CHAPTER I

INTRODUCTION

Short ranging, rapid evolution, widespread geographic distribution and sensitiveness to physical environment of fusulinacean faunas make them to be good index fossils and stratigraphic indicators. Due to, fusulinids are dominant in Carboniferous and Permian rocks, extensively distributed in Thailand, so the study of fusulinids is interesting and important to geological research and stratigraphic correlation in Thailand and adjacent countries.

The investigated area of exposed Carboniferous and Permian rocks is in the eastern part of Changwat Loei. The rock sequences consist of dark grey, massive to thick-bedded limestones intercalated with calcareous mudstone, calcareous shale and greywacke. These limestones comprise abundant fusulinids, associated with corals, pseudo-algae, crinoids, smaller foraminifers and shell fragments. Study on fusulinacean faunas and classification of carbonate rocks exposed in the area under investigation can provide the ages and depositional environments of the carbonate rocks.

The study area

The study area is situated approximately at latitude 17° 15' to 18° 15' and longitude 101° 30' to 102° 15' which is on the north-western part of Khorat Plateau. The research area in the eastern part of Changwat Loei covers 12 localities (Figure 1) including Pha Mo (grid reference 133393), Pha Mo Noi (grid reference 135367), foot of Phu Khao near Pha Mo Noi (grid reference 131367), at Km 30+050 along

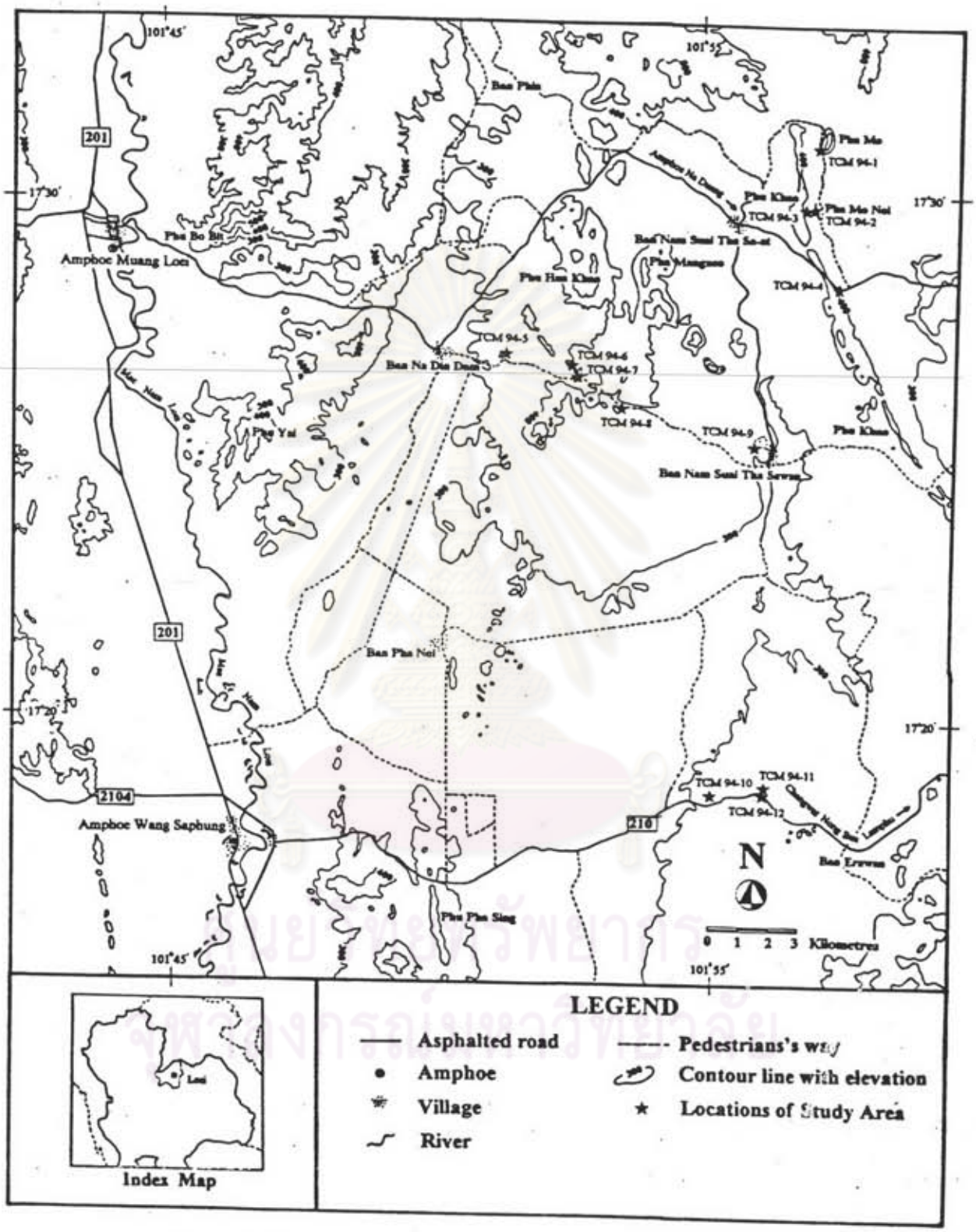

Figure 1 The research area in the eastern part of Changwat Loei.

Changwat Loei-Amphoe Na Duang road (grid reference 139343), along the road from Ban Na Din Dam to Ban Nam Suai Tha Sawan at grid references 028313, 054312, 055309 and 069298. Wat Sunantharam (grid reference 144284), along Amphoe Wang Saphung to Changwat Nong Bua Lamphu highway at Km 15+080 (grid reference 099164) and Km 17+080 (grid references 118167 and 118166). They are present in Table 1. The detailed stratigraphic studies are at the foot of Phu Khao near Pha Mo Noi, Km 30+050 along Loei-Na Duang road, Wat Sunantharam and along Amphoe Wang Saphung to Changwat Nong Bua Lamphu highway at Km 17+080. They are in the topographic maps scale 1:50,000, Series L 7017, Sheet 5344 II (Ban Sup), Series L 1707, Sheet 5343 I (Amphoe Wang Saphung) and the geologic map scale 1:250,000 Sheet NE 47-12 (Changwat Loei).

