

CHAPTER II

GEOLOGY

In order to understand the geology of the study area, detail description in this chapter is focussing upon the general stratigraphy, geological setting, and paleontology. In addition, general views of broad stratigraphy and stratigraphic nomenclature of Permian rocks on the western edge of the Khorat plateau are reviewed in order to serve as a background of the present study.

Regional Permian stratigraphy

The Permian rocks are widely exposed throughout Thailand (Fig. 1.1), excluding the northeastern part of the country where most rocks are of the Mesozoic age. They include predominantly carbonate rocks with relatively less abundant shale, sandstone and chert.

The overall thickness of Permian rocks varies considerably from 1, 450 to 4,860 metres and consist mainly of three main units; the bedded clastics with intercalation of carbonates, cherts and volcanoclastics in the lower unit (up to 1, 000 metre-thick); the gray, very thick-bedded fossiliferous carbonate rocks in the middle part (up to 1, 800 metre-thick); and the stratified carbonates with clastics and volcanoclastics in the upper unit (up to 1, 200 metre-thick).

The Permian sequence conformably overlies the Carboniferous strata and tholeiite volcanic rocks (Buam *et al.*, 1970). The Permian sequence is also conformably overlain by marine Triassic sequences (Piyasin, 1972; Bunopas, 1981; Chonglakmani and Intarawijitr, 1994; Chaodumrong, 1992) in the Northern Highland, the Eastern Gulf, and the Peninsula. In the Phetchabun Range and Khorat Plateau, although the Permian rocks conformably overlie the Carboniferous sequence, but unconformably underlie the Permo-Triassic volcanics/volcanoclastics and the

conglomerates of Upper Triassic succession. It is interesting to note that the upper Triassic conglomerate occasionally overlies the Permian carbonate sequence and Permo-Triassic volcanics/volcaniclastics.

Stratigraphic Nomenclature

In the former time, the Permian rocks in Thailand had been unanimously called the Ratburi Limestone (Brown *et al.*, 1951) or later on as the Ratburi Group (Javanaphet, 1969). However, after that the Permian sequence have been diversely designated under several names by different workers (e.g. Baum *et al.*, 1970; Piyasin, 1972; Nakornsri, 1977; Pendexter, 1980; Bunopas, 1981; 1983). Eventually, Bunopas (1992) generalized the stratigraphic names for Thailand into seven stratigraphic belts based on tectonic provinces and evolution concept of the Shan-Thai and the Indochina terranes. He rearranged the Permian rocks into three carbonate-clastic groups, and two clastic-volcanic related subduction groups (Fig. 2.1, Table 2.1).

In 1992, the Geological Survey Division, Department of Mineral Resources established the lexicon of the stratigraphic names of Thailand. The Permian rocks have been proposed into two groups (Table 2.2) as illustrated in the geological map of Thailand at the scale of 1:2, 500, 000 (Department of Mineral Resources, 1987). These are the Ratburi Group and the Saraburi Group.

The Ratburi Group

The earlier called Ratburi Limestone (Brown *et al.*, 1951) and the Ratburi Group (Javanaphet, 1969) were loosely used throughout Thailand for limestones and associated clastic sediments of Permian age (Bunopas, 1981; Hagen and Kemper, 1976; Tansatien *et al.*, 1995). The rocks were mapped as the Ratburi Group without any subdivided formation, and no designated type section. The exposures of Permian carbonate rocks in Changwat Ratchaburi are isolated outlines protruding Quaternary

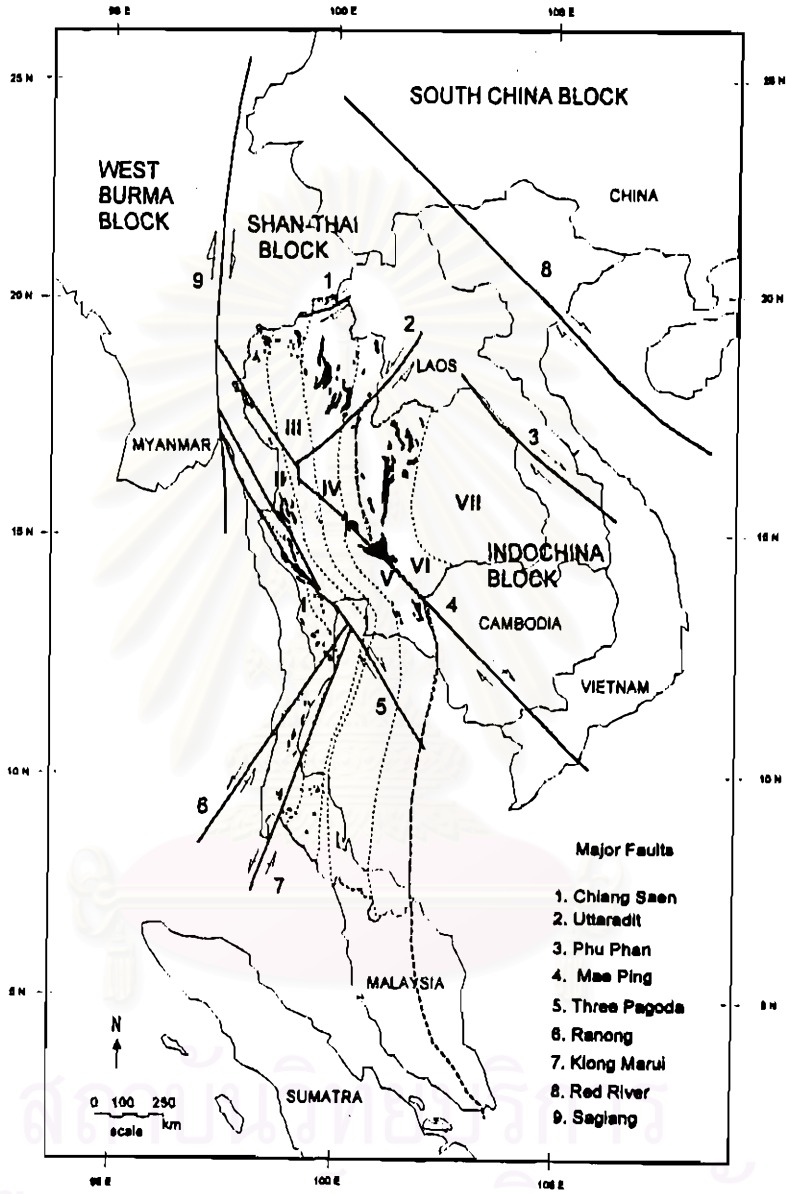


Fig. 2. 1 Index map of Thailand and mainland SE Asia showing distribution of Permian rocks in the tectonostratigraphic belts of Thailand (Bunopas, 1992), and main fault patterns with post - Cretaceous movement. Note, I, II, III, IV, V = Shan-Thai Block, VI, VII = Indochina Block (see also Table 2.1)

Table 2.1 Generalized stratigraphic nomenclature for Thailand within the seven stratigraphic belts on the Shan - Thai and the Indochina terranes by the Nan geosuture (modified after Bunopas, 1992).

