CHAPTER III

LITHOLOGY AND STRATIGRAPHY

The discussion is focusing upon the lithostratigraphic sequences and lithofacies based on the field investigation, and laboratory studies.

General lithostratigraphy of the Nam Maholan Formation

The stratigraphic sequence employed under the present study is based mainly on totally 1, 000-metre thick of the 17 measured rock-sections (Fig. 3.1) oriented approximately in the east-west direction of the protruding karstic carbonate mountain range, namely, Phu Tham Maholan, Phu Tham Nam, Phu Khum Khao, and Phu Pha Khao, respectively.

This mountain range is about 1.5-kilometre wide and 13-kilometre long aligned in the NW-SE. Its lithology is characterized by light to dark gray of very thin-to very thick-bedded, fine-to coarse-grained of partially dolomitized limestones. The association of thin-bedded and nodular black cherts, and also local greenish gray shale intercalation, are apparent. This is considered to be the stratotype of the Nam Maholan Formation.

Stratigraphically, the formation conformably overlies the Carboniferous-Early Permian Wang Saphung Formation (Fig. 2.3). The lower boundary of the Nam Maholan Formation is marked at the base of thin-bedded gray limestone. The upper boundary is located at the top of very thick-bedded white to light gray limestone unconformably underlies the Permo-Triassic volcanic rocks or conglomerates of Upper Triassic, the Huai Hin Lat Formation.

According to the earlier established lithostratigraphic sequence under the present field investigation, the approximately 500 metre-thick formation is subdivided

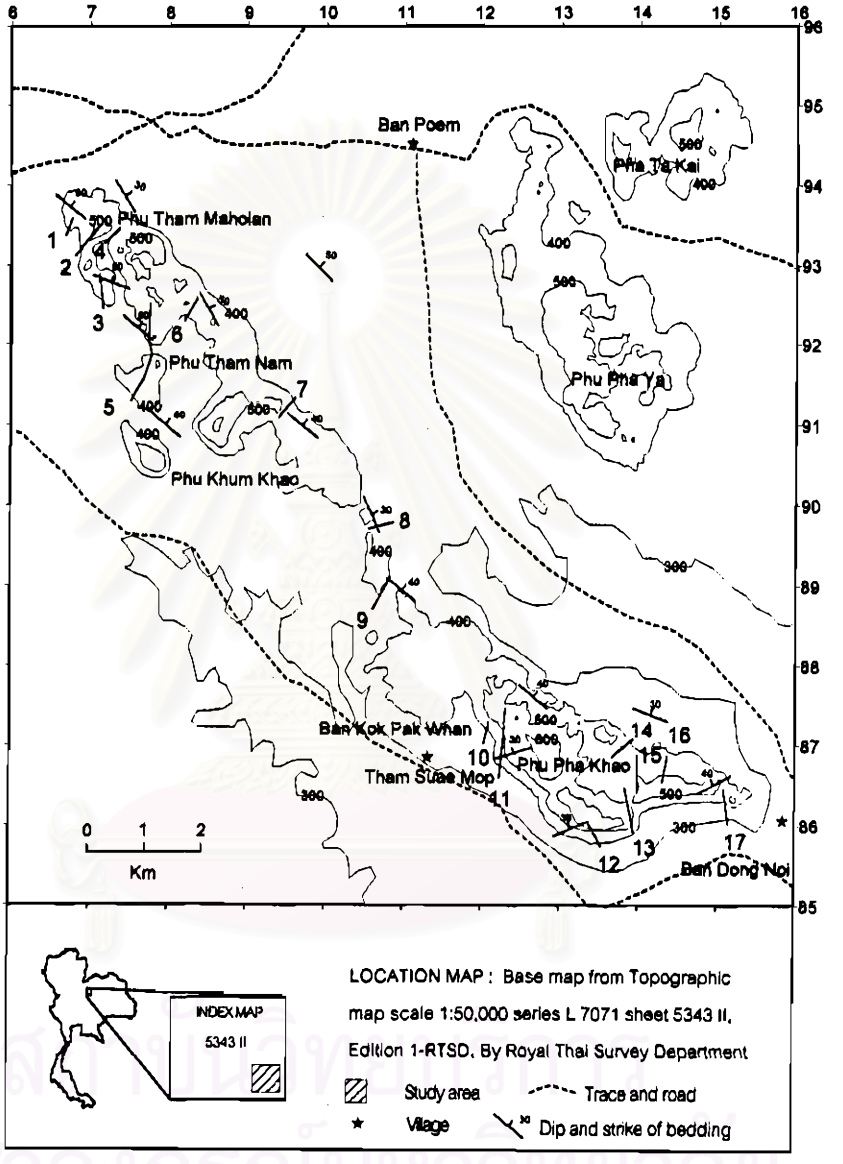

Fig. 3.1 Location map of measured sections under the present study. Note, numbers are the number of measured sections concerned.

into three members. In ascending order, these are the Tham Suae Mop, the Ban Nong Hin, and the Phu Pha Khao Members, respectively. The composit stratigraphic sequence is illustrated in Fig. 3.2, and summarized comparative lithofacies are presented in Table 3.1.

The Tham Suae Mop Member

(Thin-bedded limestone and shale facies)

The member is considered to the basal unit of the Nam Maholan Formation. At least 50-metre thick of the member displays thin- to thick-bedded, light to dark gray limestone interbedding with thin-bedded greenish gray shale and siltstone.

The lower part of this member demonstrating gradational contact of thin-bedded gray limestone overlies the sequence of thin-bedded greenish gray shale and siltstone with occasional black limestone lens of the Wang Saphung Formation. The upper part of the member conformably underlies dark to light gray limestone and chert sequence of the Ban Nong Hin Member. Good exposures are present at the west and south of Phu Pha Khao area and west of Ban Dong Noi area, particularly at Tham Suae Mop, Ban Khok Pak Whan, Amphoe Pha Khao, Changwat Loei, where the several 10-meter thick of the sequence is measured and established as the stratotype of the Tham Suae Mop Member.

Lithologically, pelmicrite, biomicrite and biosparite of Folk (1959; 1962) are the main types of limestones. These limestone are vary in colour from gray to black and vary in grain size from calcirutite to calarenite. Medium to very coarse allochems with grain size coarser than 2 mm are often present with less than 5 per cent. Almost all of allochems are skeletal fragments. The comparative degree of abundance are brachiopods, pelecypods, crinoids, smaller foraminifers, fusulinaceans, and algae, respectively in their decreasing order. They are generally fairly rounded and coated grains or rim micrite characteristic.

DESCRIPTIONS

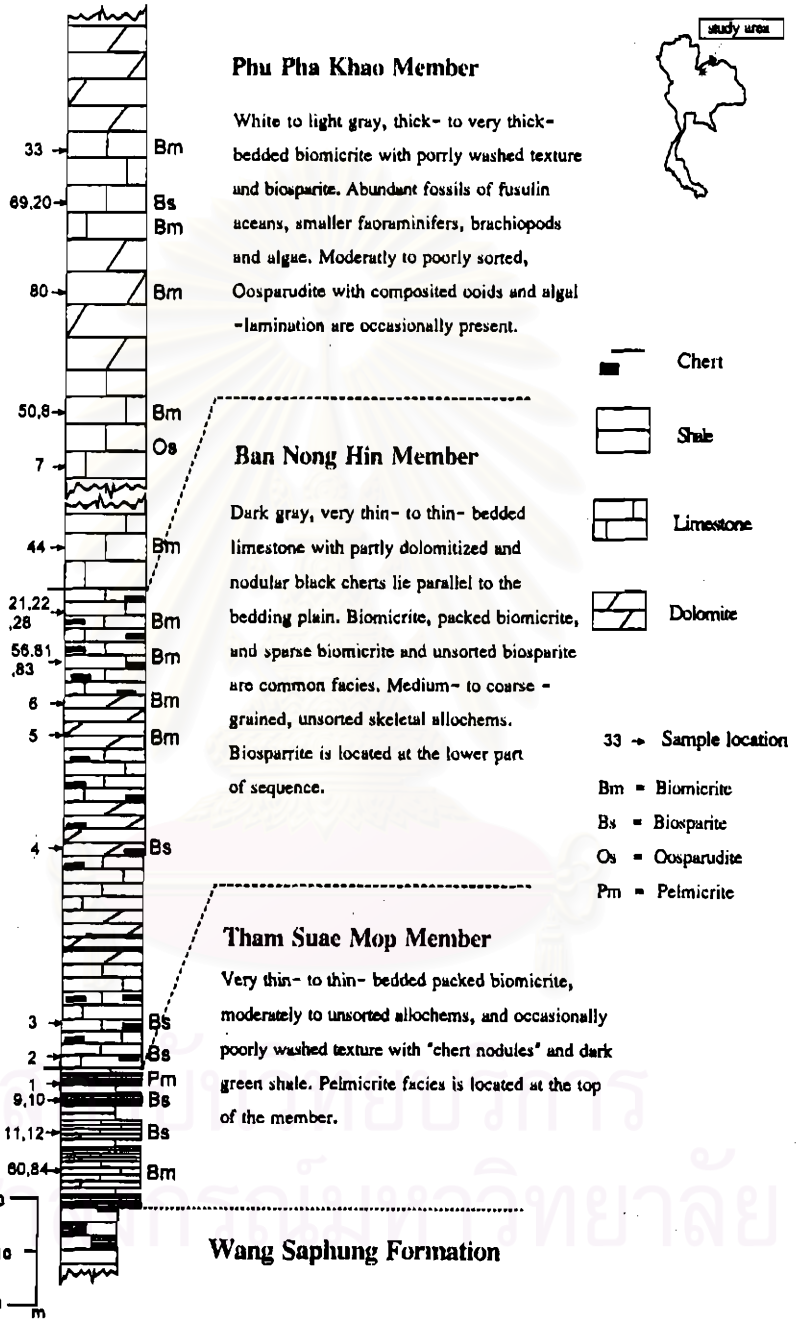

Fig. 3.2 The composited stratigraphic sequence of the Nam Maholan Formation in the study area, with the subdivision of three members.

Table 3.1 Comparative lithology of the carbonate units of the Nam Maholan Formation.

