

## CHAPTER II

### GEOLOGY

In this study, an attempt has been made to review the overall geological setting of the Lao PDR. Despite the fact that only a few geological surveys have been so far conducted systematically, the overview geology of the country has been compiled from existing maps and reports. It is against this background, the geology of the study area is subsequently presented.

The foregoing discussion will be firstly focusing upon the general geological background of the Lao PDR.

#### 2.1 Physiography

The Lao People's Democratic Republic (Lao PDR) is a landlocked country with an area of 236,800 square kilometres (91,500 sq.miles). The capital city is Vientiane. The Lao PDR is bordered by China to the north, Vietnam to the east, Cambodia to the south, Thailand to the west, and Myanmar to the northwest. The Mekong river, the only main river and also international river runs along the western border of the country from the northernmost through the southernmost.

Almost all parts of the country, except the small area in the northeast, lies within the catchment of the Mekong river. The northern part of the country is a region of rugged jungle-covered mountains with summits above 2,000 metres MSL (highest point Phu Bia, 2816 metres MSL is at the southeast of the Plain of Jars). This area is sparsely populated. Principal settlements are at Louang Prabang which is the former royal capital, Xieng Khouang and Houa Phan. Flowing across the region through a series of narrow valleys and gorges with many rapids are the Mekong river and its tributaries.

Three principal cities of the Lao PDR i.e. Thakhek, Savannakhet and Pakse are situated on the river bank of Mekong in the southern part of the country, and it is in this lowland riparian region that the bulk of estimated 3.5 million population live. To the east, the land rises gradually towards the mountainous range which is the border with Vietnam.

The plains of the southern part of the country produce most of the nation's rice and other lowland crops. Rainfall is moderate and variable over much of this region, however, larger area are covered with sparse forest and savannah where soil qualities are generally poor. The most fertile region is in the basaltic Boliven plateau, whose rich upland soils, mild climate and high seasonal rainfall are well suited to many kinds of fruits, vegetables , coffee, tea and tobacco.

