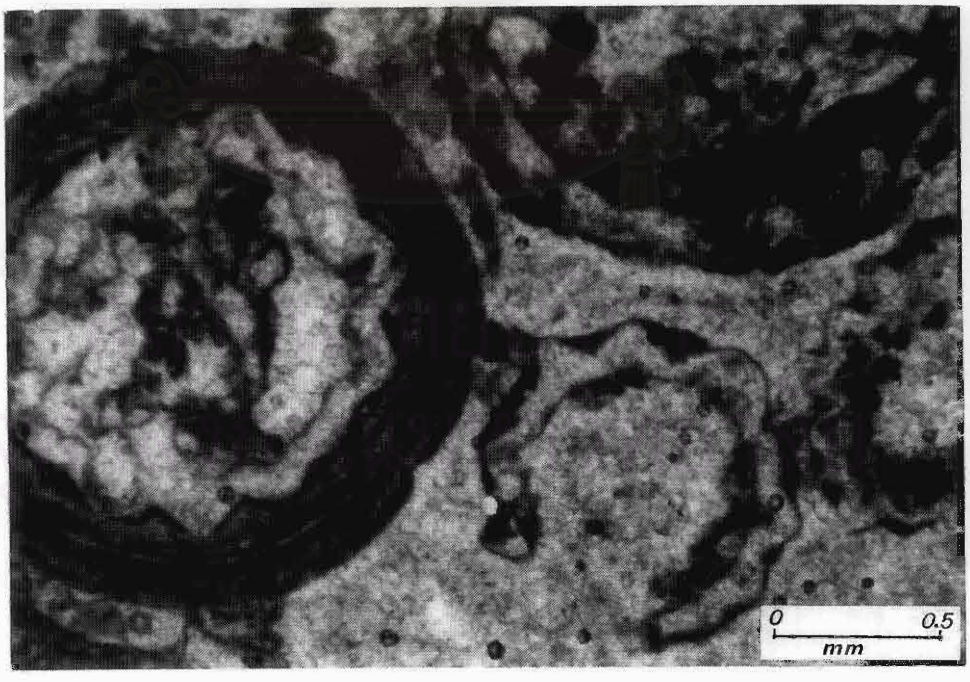

Fig. 4.6 Photomicrograph, single spherical ooids with dasycladacean algae nuclei.

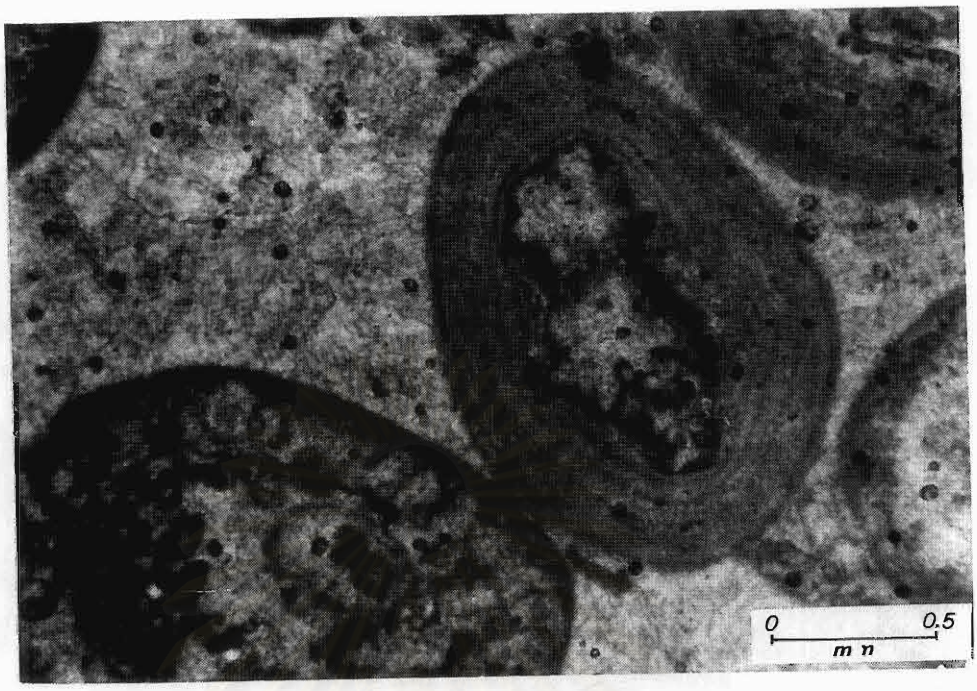

Fig. 4.7 Photomicrograph, normal ooids, the cocentric structures are developed around algal clasts. Fibrous rim cement, blocky or granular cement, and intergranular sparry cement are illustrated.

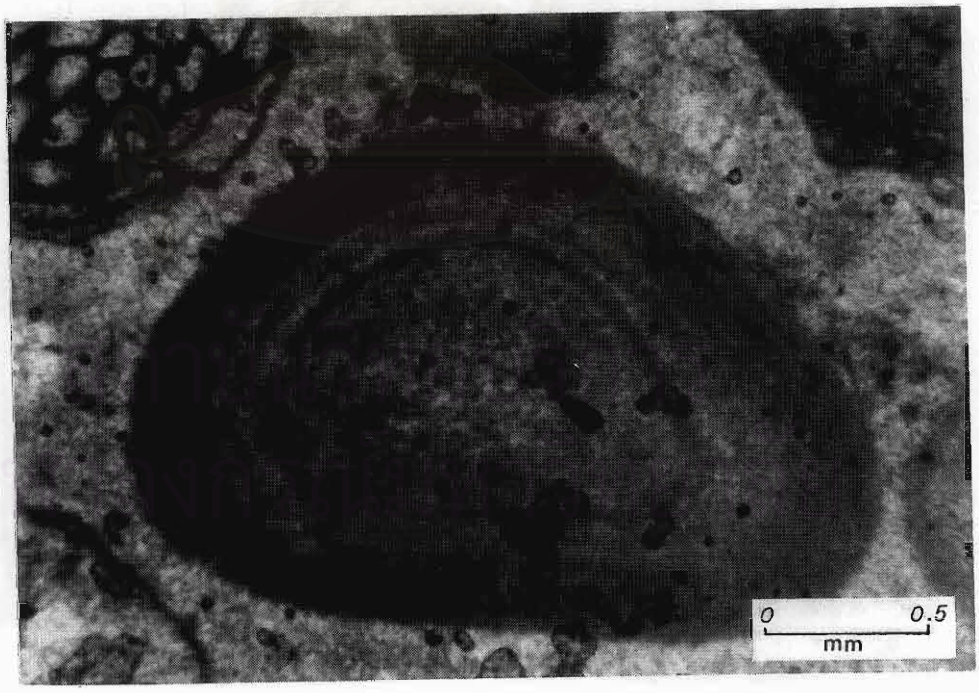

Fig. 4.8 Photomicrograph, single micrite ooids of normal type illustrating smooth concentric laminae, asymmetric subspheroidal shape.

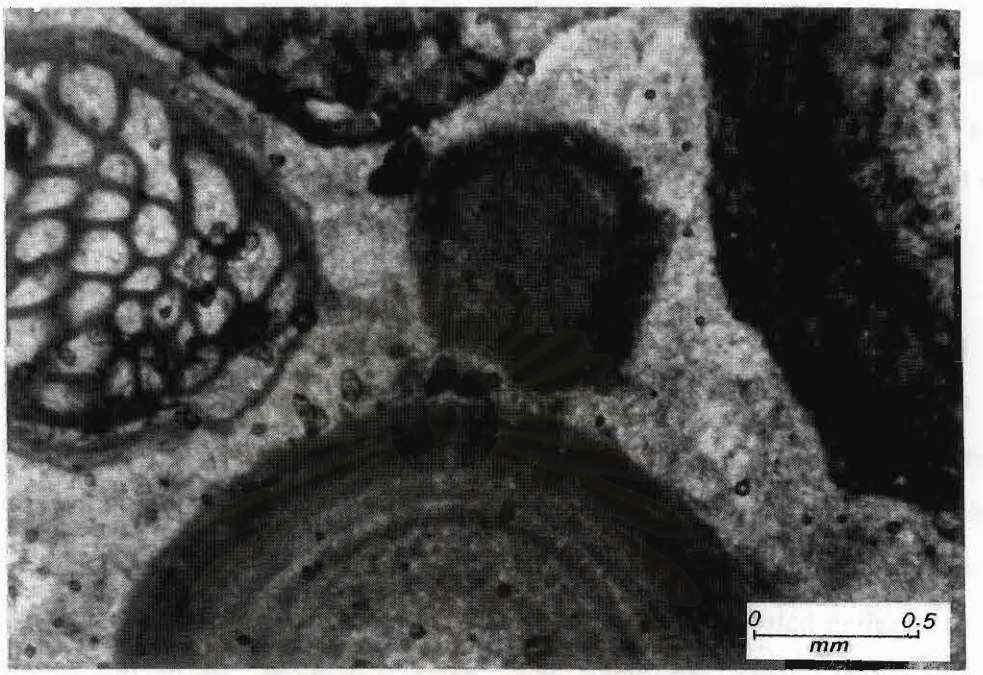

Fig. 4.9 Photomicrograph illustrated peloid ooid and micrite ring. Fusulinacean and dacyclade are coated by algae and/or bacteria.

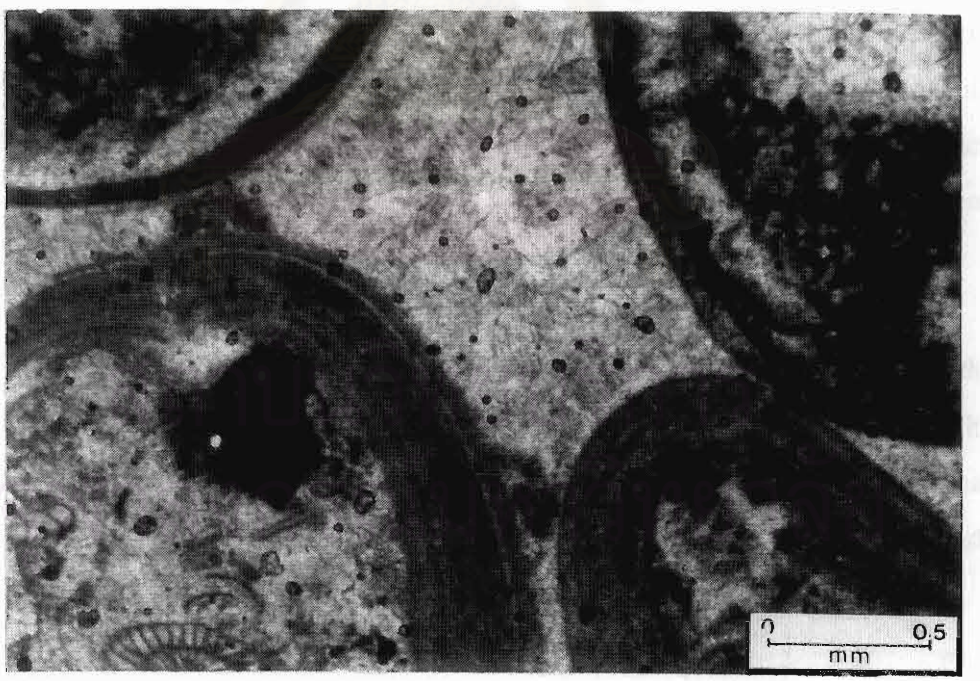

Fig. 4.10 Photomicrograph illustrates algal-coated composite grains or lumped particle serves as core of oncoids. The crack of concentric structure is originated from mechanical stress due to compaction.

At least three generations of calcareous cement are recognized on the basis of crystal morphology. The first generation is the fibrous rim cement developed from the surface of allochems. The second generation is blocky or granular cement overgrowth on the fibrous rim cement. The third generation is sparry cement infilled the rest of the intergranular pore space (Figs. 4.10 to 4.12).

The detailed petrographic study of the so-called the Microfacies I of approximately 1 metre-thick lying 90 metres above the base of the Phu Pha Khao Member has been undertaken in order to serve as a key bed for the reconstruction of depositional environment (Fig. 4.13). The lithology of this microfacies is characterized as oosparite, oosparudite, and biosparite. The allochemical components are algal fragments, fusulinaceans, oncoids, ooids, and algal-coated grains. It is noted that almost all of the skeletal fragments and composite grains exhibit the algal accretionary characteristics.

Underlying the Microfacies I is the biosparite to poorly washed biosparite of approximately 50 metre-thick. The skeletal fragments are mainly echinoderm plates, fusulinaceans, smaller foraminifers with some intraclasts. Overlying the Microfacies I is mainly biomicrite of approximately over 250 metres. The allochemical characteristics are similar to those of underlying the Microfacies I.

Upon comparison of the allochemical components of the microfacies with the carbonate depositional model of Reeckmann and Friedman (1982), it is concluded that the depositional environment of the Microfacies I of the Nam Maholan Formation lies in the zone of intertidal to subtidal zones (Fig. 4. 14) of the tropical near-shore of the open shelf sea.

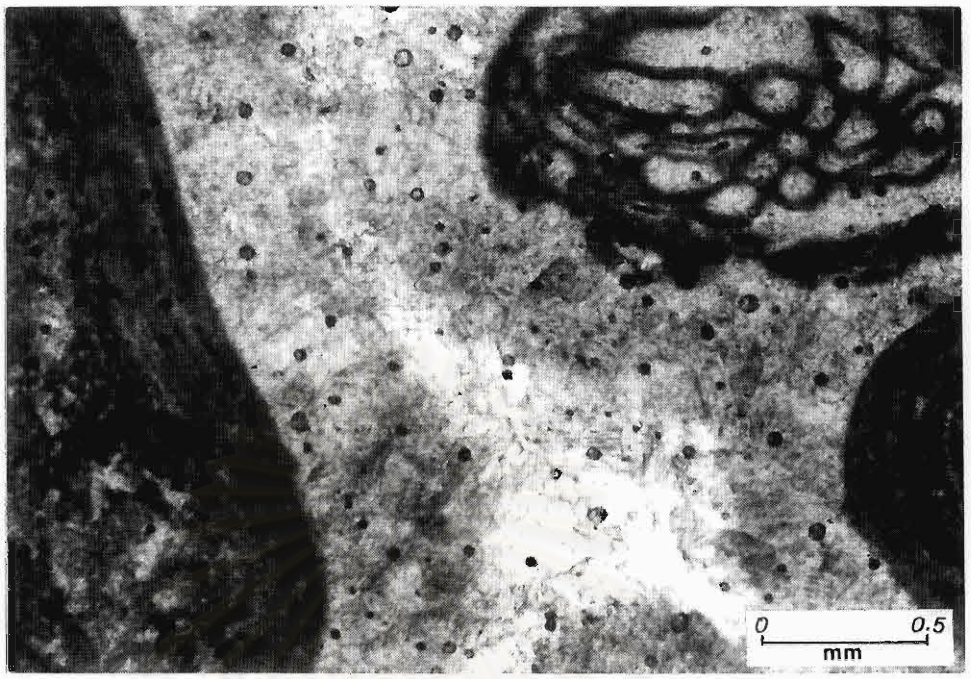

Fig. 4.11 Photomicrograph illustrates three cementing generations, early fibrous rim cement develope around grains and later blocky or granular cement. Sparry cement infilled intergranular voice space. The fusulinacean grain surface is partially dissolved during diagenesis.

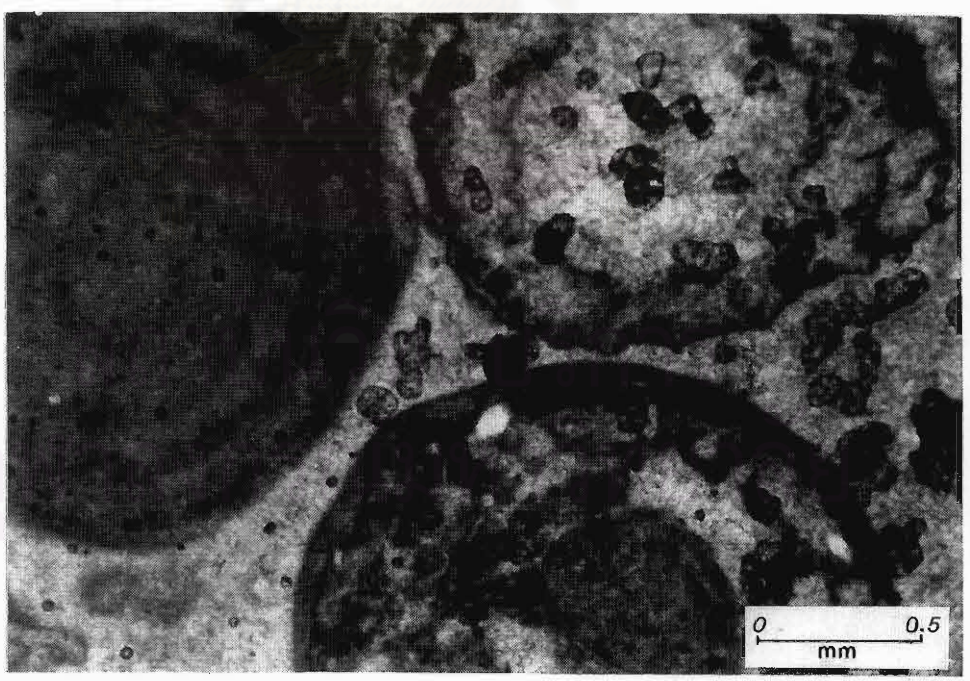

Fig. 4.12 Photomicrograph of micrite ooids showing characteristic of dark cryptocrystalline concentric layers of organic mucilase and granular calcite layers.

