

CHAPTER IV

DEPOSITIONAL MODELS AND POST-DEPOSITIONAL CHANGES

The origin of evaporites has been the subject of much controversy. This is probably arisen from the relative scarcity of present-day environments of evaporitic series deposits. The analysis of some present-day evaporite deposits elsewhere and that of the past in this study permits the many convergences in facies to be re-united and accords some evaporites, at least in the most favourable cases, to the shallow coastal origin.

Detailed knowledge of the lithostratigraphy of the Maha Sarakham Formation, which is the evaporite-bearing deposits, is most essential and has been an invaluable aid in relating to the origin of salt deposition. Furthermore, detailed studies on petrographic and some geochemical aspects of evaporitic sequences have been extremely useful in defining various sedimentary facies concerned.

4.1 Depositional Basin

In this study, evaporites can be classified on the basis of their environmental relationships, particularly with respect to the under-and over-lying sedimentary sequences as shallow epeiric sea. The sequences are dominated by marine input, with transgressive and regressive cycles across a stable interior platform. Sedimentary sequences may be either : red beds/evaporites/normal marine or normal marine/evaporites/red beds. The red beds/evaporites/normal marine association is the sequence expected if a normal marine basin becomes restricted but the marine connection remained throughout evaporite

deposition. Finally, the basin filling results in succession of red beds. However, for the normal marine/evaporites/red beds association indicates the marine transgression over an arid area with initial basin restriction.

The underlying sequences of the Maha Sarakham evaporites are the sediments of Khok Kruat Formation. This formation is characterized by the associations of sandstone, siltstone, shale, and some intraclastic limestone as well as diamictites with cross-stratification and ripple-mark. The percentage of sandstone in the succession decreases from about 60 near the base to about 20 near the top. Towards the uppermost part of the formation, beds of limestone with red coloration as well as thin beds of gypsum/anhydrite are observed. These sequences indicate the depositional environment of fluvial and coastal plain as well as clastic shoreline with short periodic marine transgression particularly towards the uppermost part. It can be further interpreted that the depositional slope of the Khok Kruat Formation is relatively very gentle to flat under the arid to semi-arid climate. This is concluded on the basis of the extensive distribution of the Formation with a rather uniform lithological association including the presence of the early stage of theoretical evaporitic sequences, namely, red coloration zone of Fe_2O_3 in the clastic sediments, carbonate sediments, and thin layers of gypsum/anhydrite. It is, however, noted that the marine transgression occurred only in a vary limited span of time and caused only restricted influence on the sediment end-products.

4.2 Lithostratigraphy and sedimentary facies

It is against the detailed lithostratigraphic background of the study area previously described in Chapter II including the

petrographic and mineralogical characteristics discussed in Chapter III, an attempt has been made in this chapter to define the sedimentary sequences concerned in terms of sedimentary facies. Generally, the sedimentary facies of the evaporite-bearing Maha Sarakham Formation can be categorized into two types : depositional faices and disturbed facies.

On the basis of the lithological, mineralogical, textural, as well as geochemical characteristics of numerous bore-hole data, the detailed lithostratigraphy of the study area has been established (Figures 2.2.1 and 2.2.2). In the area where salt anticlinal structures have been identified, the nature and characteristics of the lithostratigraphy are summarized and concluded using the term "incomplete lithostratigraphy" (Figure 2.2.2). However, in the outer zones of salt anticlinal structures within the study area, the lithostratigraphy is defined and established using the term "complete lithostratigraphy" (Figure 2.2.1).

Detailed analysis of the "complete lithostratigraphy" reveals that the sequences, in almost all parts, representing the depositional sequences with only slightly recognizable post-depositional changes. This is justified on various bases, notably, depositional sequences of evaporitic minerals, geochemical profiles, textures and structures in comparison with the depositional theoretical sequences of evaporite formation previously reviewed in Chapter I. In contrast, detailed examination of the "incomplete lithostratigraphy" indicates that the sequences have undergone post-depositional changes up to a certain degree both in terms of the structural deformation and the diagenetic chemical alterations. Therefore, the "incomplete lithostratigraphy" is further defined with respect to post-depositional changes as disturbed facies.

In this chapter, the information on "complete lithostratigraphy" is further defined in term of depositional facies will be utilized in the reconstruction of original depositional environment using the model concept. It is, however, important to take into account models of modern depositional settings when developing environmental reconstructions from geological data (Figure 4.2).

4.3 Evaporitic facies

Considering from the lithostratigraphy, mineralogical associations, geochemical profiles, as well as textural and structural characteristics of the "complete lithostratigraphy" of the evaporite-bearing Maha Sarakham Formation, three sedimentary cycles have been recognized and defined in terms of evaporitic facies. Detailed informations regarding these three cycles will be discussed in the foregoing parts.

4.3.1 The first sedimentary cycle

The first sedimentary cycle is almost exclusively composed of lower, middle, and some parts of higher orders of theoretical evaporitic facies. The cycle lies within the depth range of 74-419 meters with the total thickness of approximately 23-287 meters. The base of the evaporitic facies, ferruginous clastic sub-facies, is characterized by the precipitation of iron oxide in the medium-grained clastic rocks and consequently caused the distinctive red coloration of this zone. The main evaporitic mineral of this sub-facies is hematite with minor amount of calcite. Above the ferruginous clastic sub-facies is the calcareous clastic sub-facies. The sub-facies is characterized by the presence of calcite with small amount of anhydrite with floated detrital grains of quartz, chert and feldspar. The thickness of this sub-facies

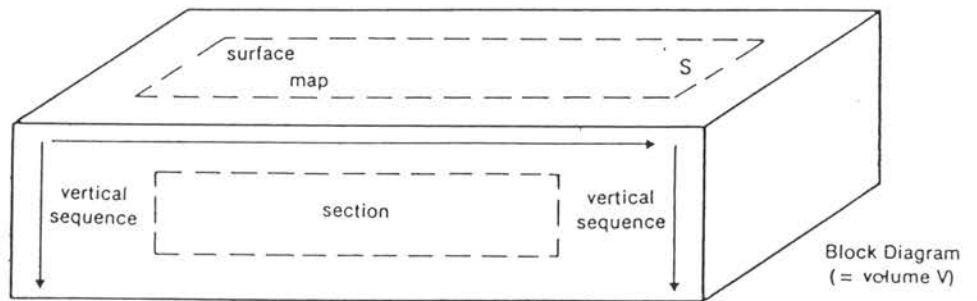
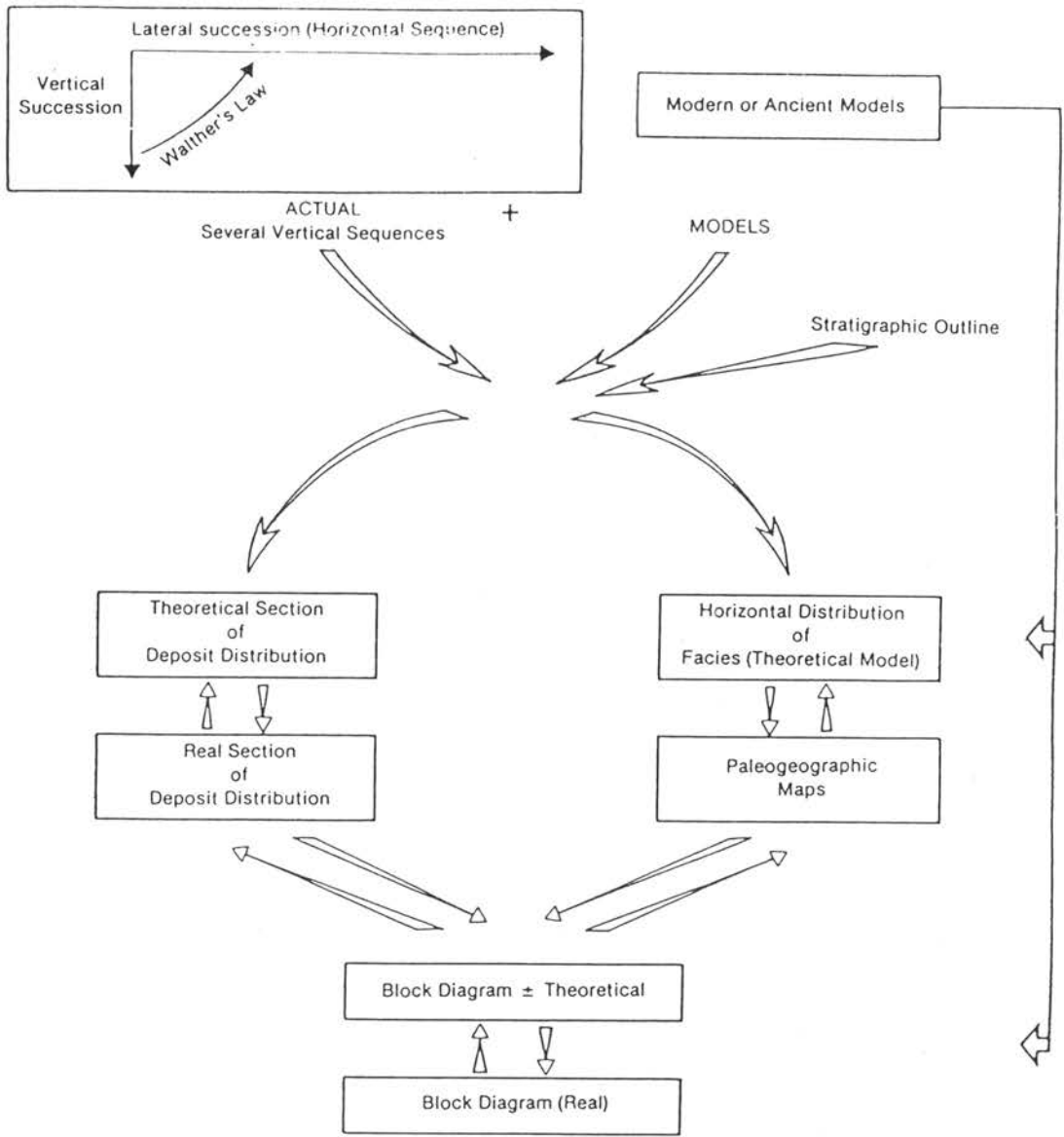