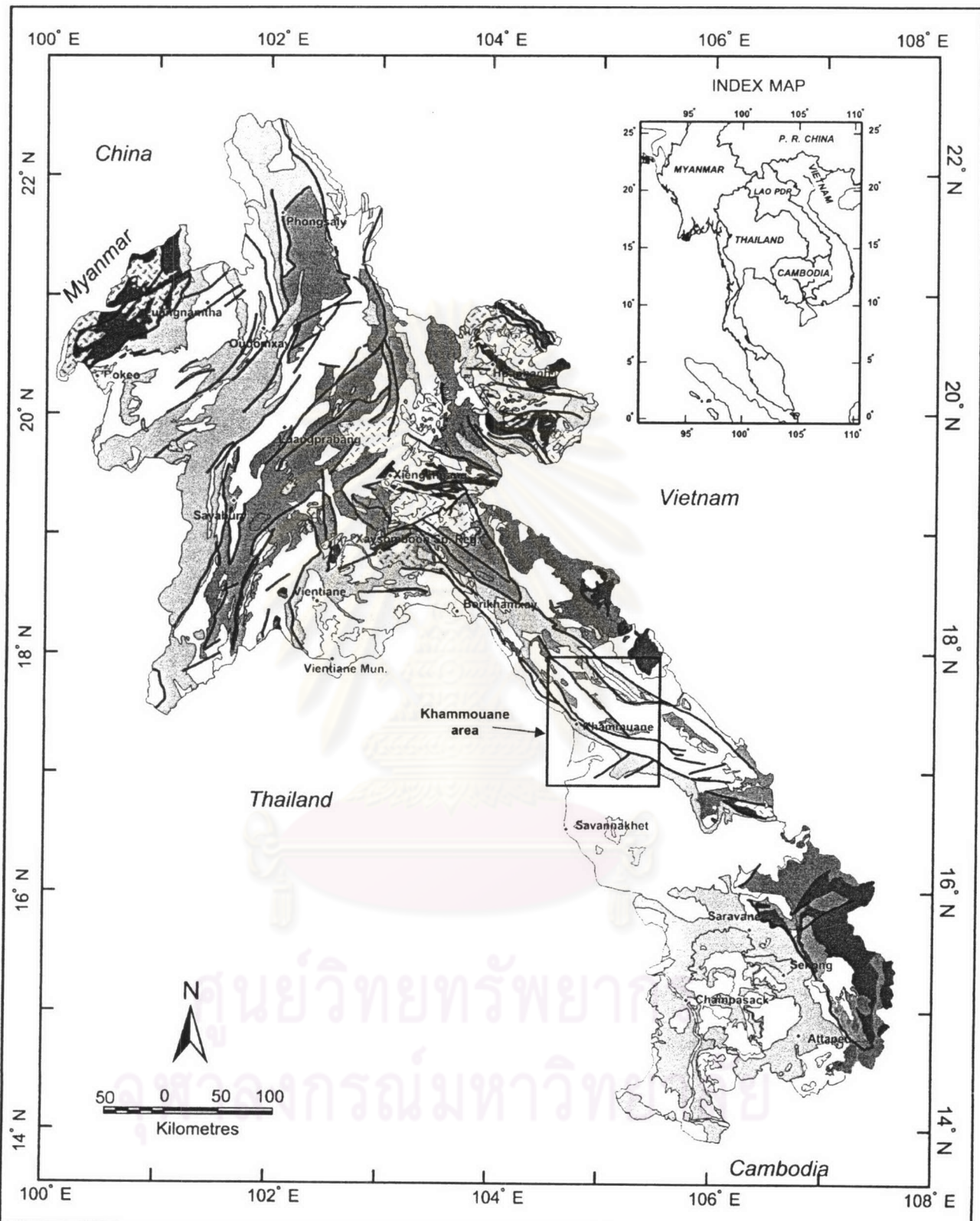
## 2.2 Stratigraphy

Regional geology of the Lao PDR is clearly demonstrated by the geological map of 1:1,000,000 scale compiled by Annells and Coats, (1990) in Fig. 2.1. However, more detailed stratigraphy of the country was reported by Stokes, (1989). Thus, the geology of the Lao PDR was summarised according to his work in ascending order of geological age as follows:

**Precambrian**

**Lower to Middle Proterozoic**

The rocks comprise paragneiss, orthogneiss, biotite-garnet-staurolite schist intercalated with quartzite and amphibolite. Their main exposures are in the southern (Attapeu Province, Sepone district), and in the northern (Xieng Khouang Province) parts of the country.



GEOLOGICAL ASSESSMENT OF SOME PERMO-CARBONIFEROUS CARBONATE SEDIMENTS IN THE SOUTHERN PART OF THE PHA HOUA XANG RANGE, MOUANG THAKHEK, KHAMMOUANE PROVINCE, THE LAO PDR.

Figure. 2.1 Geological map of Lao PDR (modified after R.N. Annells and J.S.Coats, 1990). (Box area is for figure 2.3)

KEO KHAMPHAVONG  
2003

DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE  
CHULALONGKORN UNIVERSITY



CENOZOIC		QUATERNARY		STRATIGRAPHIC UNITS		INTRUSIVE ROCKS		
TERTIARY	Neogene	2		<b>N2-Q</b> Unconsolidated gravels, sands, silts and clays mostly of fluvial origin, with some basaltic lava flows (v), ash and loess. Latentised intra-sequence erosion surfaces are present. Infermontane basin sequence of fresh-water sandstones, shales and marls with rare limestone and lignite beds and some basaltic lava flow (v).		<b>gPg</b> Minor granitoid intrusions (g); gabbro-monzonite to dacitic quartz porphyry.		
	Palaeogene			<b>vPg</b> Alkali basalt lava flows (v) (basanitoid types) with associated eruptive vents.				
MESOZOIC	Cretaceous	3		<b>Mz2</b> Mostly red continental sandstones and clays, with lagoonal mudrocks in the upper levels bearing evaporite units of halite and gypsum.				
		2		<b>Mz1</b> Mostly continental sequence with local shallow-water marine facies persisting from Upper Palaeozoic. Continental red clayey arenites with occasional thin coal seams and conglomerates in paralic intercalations. middle Triassic marine limestone		<b>gMz</b> Granitoid plutons (g); mostly granodiorite and monzogranite, with less abundant gabbro (m) and silicic subvolcanic intrusive rocks.		
		1		<b>Pz3</b> Shallow shelf sea sequence interdigitated with a volcanosedimentary sequence. Mostly sandstone, siltstone and shale in the N and NW. Some silicic, intermediate and mafic extrusive rocks (v) associated with subvolcanic intrusions. Bedded to massive dark grey to light grey marine limestone (c) from extensive karst tracts in N and E, and in the E are intercalated with siltstone, mudstone and some coal seams. Epiclastic rocks		<b>gPz3</b> Granitoid plutons (g); mostly megacrystic biotite-granite, tonalite and granodiorite.		
PALAEOZOIC	Permian	2						
		1				<b>gPz2</b> Granitoid plutons (g); mostly granodiorite to monzogranite.		
	Carboniferous	2						
		1			<b>Pz2</b> Mostly shallow shelf sea sequence of muddy limestones (c). Some continental Carboniferous in Vientiane basin, salavang (S central) and Phongsali Devonian (N). Mostly marine volcanosedimentary sequence with mudrocks, wackes, arenites, silicic and intermediate volcanic rocks, lightly metamorphosed.		<b>gPz2</b> Granitoid plutons (g); mostly granodiorite to granite, with less abundant diorite phases in the southern part of the Sanakham-Pak Lay belt.	
	Devonian	3						
		2						
Silurian	1							
	2							
ORDOVICIAN	3							
	2			<b>Pz1</b> Deep-water marine volcanosedimentary sequence, metamorphosed to low or low-medium grades in the east; mudrocks, wackes, sericite schists and arenites, amphibolite, black limestone, mafic, intermediate and silicic volcanic rocks.		<b>gPz1, mPz1</b> Granitoid plutons (g) with some associated gabbro intrusives (m).		
	1							
Cambrian	3							
	2							
PROTEROZOIC	Precambrian	1		<b>PR</b> Scattered outcrop areas of low to high grade metamorphic rocks close to the NE and SE borders with Vietnam.		<b>gPr</b> Granitoid plutons of the Truongson belt (g); alkali granites, some migmatites and tonalites.		
		2		<b>Song Ma (SE)</b> Low-grade mica-schists, quartz chlorite-sericite schists and arenites, and marbles; this sequence may continue upwards into the lower Palaeozoic rocks. Ultramafic rocks (u) occur in narrow belts. <b>Kontum Massif (SE)</b> Medium to high-grade metamorphic rocks; granitoid gneiss, mica schist (with garnet, cordierite kyanite or sillimanite), amphibolite and marble.				