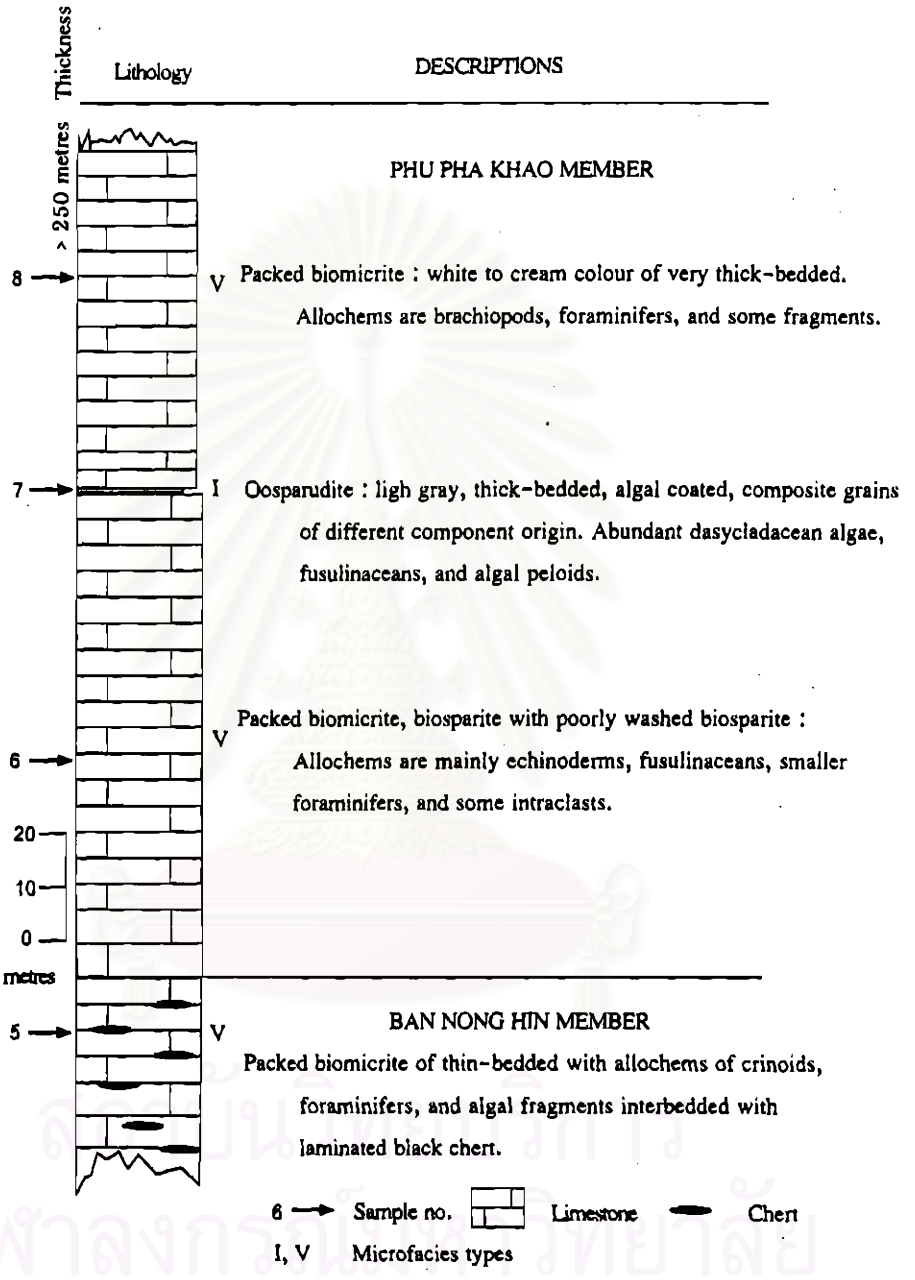

Fig. 4.13 Lithostratigraphic sequence illustrating the presence of the Microfacies I in the Phu Pha Khao Member at Tham Suae Mop area (section-11).

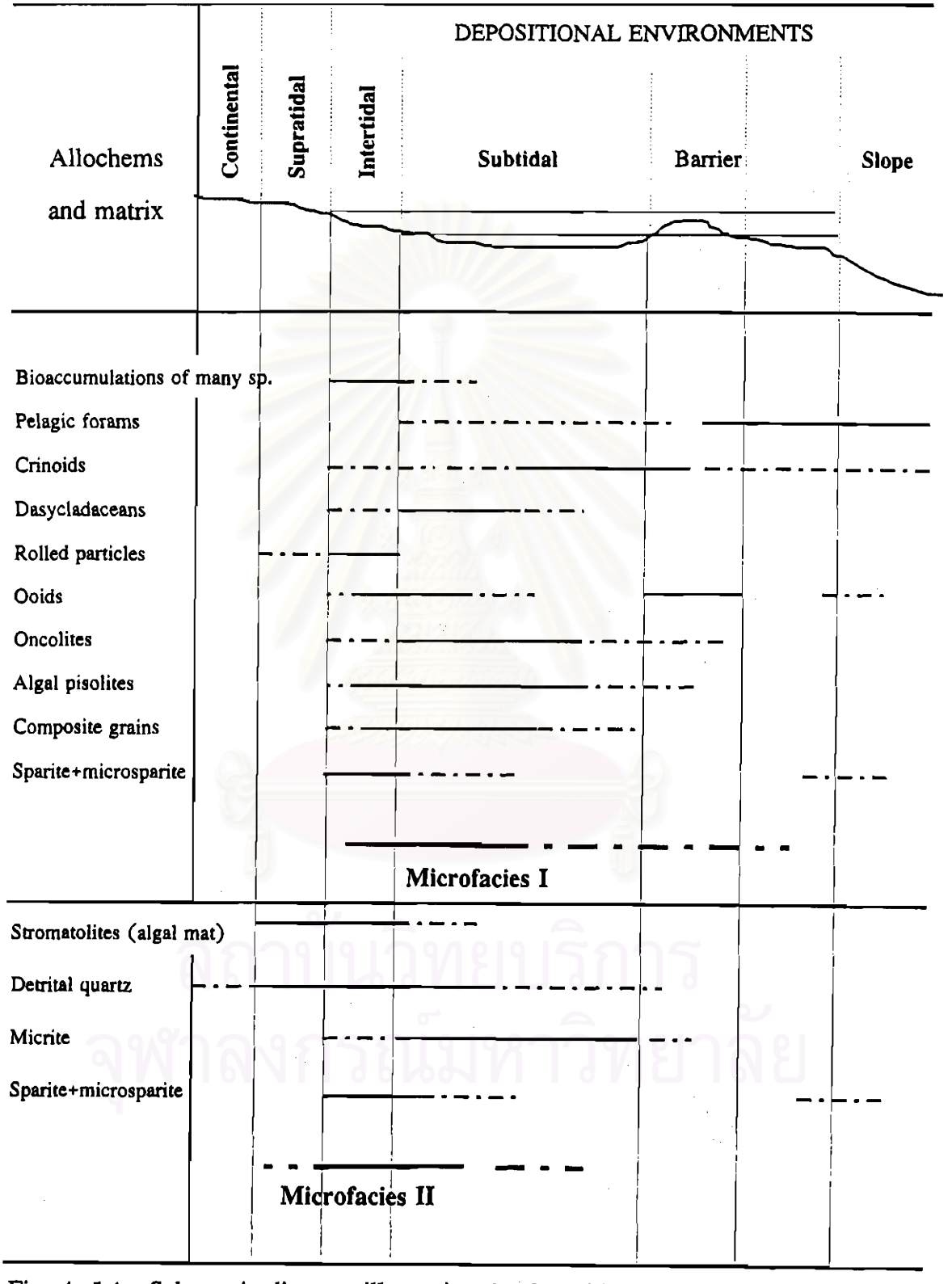

Fig. 4. 14 Schematic diagram illustrating the depositional environment of the Microfacies I and II (after Reeckmann and Friedman, 1982).

Microfacies II Algal lamination

The most diagnostic feature of this microfacies is the thin-lamination with can be observed both extensively in outcrops and in thin-sections. The microfacies is present in the sequence of thin-to thick bedded, black dolomitic limestone in the middle part of the Phu Pha Khao Member at the southern part of Phu Pha Khao mountain (section-13).

Microscopically, the irregular layering fabric can be distinguished according to the alteration of very thin layers of dark carbonaceous films and very thin layers of light-colour micrite (Fig. 4.15). The extremely thin-carbonaceous films are generally parallel or sub-parallel with each other, and characterized by relatively flat base with irregular top. The lithological characteristics of the Microfacies II is therefore concluded to be flat stromatolite-constructed micrite (algal mat). It is noted that silt-sized detrital quartz gras are a locally present.

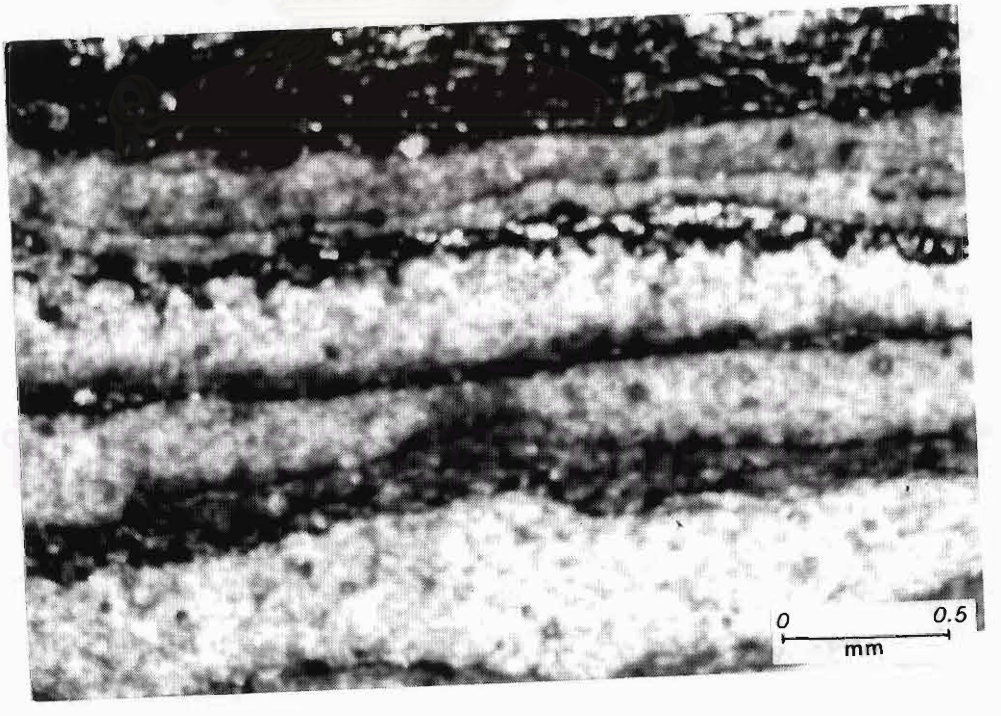

Fig. 4.15 Photomicrograph illustrating extremely thin-layers of brown calcareous films alternating with light-coloured micrite of flat stromalite-constructed micrite (algal mat). Locally, detrital silt-sized quartz grains are present.

This microfacies, of approximately 50 metre-thick, lies between the thin-to medium-bedded, dark gray biosparite of approximately 50 metre-thick, and thin-to thick-bedded, dark gray biomicrite with some poorly washed biosparite and partly dolomitized with approximately 40 metre-thick (Fig. 4.16).

This Microfacies II is concluded to represent the carbonate algal stromatolites (algal mat). Carbonate algal stromatolites are laminar deposits of an early, jelly-like material, commonly green, brown, or black on the upper surface. Their growth is controled dominantly by a dynamic relation between living blue-green algae, forming algal mat, and the entrapment and precipitation of $CaCO_3$. Carbonate stromatolites are not restricted exclusively to intertidal and supratidal zones but occur in shallow marine subtidal environments (Bathurst, 1975; Flugel, 1982). The dynamic balance between organic growth and sediment accumulation is influenced by numerous environmental factors to yield stromatolite or mats, with a vary varied range of morphologies.

The microfacies indicate intertidal and shallow subtidal zone (Wilson, 1976; Flugel, 1982; Reeckmann and Friedman, 1982; Tucker and Wright, 1994). The depositional model is summarized in Fig. 4. 14.

Microfacies III Pelmicrite

This microfacies is developed as very thin-bedded, dark gray limestone in the uppermost succession of the Tham Suae Mop Member, underlying limestone-chert sequence of the Ban Nong Hin Member at the Tham Suae Mop area (Fig. 4.17).

The lithological characteristics of the microfacies is identified as the pelmicrite (Folk, 1959, 1962), or the peloidal wackstone (Dunham, 1962). Microscopically, the dark gray fine pellets of approximately 25 per cent are embedded in micrite matrix. The peloids mainly display the size range between 0.1 and 0.5 millimetres, well-sorted (Figs. 4.18, 4.19).

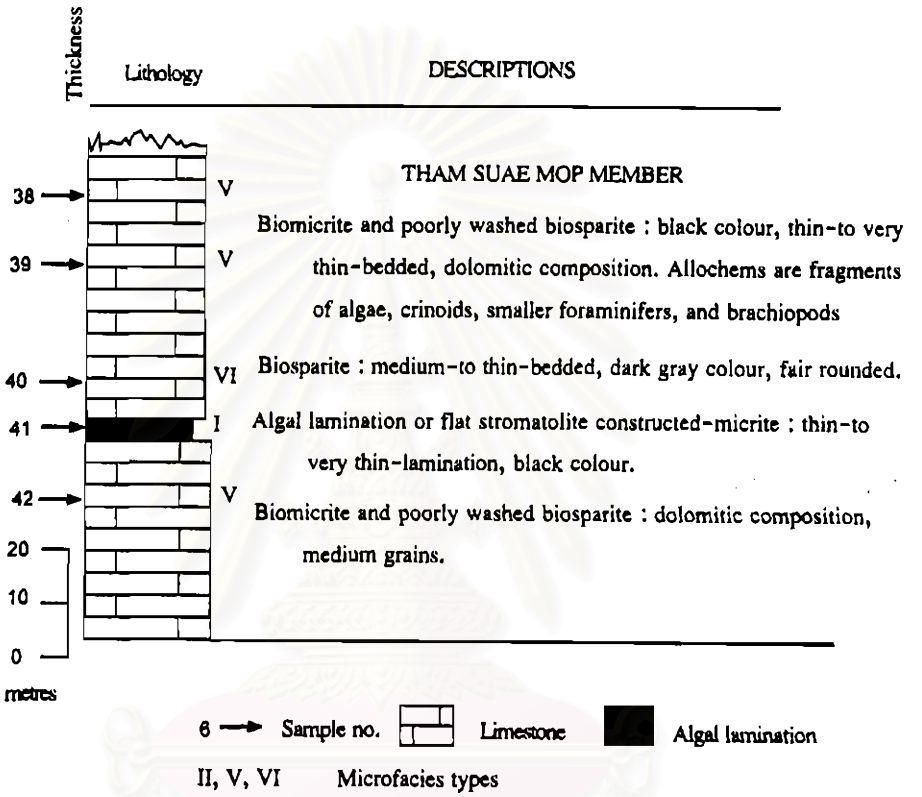

Fig. 4.16 Lithostratigraphic sequence illustrating the presence of the Microfacies II in the Phu Pha Khao at southern part of Phu Pha Khao mountain (section-13).