Figure 4.2 Stages in the three-dimensional reconstruction of basinal deposits. (After Reeckmann and Friedman, 1982)

varies within the range of 0.07-1.10 meters. Overlying the calcareous clastic sub-facies is the anhydrite sub-facies of 0.77-1.86 meters thick. The mineralogical characteristics of this sub-facies is mainly anhydrite with some calcite, small amount of dolomite and gypsum. Above the anhydrite sub-facies is the exceptional thick (21.66-191.44 meters) halite sub-facies. The sub-facies is almost exclusively composed of halite with some thin layers of anhydrite. Overlying the halite sub-facies is the potash sub-facies of 1.25-71.20 meters thick. The evaporitic minerals of this sub-facies are carnallite, halite, tachyhydrite, sylvite. It is noted that some of these evaporitic minerals are of diagenetic origin, such as, sylvite, etc. Towards the top part of the evaporitic facies of the first sedimentary cycle is marked by the presence of halite sub-facies of 0.28-15.90 meters thick.

Detailed characteristics of the evaporitic facies of the first sedimentary cycle in terms of the lithostratigraphy, evaporitic mineral suites, and the geochemical facies profiles of some water-soluble fractions (Na_2O , K_2O , CaO , and MgO) as well as the average bromine profile are summarized and presented in Figure 4.3.1.

Due to the fact that the evaporitic facies of the first sedimentary cycle is 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 sub-facies present. The proposed depositional environment in terms of the controlling mechanisms of the marine processes as well as the subsequent salinity characteristics in the evaporite depositional basin are summarized and presented in Figure 4.3.1.

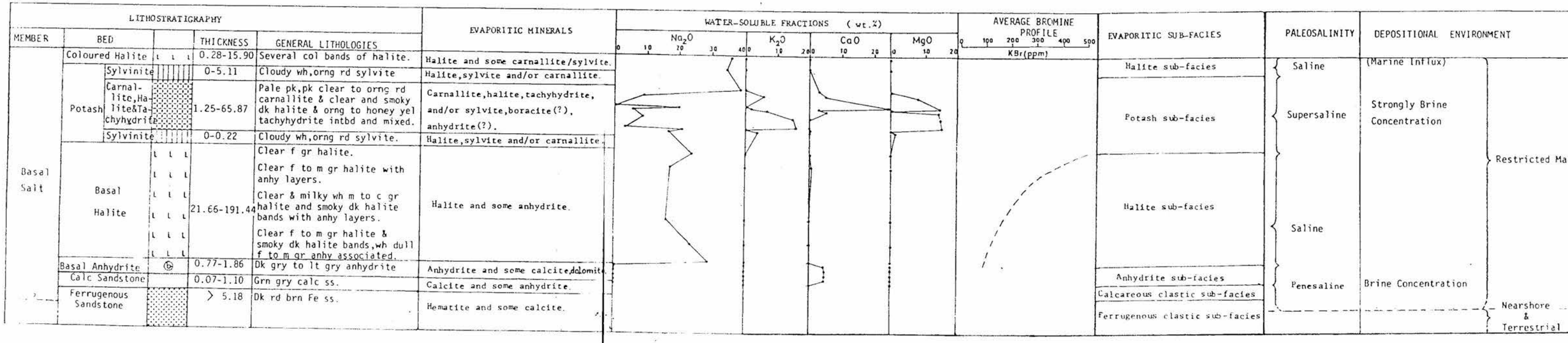
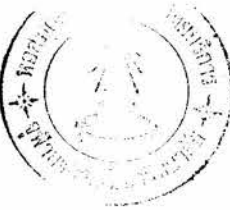


Figure 4.3.1 Evaporitic facies of the first sedimentary cycle.

4.3.2 The second sedimentary cycle

The second sedimentary cycle is generally composed of the clastics facies, and some parts of the lower as well as the middle orders of theoretical evaporitic facies. The cycle lies within the depth range of 51.00-355.02 meters with the total thickness of approximately 12.51-151.45 meters. The base of the cycle is marked by the presence of the clastic facies of 1.68-25.76 meters thick. This facies is characterized by semi-consolidated clay to claystone/mudstone with some scattering evaporitic minerals, such as, halite, anhydrite, carnallite, etc. Above the clastics facies is the evaporitic facies of the second sedimentary cycle. The base of the evaporitic facies, halite sub-facies of 10.94-22.17 meters thick, is characterized mainly by halite with traces of anhydrite, carnallite/sylvite. Overlying the halite sub-facies is the anhydrite sub-facies of 0.11-2.04 meters thick. The mineralogical characteristics of this sub-facies is mainly anhydrite with some halite. Above the anhydrite sub-facies is the thick (1.46-95.33 meters) halite sub-facies. The sub-facies is almost exclusively composed of halite with some thin layers of anhydrite. Towards the top part of the evaporitic facies of the second sedimentary cycle is marked by the presence of anhydrite sub-facies of 0-6.15 meters thick.

Detailed characteristics of the evaporitic facies of the second sedimentary cycle in terms of the lithostratigraphy, evaporitic mineral suites, and the geochemical facies profiles of some water-soluble fractions (Na_2O , K_2O , CaO , and MgO) as well as the average bromine profile are summarized and presented in Figure 4.3.2.

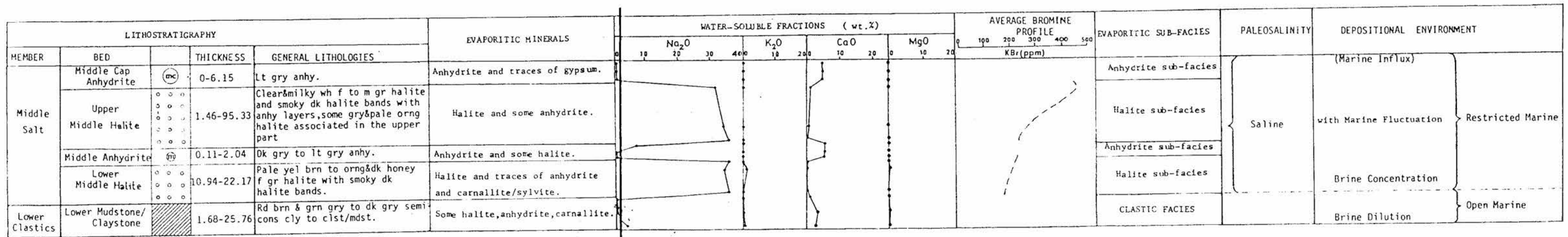


Figure 4.3.2 Evaporitic facies of the second sedimentary cycle.