(modified after Annells & Coats, 1990)

## Upper Proterozoic

The rocks consist of quartz-chlorite- sericite schist intercalated with micaceous quartzite and marble. They are exposed in the valley of Nam Ma near the Lao-Vietnam border (Houa Phan Province) and northwestern parts of the country.

## Paleozoic

### Cambrian to Lower Ordovician

These rocks comprise chlorite schist, sericite schist with little intercalation of limestone, and some mafic igneous rocks. They are distributed in the northeastern part and small portion in the central part of the country. In the upper horizon of this stratigraphic sequence, there are graptolite fossils indicating Lower Ordovician age (Fromaget, 1927).

### Ordovician to Silurian

The rocks are composed of sandstone, quartzite, slate, marlstone, black limestone, sericite schist and some igneous rocks of intermediate to felsic composition (andesite, rhyolite). They are exposed in the northeastern, northwestern, central and southern parts of the Lao PDR.

### Upper Silurian to Lower Devonian

The rocks of this period consist of slates and calcareous shales intercalated with sericite schist, sandstone, crystalline limestone and siliceous limestone. Lenses of intermediate to felsic igneous rocks are also present locally. The rocks are located in the northeastern, northwestern, central and southern parts of the country.

### **Middle to Upper Devonian**

The rocks of this period consist of slate, siltstone sandstone, calcareous shale and lenses of the dark grey crystalline limestone at some localities. The rocks are distributed in the northern part of the country.

### **Lower and Middle Carboniferous**

The rocks comprise of marl, siltstone, black limestone and coal beds. They are widespread in some areas of Xiengkhouang, Khammouane and Salavan provinces.

### **Middle Carboniferous to Permian**

The rocks of this period are black limestone intercalated with quartzite and schist in the lower part of the sequence, whereas the upper portion is composed of thickly bedded, pale grey limestone. This unit is widely distributed in some parts of Louang Prabang, Oudomxay, Xieng Khouang, Vientiane, Khammouane and Salavan provinces.

### **Upper Carboniferous and Permian**

The rocks consist of shale, siltstone and sandstone crosscut by volcanic rocks (andesite, dacite, rhyolite) in the lower part, whereas upper part is characterized mainly by limestones. They are widespread in the northwestern part of the Lao PDR.

### **Upper Permian to Lower Triassic**

The rocks of this period comprise pale purple sandstone and siltstone, black shale, limestone and slate intercalated with volcanic rocks (andesite, dacite, rhyolite, tuff). The rocks are well exposed in the northwestern part of the country.

## Mesozoic

Mesozoic rocks are largely distributed within the territory of the Lao PDR. It can be subdivided into four stratigraphic units as follows:

### Middle Triassic

The rocks of this period are volcanic rocks of felsic to intermediate composition, tuffs, conglomerate, siltstone, black and purple slate, calcareous shale, thinly-bedded siliceous limestone and very thickly-bedded grey limestones. These rocks are well distributed in the northeastern and southern parts of the Lao PDR.

### Upper Triassic

The rocks consist of conglomerate, sandstone, siltstone, carbonaceous mudstone, lenses of limestone and coal.

### Jurassic

The rocks comprise of sandstone, siltstone, conglomerate, shale and limestone. These rocks are exposed particularly in Oudomxay Province.

### Cretaceous

It is widely distributed in Vientiane and Savannakhet plains. They are composed of red sandstone, siltstone and conglomerate. In the upper part of the succession, there are halite and gypsum. This unit can be correlated with the Maha Sarakham Formation of the Khorat Group (Ward and Bunnag, 1964) in Thailand.

## Cenozoic

The Cenozoic strata can be essentially subdivided into 3 main stratigraphic units:

### Neogene

It is composed of conglomerate, siltstone, mudstone, marl, carbonaceous mudstone, coal. It occurs in intermontane basins in the northern part of the Lao PDR.

### Pliocene to Pleistocene

It is composed of basalt which is widely distributed in southern part of the country (Boliven plateau).

### Quaternary

It is entirely unconsolidated sediments consisting of pebble, sand, and clay. They were deposited mainly in the plains of Vientiane, Savannakhet and Champassack Provinces. These Quaternary deposits are located along the major rivers and valleys in the central and northern portions of the country.

## 2.3 Igneous Rocks

Igneous rocks are quite abundant in the Lao PDR with various rock types and ages. They are composed of granitoid massifs ranging in age from Upper-Proterozoic to Lower Mesozoic. At least, four magmatic cycles have been recognized:

### The Proterozoic Cycle

The rocks are composed of gneissose granodiorite, granite with migmatite and pegmatite. They are distributed in Sam Neua, Xieng Khouang regions and southeastern part of the Lao PDR.

### The Lower and Middle Paleozoic Cycle

They consist of ultramafic rocks varying from dunite, serpentinite up to granitoids such as



granodiorite, granite and plagiogranite. These rocks are distributed along deep-seated faults in fold-belts of the northeastern and northwestern parts of the country.