Objectives

Materials for the present research are thin- to thick-bedded limestones with various types of fusulinids and associated faunas. Four main purposes of the detailed studies of these limestones and fusulinacean faunas can be classified as follows :

1. To describe and classify fusulinids in the eastern part of Changwat Loei.
2. To study the stratigraphy, correlation, classification and age determination of carbonate rocks within the investigated area.
3. To study the paleoenvironment of fusulinids.
4. To study the evolution of fusulinids in limestone beds.

Methodology of the study

Field investigation and sample collection in the eastern part of Changwat Loei were carried out on May and December, 1994. The Thai army topographic maps on a

Table 1 List of the study locations in Amphoe Muang and Wang Saphung, Changwat Loei.

No.	Location	Area	Grid reference
1.	TCM 94-1	Pha Mo	133393
2.	TCM 94-2	Pha Mo Noi	135367
3.	TCM 94-3	Phu Khao	131367
4.	TCM 94-4	Km 30+050 along Changwat Loei-Amphoe Na Duang road	139343
5.	TCM 94-5	Road from Ban Na Din Dam to Ban Nam Suai Tha Sawan	028313
6.	TCM 94-6	Road from Ban Na Din Dam to Ban Nam Suai Tha Sawan	054313
7.	TCM 94-7	Road from Ban Na Din Dam to Ban Nam Suai Tha Sawan	055309
8.	TCM 94-8	Road from Ban Na Din Dam to Ban Nam Suai Tha Sawan	069298
9.	TCM 94-9	Wat Sunantharam	144284
10.	TCM 94-10	Km 15+080 along Amphoe Wang Saphung to Changwat Nong Bua Lamphu highway	099164
11.	TCM 94-11	Km 17+080 along Amphoe Wang Saphung to Changwat Nong Bua Lamphu highway	118167
12.	TCM 94-12	Km 17+080 along Amphoe Wang Saphung to Changwat Nong Bua Lamphu highway	118166

scale 1:50,000, Series L 7017, Sheet 5344 II of Ban Sup and Series L 7017, Sheet 5343 I of Amphoe Wang Saphung were used as the base maps. Rock samples were collected from 12 localities. Four localities were measured and studied in detail.

Measuring stratigraphic sections of limestones including thickness, components, colour and relative stratigraphic locations were carried out, together with collecting rock and fossil samples of those stratigraphic sections. Most samples were measured and drawn the strike and dip of a planar surface before breaking the samples from the outcrops. Also, photography was very useful in the study of specimens and in making permanent record.

In the laboratory, about 250 thin sections of limestones were prepared for petrographic and paleontologic identifications. They provide the ages and depositional environments of the carbonate rocks under study. The ages of limestones were referred to the Stage scale in the Mediterranean-Alpine fold belt (Table 1-1) which was established by Leven (Racey and others, 1994). It extensively use for the countries in Southeast Asia such as Japan, Thailand, Malaysia, etc. The classification of limestones follow Folk (1959, 1962) and Dunham (1962) which are based on composition and texture types. The interpreted shallow marine depositional conditions were compared and referred to Wilson (1975).

Morphology of fusulinid

The morphology of fusulinid has been studied by many researchers, for example, Cushman (1940), Moore and others (1952), Moore (1964), Sundharovat and Nogami (1972), Boardman and others (1987) and Personal communication from R.

Ingavat-Helmcke (1995). Their works were considered and concluded to this part as follows :

The fusulinid tests are mostly fusiform, globular or subcylindrical (rarely lenticular) in shape (Figure 2) and coiled around an axis. The tests of many different genera are similar in the external appearance, but the internal structure may be quite dissimilar. Classification on internal shell features of fusulinid can be determined from thin sections or polished slices. Two sections are indispensable which cut through the beginning chamber. They disclose most internal features of the shell. One of these slices bisecting the shell with parallel to the axis of coiling including the center of the proloculus, is called an **axial section** (Figure 3). The other, slices through the test with vertical to the axis of coiling and passing the proloculus, is called a **sagittal section** (Figure 3). A section parallel to the axis of coiling but not through the initial chamber is a **tangential section** (Figure 3). A section vertical to the axis of coiling but no passing the proloculus, is called a **parallel section**. Sections cut in directions neither parallel to the axis of coiling nor normal to it are referred to **oblique section**.

Fusulinid growth starts with a minute sub-spherical initial chamber called the **proloculus** (Figures 2 and 3). Chambers are added around the proloculus with an axis of coiling to form a coiled test. The outer or upper wall of test encloses the chamber, is called **spirotheca** (Figures 2 and 4). Shell increases in size by secretion at the outer margin of the shell, forming new chambers. Partition between chambers, commonly consisting of previous outer wall is called **septum**. As each chamber is added, the last-formed septum becomes the **antetheca** (Figure 2). **Septal pore** (Figures 2, 4 and 5) is the small perforation in septum and antetheca. The external view of shell is divided by shallow closely spaced meridional grooves, **external furrow** (Figure 2) which mark the position of the septa. Folding or corrugation of septum and antetheca transverse to

the axis of coiling, are **septal fluting** (Figure 2). The septa are essentially plane in many of the primitive fusulinids. They evolve fluting in more complex forms and **chamberlets** develop where opposing folds touch and partly divide the chambers. **Cuniculus** is tunnel-like passageways between alternate chamberlets formed by strong septal fluting. Resorbed area at base of septa in the central part of fusuline is **tunnel** (Figure 4). **Choma** is a ridge of dense calcite which deposited beside the tunnel.

