CHAPTER III

MINERALOGY AND PETROGRAPHY

3.1 General

The mineralogy and petrography of the sub-surface lithostratigraphy of the study area are 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. Factual information obtained from the present investigation is presented in this chapter. Besides, additional attempt has been made to define and describe in detail the mineralogy and petrography of the rock sequences in order to fully understand 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 lowest order to the nearly highest order of theoretical evaporitic sequences. These evaporitic minerals and their theoretical compositions are as follows :

Hematite (Fe_2O_3)

Calcite ($CaCO_3$)

Dolomite ($CaMg(CO_3)_2$)

Gypsum ($CaSO_4.2H_2O$)

Anhydrite ($CaSO_4$)

Halite ($NaCl$)

Carnallite ($KMgCl_3.6H_2O$)

Sylvite (KCl)

Tachyhydrite ($CaMg_2Cl_6.12H_2O$)

Boracite ($Mg_3ClB_7O_{13}$) (?)

The mineralogical suites are summarized and presented in some representative x-ray diffractogrammes (Appendix 1-D). Besides, the analytical results of some major and trace elements of some main litho-logical zonations are summarized and tabulated in Appendices1-C, 1-E and 1-F. Furthermore, some typical gamma-ray log patterns and bromine profiles ralated to the sub-surface lithostratigraphy of the study area have been also studied and presented in Figures 3.1.1 and 3.1.2.

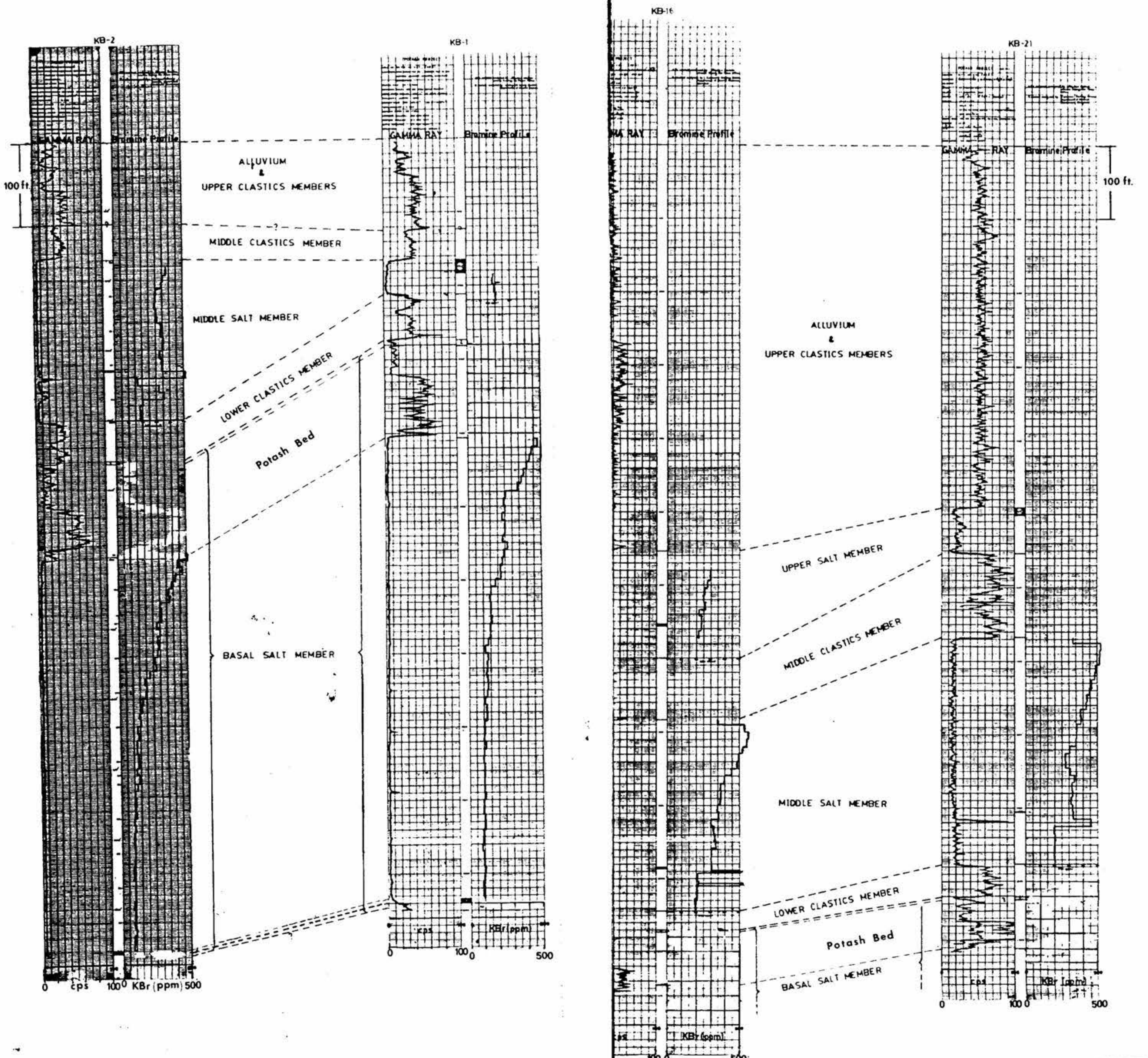
Detailed mineralogy and petrography of the lithostratigraphic sequence in the study area is being discussed in the foregoing part.

3.2 Basal Salt Member

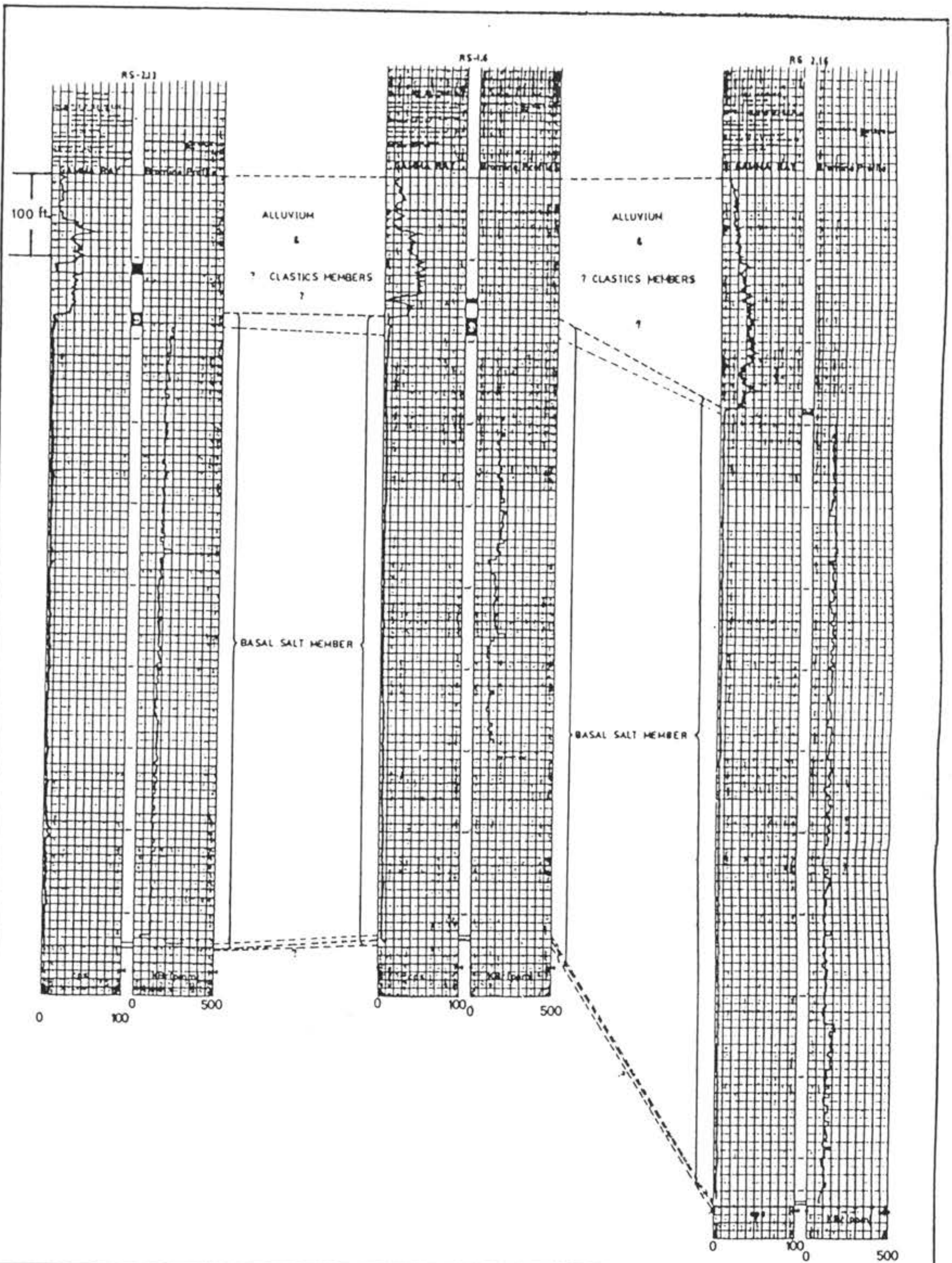
The Basal Salt Member, containing almost complete evaporitic sequences of the Maha Sarakham Formation, has been divided into seven Beds as described below :

3.2.1 Ferrugenous Sandstone Bed

From core-slabs study, the lithology of the Ferrugenous sand-stone Bed is dark reddish brown,uniformly very fine-grained, very well sorted, massive, dense and very hard. Besides, there are some calcareous patches (1x2 to 3x5 square-millimeters in size) and a few associated claystone layers. (Figure 3.2.1.1). Mineral composition is mainly quartz and some feldspar. Cementing materials are normally ferrugenous with some calcareous patches.



TYPICAL GAMMA-RAY LOG PATTERNS AND BROMINE PROFILES OF THE COMPLETE LITHOSTRATIGRAPHIC SEQUENCES	On the Origin of Evap Deposits in the Maha Sarakham Form in Bamnet Narong Area, Changwaiyaphum	SOMBAT YUMUANG DEPARTMENT OF GEOLOGY GRADUATE SCHOOL CHULALONGKORN UNIVERSITY, 1983	FIG. 3.1.1



TYPICAL GAMMA-RAY LOG PATTERNS AND BROMINE PROFILES OF THE INCOMPLETE LITHOSTRATIGRAPHIC SEQUENCES	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. 3.1.2