Rock Unit A: Tham Suae Mop Member	***Rock Unit B:*** Ban Nong Hin Member	***Rock Unit C:*** Phu Pha Khao Member
Lithofacies Thin- bedded limestone-shale serquence	Thin-bedded limestone-chert, dolomite sequence	Thin-to very thick-bedded limestone, dolomite sequence
Thickness At least 50 metres	200 to 250 metres	250 to 300 metres
Stratigraphic position Lower unit	Middle unit	Upper unit
Unit boundaries Overlap/overlie the Wang Saphung Formation	Conformably on the unit A	Conformably on unit B, and unconformably under the conglomerate, the Huai Hin Lat Formation
Lithology Thin-bedded, light to dark gray, unsorted, occasionally poorly washed, and packed biomicrite, biosparite, and pelmicrite, interbedded with thin-bedded greenish gray shale, and "chert nodules"	Thin- to medium-bedded, light gray to black colour sparse to packed biomicrite, biosparite, poorly to unsorted biosparite. Thin-to laminated and nodular black cherts, and crystalline dolomite.	Thin- to very thick-bedded, light gray packed biomicrite, biosparite, oosparudite, algal lamination, crystalline limestone and dolomite

Stratigraphically, the over 20 metre-thick carbonate sequence at the Tham Suae Mop and south of the Phu Pha Khao areas are measured (Fig. 3.3, 3.4, and 3.5). In the Tham Suae Mop area, the lower part of approximately 10-metre thick of the exposed section displays light to dark gray thin-bedded biosparite with light gray "chert nodules" (Fig. 3.6). The 3 metre-thick sequence in middle part is characterized by light to dark gray of very thin-bedded fine-grained biosparite interbedded with thinly laminated silty shale (Fig. 3.7). The 2 metre-thick sequence in the uppermost part is represented by thin-bedded fine-grained pelmicrite (Fig. 3.8) underlying the limestone and chert facies of the Ban Nong Hin Member.

The three measured rock sections in the southern part of the study area concerning this formation have been correlated, particularly regarding the upper part of the sequence (Fig. 3.9). The lower boundary is marked by the first appearance of thin-bedded limestone that conformably overlies the sequence of thin-bedded greenish gray shale/siltstone and dark gray limestone lens of the Wang Saphung Formation. The uppermost 10 metre-thick sequence consists of thin-bedded light to dark gray limestone and thin-bedded greenish gray shale (Fig. 3.10). The limestone of the three measured rock sections of this member shows a great variation in lithology. Petrographically, the skeletal allochem varies greatly to over 50 per cent, whereas the other components are mainly micrite and sparite. It is therefore suggested that due to the textural variation, the rock names (Folk, 1959; 1962) cover extensively from micrite, fossiliferous micrite, sparse biomicrite, packed biomicrite, poorly washed biosparite, unsorted biosparite, to poorly sorted biosparite.

Further north in the southeastern part of the Phu Tham Nam area (Fig. 3.11), the upper sequence of the member (20 metre-thick) displays light gray, thin- to medium bedded, with medium-to coarse-grained limestone and gray shale intercalation. Packed biomicrites with poorly washed texture are generally recognized, such as a sample from location no 84 (Fig 3.12). Fossil components are relatively abundant echinoderms, common fusulinaceans, and rare smaller foraminifers as well as brachiopods.

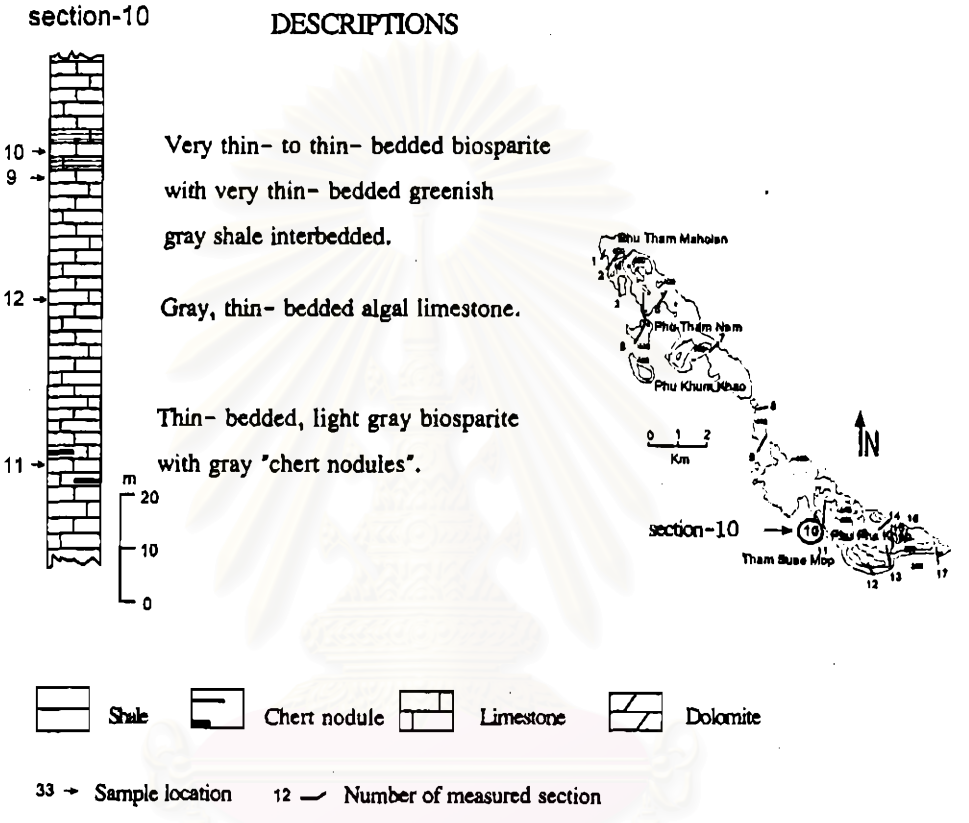

Fig. 3.3 Lithostratigraphic sequence of section-10, the Tham Suae Mop Member, southwest of the Phu Pha Khao mountain.

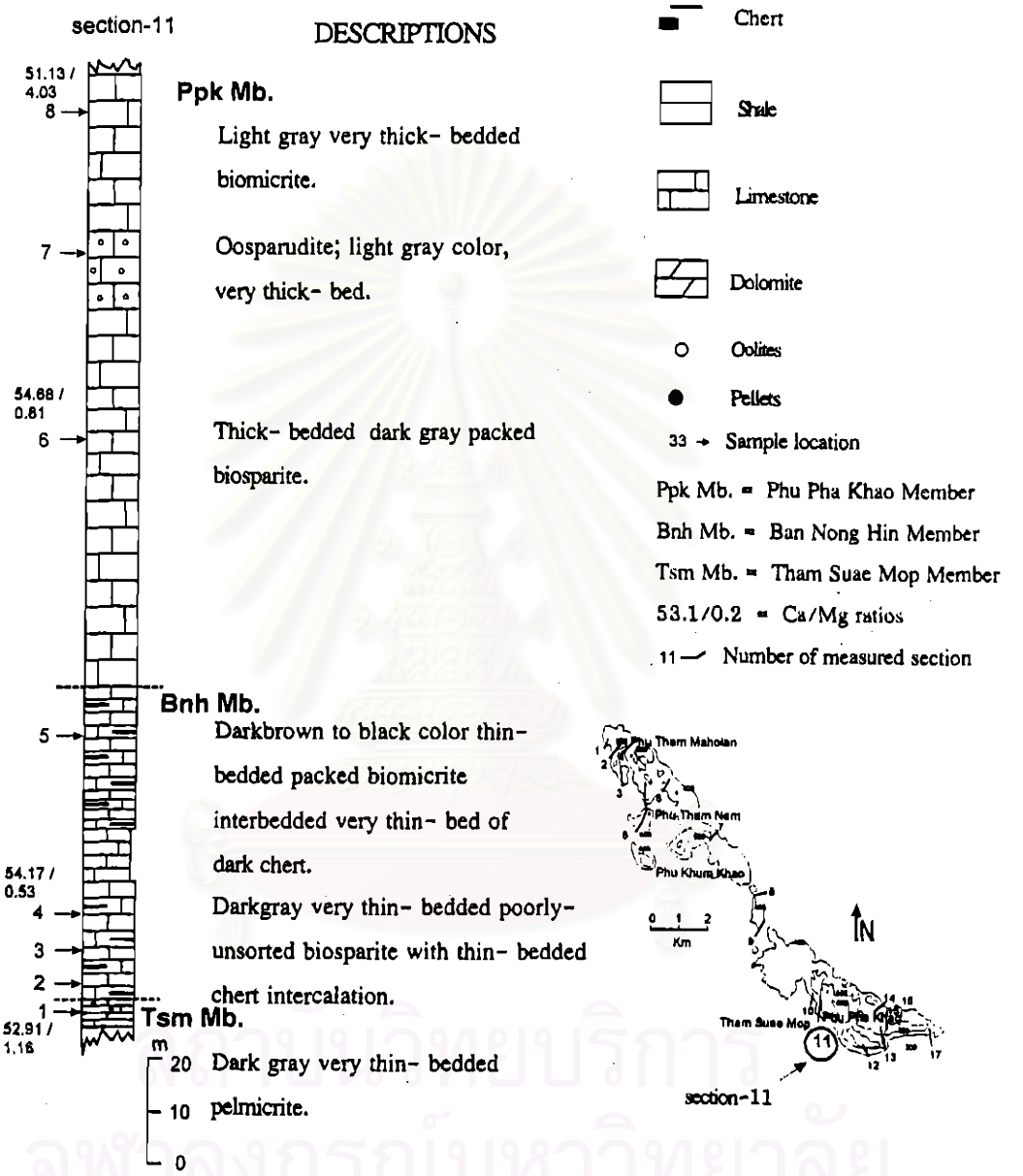

Fig. 3. 4 Lithostratigraphic sequence of section-11, in the vicinity of Tham Suae Mop area.