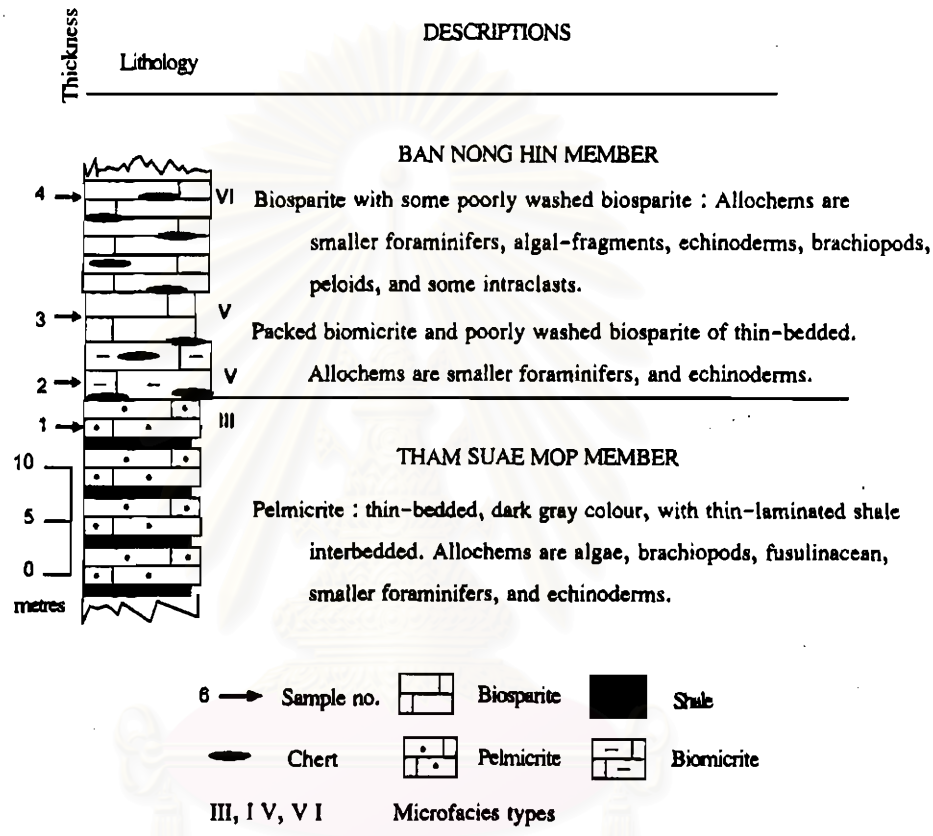

Fig. 4.17 Lithostratigraphic sequence illustrating the presence of the Microfacies III in the Tham Suae Mop Member at Tham Suae Mop area (section-11).

Traditionally, peloids are mostly common in sediments of protected environments, such as lagoons and subtidal zone (Tucker, 1982). Pelmicrite is a typical characteristic of lagoonal carbonate deposits (Selley, 1985). Peloids are an important constituent of restricted shallow-marine carbonate sediments, low-energy. They are a polygenetic group of grains, namely, facel in origin, abraded micritized grains of shell fragments, or ooids, detritus of fine-grained algal remains, and sand-sized intraclasts or lithoclasts possibly derived from pre-existing micrite substrates (Tucker and Wright, 1994).

The Microfacies III is, therefore, concluded to has been deposited in the subtidal zone of the inner shelf of carbonate depositional model (Reeckmann and Friedman, 1982) as illustrated in Fig. 4.20.

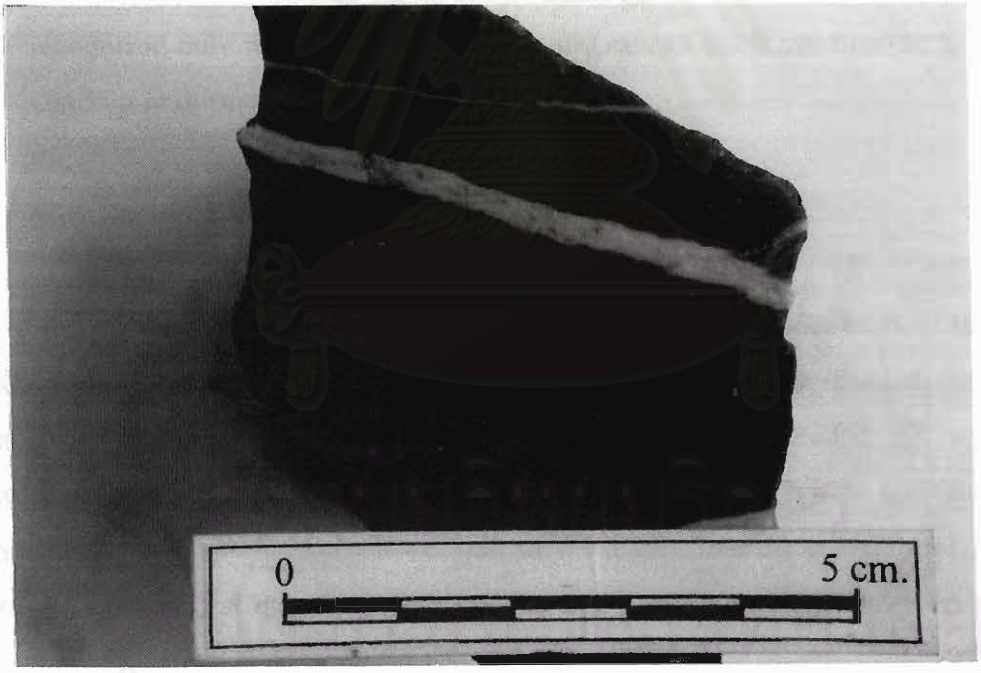

Fig. 4.18 Polished slab of pelmicrite at the uppermost part of the Tham Suae Mop Member. (sample no 1, section-11)

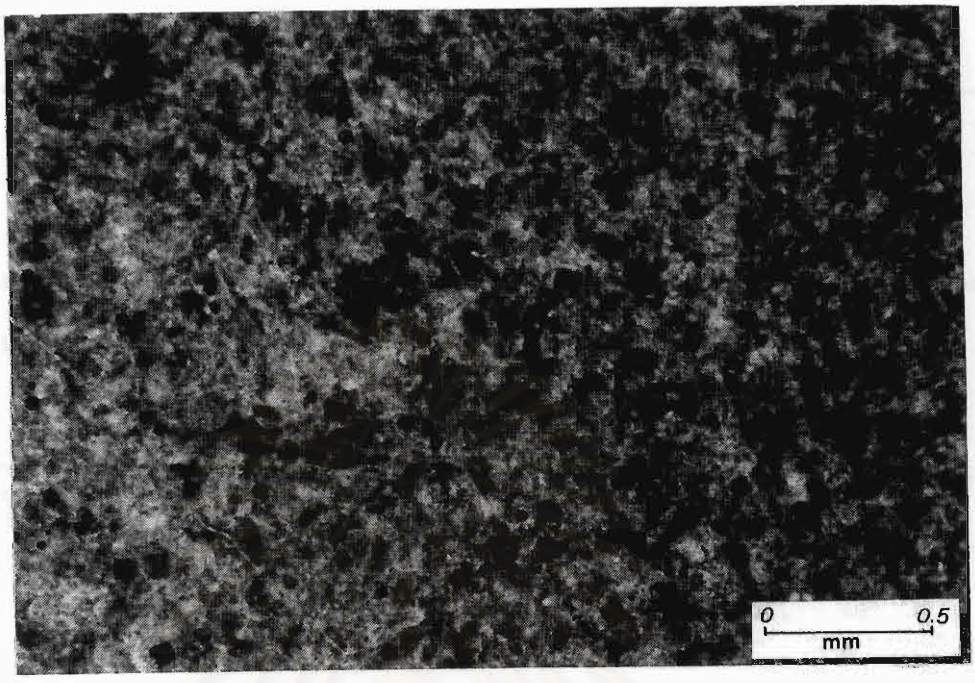

Fig. 4.19 Photomicrograph of pelmicrite illustrating well-sorted silt size pellets and sparry calcite cement with some fine-skeletal debris. Individul pellets are recognized only where mcrite isolate them. (sample no. 1, section-11). Outcrop is illustrated in Fig. 3.6).

Microfacies IV Sparse biomicrite

The microfacies is mainly recognized in the middle and upper parts of the Phu Pha Khao Member and lithologically represented by thin-to medium-bedded, darkgray limestone at Phu Tham Maholan mountain (sample no. 20, section-2), and the northwestern part of Ban Pha Khao (sample no. 80, section-15). In addition, this microfacies is also present at the lower part of the Tham Suae Mop Member (sample no. 98, section-17) at the western part of the Ban Dong Noi, where interbedding of thin-bedded mudstone and laminated greenish gray shale are apparent.

Megascopically, light gray colour and fossiliferous limestone with abundant skeletal fragments of algae, scattering echinoderms, foraminifers (Fig. 4.21), and large brachiopods (Fig. 4.22) are always observed.

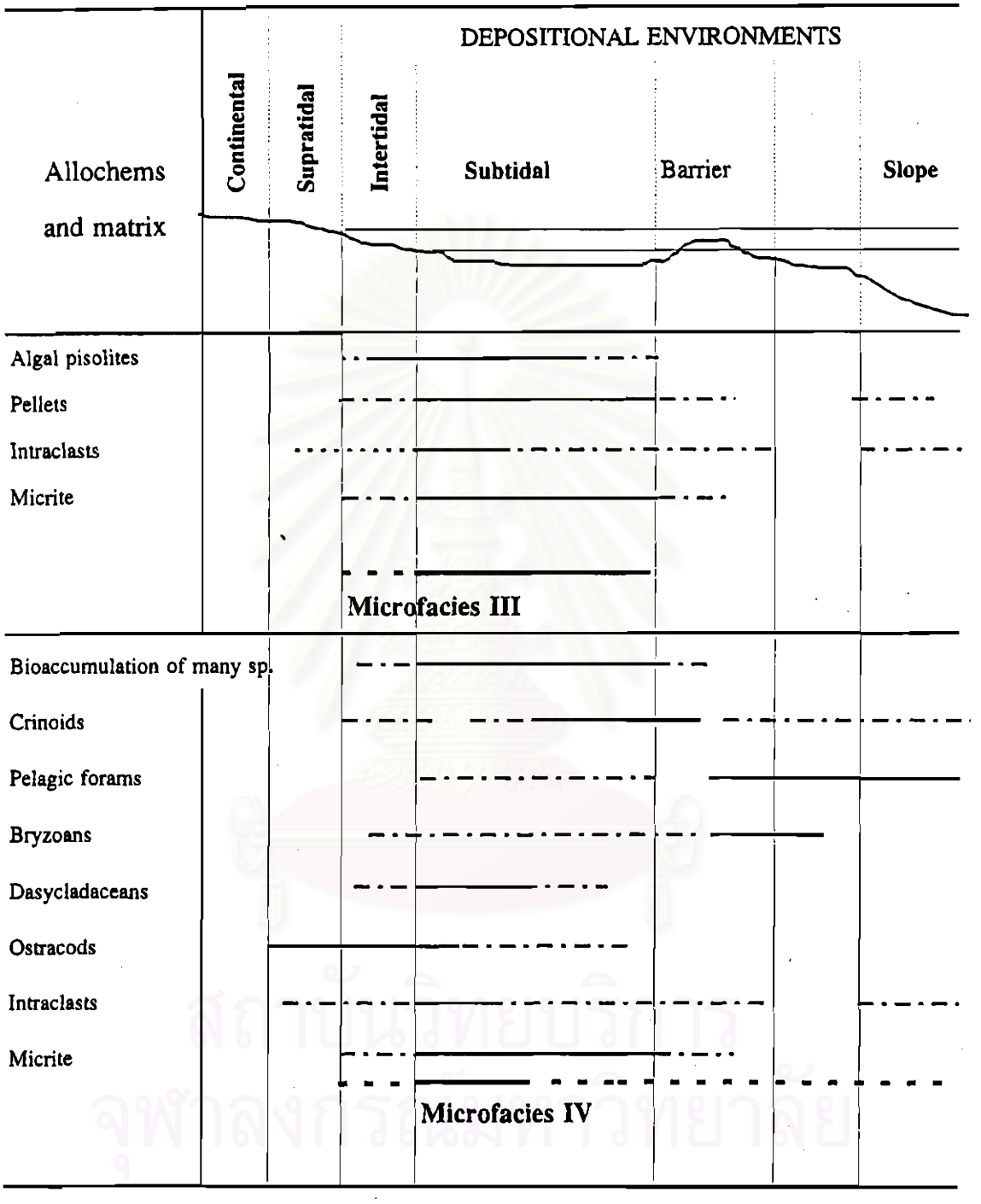

Fig. 4. 20 Schematic diagram illustrating the depositional environment of the Microfacies III and IV (after Reeckmann and Friedman, 1982).

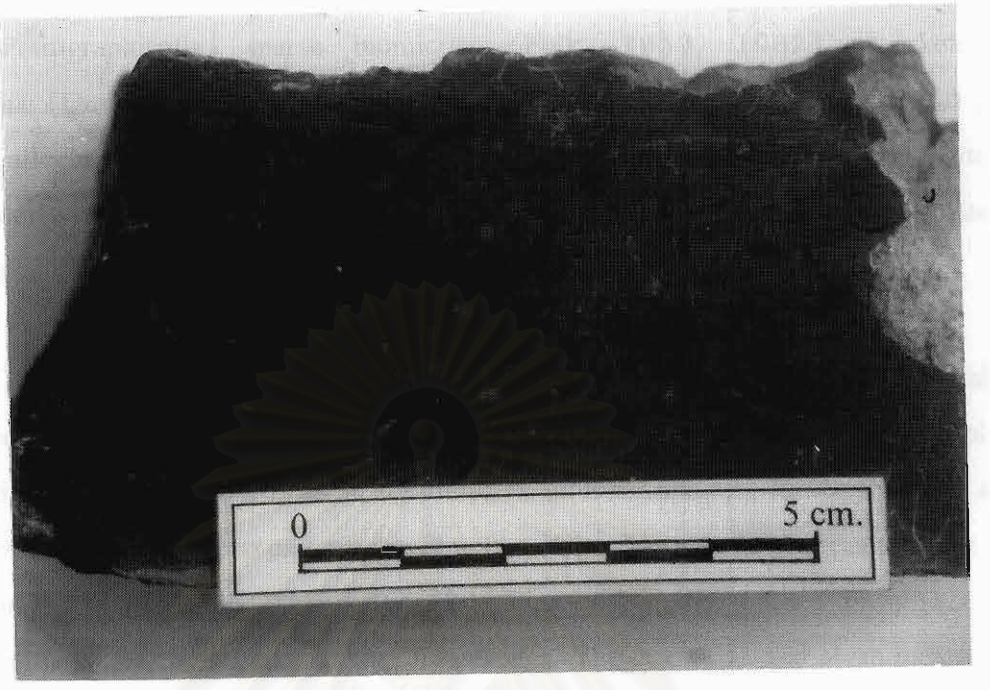

Fig. 4.21 Polished slab of sample no. 98, section 17. A sparse biomicrite illustrating fusulinaceans (black spots), echinoderms (white spots), and algae (dark fillaments). The photomicrograph is illustrated in Fig. 4.25.

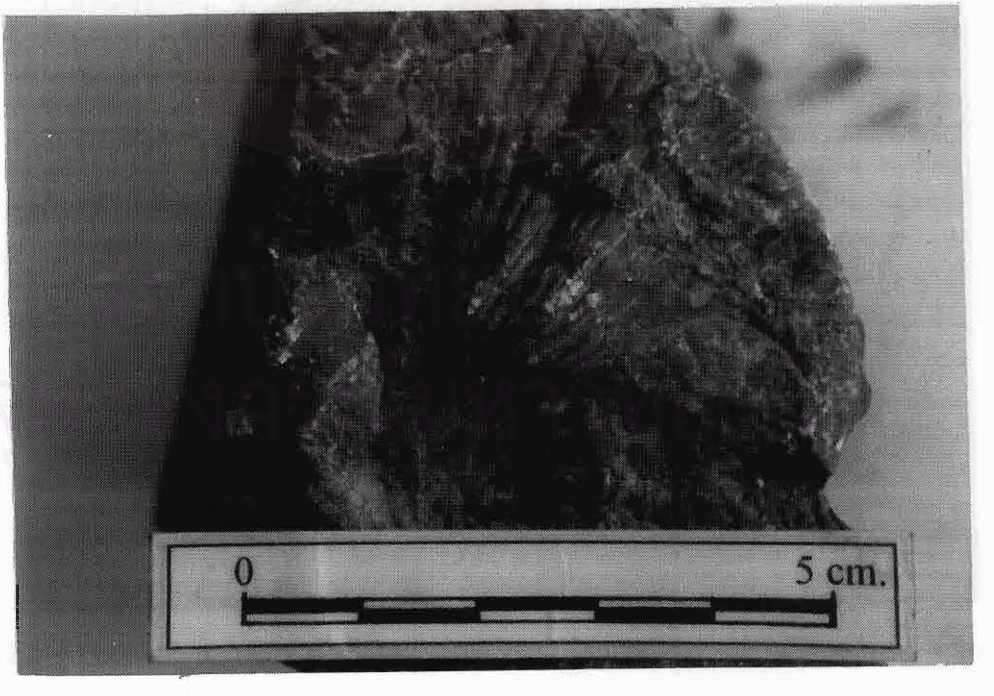

Fig. 4.22 Hand-specimen illustrating brachiopod in light gray micritic limestone (sample no. 20, section-2).

Petrographically, sparse biomicrite (Folk, 1959, 1962) or skeletals wackstone (Dunham, 1962) is recognized according to over 10 and less than 50 per cent of allochemical components are embedded in micrite matrix, or mud supported. The poorly-sorted skeletal fragments consist mainly of echinoderms plates, brachiopods, smaller foraminifers, fusulinaceans, and algae.