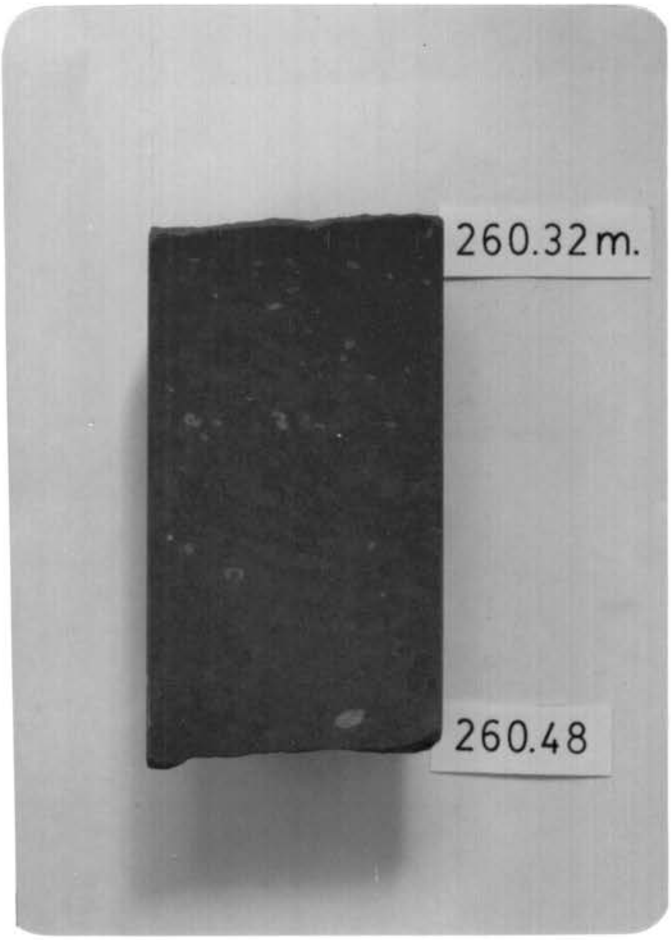


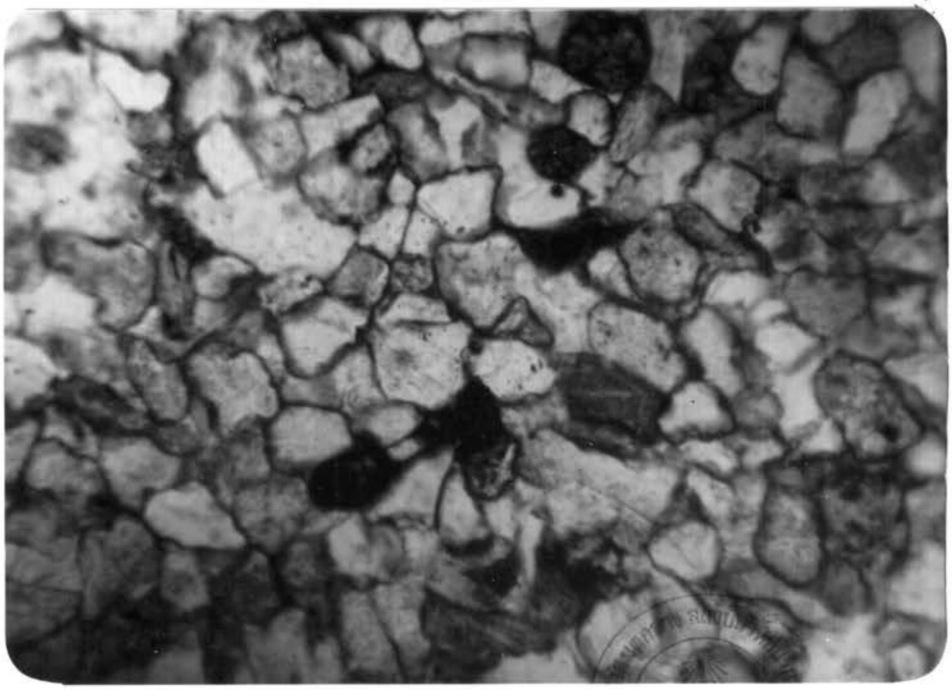
Figure 3.2.1.1 Photograph of the polished core-slab of Ferrugenous Sandstone Bed showing its general appearance. Note some assoicated calcareous patches. Core-slab width is 8 cm.
(from drilled hole no. RS-2.21, at depth 260.32-260.48 m.)

From thin-sections, the textures of the Bed generally consists of very well packed quartz-chert-feldspar framework (quartz grains partially fused) without grain-orientation, cementing materials are ferrugenous and some calcareous. The original porosity of the sandstone is partially preserved. The grainsize is very fine sand, very well sorted and matrix-free. Besides, large numbers of the framework grains are subrounded to rounded and the sphericity is in the range of 0.60-0.85 and is highly variable due to the heterogenous composition. (Figure 3.2.1.2) The Bed is texturally mature as indicated by the sorting and roundness. The mineralogy of the Bed is composed of the essential minerals of quartz, chert, plagioclase feldspar (mostly albite), and the accessory minerals of iron oxides, calcite, muscovite, biotite, opaque iron grains, anhydrite (?), pleochroic unidentified green mineral grains.

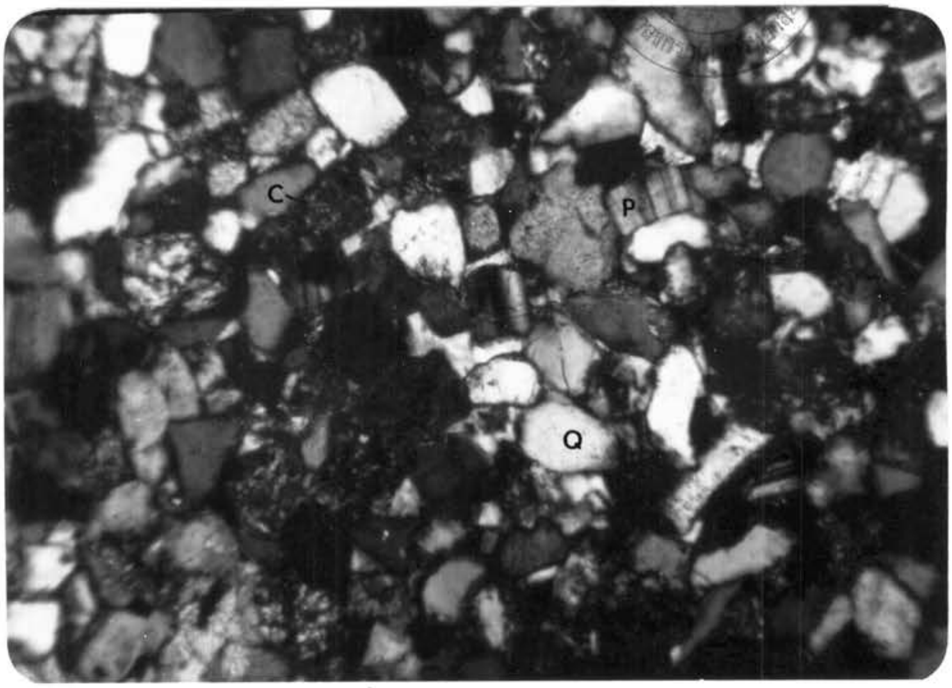
Besides, minerals in x-ray diffractogramme of the Bed (Appendix 1-D) are mainly characterized by quartz, albite, hematite, calcite, etc.

It is noted that the ferrugenous cement coated almost all of the detrital grains in the thin-sections and the iron content in the Bed is rather high up to 5,112 ppm or about 0.5112 % by weight (Appendix 1-E). This can be concluded and interpreted that the Ferrugenous Sandstone Bed represents the early stage of evaporites as Fe_2O_3 zone in the clastic basin where evaporite minerals are deposited as cementing materials.

The contact of the Ferrugenous Sandstone Bed with the overlying Calcareous Sandstone Bed is a nearly horizontal gradational type (Figure 3.2.1.3).



(a)



(b)

Figure 3.2.1.2 Photomicrographs of Ferrugenous Sandstone Bed showing

(a) ferrugenous cement coating well packed detrital grains. (uncrossed nicols, approx. x 85),

(b) well packed quartz-chert-feldspar framework in ferrugenous cement. Q-quartz, C-chert, P-plagioclase. (crossed nicols, approx. x 85)

(from drilled hole no. KB-2, at depth 355.14 m.)

Figure 3.2.1.3 Photograph of the polished core-slab of the gradational contact between Ferrugenous Sandstone and the overlying Calcareous Sandstone Beds.
(from drilled hole no. KB-2, at depth 354.90-354.98 m.)

3.2.2 Calcareous Sandstone Bed

From core-slabs study, the lithology of Calcareous Sandstone Bed is greenish grey, uniformly very fine-grained, very well sorted, massive, dense and very hard, with calcareous cement. Besides, a few claystone layers intervened have been observed (Figure 3.2.2.1). Mineral compositions is mainly quartz, and some feldspar. Cementing material is calcareous that increases in content toward the upper part of the Bed. Locally, some dark reddish brown metallic-luster spots (1x3 square-millimeters in size) are present.

From thin-sections, the textures of the Bed generally consist of quartz-chert-feldspar framework without grain-orientation. Besides, cementing material is mainly calcareous with small amount of ferrugenous. From the lower part of the Bed, the calcareous cement gradually increases in content to the upper part of the Bed until the detrital grains are floated as the cement-support framework (Figures 3.2.2.2 and 3.2.2.3). There are also some anhydrite cement disseminated in the Bed. Besides, grainsize of the Bed is very fine sand, very well sorted, and matrix-free. Mostly of the detrital grains are subrounded to rounded. Sphericity is in the range of 0.60-0.85 and is highly variable because of the heterogenous composition. Furthermore, the Bed is texturally mature. It is noted that the calcite replaces both feldspar and quartz, especially in the uppermost part of the Bed. Mineralogy of the Bed is composed of the essential minerals of quartz, chert, plagioclase feldspar (mostly albite) and coarsely crystalline mosaic of calcite and the accessory minerals of anhydrite and opaque iron grains.

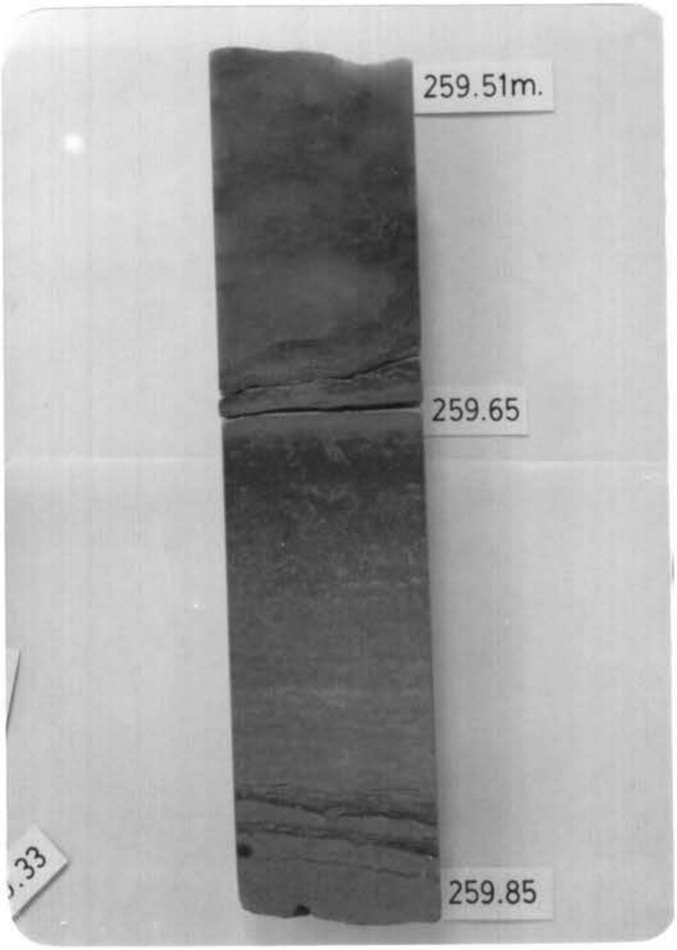


Figure 3.2.2.1 Photograph of the polished core-slab of the upper part of Calcareous Sandstone Bed contact with the overlying Basal Anhydrite Bed. Core-slab width 8 cm. (from drilled hole no. RS-2.21, at depth 259.51-259.85 m.)

