CHAPTER 1
INTRODUCTION

1.1. Vientiane basin

Vientiane basin is a production area for potash and rock salt in Lao PDR. The resource of potash deposit in Vientiane basin is about 50 billion tons (Inthavong, 2005). In addition, 3,600 tons of table salts and 700 tons of industrial salts were produced from Vientiane basin annually (Nanthavong, 1999). Gypsum, potash rock salt occurs in the evaporite of the Upper Cretaceous in Vientiane basin, Khammouane and Savannakhet provinces. The exploration results of the potash deposit located Vientiane Plain indicate up to 14 billion tons (Boupha *et al.*, 2007)

Vientiane basin is considered as a northwest extension of Sakon Nakhon basin. In 1986, exploration for the potash was carried out by Vietnamese geologists in Tha Ngon-Vientiane plain area with a maximum drilling depth of 628 meters. However, bedrock of the basin has not been reached by that drilling program. Moreover, geological mapping of Vientiane plain at a scale 1:200,000 was also carried out by Vietnamese geologists in 1988 (Phommakayson, 2001).

According to the above background information, groundwater of drinking quality is expected to be scarce in Vientiane basin, particularly Xaithani district. It should be interesting to conduct geophysical measurement in the study area in order to determine locations of potential groundwater, to determine the thickness of basin sediment. The information obtained from this research work will be useful for future development in the study area.

1.2. Location, topography and climate of the study area

The study area is located in Vientiane capital of Lao PDR, covering an area of approximately 4,000 square kilometers. It is situated on an alluvial plain bounded by Nam Ngum River in the north and Mekong River in the south, i.e. bounded by latitudes $17^{\circ}54'$ N to $18^{\circ}18'$ N and longitudes $102^{\circ}24'$ E to $103^{\circ}00'$ E. The study area covers eight districts namely Naxaythong, Sikhottabong, Sisattanak, Chanthabouri, Xaisettha, Xaithani, Hatxayfong and Pak-Ngum (Figure 1.1).

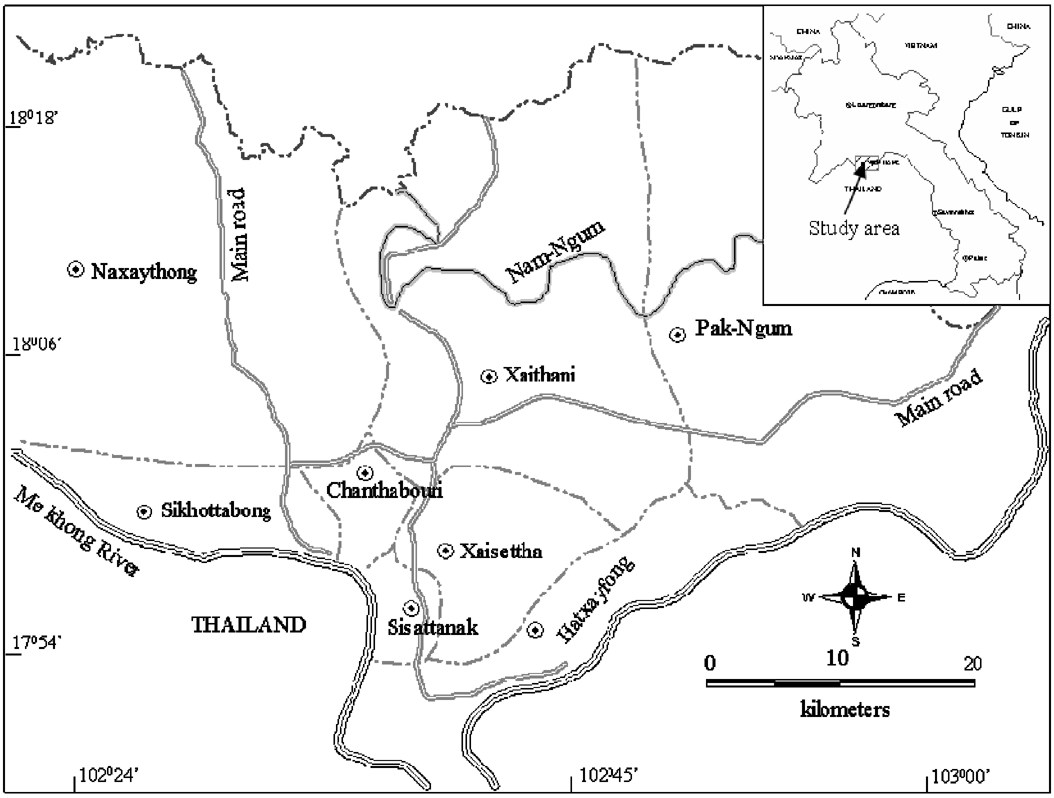

Figure 1.1 Location map of the study area

The topography of the study area is relatively flat. Its elevation is approximately 170-180 meters above mean sea level in most parts of Vientiane basin. High ground of 200 to over 500 meters is in northwest and northeast parts of the study area as shown in Figure 1. 2.