Due to the fact that the evaporitic facies of the second sedimentary cycle is essentially the primary precipitates of lower and middle orders of marine evaporites in almost all parts, the reconstruction of depositional environment and paleosalinity can, therefore, be made on the basis of successions of sub-facies present. The proposed depositional environment in terms of the controlling mechanisms of the marine processes as well as the subsequent salinity characteristics in the evaporite depositional basin are summarized and presented in Figure 4.3.2.

4.3.3 The third sedimentary cycle

Generally, the third sedimentary cycle is similar to the second sedimentary cycle. This cycle consists of the clastic facies, and some parts of the lower as well as the middle orders of theoretical evaporitic facies. The cycle lies within the depth range of 68.86-320.65 meters with the total thickness of approximately 8.94-104.30 meters. The base of the cycle is marked by the presence of the clastic facies of 8.94-53.00 meters thick. This facies is characterized by semi-consolidated clay to claystone/mudstone with some scattering evaporitic minerals, such as halite, anhydrite, etc. Above the clastic facies is the evaporitic facies of the third sedimentary cycle. The base of the evaporitic facies, halite sub-facies of 0-13.08 meters thick, is characterized mainly by halite and traces of anhydrite. Overlying the halite sub-facies is the anhydrite sub-facies of 0-1.05 meters thick. The mineralogical characteristics of this sub-facies is mainly anhydrite with some halite. Above the anhydrite sub-facies is the thick (0-30.16 meters) halite sub-facies. The sub-facies is almost exclusively composed of halite with some thin layers of anhydrite. Towards the top part of the evaporitic facies of the third sedimentary

cycle is marked by the presence of anhydrite sub-facies of 0-7.01 meters thick.

Detailed characteristics of the evaporitic facies of the third sedimentary cycle in terms of lithostratigraphy, evaporitic mineral suites, and the geochemical facies profiles of some water-soluble fractions (Na_2O , K_2O , CaO , and MgO) as well as the average bromine profile are summarized and presented in Figure 4.3.3.

Due to the fact that the evaporitic facies of the third sedimentary cycle is essentially the primary precipitates of the lower and middle marine evaporites in almost all parts, the reconstruction of depositional environment and paleosalinity can, therefore, be made on the basis of successions of sub-facies present. The proposed depositional environment in terms of the controlling mechanisms of the marine processes as well as the subsequent salinity characteristics in the evaporite depositional basin are summarized and presented in Figure 4.3.3.

4.4 Depositional models

The analyses and evaluation of bore-hole data within the study area enable to establish the sub-surface geology in terms of the detailed lithostratigraphy as well as the sedimentary facies for further interpretation. Conceptually, ancient sedimentary sequences of succession of lithologies indicate changes in the conditions within the depositional environments. However, the environmental changes that lead to a vertical succession of facies and the time interval involved in these changes are quite variable.

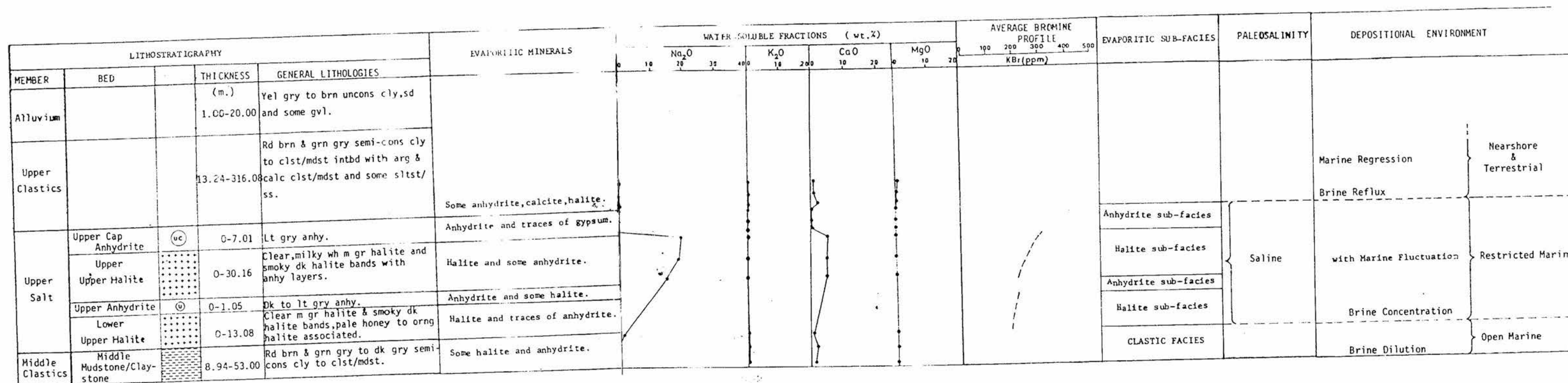


Figure 4.3.3 Evaporitic facies of the third sedimentary cycle.

It is concluded earlier that the nature and characteristics of the depositional basin is a shallow epeiric sea with gentle sloping depositional surface. Following the "bar-basin model" of Ochsenius (1877), the physical and dynamic barrier to oceanic circulation is essential to control the salinity of the brine in the evaporite basin. Hite (1970) has pointed out the cause of changes in depositional environment due to rising sea level that the resultant transgression with link to freshening and expansion of normal marine condition. Rising sea level may terminate evaporite deposition in the basin, but anaerobic hypersaline conditions are displaced onto the basin shelves and margins during this transgressive period. Circulation in marine evaporite basins includes some return flow or reflux. Reflux is controlled by change in sea level, evaporation rates, and size of accessways. In addition, the salinity changes in the evaporite basin are controlled by the runoff, differential rates of evaporation, restriction of circulation barrier, and variations in sea level.

In determining the depositional environments of evaporite deposits, the primary evaporitic minerals are the best record of salinity indicators which are also in return the best record of sea level changes. Attention has, therefore, been given in this study to the primary precipitates of various evaporitic sub-facies. However, it is realized that there are numerous limiting factors, notably, limited areal extent of the study area, limited sub-surface data and materials, and poorly defined regional geological setting and detailed stratigraphy which make the complete interpretation of the whole evaporite basin incomplete. Nevertheless, an attempt has been made to make maximum utilization of the existing data and

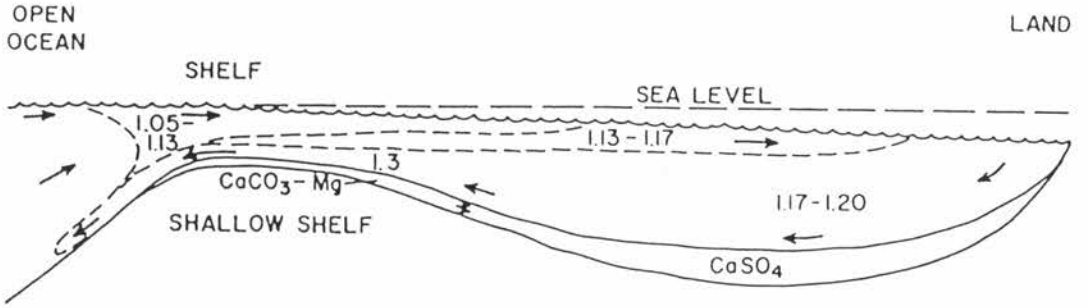
information in partial interpretation of this gigantic evaporite basin of the Khorat Plateau.