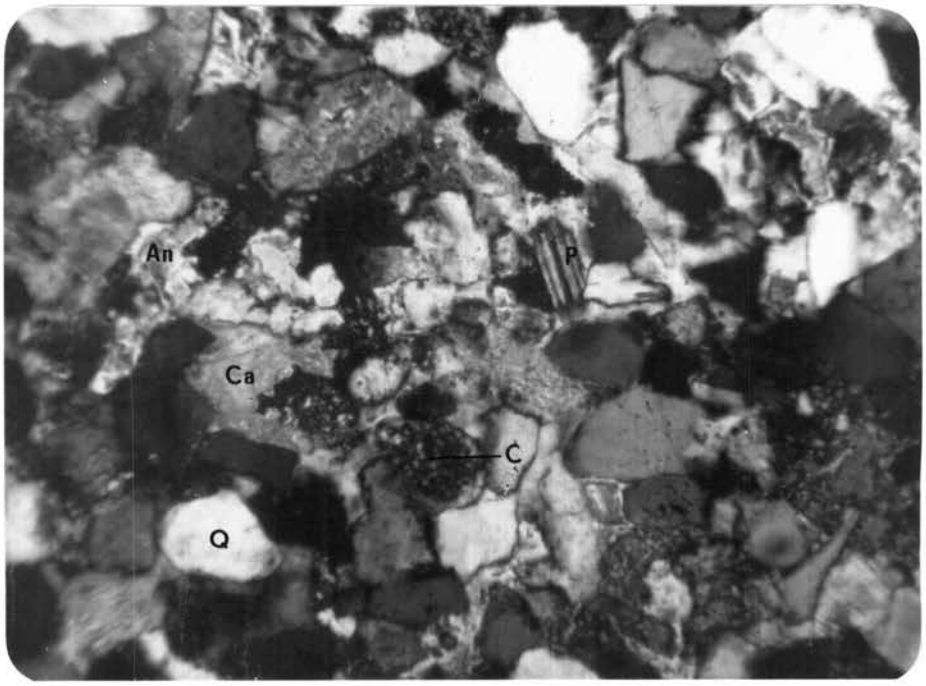
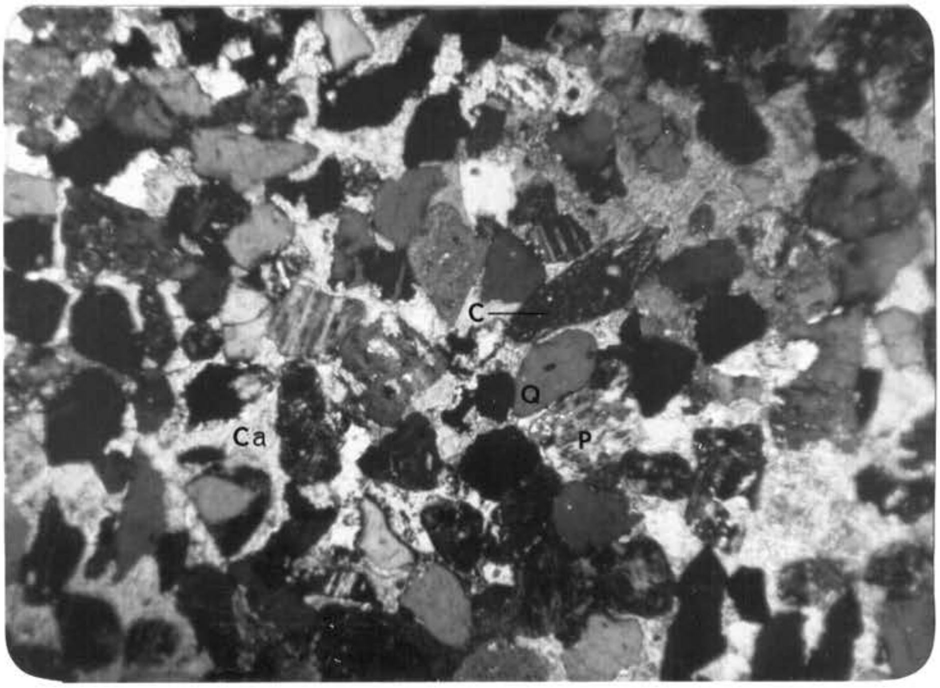
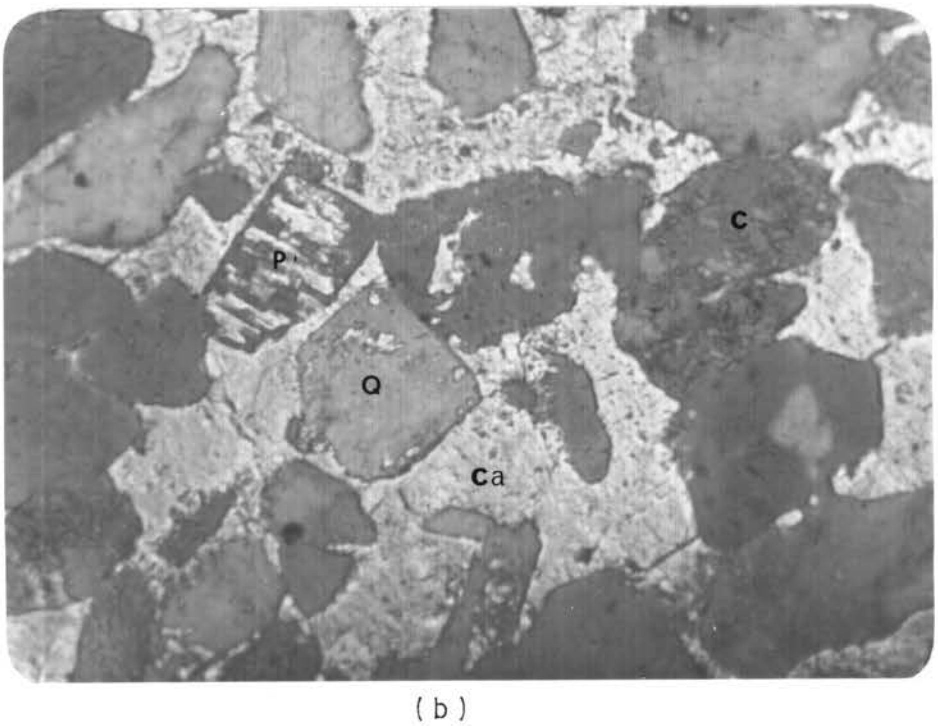


Figure 3.2.2.2 Photomicrograph of the lower part of Calcareous Sandstone Bed showing quartz-chert-feldspar framework in calcareous cement. Q-quartz, C-chert, P-plagioclase, Ca-calcite, An-anhydrite. (Crossed nicols, approx. x 85) (from drilled hole no. KB-2, at depth 354.91 m.)



(a)



(b)

Figure 3.2.2.3 Photomicrographs of the upper part of Calcareous Sandstone Bed showing the detrital grains floated in calcareous cement. Q-quartz, C-chert, P-plagioclase, Ca-calcite. Note some detrital grains replaced by calcite.

(a) crossed nicols, approx. x 85

(b) crossed nicols, with quartz compensater, approx. x 175.

(from drilled hole no. KB-2, at depth 354.35 m.)

In addition, minerals determined from x-ray diffractogramme of the Bed are mainly characterized by quartz, albite, calcite, anhydrite, etc. It is noted that calcite and anhydrite are relatively more abundant in the upper part of the Bed. Besides, results from the chemical data (Appendix 1-E) indicate that iron contents generally decrease from the Ferrugenous Sandstone Bed, from 5,112 ppm, to the top of the Calcareous Sandstone Bed, 3,422 ppm.

Concluding from the petrological characteristics described above, the Calcareous Sandstone Bed represents the $CaCO_3$ zone of evaporites that is the higher order of theoretical evaporitic sequence continued from Fe_2O_3 zone in the Ferrugenous Sandstone Bed. Evidences of this interpretation are, firstly, ferrugenous cement decreases upward to the top of the Calcareous Sandstone Bed. Secondly, calcareous cement gradually increases from the lower to upper parts of the Bed until the detrital grains are floated in coarsely crystalline mosaic of calcite cement whereas the properties of the detrital grains are not changed, but the supply of the detrital grains during deposition decreases. Thirdly, calcite replaces both feldspar and quartz indicating the pH of 8-11 and solubility control of the seawater during calcite precipitation in the nearshore or shallow marine zone (Blatt et al.,1980). (Figure 3.2.2.4).

However, it is interesting to note that the contact of the Calcareous Sandstone Bed and the overlying Basal Anhydrite Bed is nearly horizontal sharp plane, and a thin green calcareous layer (2-3 centimeters thick) is commonly associated with this contact (Figure 3.2.2.5).

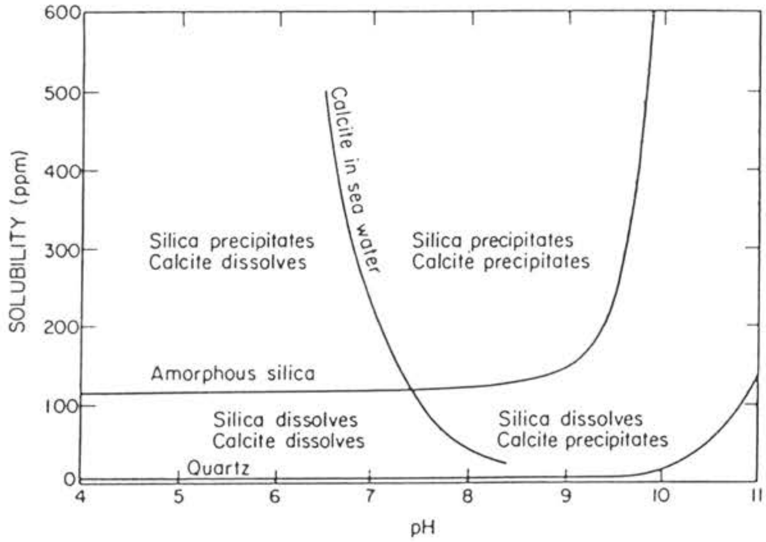


Figure 3.2.2.4 Relationship between pH and the solibilities of calcite, quartz, and amorphous silica. (After Blatt et al., 1980)

Figure 3.2.2.5 Photograph of the polished core-slab of the contact between Calcareous Sandstone and the overlying Basal Anhydrite beds.
(from drilled hole no. RS-2.21, at depth 259.61-259.70 m.)

3.2.3 Basal Anhydrite Bed

Generally, the Basal Anhydrite Bed can be divided into three parts, notably, the lower part, the middle part, and the upper part. The lower part of the Bed consists of medium light grey nodular anhydrite with some brownish grey networks of calcareous algal layers. The algal networks are abundant at the base of Basal Anhydrite Bed and decrease upwardly (Figure 3.2.3.1). The middle part, the main part of the Bed, is generally characterized by light grey nodular anhydrite surrounded by only a few calcareous algal networks (Figure 3.2.3.2). The upper part of the Bed that varies in thickness from 0.20 to 0.45 meter, and is composed of wavy-laminated medium grey anhydrite with thin brownish grey calcareous algal and black carbonaceous layers (Figures 3.2.3.3 and 3.2.3.4). It is noted that the contact between the Basal Anhydrite Bed and the overlying complete sequences of Basal Halite Bed is usually sharp in a nearly horizontal manner (0^{o}-15^{o} dipping). In contrast, the contact between the Basal Anhydrite Bed and the overlying incomplete sequences of Basal Halite Bed is generally sharp with low to high (0-45^{o}) dipping angles. (Figures 3.2.3.3 and 3.2.3.4)

Besides, mineral composition of the Bed determined from x-ray diffractogramme (Appendix 1-D) is mainly anhydrite, calcite, halite, carbon, gypsum (?), quartz (?), etc. It is noted that halite is present only in the uppermost part of the Bed.

From thin-sections, mineral composition in the lower part of the Bed consists of radiated acicular and fine-grained anhydrite developed between calcareous algal networks. Some calcite crystalline mosaic patches and a few coarsely crystalline mosaic of gypsum are

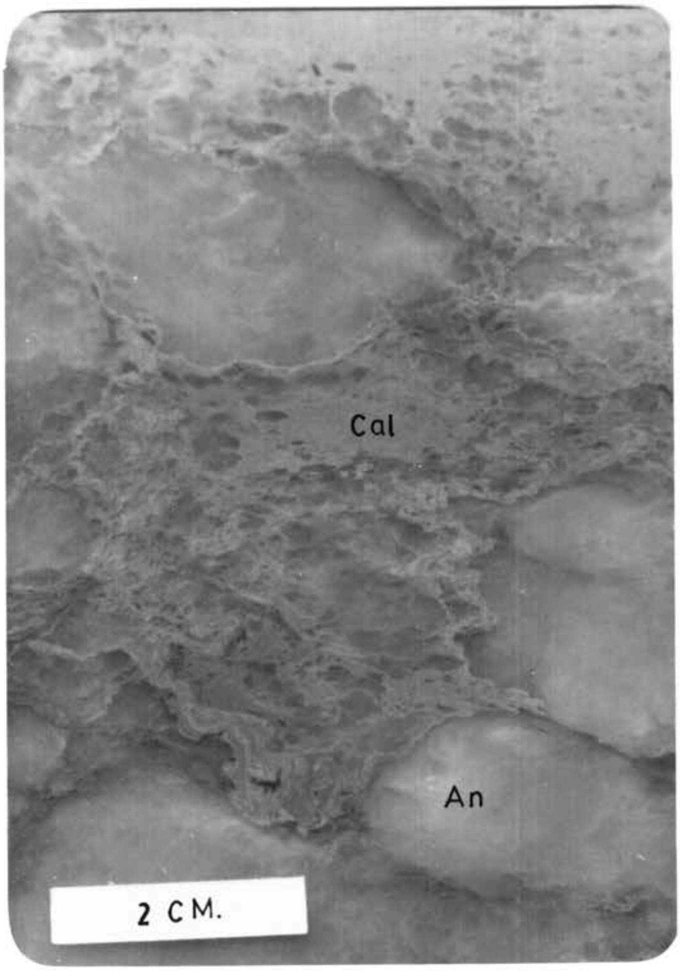


Figure 3.2.3.1 Photograph of the polished core-slab of the lower part of Basal Anhydrite Bed showing nodular anhydrite with abundant calcareous algal networks. An-anhydrite, Cal-calcareous algal networks.
(from drilled hole no. KB-2, at depth 354.24-354.32 m.)

Figure 3.2.3.2 Photograph of the polished core-slab of the middle part of Basal Anhydrite Bed showing nodular anhydrite with some calcareous algal networks.
(from drilled hole no. KB-2, depth 354.03-354.11 m.)