Brachiopod, pelecypod, ostracod, bryozone, and fusulinacean are generally observed in the upper part of the Phu Pha Khao Member at Phu Tham Maholan mountain (sample no. 20). Smaller foraminifers-*Eotuberitina* sp., *Reitlingerae* sp. are recognized from the upper part of the Phu Pha Khao Member at the eastern part fo Phu Pha Khao mountain (sample no. 80, Figs. 4.23 and 4.24). Fusulinaceans *Schubertella* sp., *Triticites* sp., smaller foraminifers *Tetrataxis* sp., and algae indicating Gzhelian age of Late Carboniferous (sample no. 98; Fig. 4.25) are identified from limestone samples in the lower part of the Tham Suae Mop Member at west of Ban Dong Noi area.

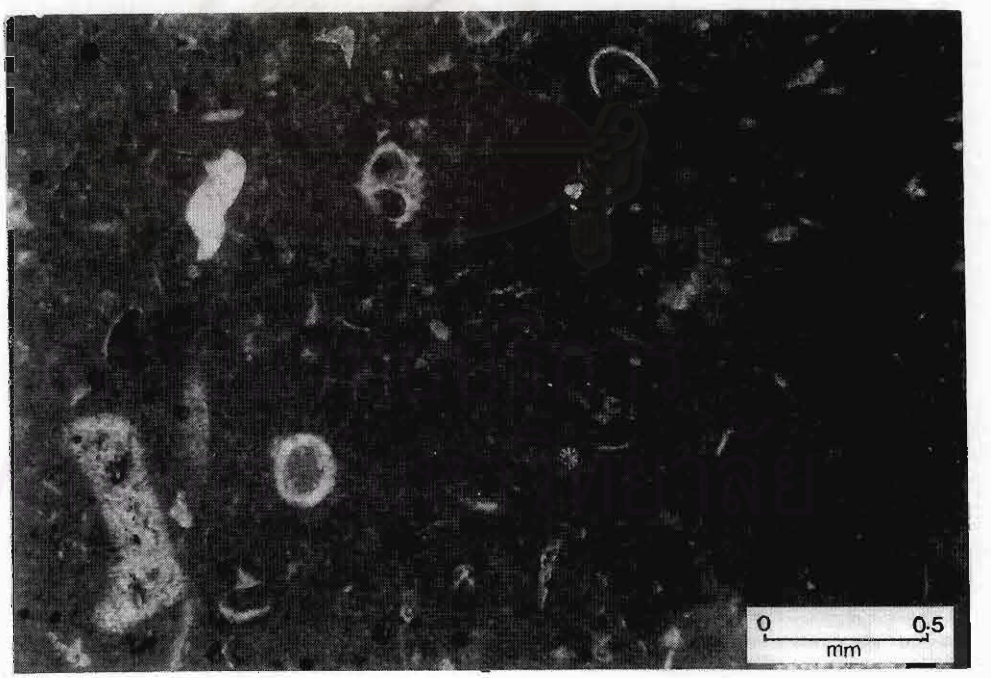

Fig. 4.23 Photomicrograph , sparse biomicrite composing of echinoderm spines, ostracods, and shred of bryozones. The crinoid stem with central canal, and arrow-head shaped particle of crinoid stem are present respectively (sample no.80, Phu Pha Khao Member, section-15).

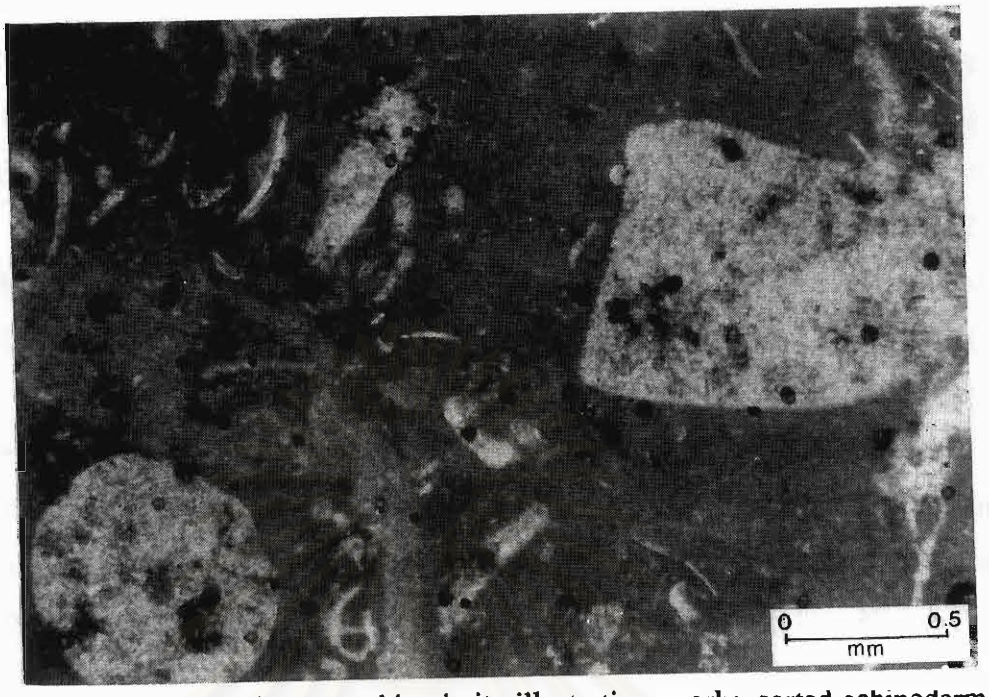

Fig. 4.24 Photomicrograph, sparse biomicrite illustrating poorly-sorted echinoderm plates embedded in micrite matrix at the northwest of Ban Pha Khao (sample no. 80, section-15).

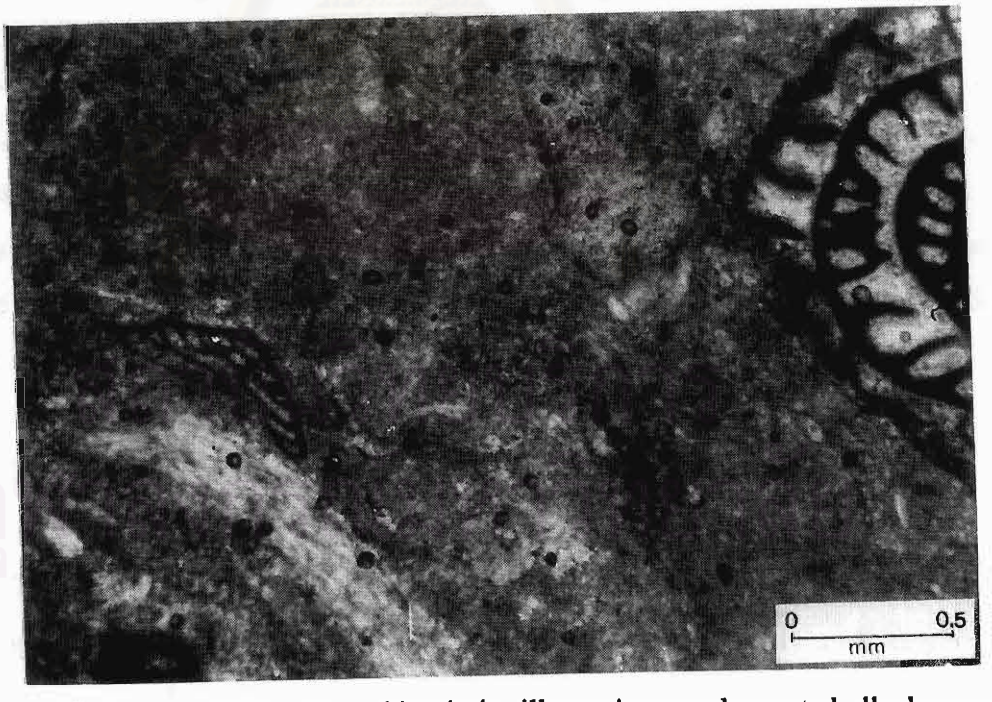

Fig. 4.25 Photomicrograph, sprase biomicrite illustrating poorly-sorted allochems of fusulinacean *Schubertella* sp., smaller foraminifers *Tetrataxis* sp., and algae embedded in micrite matrix at the western part of Ban Dong Noi (sample no. 98, section-17).

This microfacies is designated as the Microfacies IV. This 20 metre-thick microfacies sequence overlies the 50 metre-thick thick-bedded packed biomicrite with abundant brachiopods and algal fragments, and underlies the 40 metre-thick thick-bedded biosparite containing abundant fusulinaceans and algae at the Phu Tham Maholan mountain (Fig. 4.26). At the eastern part of Phu Pha Khao mountain, about the 30 centimetre-thick Microfacies IV lies between the packed biomicrite (Fig. 4.27) of totally 1 metre-thick sequence. This packed biomicrite contains skaletal fragments of echinoderms, fusulinaceans, and smaller foraminifers. Besides, the Microfacies IV is also recognized as the thin-bedded black limestone interbedded with thin-laminated shale in the Tha Suae Mop Member from the western part of Ban Dong Noi area (4.28).

The Microfacies IV is belived to represent the low-energy shallow shelf area. The lower index of deposition is reflected by the mud-supported texture, poorly-sorted and unoriented allochems. The presence of marine organisms, namely, foraminifers, brachiopods, pelecypods, ostracods, and bryozoans indicate the zone extending subtidal and/or subwave base seawardly (Flugel, 1982; Tucker, 1982; Tucker and Wright, 1994; Reeckmann and Friedman, 1982). However, the presence of abundant carbonate mud and algal fragments have the tendency to indicate the shelf zone in the vicinity of subtidal and/or subwave base (Wilson, 1975). Therefore, it is concluded that the depositional environment of the Microfacies IV lies in the zone of the subtidal and/or subwave base of open shelf sea close to the shore (Fig. 4.20).

Microfacies V Packed biomicrite

The Microfacies V, the packed biomicrite, can be observed throughout the stratigraphic succession of the Nam Maholan Formation in the study area, particulary in the upper part of the Tham Suae Mop Member, the lower and upper parts of the Ban Nong Hin Member, as well as the lower part of the Phu Pha Khao Member. It is noted that there seems to be a certain variation in degree of abundance of various skeletal components in different places.

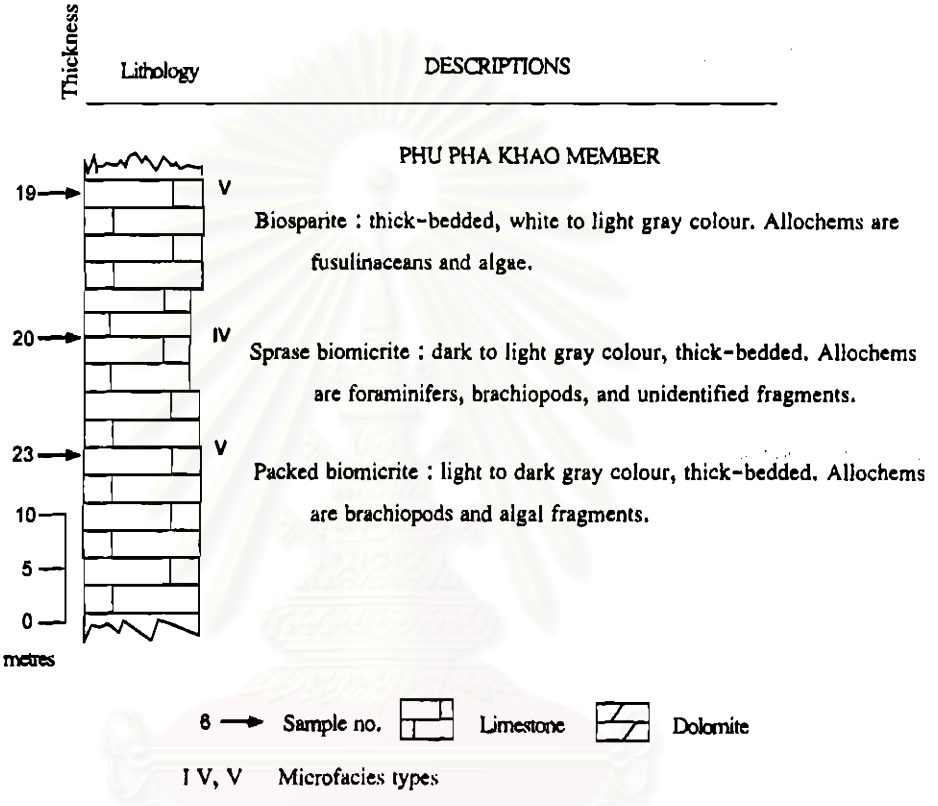

Fig. 4.26 Lithostratigraphic sequence illustrating the presence of the Microfacies IV in the Phu Pha Khao Member at Phu Tham Maholan mountain (section-2).

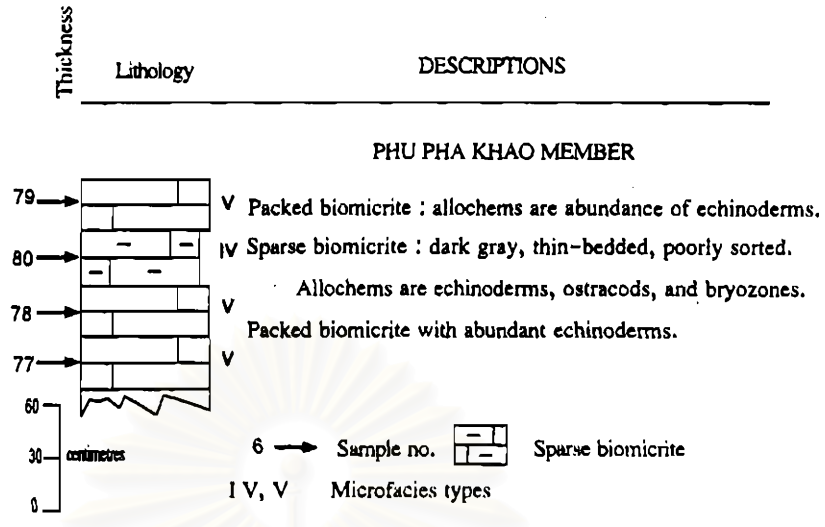

Fig. 4. 27 Lithostratigraphic sequence illustrating the presence of the Microfacies IV in the upper part of the Phu Pha Khao Member at eastern part of Phu Pha Khao muontain (section -15).

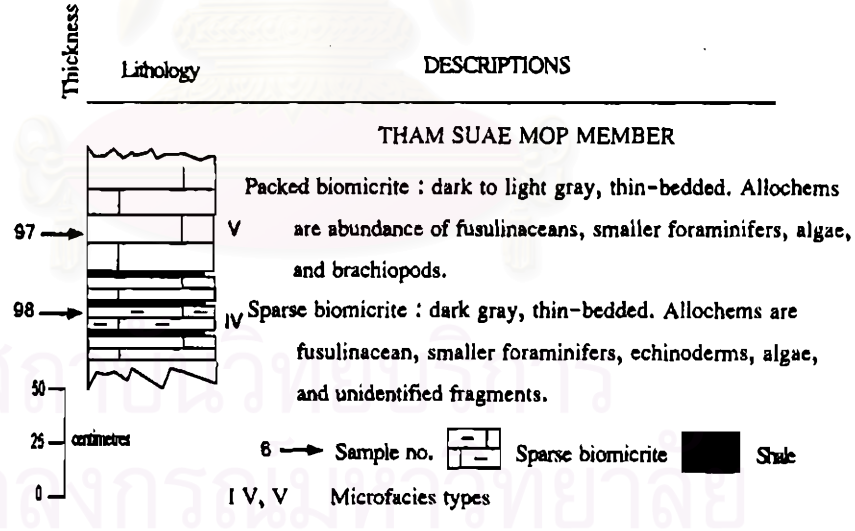

Fig. 4. 28 Lithostratigraphic sequence illustrating the presence of the Microfacies IV in the upper part of the Tham Suae Mop Member at western part of Ban Dong Noi (section-17).

The packed biomicrite, grading between packstone and wackstone, is characterized according to the amount of over 50 per cent of skeletal allochems which are mainly embedded in micrite matrix and partly cemented by sparry calcite. The content of micrite matrix is higher than that of the sparry calcite cement. The texture of this microfacies is predominantly grain-supported, poorly- to moderately-sorted, and angular to subrounded. The grain size of allochems vary greatly from very fine sand to granule with the average size of sand. Allochems consist of algae, fusulinaceans, smaller foraminifers, bryozons, and unidentified skeletal fragments, with some intraclasts and peloids.

For the succession the Tham Suae Mop Member in the eastern part of the Phu Tham Nam mountain (section-7), the packed biomicrite with some poorly washed biosparite (Fig. 4.29, sample no 84) is characterized as light gray of thin- to thick-bedded limestone interbedded with laminated shale. The allochems are moderately sorted, with grain-supported texture (Figs. 4.30, and 4.31). The most abundant allochems are fusulinaceans *Pseudufusulina* sp. and *Schubertella* sp. indicating Sakmarian-Yahtashian age (Table 3.2).