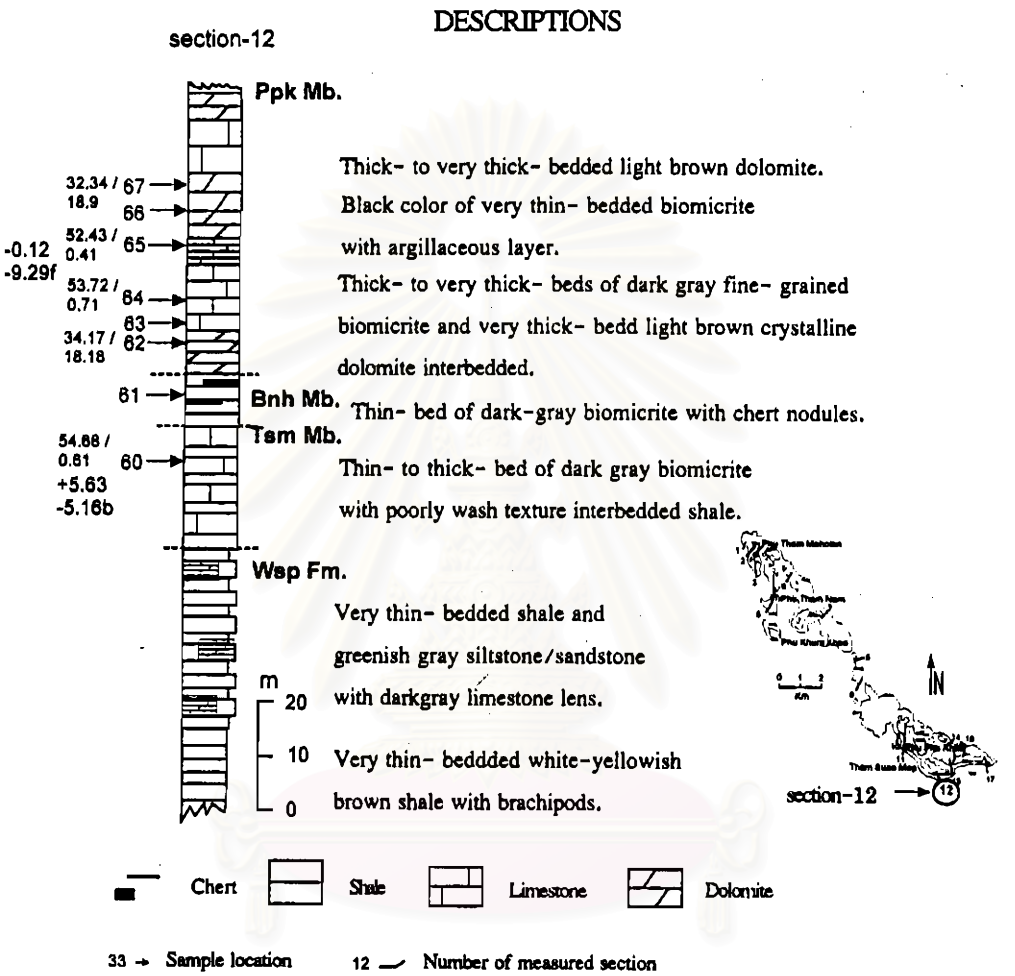

Fig. 3. 5 Lithostratigraphic sequence of section-12 south of the Phu Pha Khao mountain.

Fig. 3.6 Thin-bedded dark gray with "chert nodules" lying subparallel to the bedding plain surface at the lower sequence of the Tham Suae Mop Member (location no. 11 section-10)

Fig. 3.7 The middle sequence of the Tham Suae Mop Member showing channel deposit of very thin- to thin-bedded biosparite with very thin-bedded reddish brown shale and siltstone interbedded (Tham Suae Mop area, location nos. 9, and 10).

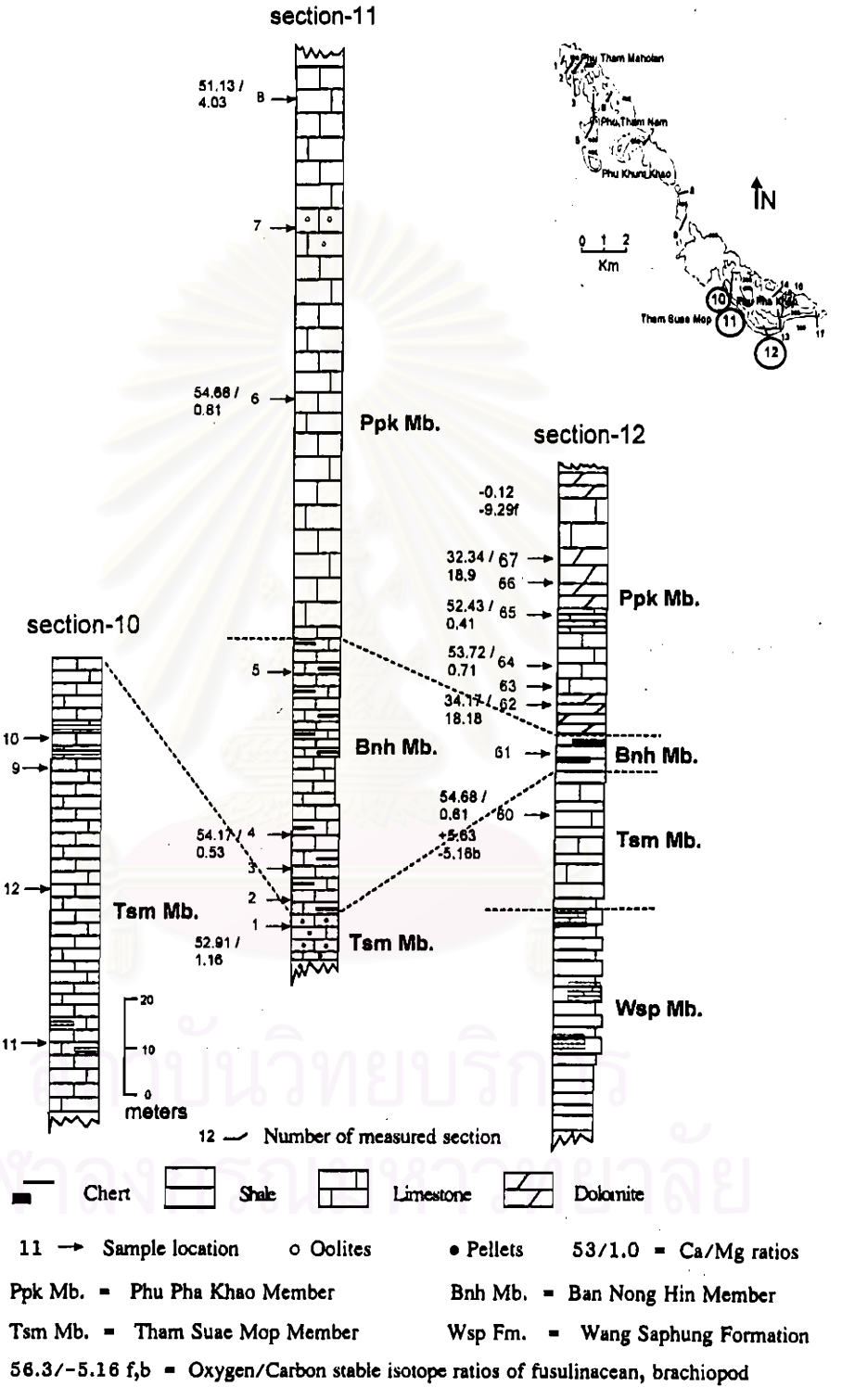

Fig. 3.9 Lithostratigraphic correlation of the measuring sections at the Tham Suae Mop and south of the Phu Pha Khao areas.

Fig. 3.8 Very thin-bedded dark gray fine-grained pelmicrite, with rare fossils underlies limestone-chert sequence of the Ban Nong Hin Member (Tham Suae Mop area, location no. 1, section-11).

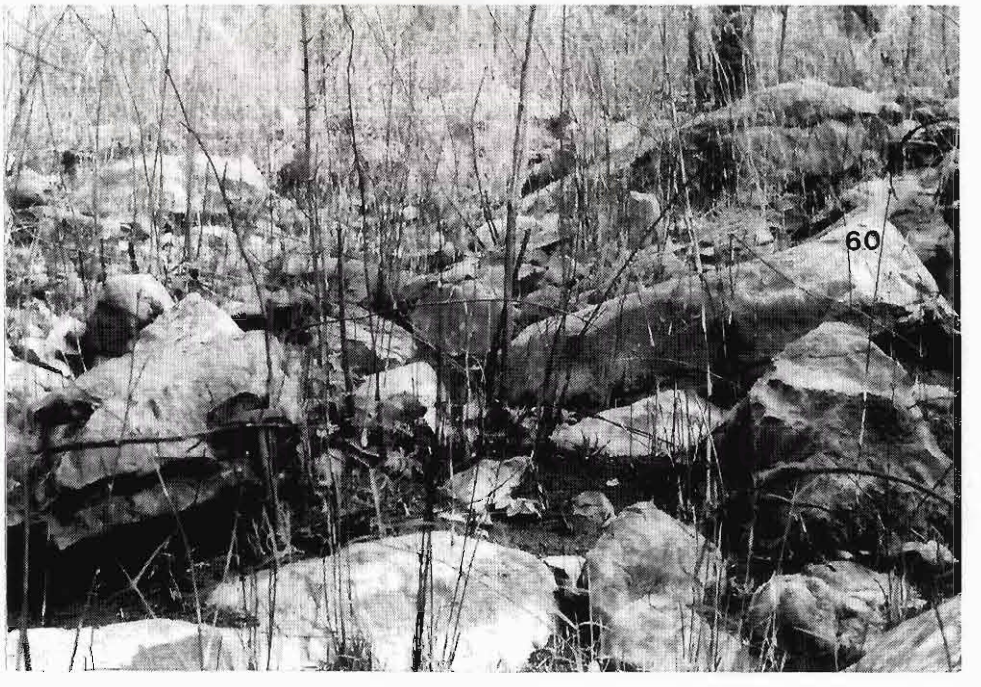

Fig. 3.10 Very thin-to thin bedded light to dark gray biomicrite interbedd thin-bedded shale at southeastern part of Phu Pha Khao mountain (location no. 60, section-12). Fossils-echinoderm, brachiopod, and fusulinacean are common.

