CHAPTER VI

DISCUSSION AND CONCLUSION

The main objective of the study is to establish the stratotype of carbonate succession representing the Nam Maholan Formation in the southeastern part of Changwat Loei. Additional attempts have been made to conduct the lithofacies analysis and reconstruction of depositional environment and associated tectonic uplift.

Classification and nomenclature of the lithostratigraphy

The most significant carbonate terrane of the country which widely exposed along the western rim of the Khorat Plateau, from Changwat Saraburi to Changwat Loei had been considered under the time-stratigraphic unit as a part of the Ratburi Limestone (Brown *et al.*, 1951) and later on it was categorized under the lithostratigraphic unit in the Ratburi Group (Javanaphet, 1969). The Saraburi Group (Bunopas, 1981; Department of Mineral Resources, 1987; 1989; 1992) has been proposed for this carbonate terrane according to their geographic distribution and plate tectonic regime. However, there are different natures of the designated formations, different palaeontoligical aspects, and different lithofacies associations in Saraburi, Phetchabun, and Loei areas.

With reference to Charoenprawat and Wongwanich (1976), and Charoenprawat *et al.* (1976), the Permian rocks in the Loei area are subdivided into three formations, namely, the Nam Maholan, the E-Lert, and the Pha Dua Formations in an ascending order. The Nam Maholan Formation is the predominant carbonate unit in the eastern part of Changwat Loei which probable eastwardly lies beneath the Mesozoic strata of the Khorat Group. The formation extends northwardly to Lao PDR (at west of Vien Tien to Luang Phra Bang), and extends southwardly to Phetcahabun, Chaiyaphum, Khon Kaen, Nakhon Ratchasima, and Saraburi areas, respectively.

However, several formation names have been designated in different areas based on geographic terrans by many workers.

Lithostratigraphy of the Nam Maholan Formation

Stratigraphically, the Nam Maholan Formation in the study area overlies the Wang Saphung Formation and conformably underlying the Huai Hin Lat Formation. With the approximately 500 metre-thick sequence in the stratotype area, altogether three members are subdivided in an ascending order:

1) the Tham Suae Mop Member (about 50 metre-thick) characterized by predominantly thin-bedded limestone and shale,

2) the Ban Nong Hin Member (about 200-250 metre-thick) comprising of thin-bedded dolomitized limestone with laminated and nodular cherts, and

3) the Phu Pha Khao Member (about 300 metre-thick) consisting of predominantly thick-to very thick-bedded limestone with partly dolomitized.

Carbonate mineral and geochemical characteristic

The carbonate mineralogy is determined only for carbonate rocks of the whole succession of the Nam Maholan Formation. The lowest member, the Tham Suae Mop Member, the carbonate mineralogy is characterized almost entirely as calcite. However, for the midle member or the Ban Nong Hin Member is characterized the high dolomite zones in the upper middle and upper most part of the sequence. For the upper most member, the Phu Pha Khao Member, the dolomite has been associated with calcite with varying degree of abundance almost throughout the length of the whole sequence except the upper most part where relatively lower content of dolomite is observed.

Geochemically, the eight major oxides contents show strongly fluctuation throughout the Phu Pha Khao Member, whereas they are slightly fluctuation in the Ban Nong Hin and the Tham Suae Mop Members.

Microfacies identification

Petrographic study reveals that carbonate texture varies from mud-supported to grain-supported. Allochems are mainly fusulinaceans, smaller foraminifers, algae, brachiopods, corals, with some lithoclasts, peloids, ooids, lumped grains, and unidentified skeletal fragments. Altogether seven microfacies are recognized throughout the succession of the Nam Maholan Formation. They are packed biomicrite, sparse biomicrite, biosparite, crystalline, oosparudite, algal lamination, and pelmicrite, in decreasing order, respectively. However, it is noted that there is also some differences in the degree of abundance of different natures of allochemical components of the same carbonate rock nomenclature.