### **The Upper Paleozoic to Lower Mesozoic Cycle**

The rocks of this cycle are more widespread than the others. The granitoid batholites of this cycle are composed of diorite, granodiorite, granite, granite-aplite; quartz-diorite, plagiogranite and granite porphyry. These rocks are distributed in many regions of the country.

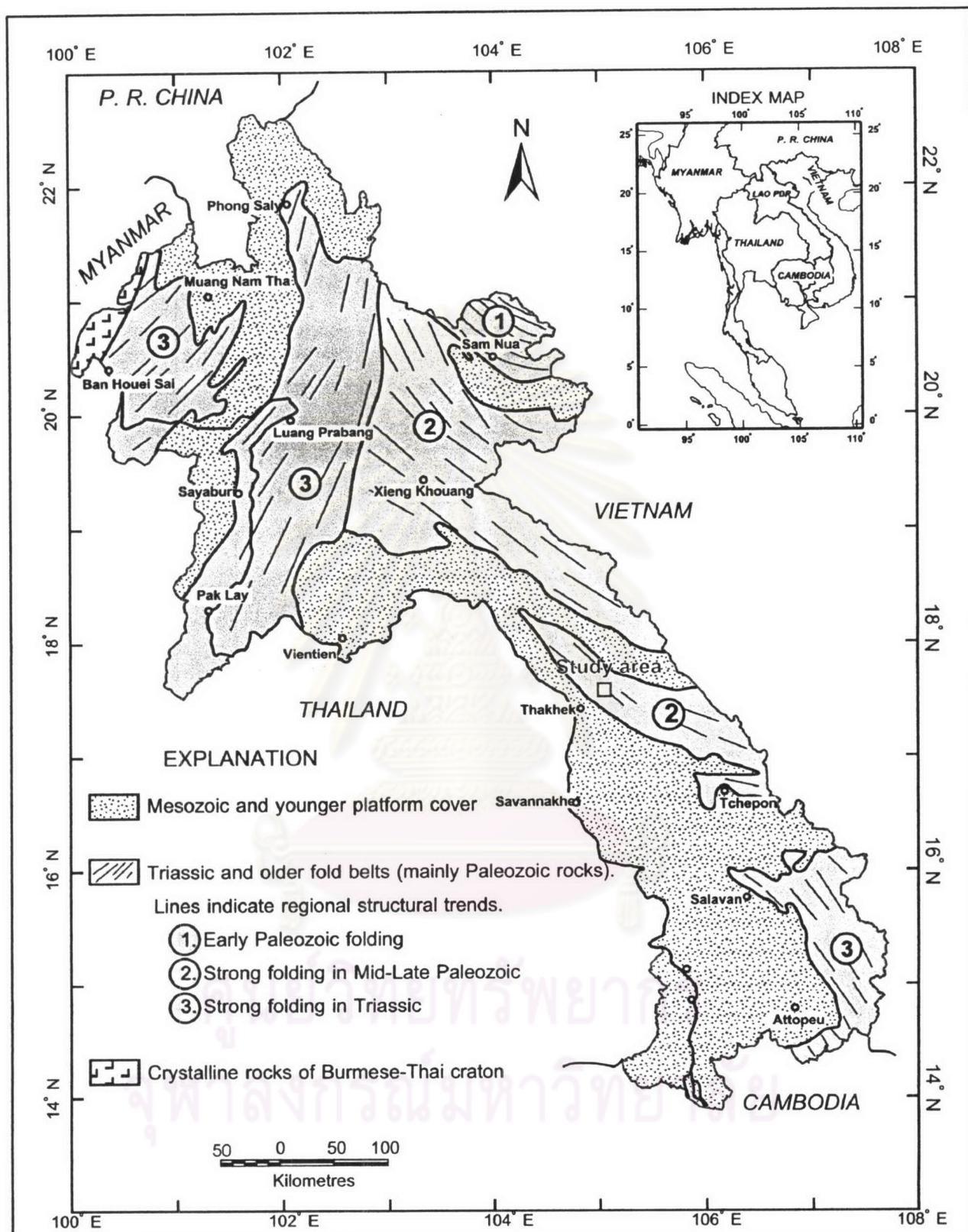
### **The Upper Mesozoic to Cenozoic Cycle**

The igneous rocks of this cycle are composed of biotite granite porphyry, biotite-muscovite granite of Cretaceous age, granosyenite porphyry of Paleogene age. Together with the mafic igneous rocks of Pliocene-Lower Pleistocene, there are intrusive mafic rocks, such as, gabbro-norite, gabbro-dolerite of Neogene- Lower Quaternary age.

## **2.4 Geological Structures**

Generally, the geological structures of the Lao PDR are known only in broad outline. It may be conveniently described in terms of tectonic elements (Fig. 2.2). In the northwest, there are gneisses and associated granites of uncertain age. They occur along the Mekong river which is the border between the Lao PDR and Myanmar. They are believed to represent a crystalline basement which has remained a positive structural element throughout Phanerozoic time.

The fold-belt crosses western part of the Lao PDR, trending NNE-SSW and occupying the country about latitude  $103^{\circ}\text{N}$ . A southward extension of the belt crosses northern, central and southeastern Thailand, while to the north, the belt extends into Yunan province of China. The oldest known rocks in this northnortheast - southsouthwest trending fold-belt are of Devonian age. Carboniferous and Permian strata are widely



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Figure 2.2 Geological structure of the Lao PDR (after United Nation, 1990)

KEO KHAMPHAVONG  
2003

DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE  
CHULALONGKORN UNIVERSITY



distributed throughout the belt, but the marine Triassic seems to be restricted to relatively small area.