Belts		I	II	III	IV	V	VI	VII	
		Upper Peninsula	West, w. North Low Peninsula	Main Western Ranges	Central North Lower Peninsula	Eastern North East. Gulf			Western Plateau Margin
Times	Belts	SHAN - THAI TERRANE					N	INDOCHINA TERRANE	
		MESOZOIC	Cretaceous						A
Jurassic	Chumpon Red beds		U. Khorat G *						
Triassic	Mae Moei G *		CRATONIC AREA	L. Khorat G *	Lampang G *	Lomsak f	Nam Pha f		
PALAEOZOIC	Permian	Ratburi G *		Dan Lan Hoi (Mae Tha G) *	Ngao G *	Phrae G	S	Saraburi G *	
	Carboniferous	Kaeng Kra chan G *	Mae Hong Son F *						Nam Pat f
	Devonian		Thong Pha Phum G *	Sukhothai G *			U	Wang Saphung f	
	Silurian						T	Pak Chom f	
	Ordovician		Thung Song G *				U	Na Mo f	
	Cambrian		Tarutao G *				R		
	PRECAMBRIAN			Lan Sang gneiss *			E		

G = Group F = Formation f = formation * Formal name

Table 2. 2 Stratigraphic subdivisions of Thailand (Department of Mineral Resources, 1992).

Region System	Western Highland	Northern Highland	Peninsula	Eastern Gulf	Central Plain	Petchabun Ranges	Khorat Plateau	
Quaternary	Mae Taeng F		-	-	Bangkok Clay	-	-	
Tertiary	Mae Moh G		Krabi G		(Mae Moh G)			
Cretaceous			Undiff.				Maharakham F Khok Krut F Phu Phan F	
Jurassic	Undiff. Sao Khua F Phu Kradung F	Phra Wihan F Phu Kradung	Undiff. Sao Khua F Phu Kradung	Phra Wihan F. Phu Kradung F		Undiff. Sao Khua F Phu Kradung F	Sao Khua F Phra Wihan F Phu Kradung F	
Triassic	Mae Moei G		Undiff. L Kho- rat G	Lampang G ?			Huai Hin Lat-NamPhong G	
		Undiff	Lampang G Nam Pat F					
Permian		Rat buri G		Ratburi G ?	Saraburi G			
Carboniferous	Mae Hong Son F	Phrae F DanLanHoi G	Kaeng Krachan F	Dan Lan Hoi G ?		Wang Saphung F		
Devonian	Thong Pha Phum G	Sukhothai G	Sukhothai G				Pak Chom F	
Silurian								
Ordovician	Thung Song G ?		Thung Song G	Thung Song G ?				
Cambrian	Tarutao G ?		Tarutao G	Tarutao G ?				
Pre-Cambrian	Lan Sang Gneiss Complex		Lan Sang Gneiss Complex ?					

(Mae Moh Group) = Concealed Group ? = Uncertain F = Formation - = Not known □ = No exposure
 G = Group Undiff = Undifferentiated

alluvial coverage (Bunopas, 1981). The group embraces to the Permian Limestone and associated clastic rocks in the Peninsular Thailand (Bunopas, 1981; Department of Mineral Resources, 1987; 1992).

Stratigraphically, the group unconformably overlies the clastic Permo-Carboniferous Kaeng Krachan Group of diamictite with of probably glacio-marine origin. (Raksaskulwong and Wongwanich, 1993). The Ratburi Group conformably underlies the Late Permian shale or volcanics, or the Mesozoic marine strata (Meesook, 1994) and/or the Mesozoic continental red beds elsewhere.

Lithologically, the Ratburi Group (about 1, 450 metre-thick) consists mainly of thin-bedded to very thick-bedded limestones and occasionally interbedded clastic rocks. Chert nodules are very common in the lower part of the sequence. Based on the field investigation and petrographic studies, limestone at several locations (Phang Nga, Surat Thani, Nakhon Sri Thammarat, Krabi, and Yala) have been heavily dolomitization.

Fossil-bryozoans, fusulinaceans, smaller foraminifers, brachiopods, and algae in the carbonate rocks, indicated to late Early Permian to middle Late Permian were reported (Sakagami, 1970; Yanagida, 1970; Hagen and Kemper, 1976; Waterhouse *et al.*, 1981; Ingavat, 1984; Fontaine and Suteethorn, 1988; Chinoroje, 1993; Raksaskulwong and Wongwanich, 1993). Foraminifers *Shanita* sp. and *Eopolydiexodina* sp. indicate to late Middle Permian (Dawson *et al.*, 1994).

The Saraburi Group

The group was previously mapped as a part of the Ratburi Group (Javanaphet, 1969; Piyasin, 1972; Bunopas, 1976; Nakhonsri, 1977). The name Saraburi Group was originally proposed by Bunopas (1981) for a mixed carbonate and clastic sequence outcropping in the eastern side of the Central Plain from Nakhon Sawan southwardly to Saraburi, and also at the western edge of the Khorat Plateau from Loei

southwardly to Saraburi or the Phetchabun Ranges (Department of Mineral Resources, 1992; Bunopas, 1992). The group has been considered to be developed along the western edge of the Indochina terrane.

Stratigraphically, the strata conformably overlie the Upper Carboniferous carbonate-clastic/volcaniclastic sequences and underlie the Permo-Triassic volcanic/volcaniclastic sequences and/or the Upper Triassic conglomerate. Fusulinaceans, smaller foraminifers and brachiopods indicate Asselian to Midian age (Dawson, 1978, Chonglakmani and Fontaine, 1990; Charoentitirat, 1995, etc.).

The Saraburi Group in the Saraburi area

The carbonate part of the group in the vicinity of Changwat Saraburi has been well demonstrated (e.g., Borax and Stewart, 1966; Tittirananda, 1976; Wielchowsky and Young, 1985). However, the six formal formations for this group were reestablished by the Department of Mineral Resources (1992) based on the works of Hinthong (1981; 1985). They are arranged in ascending order as follows:

Phu Phe Formation

This formation represents the lowermost formation of the Saraburi Group (Department of Mineral Resources, 1992). The type section (about 593 metre-thick) at Khao Phu Phe, east of km 131-132 of the Friendship Highway, consists of purplish gray to very dark gray, thick-to very thick-bedded fine-grained carbonate rocks with nodular chert and intercalated slaty shale in some parts. The boundary of the formation is upthrust (Borax and Stewart, 1966) onto the Sap Bon Formation. Fusulinaceans yield *Pseudoschwagerina* cf. *toriyamai*, *Pseudoschwagerina* sp. (*Aceroschwagerina*), *Pseudoschwagerina* (*Robustoschwagerina*) cf. *toriyamai*, *Paraschwagerina*, *Pseudoschwagerina* (*Zellia*) *turbida* Kahler, smaller foraminifers *Triticites* sp. cf. *ellipsoidalis* indicate a Sakmarian age (Hinthong, 1985).

Khao Khwang Formation

The stratigraphic position of this formation partly overlies and partly exhibit lateral facies-change with the Phu Phe Formation. The type location at Khao Khwang, Changwat Saraburi consists of black, dark to light gray, thick-bedded limestone with thin-bedded and nodular cherts. Locally, the formation has been dolomitized in various degrees and/or partly associated with purplish brown and greenish gray shale, sandstone, tuffaceous sandstone, and volcanic/volcaniclastic rocks. The thickness of the formation is about 490 metres. Fossil contents of this formation include fusulinaceans, brachiopods, bivalves, bryozoans and crinoid stems indicating a Sakmarian age (Hinthong, 1985).

