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The evaporite deposits in Bamnet Narong area, Northeastern Thailand.

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Abstract: Analyses of 65 drill-hole cores which penetrated to depths ranging from 60-465 metres within the Bamnet Narong area of approximately 170 square kilometres reveal three cycles of evaporitic sequences in the Maha Sarakham Formation of the Khorat Group. Mineralogical, petrographical, geochemical and geophysical data have been employed to define the lithostratigraphy, sedimentary facies, as well as for the reconstruction of the depositional environment and post-depositional changes.

The lower evaporitic cycle is characterized, from bottom to top, by ferruginous sandstone, calcareous sandstone, an anhydrite zone, a halite zone, and a potash zone. This sequence is almost exclusively equivalent to lower-, middle-, and some parts of higher- orders of theoretical marine evaporitic facies. The middle evaporitic and the upper evaporitic cycles are represented by the alternation of halite and anhydrite zones. These two cycles can be interpreted as lower- and middle-orders of theoretical evaporitic facies. It was also noted that all evaporitic cycles were interbedded with fine-grained clastic rocks of reasonable thicknesses.

Many lines of evidence indicate that the depositional basin was a shallow epeiric sea with a gentle sloping depositional surface. During the initial marine transgression, the sediment substrate was mainly of terrigenous clastics . The condition of the depositional environment changed from an open marine to a restricted marine under the influence of threshold depths of the basin floor elsewhere outside the study area. Subsequently, the brine concentration mechanism as well as the palaeosalinity has been attributed to a marine transgression and regression into the depositional basin under an arid to semi-arid palaeoclimate. The evaporitic sub-facies also indicate that the palaeosalinity varied within the range of penesaline, saline, to supersaline conditions according to the "bar-basin" theory.

With respect to post-depositional changes, it is recognized that in the area where the evaporitic facies have been structurally deformed to gentle anticlines, the characteristics of depositional facies have remarkably altered. In the light of groundwater activities, carnallite in the potash zone has been chemically transformed into sylvite through the process of incongruent alteration. The formation of anhydrite caps at the crests of anticlines has been explained as a residual accumulation after the leaching of halite/anhydrite layers by the groundwater.

INTRODUCTION

A potash and rock salt exploration drilling programme has been conducted by the Thai Department of Mineral Resources in the northeastern part of Thailand since 1973. As a result, one of the most promising target areas of rock salt and potash deposits was located at Bamnet Narong Area (Anderle 1979; Yumuang, 1983) (Figure 1). Therefore, a semi-detailed drilling programme in this area was carried out in order to obtain the information regarding reserves and grade of the economically important evaporite deposits.

This study primarily aims at utilizing the existing 65 drillhole core information coupled with detailed laboratory data to synthesize the sub-surface geology, and to reconstruct the depositional environment and post-depositional changes of the evaporite formation in

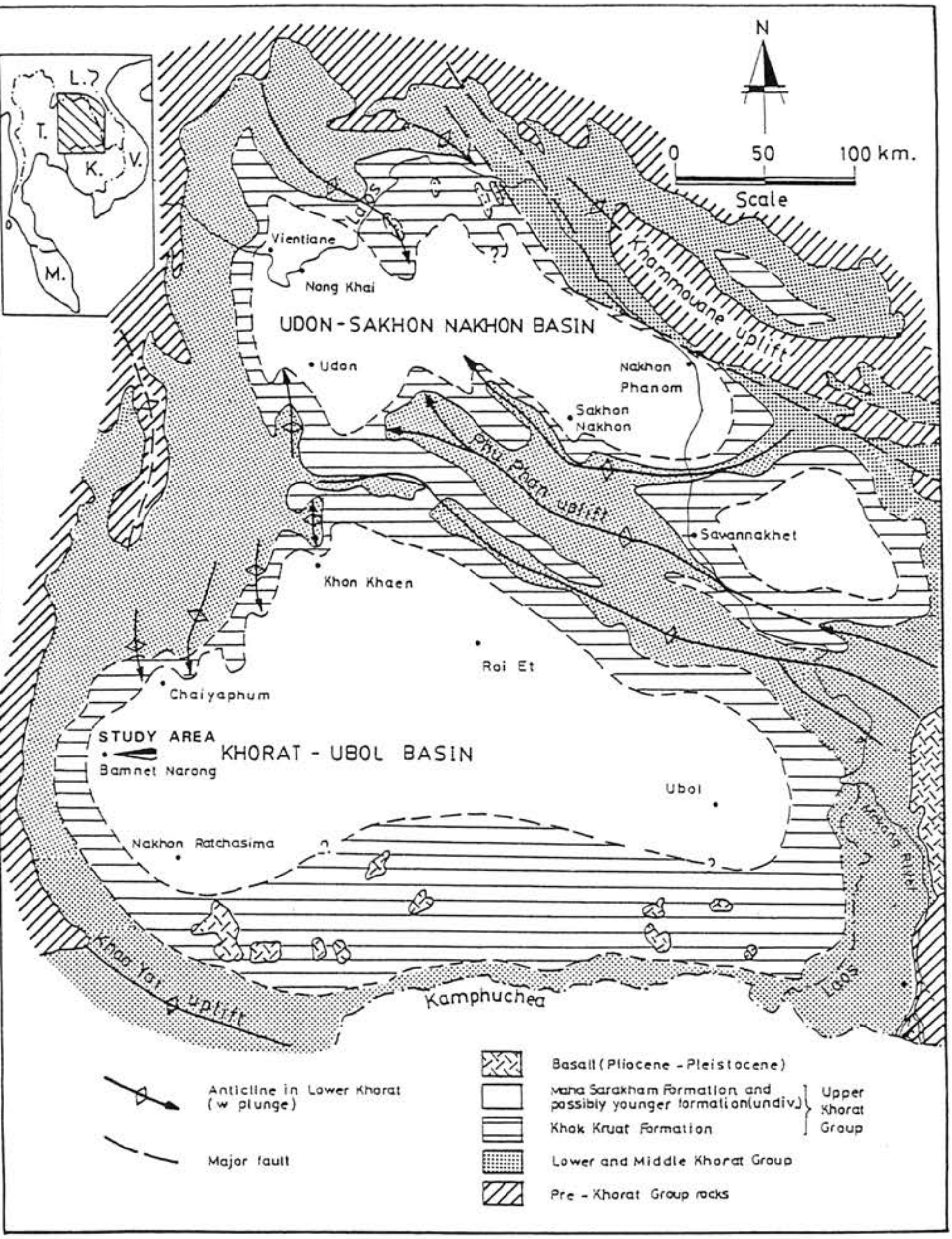

Fig. 1 Generalized geological map of northeast Thailand with location of the study area. (After Japakasetr and Workman 1981). Inset: T = Thailand, L = Laos, V = Vietnam, K = Kampuchea, M = Malaysia

Bamnet Narong Area which covers an area of approximately 170 sq. km. (Figure 2). The overall geological history and geological processes in the study area have been used to explain the existing geological deposits. The findings of this study will assist future development of such deposits elsewhere in northeastern Thailand. (Hahn, 1982; Hite, 1982; Hite & Japakasetr, 1979; Japakasetr, 1977, 1980; Jacobson & Japakasetr, 1965; Workman, 1972)

The sub-surface data employed in this investigation were obtained from the 65 drill hole cores (Figure 3). These data include lithological and gamma-ray logs. In addition, laboratory analyses have been conducted to determine the mineralogical and textural characteristics, as well as the chemical composition of selected samples. The mineral identification was based on X-ray diffraction and standard thin-section method. Textural characteristics of different lithological and mineralogical zonations were determined from thin-sections, polished rock-slabs, as well as from core-samples (Carozzi, 1960) . Selected chemical compositions of whole rock samples, notably, Na_2O, K_2O, CaO and MgO particularly in the potash zone were determined by atomic absorption spectrophotomety (Clarke, 1924). In addition, Na_2O, K_2O, CaO and MgO contents in the water-soluble fraction of the whole rock samples from some major lithological zonations were also determined using the atomic absorption spectrophotometer, model Varian AA-1275.