Two important wall structure types of fusulinid are recognized, fusulinellid and schwagerinid. The fusulinellid type, spirotheca is composed of four layers (Figure 6). The external thin dark layer is the **tectum**. Next below the tectum is a transparent layer, the **diaphanotheca**. The outer and inner layers are the tectoria, the outer one the **upper tectorium** and the inner the **lower tectorium**. The tectoria are thinner than the diaphanotheca and are intermediate in appearance between the tectum and diaphanotheca. All layers are penetrated by tiny pores known as **mural pores**. The schwagerinid type, spirotheca consists of two layers (Figure 6) : the **tectum** and the **keriotheca**, which is a relatively thick layer marked by transverse dark lines. These dark lines are the wall of **alveoli**. The keriotheca may be divisible into lower and upper keriothecal layers. Both the tectum and keriotheca are penetrated by tiny mural pores.

Previous works

Studies of fusulinid in Thailand have been carried out since 1939. Ingavat-Helmcke (1993) recorded that Dunbar was the first who reported the occurrence of Middle Permian fusulinids in limestones at Ban Dara junction, central north Thailand.

Studies of fusulinid from central north and northern Thailand include Toriyama and Kanmera (1968, 1976, 1979), Sakagami and Hatta (1982), Ingavat

SYSTEM	SERIES	STAGE						
		Eurasia		Age in Ma	Mediterranean-Alpine fold belt	U.S.A.		Age in Ma
				247				245
PERMIAN	LATE	Dorashamian			Dorashamian	Ochoan		
		Dzhulfian			Dzhulfian			
		Abadehian		253	Midian			250
	MIDDLE	Guadalupian	Pamirian		Murgabian	Guadalupian		
			Murgabian		Kubergandian			260
			Kubergandian		Bolorian	Leonardian		
				269	Yahtashian			269
	EARLY	Artinskian			Sakmarian	Wolfcampian		
		Sakmarian			Asselian			290
		Asselian		289	Gzhelian	Virgilian		
CARBONI-FEROUS	LATE	Orenburgian						
		Gzhelian			Kassimovian			300
		Kassimovian		306				

Table 1-1 Standard division of Upper Carboniferous and Permian Stages for the Eurasia, Mediterranean-Alpine fold belt and U.S.A. (Hag and Vaneysinga, 1987, Ingavat and others, 1980 and Racey and others, 1994)

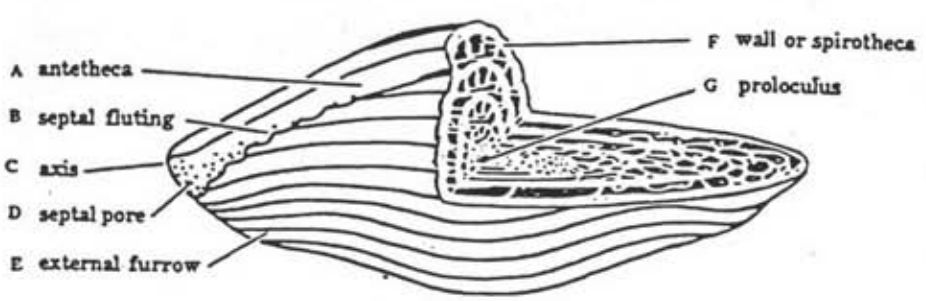

Figure 2 Diagram of a fusulinid test (*Triticites* sp.) showing structure features. (Moore and others, 1952)