The Paleozoic and Triassic rocks are moderately to intensely folded. Part of the succession (e.g. in the Paklay area) consists of low grade metamorphic rocks (phyllite, greenschist and quartzite). These are believed to be Devonian-Carboniferous rocks.

Occupying the north-center of the country and extending southeast to the Vietnam border is a tract of folded Ordovician-Carboniferous rocks with predominantly pre-Carboniferous and Triassic intrusions and small area of gneissic (Proterozoic) basement. The structural trend in this area is northwest-southeast, curving to northnorthwest - southsoutheast towards the north. This zone extends southeastwards into central Vietnam. It is believed to be essentially the result of Early Carboniferous folding which was not followed by any marked uplift. The Carboniferous and Permian limestones were deposited in shallow sea which extended across much of the area.

The southern part of the country are covered by relatively less deformed rocks. Most of the rocks are Mesozoic deposits which are laid down partly across eroded "Hercynian" and older Paleozoic fold-belts but largely on a basement of unknown, possibly post and/or pre-Cambrian age. Earlier platform that covered on the Middle Paleozoic fold-belt occurs in the area east of Thakhek in the form of moderately folded of Carboniferous and Permian limestone.

Only the area in the southern part of the Lao PRD (east of Saravan), there is definite evidence of strong folding of post-Lower Carboniferous rocks. Folding of the Late Carboniferous coal-bearing formation and Permian limestone in this area was certainly pre-Jurassic and presumably Triassic, which is in accordance with felsic volcanic rocks in the area.

The Cenozoic structural history of the Lao PDR is scarcely understood. There is some evidences from the drainage pattern and distribution of Quaternary fluvial deposits

that pronounced epirogenic uplift in the late Cenozoic was apparent (Pliocene-early Pleistocene).

## 2.5 Economic Geology

Presently, some mineral resources, that are considered to have economic potential in the Lao PDR, are as follows:

### Tin

The production of tin comes from a small mine in Nam Pathene valley about 60 kilometres north of Thakhek, Khammouane province. The principal ore, cassiterite, occurs in enriched lateritic clay resulting from weathering of tin bearing granitic rocks extending over an area of approximately 220 sq. kilometres. In some places, the lateritic clay contains pockets of quartz bearing small needles of cassiterite. Accordingly this seems to be eluvial deposition. The eluvial deposits relatively contain more tin ore than the alluvial deposits. Data from the report of former Soviet Union's geologists reveal that the potentials of tin reserves in this area is 112.9 million metric tons with 0.12 per cent ore grade.

In other parts of the Lao PDR, there are additional areas for tin mineralisation. Five areas have been reported in central part of the country, and one area in the western side (Laksao, Nam Pan, Nape and Nakadok). In addition, five other prospect areas are in Sam Nua and Xieng Khouang areas, however, the most promising of which being Hoei Cheun in Houa Phan province.

### Gypsum.

Vast deposits of gypsum have been discovered as thick and extensive Cretaceous evaporite sequence, located to the east of Savannakhet. Detailed exploration in an area of 2 square kilometres has led to an evaluation of proven reserves of 18 million

metric tons of gypsum near Dong Hene. In addition, huge deposits of gypsum have been reported in the Vientiane plain. They underlie the potash and rock salt succession.

### Rock salt

The same Cretaceous evaporite deposits in the Savannakhet and the Vientiane plains contain limitless quantities of high grade rock salt. A drilling campaign in an area of 56 square kilometres around Kengkok has outlined reserves of high grade rock salt (NaCl 95-96 per cent, KCl up to 7 per cent). Its reserve is 1.1 billion metric tons. In the Vientiane plain, the estimated reserves of rock salt are approximately 850 billion metric tons, plus the underlying gypsum estimated at about 12 billion metric tons.

### Coal

Coal is known in three regions of the Lao PDR, i.e. the south (Salavan), the center (northwest of Vientiane) and the far north (Phongsaly).

The Salavan coal lies in an area north and northeast of Salavan. The coal seams are reported in an area of strongly folded Carboniferous rocks enclosed by gently dipping Mesozoic red beds. Coal seams are ranging in thickness from 0.8 to 7.7 metres. The inferred reserves are put at about 40 million metric tons.

Coal that occurs in an area northwest of Vientiane is Upper Carboniferous age. Production of coal from the deposit at Bochan, near Vientiane, began in 1985. Reserves are estimated at about 5 million metric tons.

Coal, reported in several other areas in the far north of the country occurs in Upper Carboniferous-Upper Triassic formations. The principal reported locality is Phongsaly, where there are several seams ranging from 10 centimetres to more than 1 meter in sub-horizontal Upper Triassic strata.

## Gemstones

Sapphire bearing placers near Ban Houei Sai in the northwest of country have been a long time domestic scale mining by local people. The sapphires occur in alluvial and eluvial materials derived from Quaternary basalt. Operations have been carried out by the state mining enterprise for sapphires in 1986-1990. In 1991-1993, the government issued a limited concession area to Thai company for exploration and exploitation. In 1994, the government issued another limited concession area to a foreign company for exploration and exploitation.