In the southern part of the Phu Pha Khao area (section-12), packed biomicrite is presented as very thin- to thin- bedded, dark gray limestone interbedded with thin-bedded shale. This microfacies is examplified by the sample no. 60. The rock is dense, black- to dark gray-coloured, with apparent fossils (Fig. 4.32). Petrographically, the rock has a grain-supported texture, and is poorly-sorted. The relative degree of abundant allochems are large echinoderms plates, common brachiopods, smaller foraminifers, and algae, respectively in decreasing order (Fig. 4.33).

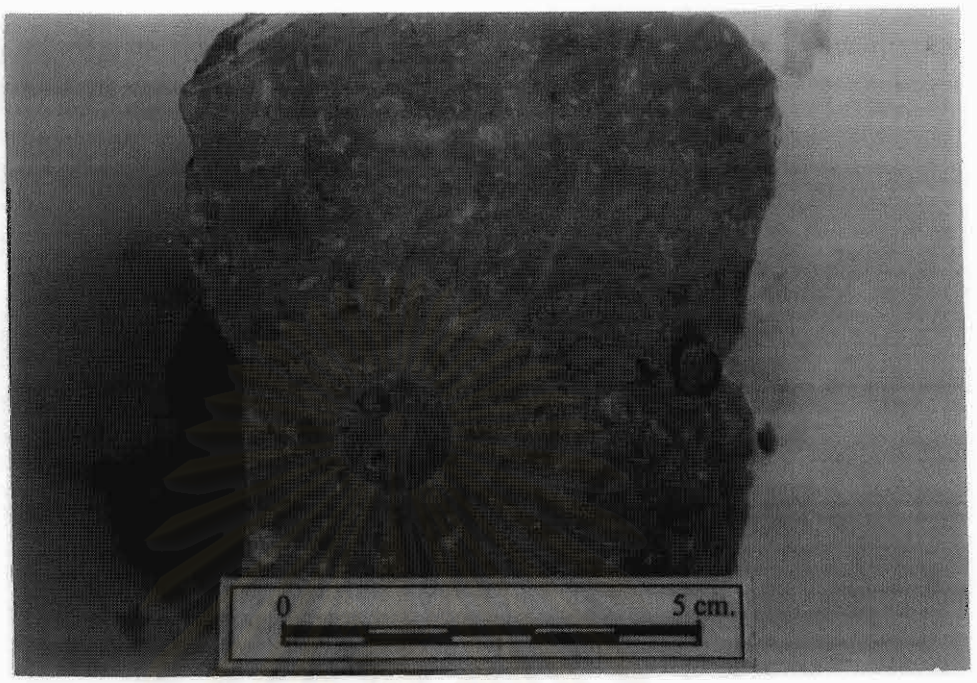

Fig. 4.29 Polished slab of light gray biomicrite west of Ban Dong Noi (sample no. 84, section-7).

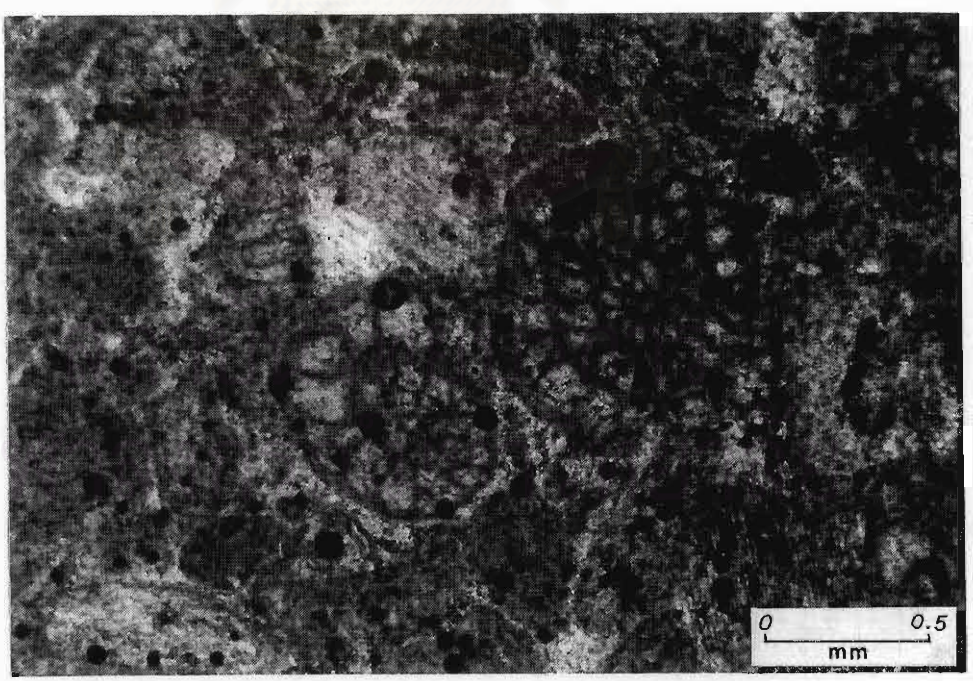

Fig. 4.30 Photomicrograph illustrating packed biomicrite with echinoderms, foraminifers and intraclasts.

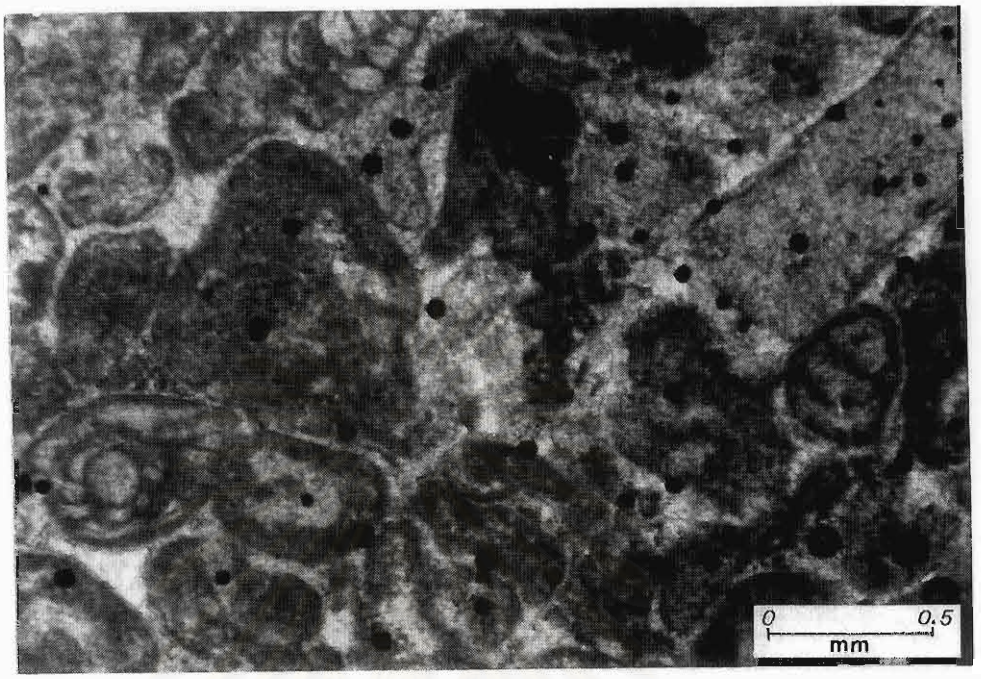

Fig. 4.31 Packed biomicrite showing poorly washed texture. Allochems are fusulinaceans *Pseudofusulina* sp., *Schubertella* sp., smaller foraminifers, echinoderms and intraclasts (sample no. 84, section-7).

Fig. 4.32 Polished slab of black biomicrite (sample no. 60, section-12).

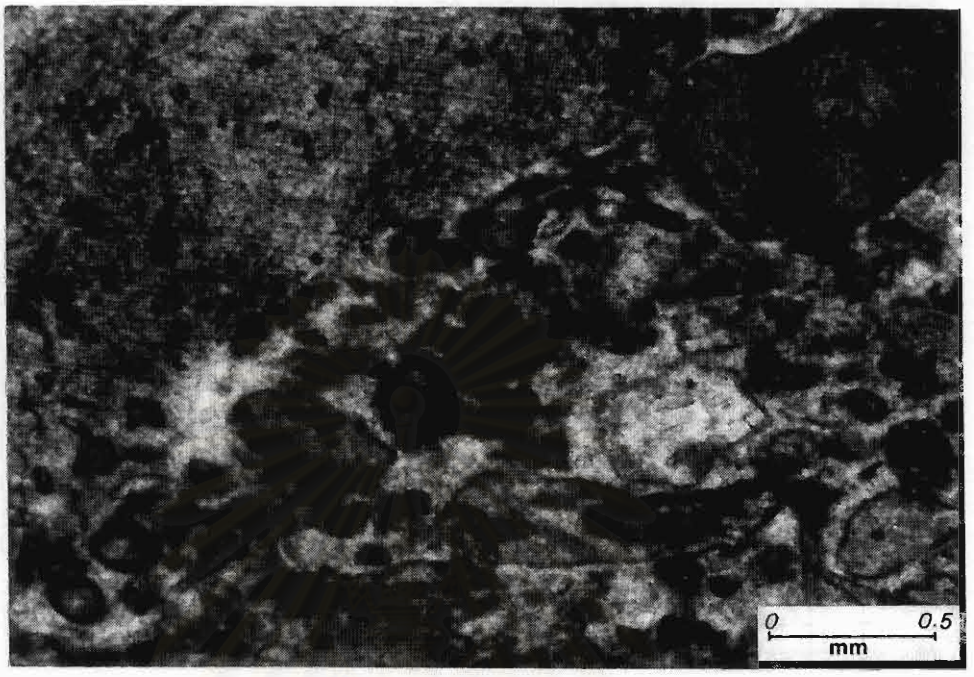

Fig. 4.33 Poorly washed biosparite illustrating large echinoderm plates, lithoclasts, smaller foraminifers, and pellets with micrite and pseudosparrite cement (sample no. 60, section-12).

The Ban Nong Hin Member, a good examplified packed biomicrite, is located in lower and upper parts of the member in the vicinity of Tham Suae Mop area (section-11). The microfacies is characterized by black, thin-bedded limestone interbedded with dark chert. The allochemical constituent contains over 50 per cent of skeletal fragments and show the relatively degree of abundance of algae, brachiopods, echinoderms, foraminifers, common ostracods and rare calcispheres, respectively in decreasing order (Fig. 4.34) . The texture is well sorted, and grain supported in micrite matrix with sparry calcite cement. The present dark bituminus or carbonaceous matter (Fig. 4.35) is possibly of algal origin. Smaller foraminifers-*Eotuberitina reitlingerae* sp., *Rugosochusenella* sp., and fusulinacean *Schubertalla* sp., indicating Late Carboniferous, are identified in the lower part of the member at Tham Suae Mop area.

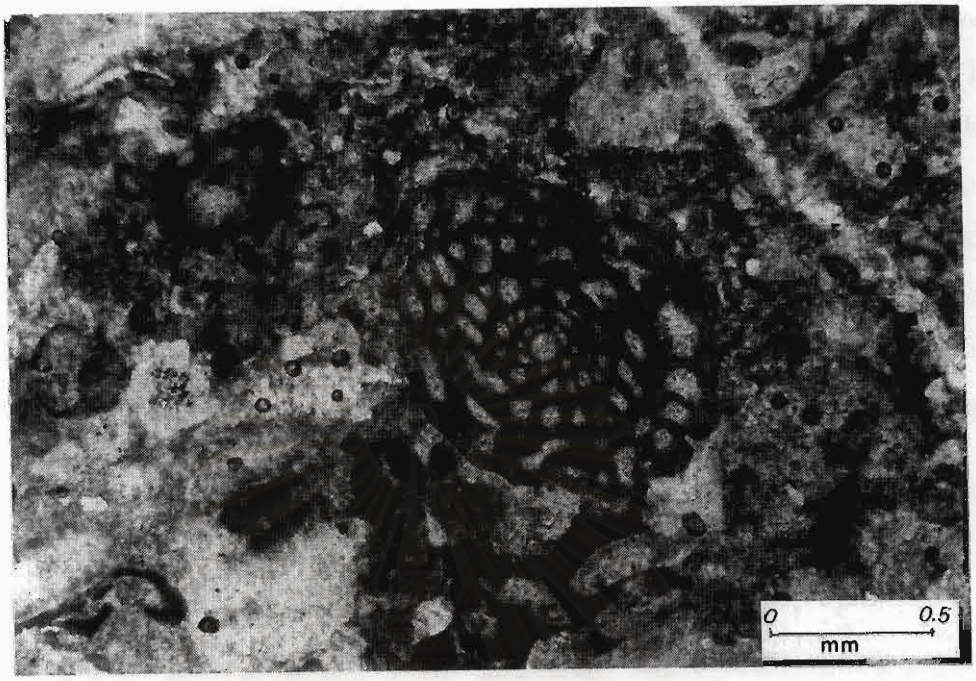

Fig. 4.34 Packed biomicrite showing poorly-washed biosparite. The compacted, poorly sorted allochems are fusulinaceans, echinoderms, and shell fragments (sample no. 2, section-11).

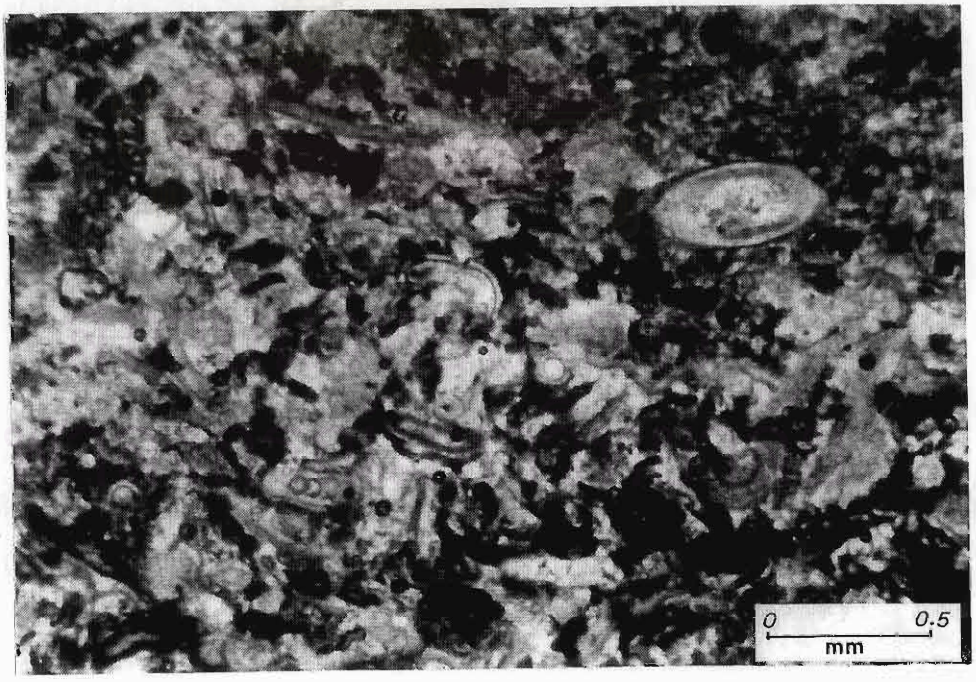

Fig. 4.35 Packed biomicrite containing more than 50 per cent skeletal allochems of algae, brachiopods, echinoderms, foraminifers, ostracods, and calcispheres. Dark bituminus or carbonaceous matters are probably of algal origin.

For the Phu Pha Khao Member, packed biomicrite with some poorly washed biosparite is recognized in thick-bedded, dark gray limestone (Fig. 4.36) in the lower part of the member at Tham Suae Mop (section-11), and southern part of Phu Khum Khao areas (section-9). The texture is grain-supported and moderately-sorted, with grain size varies between fine and very coarse sand (Fig. 4.37). Allochems consist of abundant echinoderm plates, fusulinaceans, smaller foraminifers, corals and some intraclasts. Fusulinaceans-*Pseudofusulina* sp., *Schubertella* sp., smaller foraminifers *Bradyina* sp., and algae *Tubiphytes* Obsecuse-indicate Sakmarian-Yahtashian age of Early Permian (Fig. 4.38).