Nong Pong Formation

The formation consists laminated to thin-bedded shale and limestone with locally argillite and chert intercalation. The 673-metre thick of the type locality at Ban Nong Pong, east of Khao Khwang, Changwat Saraburi. *Agathiceras* sp. and several unidentified fusulinaceans indicate Artinskian to Kungurian (Hinthong, 1985). This formation was interpreted as being deposited in rather deeper carbonate shelf environment (Pendexter, 1980).

Pang Asok Formation

The formation takes its name from Ban Pang Asok near Pang Asok railway station, Changwat Saraburi. The 366-metre thick of sequence consists of the interbedded brownish gray to greenish gray shale and slaty shale with locally limestone lens. Fossils of bivalves and leaves indicate Artinskian to Kungurian age. The formation is correlated with Khao Luak Formation in the area of Nakorn Sawan and Lopburi (Nakornsri, 1977; Bunopas, 1981).

Khao Khad Formation

The formation (up to 1,800 metre-thick) consists mainly of thin-bedded to very thick-bedded limestone with chert nodules. However, marble and calc-siticate rocks associated with locally argillite and dolomite are also present. Besides, shale, siltstone, sandstone, and conglomerate are interbedded. Abundant fusulinaceans, brachiopods, gastropods, and ammonites indicate Artinskian to Kungurian age (Pitakpaivan, 1965; Toriyama *et al.*, 1974; 1975; Tittirananda, 1976).

Sap Bon Formation

The formation was considered to be the uppermost formation of the Saraburi Group in the Saraburi area. This formation represents pale brown to pale green of interbedded shale and sandstone with locally dark gray limestone and chert nodules. The rocks are slightly metamorphosed to slate, phyllite and schist. The type section is located at Ban Sap Bon near Tab Kwang, Changwat Saraburi where 1, 100 metre-thick of the section were measured. Fusulinacean yields *Pseudofusulina* sp., *Colania* cf. *douvillei* Ozawa and *Neoschwagerina* cf. *magaritae* and ammonoid *Agathiceras* sp. indicate the Kungurian to Kazanian age were reported (Hinthon, 1981: 1985).

The Saraburi Group in the Nakhornsawan-Lopburi area.

The Permian rocks in the Nakornsawan-Lopburi of the central region is characterized by two formations, namely, the Tak Fa Formation in the Nakhorn Sawan, and the Khao Luak Formation in the Lopburi based on the works of Nakornsri (1976; 1981). However, Bunopas (1981; 1983; 1992) who originally proposed the Saraburi Group further subdivided the group into 3 formations including the Khao Luak Formation, the Saraburi Limestone, and the Dan Sai Shale in ascending order, respectively.

Tak Fa Formation

The formation was named by Nakornsri (1976), consisting of limestone with fusulinaceans, corals, brachiopods and bryozoans. These indicates Artinskian to Kungurian age. At Khao Somphot area, the light gray dolomite interbedded with very thick-bedded limestone and chert nodules are present found in the upper part of the formation. The formation could be correlated with the Saraburi Limestone and the Khao Khad Formation in the Saraburi area.

Khao Luak Formation

The formation with the total estimated 1, 500 metre-thick was first proposed by Nakornsri (1976). It unconformably overlies the metamorphic Silurian-Devonian rocks at Loei-Wang Saphung area (Bunopas, 1981; Bleackley *et al.*, 1963; Jacobson *et al.*, 1969). The type section at Khao Luak Range extending from north of Phetchabun southwardly to Lamnarai was assigned as the lowermost formation of the Saraburi Group (Bunopas, 1981). Charupongsakul (1984) reported that the lithological sequence consists mainly of interbedded shale, sandstone and thin-bedded limestone. The sandstone is slightly tuffaceous in the lower part. At place, the strata were cut by rhyolite dikes (Bunopas, 1981). Fossils including *Pseudofusulina* sp., *Triticites* sp., coral, *Pseudohuanangia* cf. *pesica* Douglas and *Verbeekina verbecki* (Nakhornsri, 1981) indicating Early to Middle Permian. The formation is correlated with the Pang Asok Formation (Hinthong, 1985).

With reference to Bunopas (1981) in the Saraburi area, the sedimentary sequence of the Saraburi Group overlying the Khao Luak Formation is further subdivided into Saraburi Limestone and Dan Sai Shale.

Saraburi Limestone

The Saraburi Limestone (Bunopas, 1981) consists mainly of very thick-bedded to thick-bedded carbonates with bedded and nodular chert. Fossils fusulinaceans, smaller foraminifers, crinoids, algae, bryozoans, and corals indicate the Sakmarian to Midian age (Dawson and Racey, 1993). The sequence with the thickness about 2,386 metres at the type locality, 7 km from the Friendship Highway to the west at Amphoe Muak Lek, Changwat Saraburi was measured by Borax and Stewart (1966). This limestone is correlated with the Khao Khad Formation in the Saraburi area (Hinthong, 1981; 1985) and the Tak Fa Formation in the Nakhon Sawan area (Nakornsri, 1977; 1981).

Dan Sai Shale

The Dan Sai Shale was proposed as the upper most formation of the Saraburi Group by Bunopas (1981). The type location is located between Loei-Dan Sai road, northwest of Changwat Loei (Bunpoas, 1981; DMR, 1992). This formation consists of micaceous sandstone, siltstone, and thin-bedded shale. Hinthong (1981; 1985) reported the appearance of limestone lens with fusulinacean at km 23 along the road to Chulaporn Dam, indicating a Late Permian. However, leaf fossil *Gigantopteris*, fusulinaceans and a brachiopod *Leptodus* indicate the Kungurian to Kazanian (Murgabian) age (Bunopas and Fontaine, 1989; Assama *et al.*, 1986). The formation is correlated with the Sap Bon Formation of Hinthong (1985) in the Saraburi area, and with the Pha Dua Formation of Charoenprawat and Wongwanich (1976) in the Loei area.

The Saraburi Group in the Phetchabun and Udonthani area

Permian formations in Phetchabun and Udonthani areas are quite different from those of the Saraburi area. This leads Chonglakmani and Sattayarak (1979) and Chonglakmani *et al.* (1979) to further subdivide them into 3 formations in ascending

order as the Pha Nok Khao, the Hua Na Kham, and the Num Duk Formations (Table 2.3).

Pha Nok Khao Formation

This formation was designated for the thick- to very thick-bedded gray limestone with nodular and thin-bedded chert, and also thin-bedded gray shale. The formation is correlated with the Nam Moholan Formation in the Loei area.

Hua Na Kham Formation

The formation consists largely of gray shale and yellowish brown sandstone with interbedded gray limestone lenses (Chonglakmani and Sattayarak, 1979). The formation was designated to be Middle Permian (Chonglakmani and Sattayarak, 1979), and was described as molasse type without limestone intercalation (Helmcke and Kraikhong, 1982). The formation is correlated with the Pang Asok Formation in the Saraburi area and lower part of the E-Lert Formation in the area of Loei.