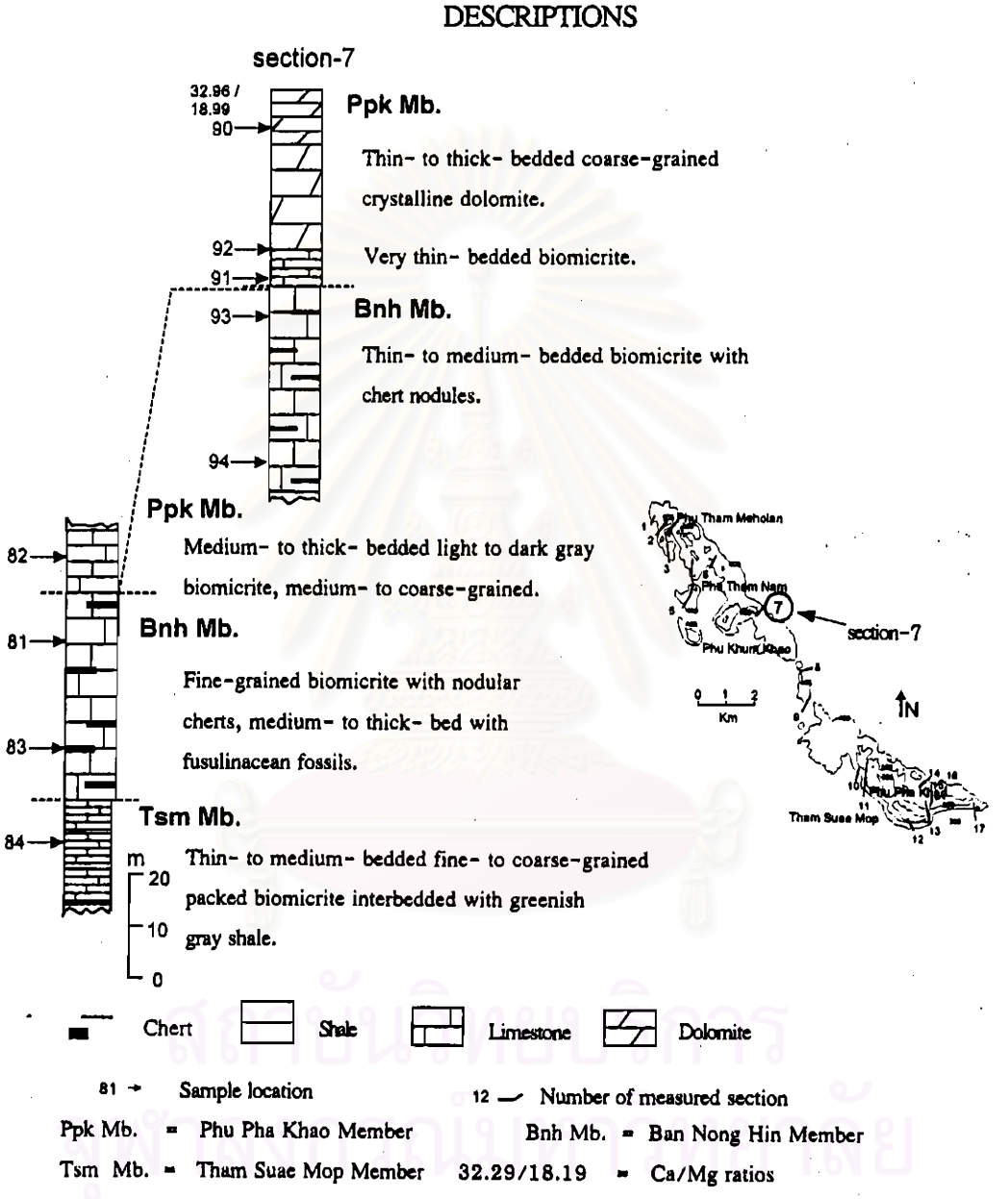

Fig. 3.11 Lithostratigraphic sequence of section-7 east of the Phu Tham Nam area.

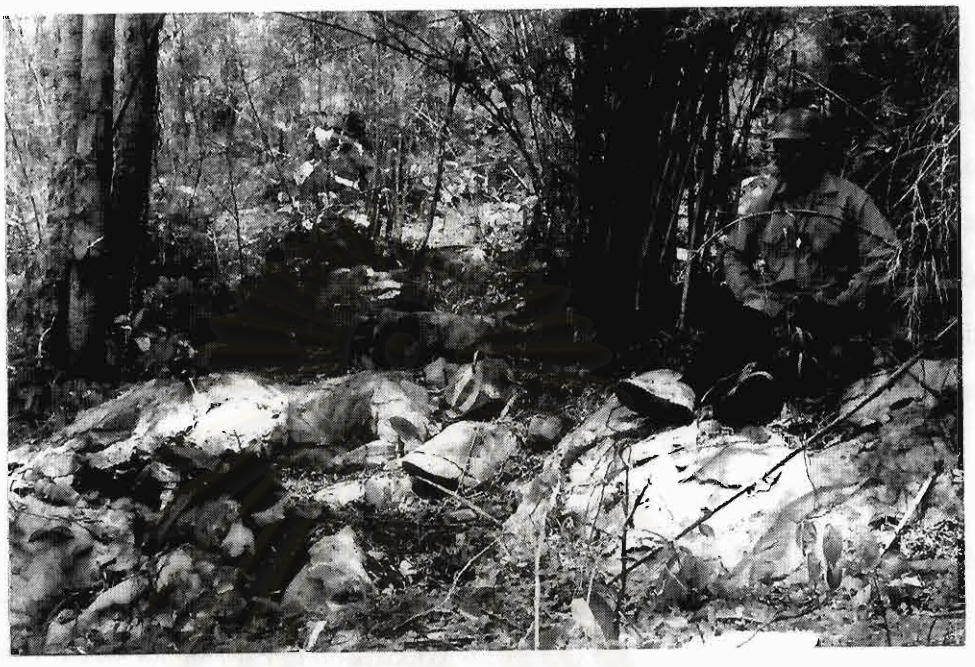

Fig. 3.12 Thin-to medium-bedded, fine-to coarse-grained dark gray packed biomicrite interbedded with shale (location no. 84, section-7).

The Ban Nong Hin Member

(Thin-bedded limestone and chert facies)

The unit is characterized by the succession of very thin- to thick-bedded dark gray to black limestone and dolomite with nodular and thin-bedded dark chert intercalation. Occasionally, thin-laminated shale is interbedded in some places. Limestones are mostly fine-grained and black in colour. Moderately to poorly sorted skeletal, poorly sorted packed biomicrite, and biosparite are generally recognized. Fossils of relatively abundant algae, common fusulinaceans, and smaller foraminifers are identified.

Stratigraphically, the member lies conformably over the Tham Suae Mop Member, and conformably underlies the Phu Pha Khao Member (Figs. 3.2, 3.4, and 3.5). The upper boundary is taken under thick-bedded, light to dark gray chert-free limestone. The lower boundary is characterized by the presence of thin-bedded and nodular black cherts that lie subparallel to the bedding plain surface. The thickness of the member ranges considerably from several meters (4-5 metres) to over 150 metres thick (see also Figs. 3.4, 3.5). Good exposures are at the Wat Phu Tham Maholan and the Tham Suae Mop areas as well as at southeastern part of the Phu Tham Nam areas (Figs. 3.4; 3.11 and 3.13).

Over 150-metre thick of the sequence (Fig. 3.13) is measured at northwestern part of the Phu Tham Maholan, Ban Nong Hin, Amphoe Phu Kradung where the name of the formation is derived. This sequence consists mainly of very thin- to thin-bedded, black colour of fine-to coarse-grained limestone with thin-bedded and nodular black cherts.

These limestones are generally black colour, medium- to coarse-grained, poorly sorted embedded in the mud matrix. The 10 metre-thick lower sequence is represented by very thin-bedded dark gray biomicrite and interbedded dark gray to black chert with occasional interbedded thin-laminated shale (Fig. 3.14). The middle

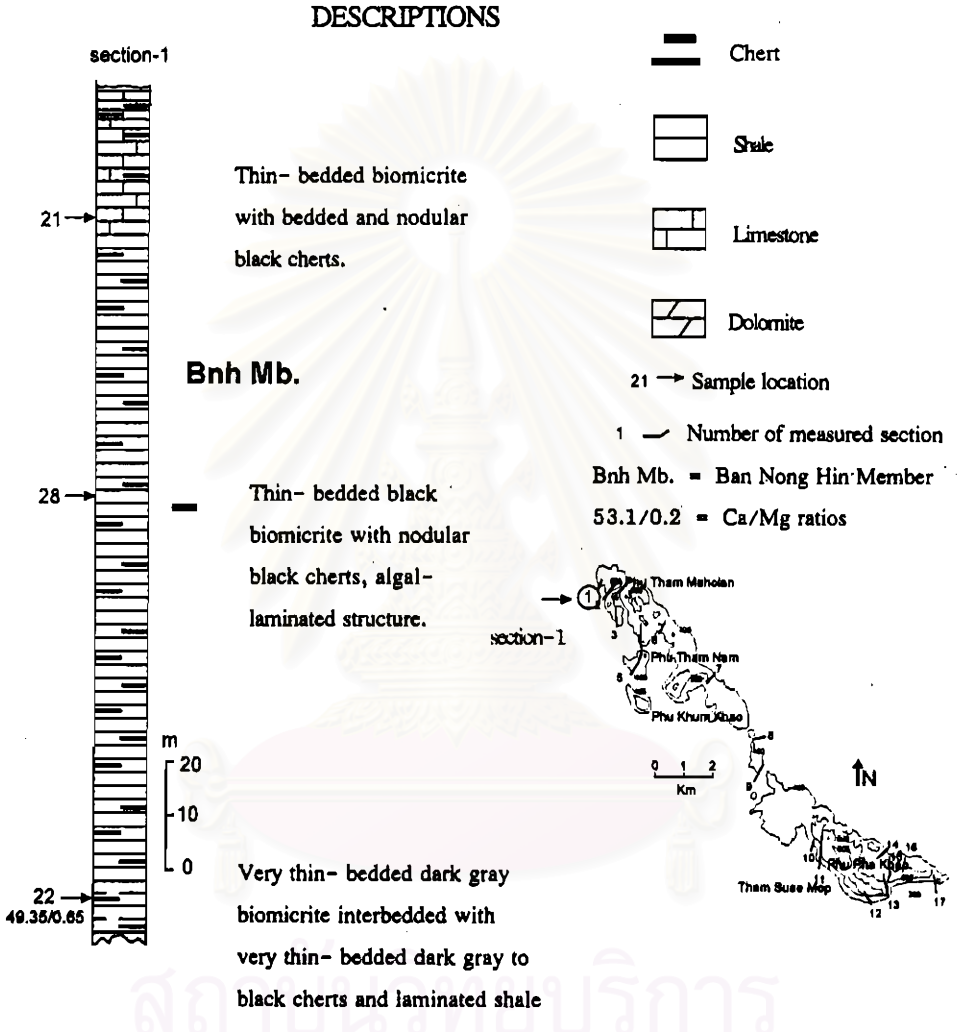

Fig. 3.13 Lithostratigraphic sequence of the section-1 west of the Phu Tham Maholan area.