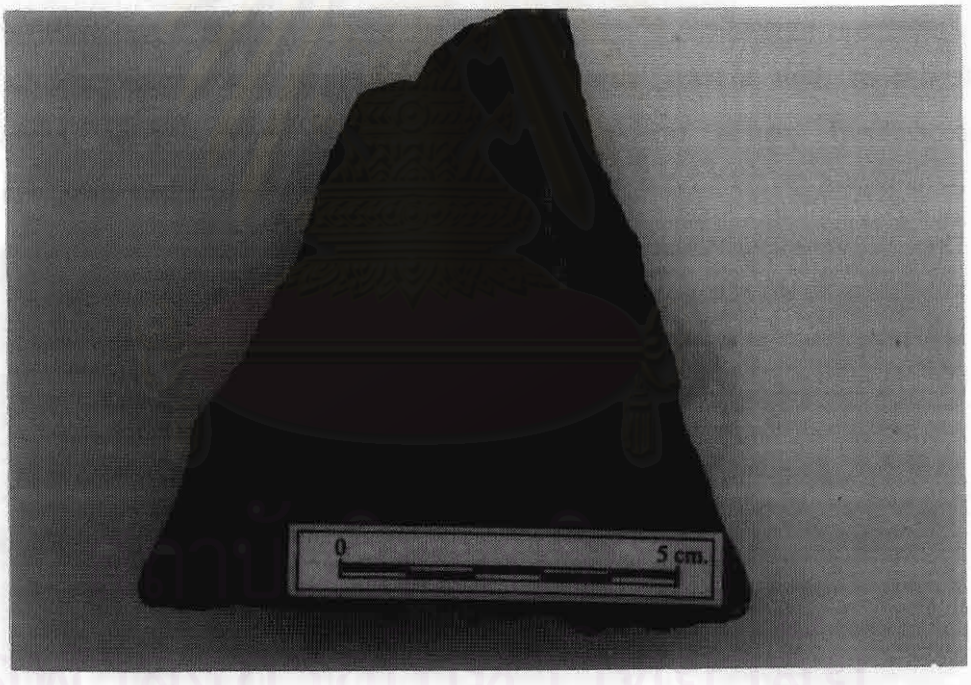

Fig. 4.36 Polished slab of packed biomicrite illustrating abundant skeletal fragments (white spots); sample no 6, section-11.

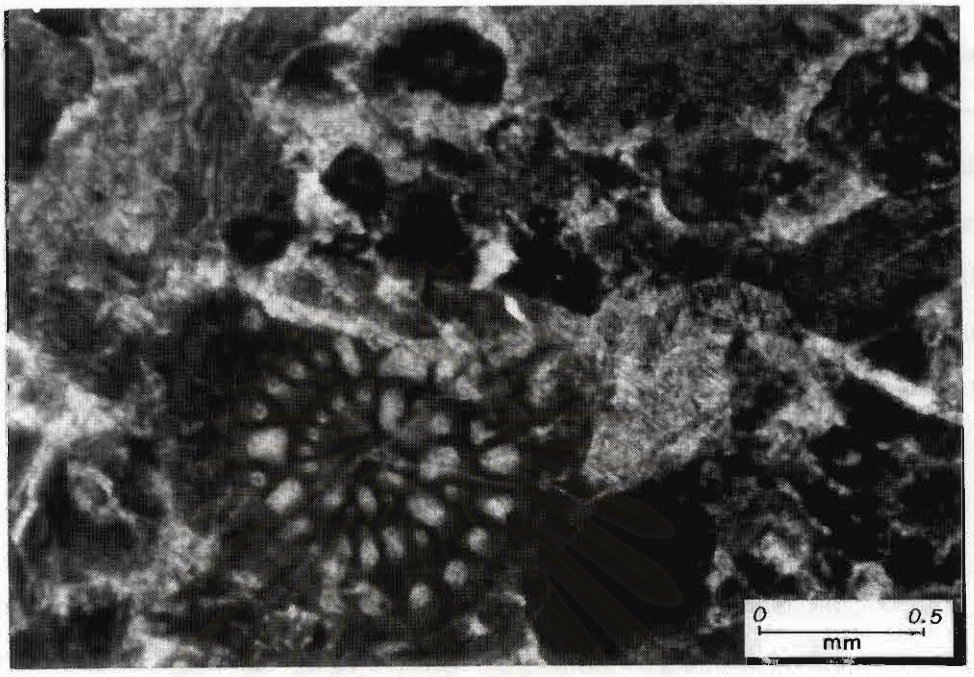

Fig. 4.37 Photomicrograph illustrating grain-supported texture with moderately-sorted packed biomicrite consisting echinoderm plates, fusulinaceans, intraclasts and algae (sample no. 6, section-11).

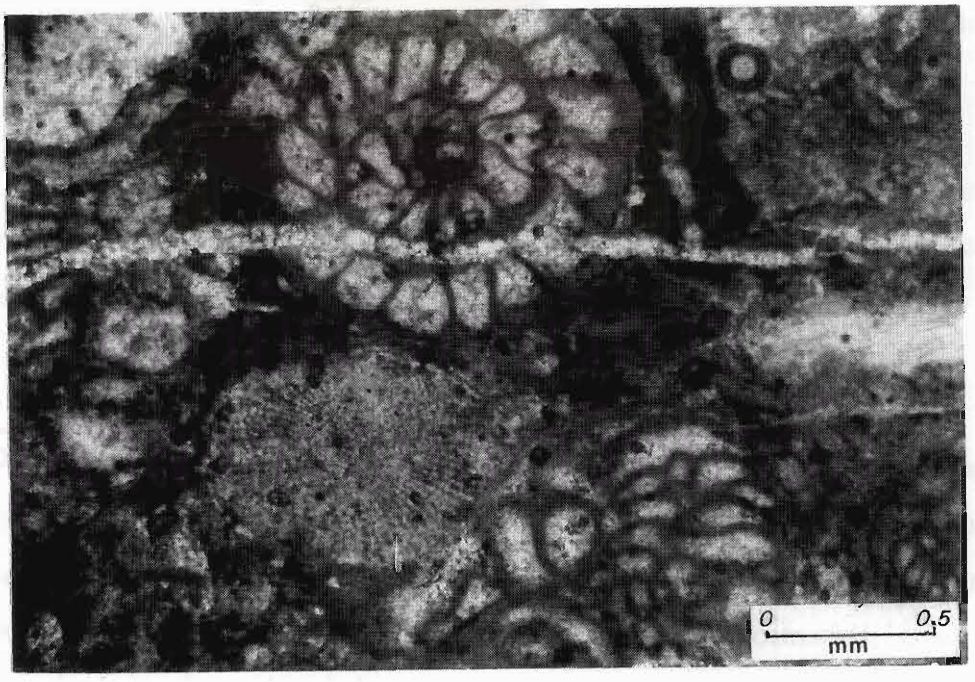

Fig. 4.38 Packed biomicrite illustrating well-sorted texture of fusulinaceans, smaller foraminifers, echinoderms, brachiopods, corals, and algae embedded in micrite matrix (sample no. 70, section-9).

The Microfacies V is characterized by the presence of the carbonate rock succession of the Nam Maholan Formation in almost measured sections. The eastern part of Phu Tham Nam area (section-7), the approximately 30 metre-thick Microfacies V in the uppermost part of the Tham Suae Mop Member is overlain by over 20 metre-thick sequence of thin-bedded packed biomicrite with interbedded chert of the lowest part of the Ban Nong Hin Member (Fig. 4.39). In addition, approximately the 15 metre-upper part of the Tham Suae Mop Member at the southern part of Phu Pha Khao mountain is presented by this microrfacies (section-12, Fig. 4.40).

The Ban Nong Hin Member at the Tham Suae Mop area (section-11) with the approximate thickness of 2-3 metres is presented at the lowermost part of the sequence. The Microfacies V also overlies the pelmicrite microfacies with thin-bedded biosparite lying on top of the limestone-chert sequence (see also Fig. 4.17).

For the Phu Pha Khao Member (section-11), the Microfacies V is represented at the lower and upper parts of the sequence with approximately 50 metre-thick in the lower part and over 40 metre-thick in the upper part (see also Fig. 4.13).

It is noted that the Microfacies V, packed biomicrite, is widely distributed in almost all measured sections, particulary the section nos. 7, 11, and 12. The graphic representation of these three mesured sections with the Microfacies V is shown in Fig. 4.41.

The relatively abundant carbonate mud matrix of the Microfacies V certainly indicates the low energy depositional environment, particularly, subtidal and subwave-base zones. The presence of over 50 per cent of mainly broken skeletal fragments of echinoderms, fusulinaceans, smaller foraminifers, brachiopods, ostracods, as well as intraclasts in decreasing order of abundance, indicates the carbonate shelf environment. Therefore, it is concluded that the Microfacies V was deposited under the carbonate

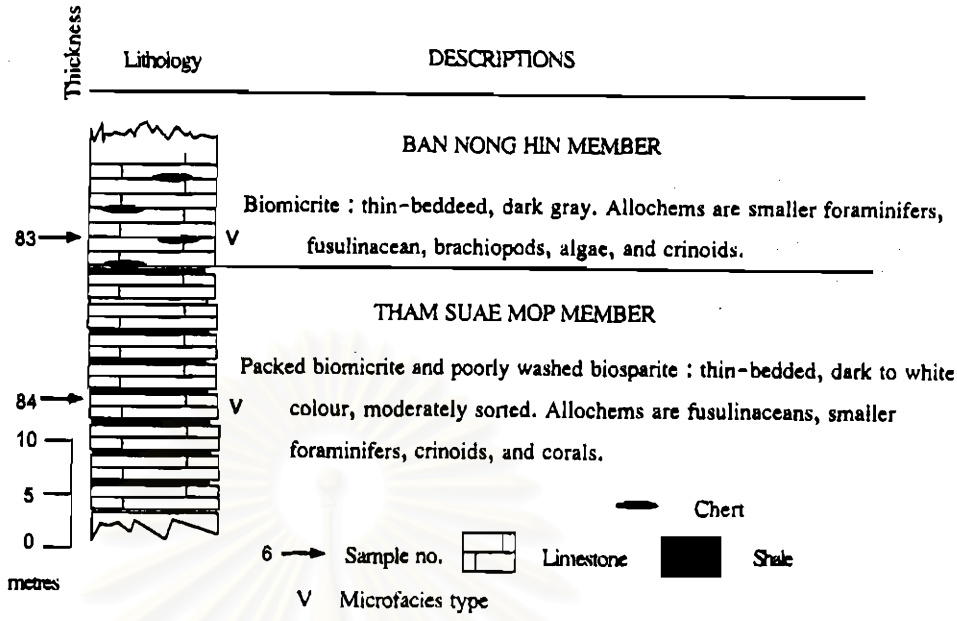

Fig. 4.39 Lithostratigraphic sequence illustrating the presence of the Microfacies V in the Tham Suae Mop Member at eastern part of Phu Tham Nam mountain (section-7).

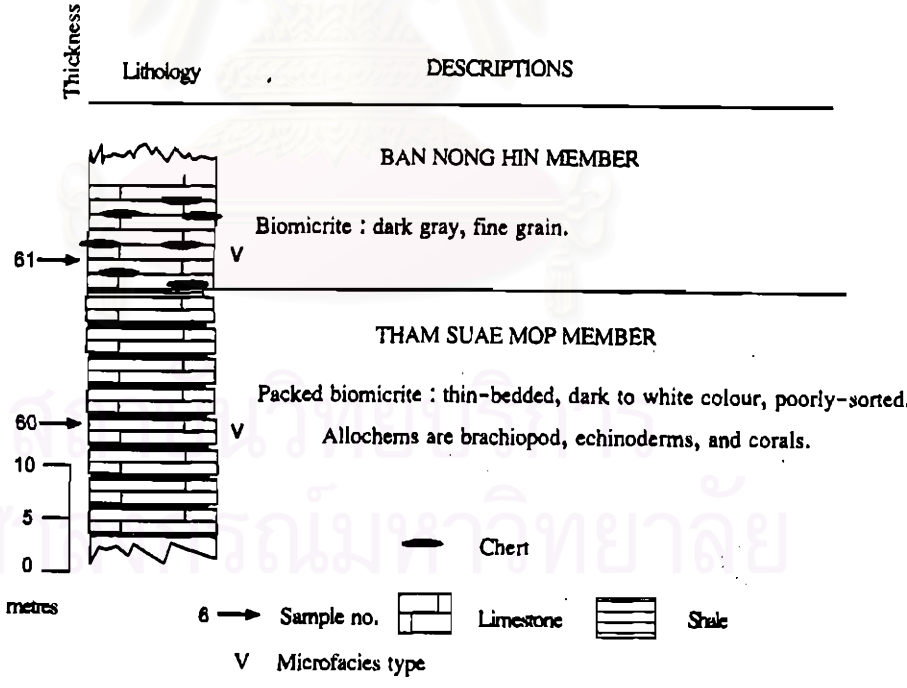

Fig. 4.40 Lithostratigraphic sequence illustrating the presence of the Microfacies V in the Tham Suae Mop Member at southern part of Phu Pha Khao (section-12).

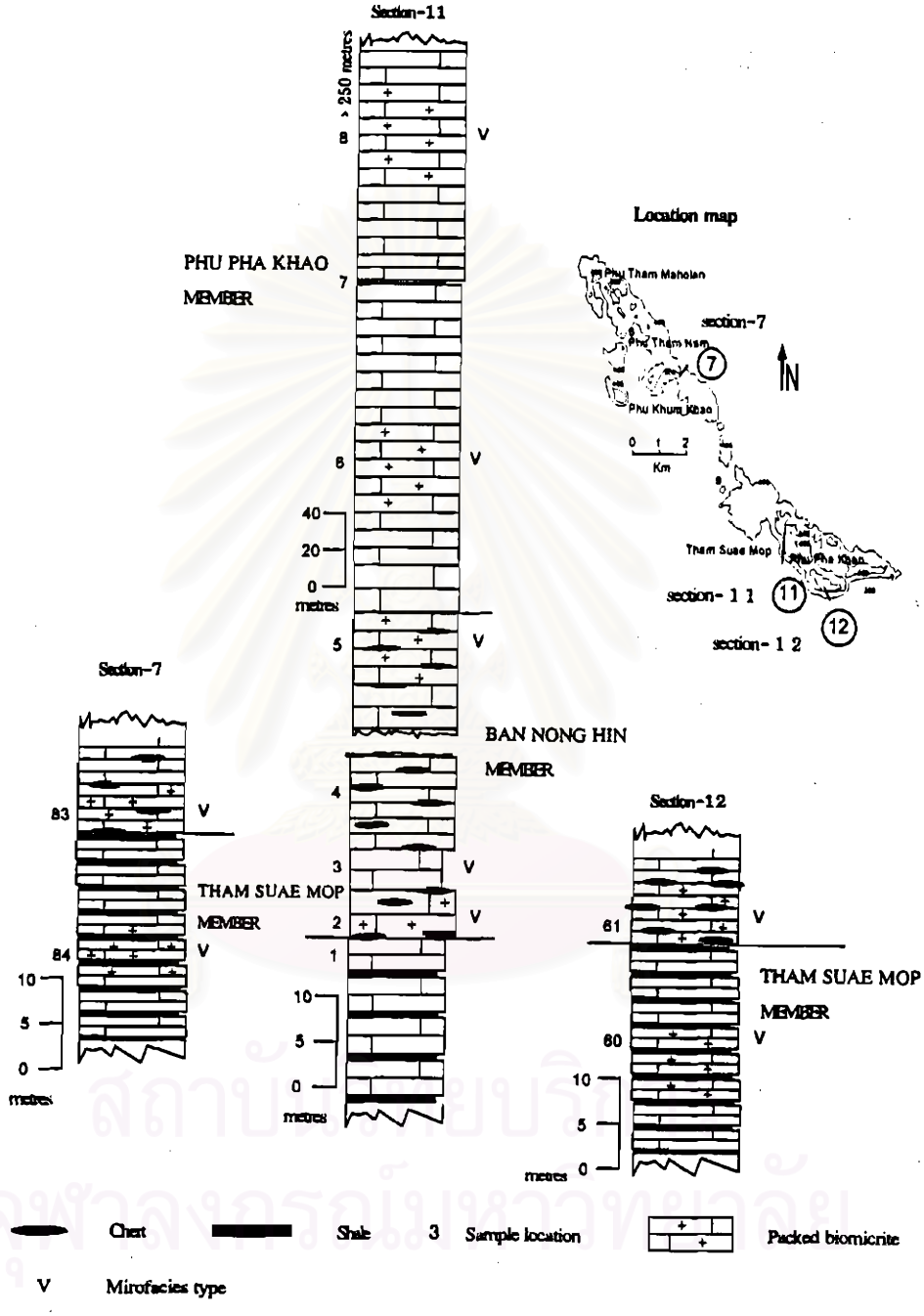

Fig. 4.41 Lithostratigraphic sequences illlustrate the distribution of Microfacies V (packed biomicrite) in the 3 measured sections.

shelf environment in the subtidal zone, preferably below the active wave base (Fig. 4.42).

Microfacies VI Biosparite

The Microfacies VI is assigned as biosparite (Folk, 1959, 1962) according to almost all of skeletal allochems are embedded in predominantly sparry calcite cement with or without small amount micrite matrix. The packstone to grainstone (Dunham, 1962) is also applied on the bases of grain-supported texture and the lack of mud matrix. The microfacies is occasionally poorly washed biosparite, or grades from packstone to grainstone. This microfacies is present in several locations in the stratigraphic sequence of the Nam Maholan Formation in the study area, particulary within the Tham Suae Mop, and the Ban Nong Hin Members.