LITHOSTRATIGRAPHY

The sub-surface lithostratigraphy of the study area is essentially based on the lithological analysis, mineralogy, texture and chemical as well as geophysical characteristics of the sedimentary sequences from the ground surface down to the depth range of 60-465 metres. From these data it is apparent that the sub-surface lithostratigraphic sequences of the Maha Saradham Formation of the Khorat Group can be subdivided into two types viz, a "complete" sequence which has not been altered after deposition and an "incomplete" sequence which has been modified after deposition and in which some members are missing. The "complete" sequence can be tentatively sub-divided into five members, namely, Basal Salt, Lower Clastics, Middle Salt, Middle Clastics, and Upper Salt (Figure 4). However, the uppermost two members overlying the Maha Sarakham Formation, notably, Upper Clastics and Alluvium should be placed under another rock formation. It is noted that in the Basal Salt Member of the Maha Sarakham Formation almost complete evaporitic sequences are present.

The "incomplete" lithostratigraphic sequences of the Maha Sarakham Formation of the Khorat Group in some localities, consists mainly of Basal Salt Member with incomplete evaporitic sequences. Besides, the uppermost Clastics Member locally rests unconformably on the Basal Salt Member (Figure 5).

Evidences from the sub-surface geological map reveal that the Maha Sarakham Formation in the study area lies at a relatively shallower depth and gently towards the southeast . The thickness of the Formation varies considerably. It has a tendency to be thicker in the central, as well as in the northern parts. It is noted that the "complete" lithostratigraphic sequences of the Maha Sarakham Formation are generally present at localities where the Formation is thin and lies at a relatively greater depth. On the other hand, the "incomplete" sequences of this Formation are always present at localities where the Formation is thick and lies at a relatively shallower depth. These are mainly controlled by the gentle salt anticlinal structures.

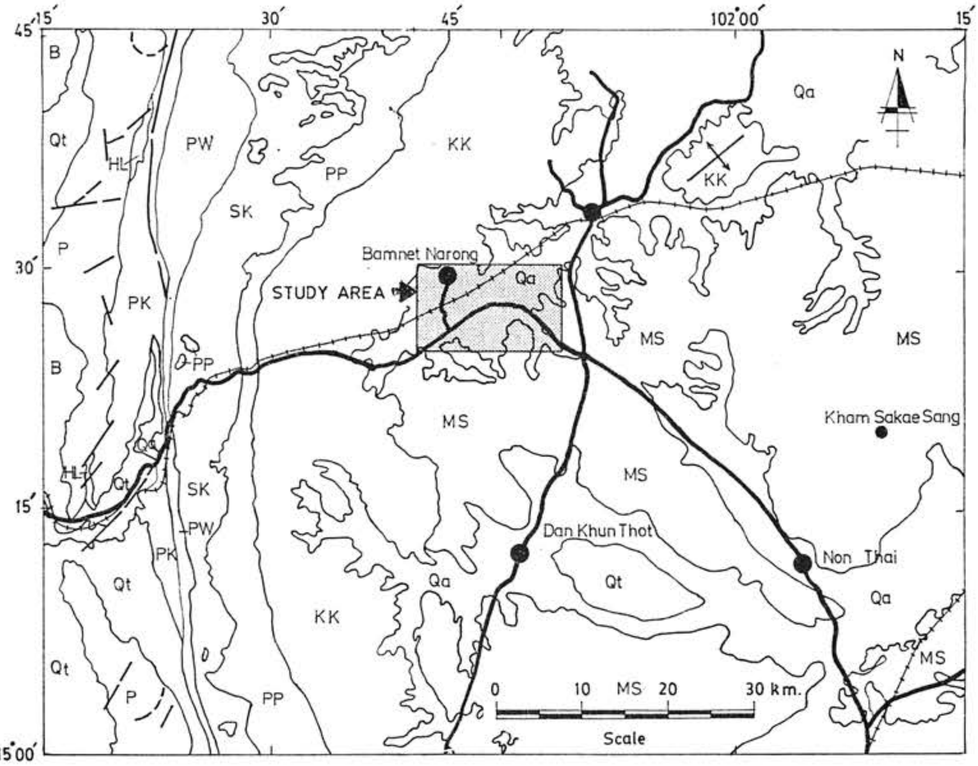

Fig. 2 Geological map of the study area. (Based on unpublished geological map of N.E. Thailand, Dept of Min. Resources, 1982)

EXPLANATION OF FIGURE 2

B = Basalt (Quaternary)

Q_a = Recent flood plain, alluvial sands, silt, back swamp deposits, beach sand.

Q_t = Terrace gravel, sand, silt, laterite and lateritic soil.

MK = Silts, shale, sandstone, brick red, purplish red, weathered white to grey, thin to thick bedded; with rock salt, potash, gysum and anhydrite.

KK = Sandstone, brown, reddish brown, partially micaceous; shale; siltstone, pale brown, pebbly, micaceous; with some lime-noduled conglomerate.

PP = Sandstone, white, pale orange; sandstone, pale orange, yellowish brown, pebbly, cross-bedded; with some shale and conglomerate.

SK = Sandstone, reddish brown, grey, micaceous; siltstone, grey, brown; lime-nodules conglomerate; purplish brown, brick red.

PW = Sandstone, white, pink, cross-bedded, massive, pebbly layering at the upper beds; with some reddish brown and grey shale.

PK = Shale, brown, reddish brown, purplish red, micaceous; siltstone, sandstone, brown, grey; with some lime-nodules conglomerate.

HL = Conglomerate; shale, grey, black; mudstone, grey, calcareous; limestone, argillaceous; sandstone, yellowish brown.

P = Limestone, light to dark grey, bedded to massive with fossils; shale, red, grey to black, carbonaceous, calcareous, laminated to thick bedded with fossils; sandstone, yellowish brown, bedded to massive, lense; chert, black, noduled or thin bedded; siltstone, conglomerate mudstone, sandy shale; micaceous sandy siltstone; tuffaceous sandstone; tuff; andesitic tuff; agglomerate; xhyolite; andesite.