Originally, the sediment substrate of the shallow epeiric sea during the initial marine transgression period was mainly medium-grained clastic type of nearshore and/or terrestrial origin. Then the condition of the depositional environment had changed from the open marine to the restricted marine under the influence of threshold depths of the basin elsewhere outside the study area that was great enough to permit a two-way flow inward. Subsequently, the brine concentration occurred indicating by the presence of primary lower order of marine evaporitic sub-facies, namely, ferruginous clastic sub-facies and calcareous clastic sub-facies, respectively. The paleosalinity was concluded to be of initial penesaline type. Then, the paleosalinity of the brine had progressively increased and caused the precipitation of anhydrite sub-facies which marked the **transition** between penesaline and saline conditions. The presence of calcareous algal bands in this sub-facies represented a low rate of marine reflux and a favorable time for algal carbonate development. The brine in the depositional basin continued to be further concentrated to the stage of saline where the halite sub-facies was precipitated. Evidence from the geochemical bromine profiles of the halite sub-facies strongly support the continuous process of brine concentration. This is indicated by the progressive increasing upward of KBr content in the halite zone. The deposition of evaporitic minerals had eventually reached the potash sub-facies under the supersaline condition which probably marked the end of the restricted marine environment.

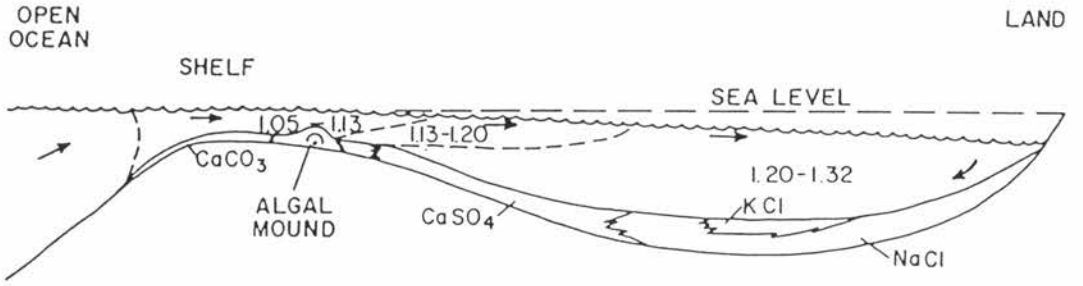
There must be a marine influx towards the end of the deposition of potash sub-facies which subsequently caused the brine dilution back to saline condition. This is indicated by the presence of the halite sub-facies at the uppermost part of evaporitic sequence of the first sedimentary cycle. Therefore, the marine transgression began towards the end of the deposition of the first sedimentary cycle.

The depositional basin had been once again influenced by the influx of detrital clastic sediments of finer grain size, mud and clay, after the marine transgression. Therefore, the depositional environment was determined as the open marine.

Afterwards, the depositional environment had changed from the open marine to restricted marine followed the marine regression and the development of threshold depths of the basin elsewhere outside the study area that was great enough to permit a two-way flow inward. The brine in the depositional basin had been concentrated and reached the saline condition to precipitate the lower halite sub-facies of the evaporitic facies of the second sedimentary cycle. Prior to the deposition of halite, there was a small amount of anhydrite precipitated indicating the initial brine concentration process. The absence of lower orders of theoretical evaporitic sequences, notably, ferruginous and calcareous sub-facies might be due to two factors. First, the concentration of the brine after the marine influx was in the suitable order to precipitate anhydrite onwards, second, the two sub-facies might be earlier precipitated in the seaward zone outside the study area following the salt load mechanics during transgressive and regressive phases of the "bar-basin model" (Figure 4.4.1).



A. BASIN-TYPE EVAPORITE MODEL
TRANSGRESSIVE PHASE



B. BASIN-TYPE EVAPORITE MODEL
REGRESSIVE PHASE

Figure 4.4.1 Models of a barred evaporite basin during (A) the transgressive phase (high sea level) and (B) the regressive phase (low sea level). (After Hite, 1970)

The deposition of the lower halite sub-facies in the second sedimentary cycle under the progressive saline condition had been interrupted by the marine influx as evidenced from the presence of thin anhydrite sub-facies on top of the lower halite sub-facies.

This marine influx was considered to be rather limited in scale and time interval on the basis of the thickness of anhydrite sub-facies. Afterwards, marine reflux and brine mechanism proceeded to precipitate the upper halite sub-facies under the saline condition.

Evidence from the geochemical bromine profiles of the lower and upper halite sub-facies of the second sedimentary cycle indicated the semi-continuous process of brine concentration, except the relatively short period of interruption of marine influx. Towards the end of the second sedimentary cycle, there was another marine influx which subsequently precipitated the anhydrite sub-facies. The depositional environment as well as the paleosalinity including the evaporitic products were similar to those of the aforementioned anhydrite sub-facies. This marine transgression marked the end of deposition of the second sedimentary cycle.

As a consequence of the marine transgression towards the end of the second sedimentary cycle, the depositional basin was the open marine shallow epeiric sea with clastic sediment deposition. The nature and characteristics of this clastic facies are mainly detrital mud and clay deposited in the sub-wave base zone.

Afterwards, the depositional environment had changed from the open marine to restricted marine followed the marine regression and the development of threshold depths of the basin elsewhere outside the study area that was great enough to permit a two-way flow inward.

The brine in the depositional basin had been concentrated and reached the saline condition to precipitate the lower halite sub-facies of the evaporitic facies of the third sedimentary cycle. Prior to the deposition of halite, there was a small amount of anhydrite precipitated indicating the initial brine concentration process. The absence of the lower orders of theoretical evaporitic sequences, notably, ferruginous and calcareous sub-facies might be due to the two factors which are similar to those of the evaporitic facies of the second sedimentary cycle.

The deposition of the lower halite sub-facies in the third sedimentary cycle under the progressive saline condition had been interrupted by the marine influx as evidenced from the presence of thin anhydrite sub-facies on top of the lower halite sub-facies. This marine influx was considered to be rather limited in scale and time interval on the basis of the thickness of anhydrite sub-facies. Afterwards, marine reflux and brine mechanism proceeded to precipitate the upper halite sub-facies under the saline condition. Evidence from the geochemical bromine profiles of the lower and upper halite sub-facies of the third sedimentary cycle indicated the semi-continuous process of brine concentration, except the relatively short period of interruption of marine influx. Towards the end of the third sedimentary cycle, there was another marine influx which subsequently precipitated the anhydrite sub-facies. The depositional environment as well as the paleosalinity including the evaporitic products were similar to those of the aforementioned anhydrite sub-facies. This marine transgression marked the end of deposition of the third sedimentary cycle.

The clastic facies overlying the third sedimentary cycle of the Maha Sarakham Formation were believed to be deposited under the nearshore and subsequent terrestrial environments, respectively after the transgression towards the end of the third sedimentary cycle followed by the marine regression. Only traces of evaporitic minerals are found associated with this clastic facies.

The simplified depositional model of the evaporitic sequences in three sedimentary cycles of the study area has been proposed and summarized in Figures 4.4.2 and 4.4.3. The time frame of this depositional model has not been discussed because of the unavailability of the chronostratigraphic controls and dating evidence. It is significant to note that full appreciation of the evaporite formation under the "bar-basin model" in terms of both lateral and vertical facies changes in different geographic position of the basin (Figure 4.4.1). Therefore, the geometry of the primary sedimentary facies must be related to the theoretical depositional model. Besides, the dynamic condition of the depositional basin particularly regarding the marine transgression and regression must be properly intergrated into the depositional model.

4.5 Post-depositional changes

Almost all of the ancient evaporite deposits exhibit some characteristics of post-depositional changes. This is basically due to the high reactivity of water-soluble evaporitic minerals and high plasticity of the evaporitic sequences. Therefore, 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.

EVAPORITIC SUB-FACIES	PALEOSALINITY	DEPOSITIONAL ENVIRONMENT	MEGASEQUENCE EVOLUTION		
			TRANSGRESSION	REGRESSION	
CLASTIC FACIES		Marine Regression Brine Reflux			
Anhydrite sub-facies	Saline	with Marine Fluctuation			Restricted Marine
Halite sub-facies					
Anhydrite sub-facies					
Halite sub-facies					
CLASTIC FACIES		Brine Dilution (Marine Influx)			Open Marine
Anhydrite sub-facies	Saline	with Marine Fluctuation			Restricted Marine
Halite sub-facies					
Anhydrite sub-facies					
Halite sub-facies					
CLASTIC FACIES		Brine Dilution (Marine Influx)			Open Marine
Halite sub-facies	Supersaline	Strongly Brine Concentration			Restricted Marine
Potash sub-facies					
Halite sub-facies	Saline				
Anhydrite sub-facies	Penesaline	Brine Concentration			
Calcareous clastic sub-facies					
Ferruginous clastic sub-facies				Nearshore & Terrestrial	

Figure 4.4.2 Proposed depositional environment model and depositional cycle of evaporite-bearing sequences of the Maha Sarakham Formation in the study area.