Generally, Laos has a tropical monsoon climate with a pronounced rainy season from May to October, a cool dry season from November to February, and a hot dry season in March and April. The annual temperature is between 19^0C and 32^0C and the average annual rainfall is around 1500 mm (Knudsen *et al.*, 2004)

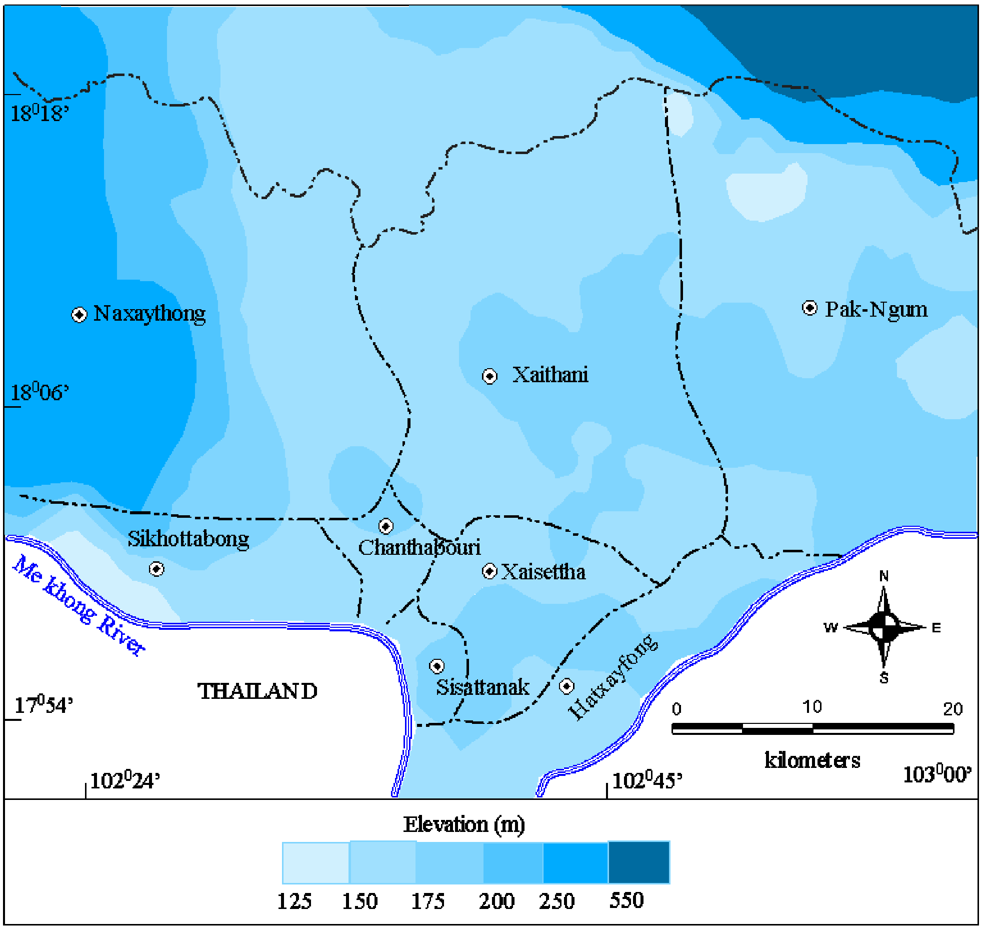

Figure1. 2 Topographic map of the study area

1.3. Geology of the study area

The study area consists of sedimentary rocks ranging from Mesozoic to Cenozoic age. The Mesozoic sedimentary rocks comprise 5 formations, namely in ascending order; Phu Lek Phai (T1-2pp), Nam Sait (T3ns), Phu Phanang (J-Kpn), Champa (K2cp) and Tha Ngon (K2tn) (Figure 1.3). These Mesozoic sedimentary rocks are overlain by Quaternary sediments which are in the plain along the valleys of the main rivers consist of gravel, sand and clay including laterite (Phommakayson, 2001).