major faults

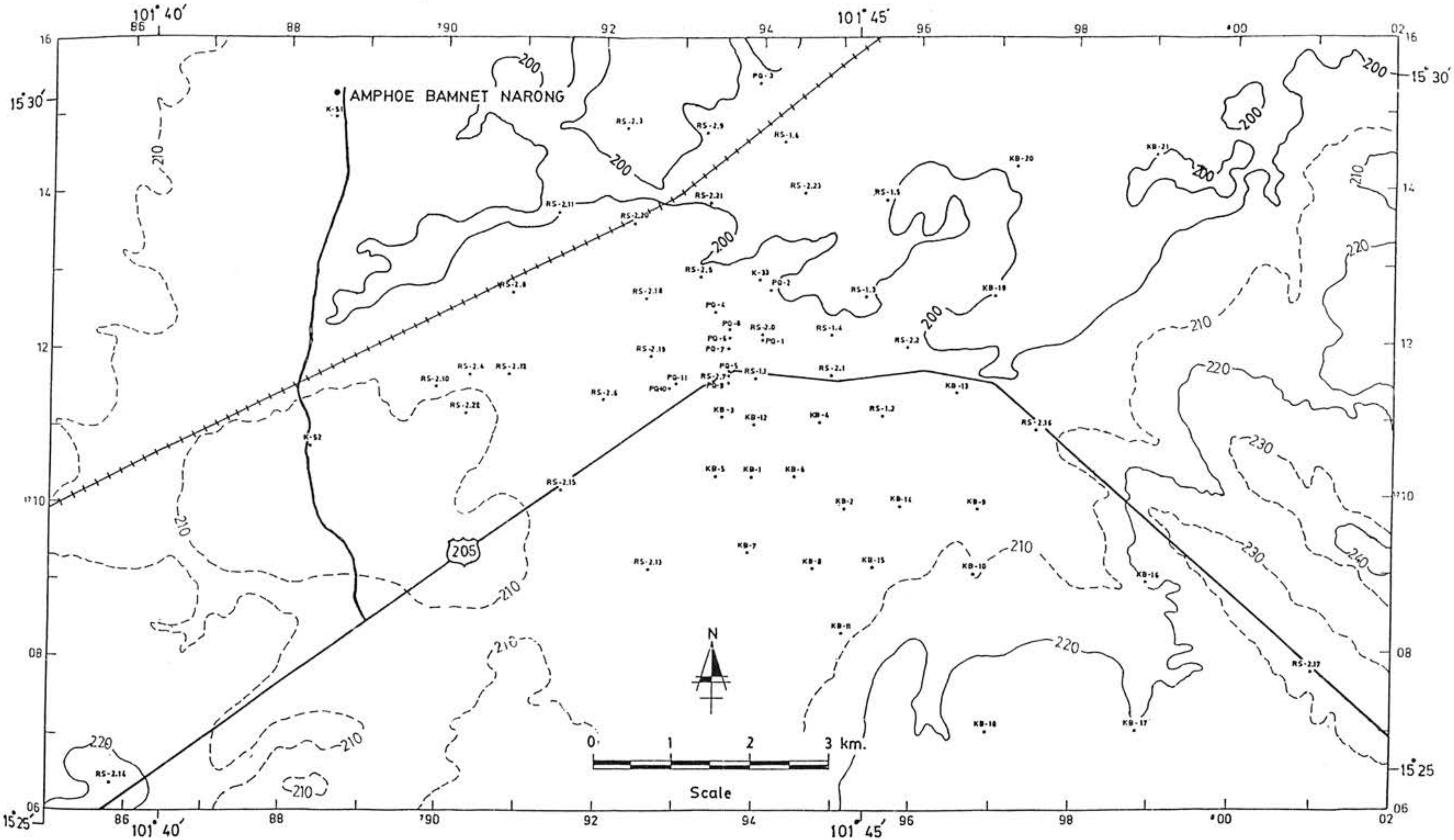

Fig. 3 Well location map of the study area.

LITHOSTRATIGRAPHY OF BAMNET NARONG AREA, CHANGWAT CHAIYAPHUM.

GROUP	FORMATION	MEMBER	BED		THICKNESS (m.)	GENERAL LITHOLOGIES
?	?	Alluvium			1.00-20.00	Yel gry to brn uncons cly,sd and some gvl.
?	?	Upper Clastics			13.24-316.08	Rd brn & grn gry semi-cons cly to clst/mdst intbd with calc clst/mdst and some sltst/ss.
KHORAT	MAHA SARAKHAM	Upper Salt	Upper Cap Anhydrite	uc	0-7.01	Lt gry anhy.
			Upper Upper Halite		0-30.16	Clear,milky wh m gr halite and smoky dk halite bands with anhy layers.
			Upper Anhydrite	u	0-1.05	Dk to lt gry anhy.
			Lower Upper Halite'		0-13.08	Clear m gr halite & smoky dk halite bands,pale honey to orng halite associated.
		Middle Clastics	Middle Mudstone/Claystone		8.94-53.00	Rd brn & grn gry to dk gry semi-cons cly to clst/mdst.
		Middle Salt	Middle Cap Anhydrite	mc	0-6.15	Lt gry anhy.
			Upper Middle Halite		1.46-95.33	Clear&milky wh f to m gr halite and smoky dk halite bands with anhy layers,some gry&pale orng halite associated in the upper part
			Middle Anhydrite	m	0.11-2.04	Dk gry to lt gry anhy.
			Lower Middle Halite		10.94-22.17	Pale yel brn to orng&dk honey f gr halite with smoky dk halite bands.
		Lower Clastics	Lower Mudstone/Claystone		1.68-25.76	Rd brn & grn gry to dk gry semi-cons cly to clst/mdst.
		Basal Salt	Coloured Halite		0.28-15.90	Several col bands of halite.
			Potash: Sylvinite		0-5.11	Cloudy wh,orng rd sylvite
			Potash: Carnallite,Halite&Tachyhydrite		1.25-65.87	Pale pk,pk clear to orng rd carnallite & clear and smoky dk halite & orng to honey yel tachyhydrite intbd and mixed.
			Potash: Sylvinite		0-0.22	Cloudy wh,orng rd sylvite.
			Basal Halite		21.66-191.44	Clear f gr halite. Clear f to m gr halite with anhy layers. Clear & milky wh m to c gr halite and smoky dk halite bands with anhy layers. Clear f to m gr halite & smoky dk halite bands,wh dull f to m gr anhy associated.
			Basal Anhydrite	b	0.77-1.86	Dk gry to lt gry anhydrite
			Calc Sandstone		0.07-1.10	Grn gry calc ss.
	? KHOK KRUAT?	?	Ferrugenous Sandstone		5.18	Dk rd brn Fe ss.

Fig. 4 "Complete" lithostratigraphy of the study area.

INCOMPLETE STRATIGRAPHIC SEQUENCES IN THE STUDY AREA						
GROUP	FORMATION	MEMBER	BED		THICKNESS (m.)	GENERAL LITHOLOGIES
?	?	Alluvium			3.05-60.96	Yel brn & gry uncons to semi-cons sd, clayey sd, gvl and some cly.
	?	? Upper Clastics & Middle Clastics & Lower Clastics ?			12.19-53.96	Rd brn & grn gry semi-cons cly to clst/mdst intbd with clst/mdst & some sltst/ss.
			Anhydrite/Gypsum		0-10.77	Wh to dk gry anhy/gypsum.
					5.06-17.90	Rd brn & grn gry to dk gry semi-cons cly to clst/mdst.
?	?					Local Unconf ?
KHORAT	MAHA SARAKHAM	Basal Salt	Basal Cap Anhydrite	bc	0-28.75	Lt to dk gry anhy/gypsum, poor cemented.
			Basal Halite		37.38-295.22	Clear & milky wh m to c elongated gr halite and smoky dk halite bands, absent or rare anhy layers (mostly high angle dipping in the upper part and decreased to lower angle dipping along depth). Clear f to m gr halite and smoky dk halite bands, with wh dull f to m gr anhydrite associated.
			Basal Anhydrite	b	0.77-1.86	Dk gry to lt gry anhydrite.
			Calc Sandstone		0.07-1.10	Grn gry calc ss.
	? KHOK KRUAT?	?	Ferrugenous Sandstone		> 5.18	Dk rd brn Fe ss.

Fig. 5 "Incomplete" lithostratigraphic sequences in the study area.

Detailed sub-surface lithostratigraphy of both "complete" and "incomplete" sequences of Maha Sarakham Formation are presented in Figures 4 and 5.

