

## CHAPTER I

### INTRODUCTION



#### 1.1 General

Increased fertilizer minerals supply is vital to the agricultural development because they are essential for increased food production to meet the demands of the expanding population. This is well recognized by all nations, and consequently stimulates the exploration of fertilizer raw material resources for fertilizer manufacturing. Many geologists have recognized that discoveries of additional fertilizer mineral deposits are possible.

Potash and rock salt are one of major components in chemical fertilizer and other industrial raw materials. They are mined as either solid minerals or as brines. The geological deposits from which these materials come are called evaporites. Most of the world's potash and rock salt come from marine evaporites which are ultimately derived from seawater. The potash is an industrial term that refers to potassium-bearing minerals that are mined both for fertilizer and chemicals, whereas rock salt is the common term for both the commodity and rock composed entirely of halite, NaCl.

The northeastern part of Thailand is a vast region covering approximately 150,000 square kilometers or about one-third of the total area of Thailand. Formerly, this region was considered to be a mineral-barren plateau except the northwestern corner where there are some non-productive economic mineral deposits. Almost all parts of the region suffer the problems of draught for quite a considerable long time.

The Thai Department of Mineral Resources has therefore launched the groundwater exploration programme to meet the demand for water in this region since 1955. It is noted that some of the groundwater drilling wells have penetrated the rock salt layers, and the groundwater qualities in some wells are considered salty. This leads to the geological hypothetical thinking that there might be extensive salt layers associated with the underlying rock sequences in this region of northeastern Thailand.

As a consequence, the potash and rock salt exploration drilling programme has been conducted by the Thai Department of Mineral Resources in both Khorat-Ubol and Udon-Sakhon Nakhon Basins of northeastern part of Thailand since 1973. As a result, one of the most promising target areas of rock salt and potash deposits is located at Bamnet Narong Area, Changwat Chaiyaphum. Therefore, semi-detailed drilling programme in this area has been carried out extensively in order to obtain the information regarding reserves and grade of the economically important evaporite deposits.

Generally, the site selection for exploratory drilling wells of potash and rock salt is defined on the basis of the salt-contaminating soil terrains or areas where the groundwater are salty. In addition, the expansion of the exploration target area is considered from the existing sub-surface information on potash and rock salt deposit without the full understanding of the geology of the deposit. It is against the existing background information obtained from the exploration drilling programme, as well as the various geological problems arisen, the present investigation is, therefore, conducted. The geological aspects which are related to the origin, distribution and all other modifications of the deposit will undoubtedly be able to brighten the

exploration concept, as well as to minimize the exploration cost. Besides, it is expected that findings from the present investigation will, in some parts, assist in the expansion of the potash and rock salt exploration programme into other important target areas in this region.

The better understanding of the geology of potash and rock salt deposits will lead to the subsequent successful exploration and development of these industrial raw materials. Consequently, the ambitious Eastern Seaboard Development will be partially accelerated considering from the industrial raw material supply, notably, potash, rock salt, natural gas, etc., for the fertilizer manufacturing project, the soda-ash industry in particular.