The Phu Lek Phai Formation of Middle Triassic age comprises granulites intercalated with sandstone, claystone, and lenticular conglomerates in the upper part. The middle part constitutes of siltstone interbedded with limestone and shale. The lower part is composed of granulite interbedded with sandstone. The thickness of this formation is about 650 m.

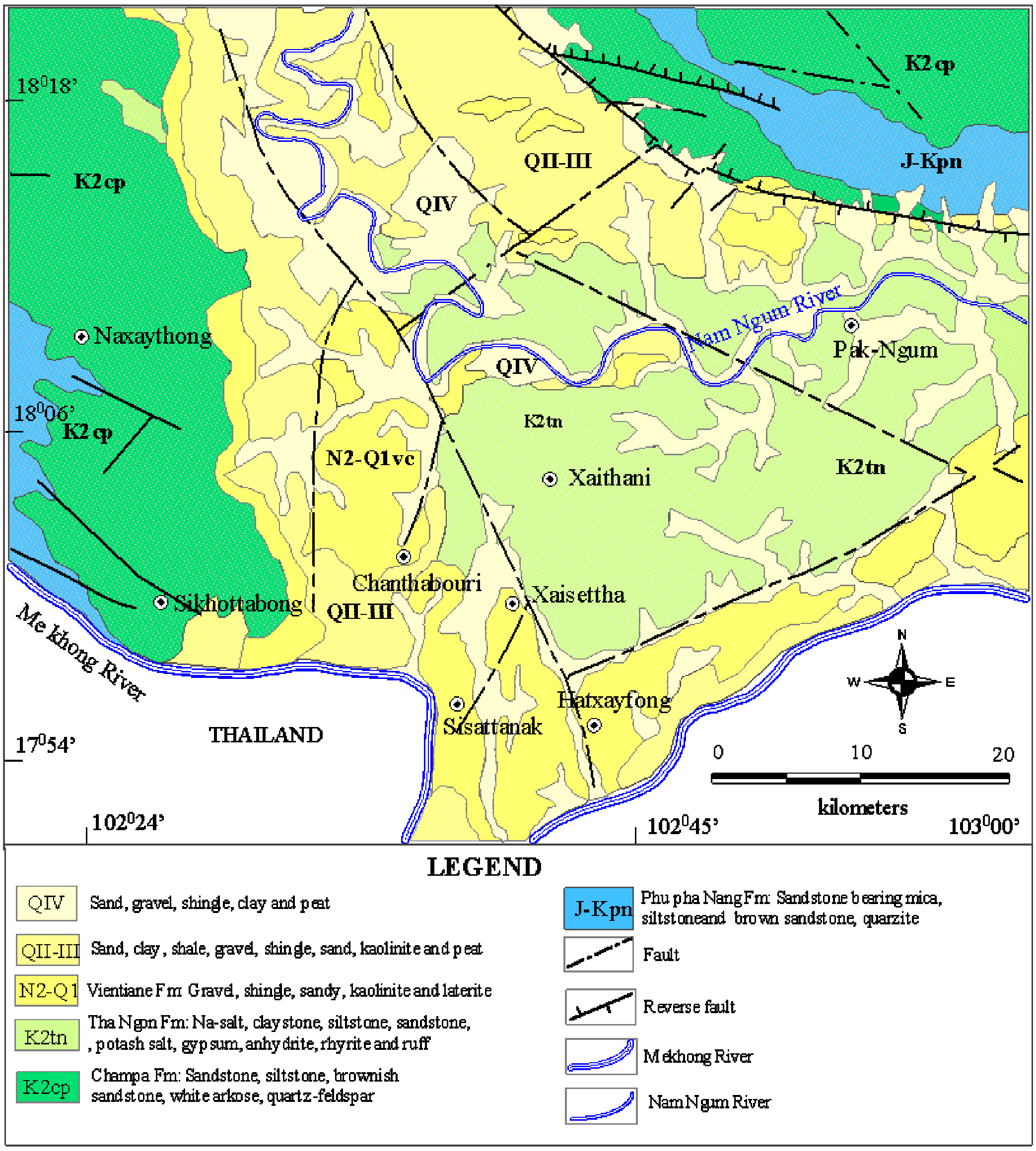

Figure1.3 Geological map of Vientiane basin of Lao PDR

The Nam Sait Formation of Middle-Triassic age comprises brown to white sandstone interbedded with claystone, shale and sandstone have lenticular gypsum and occasional black coal seams. The lower part is fine-grained sandstone and white claystone. The thickness of this formation is 700-850 m.

The Phu Phanang Formation of Jurassic to Cretaceous age is composed of sandstone with micas interbedded with laminate sandstone. The upper layer constitutes of white sandstone interbedded with conglomerates. The thickness of this formation is about 350 m.