The mineralogy of the evaporite deposits in the study area varies from the lowest order to nearly the highest order of theoretical evaporitic sequences (AAPG, 1971; Sloss, 1953; Richer & Bernburg, 1972; Dunlap & Hite, 1959; Hite, 1961; Dean & Scheriber, 1978; Mattox *et al.*, 1968; Kirkland & Evans, 1973). These evaporitic minerals identified include hematite, calcite, dolomite, gypsum, anhydrite, halite, carnallite, sylvite, tachyhydrite, boracite (?). Hematite and calcite are deposited as cementing materials in Ferrugenous Sandstone and Calcareous Sandstone Beds, respectively.

SEDIMENTARY FACIES AND DEPOSITIONAL ENVIRONMENT

Depositional basin

Evaporites can be classified on the basis of their environmental relationships, particularly with respect to the under- and over-lying sedimentary sequences as predicted in a shallow epeiric sea model. The sequences are dominated by marine input, with transgressive and regressive cycles across a stable interior platform . Sediments of the underlying Khok Kruat Formation, indicate the depositional environment of fluvial and coastal plain as well as clastic shoreline with short periodic marine transgression particularly towards the uppermost part (Hardie & Engster, 1971; Fisher 1979; Stewart, 1963; Visher, 1965). The depositional slope of the Khok Kruat formation has been interpreted to be relatively very gentle to flat under the arid to semi-arid paleoclimate. However, the marine transgression occurred only in a very limited span of time and has only limited influence on the sediment end-products.

The sedimentary facies of the evaporite-bearing Maha Saradkam Formation can be categorized into two types : depositional facies and disturbed facies. In the area where salt anticlinal structures have been identified, the lithostratigraphy may be described as "incomplete" or "complete". Detailed analysis of the "complete" lithostratigraphy reveals that the sequences, in almost all parts, represent the depositional sequences with only slightly recognizable post-depositional changes (Krumbein & Sloss, 1963: Reading, 1978) . In contrast, the "incomplete" lithostratigraphy indicated that the sequences have undergone post-depositional changes to a certain degree both in terms of the structural deformation and diagenetic chemical alterations. Therefore, the incomplete lithostratigraphy is further defined with respect to post-depositional changes as the disturbed facies.

Evaporite cycles

The "complete" lithostratigraphy that is further defined in terms of depositional facies, will be utilized in the reconstruction of the original depositional environment using the model concept. From the lithostratigraphy, mineralogical associations, geochemical profiles, as well as textural and structural characteristics of the "complete" lithostratigraphy or the depositional facies of the evaporite-bearing Maha Sarakham Formation, three evaporite cycles have been recognized in terms of evaporitic facies (Briggs, 1958; Scruton, 1953).

The lower evaporite cycle is characterized, from bottom to top, by ferrugenous sandstone, calcareous sandstone, anhydrite zone, halite zone, and potash zone. This sequence is almost exclusively equivent to lower-, middle-, and some parts of higher-orders of theoretical marine evaporite and the upper evaporite cycles are represented by the nation of halite and anhydrite zones. These two cycles can be interpreted as lower- and middle-orders of theoretical evaporite facies. All evaporite cycles are interbedded by fine-grained clastic rocks of reasonable thicknesses.

Depositional model

Due to the fact that the evaporite facies of the three evaporite cycles are essentially the primary precipitates of marine evaporites in almost all parts, the reconstruction of depositional environment and paleosalinity can, therefore, be made on the basis of successions of evaporitic sub-facies present according to "bar-basin" models (Raup, 1980) (Figure 6) . The depositional environment reconstruction model is summarised in Figures 7 & 8 and is elaborated below.

It has been concluded earlier that the depositional basin was a shallow epeiric sea with a gentle sloping depositional surface. During the initial marine transgression the sediment substrate was mainly terrigenous clastics. Then the condition of the depositional environment changed from the open marine to the restricted marine under the influences of threshold depths of the basin floor outside the study area. Subsequently, the concentration of the brine occurred as indicated by the primary lower order of marine evaporitic sub-facies, namely, the ferrugenous clastic sub-facies and the calcareous clastic sub-facies, respectively . The paleosalinity of the brine had then progressively increased into the penesaline condition causing the precipitation of the anhydrite sub-facies. The brine in the depositional basin continued to be further concentrated to the stage where the halite sub-facies was precipitated. Then the brine had progressively increased and eventually reached the potash sub-facies under the supersaline condition which marked the end of the restricted marine environment. There must have been then a marine influx towards the end of the deposition of the potash sub-facies which caused a dilution of the brine back to the saline condition . This is indicated by the presence of the halite sub-facies at the uppermost part of evaporitic sequence of the lower evaporite cycle. Therefore, the marine transgression began towards the end of the deposition of the lower evaporite cycle.

The depositional basin was once again influenced by the influx of fine-grained clastic sediments after the marine transgression. The depositional environment was then believed to be open marine. The depositional environment then changed from the open marine to a restricted marine following the marine regression under the influences of threshold depths of the basin floor outside the study area. The brine in the depositional basin was once again concentrated and reached the saline condition to precipitate the lower halite subfacies of the evaporite facies of the middle evaporite cycle. Then, the progressive saline condition had been interrupted by a short period of marine influx as evidenced from the presence of the thin anhydrite sub-facies on top of the lower halite sub-facies. Later, marine influx and brine concentration mechanism proceeded to precipitate the upper halite sub-facies under the saline condition. Towards the end of the middle evaporite cycle, there was another marine influx which subsequently precipitated the anhydrite sub-facies. This marine transgression marked the end of deposition of the middle evaporitic cycle.

As a consequence of the marine transgression towards the end of the middle evaporite cycle, the depositional basin was open marine with fine-grained clastic sediment deposition.

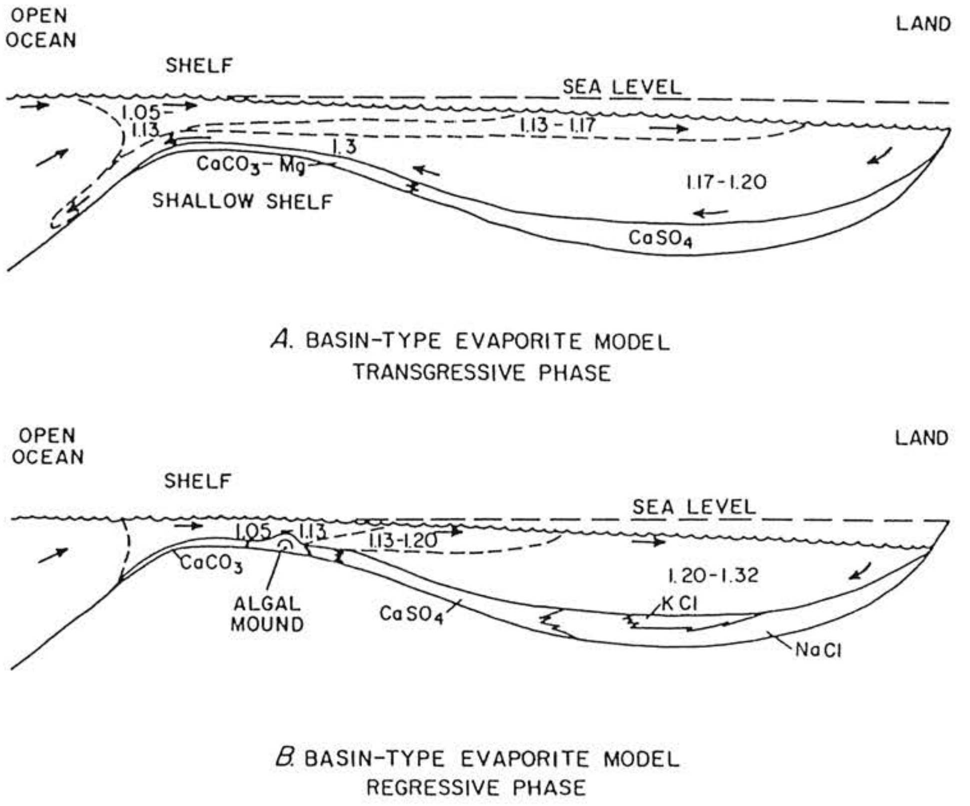

Fig. 6 Models of the barred evaporite basin during
(A) the transgressive phase (high sea level), and
(B) the regressive phase (low sea level). (After Hite, 1961).