Fig. 3.14 Very thin-bedded dark gray packed biomicrite interbedded very thin-bedded dark gray to black chert (1-2 cm.) and laminated shale (Phu Tham Maholan mountain, location no. 22, section-1).

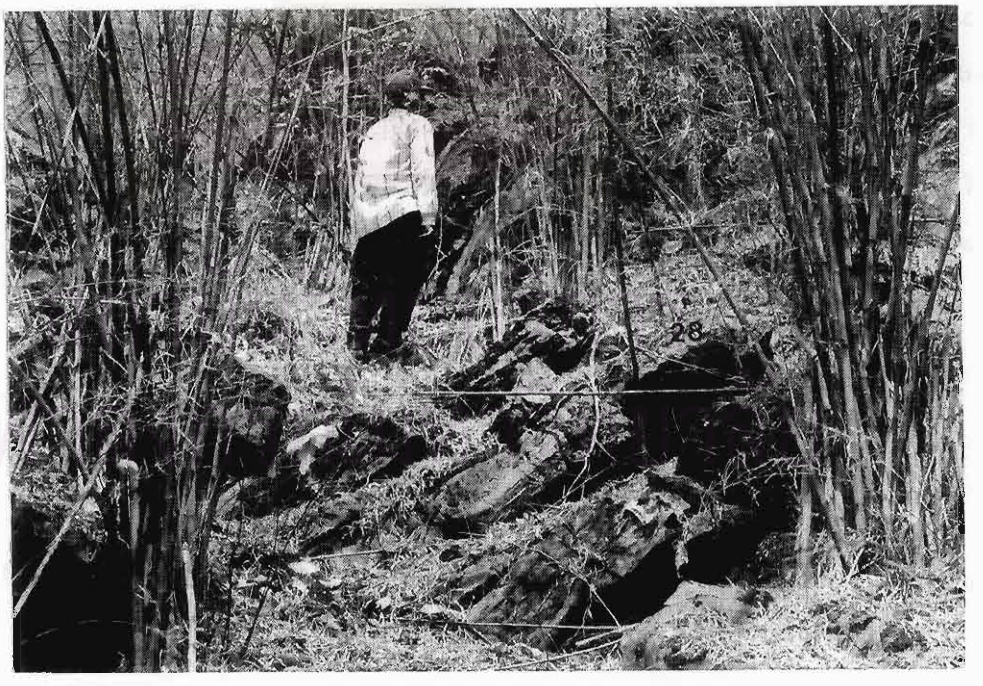

Fig. 3.15 Natural outcrop exposure of thin-bedded dark gray biomicrite interbedded with laminated and nodular black chert (Phu Tham Maholan mountain, location no. 28, section-1).

part of the sequence is approximately 120 metre-thick, displays thin-bedded black sparse biomicrite with unidentified fossil fragments and associated chert nodules (Fig. 3.15). The upper part of the sequence (15-20 metre-thick) is also characterized by thin-bedded fine-grained sparse biomicrite with laminated and nodular cherts (Fig. 3.16). The relatively abundant fine skeletal fragments of fossils, such as, brachiopods, pelecypods, etc., embedded in the matrix are always microscopically apparent.

The measured section at Tham Suae Mop area (Fig. 3.4), the 50 metre-thick sequence represents the dark brown to black-coloured thin-bedded unsorted biomicrite interbedded with very thin-bedded dark chert throughout the sequence (Figs. 3.17, 3.18, and 3.19). Abundance of algae; common crinoids, fusulinaceans, foraminifers; and rare bryozoans are recognized.

The about 100 metre-thick limestone and chert sequence exposes at the eastern part of the Phu Tham Nam area. The lower part of the sequence is represented by the medium- to thick- bedded fine-grained packed biomicrite with chert nodules. Abundant fossils of smaller foraminifers, algae, fusulinaceans, echinoderms, and brachiopods are observed. The upper part of the sequence is represented by thin- to medium-bedded packed biomicrite with chert nodules and dolomite (Fig. 3.20). The dolomite is mostly fine-grained, crystalline and displays black to browish-black colour of thin- bedded and generally interbeds with thin-bedded black chert.

The Phu Pha Khao Member
(Thin- to very thick-bedded limestone facies)

The almost entirely limestone sequence is designated as the Phu Pha Khao Member, following the name of the mountain, situated in the western part of Ban Dong Noi, Amphoe Pha Khao, Changwat Loei (Fig. 3.1). The member is considered to the uppermost member of the Nam Maholan Formation which is characterized by predominantly white to light gray, thin- to very thick- bedded limestone, and fine-to

Fig. 3.16 Outcrop of thin-bedded, black colour, fined-grained sparse biomicrite with laminated and nodular chert (Phu Tham Maholan, location 21, section 1).

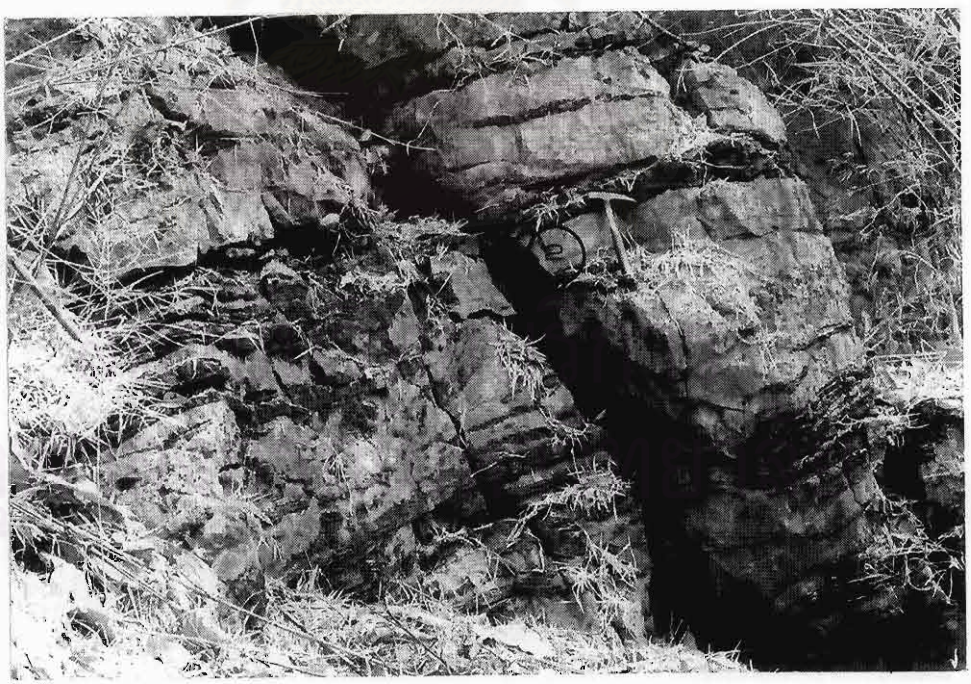

Fig. 3.17 Very thin-to medium bedded dark gray biomicrite interbedded with very thin-bedded and nodular black chert lying subparallel to the beddeing of the Ban Nong Hin Member (Tham Suae Mop area, location no. 2, section-11).

Fig. 3.18 Very thin-bedded chert interbedded with thin-bedded biosparite (vicinity of Tham Suae Mop, location no. 4 section-11).

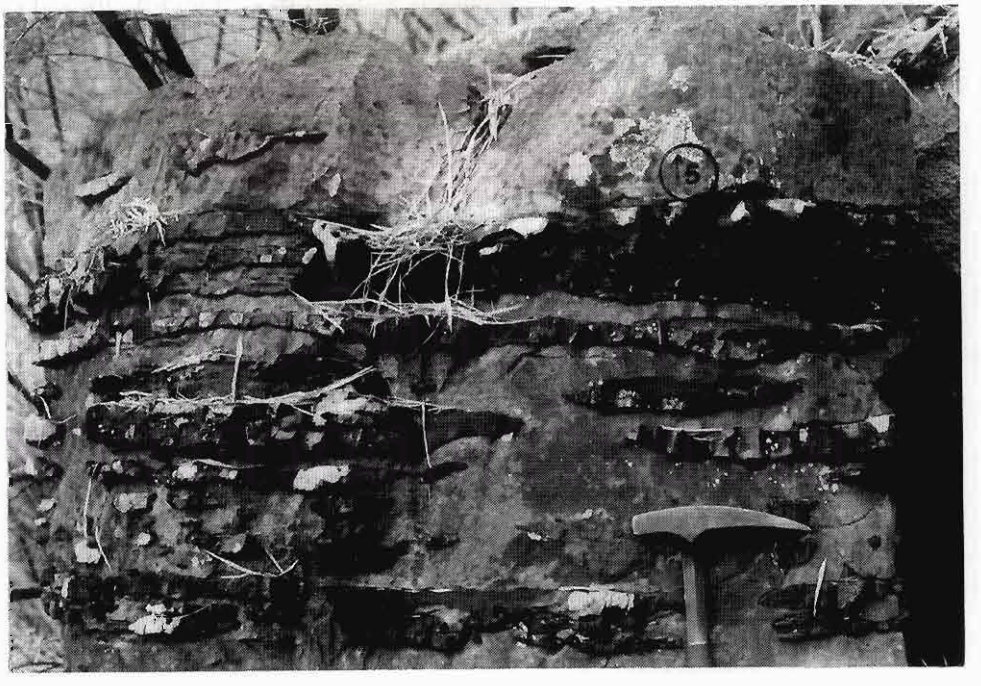

Fig. 3.19 Black colour of chert lying subparallel to surface bedding of packed biomicrite (vicinity of Tham Suae Mop, location no. 5, section-11).