The Champa Formation of Middle Cretaceous comprises quartzite-sandstone, siltstone interbedded with sandstone having medium thickness and white arkose-sandstone is in the upper layer. The thickness of this formation is about 400 m.

The Tha Ngon formation of Middle Cretaceous age consists of sandstone, siltstone, conglomerate and halite of potassium and magnesium salts in the upper horizons. The thickness of this formation is greater than 550 m.

The Mesozoic rocks in the present study area can be correlated with the non-marine Mesozoic rocks of Khorat Group in the northeastern Thailand. This Khorat Group was probably underlain by Ratburi Limestone of Late Carboniferous and Permian (Sethaput, 1985). Tha Ngon Formation corresponds to Maha Sarakham Formation and following by other Formations as shown in Table 1.1.

Table 1.1. Stratigraphy of Khorat Plateau and Vientiane basin

Khorat Plateau, Thailand (modified from Raksaskulwong *et al.,* 2007)			Vientiane basin, Laos (modified from Phommakayson, 2001)		
Age	Formation	Thickness (m)	Age	Formation	Thickness (m)
Quaternary	Sediments (Qa)	4-40	Quaternary	Sediments (QII-III)	70
Cretaceous-Tertiary	Phu Thok (KTpt)	50-785	Cretaceous	Tha Ngon (K2tn)	> 500
Cretaceous-Tertiary	Maha Sarakham (KTms)	156-1294			
Cretaceous	Khok Kruat (Kkk)	100-350	Cretaceous	Champa (K2cp)	400
Cretaceous	Phu Phan (Kpp)	120-150	Jurassic-Cretaceous	Phu Pha Nang (J-Kpn)	350
Cretaceous	Sao Khua (Ksk)	>280-420			
Jurassic-Cretaceous	Pra Wiharn (JKpw)	56-136			
Jurassic	Phu Kradung (Jpk)	800-1100			
Triassic	Nam Phong (Trnp)	0-1465	Triassic	Nam Sait (T3ns)	700-850

The Khorat group consists of more than 3,000 meters of predominantly reddish, brownish, grayish siltstone, claystone, mudstone, and sandstone, and some conglomerate beds. There are thick beds of salt in the upper 1,000 meters of claystone and mudstone (Gardner *et al.*, 1967).

The Khorat Group consists of 9 formations namely in ascending order, Huai Hin Lat, Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat, Maha Sarakham and Phu Thok Formations (Raksaskulwong *et al.*, 2007). Age of the Khorat Group which was biostratigraphically determined by using vertebrates (Buffetaut *et al.*, 1997), bivalves (Meesook *et al.*, 1995) and palynomorphs (Racey *et al.*, 1994, 1996) ranges from Upper Triassic to Cretaceous-Tertiary.

The Khorat basin was formed during Late Triassic after extension release of the Indosinian Orogeny (Cooper *et al.*, 1989). Sediments were deposited during Late Triassic to Late Cretaceous. The Himalayan Orogeny in Early Tertiary caused uplifted of the Khorat Plateau and Phu Phan Uplift. The uplift of the Phu Phan range caused a separation of basin into the south basin, presently named the Khorat basin, and the north basin, presently named the Sakon Nakhon basin. The main part of the Sakon Nakhon basin is in Thailand and a northwest extension of the basin is in Vientiane called Vientiane basin (Suwanich, 2007).

Sattayarak and Polachan (1990) proposed tectonic of the Maha Sarakham Formation in the Khorat basin that sea water intruded from the east into the basin at its western edge during Cretaceous time. The Maha Sarakham Formation was deposited in the basin until Late Cretaceous. When sea water regressed the Phu Thok Formation was then deposited. The northeastern Thailand was uplifted during Early Tertiary to form the Khorat Plateau and Phu Phan ranges. Mouret *el al.* (1993) estimated the uplift period of the Khorat Plateau of 96 to 46 Ma by using Apatite Fission Track analysis and predicted that erosion after the uplift until present of about 3,000 to 3,500 m thick.

1.4. Geophysical measurement

The objects of the geophysical measurement is to locate subsurface geological structures or bodies and where possible to determine their dimensions and relevant physical properties. Since physical properties are determined to a considerable degree by lithology, discontinuities in physical properties often correspond to geological boundaries (Griffith and King, 1981).