Subsequently, the depositional environment changed from the open marine to restricted marine following the marine regression and the development of threshold depths of the basin floor outside the study area. The brine in the depositional basin was concentrated and reached the saline condition to precipitate the lower halite sub-facies of the evaporite facies of the upper evaporite cycle. Then the progressive saline condition was interrupted by the short period of marine influx as evidenced from the presence of the thin anhydrite sub-facies on top of the lower halite sub-facies. Subsequently, marine influx and brine concentration mechanism proceeded once again to precipitate the upper halite sub-facies under the saline condition. Towards the end of the upper evaporitic cycle, there was another marine influx which subsequently precipitated the anhydrite sub-facies. This marine transgression marked the end of deposition of the upper evaporitic cycle. The time frame of this depositional model has been discussed elsewhere (Pisutha-Arnond *et al.*, 1986) . Evaporite sequences for the three evaporite cycles of the study area has been summarized in Figures 7 and 8.

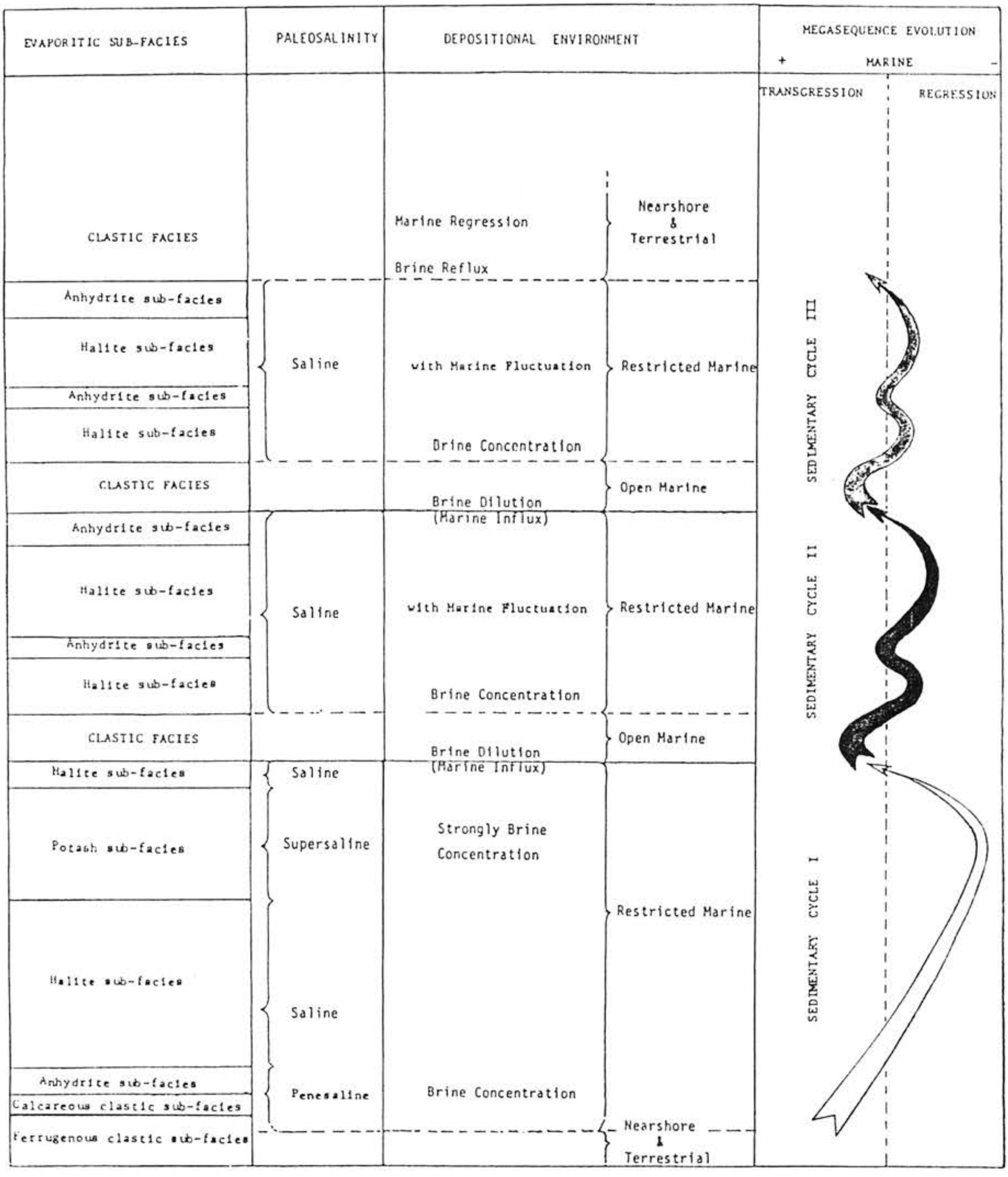

Fig. 7 Proposed depositional environment model and depositional cycle of evaporite-bearing sequences of the Maha Sarakham Formation in the study area.

SEDIMENTARY SEQUENCE I

			THICKNESS (m.)	GENERAL LITHOLOGIES
Alluvium			1.00-20.00	Yel gry to brn uncons cly,sd and some gvl.
Upper Clastics			13.24-316.08	Rd brn & grn gry semi-cons cly to clst/mdst intbd with arg & calc clst/mdst and some sltst/ss.
Upper Salt	Upper Cap Anhydrite	(uc)	0-7.01	Lt gry anhy.
	Upper Upper Halite		0-30.16	Clear,milky wh m gr halite and smoky dk halite bands with anhy layers.
	Upper Anhydrite	(u)	0-1.05	Dk to lt gry anhy.
	Lower Upper Halite		0-13.08	Clear m gr halite & smoky dk halite bands,pale honey to orng halite associated.
Middle Clastics	Middle Mudstone/Claystone		8.94-53.00	Rd brn & grn gry to dk gry semi-cons cly to clst/mdst.
Middle Salt	Middle Cap Anhydrite	(mc)	0-6.15	Lt gry anhy.
	Upper Middle Halite		1.46-95.33	Clear&milky wh f to m gr halite and smoky dk halite bands with anhy layers,some gry&pale orng halite associated in the upper part
	Middle Anhydrite	(m)	0.11-2.04	Dk gry to lt gry anhy.
	Lower Middle Halite		10.94-22.17	Pale yel brn to orng&dk honey f gr halite with smoky dk halite bands.
Lower Clastics	Lower Mudstone/Claystone		1.68-25.76	Rd brn & grn gry to dk gry semi-cons cly to clst/mdst.
Basal Salt	Coloured Halite		0.28-15.90	Several col bands of halite.
	Potash — Sylvinite		0-5.11	Cloudy wh,orng rd sylvite
	Potash — Carnallite,Halite&Tachyhydrite		1.25-65.87	Pale pk,pk clear to orng rd carnallite & clear and smoky dk halite & orng to honey ye tachyhydrite intbd and mixed
	Potash — Sylvinite		0-0.22	Cloudy wh,orng rd sylvite.
	Basal Halite		21.66-191.44	Clear f gr halite. Clear f to m gr halite with anhy layers. Clear & milky wh m to c gr halite and smoky dk halite bands with anhy layers. Clear f to m gr halite & smoky dk halite bands,wh dul f to m gr anhy associated.
	Basal Anhydrite	(b)	0.77-1.86	Dk gry to lt gry anhydrite
	Calc Sandstone		0.07-1.10	Grn gry calc ss.
?	Ferrugenous Sandstone		> 5.18	Dk rd brn Fe ss.