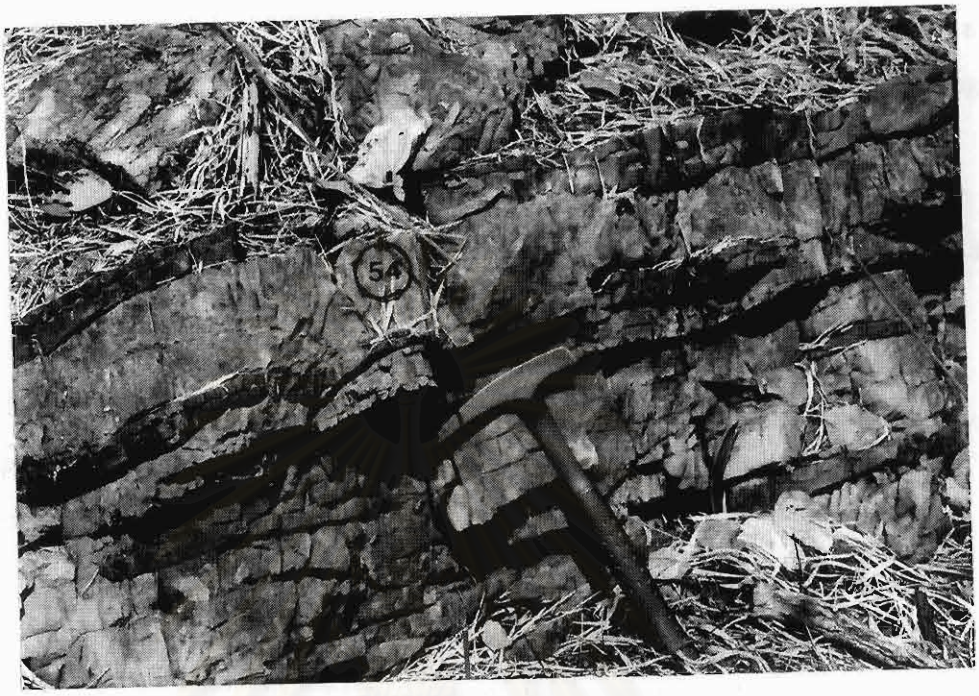

Fig. 3.20 Black coloured, thin-bedded, fine-grained dolomite with very thin-bedded black chert of the upper Ban Nong Hin Member (location no. 54, section-5). Photomicrograph is illustrated in Fig. 4.2.

coarse grained crystalline dolomite. Limestones are fossiliferous containing abundant fossils of brachiopods, pelecypods, smaller foraminifers, fusulinaceans, and algae. Algal lamination and oolites of restricted geometry are the most diagnostic lithology.

Approximately 300 metre-thick sequence continuously exposures at the Phu Tham Maholan, the Phu Kum Khao and the Phu Pha Khao areas (Fig. 3.1). Stratigraphically, the member lies conformably on the Ban Nong Hin Member. The lower boundary is marked by disappearance of chert in the sequence of thick- to very thick-bedded limestone and dolomite of white to yellowish brown, and gray colours. The upper boundary is defined by an overlain unconformity of silicified greenish gray conglomerate of the Huai Hin Lat Formation.

An approximately 150 metre-thick sequence at the Phu Tham Maholan (Fig. 3.21), consists of white to cream colour of thick- to very thick-bedded limestone (Figs. 3.22, 3.23). Fossils of brachiopods, fusulinaceans, and smaller foraminifers are generally recognized. Sparse to packed biomicrite and biosparite are the main rock types. The crystalline texture is also apparent.

The area south of the Phu Tham Maholan (Fig. 3.24), over 300 metre-thick sequence displays mostly white- to cream-coloured thick-bedded and fine-grained dolomite (sample no. 46). The "elephant skin" surface textures are generally developed on the outcrops due to differential weathering process (Figs. 3.25, 3.26). The interbedding of white to light gray of thin- to very thick-bedded limestone contains brachiopods and fusulinaceans. Biomicrite of fine-to coarse-grained nature is proposed as the rock name.

In the area of Tham Suae Mop, over 100 metre-thick sequence displays white to light gray, thick- to very thick-bedded biomicrite to biosparite. There are relatively abundant fossils of fusulinaceans, algae and skeletal fragments. Coated grains of oolites and pisolites are occasionally observed in some thin-sections.

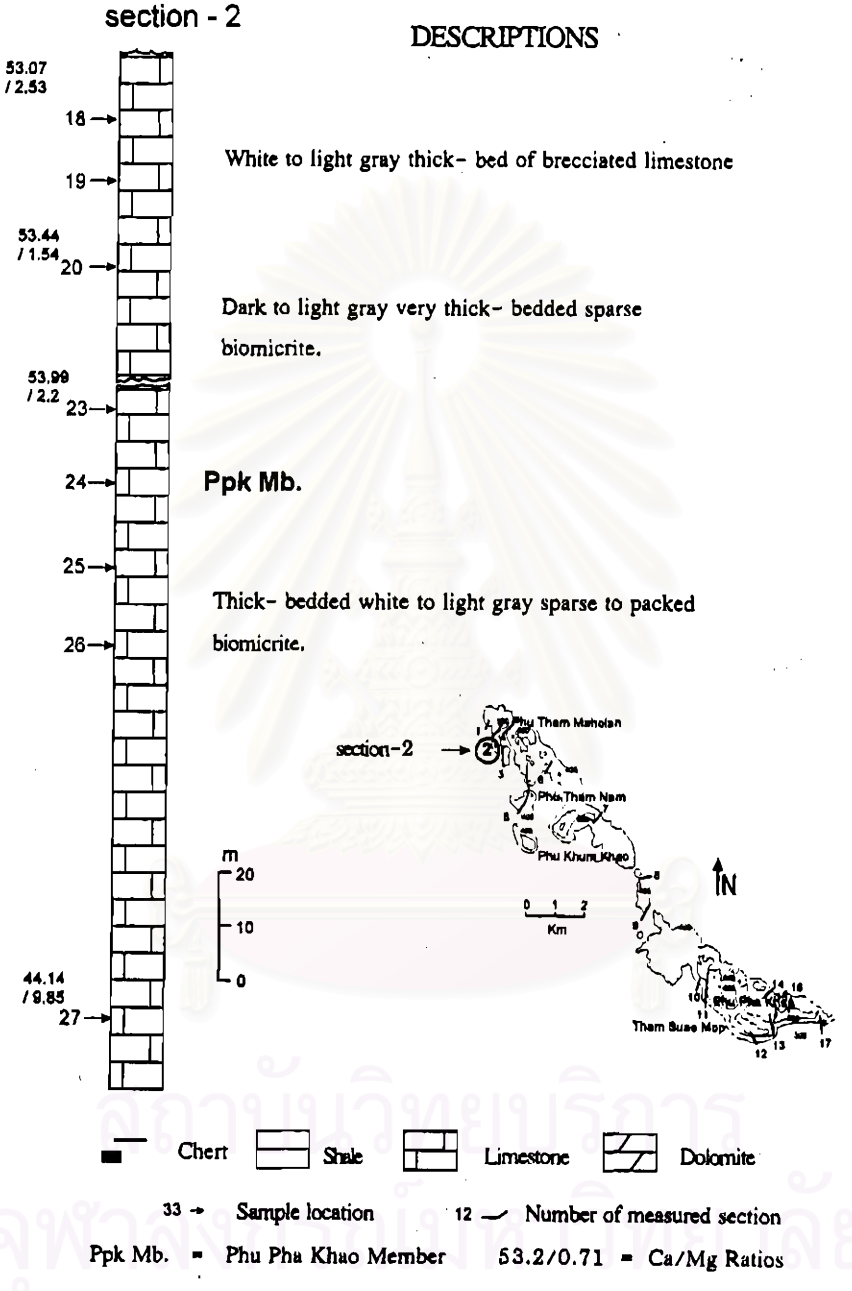

Fig. 3.21 Lithostratigraphic sequence of section-2 west of the Phu Tham Maholan mountain.

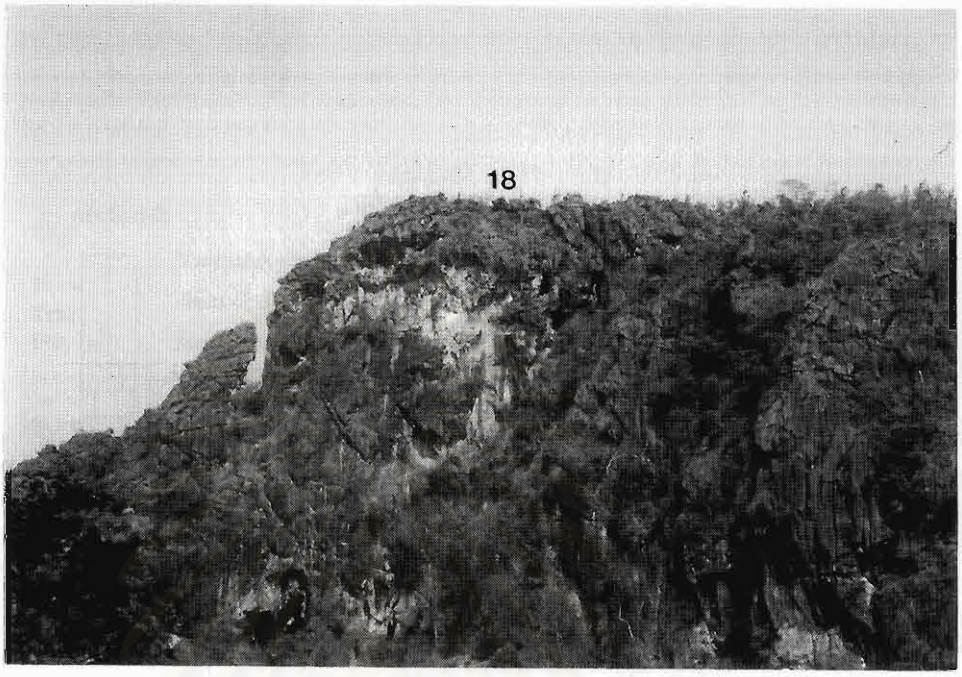

Fig. 3.22 Topographic expression of light gray, thin-to very thick-bedded limestone at Phu Tham Maholan mountain.

Fig. 3.23 White to light gray, thick-bedded crystalline limestone of the Phu Pha Khao Member (Phu Tham Maholan mountain, location no. 18, section -2). Typical weathered surface of rather pure limestone (CaO 53.07 wt%).

