CHAPTER V

CONCLUSION

This study primarily aims at utilizing the existing 65 drill-holes information coupled with detailed laboratory data to synthesize the sub-surface geology, and to reconstruct the depositional model as well as post-depositional changes of the evaporite formation in Bamnet Narong Area, Changwat Chaiyaphum covering an area of approximately 170 square-kilometers. Therefore, the overall geological history and geological processes concerned have been proposed to explain the existing geological deposits. The findings from this study will, in some parts, assist in the expansion of the potash and rock salt exploration and development programmes elsewhere in this region of northeastern Thailand from the better understanding of the origin of evaporite deposits in the study area.

Generally, the sub-surface lithostratigraphy of the study area is essentially based on the lithological analysis, mineralogical and textural determination, chemical as well as geophysical characteristics of the sedimentary sequences from the ground surface down to the depth range of 60-465 meters. Consequently, it is apparent that the sub-surface lithostratigraphy of the complete lithostratigraphic sequences of the Maha Sarakham Formation of the Khorat Group can be subdivided into five rock members, namely, Basalt Salt, Lower Clastics, Middle Salt, Middle Clastics, and Upper Salt. However the uppermost two members overlying the Maha Sarakham Formation, notably, Upper Clastics and Alluvium should be arranged under another different rock formation. It is noted that almost complete evaporitic sequences are present only in the Basal Salt Member of the Maha Sarakham Formation.

With regard to the sub-surface lithostratigraphy of 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, and the uppermost Clastics Member that rest local unconformity (?) on the Basal Salt Member.

From the synthesis of the sub-surface geological maps, the Maha Sarakham Formation in the study area gradually gentle dips towards the southeastward. Generally, this Formation is located at small depth and thickening towards the central part as well as the northern part. In contrast, this Formation gradually appears much deeper and thinner towards the southeastern and northeastern parts of the study area. It is realized that the complete lithostratigraphic sequences of the Maha Sarakham Formation is generally present at localities where the formation is thin and appears at a relatively greater depth. On the other hands, the incomplete lithostratigraphic sequences of this Formation is always present at localities where the formation is thick and appears at a relatively smaller depth that are mainly controlled by the gentle salt anticlinal structures.

The detailed sub-surface geology of the study area, from the lower part to the upper part of the lithostratigraphic sequences, is concluded here.

The Basal Salt Member, containing almost complete evaporitic sequences of the Maha Sarakham Formation, has been divided into seven Beds, namely, Ferrugenous Sandstone, Calcareous Sandstone, Basal

Anhydrite, Basal Halite, Potash, Coloured Halite, and Basal Cap Anhydrite. It is noted that the Basal Halite Bed is the major part of this Member. Above the Basal Salt Member is the Lower Clastics Member lying most distinctively between the Basal Salt and the Middle Salt Members. Generally, the Middle Salt Member has been divided into four Beds, namely, Lower Middle Halite, Middle Anhydrite, Upper Middle Halite, and Middle Cap Anhydrite. Overlying the Middle Salt Member is the Middle Clastics Member lying between the Middle Salt and the Upper Salt Members. The Upper Salt Member is subdivided into four Beds, notably, Lower Upper Halite, Upper Anhydrite, Upper Upper Halite, and Upper Cap Anhydrite. It is, however, noted that the uppermost two Members, namely, the Upper Clastics and the Alluvium, should be arranged under another different rock formation seperated from the underlying Maha Sarakham Formation of the Khorat Group because of their distinctive lithological features and considerable thickness.

Besides, additional attempt has been made to define and describe in detailed the mineralogy and petrography of the rock sequences in order to fully understanding the origin of evaporite deposits in the Maha Sarakham Formation under the present investigation. Generally, the mineralogy of evaporite deposits in the study area varies from the lowerest order to the nearly highest order of theoretical evaporitic sequences. These evaporitic minerals are hematite, calcite, dolomite, gypsum, anhydrite, halite, carnallite, sylvite, tachyhydrite, boracite (?), etc.

It is realized that the 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.

With regard to the nature and characteristics of the 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 shallow epeiric sea. The sequences are dominated by marine input, with transgressive and regressive cycles across a stable interior platform. It is noted that the sediments of the Khok Kruat Formation, the underlying sequences of the Maha Sarakham 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. 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. However, the marine transgression occurred only in a vary limited span of time and caused only rectricted influence on the sediment end-products.

Furthermore, an attempt has been made to define the sedimentary sequences concerned in terms of sedimentary facies from this study. Generally, the sedimentary facies of the evaporite-bearing Maha Sarakham Formation can be categorized into two types : depositional facies 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.

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". However, in the outer zones of salt anticlinal structures within the study area, the lithostratigraphy is defined and established using the term "complete lithostratigraphy".

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. In contrast, 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" further defined with respect to post-depositional changes as disturbed facies.

The information on "complete lithostratigraphy" that is furthered defined in terms of depositional facies will be utilized in the reconstruction of original depositional environment using the model concept. Considering 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 sedimentary cycles have been recognized and defined in terms of evaporitic facies.

The first sedimentary cycle is almost exclusively composed of lower, middle, and some parts of higher orders of theoretical evaporitic facies. The second and third sedimentary cycles are generally composed of the clastic facies, and some parts of the lower as well as the middle orders of theoretical evaporitic facies.

Due to the fact that the evaporitic facies of the three sedimentary 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.