Stable isotope determination

The over 500 metre-thick carbonate succession of the Nam Maholan Formation in the study area displays $\delta^{18}O$ values between -7.51 and -6.20 per mil on the PDB scale gathering from whole rocks, fusulinaceans, brachiopods, and dolomite samples. The displaying of fluctuation of the isotope values indicate partly restricted water circulation of the depositional basin. These $\delta^{18}O$ values probably suggest a re-equilibration of carbonate with basinal water depleted ^{18}O under elevated temperature during the diagenetic period. The providing ideal to determine the depositonal temperature, although the calculated values do not suggest temperatures of original condition, but at least, they probably reflecte a tropical climate condition. In addition, the calculation of probable salinity values ranging between 18.44 and 33.08 per mil are arranged in normal salinity tend to brackish of basinal water.

The various carbon isotope values of the carbonate succession between +2.54 and +3.67 per mil (PDB) are arranged in carbonates of marine origin, and strongly suggesting that carbon was formed by oxidation of organic matters rather than production of tectonic activities.

The combination of oxygen-and carbon-isotope ratios indicate to carbonate of shallow marine origin tend to be fresh-water contamination (Boggs, 1987) and possibly suggest evolution of carbonate rocks due to mix between original sea water composition and carbonate cement (Rollinson, 1993).

Age determination

For the Loei area, despite the several exposures of Devonian to Lower Carboniferous carbonate rocks (Chairangsee *et al.*, 1990; Fontaine *et al.*,1990; Bunopas, 1981, 1983 etc.), the Nam Maholan Formation has been dated palaeotologically to be Gzhelian to Murghabian age based mainly on brachiopods (Yanagida 1967; Piyasin, 1981), fusulinaceans and smaller foraminifers (Igo *et al.*, 1993; Fontaine *et al.*, 1994, 1995; Ueno *et al.*, 1993, 1994, 1995 and 1996; Ingavat, 1994; and Charoentitirat, 1995, etc.). Subsequently, neither Midian (Altermann, 1987) nor Dzhulfian and Dorashamian fossils have been found in carbonate rocks in this area. However, the appearance of *Giantopteris* and plant fossils indicating the Late Permian in the overlying clastic formation (Pha Dua Formation), have been reported (Asama *et al.*, 1968; Pendexter, 1980; Bunopas, 1981; Charoenprawat and Wongwanich, 1986; Altermann, 1987; Bunopas and Fontaine, 1989). It is noted that, Dzhulfian to Dorashamian age of the Uppermost Permian period has been reported by Dawsan *et al.* (1993; 1994), based on fusulinaceans *Conodofususiella, Paleofusulina,* and smaller foraminifers *Colaniella* in limestone at northern part of Changwat Loei along the Mae Khong River.

The carbonate succession in the study area is dated restrictly from Gzhelian to Yahtashian age (Late Carboniferous to late Middle Permian), based solely upon the

index fossil-fusulinaceans *Pseudofusulina* sp., *Parafusulina* sp., *Schwagerina* sp., *Triticites* sp., smaller foraminifers *Schubertella* sp., *Tetrataxis* sp., *Bradyina* sp., (see also Table 3.2). Additionally echinoderms, green algae Dasycladacean, *Tubiphytes* sp., *Mizzia*, Phylloidal algae, bryozoans, gastropods, ostracods, and corals are also abundant in decreasing order, respectively.

Depositional environments

The depositional environment of the Upper Palaeozoic carbonate rocks in the southeastern part of Changwat Loei have been reconstructed by several workers (Pendexter, 1980; Piyasin, 1981; Wielchowsky and Young, 1985; Kozar *et al.*, 1992; Chinoroje and Bhasavanija, 1988; Mouret, 1994; Charoentitirat, 1995, etc.). Most of all previous interpretations suggested that these carbonate rocks were deposited predominantly under the shallow marine of an open sea with normal salinity environment and formed a shelf carbonate facies (Chonglakmani and Sattayalak, 1979; Piyasin, 1981; Altermann *et al.*, 1983; Altermann, 1987; Kozar *et al.*, 1992). Besides, reef or patch reef, and also organic built-up were diagnosed (e.g., Pendexter, 1980; Piyasin, 1981; Wielchosky and Young, 1985; Charoentitirat, 1992; and Chinoroje and Bhasavanija, 1988 etc.).