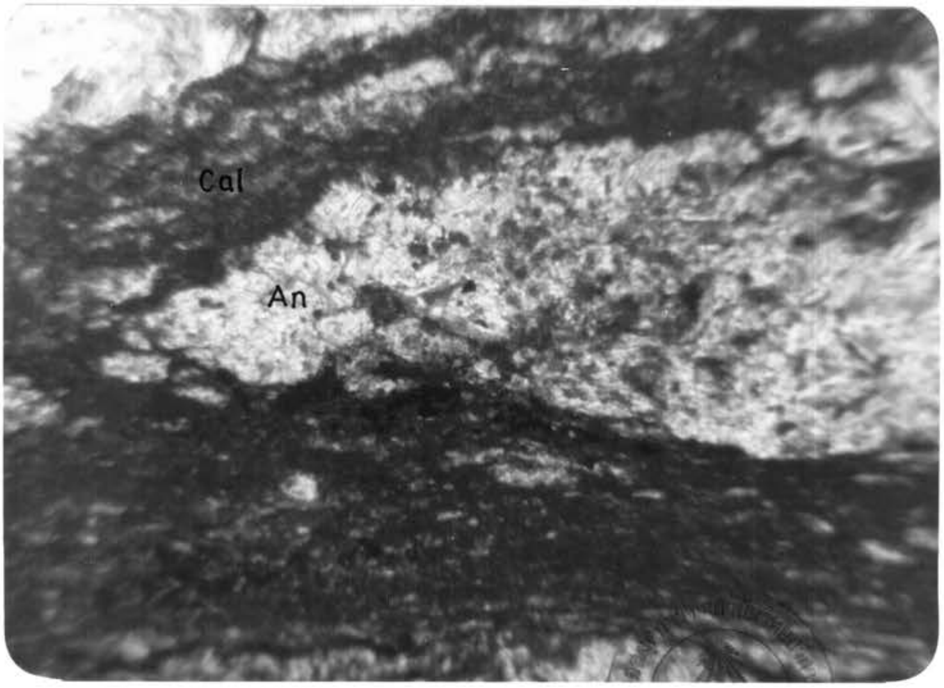
Figure 3.2.3.3 Photograph of the polished core-slab of the upper part of Basal Anhydrite Bed showing wavy-laminated anhydrite associated with calcareous algal and carbonaceous thin layers. An-anhydrite, Cal-calcareous algal, Car-carbonaceous. Note the uppermost part of the bed in contact with the overlying Basal Halite Bed.
(from drilled hole no. KB-2, at depth 353.35-353.45 m.)

Figure 3.2.3.4 Photograph of the polished core-slab of the contact between Basal Anhydrite Bed (wavy-laminated anhydrite) and the overlying incomplete sequences of Basal Halite Bed. Note the sharp contact and high-angle dipping. Wavy-laminations in Basal Anhydrite are generally parallel with the contact plane.
(from drilled hole no. RS-2.21, at depth 258.66-258.76 m.)

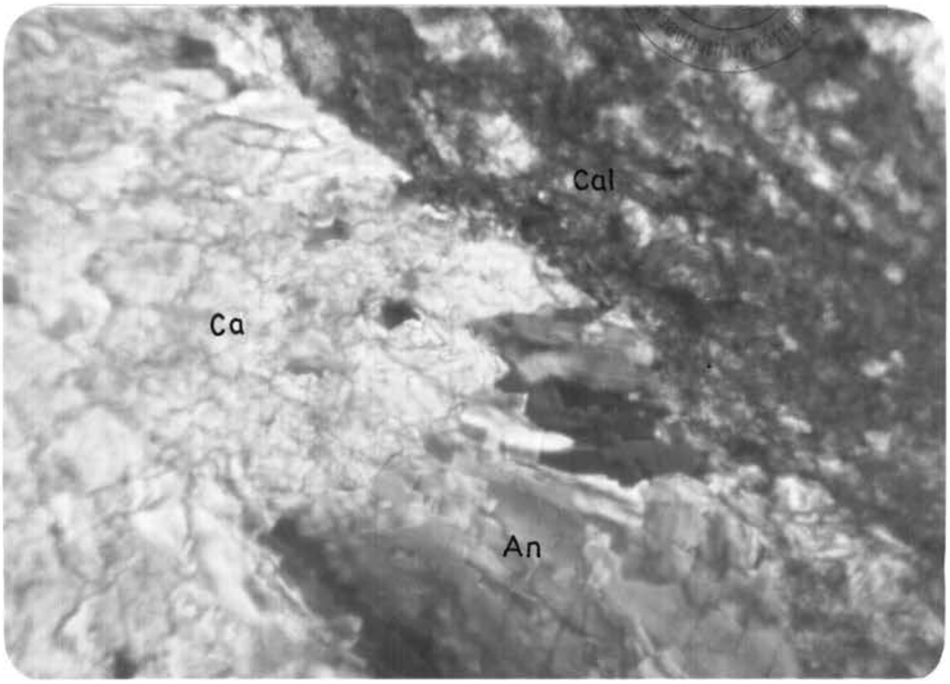
also scatteringly present (Figures 3.2.3.5 and 3.2.3.6). The middle part of the Bed is composed of fine-grained anhydrite with some aggregates of acicular anhydrite, calcite crystalline mosaic patches and a few calcareous algal layers (Figure 3.2.3.7). Besides, mineral composition in the upper part of the Bed is characterized by wavy-laminated acicular anhydrite with calcareous fine-grained layers, calcite in both micritic and sparry forms, and some carbonaceous layers. Furthermore, there are some gypsum (dissiminated, aggregated, tabular and rosette forms), subhedral dolomite crystals, and a few disseminated detrital quartz (?) grains in the upper part of the Bed. (Figures 3.2.3.8 and 3.2.3.9)

Generally, the textures of the Bed consist of acicular anhydrite in radiated form and acicular crystals parallel to the wavy-lamination. Within anhydrite nodules, the textures are mainly fine-grained with some associated acicular anhydrite aggregates. Besides, the diagenetic fabric of the Bed is characterized by the dolomitization of calcite and the replacement of calcite by anhydrite and gypsum. Both calcite and gypsum also replace acicular anhydrite. Some parts of coarsely crystalline mosaic gypsum is replaced by acicular anhydrite. Besides, some subhedral dolomites are replaced by acicular anhydrite in the uppermost part of the Bed.

However, it is noted that the Basal Anhydrite Bed is in the $CaSO_4$ zone of theoretical evaporitic sequences that is the higher order continued from $CaCO_3$ zone of the underlying Calcareous Sandstone Bed.



(a)



(b)

Figure 3.2.3.5 Photomicrographs of the lowest part of basal Anhydrite bed contact with the underlying Calcareous Sandstone Bed. An-anhydrite, Ca-calcite, Cal-calcareous algal networks.

(a) crossed nicols, approx. x 35.

(b) crossed nicols, approx. x 85.

(from drilled hole no. KB-2, at depth 354.32 m.)

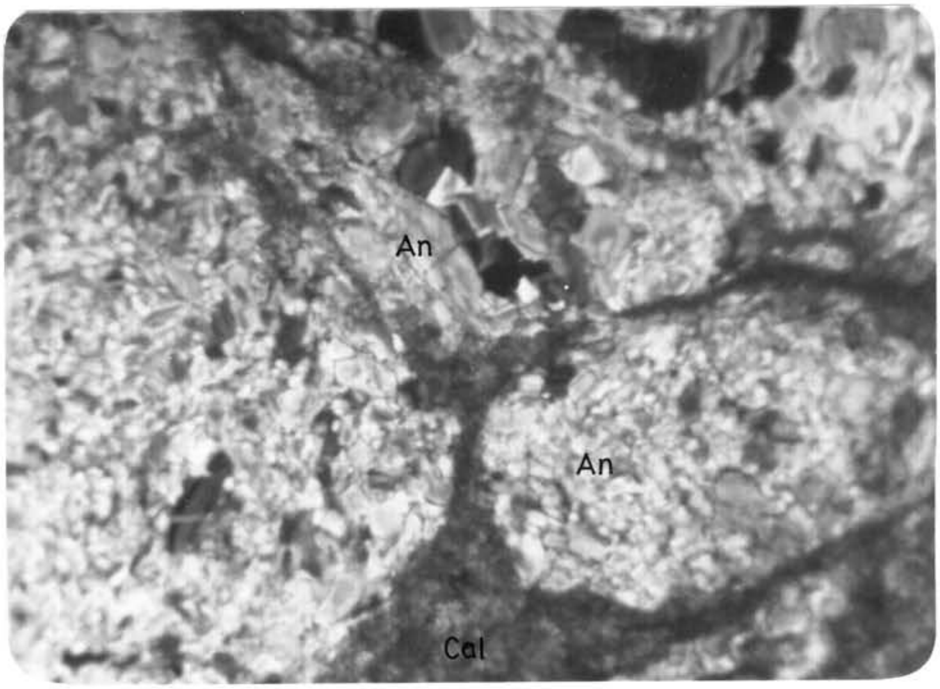
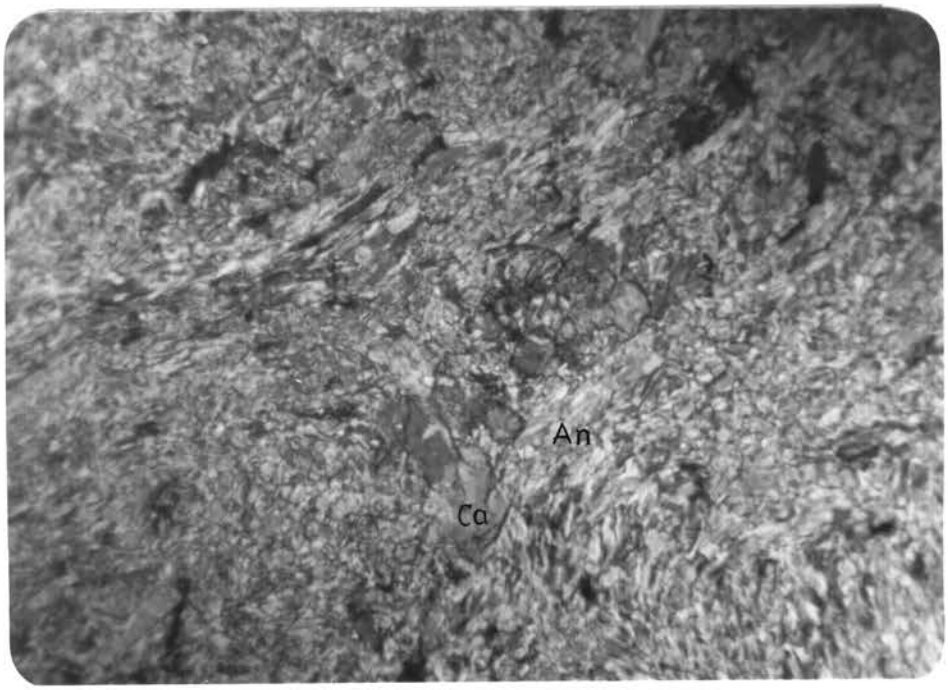
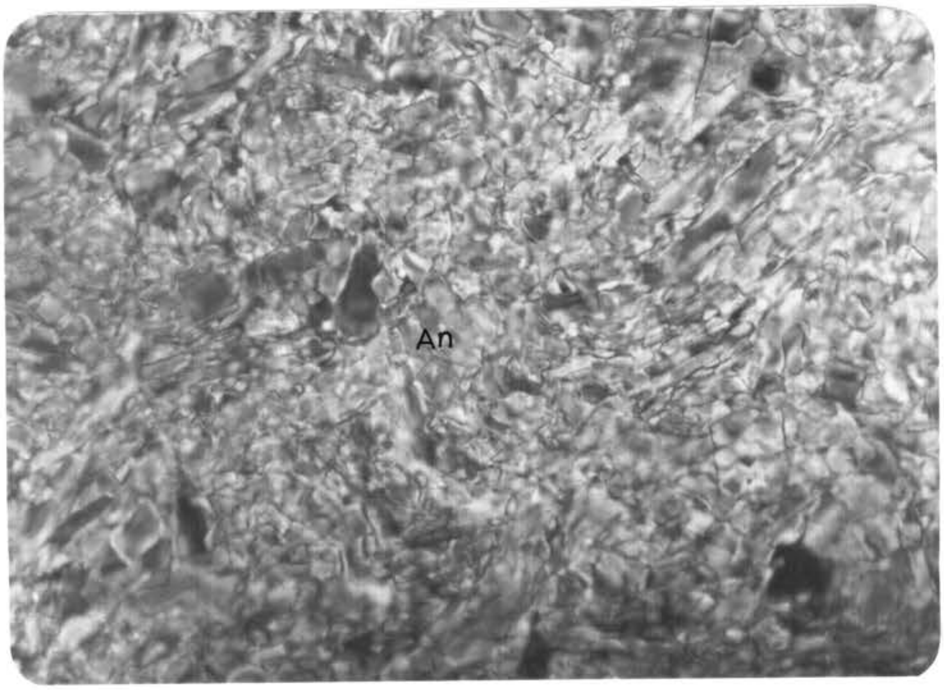


Figure 3.2.3.6 Photomicrograph of the lower part of Basal Anhydrite bed showing anhydrite nodules composed of fine-grained anhydrite and surrounded by calcareous algal networks or layers. An-anhydrite, Cal-calcareous algal networks. Crossed nicols, approx. x 85.
(from drilled hole no. Kb-2, at depth 354.29 m.)