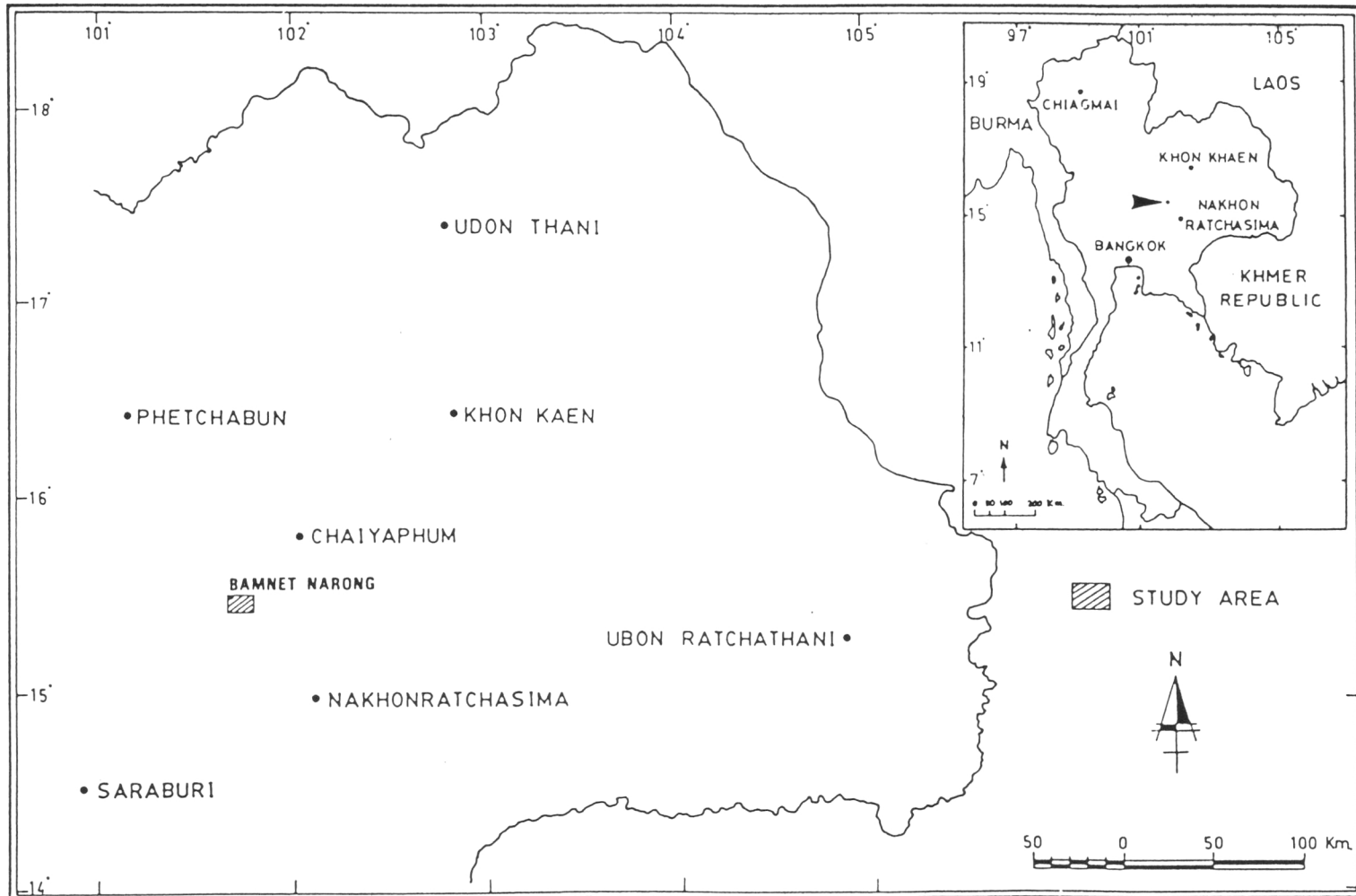
## 1.2 Study area

### 1.2.1 Location

The study area is mainly confined to Amphoe Bamnet Narong, Changwat Chaiyaphum and some parts of Amphoe Chatturat, Changwat Chaiyaphum and Amphoe Dan Khun Thot, Changwat Nakhon Ratchasima. Total area is approximately 170 square kilometers, from latitude  $15^{\circ}25'$  N to  $15^{\circ}30'$  N and longitude  $101^{\circ}39'$  E to  $101^{\circ}49'$  E (Figures 1.2.1.1 and 1.2.1.2).

### 1.2.2 Distribution of drilling wells

There are altogether 65 drill-holes in the study area (Figure 1.2.1.2) from the ground surface down to the depth range of 60-465 meters. These drill-holes are mostly concentrated in the central part of the area with the well-spacing range of 0.1-1 kilometer, but in the outer most parts of the area the spacing between the drill-holes vary from 1 to 5 kilometers.



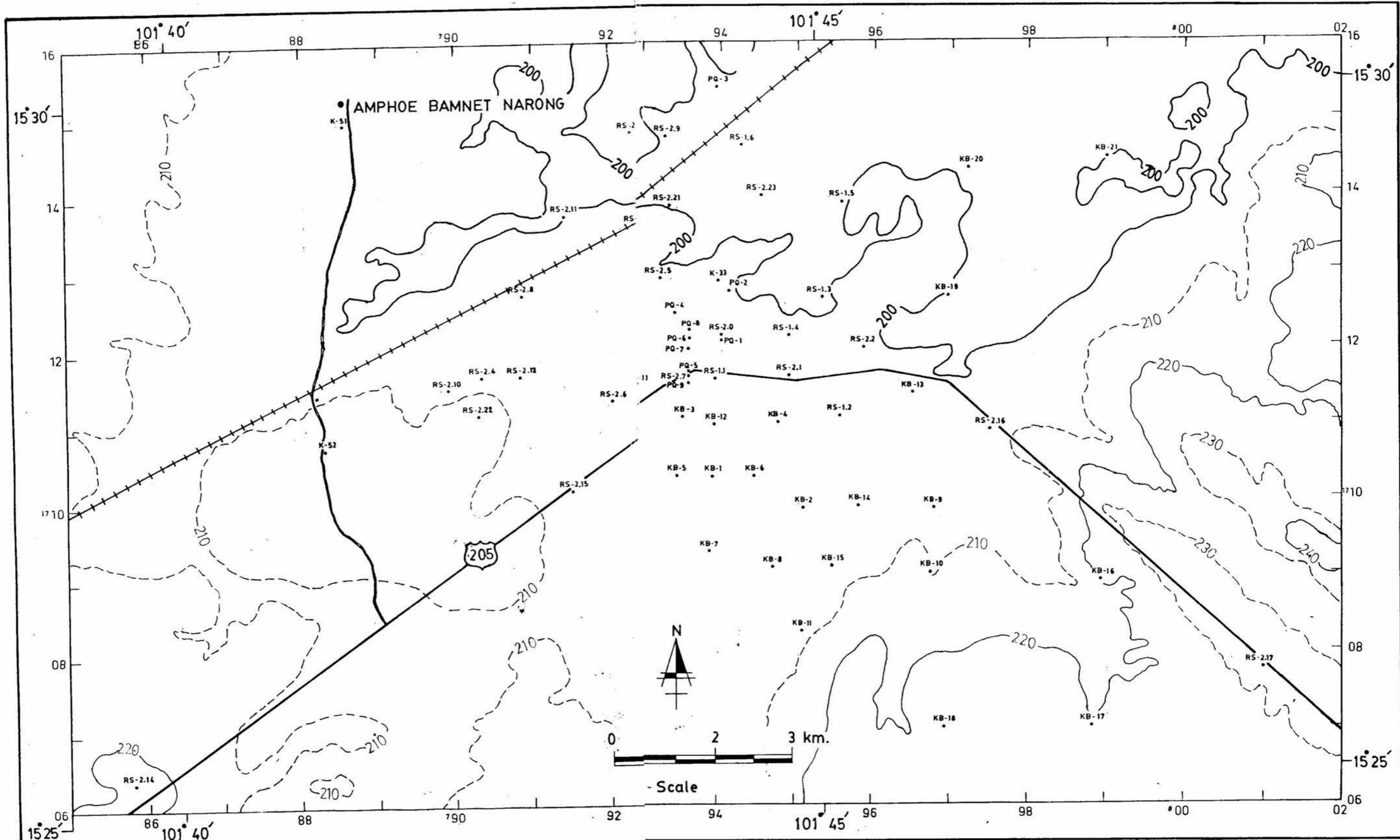
INDEX MAP OF THE STUDY AREA

On the origin of evaporite deposits in the Maha Sarakham Formation in Bamnet Narong Area, Changwat Chaiyaphum