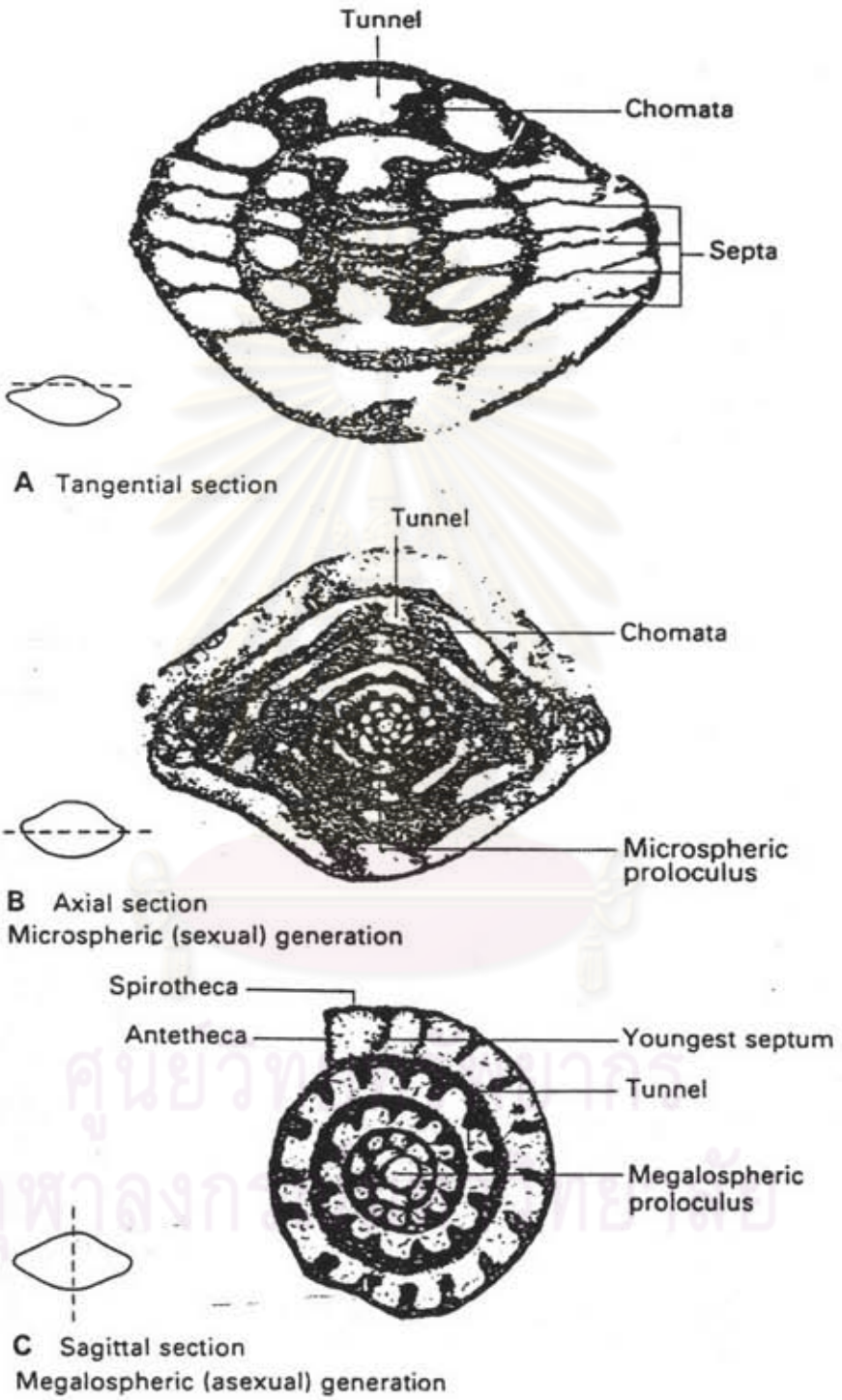

Figure 3 Microspheric and megalospheric generations of *Fusulinella* sp.
A) Tangential, B) axial and C) sagittal sections.
(Boardman and others, 1987)

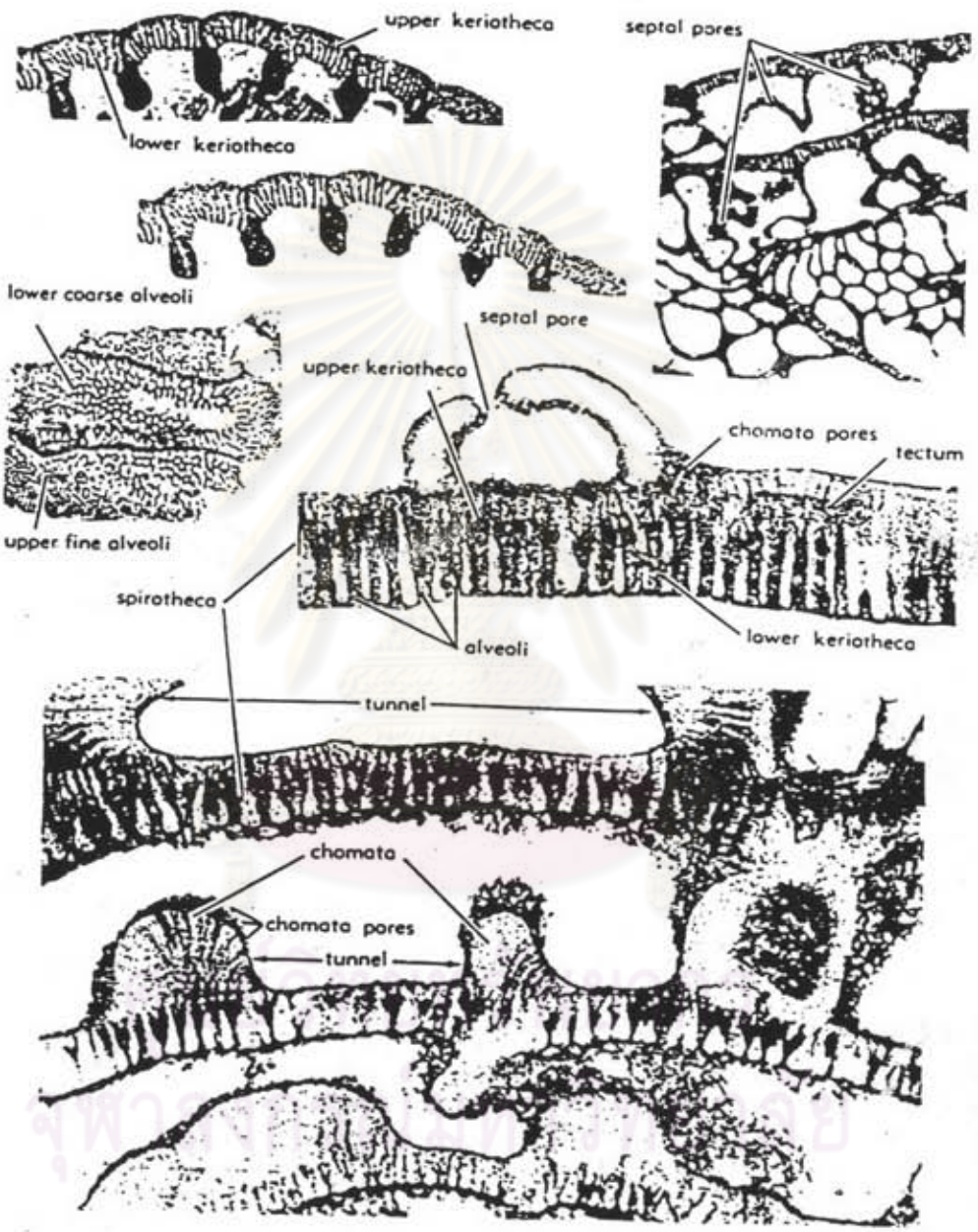

Figure 4 Spirotheca and septal structure of fusulinids. (Moore, 1964)