(a)



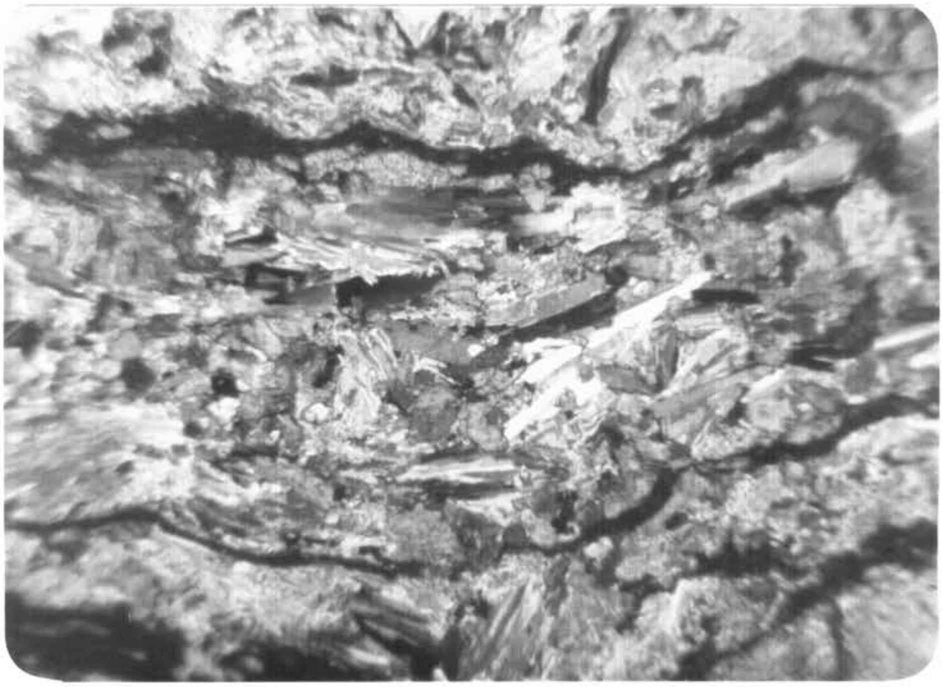
(b)

Figure 3.2.3.7 Photomicrographs of the middle part of basal Anhydrite bed showing fine-grained anhydrite with some aggregates of acicular anhydrite and a few calcite mosaic patches. An-anhydrite, Ca-calcite.

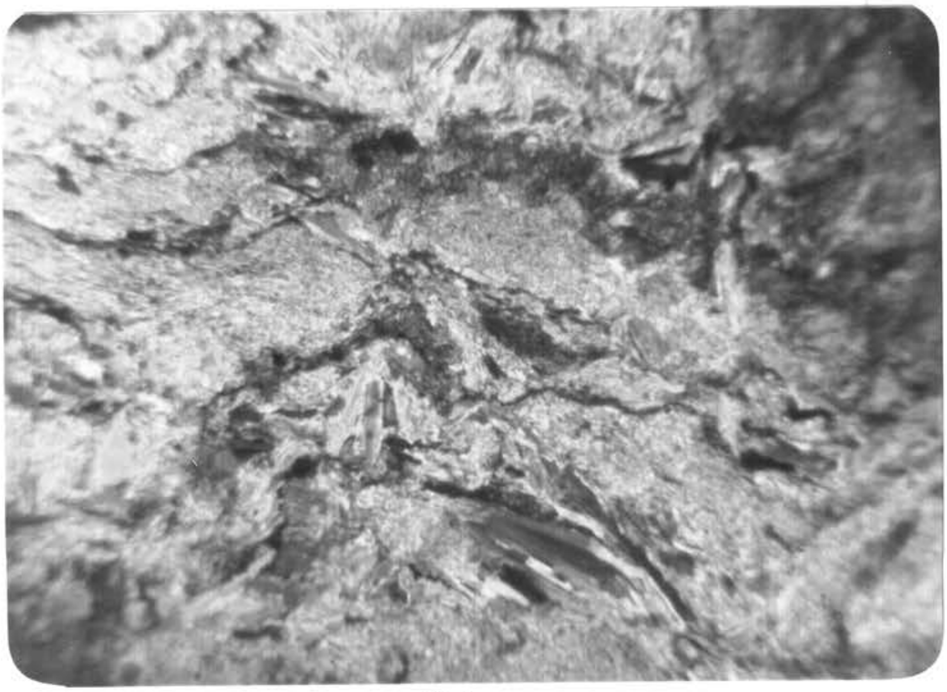
(a) crossed nicols, approx. x 85.

(b) crossed nicols, approx. x 175.

(from drilled hole no. Kb-2, at depth 354.21 m.)



(a)



(b)

Figure 3.2.3.8 Photomicrographs of the upper part of Basal Anhydrite Bed showing wavy-laminations of acicular and fine-grained anhydrite, and calcareous algal layers.

(a) from drilled hole no. KB-2, at depth 353.44 m.

(b) from drilled hole no. KB-2, at depth 353.36 m.

(crossed nicols, approx. x 35)

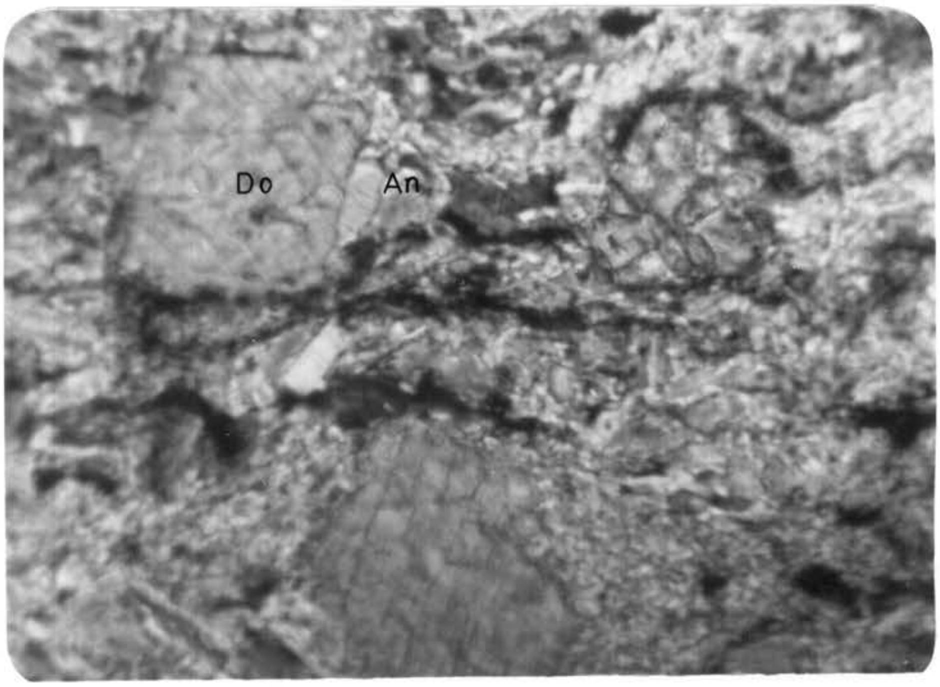


Figure 3.2.3.9 Photomicrograph of the upper part of Basal Anhydrite Bed showing replaced subhedral dolomite in wavy-laminated fine-grained anhydrite. Do-dolomite, An-anhydrite. (crossed nicols, approx. x 85). (from drilled hole no. KB-2, at depth 353.36 m.)

In addition, geochemistry of some trace elements (Mn, Fe, Sr, Ba) in Basal Anhydrite Bed are studied and presented in Appendix 1-E. These trace elements show specific patterns of behavior during the deposition of marine evaporites; strontium is concentrated in the earlier products of deposition, particularly in the sulphate zone (Stewart, 1963); strontium and manganese show significant differences in concentration in gypsum and anhydrite, etc.

Strontium replaces calcium in sulphates and carbonates, and average values of strontium for anhydrite in evaporite rock is up to 800 ppm (Stewart, 1963). Noll (1934) found that gypsum which had replaced earlier anhydrite at ordinary temperatures cannot always retain all the strontium of the anhydrite, and so celestite is formed (Stewart, 1963). This may explain the generally higher strontium values in the anhydrite. Besides, this may give an indication of anhydrite deposits, and enable a distinction between primary anhydrite with high strontium concentration and anhydrite which has replaced primary gypsum. The SrO figures in evaporite rock that Stewart (1963) cited (after Noll, 1934) are highest in anhydrite rock : 0.17-0.69%; 0.003-0.13% in gypsum rock, etc.

Strontium values in Basal Anhydrite Bed vary from 663 to 903 ppm and generally high towards the base of the Bed. This may explain the initial deposition of calcium sulphate as anhydrite.

Manganese occurs as evaporite rock impurities and is also concentrated in dolomite, where it presumably substitutes for magnesium. Kropachev (1960) reported average values of 120 ppm manganese in 80 anhydrite rocks and 370 ppm in epigenetic gypsum rocks (Stewart, 1963).

Manganese values in Basal Anhydrite Bed vary from 39 to 344 ppm and generally high towards the base of the Bed. Significant concentrations are present in the contact zone with the underlying Calcareous Sandstone Bed, up to 1,125 ppm. Generally, the quantities detected in the Bed are typical for initial deposition of calcium sulphate as anhydrite.

Like strontium, barium replaces calcium in sulphates and carbonates (Stewart, 1963). Van Engelhardt found 1-3 ppm in anhydrite rock, and 3-10 ppm in gypsum, in German evaporites (Stewart, 1963).

In Basal Anhydrite Bed, barium amounts are generally below 50 ppm which is the lower limit of detection of barium. The low values which are expected in evaporite minerals connot be measured.

Besides, iron values in the Bed vary from 68 to 433 ppm and show no obvious trend with depth.

In addition, the chemical data of some water soluble components of some components of representative samples of the Basal Anhydrite Bed are summarized and tabulated in Appendix 1-C. It is noted that the weight precent of soluble components of the Bed is in the range of 53.32-58.32.

3.2.4 Basal Halite Bed

The Basal Halite Bed, the major part of the Basal Salt Member, is found extensively throughout the study area. The complete sequences of the Bed are subdivided very generally into four parts with their nearly horizontal gradational contacts to each other. The lowest part of the Bed consists of clear fine-to medium-grained halite interbedded with smoky dark halite bands (Figures 3.2.4.1 and 3.2.4.2). Besides, some white-dull fine-to medium-grained anhydrite are scatteringly present and increase downwardly.

The second part of the Bed is characterized by clear and milky white medium-to coarse-grained halite interbedded with smoky dark halite bands and anhydrite layers (Figure 3.2.4.3). Milky white halite grains and anhydrite layers (.05-.60 meter thick) decrease in their degree of abundance downwardly. In contrast, the smoky dark halite bands (0.03-0.30 meter thick) that are interbedded in every 1.50-1.80 meters interval, increase downwardly. It is noted that the lowest and second parts of the Bed have nearly the same thickness and they are the major parts, about three-fourth of the total thickness, of the Basal Halite Bed.

The third part of the Basal Halite Bed consists of clear fine-to medium-grained halite with some anhydrite layers (Figure 3.2.4.4). The anhydrite layers, 0.1-5.0 centimeters thick, are interbedded in every 0.05-0.60 meter interval. Besides, the thickness of the anhydrite layers increases downwardly, the interval between the anhydrite layers simultaneously decreases. Some milky white halite grains are disseminated and increase in the degree of abundance downwardly.

The uppermost part of the Basal Halite Bed has generally only clear fine-grained halite (Figure 3.2.4.5). The thickness of this part is rather small as compared with other parts of the Bed. It is noted that the contact between this part and the overlying Potash Bed is gradational type (Figure 3.2.4.6).

Figure 3.2.4.1 Photograph of the core-slab of the lowest part of basal halite bed showing clear fine-to medium-grained halite with interlocked crystalline mosaic texture.
(from drilled hole no. KB-2, at depth 353.08-353.16 m.)

Figure 3.2.4.2 Photograph of the core-slab of the lowest part of basal Halite Bed showing clear fine-to medium-grained halite interbedded with smoky dark halite band. (from drilled hole no. KB-2, at depth 323.63-323.75 m.)

Figure 3.2.4.3 Photograph of the core-slab of the second part of basal halite bed showing clear and milky white medium- to coarse-grained halite interbedded with smoky dark halite bands and anhydrite layers.
(from drilled hole no. KB-2, at depth 286.60-286.72 m.)

Figure 3.2.4.4 Photograph of the core-slab of the third part of basal halite bed showing clear and milky white fine-to medium-grained halite interbedded with anhydrite layers. (from drilled hole no. KB-2, at depth 203.92-204.14 m.)