Geologically, similar area of Quaternary basalt in Attapeu area in the southern part of the country also possess a potential for gemstones, especially sapphire and zircon.

## Gold

There are many records of gold deposits in the Lao PDR. Primary deposits are reported as dissemination of gold in quartz veins, associated with granodioritic rocks and rhyolitic-dacitic rocks and in association with strata-bound copper mineralisation. Gold panning happens at several localities in both the north and the south and official estimate of the yield along the Sekong river in the south is about 20 kilograms per annum.

Other gold potential areas in the country are as follows:

Sepone-Angkham area: exploration activities during the years 1983-85 had led to an evaluation of alluvial gold in an extensive area of more than 400 square kilometres of Namkok and Nam Segi valleys; mainly of low grade ores (0.01-0.10g of gold per cubic metre), although in some places, the range is 1.0-5.0g per cubic metre.

Sanakham-Nam Ou area: Sanakham-Nam Ou zone located in Paklay-Luang Prabang fold- belt, where gold indications are widespread. Gold occurs in ancient and

recent alluvium, eluvium, and also in primary quartz veins and stockworks around Mouang Sanakham and towards the northwest. The entire valley of Nam Ou, up to the level of Phongsaly was recently the scene of very active gold panning at many places and should be a prime target area for future reconnaissance survey. Primary gold mineralization in the Sanakham-Nam Ou area is typically in quartz veins cutting Middle to Upper Paleozoic sedimentary rocks in proximity to granodiorite intrusions and to a lesser extent subvolcanic intrusions.

Nape-Rao Co area: the Nape-Rao Co area, located in northeast of Thakhek, is similar to that of the Sepone-Angkham area. Gold occurs in older metamorphic rocks surrounded by high-grade metamorphosed Ordovician-Devonian terrain which had been intruded by Carboniferous and Triassic granite and granodiorite. In many places, there is gold in association with cassiterite.

In the Nakadok area, domestic-scale gold production by the local people are reported.

### **Iron ore**

In the Lao PDR, there are two best known iron deposits named Phalek and Phou Nhouan. They are considered to have economic potentials.

Phalek: it is a mountain situated 60 kilometres south-southwest of Xiengkhouang province. The area of interest for iron deposits covers a few square kilometres. The iron bodies are all in the form of lenses occurring near the contact between small granitic-granodiorite intrusions and the strongly folded shale, sandstone and limestone. The ore mineral is massive magnetite.

Phou Nhouan: it is situated on the mountain ridge of that name 5 kilometres north of the Xieng Khouang. The ridge is made up of sandstone, shale, and conformable beds of ironstone in the upper part. Most of the crest of the ridge is formed by ironstone,

extending over a length of 4 kilometres. The ore is high-grade, up to 70 per cent Fe, consisting of dense, compact, grey magnetite-haematite with some bands of lustrous red hematite. Reserves might be a total of few hundreds of million metric tons.

### **Carbonate rocks**

Carbonate rocks, mainly limestone are widely distributed in different parts of the Lao PDR , particularly in Khammuane. Although its reserves are vast, but the utilization of these rocks for economic purposes is very limited. At present, there are some quarries of limestones in the country as follows:

Limestone around Vang Vieng have been mined for a small cement plant. It has been also quarried at domestic scale for lime production in the north of Thakhek about 9 kilometres. Besides, there are many crushed limestone produced at plants near Thakhek which have been used locally for highway construction and exported to Thailand.

## **2.6 Regional geology of Khammouane area**

The region of Khammouane and its vicinity comprises sedimentary rocks and unconsolidated sediments of various ages ranging from Proterozoic to Quaternary.