DEPARTMENT OF GEOLOGY, GRADUATE SCHOOL  
CHULALONGKORN UNIVERSITY, 1983

SOMBAI YUMUANG

FIG. 1.2.1.1



WELL LOCATION MAP OF THE STUDY AREA

On the Origin of Evaporite Deposits in the Maha Sarakham Formation in Bamnet Area, Changwat Chaiyaphum

SOMBAT YUMUANG  
 DEPARTMENT OF GEOLOGY  
 GRADUATE SCHOOL  
 CHULALONGKORN UNIVERSITY, 1983

FIG. 1.2.1.2

### 1.3 Objectives

The study primarily aims at utilizing the existing drill-hole data coupled with detailed laboratory data to synthesize the sub-surface geology of the study area from the ground surface down to the depth range of 60-465 meters. In addition, the depositional model of evaporite formation as well as the post-depositional changes have been reconstructed and presented. Therefore, the overall geological history and geological processes concerned have been proposed to explain the existing geological deposits. The model obtained from the present investigation can be used in predicting the evaporite deposits with the similar geological setting elsewhere in this region.

### 1.4 Approach to the study and methodology

In order to fulfill the objectives of the present investigation, 4 steps of approach have been formulated. In each approach, appropriate method of study has also been specified in order to obtain required data and information. They are as follows:

#### 1.4.1 Literature survey

It is essentially required to obtain the state of the arts regarding the evaporite formation as well as the overall prospective of the geological setting of the area prior to the actual detailed study. Therefore, the fundamental step on literature survey has been carried out to cover the following aspects, namely, theoretical background of the evaporite formation, previous works of the study area, and relevant case-studies elsewhere.

#### 1.4.2 Field investigation

The direct field investigation concerning geological and geophysical drill-hole loggings as well as the sampling programme has been conducted during March to June, 1981 and February, 1982 at the drilling sites in Bannet Narong, Changwat Chaiyaphum. Besides, additional observation on the drill-hole materials for both cores and cuttings of the previously completed drill-holes including the sampling programme have been carried out several times at the drill-hole material storage at Changwat Khon Khaen.

#### 1.4.3 Data acquisition, compilation, and analysis

All the existing drill-hole data collected and compiled including additional subsequent laboratory studies can be classified into 4 categories as follows:

##### a) Lithological logs

Altogether the lithological data obtained from 65 drill-holes are determined, compiled, and tabulated (Appendix 1-A). Additional attempt has been made to correlate the lithology of all drill-holes from the prepared geological cross-sections. Finally, the sub-surface geology of the study area has been synthesized on the basis of various lithostratigraphic units (Appendix 1-B). Besides, the structural contour and isopach maps of some important stratigraphic units have been prepared to further illustrate the subsurface geological conditions in the study area.

##### b) Geophysical logs

Due to the fact that the geophysical gamma-ray logging is a standard practice for almost every drill-hole, an attempt is, therefore,

made to utilize this data for the confirmation of lithological data previously obtained from the direct lithological logging. Furthermore, the geophysical data has been proved to be a very useful tool in correlation.

c) Mineralogical and textural characteristics

The mineral identification and the determination of mineralogical suite which are the important keys have been extensively studied using the x-ray diffraction technique and thin-section method. The x-ray diffractometer employed in this study is the Philips x-ray generator model PW 1730/10 and the goniometer model PW 1050/70. The operating conditions of the equipment as well as the mineralogical suites are summarized in Appendix 1-D.

The textural characteristics of different lithological and mineralogical zonations are determined from the thin-sections, and polished rock-slabs as well as from the core samples.

d) Chemical compositions

Selected chemical composition of certain lithological and mineralogical zonations have been determined. The contents of  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{CaO}$  and  $\text{MgO}$  in the potash zone from the whole rock sample of 28 drill-holes have been analysed by the Thai Department of Mineral Resources using the atomic absorption spectrophotometry method (VARIAN, AA-4).

In addition, the contents of  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{CaO}$  and  $\text{MgO}$  in the water-soluble fraction of the whole rock samples obtained from some major lithological zonation are determined using the atomic absorption spectrophotometry method (VARIAN, AA-1275).



Emphasis has also been extended to cover the characteristics of some trace elements, particularly in halite zones. The KBr content in the halite zones as well as the Sr, Ba, Mn and Fe contents in certain anhydrite zones, calcareous sandstone zone, and ferruginous sandstone zone has been determined by the Office of Atomic Energy for Peace using the isotope x-ray fluorescence spectrophotometry method (KBr, Sr, Ba) and the atomic absorption spectrophotometry method (Mn and Fe).

The analytical results are tabulated in Appendix 1-C, 1-E, and 1-F, and some geochemical profiles have been constructed.

#### 1.4.4 Evaluation and interpretation

The information and data regarding lithological and mineralogical characteristics as well as geochemical and geophysical patterns of the sub-surface geology within the study area are finally integrated and evaluated. As a result, various sedimentary facies are defined for the purpose of reconstruction of depositional environments. Facies models are used as a basis for understanding depositional environments and are constructed from real and theoretical study, both of the rock record and of modern environment.

It is, however, recognized that post-depositional changes have inevitably played important role on the deposits under the present investigation. Therefore, additional attempt has been made to consider post-depositional changes of evaporitic facies in particular. These changes can be categorized into two types, notably, the structural deformation of the lithostratigraphic sequences, and the diagenetic chemical alterations.

Finally, the overall geological history as well as post-depositional changes including processes and products concerned are proposed to explain the present geological setting of the area.