A geophysical survey consists of a set of measurement, usually collected to a systematic pattern over the earth's surface by land, sea or air, or vertically in a borehole. The measurements may be of spatial variations of static fields of force – the gradients of electrical, gravitational or magnetic "potential" or of characteristics of wave fields, more particularly of travel-times or electromagnetic waves. These force and wave fields are affected by the physical properties and structure of the subsurface rocks. The properties of rocks of which most use is made in geophysical prospecting are elasticity, electrical conductivity, density, magnetic susceptibility, remanence and electrical polarizability.

Even though Vientiane basin is the northwest extension of Sakon Nakhon basin of Khorat Plateau in Thailand, little is known about geology at depth in the basin. So far only surface geology and subsurface information to a maximum depth of about 700 m obtained from Potash drilling wells are known. Areal extent of the basin, thickness of basin sediment, vertical displacement of faults and locations for good quality groundwater has not been studied. This background information on geology at depth will be useful for development of Vientiane basin in the future.

In the present work, gravity measurement and vertical electrical sounding will be carried out in order to determine boundary of Vientiane basin, location and vertical displacement of faults, and locations for good quality groundwater wells.

In gravity method, the earth's gravitational field or gravity at different locations on the earth's surface is measured. Spatial variation in observed gravity is caused by horizontally change in subsurface density which, in most cases, related to subsurface geological structures. The gravity method is applied in engineering problem, environmental problems, and geological problem, for examples; determination of basin boundary and depth to basement rock, detection of salt dome and sinkholes, determination of buried sediment valleys and locations of fault, etc. (Griffiths and King, 1981)

In vertical electrical sounding measurement, variation in resistivity of the ground with depth will be determined. In general, the resistivity of the ground is controlled by its porosity, degree of water saturation, and resistivity nature of fluid in pore-spaces. This method has been widely used for stratigraphical mapping and determination of groundwater layers in sedimentary area. It can be applied for delineation of brine plumes and sea water intrusion (Loke, 1999)

1.5. Literature review

Vientiane basin is considered as a northwest extension of Sakon Nakhon basin of the Khorat Plateau, Thailand. This plateau is bounded by latitudes 14°N to 19°N and longitudes 101°E to 106°E, covering an area of about 170,000 square kilometers in northeastern of Thailand and central Laos (Figure 1.5). The bedrock of this plateau consists of a continental sequence of red-beds of Mesozoic age. The potash deposits in the Maha Sarakham Formation of the Khorat basin in Cretaceous age. The maximum thickness of the formation could exceed 1,000 meters (Supajanya, 1985). The Phu Phan range separates Khorat Plateau into two basins, the Khorat basin in south covering an area of about 36,000 square kilometers and Sakon Nakhon basin in north covering area of about 21,000 square kilometers (Hite *et al.*, 1979; El Tabakh *et al.*, 1999, 2003; and Keith *et al.*, 2005).

The Maha Sarakham Formation is composed of claystone, shale, siltstone, sandstone, anhydrite, gypsum, potash, and rock salt. This formation is underlain by sandstone and siltstone of Khok Kraut Formation. A complete sequence from the bottom to top of this formation consists of a basal anhydrite, lower salt, potash zone, color-banded salt, lower anhydrite, lower clastic rocks, middle salt, middle anhydrite, middle clastic rocks, upper salt and upper anhydrite (Satarugsa *et al.*, 2004, 2005; Cotanont, 2005; and Jenkunawat, 2005).