Microscopically, it is poorly-sorted, angular to subrounded, allochems of fusulinaceans, echinoderms, smaller foraminifers, algae, with some intraclasts, and peloids. The grain size ranges from 0.02 to 2 millimetres with less than 5 per cent volumetric component of grain coarser than 2 millimetres in diametre.

The microfacies is represented in the stratigraphic sequence of the Tham Suae Mop Member in the vicinity of Tham Suae Mop cave. It is thin-bedded limestone with silty shale intercalation (sample no. 9 of section-10) as shown in Figs. 4. 43 and 4. 44. Poorly-sorted allochems consist mainly of algal fragments, brachiopods, smaller foraminifers, some intraclasts and peloids with partly orientation. Phylloidal algae *Mizzia*, *Tubiphytes* sp., smaller foraminifers *Tetrataxis* sp., *Tuberitina collosa*, fusulinaceans *Schubertella* sp., indicate Lower Permian in age.

For the Ban Nong Hin Member, the Microfacies VI is represented at the lower and the middle part of the member (sample nos. 3, 4) at Tham Suae Mop area where thin-bedded limestone and interbedded chert are present. Allochems are fusulinaceans, smaller foraminifers, algal fragments, and intraclasts of common

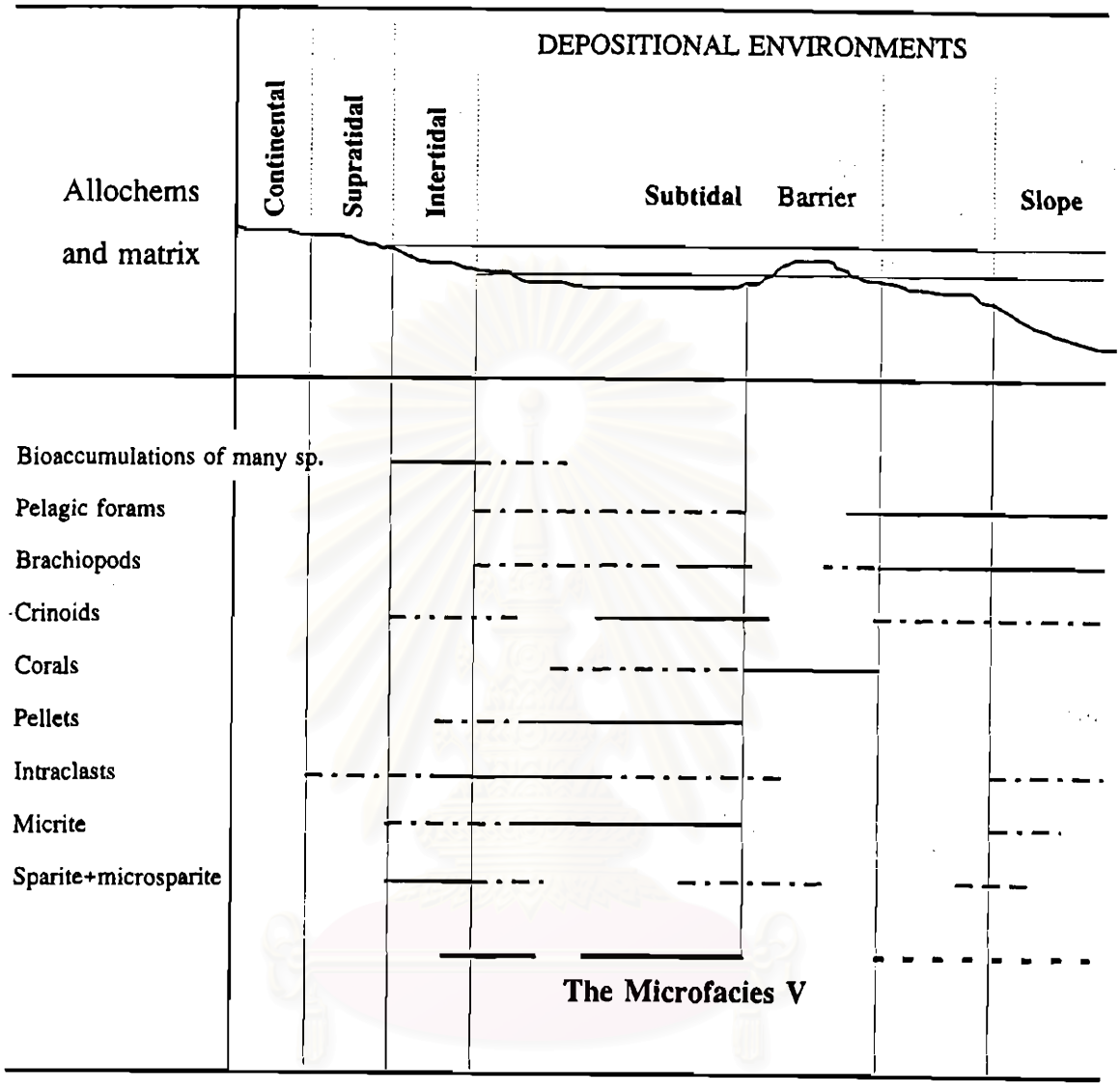

Fig. 4. 42 Schematic diagram illustrating the depositional environmnts of the Microfacies V (after Reeckmann and Friedman, 1982).

echinoderm plates, brachiopods, and peloids, respectively in decreasing degree of abundance (Figs. 4.45, and 4.46).

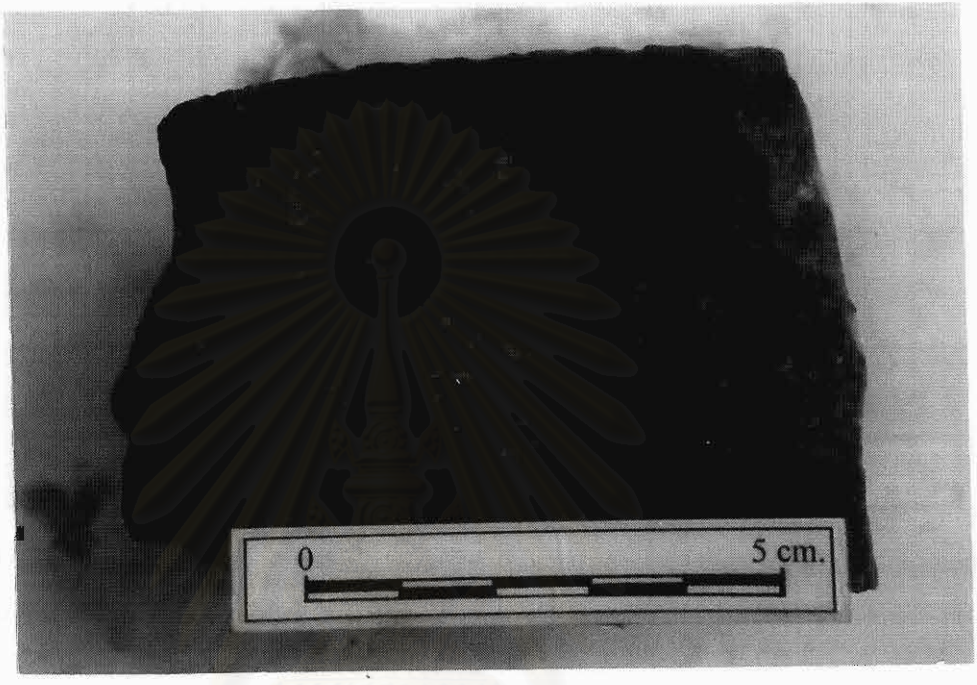

Fig. 4.43 Polished slab showing dark gray poorly washed biosparite with scattering fossils (white) of brachiopods, foraminifers, and echinoderm plates (sample no.9, section-11).

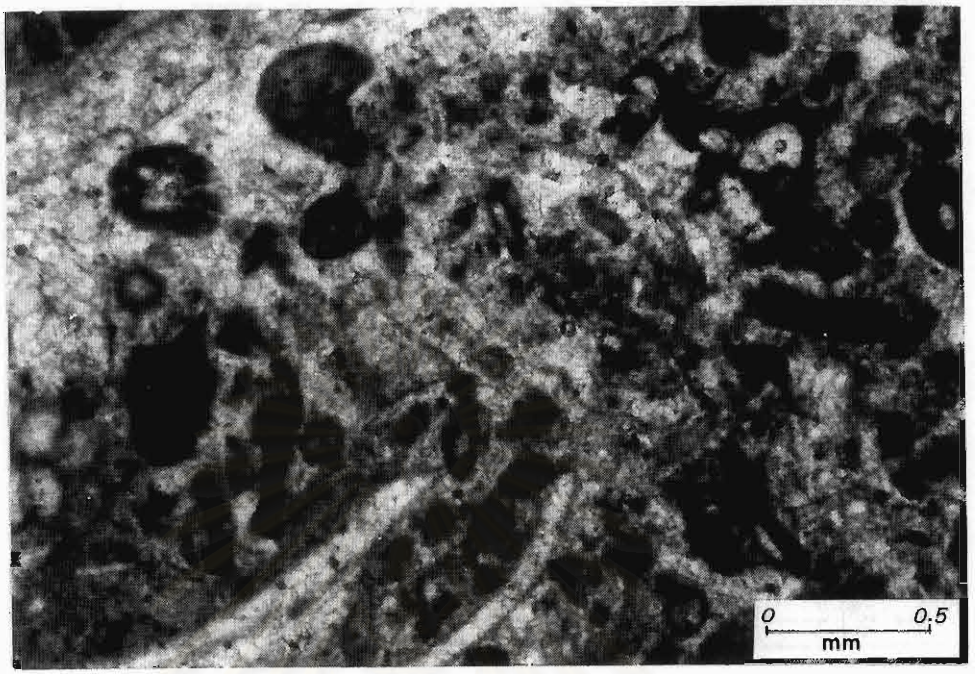

Fig. 4.44 Photomicrograph of poorly washed biosparite consisting of algal fragments, intraclasts, pelecypods, smaller foraminifers, and crinoids (sample no.9, section-11).

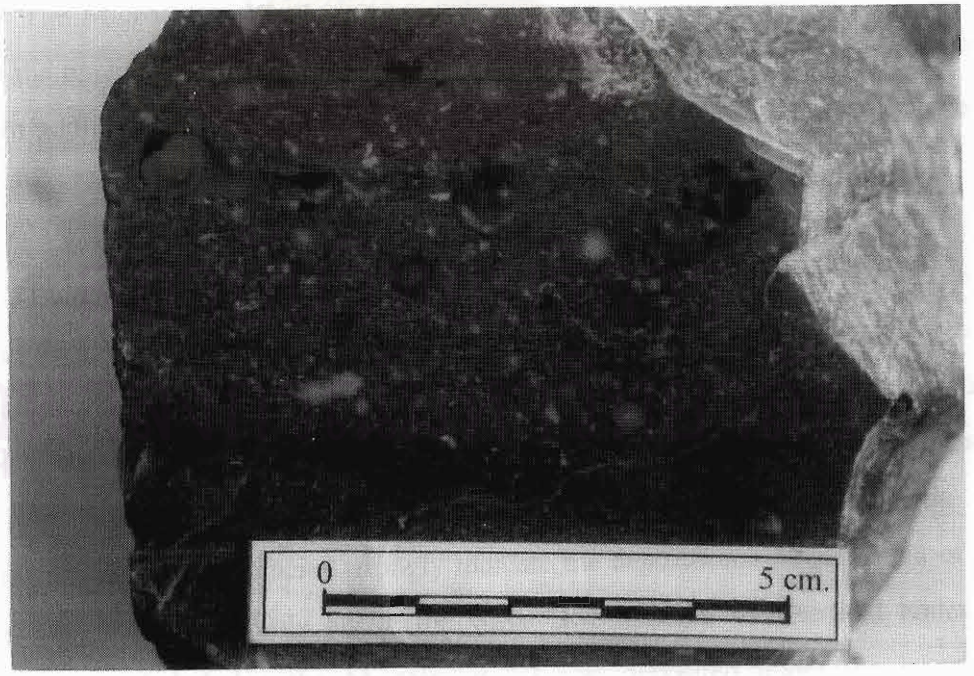

Fig. 4.45 Polished slab of rock sample no.3 illustrating dark gray biosparite with fossils of brachiopods, crinoids, and foraminifers.

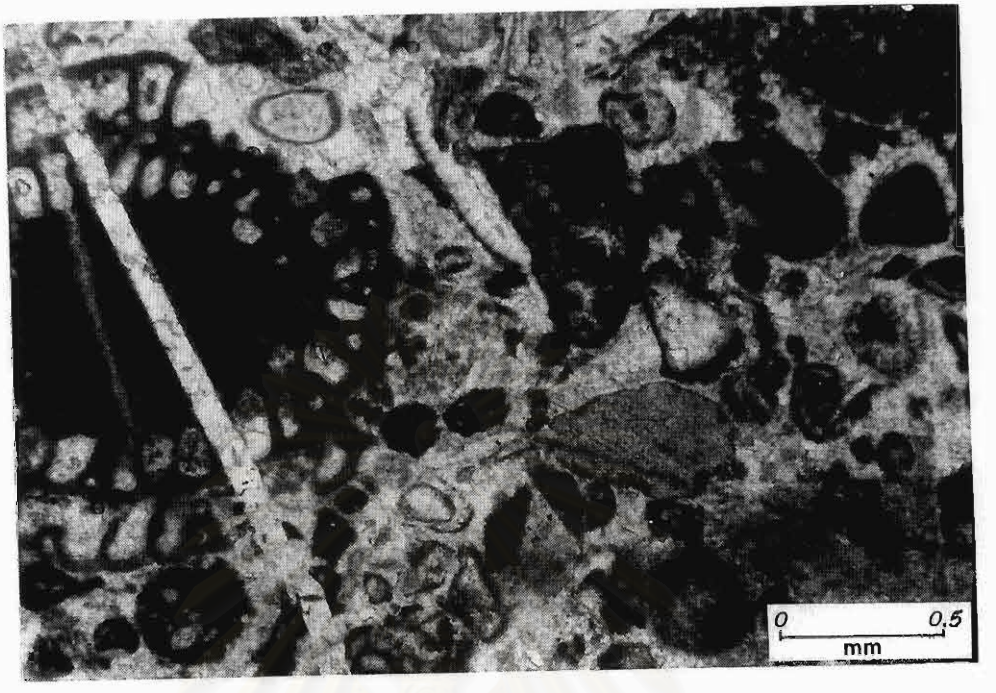

Fig. 4.46 Photomicrograph of overpacked poorly-sorted biosparite consisting of fusulinaceans, smaller foraminifers, echinoderm plates, brachiopods, algae, intraclasts, and lumped pellets (sample no.3, section-11).

The Microfacies VI of approximately 10-metre thick sequence (section-10), lies in the upper part of the Tham Suae Mop Member at Tham Suae Mop area (Fig. 4. 47). In addition, this approximately 50 metre-thick microfacies lies in the lower part of the Ban Nong Hin Member (see also Fig. 4.17).

Evidences of various skeletal allochems, namely, fusulinacean, smaller foraminifers, and brachiopods with poorly-sorted and grain-supported texture indicate the carbonate shelf to intertidal environment, preferably under high energy conditions. Besides, the presence of intraclasts, algal fragments, and algal peloids suggest that they were deposited in the near-shore subtidal to intertidal zones. Lastly, the mud-free texture of this microfacies strongly indicate the depositional environment of high-energy condition, preferably above the wave base subtidal to intertidal zones. It is therefore, concluded that the Microfacies VI was deposited under the intertidal to near-shore subtidal above the wave base zones (Fig. 4.48).

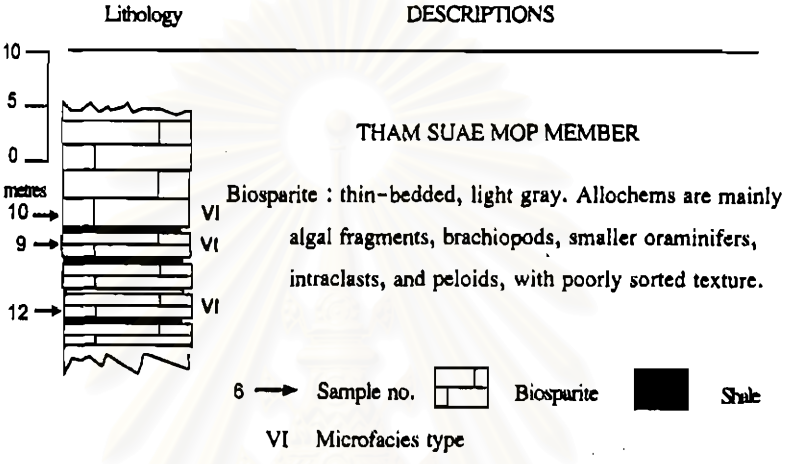

Fig. 4.47 Lithostratigraphic sequence illustrating the presence of the Microfacies V in the Tham Suae Mop Member at vicinity of Tham Suae Mop area (section-10).