The depositional environment of the study area is believed to be the marine shelf of carbonate accumulation since Late Carboniferous to late Early Permian. The carbonate lithology with abundant and diversified fauna fossils indicate the sun-lit and clear water of shallow marine. Various microfacies types representing the intertidal and subtial carbonate facies develop under influence of low-to high-energy water condition, probably partly restricted water circulation. Tropical shallow marine with normal salinity is advocated by the presence of common echinoderms, and abundant fauna fossils. Warm water with probably palaeotemperature above 20 ^{0}C of tropical area are also suggested based on oolite and dasycladacean algae (Flugel, 1982).

The characteristic of the Microfacies I, II and VI with the oolite, algal peloids, an algal mat as the main allochemical components strongly indicate the depositional environment of intertidal zone. Besides, the characteristics of the Microfacies III, IV, and V with abundant and diversified shelf fauna indicate the depositional environment of subtidal zone. However, the abundance of micrite and mud-supported texture of the Microfacies III, IV, and V suggest the relatively low energy of depositional environment, probably under restricted circulation i.e. lagoonal and/or subwave-base zones.

Therefore, it is concluded that the Microfacies I, II, and VI represent the intertidal zone, whereas the Microfacies III, IV, and V represent the subtidal zone.

Vertical facies variation, the changing from coarse-to fine-grained carbonate upward stratigraphy of the Tham Suae Mop Member representing fining-upward sequence, and suggesting decreasing energy toward the top. These may indicate sea level rise and or marine transgression and/or subsided basin. The change of pelmicrite microfacies from the top of the Tham Suae Mop Member to biomicrite and biosparite in limestone-chert sequence at the bottom and the middle part of the Ban Nong Hin Member suggest to coarsening upward sequence with representing energy increasing toward the top. These may indicate to change of depositional environment due to sea level low possibly marine regression. However, the occurrence of nodular chert and association of predominantly thin-to medium-bedded biomicrite and biosparite with abundant fauna fossils, may indicate clear warm water of relatively low to moderate energy of water condition in depositional basin. The changing from limestone-chert sequence to predominantly thick-to very thick-bedded limestone of the Phu Pha Khao Member with various microfacies types such as biomicrite, biosparite, oosparudite, and algal lamination suggest to alternation of fine- and coarse-grained carbonate facies. These may indicate to fluctuation and agitation of water condition, possibly due to regression and/or uplift of the depositional basin with time.

Overall interpretation herein, lithofacies and palaeontology as well as isotopic results of the carbonate succession indicate a carbonate shelf of normal marine with partly restricted water circulation. Various microfacies types indicate the carbonate facies develop under the influence from low- to high-energy water condition in the depositional zones of subtidal and intertidal regimes.

Tectonic implication

The western part of the Indochina terrane has been considered as a regime of the active margin during Midle Paleozoic and later changed to rifted passive margin throughout Late Paleozoic (Bunopas, 1981; 1992). Tectonic event and terrane evolution of the study area may be a closed relationship to the Indochina, particularly the evolution and basin development of northeastern Thailand.

The study area has been located on the western margin of the Indochina terrane with no older rocks than Devonian period has been reported. The area had been a passive margin since Late Carboniferous through late Middle Permian with the shallow sea water flood over vast area of the land mass (Sattayarak, 1985), regarding to existing carbonate platform of which dated paleontologically in Late Carboniferous to late Middle Permian (Gzhelian to Murghabian age). This carbonate platform was probably built up on to passive margin of oceanic plate that formed by tectonism in Late Carboniferous. This rifting has been thought to be a dominant event in the development of the Khorat basin and responsible for generating a north-south trending sea way (Kozar *et al.*, 1992). During the carbonate accumulation, the area was formed a tectonically stable with subsident areas extend to west and south. Microfacies indicate low- to high-energy carbonate shelf, located intertidal and subtidal regimes. Litho- and bio-facies as well as stable oxygen- and carbon-isotope results indicate that these carbonate rocks are a normal marine origin with shallow shelf depositional environment. Warm and humid climates with occasionally fresh water influxed are suggested. In addition, the plant remains *Giantopteris* (Assama *et al.*, 1986) in the upper clastic formation (Pha Dua Formation or Dan Sai Shale) has been also indicated

westwardly beside the continental margin during Late Permian. The upper clastic formation in Loei area was described as a flysh facies (Helmcke and Kraikhong, 1982; Alterman, 1987), implying rapid terrigenous influx due to tectonic subsidence. The Nam Maholan platform is interpreted herein as the post tectonic cover of older Variscan orogeny located futher east and now covered by the Mesozoic Khorat red beds such as the interpretation of the Pha Nok Khao platform (Altermann, 1987; Altermann *et al.*, 1983).