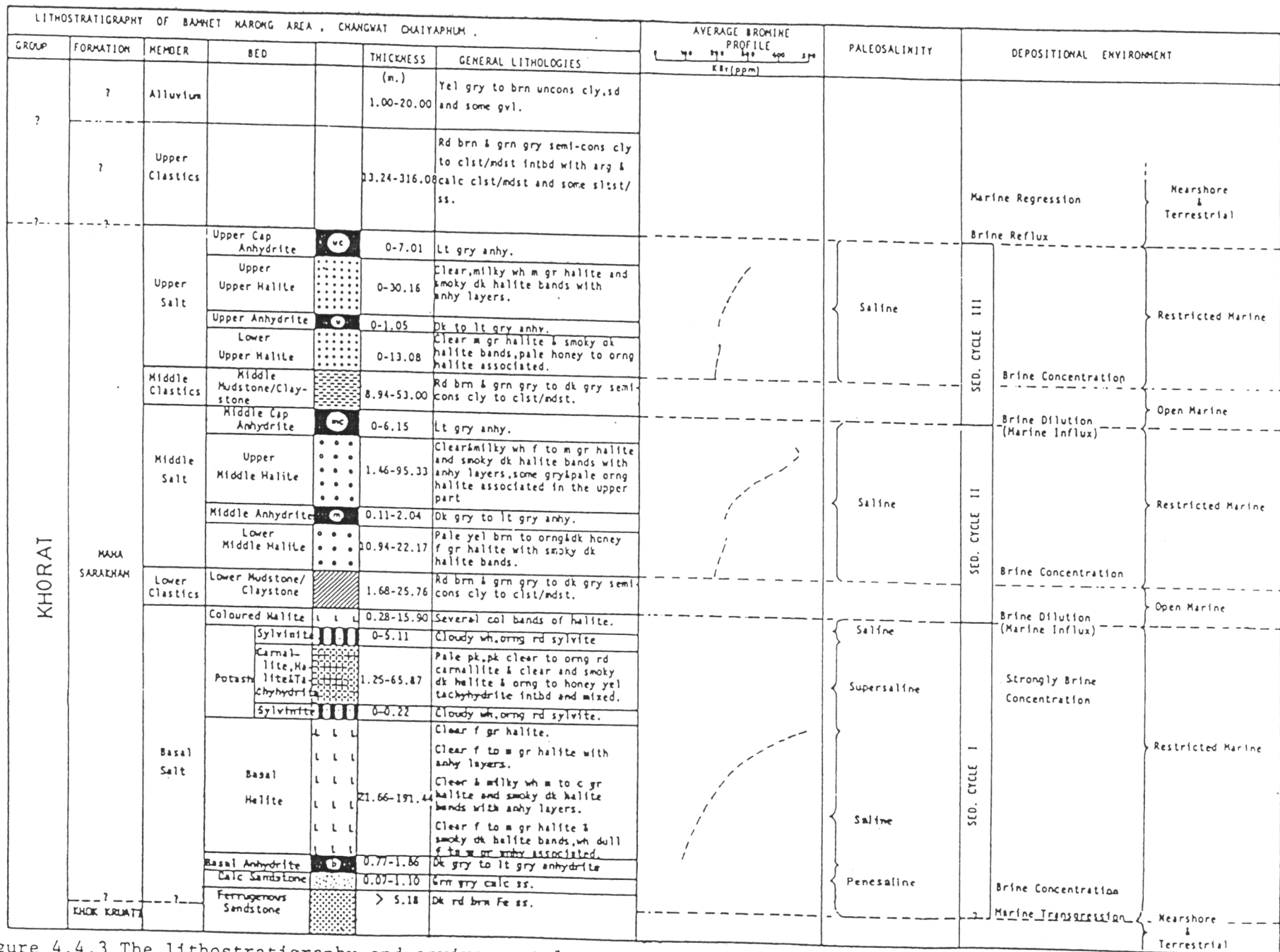


Figure 4.4.3 The lithostratigraphy and environmental reconstruction of the evaporite-bearing Maha Sarakham Formation.

In this study the "incomplete lithostratigraphy" in the salt anticlinal areas has been redefined as disturbed facies and used in the reconstruction of post-depositional changes. Furthermore, the regional as well as local geological structures have been taken into consideration.

Apart from the structural deformation which might disturb the ancient evaporite deposits, post-depositional chemical alterations of the evaporitic mineral suites among the minerals themselves, as well as among the minerals and water in the sub-surface water system must be appreciated. The foregoing explanation is, therefore, intended to propose post depositional changes in both aspects, namely, structural deformation and chemical alterations.

4.5.1 Structural deformation

Considering the regional geological structure of the Khorat Plateau at the present time, there are two major structural basins, namely, Udon-Sakhon Nakhon Basin and Khorat-Ubol Basin separated by the Phu Phan folded belts which are oriented in the east-west trend across the plateau. Along the western margins of both basins, there are a series of anticlinal folds with axes approximately oriented in the north-south direction. To the north of Udon-Sakhon Nakhon Basin, there are a series of folded belts with their axes trending roughly northwest-southeast. It is apparent that these foldings can be separated into two axial directions : one W or WNW and another N or NNE. They are recognized in the outcrop patterns of the Mesozoic formations of the Khorat Group, and are dated as the post-Cretaceous folding. The Khorat-Ubol Basin, the largest structural Mesozoic basin, is oval-shaped basin with the long axis trending approximately

east-west and bounded by Paleozoic folded rocks on the west and east as well as by the Phu Phan anticline on the north. All the rock formations of Khorat-Ubol Basin had been similarly subjected to the effect of the Himalayan Orogeny during Cretaceous and Tertiary. Besides, there are also disturbed by the Pliocene-Pleistocene volcanic activity particularly along the southern margin of the basin.

Within the study area, sedimentary sequences of the Maha Sarakham Formation generally exhibit the monoclinical structure with gentle dipping of less than 15 degrees to the southeast direction (Figure 2.2.1.b, Plates 1 and 2). Detailed sub-surface information regarding the evaporitic facies of the Maha Sarakham Formation further reveals that there are a few gentle salt anticlinal structures in the central and northern part of the study area with the major axial direction in the ESE (Figure 2.2.1.d.1 and Plates 3 to 6). In addition, there are evidences of thickening and thinning of the sedimentary sequences particularly in the evaporite successions caused by the salt flowage. The salt flowage are clearly indicated in the detailed structures of core-slabs and the geochemical bromine profiles.

From the core-slabs, the salt flowage is clearly shown as a marked angular contact plane between the deformed Basal Halite Bed and the relatively more competent underlying Basal Anhydrite, and the progressive of dipping-angle towards the upper part of the deformed Basal Halite Bed in the "incomplete lithostratigraphy (Figures 3.2.3.4 and 3.2.4.7). Besides, the average geochemical bromine profile of the deformed Basal Halite Bed generally varies with the narrow range of averaging 100 KBr content throughout the Bed (Figure 3.4.5.1).