#### 1.5 Background theories of the evaporite deposits

Consideration of stratigraphic sequences containing marine evaporites from most parts of the world lead to the recognition of a major cyclical successions of various salts. These salt deposits indicate successive environmental conditions from normal marine, through stages of increasing salinity, to evaporitic conditions in a somewhat restricted basin where evaporation exceeds precipitation and runoff. When high concentrations of seawater are developed, a strong horizontal salinity gradient exists which produces lateral segregation of different evaporites during precipitation and the order in which evaporites occur in the vertical column can be predicted from oceanographical and chemical data (Scruton, 1953; and Sloss, 1953).

Studies of evaporites in the past have produced some notable differences of opinion which can be summarized in the foregoing part. The "bar theory" by Bischof-Ochsenious (1877, 1888, 1893) explains the thick accumulations of salts in a continuous supply and persistent subsiding basin in an arid region. Later on, Branson (1915) has proposed to modify this classic theory to explain the relationships which he observed. Major conflict has, however, arisen in 1900 when Walther published his "desert theory" as an explanation for the origin of evaporites by the paucity of marine faunal remains in evaporites or if they were found they were exclusively non-marine indicating that the salts are not coastal lagoon deposits. This theory has been later on ignored in favour of the bar theory.

Besides, there have been many other new theories of the origin of evaporites proposed, but none of them have survived, notably, "saline lava theory" by Lichtenberger (1927), "infiltration theory" by Fulda (1927), "great tidal flood theory" by Wilfarth (1933), and "replacement theory" by Kudryavtsev (1971).

Another modification of the bar theory was introduced by King (1947) in an attempt to explain the thick anhydrite. His "theory of reflux" has survived and been supported by observations in modern estuaries. Recently, the concept of land-locked basin has been revived by Üsü (1972) in his surprising explanation of the origin of the evaporites of the western Mediterranean.

In recent years, the classical bar theory for the origin of evaporites has been seriously challenged. Marine evaporites are considered to form under multiple conditions --- in sabkha (Sherman, 1966; Friedman and Sanders, 1967; Kinsman, 1969; Sherman, and Fuller, 1969), in bar basin (Scruton, 1953; Borchert and Muir, 1964; and Schmalz, 1969), and in shallow epeiric shelves (Richter-Bernberg, 1955, 1968). In addition, the bar basin concept embraces two schools of thought, namely, the "deep-water" school and the "shallow-water" school.

#### 1.5.1 Environmental classification of evaporites

Interpretation of the lithological and paleontological associations of evaporite deposits makes possible classification and mapping of the environments involved in evaporite occurrences. Generally, the consideration of stratigraphic sequences containing evaporites leads to recognition of a major cycle made up of successive environmental conditions from normal marine, through stages of increasing

salinity, to evaporitic conditions (Scruton, 1953; and Sloss, 1953).

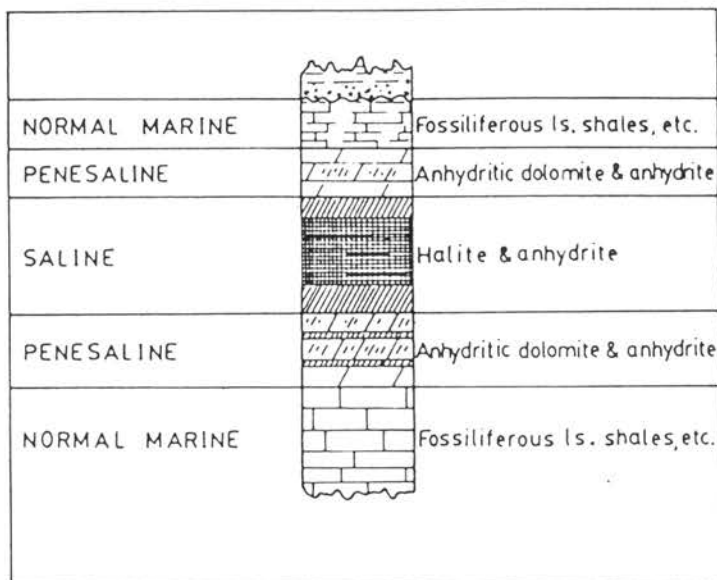
They are as follows:

- + brackish and terrestrial environments,
- + normal marine environments,
- + euxinic environments,
- + penesaline environments,
- + saline environments, and
- + supersaline environments.

The diagrammatic interpretation of the major cycle of which each important evaporite accumulation can be summarized and presented in Figure 1.5.1. The ideal major cycle is initiated in a section dominated by fossiliferous limestones indicative of open circulation and normal marine salinities. This normal marine section is superseded by interbedded dense dolomites and thin anhydrites lacking fossils of indigenous benthonic origin. These beds represent the partially restricted penesaline environment and are followed in upward succession by massive anhydrite and halite beds of the markedly restricted saline environment. In rare instances extreme restriction prevails for a sufficient length of time to account for the development of significant supersaline deposits as potassium and magnesium salts.

#### 1.5.2 Deposition of evaporites

The foregoing background information, derived from studies of circulation in estuaries and evaporation basins, chemical experiment, and theoretical consideration, permits a general reconstruction of events and circumstances leading to evaporite deposition (Scruton, 1953).



( After Sloss , 1953 )

<p>DIAGRAMMATIC REPRESENTATION OF A MAJOR EVAPORITIC CYCLE</p>	<p>On the Origin of Evaporite Deposits in the Maha Sarakham Formation in Bamnet Narong Area, Changwat Chaiyaphum</p>	
<p>DEPARTMENT OF GEOLOGY, GRADUATE SCHOOL CHALONGKORN UNIVERSITY, 1983</p>	<p>SOMBAT YUMUANG</p>	<p>FIG. 1.5.1</p>

a) Oceanographic data

Modern oceanographic studies in estuaries and other restricted arms of the sea have shown that a characteristic circulation exists. Surface currents flow from regions of low salinity to regions of higher salinity in response to hydrostatic head and are accompanied at a depth by oppositely directed currents flowing from high to low salinity regions because of density distribution (Sverdrup et al., 1946; Tully, 1937, 1949; Redfield, 1950; Ketchum, 1951; Pritchard, 1950, 1951); Stommel and Farmer, 1952 b; Redgpath, 1950, 1953; and Scruton, 1953).