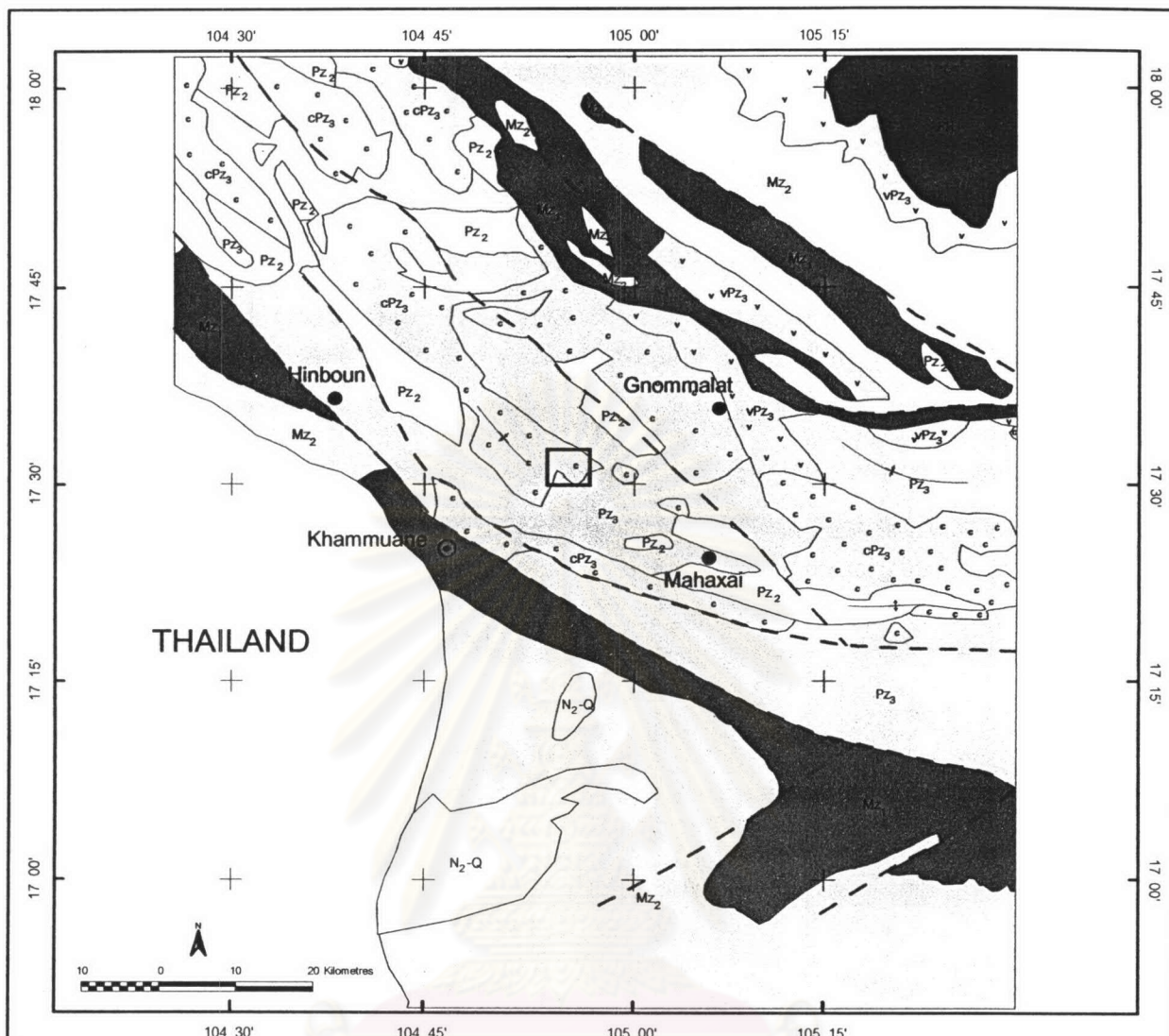
The sedimentary rocks are mainly distributed in the highland located in the central throughout the northern and southern parts of Thakhek area, whereas, the unconsolidated sediments generally exist on the plain in the southern part of this area (Fig.2.3).

### **2.6.1 Stratigraphy**

#### **Precambrian**

The lithology of this sequence consists of low-grade mica-schists, quartz chlorite-sericite schists and marbles; this sequence may unconformably overlain by the lower



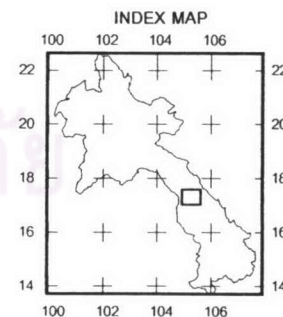


**EXPLANATION**

- N<sub>2</sub>-Q Unconsolidated gravel, sands, silts and gravallite conglomerate, siltstones, mudstone.
- Mz<sub>2</sub> Mostly red continental sandstones and clays, with lagoonal mudrocks in the upper level bearing evaporite units of halite and gypsum
- Mz<sub>2</sub> Continental red clayey arenites with occasionally thin coal seams and conglomerate
- Pz<sub>3</sub> Mostly sandstone, siltstone and shale
- v VPz<sub>3</sub> Sandstone, siltstone and shale. some silicic intermediate and mafic extrusive rocks (v) associated with subvolcanic intrusive centres
- c cPz<sub>3</sub> Bedded to massive dark gray to light gray marine limestone forming extensive karst tracts intercalated with siltstone, mudstone and some coal seams
- Pz<sub>2</sub> Mostly marine volcano sedimentary sequence with mudrocks, wackes, arenite, silicic and intermediate volcanic rocks, slightly metamorphosed
- Mz<sub>2</sub> Low grade mica-schists, quartz chlorite-sericite schists and arenites, and marble

**GEOLOGICAL SYMBOLS**

- Geological contact
- - - Fault trace
- ⊕ Syncline
- ⊖ Anticline
- ⊙ Provincial city
- District
- Study area



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Figure 2.3 Geological map of Khammouane area showing location of the study area.  
(after R.N. Annells and J.S. Coats, 1990)

KEO KHAMPHAVONG  
2003

DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE  
CHULALONGKORN UNIVERSITY



Paleozoic. They are exposed in extremely northeastern part of the area.

**Paleozoic:**

### **Middle Paleozoic (PZ<sub>2</sub>)**

Upper Silurian to Lower Devonian: the lithology of rock sequences are composed of slates and calcareous shales intercalated with sericitic schists, sandstone, crystalline limestone and siliceous limestone. These rock sequences are exposed in the central part of the area. Its trend is in the northwest-southeast direction.

### **Upper Paleozoic (cPZ<sub>3</sub>, vPZ<sub>3</sub>)**

Lower and Middle Carboniferous: the lithology of rock sequences consist of marl, siltstone, black limestone and coal bed. They are relatively widespread in the central part of Thakhek area.