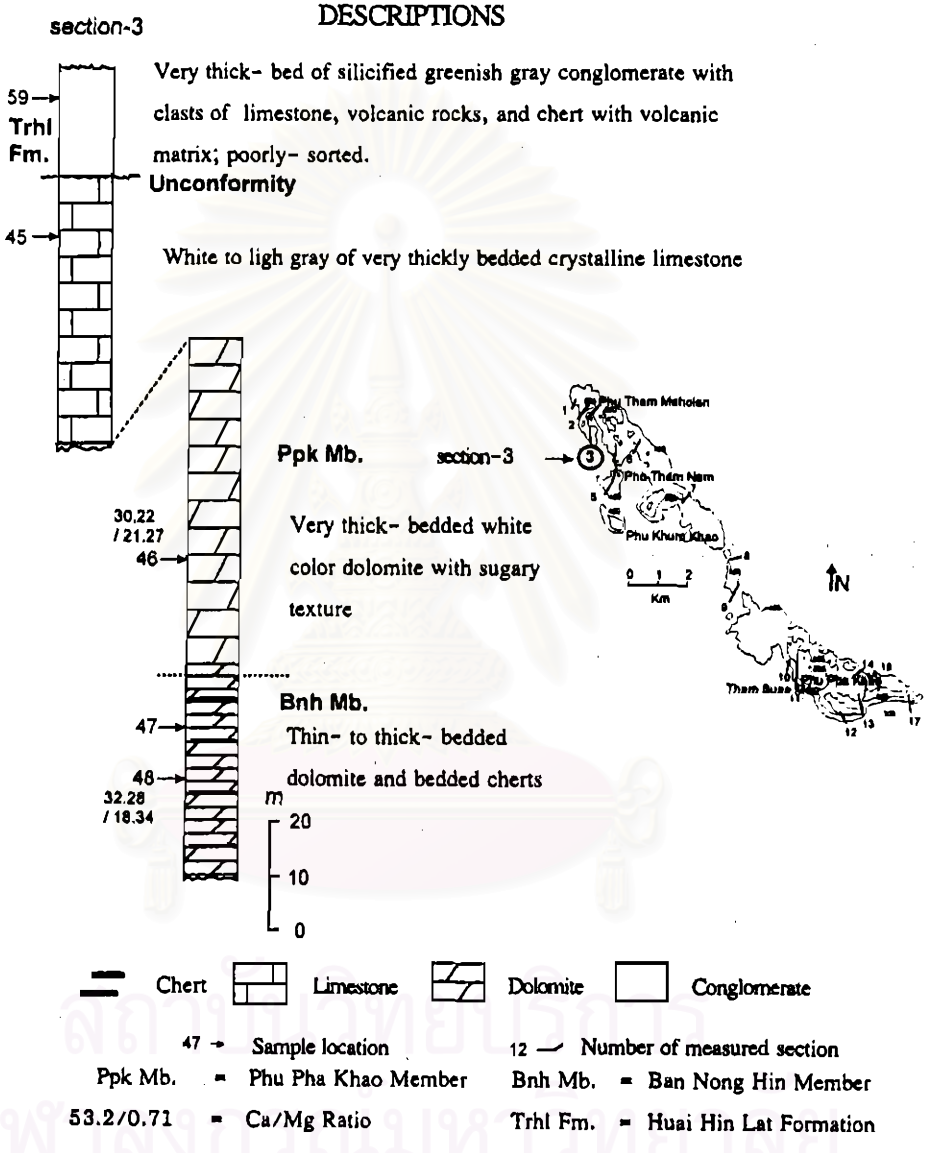

Fig. 3.24 Lithostratigraphic sequence of section-3 south of the Phu Tham Maholan mountain.

Fig. 3.25 Thick-bedded white colour, fine-grained dolomite with sugary texture showing the "elephant skin" weathered surface (location no. 46, section-3). Photomicrograph is illustrated in Fig.4.3. Geochemically, the rock contains MgO 21.27 wt%.

Fig. 3.26 Medium-bedded dark gray of fine-grained dolomite with sugary texture and typical "elephant skin" weathered surface (location no. 53, section-5).

The area south of the Phu Pha Khao (Figs. 3.5 and 3.27), approximately 100 metre-thick succession of thin- to thick-bedded, light gray to yellowish brown dolomite and limestone (Fig. 3.28). Occasionally, the algal lamination in the outcrops appears as very thin-laminated limestone (Fig. 3. 29).

Age determination

The Upper Palaeozoic carbonate platform covering the western region of the Khorat Plateau from north to south and also the eastern Loei region, have been dated palaeontologically as Late Carboniferous (Gzhelian age) to late Middle Permian (Murghabian age) based mainly on foraminifers with associated brachiopods and algae (Igo, 1972; 1974; Yanagida, 1967; Kobayashi and Hamada, 1979; Ingavat and Janvier, 1981; Chairangsee *et al.*, 1990; Fontaine and Sutheetorn, 1988; Fontaine *et al.*, 1981; 1991; 1994, 1996; Dawson, 1976; 1978; Dawson and Racey, 1993; Ueno and Sakagami, 1993; Ueno *et al.*, 1995; 1996; Chonglakmani and Fontaine, 1990; Chonglakmani *et al.*, 1990; Charoentitirat, 1995, Wielchowsky and Young, 1985, etc.)

The correlation scheme of tentative carbonate stratigraphy of the Loei, Phetchabun-Lamnarai and Saraburi areas (Fig. 3.30) based on those identified key fossils indicate that these ancient carbonates were formed in Late Viscean both in the Loei and Phetchabun-Lamnarai areas. Excluding small isolated Silurian-Devonian limestone mountains, the platform carbonate was accumulating since Gzhelian through Murghabian age in the Loei area (Pha Nok Khao or Nam Maholan platform herein), during Gzhelian to Midian age in the Phetchabun-Lamnarai area (part of Num Duk basin and Khao Khwang platform), and during Sakmarian to Midian age in the Saraburi areas (Khao Khwang platform).

The carbonate rocks in the study area show abundance of fusulinaceans, smaller foraminifers, brachiopods, algae, and common echinoderms, pelecypods, gastropods, and bryozones The age detemination of rocks in the area is based mainly

on foraminifers (Table 3.2), suggesting Gzhelian to Yahtashian age (Late Carboniferous to late Early Permian).

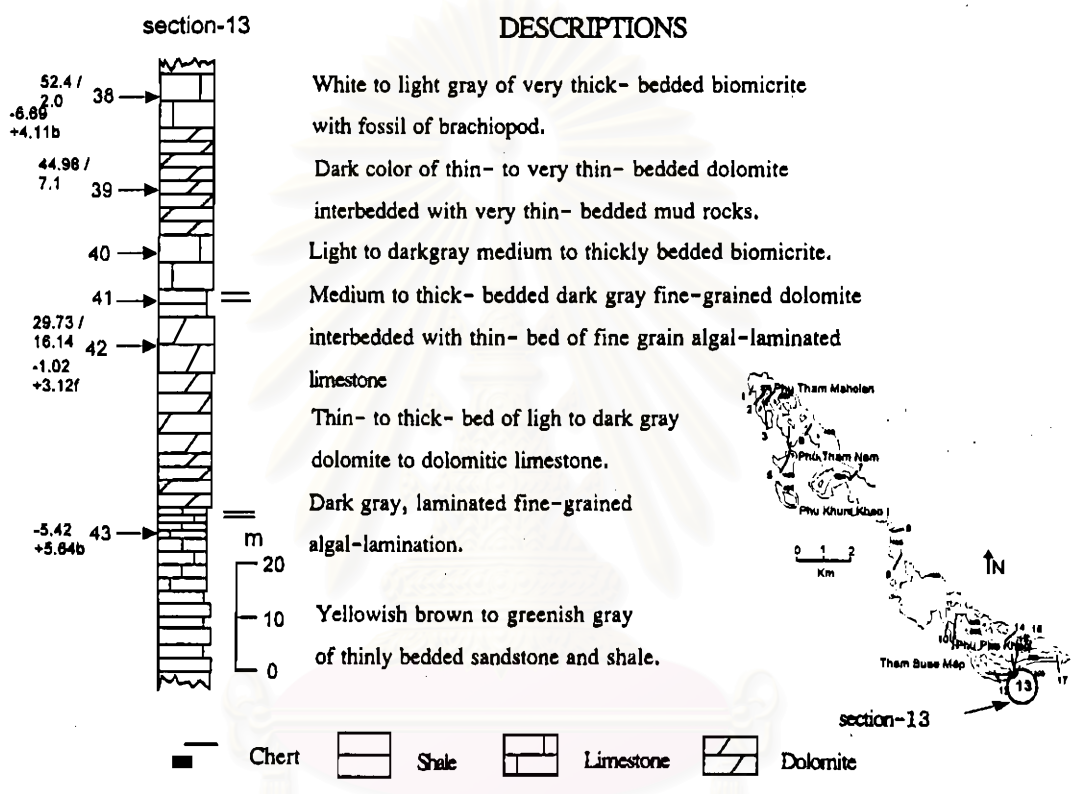

Fig. 3.27 Lithostratigraphic sequence of section-13 south of Phu Pha Khao moutain.