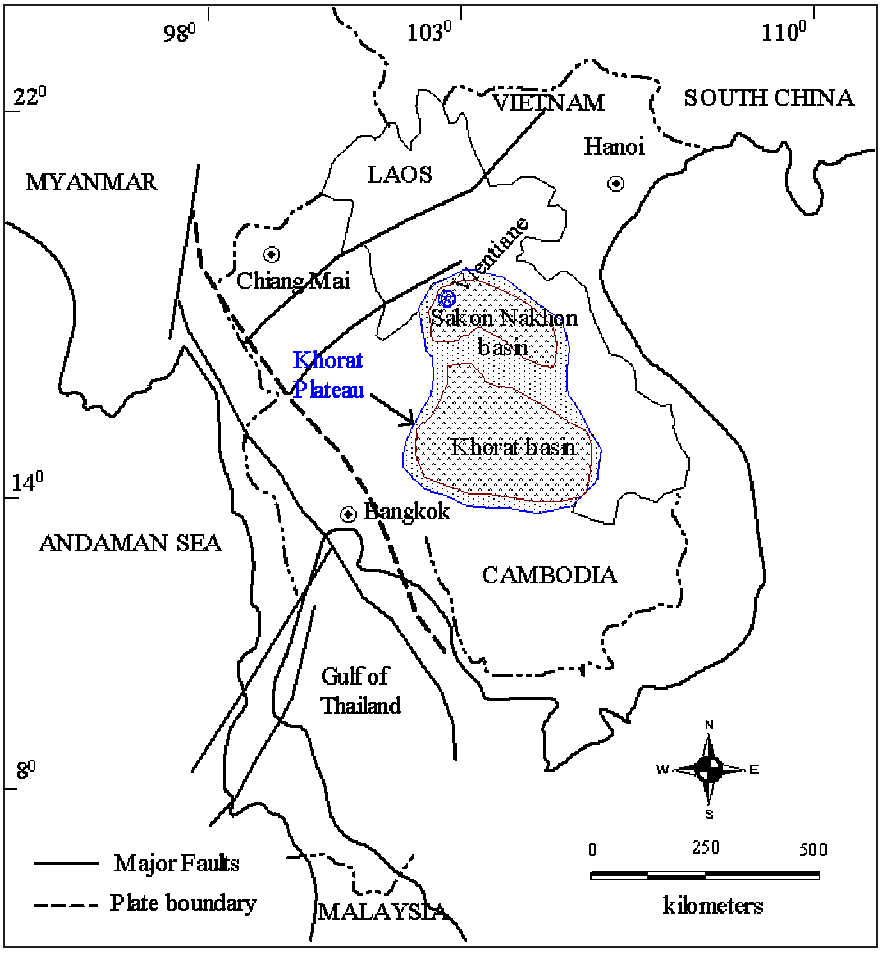

Figure1. 5 Location of the Khorat and the Sakon Nakon basins in the Khorat Plateau region (modified from El Tabakh *et al*., 1999)

Fan (2000) reported that immense rock salt, rich potash and gypsum are deposited near Vientiane of Laos. The salt deposits at shallow depth are in the northern extension of salt deposits of the northern Khorat Plateau. Drilling wells in the Khorat Plateau, Thailand near the Laos border indicated that 145-feet thick bed of carnallite of Cretaceous salt- bearing beds may develop into one of the worlds largest potash deposits. In addition, Phosphate, halite, and potash deposits occur in central Laos and red-bed copper deposits are found in southeastern Laos (Figure 1.6).

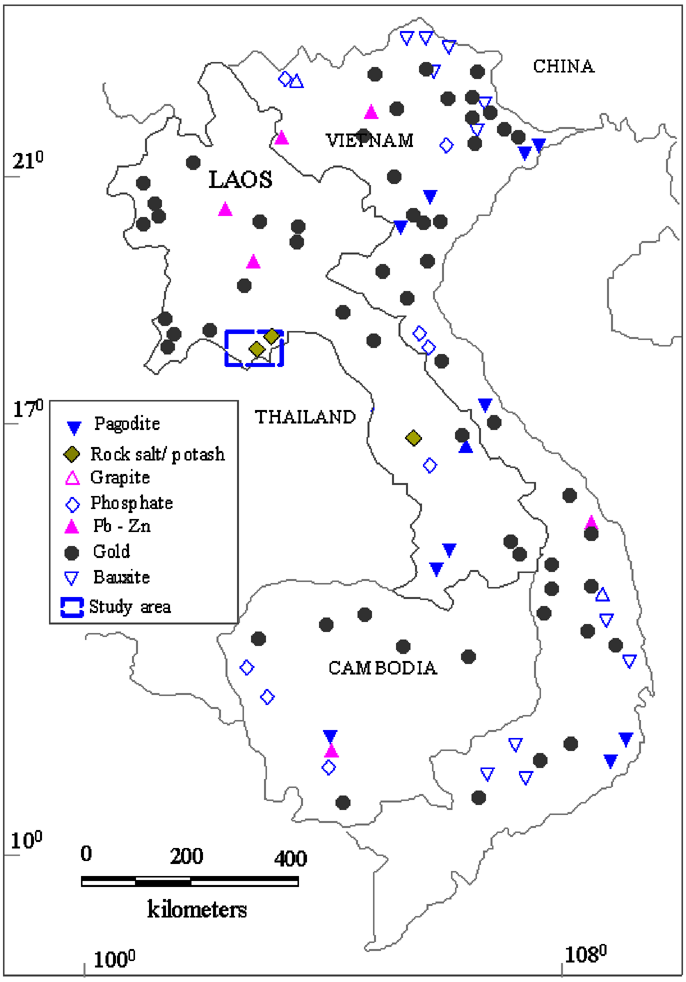

Figure 1.6 Minerals deposit of Indochina (modified from Fan, 2000)

Srisuk *et al.* (1999) reported that the shallow ground of Houy Sone and Houy Sou, 20 km northwest of Vientiane capital consists of four main hydrostratigraphic units. The first unit consists of clay, sand and silt, the second unit consists of gravel, sand silt and clay, the third unit consists of siltstone and shale and the bottom unit consists of conglomeratic sandstone and siltstone.