Middle Carboniferous to Permian: the lithology of this sequence comprises of black limestone intercalated with siliceous schist in the lower part, whereas the upper part consists of thickly-bedded, pale grey limestone. This rock sequence is distributed in the central part of the area.

Upper Carboniferous to Permian: the lithology of this sequence comprises shale, siltstone and sandstone intercalated with volcanic rocks (andesite, dacite, rhyolite) in the lower part, whereas the upper part is composed mainly of limestone. They are exposed in the central part of the area.

## Mesozoic

Upper Triassic: the lithology of the rock sequences comprise conglomerate, sandstone, siltstone, mudstone, lenses of limestone and coal bed. These rock sequences are distributed as belt trending in the northwest-southeast direction.

Cretaceous: the lithology of the rock sequence consists of red sandstone, siltstone and conglomerate. In the upper succession, there are halite, potassium and magnesium salts and gypsum. This rock unit can be correlated with the Khorat Group in Thailand (Kondratiev, et al.1984). This rock sequence is widespread in the northern and southern parts of Thakhek area.

## Cenozoic:

Neogene: this rock sequence consists of conglomerate, siltstone, mudstone, marl and carbonaceous mudstone. They are exposed in the intermontane basin in the southern part of this area.

Quaternary: the Quaternary sediments are composed of pebble, sand, and clay. They are commonly deposited on the plain in the southern part of Thakhek.

### 2.6.2 Geology of Khammouane area

Prior to the present study, the Khammouane area was investigated by many geologists on the regional geology bases. For instance, Deprat (1915) studied on fossils in north Indochina, including the fossils from the limestone of Khammouane area. The fossils indicate Carboniferous-Permian age, consequently, French geologists studied the geology of Indochina and named these sediments as "Khammouane limestone" Geologists of Siam Cement Public Company (1995) conducted the exploration program for cement raw materials in the study area and its vicinity. They classified these carbonate rocks into 3 units in ascending order as follows:

PC-I: bedded limestone, grey micritic texture, normally medium beds (10-15 centimetres thick) interbedded with brownish grey to dark grey and thinly-bedded chert.

PC-II : light-grey to brownish-grey, very thickly-bedded limestone, microsparitic texture with calcite veins, normally alternated with grey to dark grey limestone, occasionally associated with dark grey, crystalline dolomite nodules.

PC-III : Dolomite, dolomitic limestone, light grey to grey, very thickly-bedded, locally intercalated with light brownish grey to dark-grey limestone.

During the process of geological survey in mid central Lao PDR (1996-2000), geologists from Department of Geology and Mines ( Lao PDR) and geologists from InterGeo II (Vietnam) had carried out many field trips across the Khammouane limestone terrain, and recognized that it is an unique stratigraphic body. Therefore, they described it as "Khammouane Formation" which consists of two distinct parts. The lower part is composed of black-grey, thinly-bedded limestone, grey limestone bearing chert nodules, whereas the upper part consists of light-grey, thickly-bedded, locally weakly dolomitised limestone. The stratotype of Khammouane Formation have been established in the west of Khoun Kham village, named Khoun Kham section. The Khoun Kham section has been surveyed along the road no 8, about 2 kilometres west of Khoun Kham village. The rocks are well exposed and classified into 7 members as follows:

Member 1 : black-grey, thinly-bedded (3-10 centimetres) limestone. Its thickness is 27 metres. This member lies conformably upon a member of light-grey chert bearing many crinoid fossils and some forams.

Member 2 : grey, thickly-bedded limestone bearing dark-grey chert nodules of some millimeters to 20 centimetres in size. Its thickness is 35 metres.

Member 3 : dark-grey, massive structure, microgranular limestone, bearing poorly preserved organic remains. This member is penetrated by many calcite small veinlets. It yields an abundant assemblage of fusulinids. Its thickness is 15 metres.

Member 4 : light-grey limestone, bearing many penetrating calcite veinlets. Thickness of this member is 10 metres.

Member 5 : light-grey, fine-grained, very thickly-bedded limestone. Thickness is 5 metres.

Member 6 : light-grey, fine-grained, very thickly-bedded limestone bearing fusulinids and crinoids with thickness of 70 metres.

Member 7 : white- grey dolomitized limestone with thickness of approximately 30 metres.

The total thickness of Khammouane Formation in this section is 192 metres.

### 2.6.3 Geological structures

The geological structures of Khammouane area and its vicinity is known only in broad outline as shown in Figs.2.1, 2.2, 2.3. Occupying the Khammouane and its vicinity area to the Vietnam border is a tract of folded Ordovician-Carboniferous rocks with major Pre-Carboniferous and Triassic granite intrusion and small area of gneissic (Proterozoic) basement ( ESCAP,1990). The structural trend in this area is generally northeast-southwest, curving to northnorthwest-southsoutheast towards the north. This zone extends southeastward into central Vietnam. It is believed to be essentially the result of Early Carboniferous folding.

The Khammouane and its vicinity are underlain by relatively less deformed rocks. These rocks are most of Mesozoic deposits which lay down partly across eroded "Hercynian" and older Paleozoic fold belts, but largely on a basement of unknown,

possibly post-Precambrian age. Earlier platform that cover the Middle Paleozoic fold belt, occurs in the area east of Thakhek in the form of moderately folded Carboniferous and Permian limestone.



ศูนย์วิทยทรัพยากร  
จุฬาลงกรณ์มหาวิทยาลัย