Nam Duk Formation

The Nam Duk Formation has been proposed according to the type section at km 16.5-21.0 Lom Sak-Chum Pae Highway, Ban Nam Duk, Changwat Phetchabun. *Agathiceras* sp. suggest upper Middle Permian (Chonglakmani *et al.*, 1979; Chonglakmani and Sattayarak, 1979), and fusulinaceans *Pseudofusulina* sp., *Dunbarella* sp., and *Nakinella* sp. indicate Lower Permian (Helmcke and Kraikhong, 1982; Helmcke and Lindenberg, 1983; Helmcke *et al.*, 1985; Winkel *et al.*, 1983). This formation comprises of gray to black shale, black to dark gray sandstone and dark gray thin-bedded limestone. Alloedapic limestone with chert (Helmcke and Kraikhong, 1982) and Bouma-T sequence (Altermann, 1989) indicating the pelagic and flysch-type sediments (Helmcke and Kraikhong, 1982).

Table 2.3 Stratigraphic correlation of Permian rocks in Central and Northeastern regions (Assavapatchara, 1997).

AGE (Ma)		Brown <i>et al.</i> (1951)	Javanaphet (1969)	Charoenprawat and Wongwanich, (1976) Loei - Nong Bua Lumphu	Nakornsri (1977;1981) Nakorn Sawan - Lopburi	Hinthong (1981; 1985) Saraburi	Bunopas (1981;1983) Saraburi-Loei	Chonglakmani <i>et al.</i> (1979) Phetchabun-Chaiyaphum	DMR (1992)					
PERMIAN	245 UPPER	RATBURI LIMESTONE	* RATBURI	* RATBURI	* RATBURI	* RATBURI	* SARABURI	Nam Duk f	* SARABURI					
	258 MIDDLE									Pha Dua f	Tak Fa f	Sap Bon F	Dan Sai shale	Sap Bon F
	268 LOWER									E-Lert f	Khao Luak f	Khao Khad F Pang Asok F	Saraburi limestone	Hua Na Kham f
CARBONIFEROUS			GROUP	GROUP	GROUP	GROUP	GROUP	Pha Nok Khao f	GROUP					
				Nam Mahoran f	Khao Luak f	Nong Pong F Khao Khwang F Phu Phe F	Khao Luak f		Nong Pong F Khao Khwang F Phu Phe F					