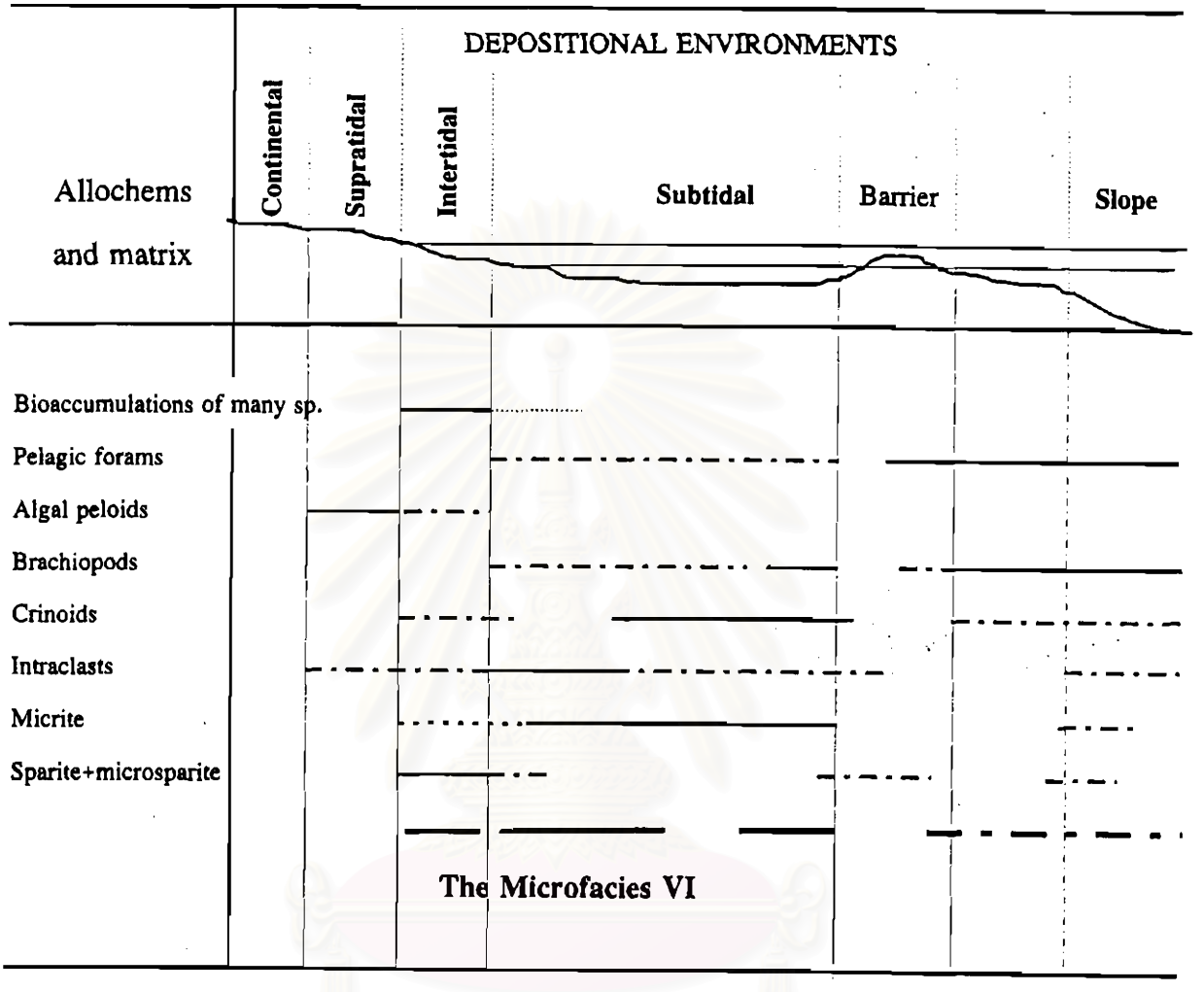

Fig. 4. 48 Schematic diagram illustrating the depositional environment of the Microfacies VI (after Reeckmann and Friedman, 1982.)

Summary

The carbonate rocks in the study area are recognized into seven microfacies based on limestone classifications those developed either by Folk (1959, 1962), or Dunham (1962), and Embry and Klovan (1971) as well as carbonate textures. Excluding crystalline microfacies, the packed biomicrite, sparse biomicrite, biosparite, algal-lamination, pelmicrite, and oosparudite are present in decreasing order of abundant. These microfacies representing carbonate facies develop under influent from low to high energy water in subtidal to intertidal regims (Figs. 4.49, 4.50, and Table 4.1).

Palaeontologic significant suggested to tropical shelf sea of normal marine. Additional open circulation is suggested by presence of echinoderm (Wilson, 1975), and advocated by diversified fauna and amount green calcareous algae such as dasycladacean and *Mizzia*. The sun-lit and clear water is also interpretated herein regarding above mention.

The presence of predominantly low energy microfacies such as packed biomicrite an sparse biomicrite suggest to subtidal zone below wave base, particularly pelmicrite indicates to low energy of lagoonal environment. In addition, agitated water and high energy microfacies representing oosparuite and biosparite indicate the depositional environment of intertidal zone. These variations of microfacies types gathering palaeontological evidences suggest to carbonate shelf of normal marine with partly restricted water circulation.

The Tham Suae Mop Member

The Tham Suae Mop Member is considered as a tropical shelf and near-shore depositional environment. The about 50 metre-thick mixed carbonate-siliciclastic facies consists of thin-bedded limestone of light gray color with seldom "chert nodules" and interbedded with very thin-bedded greenish gray

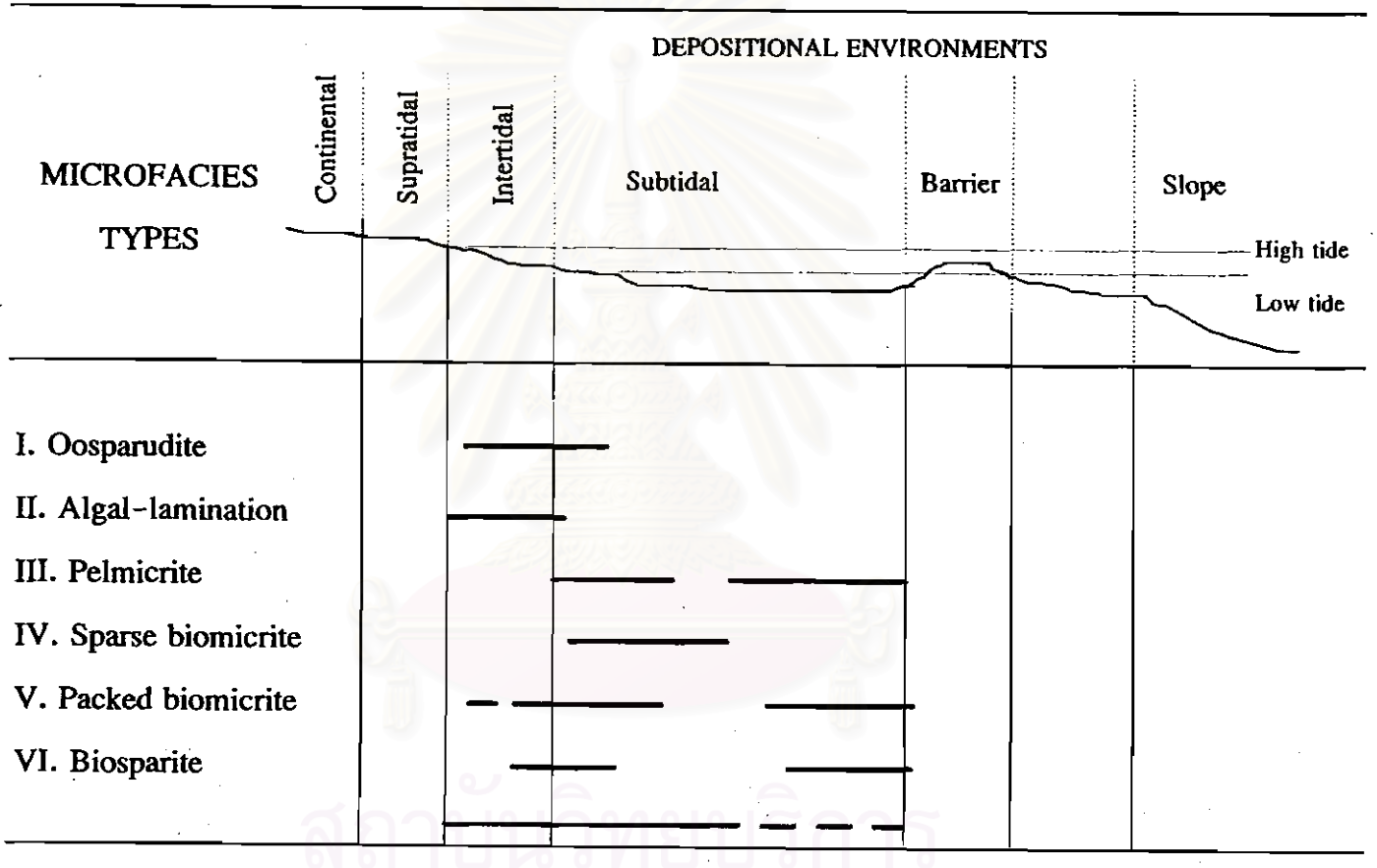

Fig. 4.49 Illustration of microfacies types and depositional zones of the Nam Maholan Formation.

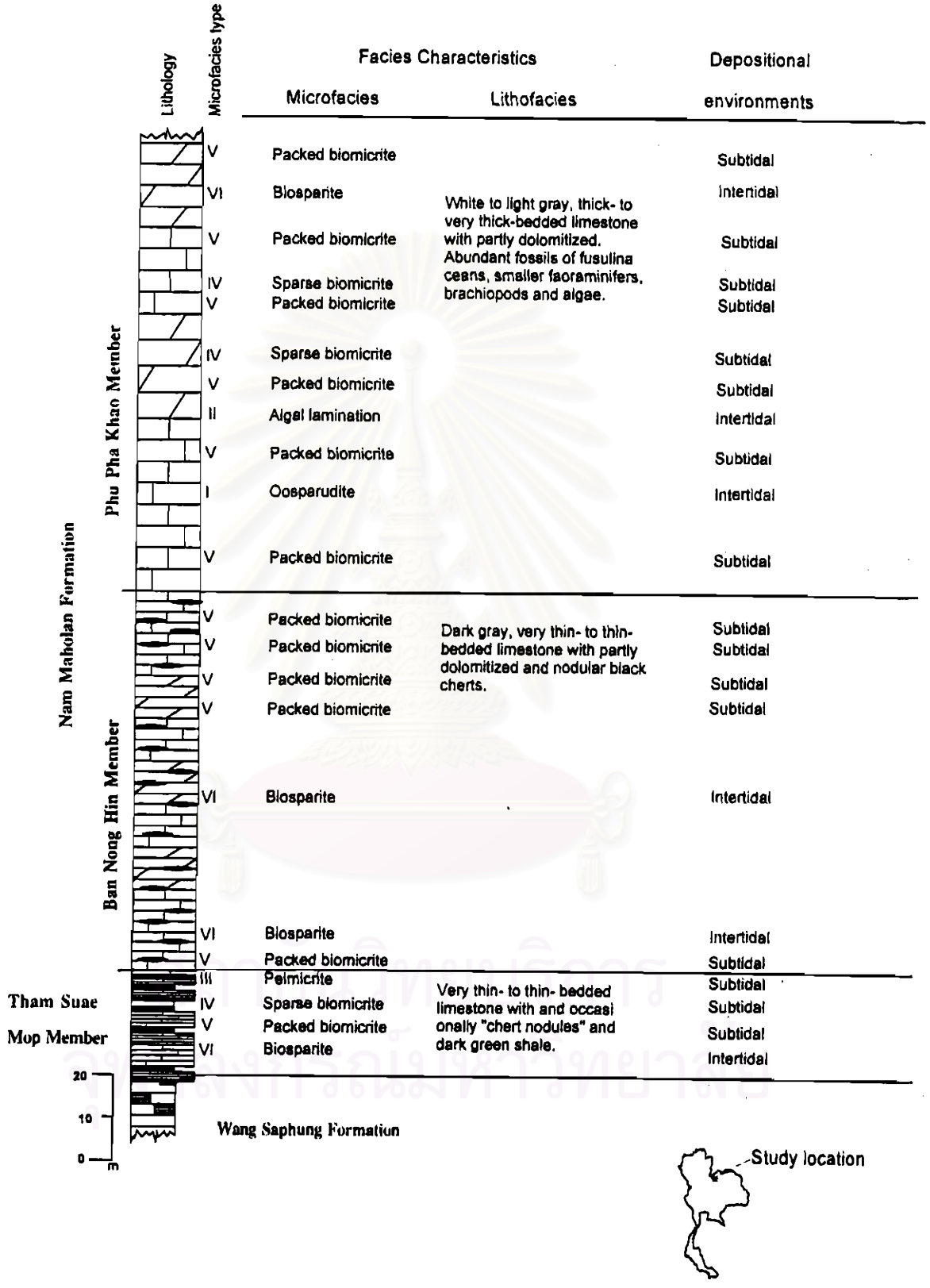

Fig. 4.50 Association of stratigraphic sequence of the Tham Nam Maholan Formation and its subdivisions with microfacies characteristics and depositional environments.

siltstone and shale. The sequence displays a carbonate-clastic ratio at 85/25. Petrographically, packed biomicrite and sparse biomicrite with moderately- to poorly-sorted, medium-to coarse-allochems are predominantly recognized. Pelmicrite microfacies is restricted in thin-bedded limestone in uppermost part of the sequence.

The Tham Suae Mop Member shows microfacies variation from biosparite, packed biomicrite, sparse biomicrite, and pelmicrite upward stratigraphically (Fig. 4.50). These representing characteristics of fining upward sequence and energy decreasing toward the top. They may suggest the changing of depositional environment condition of shallow water with some degree of current activities to low or less agitated water depend on the time. These depositional environment may be undertaken by the influence of sea level rise due to marine transgression and/or subsidence of the depositional basin.

The Ban Nong Hin Member

The change from pelmicrite at the uppermost part of the Tham Suae Mop Member to packed biomicrite at the lowermost part of the Ban Nong Hin Member, and then to biosparite at the middle part, indicate the change from relatively low to high energy of water condition. The packed biomicrite are arranged in all the upper part of the Ban Nong Hin Member indicating lower energy condition relative to the middle part of the member. These may suggest a sea level rise or subsided basin during the carbonate facies accumulation.

In addition, cherts are exhibited throughout in the carbonate sequence of the Ban Nong Hin Member, whch is characterised by predominant succession of thin-bedded dark gray limestone with partly dolomitized and interbedded with

laminated or nodular black cherts. The about 250 to 300 metre-thick member displays carbonate-chert ratio at 60/40.

Conventionally, the carbonate-chert facies is the most develope in central basin referred to the model of Selley (1985). The member representing basinal carbonate deposition and corresponding to mainly micrite associated laminated cherts, are very common. Intraclasts and skeletal fragments are probably produced by erosional and movement in water body before redepositing in quiet-water. Warm and sun-lit water is diagnosed by the presence of green calcareous algae, smaller foraminifers, fusulinaceans, brachiopods, and bryozoans.

The Ban Nong Hin Member, concentrated cherts along visible bedding planes, presumably reflecting migration paths of the silica dissolved from the siliceous shells. Thin-bedded to laminated and nodular cherts of which their individual beds, show a sharp lower boundary and some grading may indicating primary origin of chert of syndiagenetic process (Ehler and Blatt, 1980).

The Phu Pha Khao Member

Approximately 250-300 metres of thick- to very thick-bedded limestones with occasionally dolomitized of the Phu Pha Khao Member is suggested to lower energy condition of depositional basin regarding to mainly packed biomicrite with some sparse biomicrite throughout the succession. However, the occasionally appearance of oosparudite, algal lamination, and biosparite, between these packed biomicrite succession suggest to agitated water or restricted high-energy water condition, possibly due to fluctuation of marine transgression and regression cycles.

Oosparudite is an evidence of high energy with well agitated environment. Several reports and texts pointed out that oolite is generally deposited in the high-energy of shallow agitated water environment (such as Flugel, 1982) and is generally recognized as intertidal zone.

The occurrence of fine carbonate lamination with algal lamination fabric (sample no. 43, Figs. 3.29 and 4.15) indicate to sun-lit and very shallow water or subaerial environment. The appearance of appreciable carbonaceous and organic matter in carbonate rock samples suggest peritidal, especially the intertidal zone. The fine- and coarse-allochem association indicates to sedimentation affected by wave action or strom (Hardie and Ginsberg, 1977; Tucker and Wright, 1994).

The Phu Pha Khao Member was deposited in shallow water of normal marine with partly restricted condition in subtidal to intertidal zones, according to present low- and high-energy microfacies and abundant of fossils such as echinoderms, fusulinaceans, smaller foraminifers, algae, brachiopods, and bryozoans.