INCOMPLETE STRATIGRAPHIC SEQUENCES AFTER SECONDARY CHANGES						AVERAGE BROMINE PROFILE	
GROUP	FORMATION	MEMBER	BED	THICKNESS	GENERAL LITHOLOGIES	0 500 KBr (ppm)	
KHORAT	?	Alluvium		(m.) 3.05-60.96	Yel brn & gry uncons to semi-cons sd, clayey sd, gvl and some cly.		
		?	Upper Clastics & Middle Clastics & Lower Clastics		2.19-53.96		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 ? -----						
		MAHA SARAKHAM	Basal Salt	Basal Cap Anhydrite	bc 0-28.75		Lt to dk gry anhy/gypsum, poor cemented.
				L L L	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).
				L L L			
				L L L			
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	L L L						
		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?	Ferruginous Sandstone	> 5.18	Dk rd brn Fe ss.			
AVERAGE BROMINE PROFILE IN THE INCOMPLETE LITHOSTRATIGRAPHIC SEQUENCES AFTER SECONDARY CHANGES					On the Origin of Evaporite Deposite in the Maha Sarakham Formation in Bamnet Narong Area, Changwat Chaiyaphum		
DEPARTMENT OF GEOLOGY, GRADUATE SCHOOL CHULALONGKORN UNIVERSITY, 1983				SOMBAT YUMUANG		FIG. 4.5.1.1	

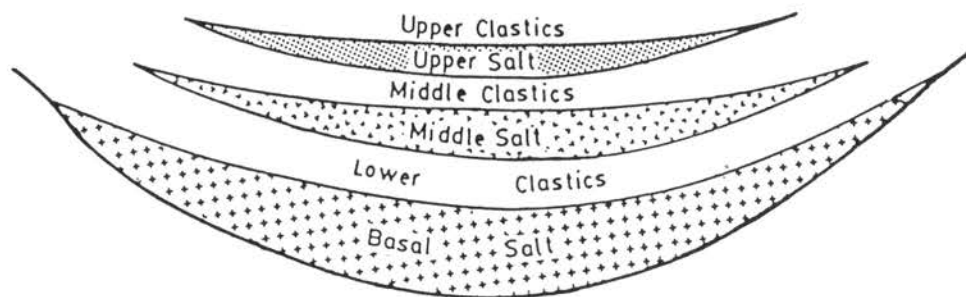
Since Bromine is also sensitive to secondary alteration and it is generally relatively low in content as compared with that of in the primary salts. In this study, the geochemical bromine profiles of the deformed halite zones might indicate the recrystallization of salts caused by the structural deformation.

Therefore, evidences from the sub-surface data of several bore-holes strongly indicated that the evaporitic facies had been subjected to the structural deformation. The mechanisms which cause this deformation of salts might be either the differential loading of the overlying sediments and the high plasticity of the evaporitic sequences or regional tectonic disturbances or the combination of both. Simplified structural deformation model of the three evaporitic facies in the Maha Sarakham Formation has been proposed and presented in Figure 4.5.1.2.

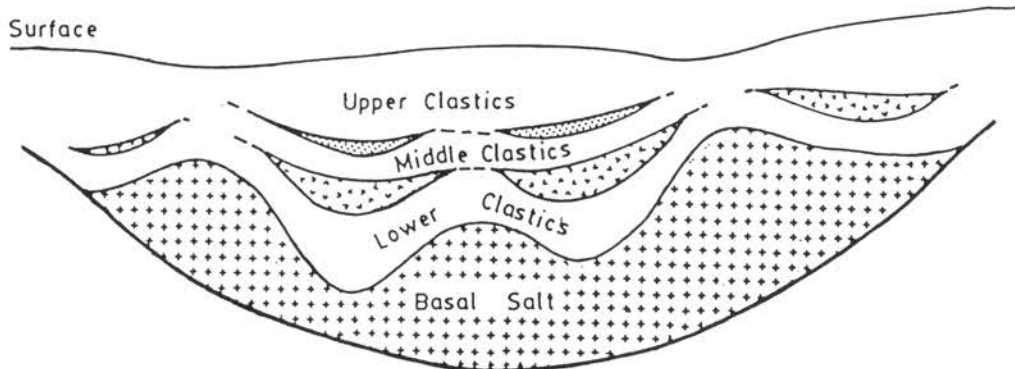
4.5.2 Chemical alterations

There are numerous evidences of post-depositional chemical alterations in the evaporitic facies of the Maha Sarakham Formation. First, the present-day characteristics of evaporitic mineral assemblages or zonations are different from the primary depositional mineral associations. In the area where the Basal Salt Member had been folded to form the gentle anticlinal structures, the cap of the salt anticline of Basal Halite Bed is characterized by the presence of basal cap anhydrite zone and the potash zone is absent. On the anticlinal flanks, the sylvite/carnallite zone surrounds the basal cap anhydrite zone of the salt anticlines. Besides, the carnallite zone or the depositional complete sequences of potash zone is always present in the outermost parts of the anticlinal zones (Figure 4.5.2.1).

SEQUENCES OF SEDIMENTATION



DEFORMATION



(Modified after Hite, 1982)

SEQUENCES OF SEDIMENTATION AND THEIR POST-DEPOSITIONAL STRUCTURAL DEFORMATION

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

SOMBAT YUMUANG

FIG. 4.5.1.2

Second, the textural characteristics of the evaporitic facies, especially in the salt anticline areas and the anticlinal flanks are effected by the chemical alterations. Halite is extremely coarsely crystalline, colourless, with preferred-orientation fabric. Sylvite is generally coarsely crystalline, colourless, showing graphic inter-growth texture with recrystallized halite. The basal cap anhydrite shows distinctive gneissoid, tightly packed textures, and strongly fractured.

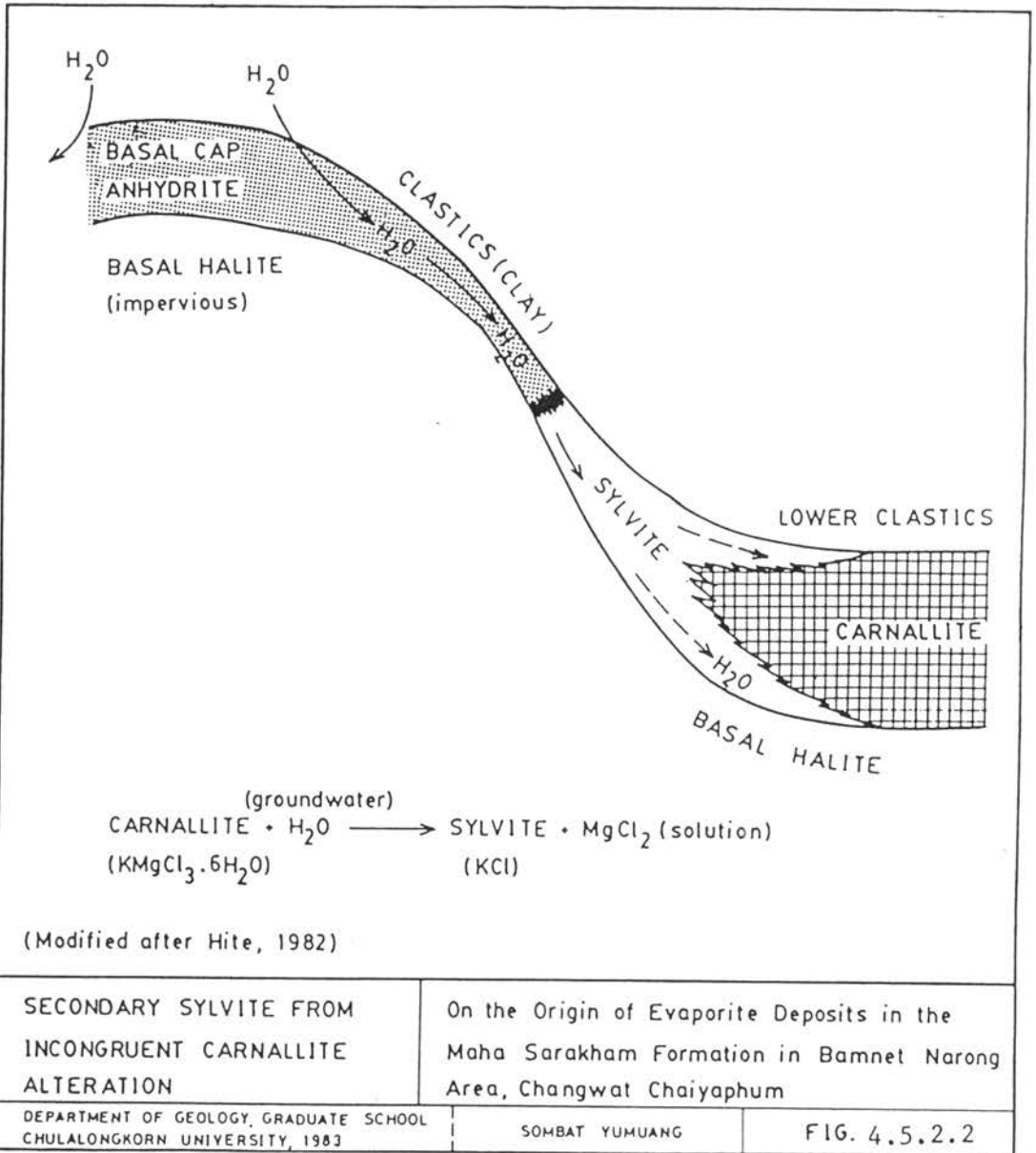
It is interesting to note that in the salt anticline areas, the steeply inclined bedding plane of the underlying Basal Halite Bed of the Basal Salt Member shows the angular relationships with the Basal Cap Anhydrite Bed. Besides, the anhydrite layers are rare or absent in the Basal Halite Bed in the salt anticline areas, whereas they are always present in the outermost parts of the anticlinal zones. In addition, if the Sylvinite Sub-Bed is present in the Potash Bed of Basal Salt Member, the bedding plane of the Bed is usually of high dipping-angle (upto 55°) type.