b) Chemical data

The first important experiments on the crystallization of sea salts were carried out by Usiglio (1849). Later on, analyses of the water itself and of three bitters of different densities, representing different stages of evaporation, have been presented by Clarke (1924) and are given in Table 1.5.2.1. Data on the composition and amount of salts precipitated during concentration of the seawater have been summarized and presented by Stewart (1963), reproduced in Table 1.5.2.2. Usiglio's order of precipitation indicates that the first material to be deposited would be iron oxide. As the water becomes more concentrated, the zone of iron oxide precipitation moves toward the entrance of the basin, and calcium carbonate is precipitated in the distal portion. Further concentration results in calcium sulphate coming from solution in the distal portion and entrance-ward movement of the zone of calcium carbonate precipitation. Still greater concentration of the water brings sodium chloride from solution in the distal region. Thus, a vertical section through the resulting deposit would show, at the base, beds containing iron oxide overlying in ascending order by limestone,

Table 1.5.2.1 Analyses of Mediterranean water and bitterns (Weight percentages of total solids) (After Clarke, 1924)

	A	B	C	D
Cl - - - - -	54.39	56.18	49.99	49.13
Br - - - - -	1.15	1.22	2.68	3.03
SO <sub>4</sub> - - - - -	7.72	5.78	14.64	17.36
CO <sub>3</sub> - - - - -	.18	- -	- -	- -
Na - - - - -	31.08	32.06	20.39	12.89
K - - - - -	.71	.78	2.25	3.31
Ca - - - - -	1.18	.26	- -	- -
Mg - - - - -	3.59	3.72	10.05	14.28
Total - - -	100.00	100.00	100.00	100.00
Salinity, percent -	3.766	27.546	33.712	39.619

A. The water itself, density 1.0258

B. Bittern of density 1.21

C. Bittern of density 1.264

D. Bittern of density 1.32

Table 1.5.2.2 Salts laid down during concentration of seawater.  
(After Stewart, 1963)

Density†	Volume	Fe <sub>2</sub> O <sub>3</sub>	CaCO <sub>3</sub>	CaSO <sub>4</sub> ·2H <sub>2</sub> O	NaCl	MgSO <sub>4</sub>	MgCl <sub>2</sub>	NaBr	KCl
1.0258	1.000	0.0030‡							
1.0500	0.533		0.0642						
1.0836	0.316		Trace						
1.1037	0.245		Trace						
1.1264	0.190		0.530	0.5600					
1.1604	0.1445			0.5620					
1.1732	0.131			0.1840					
1.2015	0.112			0.1600					
1.2138	0.095			0.0508	3.2614	0.0040	0.0078		
1.2212	0.064			0.1476	9.6500	0.0130	0.0356		
1.2363	0.039			0.0700	7.8960	0.0262	0.0434	0.0728	
1.2570	0.0302			0.0144	2.6240	0.0174	0.0150	0.0358	
1.2778	0.023				2.2720	0.0254	0.0240	0.0518	
1.3069	0.0162				1.4040	0.5382	0.0274	0.0620	
Total									
deposit		0.0030	0.1172	1.7488	27.1074	0.6242	0.1532	0.2224	
Salts in last									
bittern					2.5885	1.8545	3.1640	0.3300	0.5339
Sum			0.0030	0.1172	1.7488	29.6959	3.3172	0.5524	0.5339

† Given by Usiglio in Baumé degrees. Restated here in specific gravities.

‡ Values given in grams for one liter of sea water.



gypsum or anhydrite, and rock salt, initially with some  $\text{CaSO}_4$ , later containing more potassium and magnesium salts (Usiglio, 1849; Lang, 1937; Hills, 1942; Adams and Frenzel, 1950; Scruton, 1953; and Hite, 1970, 1973, 1982).

Besides, the bromine geochemistry has been used as the indicator for reconstruction of depositional environments in evaporite basins and as the criteria for potash exploration (Reup, 1966; Kühn, 1968; and Hite, 1978).

c) Mineralogical data

The minerals of marine evaporites, excluding those of detrital origin, are listed in Table 1.5.2.3. Those marked with an asterisk rank as major constituents. (Steward, 1963).

From the general observation on the geological setting, as well as sub-surface factual information, it is rather conclusive that the evaporite model of the "bar-basin theory" could be used as a basis to explain the origin of evaporite deposits under the present investigation. Under this model, evaporites are deposited in restricted arms of the sea where evaporation exceeds precipitation plus runoff. The necessary restriction of the estuary or basin are in part dynamic and in part static. Dynamic restriction is caused by the hydrostatic head and by frictional stresses between the bottom current and the channel floor. Static restriction is produced by topographic confinement as physical barriers.

When high concentrations are developed a strong horizontal salinity gradient exists which produces lateral segregation of different evaporites during precipitation. The escaping deep current returns to

Table 1.5.2.3 Minerals of marine evaporites (After Steward, 1963).