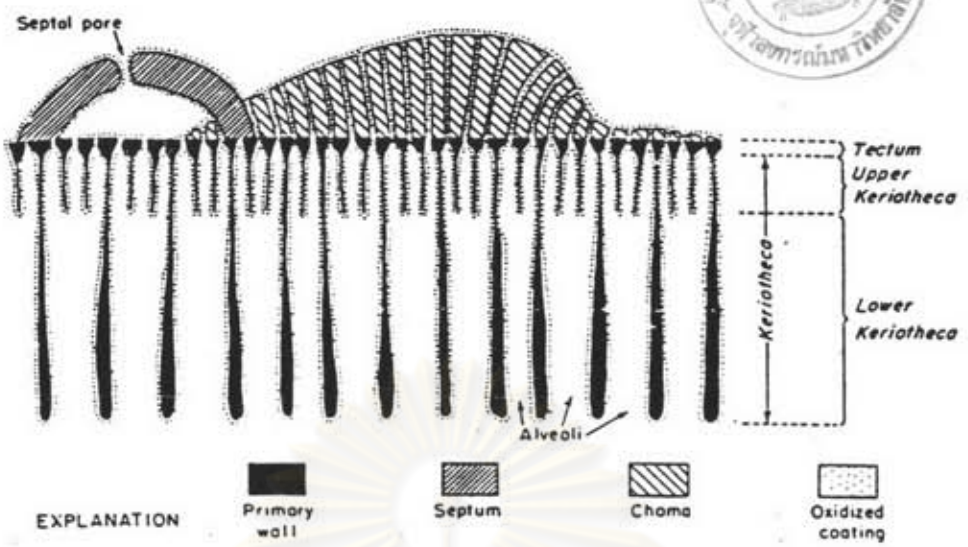

Figure 5 Diagram of spirotheca showing pendant-like walls of alveoli, choma and septal pore of *Schwagerina campensis* Thompson, Lower Permian (Moore, 1964)

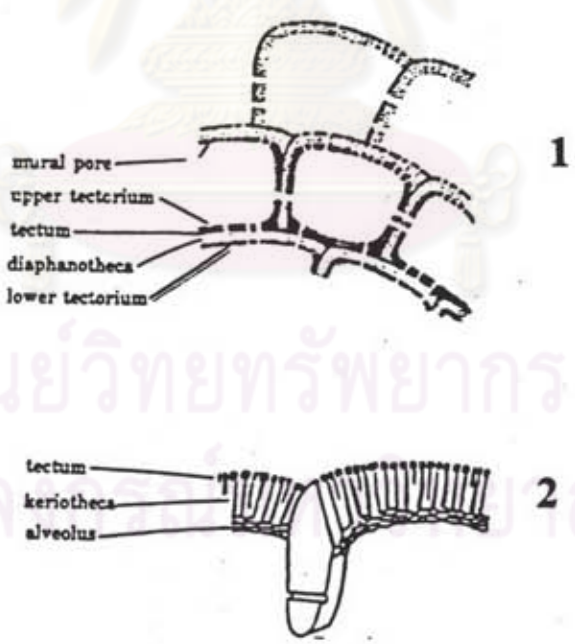

Figure 6 Comparison of fusulinellid (1) and schwagerinid (2) wall structure. (Moore and others, 1952)

(1984), Caridroit and others (1990), Ueno and Sakagami (1991), Ishibashi and others (1993).

Those from northeast Thailand include Pitakpaivan and others (1969), Igo (1972), Sakagami and Iwai (1974), Toriyama (1976), Pitakpaivan and Ingavat (1980), Toriyama (1982), Winkel and others (1983), Ingavat (1984), Vachard (1990), Fontaine and others (1991), Igo and others (1993), Ueno and Igo (1993), Ueno and Sakagami (1993), Ueno and others (1994), Ueno and others (1995).

Whereas the ones from central and eastern Thailand include Toriyama and Pitakpaivan (1973), Sugiyama and Toriyama (1981), Bunopas (1983), Ingavat (1984), Chonglakmani and Fontaine (1992).

And studies from western and southern peninsular Thailand include Pitakpaivan (1965), Sakagami (1969), Ingavat and others (1980), Ingavat and Douglass (1981), Ingavat (1984), Fontaine and Suteethorn (1988), Ingavat-Helmcke (1993), Dawson and Racey (1993), Dawson and others (1993), Baird and others (1993).

The detailed study of fusulinids especially in which is the present Loei investigated area have been studied by many researchers. Igo (1972) studied the fusulinaceans that were collected from the Wang Saphung-Loei area and Petchabun-Lom Sak area. This paper was the first report describing the Carboniferous fusulinaceans of Thailand including contains species of *Pseudoendothyra*, *Profusulinella*, *Pseudostaffella*, *Fusulinella*, *Beedeina*, *Fusulina*, *Hemifusulina* (?) , *Triticites*, *Pseudofusulina* (*Daixina*), *Rugosofusulina*, *Pseudoschwagerina*, *Paraschwagerina* and others.

Vachard (1990) reported Bashkirian fusulinids (*Profusulinella* sp.), smaller foraminifers, algae and corals that were found at Ban Tat So, Phu Tham Pha Tang, Changwat Loei.

Fontaine and others (1991) described Moscovian fauna in limestone-shale sequence at Huai Nam Suai and Ban Na Duang, southeast of Loei. The rock comprises fusulinids (*Triticites* sp., *Eostaffella* sp.), smaller foraminifer (*Bradyina* sp.), corals (*Sestrophyllum* sp., *Caninophyllum* sp.), algae (*Dvinella* sp.) associated with brachiopods, pelecypods and bryozoan fragments. At Ban Nachareon, Amphoe Wang Saphung fasciculate corals were found in small limestone hill associated with fusulinids (*Eostaffella acta* Grozdilova and Lebedeva) which suggest Early Moscovian in age. Corals (*Kueichouphyllum* sp., *Siphonodendron* sp.) together with fusulinids (*Endostaffella* sp., *Eostaffella* sp.) and smaller foraminifer (*Ateroarchaediscus* sp.) were found in a limestone-shale sequence at Huai Sangao and Khao Sam Ngae, Changwat Loei, indicating Late Visean age.

Ueno and Igo (1993) reported two important fusulinacean species in the limestones from Ban Na Din Dam, east of Loei, namely, *Triticites* (*T.*) *samaricus* Rauser-Chernoussova and *Jigulites grandis* Ueno and Igo. These species strongly indicate a Gzhelian (Latest Carboniferous) age.