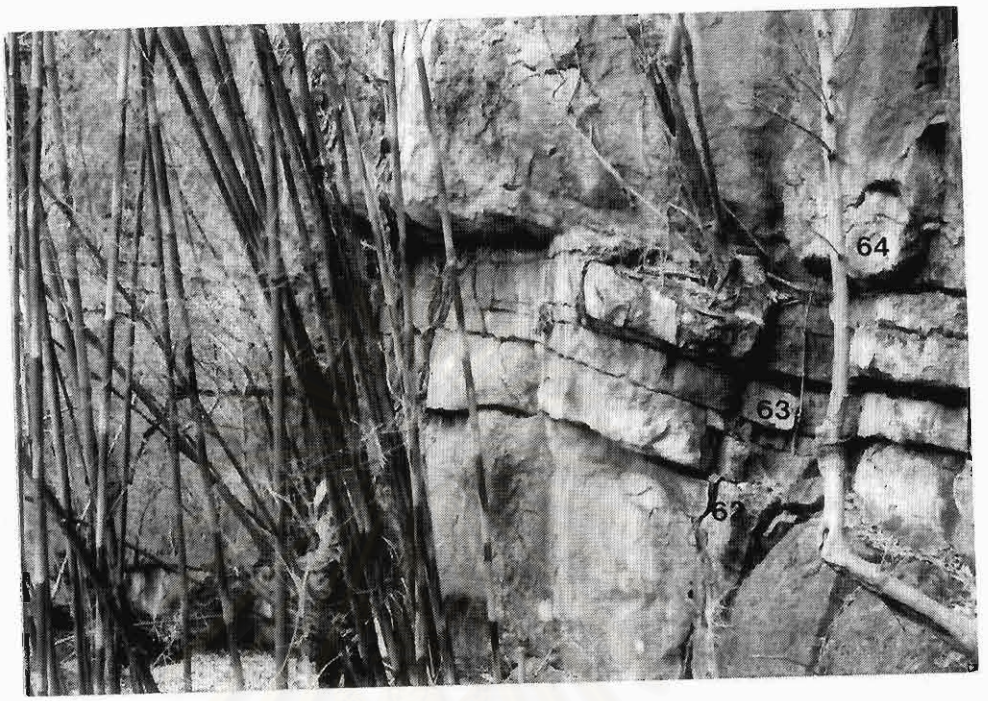

Fig. 3.28 Interbedding of thin-to thick-bedded light gray to yellowish brown limestone and dolomite of the Phu Pha Khao Member (southern part of Phu Pha Khao mountain, location nos. 62, 63, and 64, section-12).

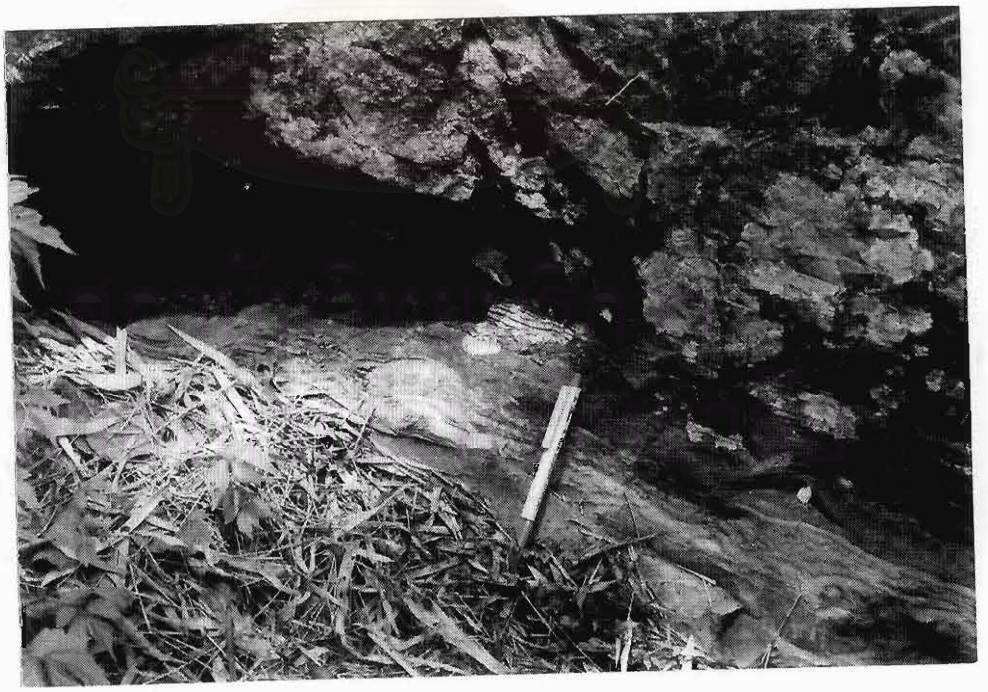

Fig. 3.29 Algal lamination in limestone of the Phu Pha Khao Member (location no. 43-1).

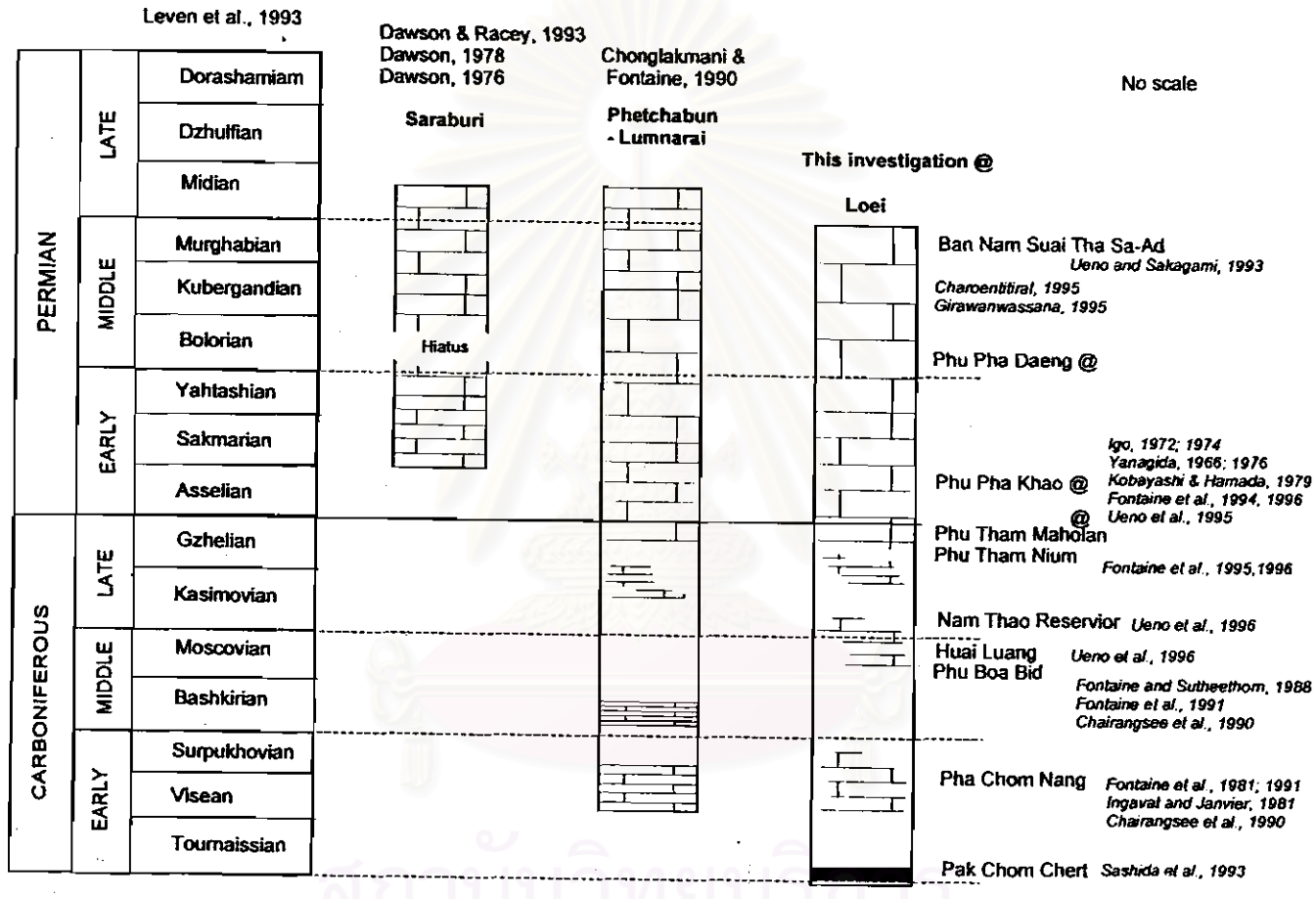

Fig. 3. 30 Correlated stratigraphic scheme of the carbonate columns of the Saraburi, Phetchabun, and Loei areas. Established on identified key palaeontologcal evidences by several workers.

Table 3.2 List of fossils identification of the study area.
(Identified species by Jumnongthai, J. 1997).

Sample no.	Fossils
2	*Eotuberitina reitlingerae Rugosochusenella* sp.
6	*Tubiphytes obscurus, Schubertella* sp., *Pseudofusulina* sp., *Bradyina* sp.
7	Fusulinaceans: *Pseudofusulina* sp., *Schubertella* sp., Smaller foraminifers; *Tetrataxis* sp.
10	*Tubiphytes* sp., *Tetrataxis* sp., *Schwagerina* sp., *Tuberitina collosa.*
20	Brachiopod; *Productus* sp., Pelecypod, Ostracod, Bryozoa Fusulinacean; *Schwagerina* sp.
- 33	Algae; *Tubiphytes* sp., Fusulinacean; *Schwagerina* sp.
34	Fusulinaceans; *Pseudofusulina* sp., *Schubertella sp.*
38	Pelecypod, Fusulinaceans.
44	Bryozoan, *Schagonella* sp., *Tubiphytes* sp.
50	Fusulinaceans; *Pseudofusulina sp. Parafusulina* sp. Smaller foraminifers; *Bradyina* sp.,*Climacammina* sp., *Eotuberitina reitlingerae, Palaeotextularia sumatrensis*
69	Fusulinaceans; *Pseudofusulina sp., Protonodosaria* sp.
70	Fusulinacean; *Pseudofusulina* sp., Smaller foraminifer.
71	Fusulinacean; *Pseudofusulina* sp. Smaller foraminifera fragments, *Bradyina* sp., Algae, Gastropods
73	Fusulinaceans; *Pseudofusulina sp., Schubertella* sp., *Deckerellina sp.*
80	Ostracod, Echinoderm spine
82	Fusulinacean; *Pseudofusulina* sp., *Schubertella* sp. *Smaller foraminifer; Bradyina* sp., *Climacammina* sp., *Tetrataxis* sp. *Protonodosaria* sp.
83	Fusulinacean; *Pseudofusulina* sp., *Smaller foraminifers; Cribrogenerina* sp. *Protonodosaria* sp.
84	Fusulinacean; *Schubertella* sp.

Table 3.2 (cont.)

85	Fusulinaceans; *Schwagerina* sp., Smaller foraminifers; *Climacammina sp.*, Pelecypod.
88	Fusulinacean; *Pseudufusulina* sp., Ostracod, Smaller foraminifera; *Spiroplectammina* sp. *Calcitornella* sp., *Eotuberitina* sp., *Turbiphyte* sp.
98	Fusulinaceans; *Schubertella* sp. *Triticites* sp. *Smaller foraminifers; Tetrataxis* sp., Algae.