Sak-apa (2005) conducted 858 gravity stations and interpreted aeromagnetic data for delineating salt dome in Sakon Nakhon basin of the Khorat Plateau. Low gravity anomaly was observed in eastern part of their study area and high gravity anomaly in southwestern part of that area. The low gravity anomaly is caused by low density of subsurface salt deposit. Gravity interpretation showed that salt deposit is at 400 meters depth and more than 1,000 meters thick. In addition, the contour lines of magnetic anomaly are parallel to northwest-southeast faults in their study area.

Jallouli *et al.* (2005) conducted gravity measurements in the Tunisian Alas in order to delineate salt diapiric structure. The complete Bouguer gravity anomaly map shows high gradient of negative anomaly over the Triassic evaporite outcrops. The horizontal gravity gradient map showed the location of the lateral density changes along northeast structural trends caused by Triassic/Cretaceous lithological differences. Results of gravity model in their study area indicated that the Triassic evaporitic bodies are thick and deeply rooted involving a dome/diapiric structure and that the Triassic material has pulled upward the younger sediments.

Pinto *et al.* (2005) conducted gravity measurements in northern part of Spain. Gravity measurements integrated with available geological and geophysical data was carried out in central and marginal regions of the basin. Their gravity modeling was constrained by well log information and available geological and reflection seismic data. Gravity anomaly changes due to non-outcropping salt in that area. The gravity signature of the Murguia diapir showed an intense gravity high probably due to the presence of high-density rocks in the cap rock or more probably due to the existence of Triassic volcanites of ophitic texture pinched-off into the diapir.

Yegorova *et al.* (2007) studied the gravity signals from the lithosphere of the central European basin system for delineating subsurface geological structures in the North-German basin and the Polish Trough. Results of gravity measurements showed negative gravity anomaly ranges from 100 to 150 g.u lies on Permian salt structures. These anomalies correspond to the North-German Basin with negative gravity anomaly ranges from 1,100 to 1,500 g.u. which continues into the Polish Trough with particularly strong amplitudes up to -2000 g.u in the Triassic Graben structures caused by Moho topography and density heterogeneities in the pre-Permian crust and upper mantle.

Shaaban (2001) conducted 43 sounding points for evaluating the hydrogeological and structural characteristics of the subsurface sequence to a depth of about 200 m below the ground surface in Egypt. The results showed that low resistivity ranges from 11 to 24 ohm-m caused by a shallow brackish to fresh water bearing limestone aquifer and a deep saline water bearing sandy limestone of Miocene age. In addition, interpretation of resistivity data was correlated to the chemical analyses of the groundwater samples from this aquifer. Integrated resistivity measurements and chemical analysis data can delineate between brackish water and fresh water, brackish water occurs in the north of the area and fresh water occurs south and southwest of that area.

Choudhury *et al*. (2001) conducted geophysical measurements comprising electrical resistivity and shallow seismic refraction methods in the alluvial coastal belt of India for delineating different subsurface geological formations such as sand, top sandy soil, saline sand and saline clay on the basis of their characteristic resistivity and velocity signatures. In generally, low resistivity at shallow depth ranges from 0 to 10 m and 40 to 60 m was observed in most parts of that area which may be caused by saline water intrusion in the area. However, depth to aquifer ranges from 80 to 100 m and 130 to 150 m is devoid of any significant saline water contamination. This is because clay formation at shallow depth prevents saline water intrusion in the underlying aquifer zones.

Gowd (2004) conducted electrical resistivity measurements for delineating groundwater potential aquifers in India. 99 sounding points were conducted by using Schlumberger electrode configuration with maximum half current electrode spacing of 90m. Based on the VES interpretation, the top layer contour map, longitudinal conductance map, depth to bedrock map, and the groundwater potential map are prepared at different depths of 1.5 m, 10 m, 50 m, and 90 m. Groundwater quality was classified based on resistivity contour maps at different penetration depth.

Sainato *et al*. (2003) conducted resistivity measurements in Argentina in order to determine the depth, thickness, and continuity of shallower aquifers. Both maps of water table and the electrical conductivity distribution of free aquifers were achieved from well data and resistivity results using geostatistical techniques. Contour map of depth to the fresh-salty water interface showed different values over the Pergamino River. Groundwater quality zones were identified based on contour map of electrical conductivity distribution of free aquifers.