————— Sharp Boundary
 - - - - - Gradational Boundary
 ~~~~~ DMR Unconformity Department  
 f, F formation of Mineral Resources  
 \* , F Formal name  
 f informal name

## Geology of the study area

The geological literature of the Loei area has been extensively reviewed and illustrated in Table 2.4. The geological report of Charoenprawat and Wongwanich (1976) with illustrated geological map on the 1: 250, 000 scale of sheet NE 47-12 (Changwat Loei), was published by the Department of Mineral Resources (1976). After that the geological map on the 1: 50,000 scale of sheet 5343 II (Ban Nong Hin) was published by Silapalit *et al.* (1987).

The geology in the vicinity of study area is represented by a number of rock units of sedimentary, igneous, and metamorphic origins ranging in age from Silurian/Devonian to Holocene (Table 2.4; Fig. 2.2).

### Carboniferous rocks

The Carboniferous rocks exposed in the Loei area are represented by the Nong Dok Bua and the Wang Saphung Formations (Charoenprawat and Wongwanich, 1976; Charoenprawat *et al.*, 1976; and Department of Mineral Resources, 1992). However, it is noted that these two formations have not been formally incorporated in any larger lithostratigraphic unit of group level.

### Nong Dog Bua Formation

The type location is located at the Phu Nam Pha, northeast of Ban Nong Dog Bua, Changwat Loei. The formation consists of thin-bedded chert, sandstone, siltstone, quartzite, tuff, and thin-bedded limestone with some conglomerate. The Early Carboniferous spores in sandstone and mudstone were identified by Lavein *et al.* (1994). Additional abundant fossils including crinoid stems, bryozoans, fenestella, trilobites, leave fossils, brachiopods, calcispheres, foraminifers, and corals of Late Devonian to early Middle Carboniferous were

Table 2.4 Stratigraphic correlation of rock units of Loei and adjacent area.

| AGE        |            | Bleakley et al. (1965)                 | Jacobson et al. (1969)                                            | Charoenprawat et al. (1976)                                       | Chonglakmani et al. (1987)                                        | Putthapiban (1978)                                                 | DMR (1988)<br>Loei and w. Loei Loei-Udon Thani                                | Bunopas (1992)                               | Assavapatchara (1998)                                                       |                                                                |
|------------|------------|----------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------|
| CENOZOIC   | Quaternary | alluvial alluvial terrain              | unnamed alluvial laterite                                         | alluvial, terrace talus, colluvial                                | alluvial, terrace                                                 | unnamed unconsolidated                                             | meander-channel, alluvial floodplain, terrace deposits                        | w. plateau Khorat plateau Indo-China Terrane | unconsolidated alluvial, terrace                                            |                                                                |
|            | Tertiary   | —                                      | —                                                                 | —                                                                 | Phu tok F<br>Mahasarakham F                                       | —                                                                  | —                                                                             | —                                            | —                                                                           |                                                                |
| MESOZOIC   | Cretaceous | K h<br>Phu Phan F<br>Phra Wihan F      | K h<br>Maha Sarakam F<br>Khok Kruat F<br>Phu Phan F               | K h<br>undifferentiated<br>Phu Phan F<br>Sao Khua F               | K h<br>Khok Kruat F<br>Phu Phan F<br>Sao Khua F                   | K h<br>Phu Phan F                                                  | Maha Sarakam F<br>Khok Kruat F<br>Phu Phan F                                  | Khorat G                                     | K h<br>Maha Sarakam F<br>Khok Kruat F                                       |                                                                |
|            |            | o<br>Phu Kradung F<br>Huai Hin Lat F   | o<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F   | o<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F   | o<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F   | o<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Huai Hin Lat F | o<br>Phu Phan F<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F                |                                              | o<br>Phu Phan F<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F              | o<br>Phu Phan F<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F |
|            | Jurassic   | r a<br>Phu Kradung F<br>Huai Hin Lat F | r a<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F | r a<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F | r a<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F<br>Nam Phong F | r a<br>Phra Wihan F<br>Phu Kradung F<br>Huai Hin Lat F             | r a<br>Phra Wihan F<br>Phu Kradung F<br>Huai Hin Lat F                        |                                              | Sao Khua F<br>Phra Wihan F<br>Phu Kradung F                                 | r a<br>Sao Khua F<br>Phra Wihan F<br>Phu Kradung F             |