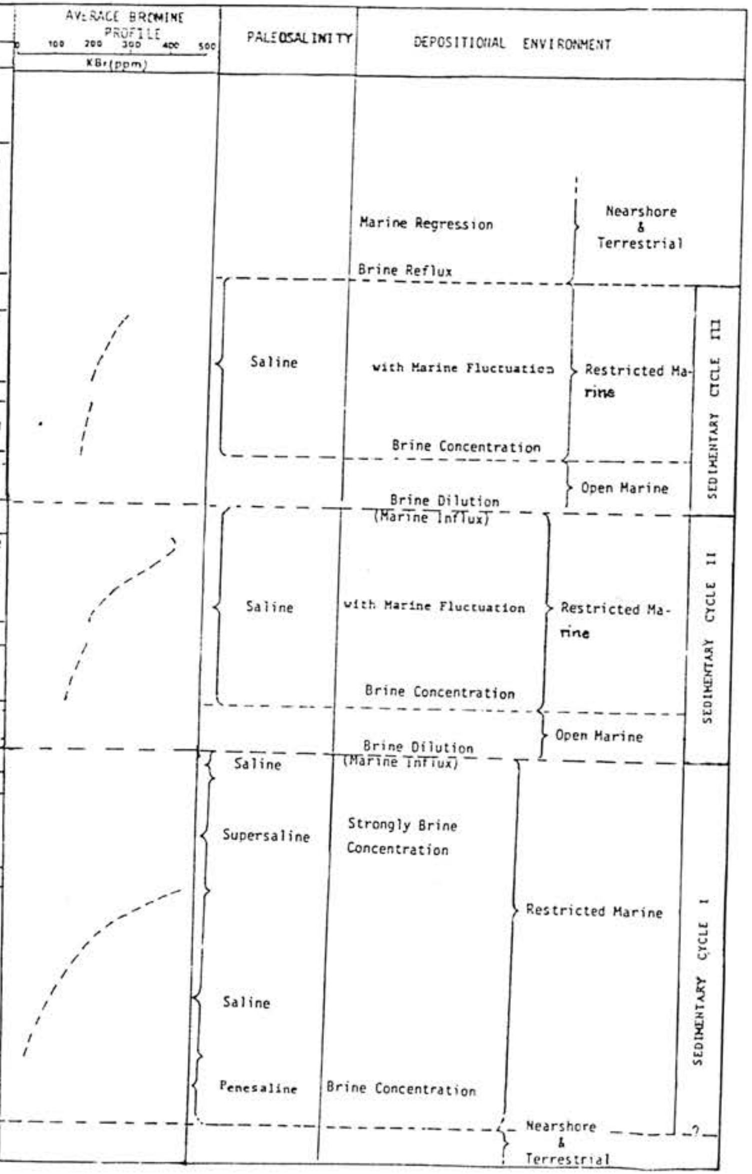

Fig. 8 The lithostratigraphy and environmental reconstruction of the evaporite-bearing Maha Sarakham Formation.

POST-DEPOSITIONAL CHANGES

Almost all of ancient evaporite deposits exhibit some characteristics of post-depositional changes (Borchert & Muir, 1964; Braitsch, 1971; Wells, 1980). This is due to the high reactivity of the water-soluble evaporite minerals and the high plasticity of the evaporite sequences. Hence, in order to reconstruct the depositional environment of evaporite deposits properly, the problems of post-depositional changes must be fully solved and the processes concerned must be well understood.

In this study the "incomplete" lithostratigraphy in the salt anticlinal areas has been redefined as a disturbed facies and used in the reconstruction of post-depositional changes. Futhermore, the regional as well as local geological structures have to be taken into consideration. The post-depositional changes are considered under two headings, namely, structural deformation and chemical alterations.

Structural deformation

Within the study area, the sedimentary sequences of the Maha Sarakham Formation exhibit the monoclinal structure with the beds gently dipping less than 15 degrees to the southeast direction. Sub-surface data, detailed structures of core-slabs as well as the geo-chemical bromine profiles strongly indicates that the evaporite facies in the Formation have been subjected to structural deformation. The mechanisms which caused the deformation of the salts could be either the differential loading of the overlying sediments and the high plasticity of the evaporitic sequences or regional tectonic disturbances or a combination of both. A simplified structural deformation model of the three evaporite cycles in the Maha Sarakham Formation is presented in Figure 9.

Chemical alterations

Numerous evidences indicate chemical alteration in the Formation. First, the present-day characteristics of evaporitic mineral assemblages or zonations are different from the primary depositional mineral associations (Figure 10). Secondly, the textural characteristics of the evaporite facies, especially in the salt anticlinal areas and the anticlinal flanks are effected by the chemical alterations. Finally, additional evidences of the bromine contents in the minerals and zonations of the evaporite facies are also useful indicators of chemical alterations (Raup, 1980).

From these evidences of post-depositional chemical alterations in the evaporitic facies of the Maha Sarakham Formation, it is believed that, firstly, that the groundwater percolating from the cap of the anticlinal salt structures down the flanks, is mainly responsible for transforming carnallite to sylvite through the process of incongruent alteration (Figure 11) (Wardlaw, 1968). The problem of the $MgCl_2$ solution left from this incongruent alteration reaction has not yet been solved. Secondly, the formation of anhydrite caps at the crests of anticlines was the result of a residual accumulation after the leaching of the halite/anhydrite layers by the groundwater.

The overall model of post-depositional chemical alterations and the structural deformation has been synthesized and presented in Figure 12. Special reference, however, is made to the origin of secondary sylvite which is the most economical potash mineral.