According to lithofacies and key palaeontology identification, the change of the siliciclastic to the carbonate sedimentation on the Nam Maholan platform is active before carbonate accumulation on the Khao Khwang platform. The high sea level in Kubergandian to Murghabian age of Middle Permian has been suggested as the major time of carbonate accumulation on the Khao Khwang platform (Altermann, 1987; Altermann *et al.*, 1983; Helmcke, 1983; 1985; Wielchowsky and Young, 1985; and Vail *et al.*, 1977), but the older, the Gzhelian to Murghabian age is the major time for carbonate built up of the Nam Maholan platform. These may imply high sea level stand in the area during this time. The slow rise of sea level is suggested by the Tham Suae Mop and the Ban Nong Hin Members, whereas the slow down and fluctuation of sea level is represented by the Phu Pha Khao Member. These imply to marine transgression and regression with fluctuation of sea level in the global eustatic declined period. The presence of large amount of terrigenous sediments with carbonate-free may suggest to rapidly subsided basin due to tectonic event later.

Lithofacies and stable isotope results advocating fusulinaceans suggest that sea level was dropped toward the end of Permian, while temperature increased. The stable isotope results illustrate that temperatures tend to increase upward stratigraphy, at least from Late Carboniferous to late Early Permian (Gzehlian to Yahtashian age). These probably indicate that the main trend of global sea level is not only controlled by climate during the Permian time, but plate-tectonic influent also (Ingavat and Helmcke, 1986). Then the lithofacies was controlled by both eustatic sea level

variation and resemble tectonic event (Wielchosky and Young, 1985; Ingavat and Helmcke, 1986).

Litho-, bio-stratigraphy, as well as isotopic information strongly suggest to the Late Palaeozoic carbonate occurred in tropical climate condition and was probably situated close to palaeoequator of the palaeotethys during that time. Additionally, the occurrence of Middle to Late Palaeozoic basaltic ocean floor and associated deep-water radiolarian cherts may point to limestone terrane occurring onto the ocean basin prior to the advent of subduction-related Permo-Triassic arc-type magmatism. This also confirms that the Late Paleozoic carbonate terrane may have become parts of Indochina during Triassic Period.

Some economic aspects

Some economic aspects have been considered on the bases of field survey as mapping lithostratigraphy and assess the geological features such as proportion of chert, interbedded shale, and distribution of dolomite, *etc.* The distribution of the carbanate rocks has been mapped into several lithologic units (Fig. 6.1). These are very thin- bedded dark gray limestone interbedded with very thin- bedded shale and fine-grained sandstone unit (the Tham Suea Mop Member), thin-bedded dark gray limestone interbedded with black chert (the Ban Nong Hin Member), thick- to very thick- bedded light gray limestone with occasionally dolomitized (the Phu Pha Khao Member), and thin-to thick bedded dolomite unit. The non-carbonate rocks are also mapped, these are volcanic, and clastic conglomerate-sandstone units.

Several locations of these limestones have been exploited for mainly aggregate and roadstone consumptions besides the southern and northern part of the study area. The limestones of all recognition can be primary used for cement and lime according to content $CaCO_3$ at 85-92 % (analogous low purity of the BGS's scheme) is generally suggest suitably for the cement by their good homogenuous blended raw

material characteristics (Department of Mineral Resources, 1995). However, their impurities due to lithologic characteristics are virtually classified in the outcrop area.

Analytical results indicating these limestones are faired for cement, lime and aggregate proposes, particularly the Phu Pha Khao Member, according to not only slightly impurity and widely spread as a big amount capacity, but also convenient accessibility. The Ban Nong Hin Members seem to be not suitable for present economic subjects corresponding to their outcrop impurities such as cherts, whereas the Tham Suae Mop Member is fair for crushing and aggregate although it is interbedded shale at outcrop scale. The summary of these limestone resources is illustrated in Table 6.1.