Igo and others (1993) reported the fusulinacean limestones which exposed along a roadside gutter near Ban Phia. The geologic age of the fusulinacean fauna discriminated in this paper is Yahtashian (late Early Permian). The fusulinacean fauna is characterized by the abundant occurrence of the species belonging to the genera : *Staffella* ?, *Nankinella* ?, *Pamirina*, *Darvasites*, *Pseudofusulina*.

Ueno and Sakagami (1993) studied the foraminifers from Ban Nam Suai Tha Sa-at, Changwat Loei. The foraminifers including such fusulinaceans as *Verbeekina verbeeki* (Geinitz), *Pseudodoliolina* cf. *pseudolepida* (Deprat), *Presumatrina* cf. *neoschwagerinoids* (Deprat) are found from a small limestone outcrop in this area. These fusulinaceans indicate late Middle Permian age.

Ueno and others (1994) reported the foraminiferal fauna in impure limestones of the Wang Saphung Formation exposed at the Nam Thao Reservoir about 4 km east of Ban Sup, northeast of Loei. The fusulinaceans which are found in this area, indicating Late Moscovian (probably early Myachkovsky Horizon) age. They comprise *Beedeina paradistenta* (Safonova), *Pseudotriticites* aff. *thaiensis* (Igo), *Neostaffella subquadrata* (Grozdilova and Lebedeva), *Eostaffella acuta* Grozdilova and Lebedeva, *Ozawainella mosquensis* Rauser-Chernoussova, *O. angulata* (Colani), *Eoschubertella subkingi* (Putrja) and *E. mjachkvensis* (Rauser-Chernoussova).

Ueno and others (1995) studied the Upper Carboniferous foraminifers from Phu Tham Moholan, southeast of Wang Saphung, Changwat Loei. Four species of fusulinaceans and five species of smaller foraminifers were identified. Among fusulinaceans, four species belong to *Schagonella implexa* (Bensh), *S.* sp., *Jigulites* cf. *magnus* (Rozovskaya) and *Nankinella* sp.

Fusulinid zonation

The fusulinid zonation of the Tethys Province have been well established in Japan, South China, Thailand, Indochina and Pamir. In Thailand, Igo (1972) has established the Middle and Upper Carboniferous and the lower Lower Permian

fusulinid zonation from the Wang Saphung-Loei areas and Petchabun-Lom Sak areas (Table 2).

The biostratigraphic zonation of the Ratburi Limestone* in the Khao Phlong Phrab area, Changwat Sara Buri has been established by Toriyama and others (1974). They expected that this section may be designated as the upper Lower to middle Middle Permian standard biostratigraphic units in Thailand.

Ingavat and others (1980) summarized the Carboniferous and Permian fusulinid zonation of the Ratburi Limestone in Thailand and its equivalents in Malaysia. The fusulinid zonation of Table 3 could be the standard biostratigraphic zone covering the upper Lower Carboniferous to the Upper Permian formations in Thailand and Malaysia. Biostratigraphic zonal correlation between the sections of Thailand and other parts in the Tethyan realm is presented in Table 4.

Ingavat (1984) compared the foraminiferal faunas recorded from western, central and eastern provinces of Thailand. The correlation of these faunas is summarized in Table 5.

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* The name Ratburi Limestone (Brown and others, 1951 quoted in Bunopas, 1992) and the Ratburi Group (Javanaphet, 1969 quoted in Bunopas, 1992) which include all the Permian carbonate and clastic sequence all over Thailand is redefined for that sequence only on the west of the Western Mountains and the peninsular Thailand thought to be deposited on the western passive margin of Shan-Thai Terrane only.

Dawson and Racey (1991) studied the fusulinacean fauna in Saraburi Limestone, Central Thailand and established the fusulinid zonation as shown in Table 6.

Table 2 Fusulinid zonation in Thailand and other parts of Tethys. (Toriyama and others, 1975)