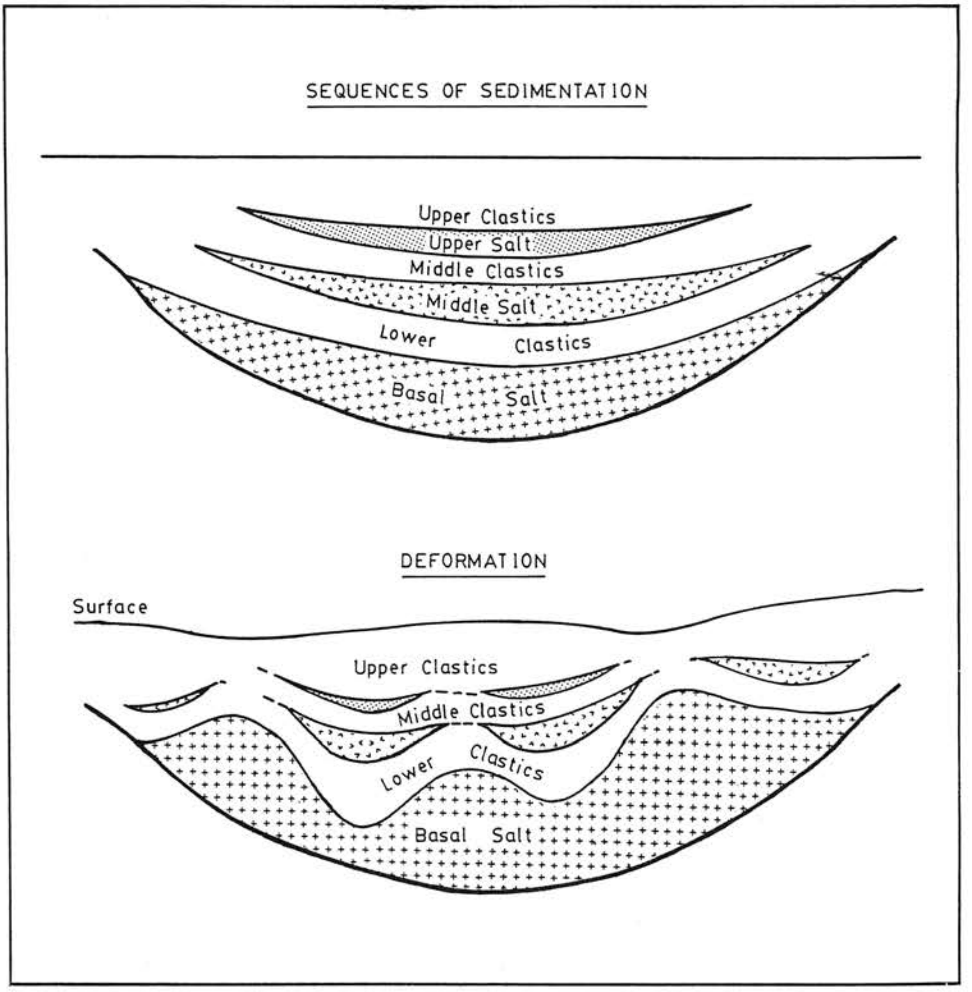

Fig. 9 Sequences of sedimentation and their post-depositional structural deformation (Modified after Hite, 1982).

CONCLUSION

The subsurface lithostratigraphy of the evaporite-bearing Maha Sarakham Formation of the Khorat Group in Bamnet Narong Area, northeastern Thailand can be categorized into two types, namely, the "complete" lithostratigraphic sequences, and the "incomplete" lithostratigrphic sequences. The so-called "complete" lithostratigraphic sequences are generally present at localities where the Formation is thin and lies at a relatively greater depth. On the other hand, the so-called "incomplete" lithostratigraphic sequences are always present at localities where the Formation is thick and lies at a relatively shallower depth. These are mainly controlled by the gentle salt anticlinal structures. The "complete" lithostratigraphic sequences of the Maha Sarakham Formation can be further subdivided into five members,

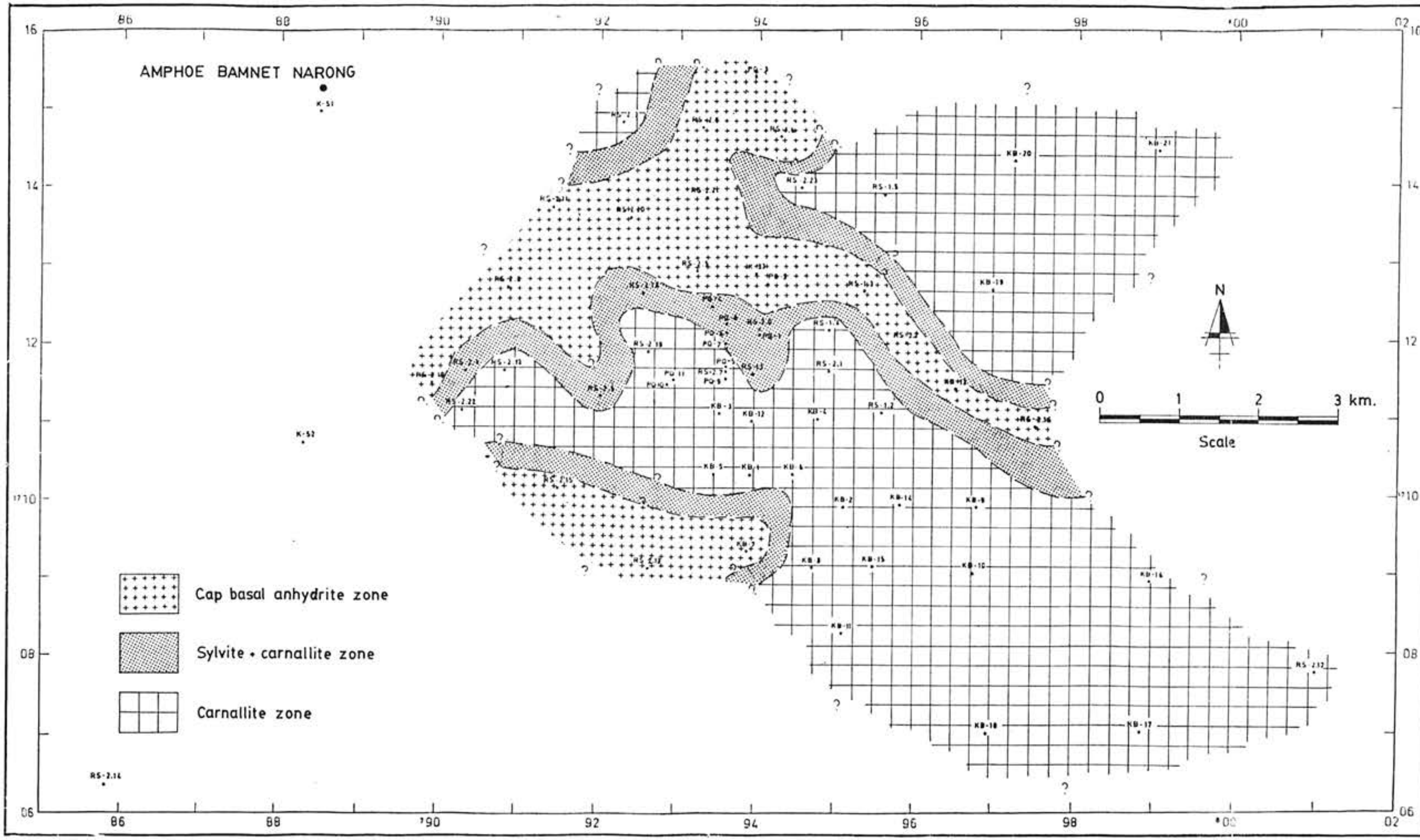

Fig. 10 Distribution of different evaporite zones of Basal Salt Member after secondary changes.