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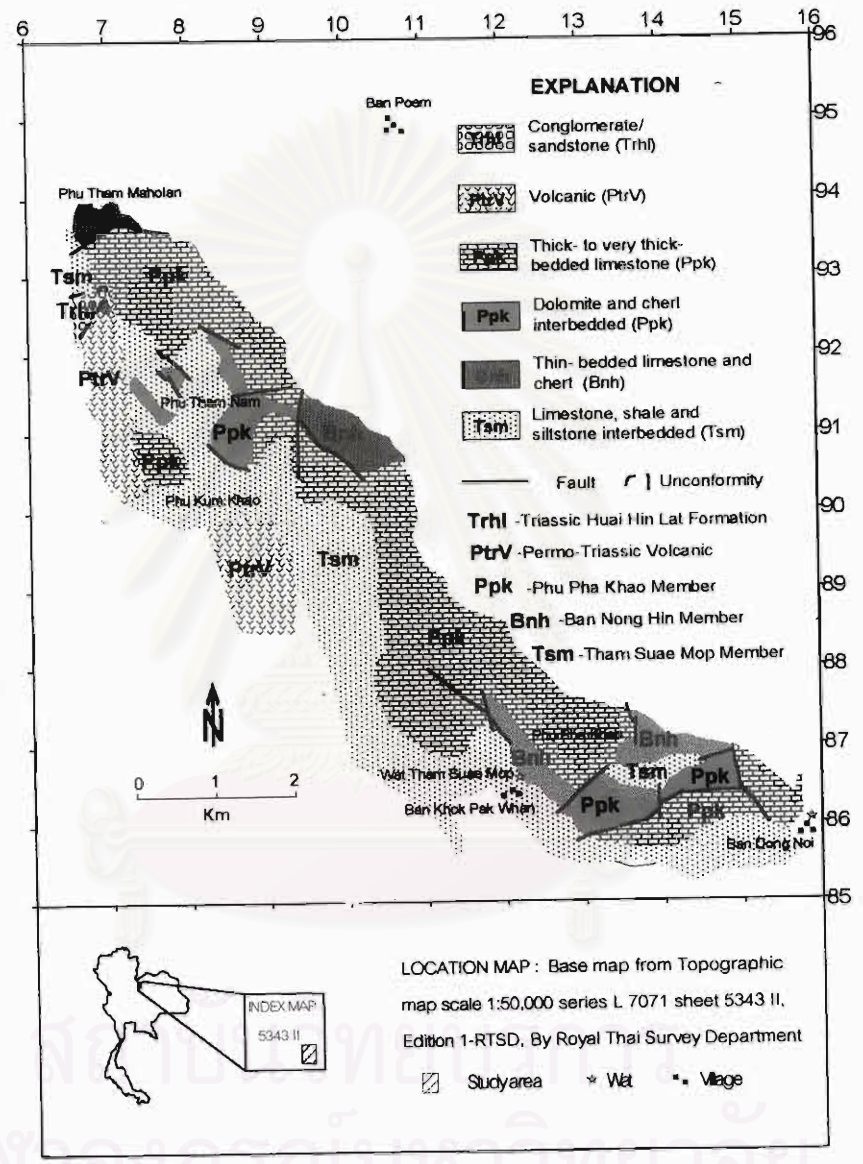

Fig. 6.1 Resources map illustrating lithologic units and members of the Nam Maholan Formation in the study area.

Table 6.1 Summary of limestone resources.

Rock Unit	Lithofacies	Thickness (metre)	Resources category
Phu Pha Khao	Thin- to very thick- bedded limestone and occsionally dolomite interbeds, light gray to white colour.	> 250	Moderately to high purity
Ban Nong Hin	Thin- bedded dark gray limestone interbedded with thin-bedded and nodular black cherts.	200-250	Low to moderately purity
Tham Suae Mop	Thin- to medium- bedded limestone with slightly "silica nodules" and interbedded shale	>50	Moderately purity
Variation (Permian)	Fine- to coaese- grained, thin- to thick-bedde dolomite, white to black colour. .	Variable	Dolomite , mostely Mgo > 17.6 %
Carboniferous-Permian clastic rocks	Shale, siltstone and sandstone with limestone lens	-	not asscessment

Remark: Resources category is referred to BGS's scheme.

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