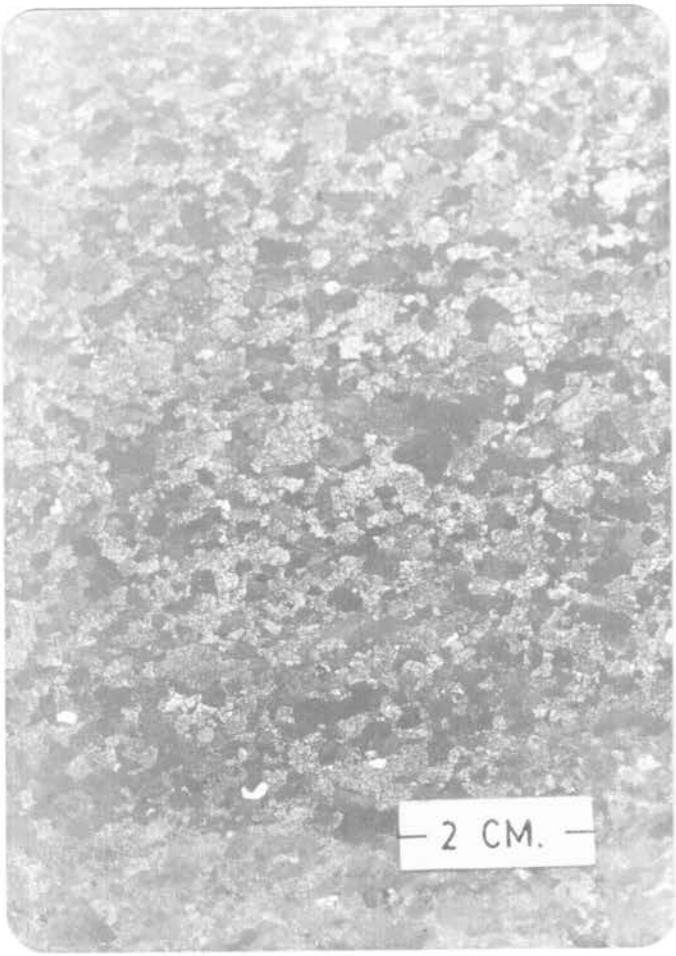


Figure 3.2.4.5 Photomicrograph of the core-slab of the uppermost part of basal halite bed showing clear fine-grained halite with interlocked crystalline mosaic texture.
(from drilled hole no. KB-2, at depth 182.63-182.75 m.)

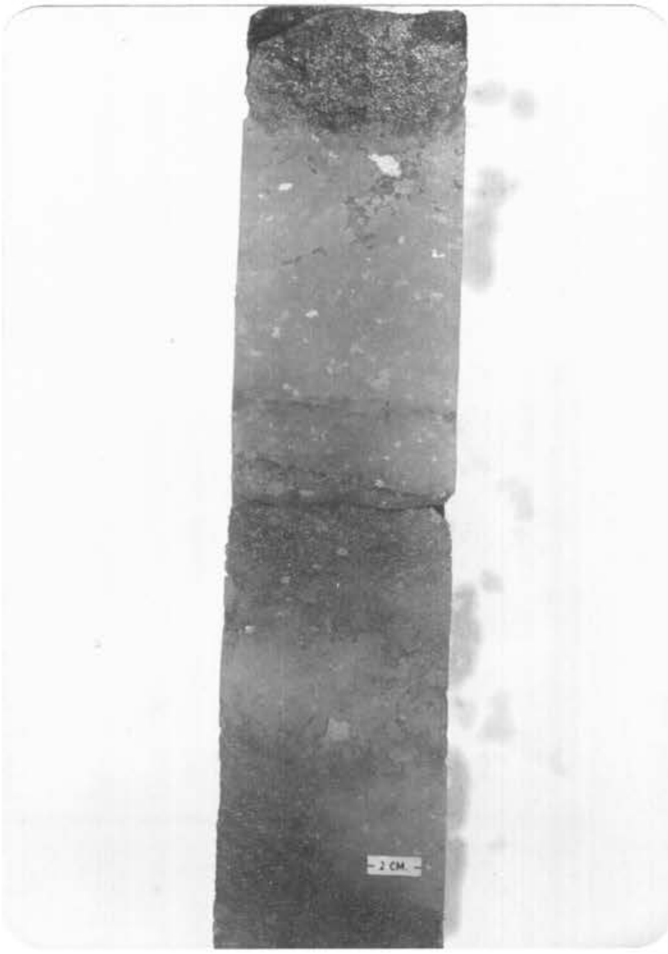


Figure 3.2.4.6 Photograph of the core-slab of the gradational contact zone between Basal Halite and Potash Beds.
(from drilled hole no. Kb-2, at depth 179.71-180.10 m.)

Besides, the texture of most halite grains in the Basal Halite Bed are interlocked crystalline mosaic.

In addition, the mineral composition of the Potash Bed determined from the representative diffractogramme (Appendix 1-D) is mainly halite with some anhydrite, gypsum (?), etc. Besides, the chemical data of some water soluble components of representative samples of the Potash Bed are summarized and presented in Appendix 1-C.

In the incomplete sequences of the Basal Halite Bed, only the lowest and second parts of the complete sequences of the Basal Halite Bed are commonly present. In contrast, the third and uppermost parts of the complete sequences of the Bed are mostly absent. Generally, the incomplete sequences of the Bed are subdivided into two major parts, namely, the lower part and upper part.

The lower part of the incomplete sequences of the bed, similar to the lowerest part of the complete sequences of the Bed, is characterized by clear fine-to medium-grained halite interbedded with smoky dark halite bands. Besides, some white-dull fine-to medium-grained anhydrite are scatteringly present.

The upper part of the incomplete sequences of the Bed generally consists of clear and milky white medium-to coarse-elongated grains of halite. Some smoky dark halite bands are interbedded. Besides, anhydrite layers are absent or rare in this part. It is noted that the dipping-angle of the incomplete sequences of the Bed progressively increases upward from low-angle dipping in the lower part to very high-angle dipping in the upper part (Figure 3.2.4.7).

Figure 3.2.4.7 Photograph of the core-sample of Basal halite bed of the incomplete sequences showing very high-dipping angle of the anhydrite layers and smoky dark halite band.

(from drilled hole no. RS-2.21, at depth 257.64-257.84 m.)

In addition, the deformation of the incomplete sequences of the basal halite Bed is stronger than in the complete sequences of the Bed. The evidences are, firstly, a marked angular contact plane representing salt flowage along a more competent underlying Basal Anhydrite Bed (Figure 3.2.3.4). Secondly, the attitude of the incomplete sequences of Basal Halite Bed generally increases upwardly from low-angle to very high-angle dipping (indicated by a few thin anhydrite layers, smoky dark halite bands, as well as oriented-elongated halite grains). Thirdly, the bromine profiles of the incomplete sequences of Basal Halite Bed (Figure 3.1.2) are in average of about 100 ppm of KBr content throughout the sequences. In contrast, the KBr content in the complete sequences of Basal halite Bed progressively increases from the lowest part of approximately 100 ppm KBr, to the uppermost part of about 500 ppm KBr (Figure 3.1.1).

However, the Basal Halite Bed is mainly in the NaCl zone of theoretical evaporitic sequence that is the progressive higher order continued from the $CaSO_4$ zone of evaporites in the underlying Basal Anhydrite Bed.

3.2.5 Potash Bed

The Potash Bed, containing the highest order evaporites of the Basal Salt Member, is generally subdivided into three Sub-Beds, notably, the lower Sylvinite, Carnallite-Halite-Tachyhydrite, and the upper Sylvinite. It is noted that the Carnallite-halite-Tachyhydrite Sub-Bed is the major and most common part of the Potash Bed. Besides, mineral composition, determined from some representative x-ray diffractogrammes of the Potash Bed (Appendix 1-D), is characterized by carnallite, halite, tachyhydrite, sylvite, anhydrite (?), etc.

The lower Sylvinite Sub-Bed is rather rare and only present in the western part of the area as shown in the stratigraphic cross-section (Plate 4). The Sub-Bed is characterized by amoeboidal or graphic intergrowths of halite and sylvite (Figure 3.2.5.1). However, this Sub-bed consists entirely of sylvite and halite with few magnesium salts. The general lithology of the Sub-Bed is mainly composed of clear, blue and/or violet-blue medium-to coarse grains halite intergrowths in amoeboidal or graphic texture with cloudy white, pale orange and/or orange-red sylvite grains. Locally, some orange-red carnallite grains are scatteringly present.

The Carnallite-Halite-Tachyhydrite Sub-Bed, the most common Sub-Bed in the Potash Bed, can be generally subdivided into three parts, notably, the lower, the middle and the upper parts which grade to each other. The lower part of the Sub-Bed is mainly composed of pale-pink, violet-pink, clear and/or pale orange to orange-red medium-grained carnallite. Some clear and/or smoky dark medium-to coarse-grained halite are present in the form of interlocked crystalline mosaic mixing and alternating with carnallite bands (Figure 3.2.5.2). This part of the Sub-Bed is the major part and the highest grade of carnallite. The associated halite bands, 0.15-1.00 meter thick, increase in content downwardly. Besides, some white-grey coarse-grained halite, carnallite, sylvite, anhydrite (?), etc. (determined from x-ray diffractogramme in Appendix 1-D) are disseminated in this part (Figure 3.2.5.3). A few yellowish white minerals (boracite ?) are also scatteringly present in this part too. Locally, deep orange-red sylvite grains are associated with deep orange-red carnallite grains.

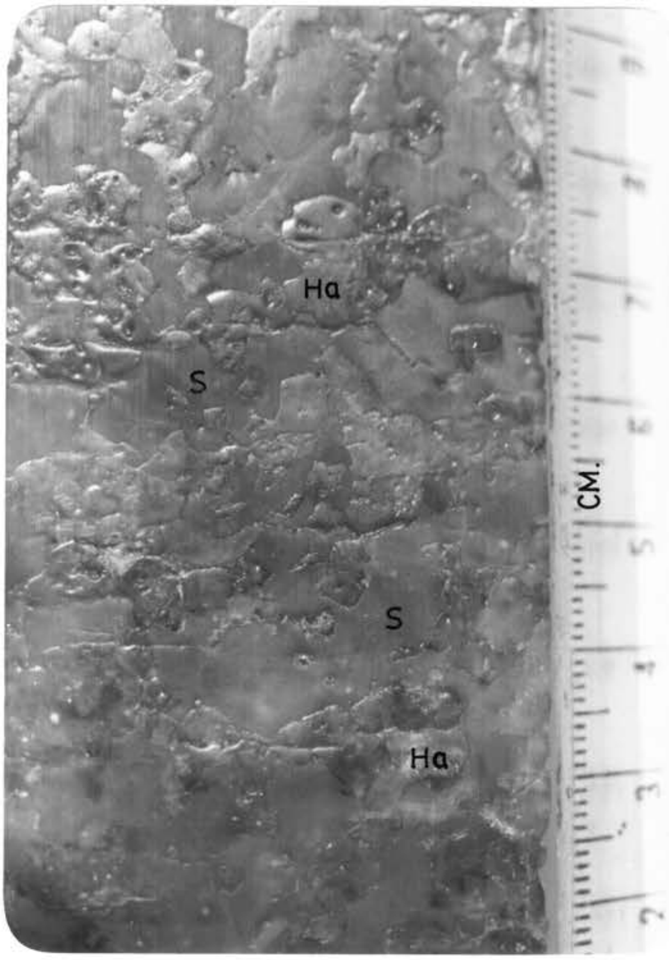


Figure 3.2.5.1 Photograph of the core-sample of Sylvinite Sub-bed showing amoeboidal (or graphic) intergrowths of halite and sylvite. Ha-halite, S-sylvite.
(from drilled hole no. K-47 in Khon Khaen Area, at depth 436'-436' 5").