Third, the additional evidence of the bromine contents of the Khorat Plateau sylvites indicate that they are about 450 ppm (Hite and Japakasetr, 1979). This value of the bromine content is considered to be much lower than the primary precipitate of sylvite (Braitsch, 1966). In contrast, the pure samples of some of the Khorat Plateau carnallites show bromine values of 3,100 to 3,400 ppm (Hite and Japakasetr, 1979), which fall in the range of primary carnallite concentration (Braistch, 1971). Besides, bromine profiles of the Basal Halite Bed of Basal Salt Member underlying the carnallite deposits are the ideal examples of what is expected under conditions of

primary deposition. The profiles show that the KBr content of the halite zone of Basal Halite Bed progressively increases rapidly upward and reaches the value of over 450 ppm just before the onset of carnallite deposition. From these data, this leads to conclude that the carnallite is a primary deposit that was initially probably a thick continuous layer over most of the study area.

In addition, the average bromine profile of the deformed Basal Halite Bed in the salt anticline areas generally varies within the narrow range of averaging 100 KBr content throughout the Bed (Figure 3.4.5.1). Since bromine is also sensitive to secondary alteration and it is generally relatively low in content as compared with that of the primary salts. In this study, the geochemical bromine profiles of the deformed halite zones indicate the recrystallization of salts.

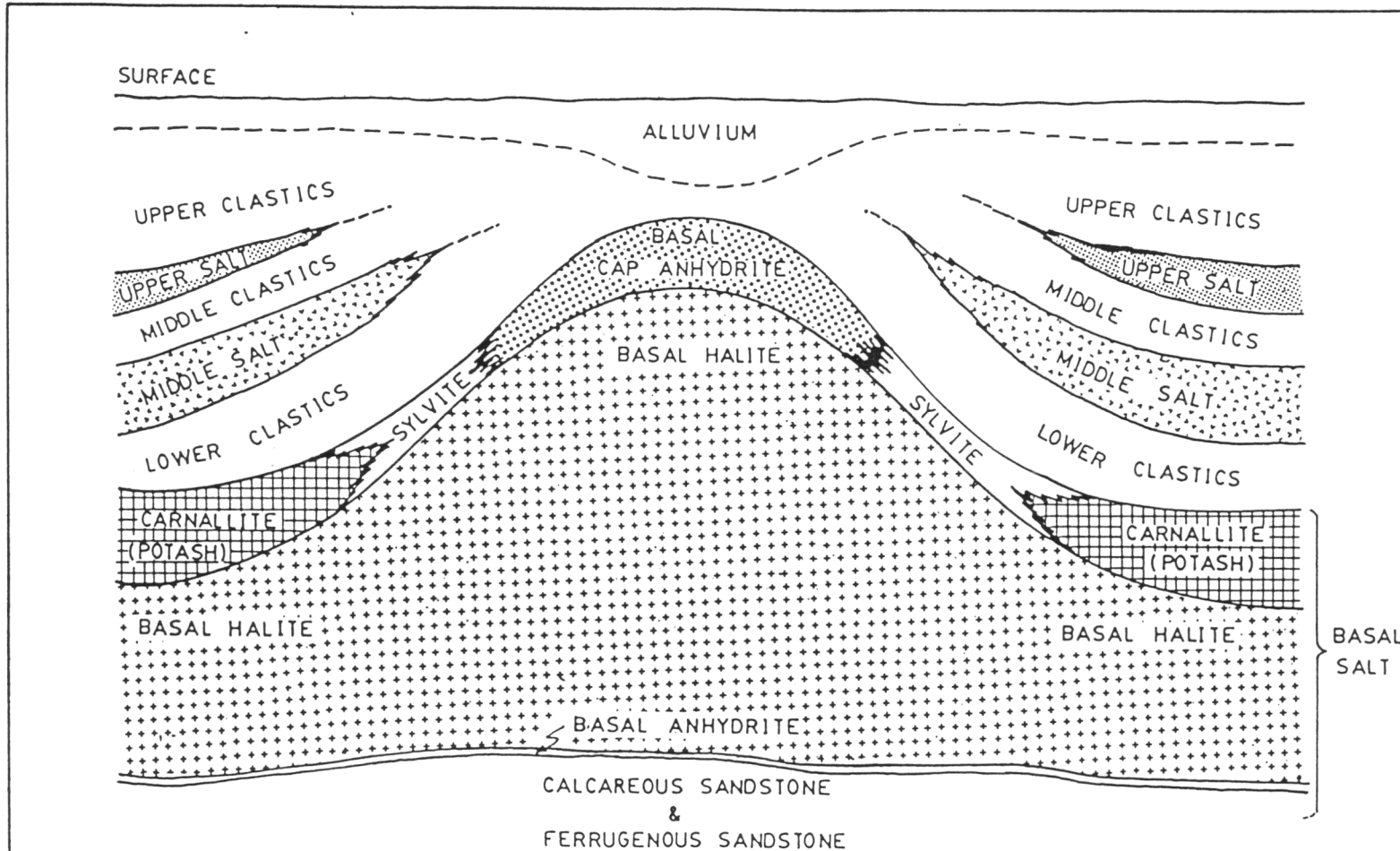
From these evidences of post-depositional chemical alterations in the evaporitic facies of the Maha Sarakham Formation, it is believed that, firstly, the occurrence of sylvite in the sylvite/carnallite zone is resulted from the percolating groundwater contact with the carnallite zone. It is well known that any solution in contact with carnallite becomes quickly saturated, or nearly so, with respect to $MgCl_2$. Where this occurs, the KCl, which was also derived from the solutioning of carnallite but less soluble than $MgCl_2$, will be salted out and forming the sylvite. This important process has been termed "incongruent alteration", that is probably the most important process in the alteration of potash salts (Braistch, 1971). In the study area, the percolating groundwater from the cap of the anticlinal salt structure down the franks is mainly responsible for the mechanism of transforming of carnallite to sylvite through the process of incongruent alteration (Figure 4.5.2.2).



It is noted that the problem of the $MgCl_2$ solution left from the incongruent carnallite alteration cannot be solved. The idea that the $MgCl_2$ solution may be captured in the overlying Lower Clastics zone is not valid because the soluble magnesium oxide content in that zone is in the same level as the other Middle and Upper Clastics zones (Appendix 1-C). The other possibility is that the $MgCl_2$ solution from the incongruent carnallite alteration may have the relationships with the occurrence of some parts of tachyhydrite mineral in the potash zone of the study area (?).

Second, the Basal Cap Anhydrite Bed was the result of a residual accumulation from anhydrite layers leached from the dissolution in the upper part of a considerable thickness of salt of the Basal Salt Member. It was formed on contact with percolating groundwater. In addition, detailed field and laboratory investigations have revealed that the anhydrite zones of the cap rocks, covering upper contours of the rock salt of salt domes in many parts of the world, are similar occurrence as a residual accumulation of disseminated anhydrite grains from the salt (Taylor, 1972). The cap anhydrite originated from the residual accumulation from the leaching of anhydrite/halite beds shows typical gneissoid texture.

The overall model of post-depositional chemical alterations as well as the structural deformation has been synthesized on the basis of factual information obtained from this study. This is accordingly simplified and presented in Figure 4.5.2.3. The model intends to cover both zones, namely, single salt layer profile as well as multiple salt layer profile. Special reference, however, is made with respect to the origin of secondary sylvite which is the most economical potash mineral.