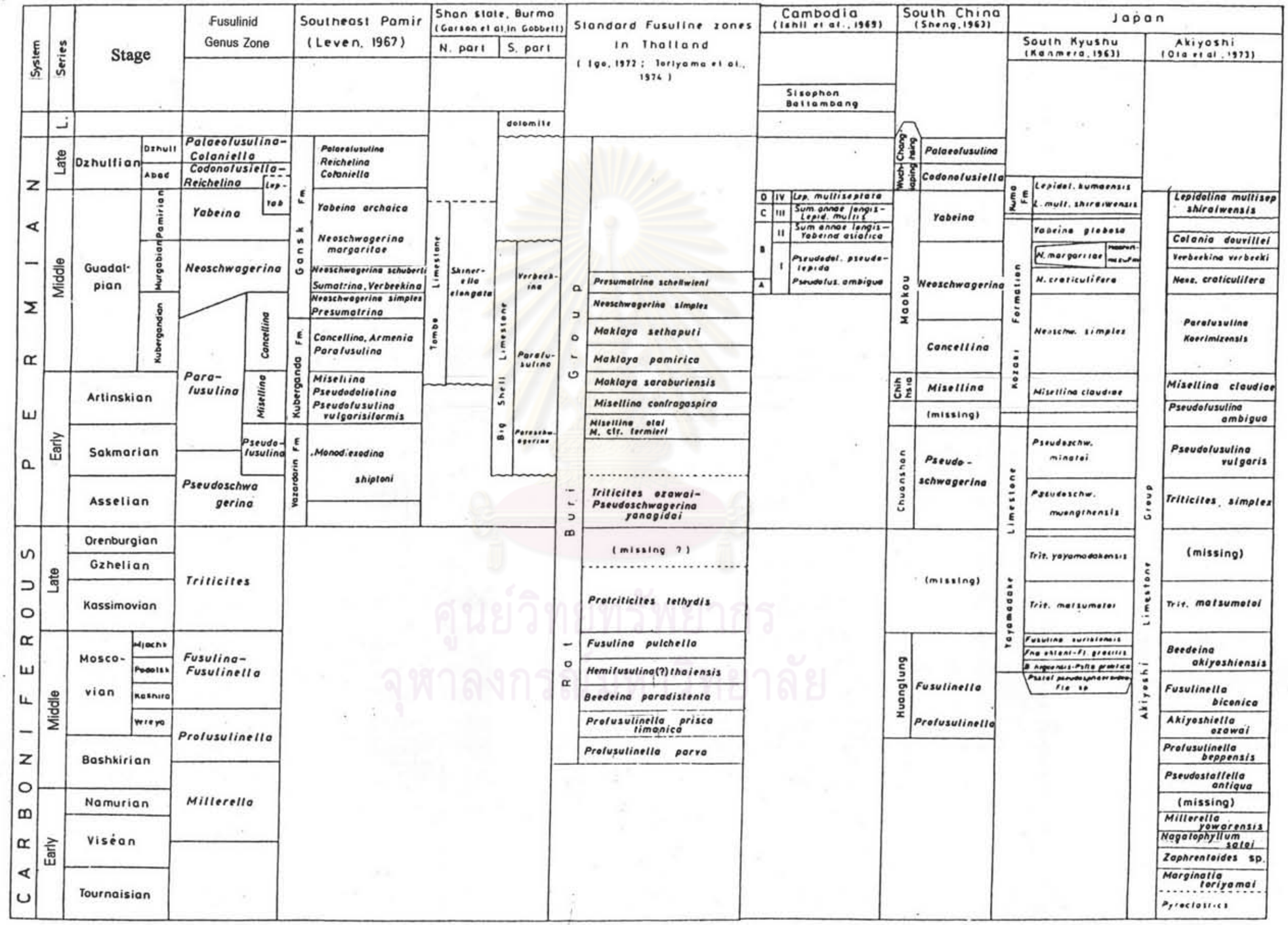

Table 3 Fusulinid zonation of Ratburi Group in Thailand and its equivalents in Malaysia. (Ingavat and others, 1980)

System	Series	Fusuline Zonation
PERMIAN	Upper	*Palaeofusulina* aff. *bella* – *Colaniella parva* zone
	Middle	*Lepidolina multiseptata multiseptata* zone *Colania douvillei* – *Verbeekina verbeeki* zone *Neoschwagerina haydeni* zone *Afghanella schencki schencki* zone *Presumatrina schellwieni* zone *Neoschwagerina simplex* zone *Maklaya sethaputi* zone *Maklaya pamirica* zone
	Lower	*Maklaya saraburiensis* *Misellina otai* – *Misellina termieri* zone (missing?) *Triticites ozawai* – *Paraschwagerina yanagidai* zone
CARBONIFEROUS	Upper	(missing?) *Protriticites tethydis* zone
	Middle	*Fusulina pulchella* zone *Hemifusulina* (?) *thaiensis* zone *Beedeina paradistenta* zone *Profusulinella prisca timanica* zone *Profusulinella parva* zone
	Lower	(missing?) *Eostaffella mosquensis* – *Millerella rossica* zone

Table 4 Fusulinid zonation between the sections of Thailand and other parts in the Tethyan realm. (Ingavat and others, 1980)