Chlorides:

Hallite*	NaCl
Sylvite*	KCl
Bischofite	$MgCl_2 \cdot 6H_2O$
Koenenite	$Mg_9Al_4Cl_8(OH)_{22} \cdot 7H_2O$
Zirklerite	Basic chloride of Al and $Fe^{2+}$ , with minor Ca and Mg
Chlorocalcite (= hydrophilite).	$KCaCl_3$
Carmallite*	$KMgCl_3 \cdot 6H_2O$
Tachyhydrite	$CaMg_2Cl_6 \cdot 12H_2O$
Douglasite	$K_2FeCl_4 \cdot 2H_2O$
Erythrosiderite	$K_2FeCl_5 \cdot H_2O$
Rinneite	$NaK_3FeCl_6$

Fluorides:

Fluorite	$CaF_2$
Sellaite	$MgF_2$

Sulfates:

Aphthitalite (glawerite)	$(K,Na)_3Na(SO_4)_2$
Thenardite	$Na_2SO_4$
Barite	$BaSO_4$
Celestite	$SrSO_4$
Anhydrite*	$CaSO_4$
Vanthoffite	$Na_6Mg(SO_4)_4$
Glauberite	$Na_2Ca(SO_4)_2$
Langheinrite*	$K_2Mg_2(SO_4)_3$
Mirabilite	$Na_2SO_4 \cdot 10H_2O$
Syngenite	$K_2Ca(SO_4)_2 \cdot H_2O$
Loewelite	$Na_4Mg_2(SO_4)_4 \cdot 5H_2O$
Blödite (Astrakanite)	$Na_2Mg(SO_4)_2 \cdot 4H_2O$
Leonite	$K_2Mg(SO_4)_2 \cdot 4H_2O$
Picromerite (Schoenite)	$K_2Mg(SO_4)_2 \cdot 6H_2O$
Polyhalite*	$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$
Görgeyite	$K_2Ca_5(SO_4)_6 \cdot H_2O$
Bassanite	$2CaSO_4 \cdot H_2O$
Kieserite*	$MgSO_4 \cdot H_2O$
Sanderite	$MgSO_4 \cdot 2H_2O$
Gypsum*	$CaSO_4 \cdot 2H_2O$
Starkeyite (Leonhardtite)	$MgSO_4 \cdot 4H_2O$
Pentahydrate (Allenite)	$MgSO_4 \cdot 5H_2O$
Hexahydrate	$MgSO_4 \cdot 6H_2O$
Epsomite (Reichardtite)	$MgSO_4 \cdot 7H_2O$
Kainite*	$KMg(SO_4)Cl \cdot 3H_2O$
Anhydrokainite	$KMg(SO_4)Cl$
D'Ankrite	$MgNa_{21}(Cl_3SO_4)(SO_4)_9$

Carbonates:

Calcite*	$CaCO_3$
Magnesite*	$MgCO_3$
Siderite	$FeCO_3$
Aragonite	$CaCO_3$
Strontianite	$SrCO_3$
Dolomite*	$CaMg(CO_3)_2$
Ankerite	$Ca(Fe, Mg)CO_3$

Borates:

Pinnoite	$Mg(BO_2)_2 \cdot 3H_2O$
Kurgantaite	$(Sr, Ca)_2B_4O_8 \cdot H_2O$
Priceite (Pandermite)	$Ca_4B_{10}O_{19} \cdot 7H_2O$
Ulexite	$NaCaB_5O_9 \cdot 8H_2O$
p-Veatchite	$SrB_6O_{10} \cdot 2H_2O$
Colemanite	$Ca_2B_6O_{11} \cdot 5H_2O$
Hydroboracite	$CaMgB_6O_{11} \cdot 6H_2O$
Inderborite	$CaMgB_6O_{11} \cdot 11H_2O$
Inyoite	$Ca_2B_6O_{11} \cdot 13H_2O$
Kurnakovite	$Mg_2B_6O_{11} \cdot 15H_2O$
Inderite	$Mg_2B_6O_{11} \cdot 15H_2O$
Howlite	$Ca_2SiB_5O_9(OH)_5$
Paternoite	$MgB_8O_{13} \cdot 4H_2O$
Ginorite	$Ca_2B_{14}O_{23} \cdot 8H_2O$
(Cryptomorphite)	
Kaliborite	$KMg_2B_{11}O_{19} \cdot 9H_2O$
Volkovite	Hydrous borate of Sr and K
Ivanovite	Hydrous chloroborate of Ca (and K?)
Szaibelvite (Ascharite)	$(Mg)(BO_2)(OH)$
Boracite	$Mg_3B_7O_{13}Cl$
Ericaite	$(Fe, Mg, Mn)_3B_7O_{13}Cl$
Hilgardite	$Ca_8(B_6O_{11})_3Cl_4 \cdot 4H_2O$
Parshilgardite	$Ca_8(B_6O_{11})_3Cl_4 \cdot 4H_2O$
Strontiohilgardite	$(Ca, Sr)_2(B_5O_8)(OH)_2Cl$
Heidornite	$Na_2Ca_3Cl(SO_4)_2 \cdot B_2O_3(OH)_2$
Lueneburgite	$Mg_3B_2(OH)_6(PO_4)_2$
Sulphoborite	$Mg_6H_4(BO_3)_4(SO_4)_2 \cdot 7H_2O$
Danburite	$CaSi_2B_2O_8$

Elements, sulfides, oxides, silicates, phosphates:

Sulfur, pyrite, hauerite, hematite, goethite (limonite), magnetite, quartz, opal, talc, illite, kaolinite, goya

\* major constituents.