(Modified after Hite, 1982)

PROPOSED MODEL OF SECONDARY
CHANGES OF EVAPORITIC FACIES

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

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FIG.4.5.2.3

The characteristics and origins of important evaporitic minerals have been separately discussed as follows :

a) Dolomite

Dolomite is scatteringly present as subhedral rhombs in anhydrite rocks. The dolomite megacrysts are always partially replaced by acicular anhydrite crystals. Considering the origin of dolomite, it is quite certain that this mineral was formed by early diagenetic dolomitization of pre-existing fine-grained calcite and/or aragonite. The calcium carbonate is of early order of evaporitic origin. Textural relationships between acicular anhydrite crystals and dolomite rhombs suggest that the acicular anhydrite has been post-dolomitization partially recrystallized. With reference to the source of magnesium for dolomitization of pre-existing calcium carbonate minerals, it is probably supplied by the magnesium-rich interstitial pore-fluid of marine origin.

b) Anhydrite

The anhydrite is commonly present in the Basal Anhydrite Bed of the Basal Salt Member. Generally, the textures of this Bed consist of acicular anhydrite in radiated form and acicular crystals parallel to the wavy-lamination. Within the anhydrite nodules, the textures are mainly fine-grained with some associated acicular anhydrite aggregates. There are some calcareous algal networks as well as wavy-laminated layers, calcite crystalline mosaic patches, gypsum (dissiminated, aggregated, tabular and rosette forms), and subhedral dolomite rhombs associated with this Bed. It is noted that the diagenetic fabric of the Bed is very complicated.

Besides, the results of the chemical analysis of some trace elements indicate that the strontium and the manganese values in the Bed are typical for initial deposition of calcium sulphate as anhydrite.

It is also realized that gypsum and anhydrite are by far the most abundant and commonly form massive beds overlying the main carbonate zones in theoretical evaporitic sequences. The present distribution of these two minerals is largely secondary and bears a close relationship to their depth of burial. Gypsum is predominant in near-surface deposits, and anhydrite is predominant in deeply buried deposits. The primary distribution depends on the temperature and salinity at higher salt concentrations and at higher temperatures than gypsum, assuming conditions of thermodynamic equilibrium. The results of the investigation of solubility of anhydrite, gypsum, and hemihydrate in water at different temperature are shown in Figure 4.5.2.4. From the solubility curves, gypsum is the stable form below the temperature at 42° C whereas anhydrite is stable above that temperature.

Therefore, it is difficult to determine whether anhydrite is primary or not. However, the alignment of the laths or acicular crystals parallel to the wavy-lamination with slightly folding, and the chemical results of some trace elements suggest that initial deposition of calcium sulphate in the Basal Anhydrite Bed of Basal Salt Member is anhydrite.

In addition, the origin of the anhydrite in the Middle Anhydrite Bed of the Middle Salt Member cannot be solved because the evidences from this study are inadequate to conclude whether it is primary or secondary. It is, however, note that the chemical

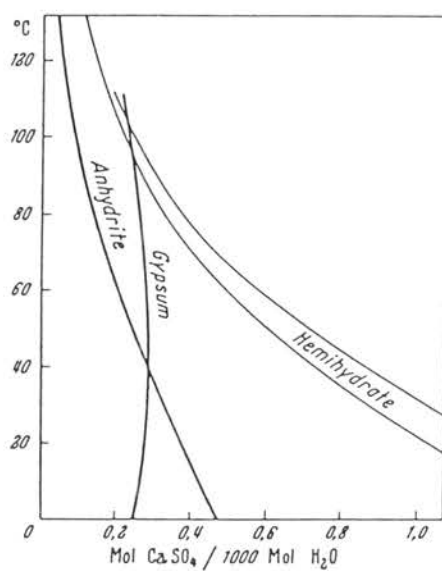


Figure 4.5.2.4 Solubility of anhydrite, gypsum, and hemihydrate in water at different temperatures. (After Braitsch, 1971)

results of some trace elements (strontium and manganese) are the lower values than the average for primary anhydrite in evaporite rocks.

c) Halite

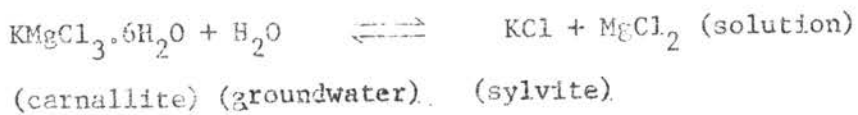
The halite in the salt anticline areas is commonly effected by the secondary changes. The halite is extremely coarsely crystalline, colourless, with preferred-orientation textures. Besides, in the salt anticline areas the steeply inclined bedding plane of the Basal Halite Bed of the Basal Salt Member is commonly present particularly in the upper part of the Bed and shows the angular relationships with the Basal Cap Anhydrite Bed. Generally, the bedding plane of the Basal Halite Bed in the salt anticline areas gradually increases in degree of dipping angle from low angle in the lower part to very high angle in the upper part.

Furthermore, the average bromine profile of the deformed Basal Halite Bed in the salt anticline areas generally varies within the narrow range of averaging 100 KBr content throughout the Bed. Since bromine is also sensitive to secondary alteration and it is generally relatively low in content as compared with that of the primary salts in the outer zones of the anticline areas. In this study, the geochemical bromine profiles of the deformed halite zones also indicate the recrystallization of salts. However, the halite in the outer zones of the salt anticlines is only slightly recrystallized, too.

d) Sylvite

Sylvite is generally present in the sylvite/carnallite zone on the anticline flanks around the basal cap anhydrite zone, especially

in the middle part of the study area (Figure 4.5.2.1). The sylvite in this zone is commonly coarsely crystalline, colourless, showing graphic or amoeboidal texture with recrystalline halite. It is proposed that this sylvite was originated from the process of incongruent carnallite alteration. Carnallite was changed to sylvite with removal of $MgCl_2$ when groundwater enters the primary carnallite zone of Potash Bed of Basal Salt Member :



In general, the solutions become enriched in $MgCl_2$ as they percolate downward. The problem of $MgCl_2$ -rich interstitial pore fluid might be transported and precipitated as secondary evaporitic minerals or adsorbed by the clayey materials elsewhere, and therefore remains unsolved in this study.

In addition, primary sylvite is scatteringly present in the potash sub-facies of the evaporitic facies in the first sedimentary cycle. The sylvite in this sub-facies is deep orange-red and disseminated in the form of interlocked crystalline mosaic mixing with pale orange to orange-red carnallite. This primary sylvite is mainly distributed in the outer zones of the salt anticline areas.

e) Cap anhydrite

The cap anhydrite is generally present in the salt anticline areas. This cap rock shows distinctive gneissoid, tightly packed textures, and strongly fractured. This cap anhydrite was originated by the residual accumulation of the anhydrite layers from the leaching of anhydrite/halite beds in the Basal Halite Bed of Basal Salt Member. The cap rock doubtlessly represents the residuum left after the

dissolution of a considerable thickness of salt. It was formed either on contact with groundwater at depth. The continuous upward movement of halite with disseminated and/or interbedded anhydrite causes more halite to be exposed to solution. By a process of solution and compensating upward movement, large amounts of halite were leached, leaving a residue of anhydrite fragments. Within the area under the present investigation all cap anhydrites are only confined on the crests of the salt anticlines.

It is also suggested that the cap anhydrite on top of the Middle Salt Member as well as Upper Salt Member might be generally originated in the same manner as those of the cap anhydrite on the crests of the salt anticlines.

From thin-section evidences, all of the cap anhydrites in the study are characterized by fine-grained anhydrite with some fibrous to fibroradiated acicular anhydrite patches. In addition, the results of the chemical analysis of some trace elements indicate that the strontium and the manganese values are much lower than that of the primary anhydrite in evaporite rocks.

Therefore, it is suggested from these evidences that all of the cap anhydrites in the study should be the secondary anhydrite.

f) Tachyhydrite

The tachyhydrite is commonly found associated with the potash sub-facies particularly in the middle part. There are carnallite, halite, and tachyhydrite in the potash sub-facies with their decreasing degree of abundance, respectively. This tachyhydrite is yellow, orange-yellow and yellowish brown, as well as is associated with halite