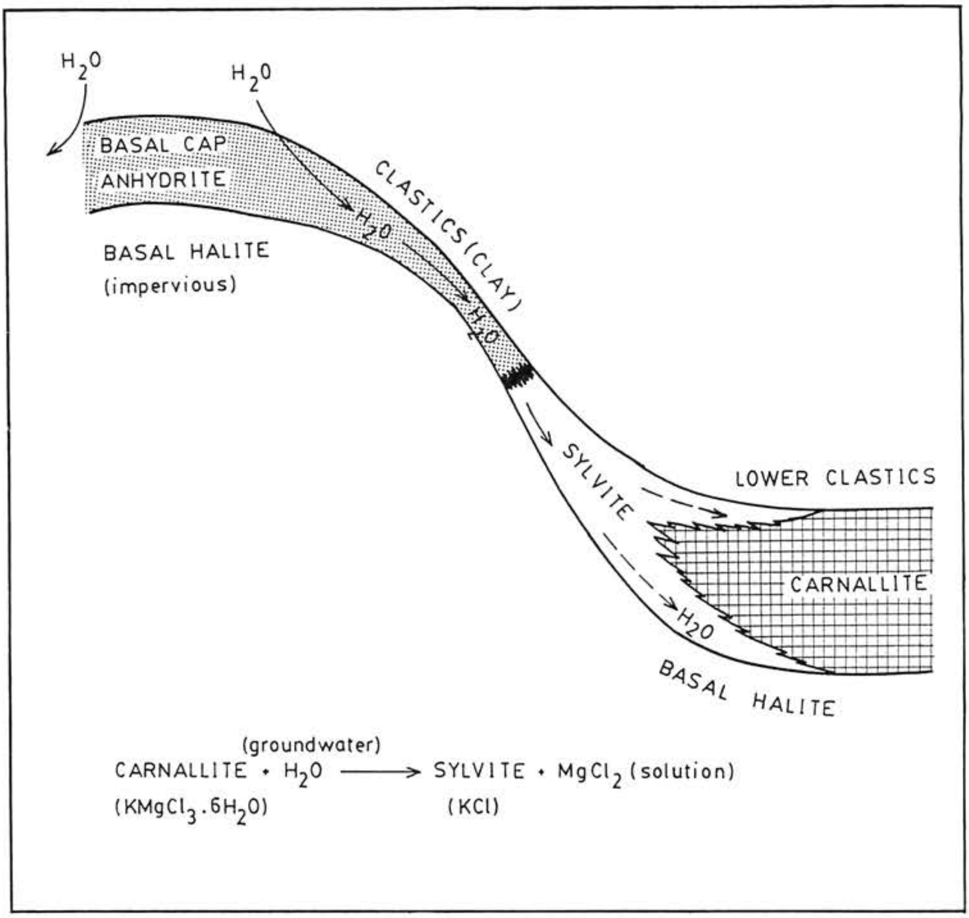

Fig. 11 Secondary sylvite from incongruent alteration of carnallite (Modified after Hite, 1982).

namely, Basal salt, Lower Clastics, Middle Salt, Middle Clastics, and Upper Salt. In contrast, the "incomplete" lithostratigraphic sequences consist mainly of the Basal Salt Member.

Detailed analysis of the "complete" lithostratigraphy of this Formation indicates that it represents the original depositional sequences with only faintly recognizable post-depositional changes. The "incomplete" lithostratigraphy however, represents the post-depositional changes both in terms of structural deformation and diagenetic chemical alterations.

The "complete" lithostratigraphy or the depositional facies of the evaporite-bearing Maha Sarakham Formation represents three sedimentary cycles. The first cycle is almost exclusively composed of lower, middle, and some parts of higher orders of theoretical evaporite facies. The second and third sedimentary cycles are generally composed of clastic facies, which some parts of the lower represent lower as well as the middle orders of theoretical

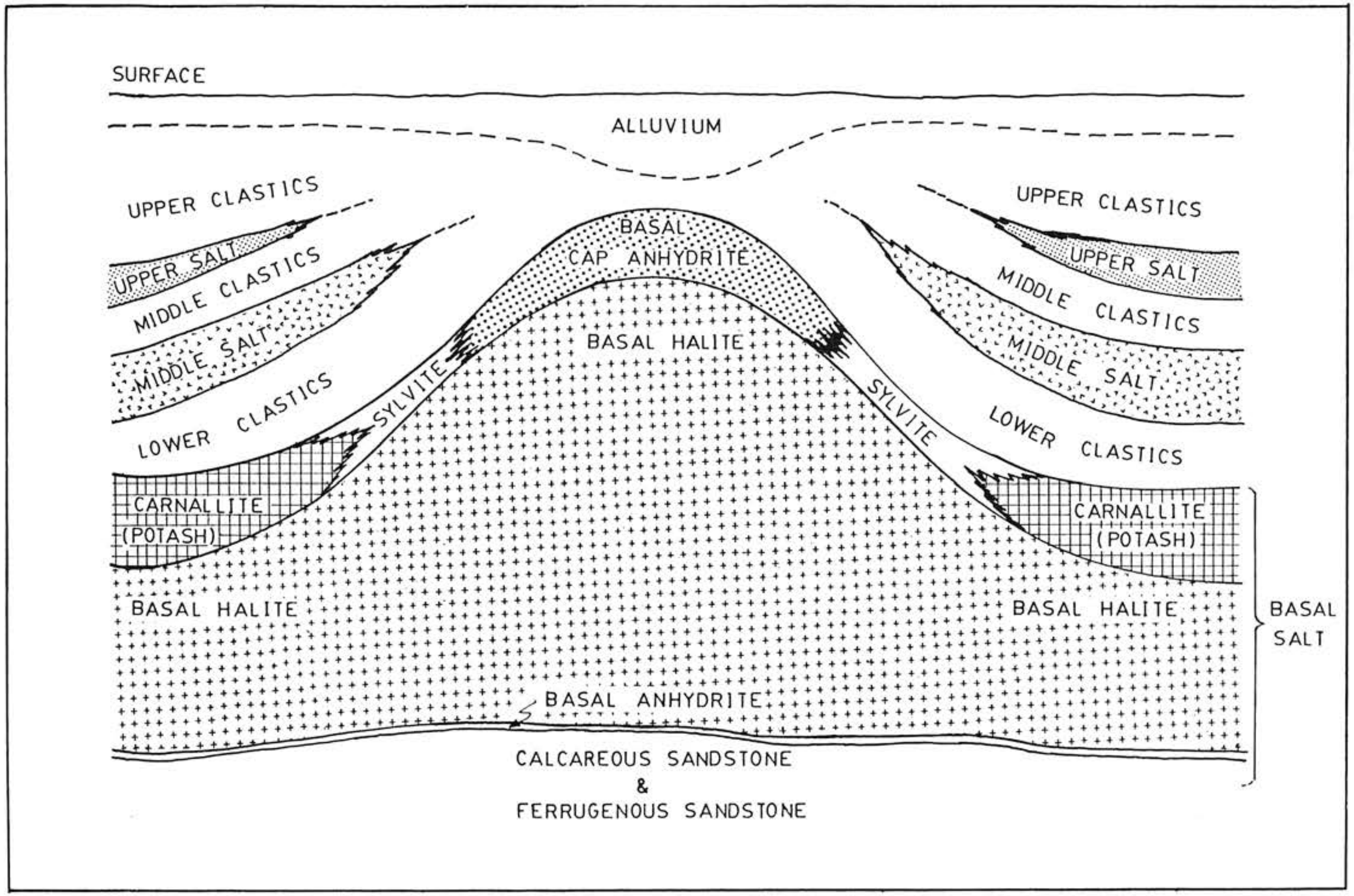

Fig. 12 Proposed model of secondary changes of evaporitic facies (Modified after Hite, 1982)

evaporite facies. These evaporite facies are essentially the primary precipitates of marine evaporites in almost all parts.

The nature and characteristics of the depositional basin is reconstructed to be a shallow epeiric sea with a gentle sloping depositional surface. The original sediment substrate prior to the marine transgression period was mainly a medium-grained clastic type of nearshore and/or of terrestrial origin. At least three phases of marine transgression and regression over the depositional basin were believed to be responsible for the evaporite formation according to be "bar-basin" theory. Periodic influx of detrital clastic sediment of finer grain size marked the end of each marine transgression. Different paleosalinity condition of the depositional basin ranging from penesaline to supersaline as represented by evaporitic mineral associations were also reconstructed.

For post-depositional changes, the "incomplete" lithostratigraphy indicates that structural deformation of the sequences is apparent. A possible mechanism which caused the anticlinal deformation might be the differential loading of the overlying sediments and the high plasticity of evaporitic sequences or regional tectonic disturbances or a combination of both. Besides, diagenetic chemical alterations as evidenced from the unusual evaporitic mineral associations, textural characteristics, and geochemical bromine profiles are also superimposed on the structurally deformed sequences. The presence of sylvite on the flanks of anticlinal structures is believed to be the result of chemical transformation of carnallite to sylvite through the process of incongruent alteration under the influence of groundwater.

In addition, the formation of anhydrite caps at the crests of anticlinal structures can be explained as a residual accumulation after leaching of the original halite/anhydrite layers by groundwater.

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