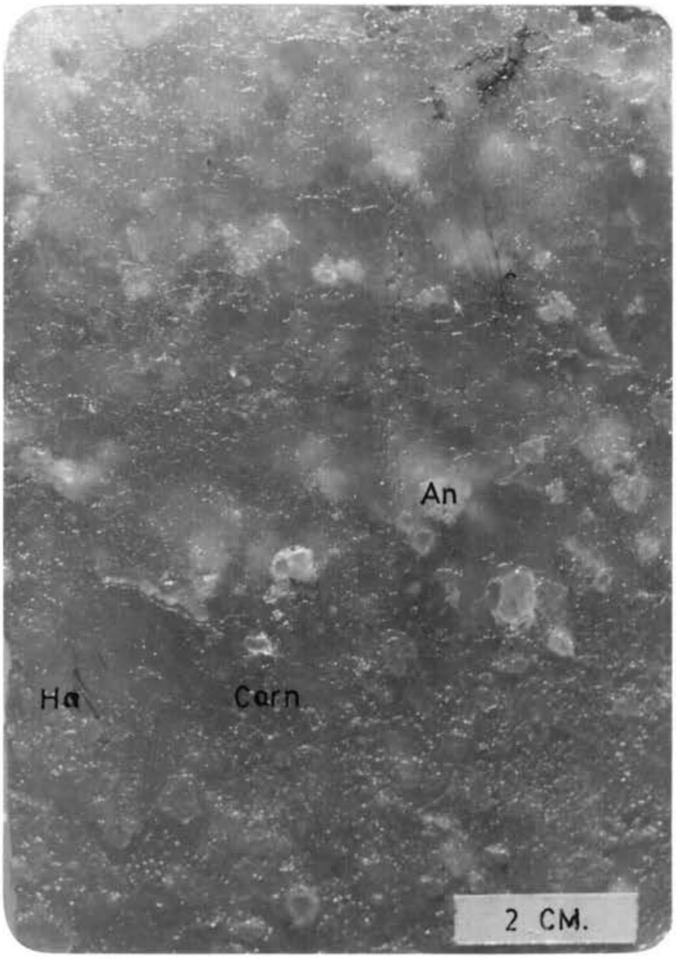


Figure 3.2.5.2 Photograph of the core-slab of the lower part of Carnallite-halite-Tachyhydrite Sub-Bed. Carn-carnallite, ha-halite, An-anhydrite (?) (from drilled hole no. KB-2, at depth 171.40-171.50 m.)

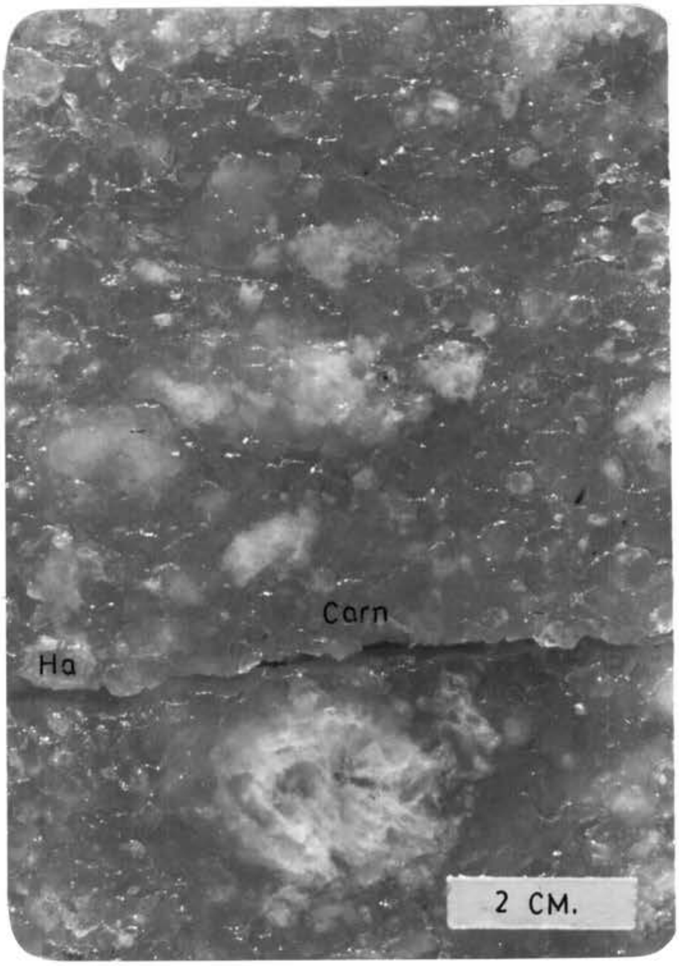


Figure 3.2.5.3 Photograph of the core-slab of the lower part of Carnallite-Halite-Tachyhydrite Sub-Bed with some disseminated white-grey coarse grains of halite, carnallite, sylvite, anhydrite (?).

Carn-carnallite, Ha-halite.

(from drilled hole no. KB-2, at depth 166.46-166.56 m.)

The middle part of the Sub-Bed is mainly characterized by yellow, orange, orange-yellow, honey yellow and/or yellowish brown tachyhydrite. Some clear medium-to coarse-grained halite are associated in the form of interlocked crystalline mosaic mixing and alternating with tachyhydrite bands (Figure 3.2.5.4). The tachyhydrite grains are normally large, 1-4 centimeters wide, as well as they decrease in size but increase in content downwardly. Besides, the texture of tachyhydrite is sugary, very brittle and easily dissolved. There are also some carnallite present in the form of interlocked crystalline mosaic mixing and alternating with tachyhydrite bands. A few white-grey anhydrite (?) grains and yellowish white boracite (?) minerals are scatteringly present in this part. It is noted that carnallite and tachyhydrite normally occurred as the crystalline intergrowths.

The upper part of the Carnallite-Halite-Tachyhydrite Sub-Bed consists mainly of clear, white, honey and/or smoky dark medium-to coarse-grained halite. Some orange to deep red, honey brown and/or pink fine-to coarse-grained carnallite are associated with halite and exhibiting the crystalline intergrowths textural relationships mixing and alternating with halite bands (Figure 3.2.5.5). The thicknesses of halite beds and carnallite beds vary in the range of 0.05-1.00 meter and 0.05-0.50 meter, respectively. Besides, there are a few white-grey coarse-grained anhydrite (?) associated with this part.

In the uppermost part of the Carnallite-Halite-Tachyhydrite Sub-Bed, some dark grey clay layers and halite bands are interbedded with deep orange-red carnallite and/or sylvite bands. It is noted that mineral composition in the dark grey clay layers, determined from x-ray diffractogramme (Appendix 1-D), is mainly halite, anhydrite,

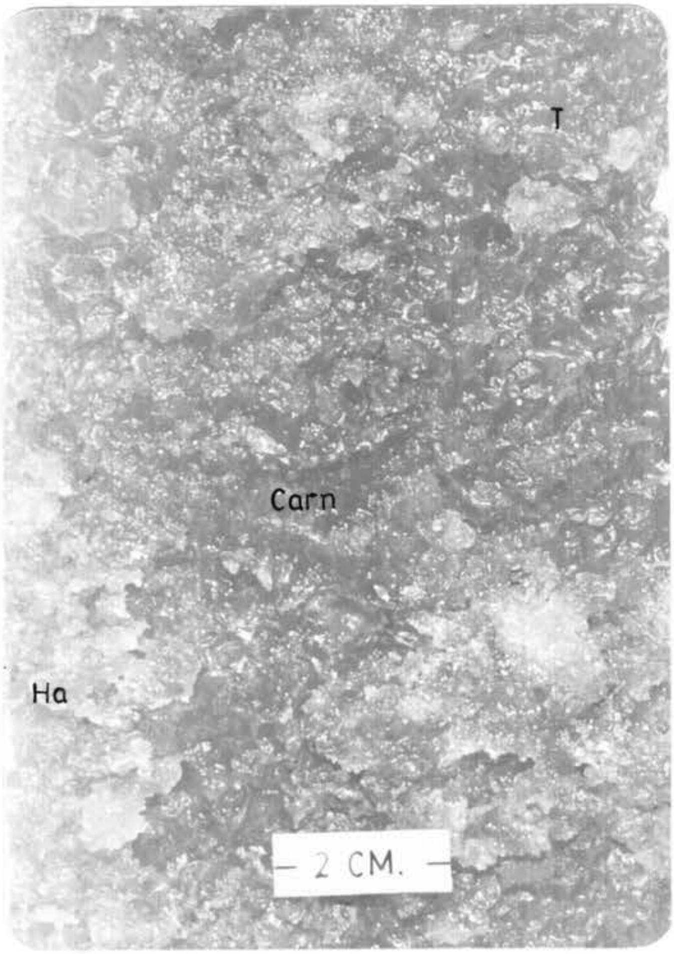


Figure 3.2.5.4 Photograph of the core-sample of the middle part of Carnallite-halite-Tachyhydrite Sub-bed. T-tachyhydrite, Carn-carnallite, Ha-halite.
(from drilled hole no. Kb-2, at depth 155.10-155.21 m.)

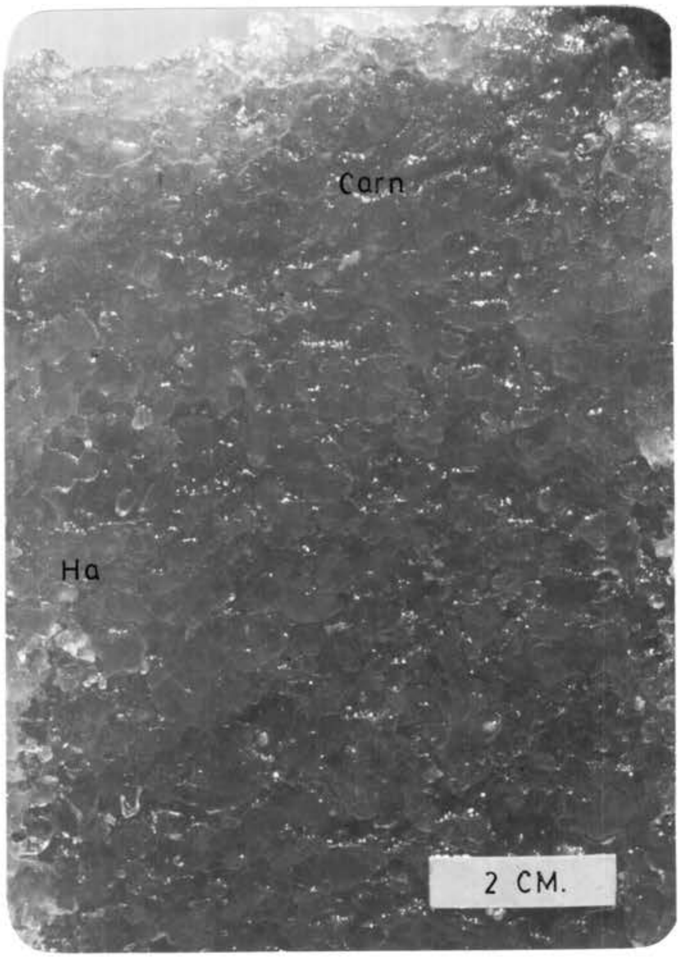


Figure 3.2.5.5 Photograph of the core-slab of the upper part of Carnallite-halite-Tachyhydrite Sub-Bed. Ha-halite, Carn-carnallite.
(from drilled hole no. KB-2, at depth 147.90-148.00 m.)

quartz, illite, kaolinite, etc. For minerals of the deep orange-red band, they are generally halite, carnallite, sylvite, etc.

The upper Sylvinite Sub-Bed of the Potash Bed has the general characteristics similar to those of the lower Sylvinite Sub-Bed. But its distributions in the area are more extensive than the lower Sylvinite Sub-Bed, as shown in the lithostratigraphic cross-sections (Plates 4 and 5). It is interesting to note that the amoeboidal or graphic texture of the lower and upper Sylvinite Sub-Beds indicates secondary origin. Besides, tachyhydrite mineral is rare or absent in these Sylvinite Sub-Beds.

The chemical data of some water soluble components of representative samples of the Potash Bed are summarized and presented in Appendix 1-C. The profiles and matrix correlation of Na_2O, K_2O, CaO, MgO content, and gamma ray (C.P.S.) in the Potash Bed, are analyzed using HP-85 microcomputer with the programme package named 'BA[illegible]T' developed by the Department of Geology, Chulalongkorn University (Sriisraporn, S., 1982, personal communication) are summarized and presented in Appendix 1-F. Generally, the weight percent of K_2O in Carnallite-Halite-Tachyhydrite Sub-Bed varies in the range of 1-15. It is noted that the K_2O weight percent is rather high, in the range of 10-15, in the lower part of Carnallite-Halite-Tachyhydrite Sub-Bed. The K_2O weight percent in the Sylvinite Sub-Beds is apparently much higher, up to 20%. However, the weight percent of Na_2O in the Potash Bed has the negative relationships with both of the weight percents of MgO and K_2O. In contrast, MgO and K_2O weight percents generally have the positive relationships with each other.

3.2.6 Coloured Halite Bed

The coloured Halite Bed is mainly characterized by the interbedding of several coloured bands of halite, carnallite and/or sylvite, and darker clay layer (Figure 3.2.6). The halite bands, 1-5 centimeters thick, are fine-to coarse-grained, clear, grey to dark grey, smoky dark, yellowish brown and orange. The bands of darker clay layer, 0.5-2 centimeters thick, are black and dark grey in colour. Besides, some deep orange-red carnallite and/or sylvite bands (0.5-1 centimeter thick) and grains are intercalated and disseminated in the halite bands respectively.

In a relatively thick sequence of the Coloured Halite Bed, the lower part of the Bed is usually clear coarse-grained halite interbedded with thick smoky halite bands. There are some white-grey grains and layers of anhydrite, as well as the traces of carnallite and tachyhydrite associated in this lower part of the Bed too.