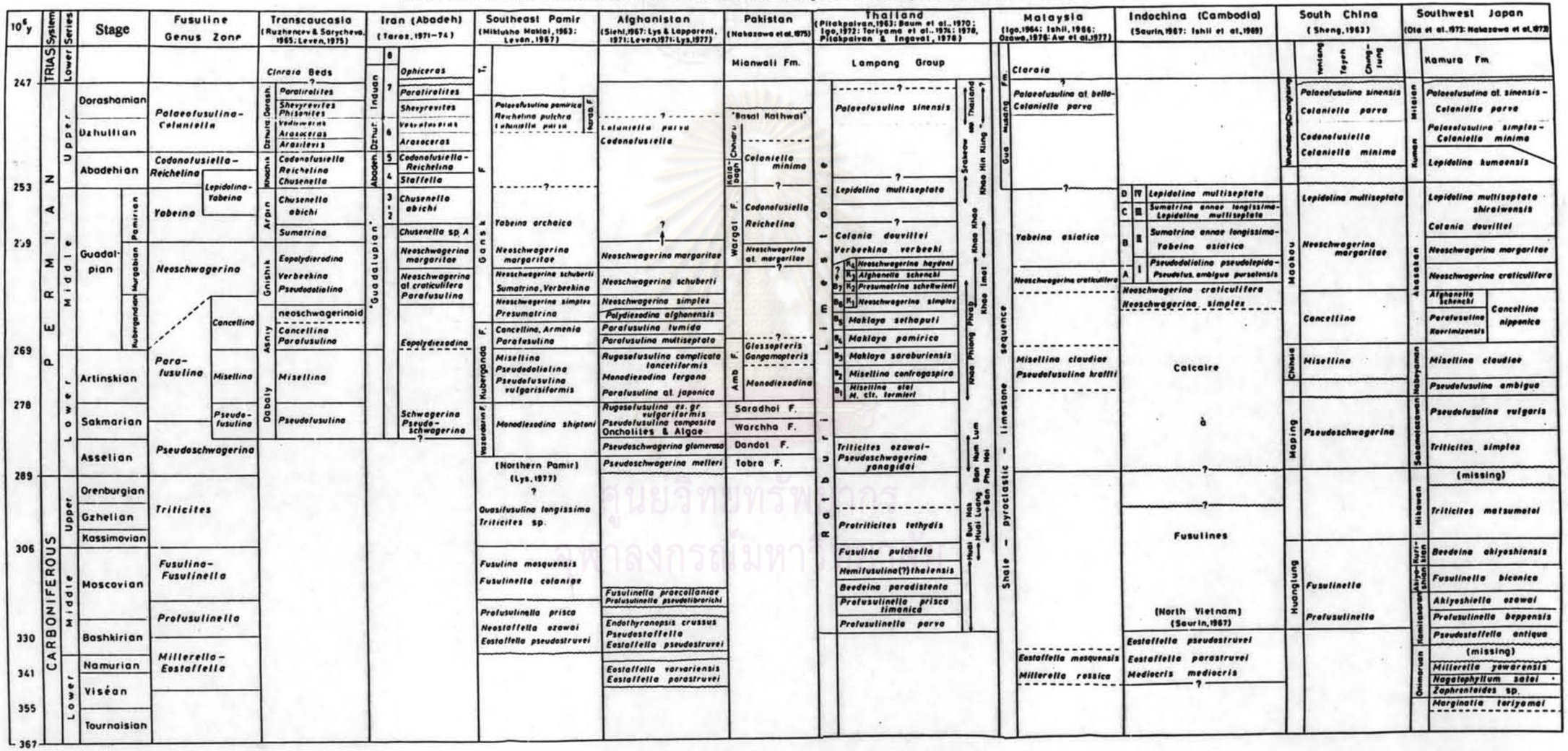

Table 5 Zonation and correlation on foraminiferal faunas from the western, central and eastern provinces in Thailand. (Ingavat, 1984)

System	Stage (Leven 1981)	Fusulinid zone		Thailand Pitakpaivan 1963, Baum et.al 1970 Igo 1972, Toriyama et. al 1974, 1978, Pitakpaivan & Ingavat 1978, Ingavat & Douglass 1980, Sakagami 1982	Fossil Location of Western Province	Fossil Location of Central Province	Fossil Location of Eastern Province
UPPER PERMIAN	Dorashamian	*Palaeofusulina*		*Palaeofusulina sinensis* *Colaniella parva*		Doi Pha Phlung fauna Nan fauna Phrae fauna	
	Dzhulfian	*Reichelina*	*Codonofusiella*	*Shanita intercalaria* ?	Khlong Phra Saeng fauna Phangnga fauna		
	Midian	*Lepidolina* *Yabeina*		*Lepidolina multiseptata* *Codonofusiella*	Chumphon fauna → Ang Thong islands fauna → Mae Hong Son fauna → Thong Pha Phum fauna		Sra Keow fauna
MIDDLE PERMIAN	Murgabian	*Neoschwagerina*		*Colania douvillei*, *Verbeekina verbeeki* K4 *Neoschwagerina haydeni* K3 *Afghanella schencki* B7 K2 *Presumatrina schellwieni* B6 K1 *Neoschwagerina simplex*	San Kam Pang fauna Mae Sarieng fauna	Ta Wang Pha fauna	
	Kubergandian	*Cancellina*		B5 *Maklaya sethaputi* B4 *Maklaya pamirica* B3 *Maklaya saraburiensis*	Sri Racha fauna Ban Na San fauna Kui Buri fauna Umphang fauna	Phrae fauna	Lop Buri–Muak Lek fauna Khao Klong Pun fauna
	Bolorian	*Parafusulina*	*Misellina*	B2 *Misellina confragaspira* B1 *Misellina otai* *M. cfr. termieri*	Sai Yok fauna		
LOWER PERMIAN	Yahtashian	*Parafusulina*	*Chalaro-schwagerina*	*Monodiexodina shiptoni* *M. sutchanica*	Sri Sawat fauna Mae Sarieng fauna Mae Ramad fauna Chiang Dao fauna		Huey Sam Pod fauna Khao Chakan fauna
	Sakmarian		*Pseudofusulina* *Robusto-schwagerina* *Paraschwa-gerina*	*Robustoschwagerina tumida*	Pak Tho fauna Pra Chuab Kiri Khan fauna Chumphon fauna Surat Thani fauna	Chiang Rai fauna — Nan fauna — Wang Nau fauna	Pha Duk Chik
	Asselian	*Pseudoschwagerina*		*Triticites ozawai* *Pseudoschwagerina yanagida*	Doi Huato fauna Pai fauna Phrao fauna	Kiu Lom fauna	Khao Singto fauna Khao Chon To fauna Ban Tok fauna Tham Nam Mahoran fauna Ban Nam Lum fauna Pha Doen fauna

Lomsak Chumphae highway fauna
Chaiyaphum → Khao Phrong Phrab fauna → Chaiyaphum fauna
Khao Khao fauna → Khao Irmot fauna → Phu Rau fauna
Maoteetang fauna → Lôon Thani fauna
Cheon River fauna → Pha Lom fauna
Nakhon Ratchasima fauna
Uthai Thani fauna → Pha Yok Khao fauna

Table 6 Fusulinid assemblage zones from Saraburi Limestone.
(Dawson and others, 1993)

System	Permian Tethys stage scale in the Mediterranean–Alpine fold belt; after Leven,1981.	Fusulinid Generic Zone		Fusulinid Assemblage Zones from Saraburi Limestone (Dawson, 1991)
Late Permian	Dorashamian	*Palaeofusulina*		
	Dzhulfian	*Reichelina*	*Conodofusiella*	
	Midian	*Lepidolina* *Yabeina*		
Middle Permian	Murgabian	*Neoschwagerina margaritae*		*Metadolilina lepida-Verbeekina verbeeki*
		Neoschwagerina craticulifera		*Neoschwagerina haydeni* *Afghanella schencki*
		Neoschwagerina simplex		*Neoschwagerina craticulifera* *Afghanella pesukensis* *Pseudodoliolina pseudolepida* *Afghanella megaspherica* *Neoschwagerina simplex*
	Kubergandian	*Parafusulina*	*Cancellina*	*Parafusulina-Paraverbeekina* *Chusenella*
	Bolorian		*Misellina*	*Armenina* *Misellina confragaspira* *Misellina otai*
Early Permian	Yahtashian	*Pseudofusulina*	*Chalaro-schwagerina*	*Pseudofusulina vulgaris* *Chalaroschwagerina*
	Sakmarian		*Robusto-schwagerina* *Paraschwa-gerina*	*Robustoschwagerina-Nagatoella*
	Asselian	*Pseudoschwagerina*		