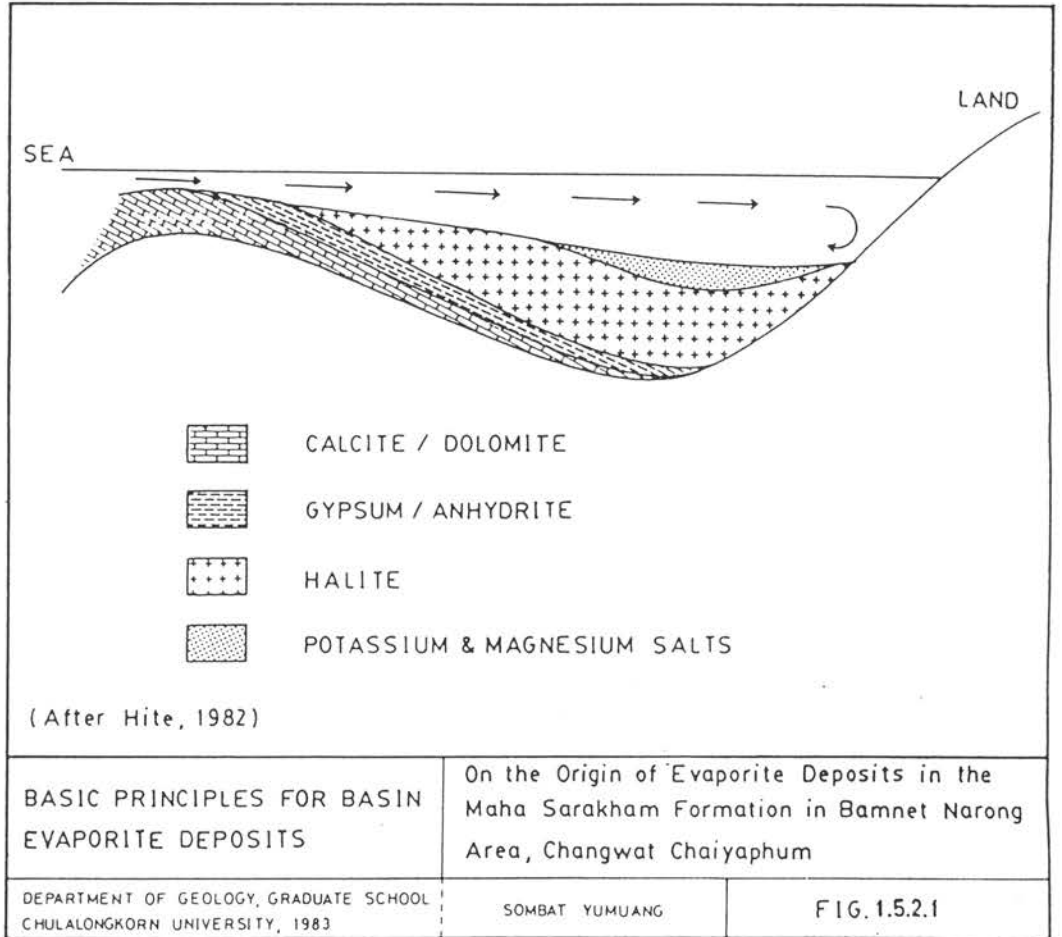
the sea these evaporites which have not been precipitated. Fluctuation in equilibrium caused principally by changes in excess of evaporation or in degree of channel closure cause migrations of the horizontal salinity gradient along the longitudinal axis of the basin which produce vertical differentiation of evaporites. Basic principles for horizontal segregation of evaporite deposits and nature of the inferred vertical sequences are presented in Figure 1.5.2.1.

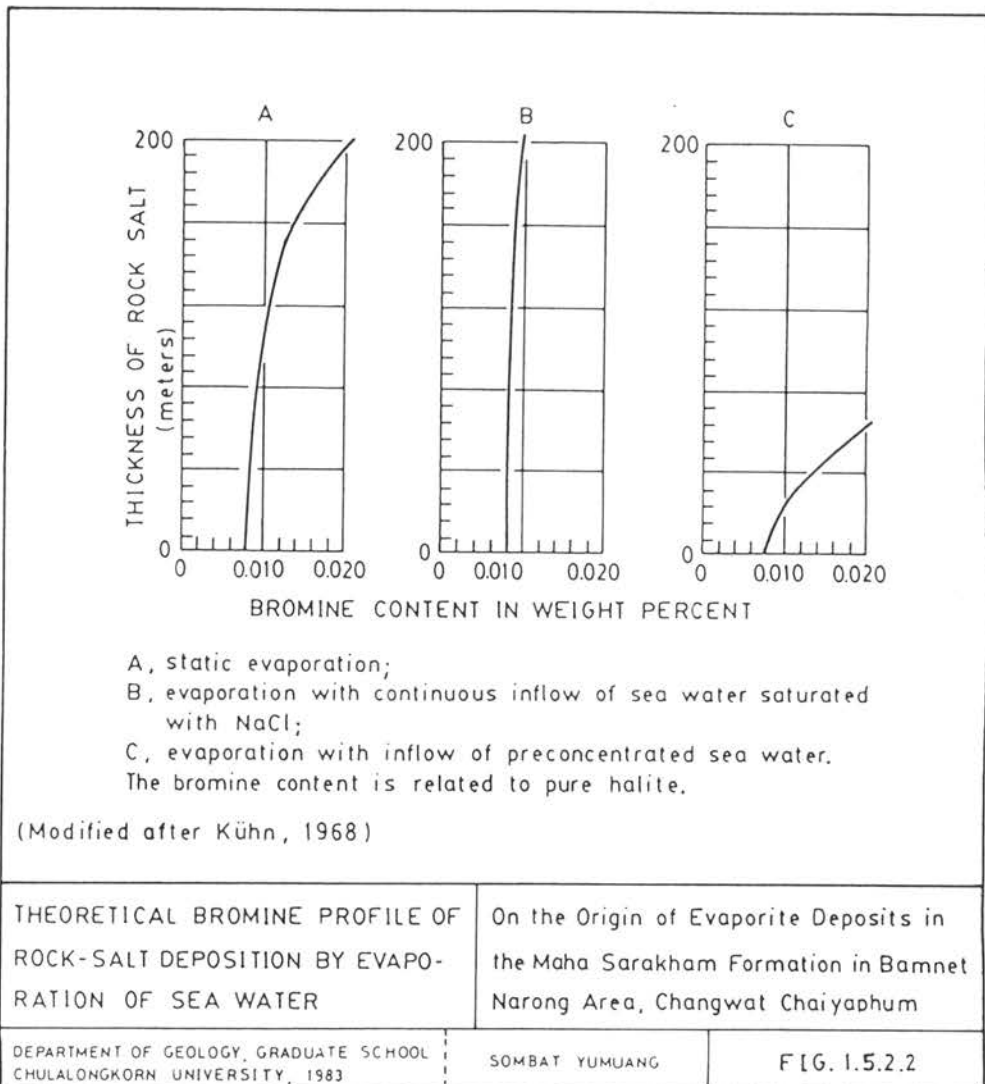
Besides, the distribution of bromine in the chloride facies of marine evaporites is used in the reconstruction of the paleosalinities in evaporite basins and provides an important geochemical tool in the exploration for potash deposits. Detailed stratigraphic profiles of bromine distribution are also useful in resolving problems in understanding some of the post-depositional processes that have occurred in the evaporite rocks (Raup, 1966; Kuhn, 1968; and Hite, 1978).