|            |            | Triassic                               | Volcanic<br>granodiorite, tonalite                                | unnamed volcanic<br>unnamed intrusive rocks                       | granite<br>volcanic rocks                                         | volcanic tuff<br>granite, granodiorite                             | volcanic rocks                                                                |                                              | granodiorite<br>volcanic and pyroclastic                                    | Lomsak, Nam Pha F<br>Nam pat F                                 |
| PALAEOZOIC | Permian    | Calcareous Series<br>argillite Sr      | Kanchanaburi Sr<br>Ratburi limestone                              | Ratburi G<br>Pha Dua F<br>E-Lert F<br>Nam Mahoran F               | Pha Dua F<br>Huai E-Lert F<br>Nam Mahoran F                       | Saraburi G<br>Pha Dua F<br>Huai E-Lert F<br>Nam Mahoran F          | Saraburi G<br>Pha Dua F<br>Huai E-Lert F<br>Nam Som Ist<br>Tham Nam Mahoran F | Saraburi G                                   | Saraburi G<br>Pha Dua F<br>E-lert F<br>Nam Mahoran F                        |                                                                |
|            |            | Carboniferous                          | unnamed                                                           | unnamed                                                           | ultramafic rocks<br>Wang Saphung F                                | Huai Som F<br>Wang Saphung F                                       | Wang Saphung F<br>Ban Sa Ngow F                                               | Wang Sa<br>Phung M<br>Nong Dok<br>Bua M      | Basalt and<br>serpentine<br>Wang Saphung F                                  | Wang Saphung M<br>serpentine<br>basalt                         |
|            |            |                                        | metamorphic rocks                                                 | unnamed                                                           | Nong Dok Bua F                                                    | unnamed                                                            | Pak Chom F                                                                    | Pak Chom F<br>Hat Kum Pee F                  | Pak Chom<br>F                                                               | Pak Chom F<br>Nong Dok Bua M<br>serpentine<br>basalt           |
|            | Devonian   | metamorphic rocks                      | metamorphic rocks                                                 | unnamed                                                           | Namo F                                                            | Namo F                                                             | Namo F                                                                        | Namo F                                       | Pak Chom F<br>Nong Dok Bua M<br>rhyolite,<br>Chomcht tuff<br>Ban Nong Shale |                                                                |
|            | Silurian   |                                        |                                                                   |                                                                   |                                                                   |                                                                    |                                                                               |                                              | Namo F                                                                      |                                                                |

G = Group  
Sr = Series  
F = formation  
cht = chert  
M = member  
Ist = limestone  
— = unexpose

DMR = Department of Mineral Resources

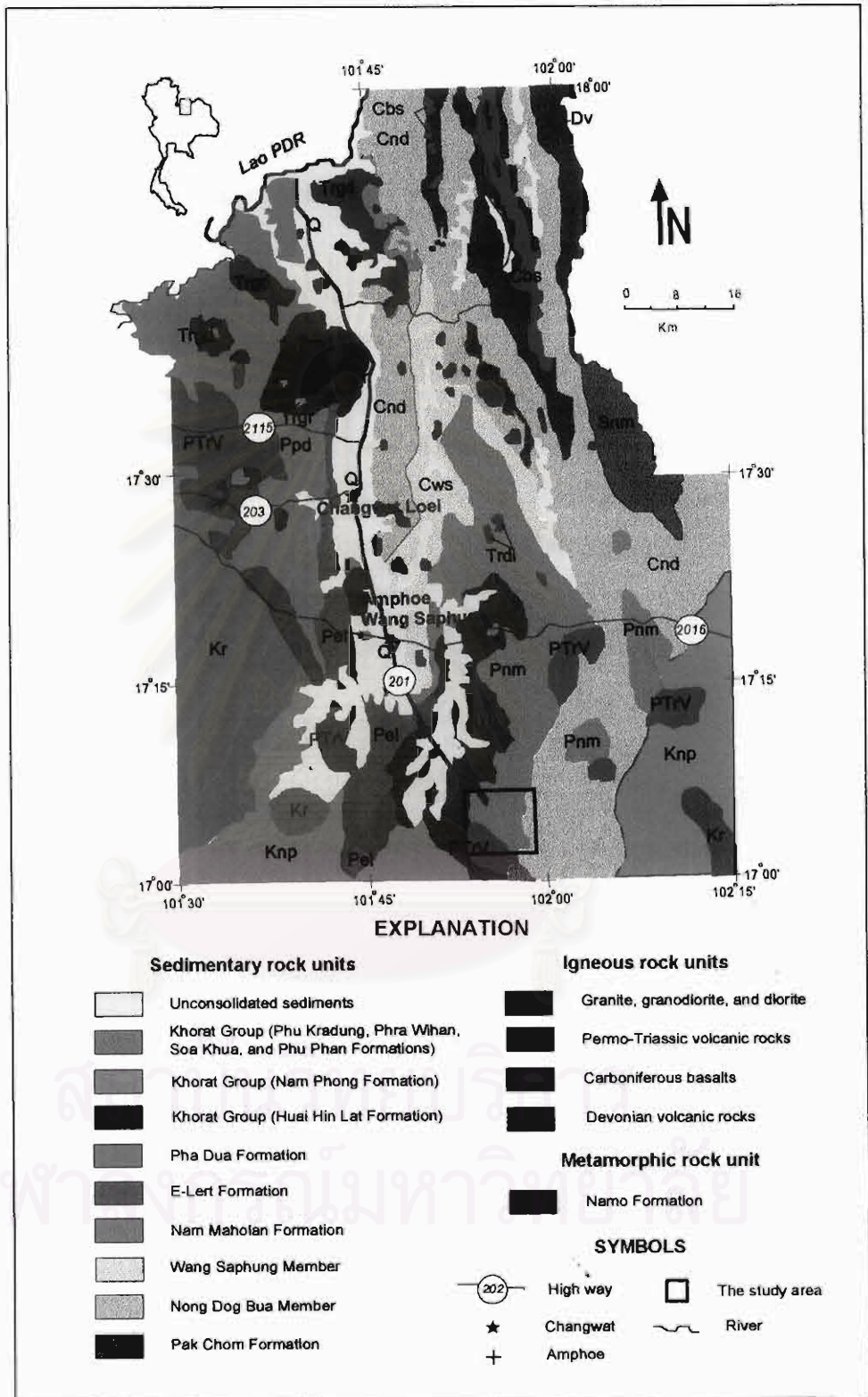


Fig. 2.2 Regional geology demonstrating the distribution of rock units and the study area (modified after Charoenprawat et al., 1976; Chonglakmani et al., 1979 ; Department of Mineral Resources, 1988; Vimuktananda, 1988; and Charusiri, 1989 ).



reported (Charoenprawat and Wongwanich, 1976; Department of Mineral Resources, 1988).

### **Wang Saphung Formation**

The type location is located at Huai Luang and Huai Bunnag, east of Amphoe Wang Saphung. The approximately 440 metre-thick formation consists of interbedded greenish gray to dark gray shale, siltstone, sandstone, and bedded chert with occasionally limestone lens. The intercalation of red shale is locally observed. A Moscovian foraminifers (Ueno *et al.*, 1993) were identified from limestone lens at Huai Luang, and also a Tournaisian fossils of Lower Carboniferous from limestone at Pha Chom Nang were reported (Fontaine *et al.*, 1994).

### **Permian Rocks**

The Permian rocks in the Loei area and northwest rim of the Khorat plateau, originally assigned under the Ratburi Group, are later designed under the Saraburi Group (Bunopas, 1981; 1992; Department of Mineral Resources, 1992). It is noted that the sedimentary facies and lithology of the Permian succession in the Loei area are different to those in the Saraburi area. They are divided in to three formations as the Nam Maholan, the E-Lert, and the Pha Dua respectively, in ascending order following Charoenprawat and Wongwanich (1976) and Charoenprawat *et al.* (1976). Various lithostratigraphic classifications of Permian rocks in the Loei area are summarized in Table 2.3.

### **Nam Maholan Formation**

The Nam Maholan Formation (Charoenprawat *et al.*, 1976) was first named as the Phu Tham Nam Maholan Formation by Charoenprawat and Wongwanich (1976). The formation has been demonstrated as a map unit in the geological map of Thailand on 1: 250, 000 scale, sheet NE 47-12 (Changwat Loei) which was