Lashkaripour (2003) conducted resistivity measurements for groundwater conditions in Iran. 596 sounding points with Schlumberger electrode configuration and maximum half current electrode spacing of 200 to 400 m were carried out to determine depth, thickness, location of the aquifer and quality of groundwater. The observed resistivity for alluvium, aquifers and bedrock are 3 to 800 ohm-m, 2 to 100 ohm-m and more than 100 ohm-m respectively. Resistivity data confirmed that the Korin aquifer consists mainly of an alluvial aquifer. The high resistivity in the southeast and northwest of the aquifer is caused by higher water quality and the existence of alluvial with coarse grain materials. The lower resistivity in the central and northern parts of the aquifer is caused by finer materials.

Emenike (2001) conducted resistivity measurements for groundwater in sediments area in Nigeria. 5 sounding points were conducted by Schlumberger electrode configuration with Maximum half current electrode spacing of 500 m. Resistivity values ranging from 500 to 960 ohm-m appears on sandstone aquifer of more than 200 m thick. Moderate resistivity ranging from 200 to 320 ohm-m may relate to good quality groundwater (fresh water). Results of resistivity soundings in correlation with well log lithology can indicated high groundwater potential area.

Lashkaripour (2005) conducted resistivity measurement in Iran. 207 sounding points with maximum current electrode spacing from 200 to 600 meters were carried out in that area. Resistivity of thin top layer, alluvium, aquifer, and bed rock is 70, 74, 12, and 113 ohm-m in the east and 175, 116, 46, and 106 ohm-m for bed rock in the west respectively. Very low resistivity ranges from 1 to 3.5 ohm-m was observed in central part of the aquifer. The high resistivity in the western part is due to the water quality and the existence of alluvial with coarse grain materials. Low aquifer resistivities in the east are associated with finer materials and also brackish water infiltration from the adjacent basin mainly in the central part of the aquifer.

Abd Alla *et al.* (2005) conducted resistivity measurements in Egypt. 30 sounding points were conducted by Schlumberger array with maximum half current electrode spacing of 500 meters. Results of interpretation resistivity data indicated that resistivity ranges from 8 to 69 ohm-m with thickness varies from 50 to 150 meters. The moderate resistivity ranges from 50 to 100 ohm-m at the bottom layer that is considered to be suitable area for good quality groundwater.

Gnanasundar *et al.* (1999) conducted resistivity measurements for assessment of groundwater aquifer in India. 80 sounding points were conducted by Schlumberger electrode configuration with maximum current electrode spacing of 33m.

Results of study showed that moderate resistivity of about 50 ohm-m were observed along the central part of the coastal aquifer which may be suitable areas for good quality groundwater. Low resistivity of less than 10 ohm-m was observed in the eastern and western margins of aquifer and it was probably caused by poor quality groundwater.

Santos (2006) conducted resistivity and gravity measurements in Egypt in order to detect water-bearing zones and shallow structural elements that affected the geometry of the groundwater aquifers. 39 sounding points with current electrode spacing ranging from 1.5 to 500 m and 131 gravity stations were measured in their study area. Results of gravity measurement showed low gravity of -190 g.u. in the northern part and high gravity of up to 160 g.u. in the southwestern part of his study area. In gravity modeling, the thickness of young sediment overlying limestone bedrock ranges from 80 to 180 m with northward increasing. Three-layer earth model was determined from resistivity surveys in the study area. The first layer of 100 to 5000 ohm-m resistivity and 3.5 to 39 m thick corresponds with a layer of dry sand whereas the second layer of 2 to12 ohm-m resistivity and 30 to 120 m thick and the third layer of 0.5 to 2 ohm-m correlate with sand layer saturated with saline water intruding from Mediterranean Sea.

Overmeeren (1980) integrated gravity, seismic and resistivity methods for groundwater exploration in Sudan. 521 gravity stations with spacing between stations of 2 kilometers, 16 sounding points with maximum current electrode spacing of 2 kilometers and seismic refraction measurements were conducted in that area. Results obtained from gravity modeling indicated that depth to bedrock is more than 1,000 meters and sounding results showed that low resistivity of about 1.8 ohm-m, may be caused by saline water. In addition, results of seismic refraction measurements confirm depth and thickness of subsurface geological determined by resistivity sounding.

1.6. Objectives of the study

1. To determine subsurface geological structures of Vientiane basin with gravity method.
2. To delineate potential area for fresh groundwater in Xaithani district with resistivity method.