The basis for the bromine method is the diadochal substitution of bromine for chloride in the structures of the chloride minerals. Bromine content in the halite deposits is a sensitive measure of its concentration in the solution and the bromine profile indicates the change in concentration that occurred during the separation of the rock salts (Kühn, 1968). Theoretical bromine profile of rock-salt deposition by evaporation of the seawater is presented in Figure 1.5.2.2.

#### 1.6 Previous investigation

Thick beds of rock salt were discovered in northeast Thailand in the 1950's after the groundwater resource development programme conducted by the Thai Department of Mineral Resources (LaMoreaux et al., 1959). By 1963, several hundred groundwater wells had been put down,





most less than 60 meters deep, but some as much as 600 meters. Rock salt had been encountered in about 70 of the deepest wells, most of which were abandoned soon after reaching the salt. The results of this early work were summarized by Gardner et al. (1967).

In 1963-1964, five holes were drilled to investigate the rock salt deposits. This programme was carried out by a joint Thai Department of Mineral Resources/U.S. Geological Survey team with funding by the United Nations Special Fund, as part of the U. N. - sponsored lower Mekong basin development project. The locality chosen for the rock salt drilling was Chaiyaphum which was established that over 600 million tons of proven and probable reserves of good quality rock salt (Jacobson and Japakasetr, 1965).

In 1976, the five ASEAN countries of Indonesia, Malaysia, the Philippines, Singapore, and Thailand, agreed to cooperate in promoting a number of priority industrial projects. One of these was the manufacture of soda ash in Thailand. Bamnet Narong Area is one of the target areas that have been tested for rock salt. In 1977-1978, a detailed investigation for the feasibility study on rock salt and soda ash project was carried out in the Bamnet Narong Area. Furthermore, a technical and economic feasibility study of establishing a rock-salt mine at Bamnet Narong Area is being carried out with assistance from the Asian Development Bank.

Meanwhile, it had long been recognized that the Khorat Plateau evaporites provided a target for potash exploration. In 1970-1971 an evaluation of the potash potential was carried out and recommendations for drilling were made by R.J. Hite of the U.S. Geological Survey (Hite, 1971). The Thai Department of Mineral Resources then embarked

on a programme for potash exploration in Khorat Plateau. Bannet Narong Area is also one of the target areas that have been tested for potash. In 1979, the Bannet Narong Area has been developed into a part of soda ash project with an excellent potential for potash development.

In 1976, Sundharovat presented the idea of the origin of potash in northeastern Thailand related with the warping of the rocks in Khorat Group, transgression of sea water and the deposition of evaporites in Late Tertiary or Pleistocene.

In 1977, Sundharovat proposed the "Taokhanomkrok" hypothesis of potash in northeastern Thailand. According to this hypothesis, potash should be deposited in the small basins (structural low) dissipated in the Khorat Plateau and sylvite should be related with the deepest parts of these small basins.

In 1978, Sundharovat reviewed the history of rock salt in northeastern Thailand that he had already presented since 1976 and 1977. In the same year, Thiramongkol (1978) presented that the rock salt in northeastern Thailand were deposited in inland sea or lagoon environment in Upper Cretaceous and was effected later by epeirogenic movements as warping and block faulting. Later on, Suvanich (1978) published the details of the stratigraphy, structure and age of Maha Sarakham or Rock Salt Formation. He presented that there was only one layer of rock salt with clay lens intervened, and there was unconformity occurred between Khok Kruat Formation and Maha Sarakham or Rock Salt Formation of Upper Tertiary or Quaternary age. Later on, Denusawasdi et al. (1978) conducted geophysical survey in Bannet Narong Area as a detailed deep reflection seismic survey and a detailed resistivity survey which the results of these investigations gave a few useful informations. In the

same year, Japakasetr (1978) reported the result of potash drilling programme in Khorat Plateau. He presented the stratigraphy of Maha Sarakham Formation by dividing it into three layers of salt interbedded by clay layers and the potash zone only presented in the upper part of basal salt layer. Besides, he conducted the economic consideration of potash zone in Khorat Plateau.

In 1979, ESSO Exploration and Production Khorat Inc. conducted the regional gravity survey of northeastern Thailand as bouguer gravity map in scale 1:1,000,000. Later on, Hite and Japakasetr (1979) published the details of potash deposits of the Khorat Plateau in the view of regional geology, tectonic history of the Maha Sarakham Formation of Cretaceous age, bromine geochemistry of three layers of salt and the origin of sylvite resulted from leaching of the primary carnallite. In the same year, Anderle (1979) reported the progress of potash and rock salt investigation in northeastern Thailand, especially in Bannet Narong Area. This report was concluded in more details of geological structure of three salt layers and occurrence of salt anticlines related with incongruent alteration of potash zone in basal salt layer.

In 1980, Japakasetr carried out the most comprehensive final report of potash deposits of northeastern Thailand. This report covered the regional structure, revised the stratigraphy of Salt or Maha Sarakham Formation.

In 1981, Japakasetr and Workman presented the latest informations of evaporite deposits of Northeast Thailand summarized from 68 core logs of rock salt and potash drilling programmes in Khorat Plateau. They presented the diagrammatic columnar section through the Maha Sarakham Formation.



In 1982, Hite presented the more details of potash deposits at Bamnet Narong Area in the views of geological structure and the salt anticline model of secondary sylvite in this area.