published by the Department of Mineral Resources (1976). The type location was located at the Phu Tham Maholan, 2 kilometres east of km 42 of the Highway no. 201, Ban Nong Hin, Amphoe Phu Kradung, Changwat Loei with grid reference of 0670, 9340 on a 1: 50, 000 scale topographic map, sheet 5343 II (Ban Nong Hin).

The formation consists mainly of thick- to very thick-bedded limestone with occasionally interbedded shale, reddish brown sandstone and chert. The formation conformably overlies and/or interfingering with the marine clastic-carbonate facies of the Wang Saphung Formation (Fig. 2.3). The formation was suggested to underlie the clastic-carbonate facies of the E-Lert Formation (Charoenprawat *et al.*, 1976; Putthapiban, 1987, etc.). However, there is no evidence of vertical stratigraphic contact. It is believed that the lateral and vertical facies variation or the interfingering characteristic relationship between the Nam Maholan and the E-Lert Formations on the basis of existing relative age as determined from fossil records.

The Nam Maholan Formation was considered to be of earliest Permian Period (Ingawat, 1994; Bunopas, 1981; Department of Mineral Resources, 1987; 1992) from fossil evidence. Fusulinaceans, smaller foraminifers, brachiopods, pelecypods, algae, crinoids and corals indicate Asselian age (Igo, 1972; Yanagida, 1974; 1975). Emphatically, the section at the Phu Tham Maholan had been dated as Asselian to Artinskian based on brachiopods identification (Yanagida, 1967), and was recognized to Triticites ozawai-Paraschwagerina Yanagidai zone of Lower Permian (Igo, 1972; 1974).

In contrast, fusulinacean *Schagonella implexa* at the Phu Tham Maholan was recently designated as middle Gzhelian (Late Carboniferous) by Ueno *et al.* (1995). In addition, Early Murgabian foraminifers (*Verbeekina verbeeki*, etc.) from limestone at Ban Nam Suai Tha Sa-at, northeast of Phu Tham Maholan were also reported (Ueno and Sakagami, 1993). These fusulinaceans, smaller foraminifers, corals and giant pelecypods, indicate middle Gzhelian to Murghabian age.

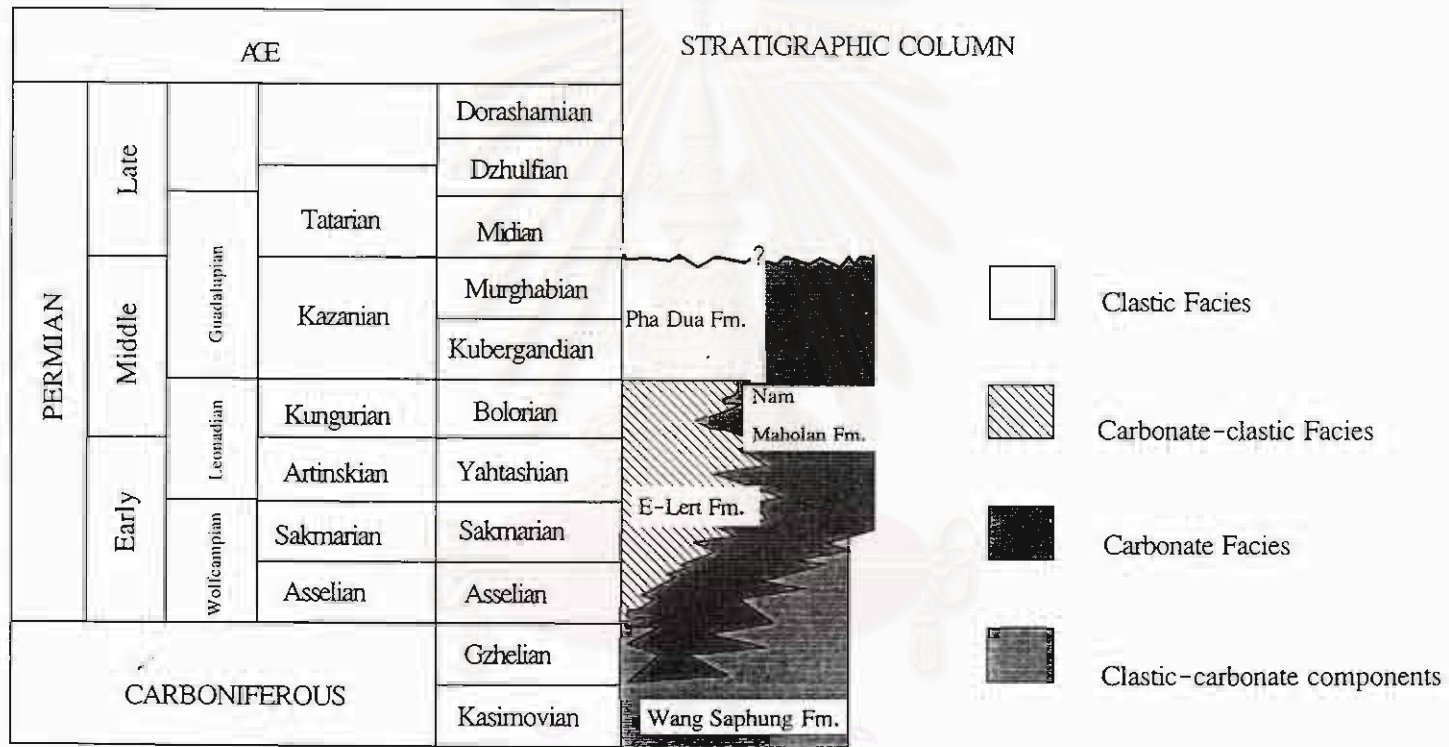


Fig. 2.3 Generalized stratigraphy of study area illustrated the correlated formations.

### E-Lert Formation

The formation was assigned to the Middle Permian sequence (Charoenprawat and Wongwanich, 1976). The sequence mainly exposes as long-narrow trends, subparallel to the western side of the Loei River (Fig. 2.2). The formation is represented by mainly shale interbedded with chert (Figs. 2.4 and 2.5) with occasionally tuffaceous (Fig. 2.6) and limestone lens. Brown and gray shale, yellowish brown sandstone, thin-bedded darkgray limestone and chert have been described at the type location at Huai E-Lert, east of Amphoe Wang Saphung (Department of Mineral Resources, 1992). Very thin-bedded light gray limestone and thin-bedded chert are present at the lower part. Thin-bedded sandstone, shale and siltstone are intercalated at the upper part of the sequence (Charoenprawat and Wongwanich, 1976). Small cross-bedding and wavy laminations are reported in fine-grained sandstone, possibly representing A-type Bouma sequence (Altermann, 1989). This formation is correlated with the Pang Asok Formation of Hinthong (1985) in the Saraburi area and the upper part of the Hua Na Kham Formation of Chonglakmani *et al.* (1979) in the Phetchabun area.

The Permian ammonoids *Agathiceras suessi* from siliceous shale and fusulinacean *Parafusulina* sp. from limestones indicate Asselian to Kubergandian age (Charoenprawat and Wongwanich, 1976; Ishibashi *et al.*, 1996). Subsequently, Asselian to Kubergandian foraminifers from limestone at Khao Phu, 10 km north of Changwat Loei were reported (Altermann, 1989). Fusulinacean *Schwagerina* sp., smaller foraminifer *Tetrataxis* sp., and bryozoan from thin-bedded chert outcrop at Loei-Thali Highway, km 2.8 (Fig. 2.4) indicating Asselian-Yahtashian are identified (Altermann, 1987). According to paleontological data and field investigation, the formation is considered to be interfingered with the Nam Maholan Formation.



Fig. 2.4 Thin-bedded chert interbedded with very thin-bedded shale of the E-Lert Formation. The fusulinacean *Schwagerina* sp. is present in chert beds (Grf. 873436, map sheet 5344 III of scale 1: 50, 000, Loei-Thali road).

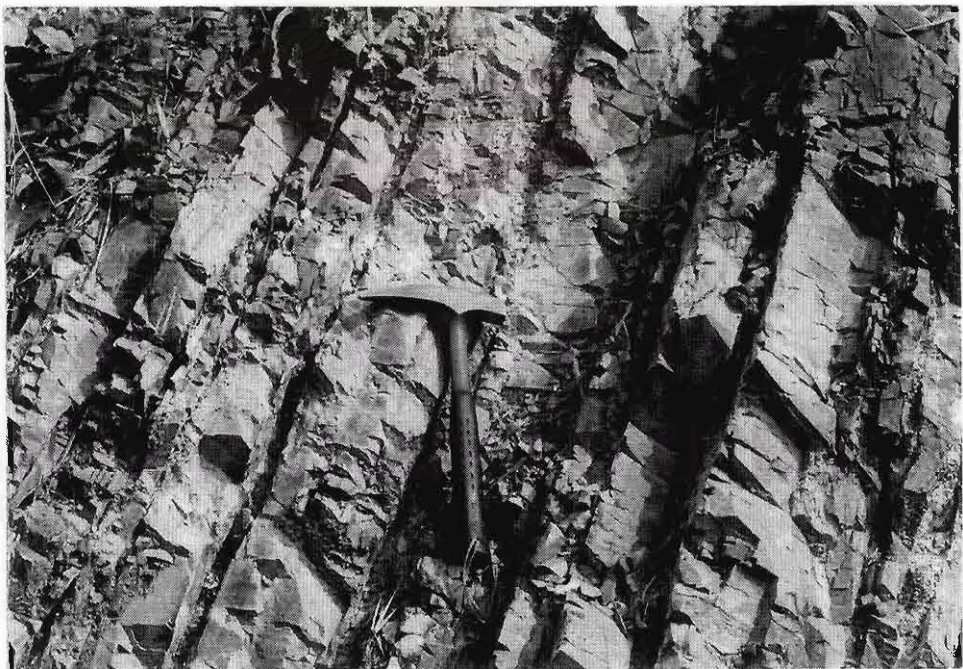


Fig.2.5 The quarry 2 km NW of Changwat Loei showing well-bedded reddish brown chert interbedded with very thin-bedded yellowish brown shale of the E-Lert Formation (Grf. 871384, map sheet 5344 II of scale 1: 50, 000).



**Fig. 2.6** Thin-bedded, light gray limestone interbedded with greenish to purplish tuffaceous bed of the E-Lert Formation. Quarry NW of hangwat Loei (Grf. 873391, map sheet 5344 III of scale 1: 50, 000, St. 2/40).



**Fig. 2.7** The Pha Dua Formation showing broad folding of well-bedded greenish gray to yellowish brown feldspathic siltstones and fine sandstone interbedded shale (Chiang Kan-Thali road along Nam Huaeng, Ban Tha Dee Mee).

### Pha Dua Formation

The Pha Dua Formation is probably to the upper most Permian succession in the Loei area with exclusively clastics in nature. The formation was named after Ban Pha Dua, Changwat Loei, and is characterized by thin-bedded and very thin-bedded greenish to brown shale, sandy shale, micaceous sandstone and also interbedded siltstone (Charoenprawat and Wongwanich, 1976). Besides, the sequences are often interbedded with pyroclastic tuff (Putthapiban, 1987). The small cross-bedding, winnowing, and Bouma-T sequences were observed (Altermann, 1989). It is noted that the sedimentary succession of the Pha Dua Formation has been gently to intensely folded (Figs. 2.7, 2.8 ) in most parts.