It is concluded earlier that the nature and characteristics of the depositional basin is a shallow epeiric sea with gentle sloping depositional surface. However, it is realized that there are numerous limiting factors which make the complete interpretation of the depositional models 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 influences of threshold depths of the basin elsewhere outside the study area. Subsequently, the brine concentration occurred indicating by the primary lower order of marine evaporitic sub-facies, namely, the ferrugenous clastic sub-facies and the calcareous clastic sub-facies, respectively. Then, the paleosalinity of the brine had progressively increased into the penesaline condition and caused the precipitation of the anhydrite sub-facies. The brine in the depositional basin continued to be further concentrated to the stage of saline 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. Afterwards, there must be a marine influx towards the end of the deposition of the potash sub-facies which 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 environement was determined as the open marine. Afterwards, the depositional environment had changed from the open marine to restricted marine followed the marine regression under the influences of threshold depth of the basin elsewhere outside the study area. 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. Then, the progressive saline condition had been 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. Afterwards, marine reflux and brine mechanism proceeded to precipitate the upper halite sub-facies under the saline condition. Towards, the end of the second sedimentary cycle, there was another marine influx which subsequently precipitated the 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 with fine-grained detrital clastic sediment deposition. Afterwards, the depositional environment had changed from the open marine to restricted marine followed the marine regression and the development of threshold depth of the basin elsewhere outside the study area. 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. Then the progressive saline condition had been 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. Afterwards, marine reflux and brine mechanism proceeded to precipitate the upper halite sub-facies under the saline condition. Towards, the end of the third sedimentary cycle, there was another marine influx which subsequently precipitated the 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.

It is, however, noted that the time frame of this depositional model has not been discussed because of the unavailability of the chronostratigraphic controls and dating evidences.

Furthermore, 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. Generally, the post-depositional changes are proposed in two aspects, namely, structural deformation and chemical alterations.

With regard to the structural deformation, the sedimentary sequences of the Maha Sarakham Formation within the study area exhibit the monoclinal structure with gentle dipping less than 15 degrees to the southeast direction. The evidences of the sub-surface data, detailed structures of core-slabs as well as the geochemical bromine profiles strongly indicated that the evaporite facies in the Formation had been subjected to the structural deformation. The mechanism which caused 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.

Considering the post-depositional chemical alterations in the evaporitic facies of the Maha Sarakham Formation, there are numerous evidences indicating this aspect. First, the present-day characteristics of evaporitic mineral assemblages or zonations are different from the primary depositional mineral associations. Second, the textural characteristics of the evaporite facies, especially in the salt anticline areas and the anticlinal flanks are effected by the chemical alterations. Third, the additional evidences of the bromine contents in the minerals and zonations of the evaporitic facies are also the useful indicators for the chemical alterations.

From these evidences of post-depositional chemical alterations in the evaporite facies of the Maha Sarakham Formation, it is believed that, firstly, the percolating groundwater from the cap of the anti-clinal salt structures down the flanks is mainly responsible for the mechanism of transforming of carnallite to sylvite through the process of incongruent alteration. It is noted that the problem of the $MgCl_2$ solution left from this incongruent alteration cannot be solved. Secondly, the basal cap anhydrite in the anticline areas was the result of a residual accumulation from the 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 groundwater. Furthermore, the characteristics and origins of important evaporitic minerals have also been seperately discussed and concluded here.

The dolomite that is scatteringly present as subhedral rhombs in the anhydrite rocks was formed by early diagenetic dolomitization of pre-existing fine-grained calcite and/or aragonite. The anhydrite in the Basal Anhydrite Bed of the Basal Salt Member is suggested to be the initial deposition of calcium sulphate, whereas the origin of anhydrite in the Middle Anhydrite Bed of the Middle Salt Member cannot be solved. Besides, the halite is strongly recrystallized in the salt anticline areas and only slightly recrystallized in the outer parts of the salt anticlines.

Besides, the sylvite that is present in the sylvite/carnallite zone in the anticlinal flanks around the basal cap anhydrite zone was believed to be originated from the process of incongruent carnallite alteration. It is also noted that the primary sylvite is also scatteringly present in the potash sub-facies of the evaporitic facies in the first sedimentary cycle. In addition, the cap anhydrite that is generally present in the salt anticline areas was originated by the residual accumulation of the anhydrite layers and/or dissiminated anhydrite grains from the leaching of the considerable thickness of salts in the Basalt Halite Bed of the Basal Salt Member. 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. For the origin of tachyhydrite that is associated with the potash sub-facies, it is difficult to conclude clearly whether tachyhydrite is primary or not.

Despite the fact that an attempt has been made in this study in reconstructing the depositional environment and post-depositional changes of marine evaporites in the Maha Sarakham Formation, some of the problems regarding this matter remain unsolved. It is, therefore, proposed herewith suggestions for further study.

a) Analysis of the sub-surface geology of the evaporite-bearing Maha Sarakham Formation throughout the region of Khorat Plateau using additional bore-hole data.

b) Establishing the chronostratigraphic controls particularly regarding the dating of sedimentary deposits concerned.

c) Conducting detailed geochemical study of evaporites in order to differentiate the primary and secondary mineral suites.

d) Reconstruction of the structural deformation of salt deposits.

e) Reconstruction of the paleogeography of the evaporite deposits with reference to the regional geological setting.