The formation is believed to unconformably underlie the Mesozoic strata without any field evidence, and conformably overlies the E-Lert Formation. It is correlated with the Dan Sai Shale of Bunopas (1981) with the type section at Loei-Dan Sai road between km 4 to km 20. Although the Pha Duae Formation in the Loei area might be correlated with the Sap Bon Formation in the Saraburi area (Hinthong, 1985), but the characteristic of lithological sequence in the Loei area is entirely different.

Several plant fossils indicate the Kazanian age (Charoenprawat and Wongwanich, 1976), advocated by Middle Permian ammonoids fragments *Agathiceras* sp. (Altermann, 1989), and plant remains have been found from several outcrops between Loei-Dan Sai (km 7, km 8, etc.) and Loei-Tha Li Roads (km 3.3, km 7.6 to 7.7) that lies subparallel to the west.



Fig. 2.8 Folding of slightly silicified, yellowish greenish shale and siltstone of the Pha Dua Formation near Ban Tha Dee Mee, northwest of Changwat Loei.

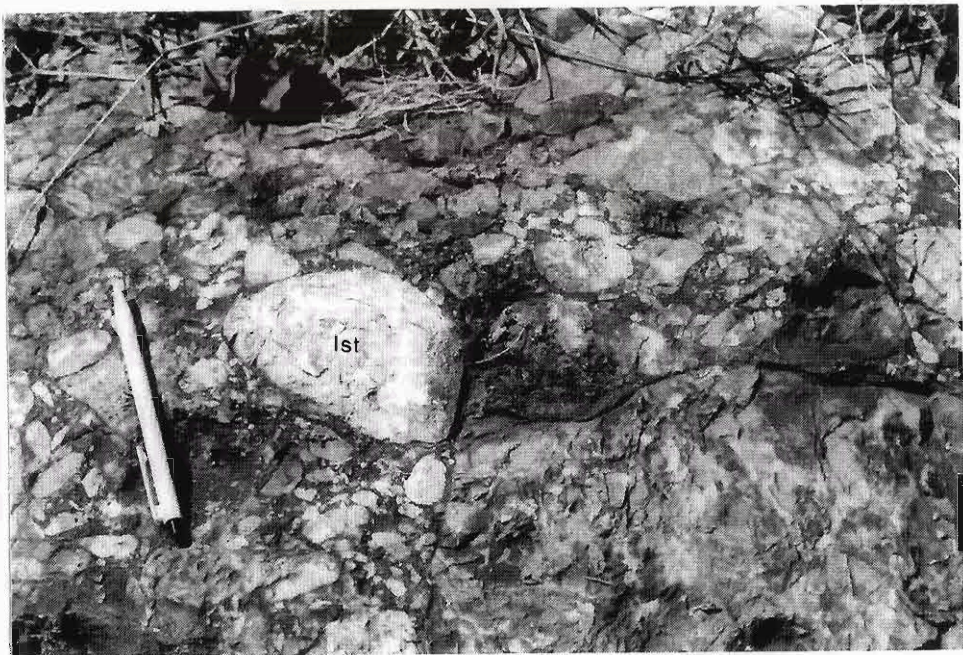


Fig. 2.9 Poorly-sorted limestone conglomerate with siliceous cement and clay matrix in the Huai Hin Lat Formation (Ban Dong Noi, Wang Saphung-Phu Kradung Highway, km 315+800).



## Triassic rocks

### Huai Hin Lat Formation

The Huai Hin Lat Formation (Ward and Bunnag, 1964, Iwai *et al.*, 1966, Charoenprawat and Wongwanich, 1976) was designated for the Triassic rock unit of lacustrine origin. Current seismic survey data reveal that the geometry of this formation is a series of isolated “half-graben” deposits and conformably underlies the Nam Phong Formation (Sattayalak, 1985; 1997).

Exposed lithology is characterized by greenish gray, poorly sorted conglomerate with mainly limestone clasts of angular to subangular shape (Fig. 2.9). A mixed small amount of rounded to subrounded clasts of rhyolitic tuff andesite with a volcanic matrix are well cemented by silica cement (Figs. 2.10, 2.11). The different lithology of clast components probable depend on the type of base rocks and intensity of the erosion.

The formation rests unconformably on the Middle Permian carbonate and purple to greenish rhyolitic tuff of the Permo-Triassic volcanic rocks. The upper contact has not been yet observed in the studied area.

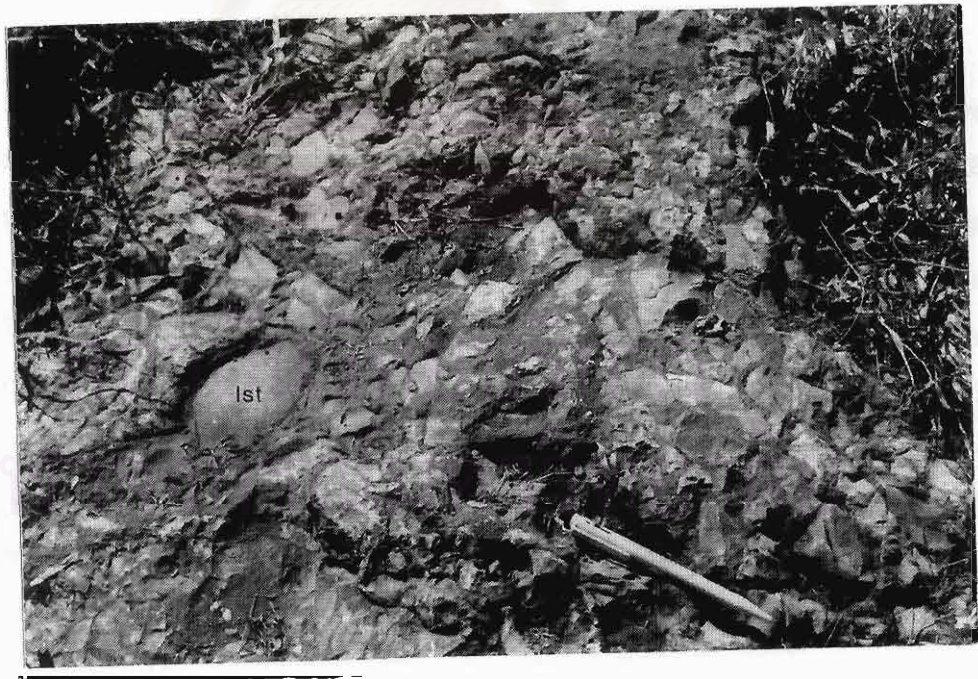
## Igneous rocks

### Granite-Granodiorite

The granitoid rocks of the Loei area belong to the Eastern granitic Belt of Thailand. They form batholiths and small stocks intruding Carboniferous and Permian rocks. The I-type granite (Charusiri, 1989; Putthapiban, 1997) has been recognized, representing a characteristic arc-type-arc-alkali tonalite of monzo-granite series. The variation in compositions from granite to tonalitic granite and granodiorite suits are apparent. Medium- to coarse-grained pinkish granites contemporaneously



**Fig. 2.10** The conglomerate consists of abundant volcanic clasts of rhyolitic, andesitic tuff, and limestone in volcanic matrix, with moderately- to well-cemented (Ban Dong Noi, Wang Saphung-Phu Kradung Highway, km 316+500).



**Fig. 2.11** Poorly-sorted and angular to subrounded clasts in the Huai Hin Lat Formation, consists mainly of limestone with sandstone and chert. Reddish silt matrix and slightly cemented (Wang Saphung-Nong Bua Lumphu Highway, approximately km 16).

occur with coarse-grained biotite hornblend granite and diorite as well as hornblendite. Result of  $^{40}\text{Ar}/^{39}\text{Ar}$  dating (Charusiri, 1989; Charusiri *et al.*, 1991) and K/Ar isotopic age determination (Jacobson *et al.*, 1969) indicated a narrow time interval (227 Ma to 235 Ma) in Early to Middle Triassic. The occurrence of these granites have been considered due to collision between the Shan-Thai and the Indochina terranes (Charusiri, 1989).

### Volcanic Rocks

The distribution of volcanic rocks have been separated in three nearly north-south belts along the eastern, western, and central parts of the Loei area (Jungyusuk and Khositant, 1992; Panjasawatwong, 1997). These rocks include Devonian rhyolite, Middle Devonian-Lower Carboniferous basalts and Permo-Triassic andesite, respectively (Intasopa, 1993). They are included the Loei-Phetchabun Volcanic Belts (Barr and McDonald, 1991), or in the east central Thailand Volcanic Belt (Intasopa and Dunn, 1991).

The volcanic rocks as andesite, dacite, rhyolite, agglomerate, and tuff were earlier mapped as Permo-Triassic age (Department of Mineral Resources, 1988). They were intruded by small bodies of granite, granodiorite, and diorite. The volcanic rocks unconformably overlie the Permian carbonates and unconformably underlie the Upper Triassic conglomerates. Chairangsee *et al.* (1990) pointed that the tuff unconformably underlies the Nam Pong Formation, and locally underlies the Huai Hin Lat Formation (Jungyusuk and Khositant, 1992). The occurrence of these volcanic rocks has been interpreted to be the products of arc volcanic (Panjasawatwong, 1997) and have formed above an eastward dipping subduction zone (Bunopas, 1981; Hutchison, 1989). The volcanic facies was developed due to the emplacement of subduction-related I-type plutonics (Charusiri, 1989; Charusiri *et al.*, 1994) in Late Paleozoic before the suturing between the Shan-Thai and the Indochina terranes.

### Quaternary Deposits

The unconsolidated surficial deposits occupy mainly the flat plain area, corresponding to the weathering of parent rocks under the influence of fluvial processes. The deposits are generally only a few-metre thick and consists of a mixture clay, silt, sand, and gravel in various proportions.



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