However, the darker clay layers in the Bed increase in content upwardly indicating the gradational contact with the overlying Lower Clastics Member.

3.2.7 Basal Cap Anhydrite Bed

Generally, the Basal Cap Anhydrite Bed is mottled very light grey. Mineral composition is mainly anhydrite with some black carbonaceous matters, gypsum and dolomite. Anhydrite grains are in the lenticular-shaped nodular texture having the preferred oreintation or gneissoid texture (Figure 3.2.7.1). Besides, the Bed is rather tightly packed, and strongly fractured. In the upper part of the Bed, some euhedral gypsum crystals are scatteringly present. It is noted that the

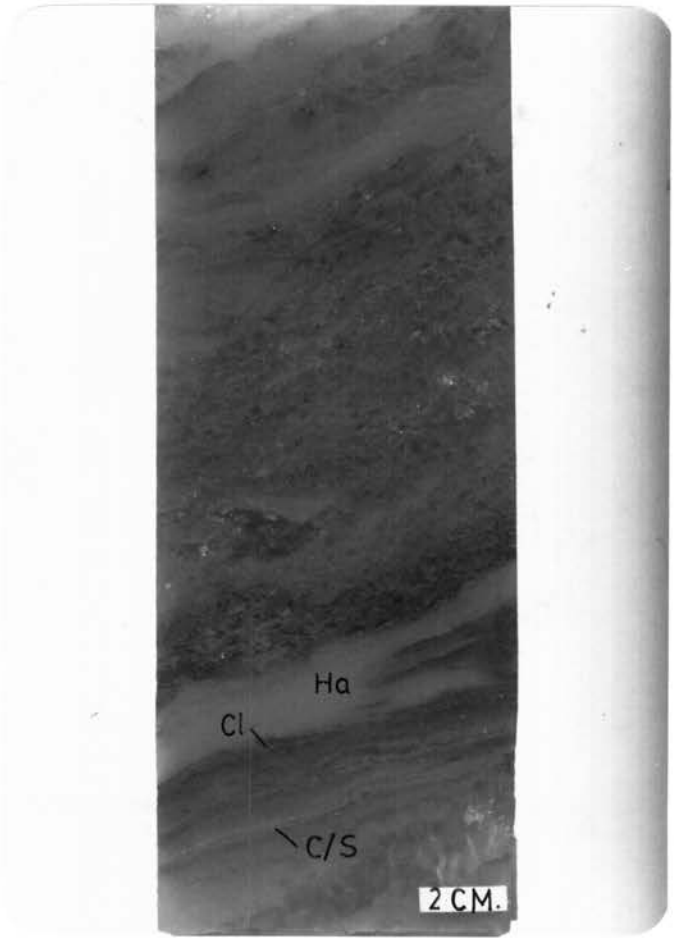
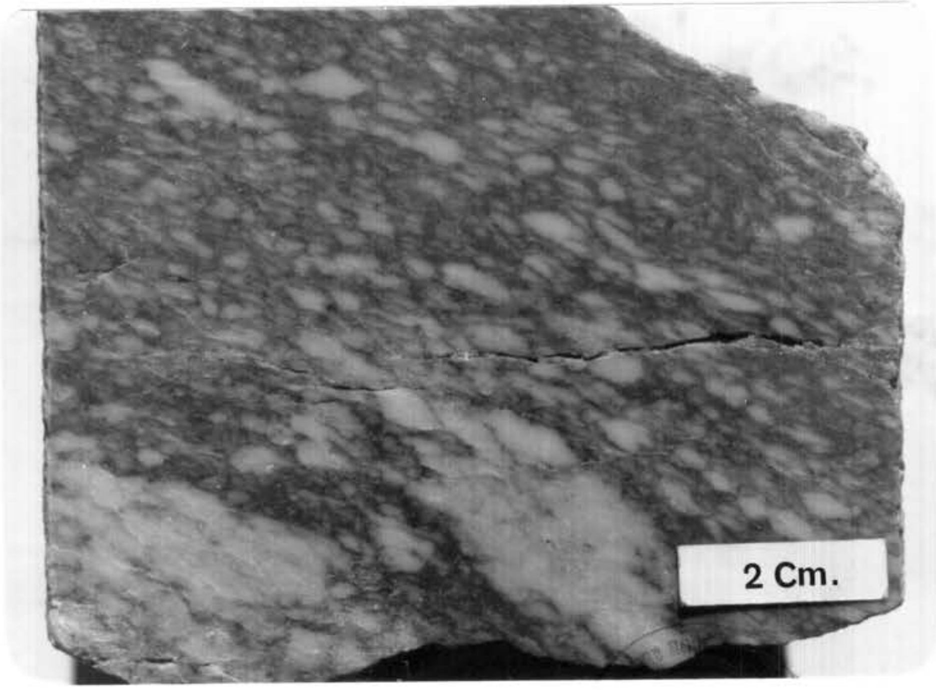
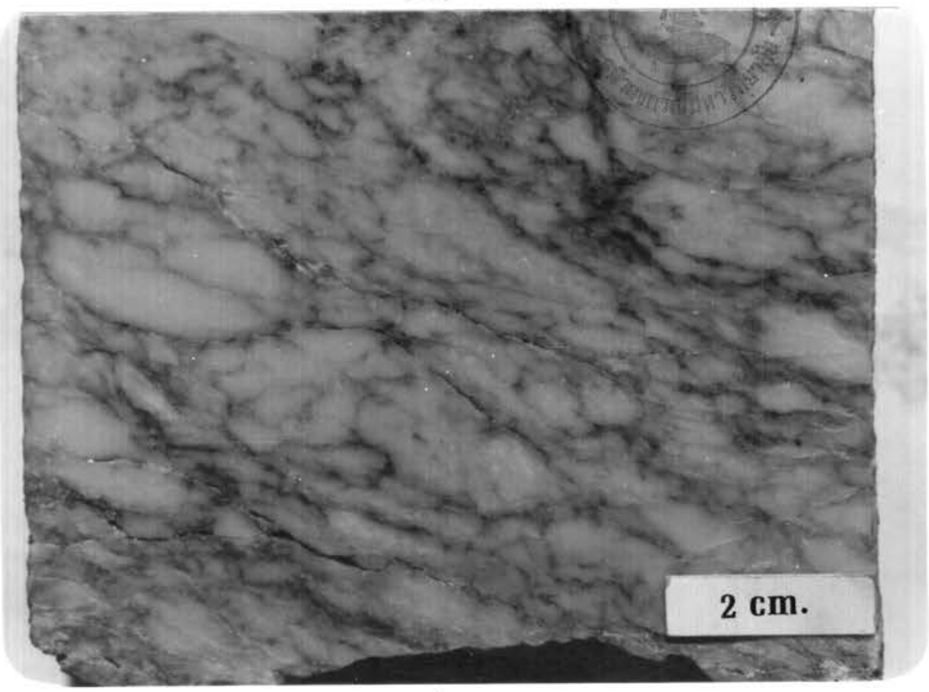


Figure 3.2.6 Photograph of the core-slab of Coloured Halite Bed showing interbeds of several coloured bands of halite (Ha), carnallite and/or sylvite (C/S), and clay layers (Cl).
(from drilled hole no. KB-2, at depth 140.80-141.02 m.)



(a)



(b)

Figure 3.2.7.1 Photographs of the core-slab of basal Cap Anhydrite bed showing gneissoid texture of anhydrite nodules and black carbonaceous layers.

(a) from drilled hole no. RS-2.21, at depth 68.11-68.17 m.

(b) from drilled hole no. RS-2.21, at depth 66.07-66.13 m.

carbonaceous layers normally increase in their abundance downwardly.

From thin-sections, mineral composition in the lower part of the Bed consists of main fine-grained anhydrite with some fibrous to fibroradiated acicular anhydrite patches. A few large disseminated subhedral dolomite crystals are present in the Bed too (Figure 3.2.7.2).

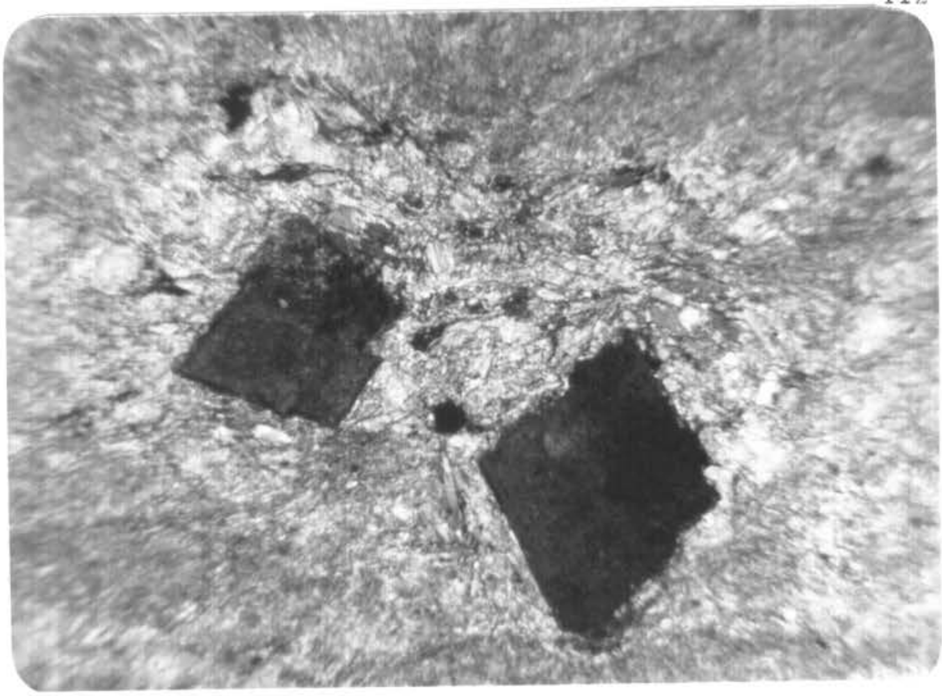
It is noted that acicular anhydrite generally shows fibrous to fibroradiated texture. The large disseminated subhedral dolomite crystals are commonly replaced by acicular anhydrite crystals (Figure 3.2.7.2).

However, the mineral composition of the Basal Cap Anhydrite Bed determined from x-ray diffractogramme (Appendix 1-D) is mainly composed of anhydrite, some gypsum, etc.

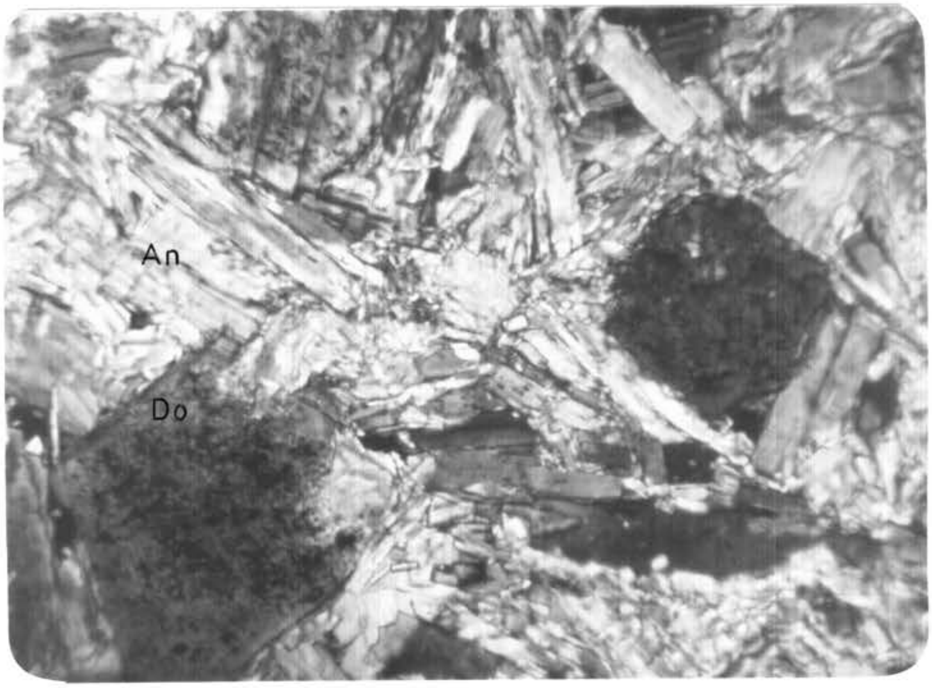
From the field relation and petrological characteristics of the Basal Halite and Basal Cap Anhydrite Beds, the Basal Cap Anhydrite Bed seems to be the result of a residual accumulation from the anhydrite layers leached from the dissolution in the upper part of the complete sequences of the Basal Halite Bed.

In addition, the geochemistry of some trace elements (Mn, Fe, Sr, Ba) in Basal Cap Anhydrite Bed are analysed and presented in Appendix 1-E.

Strontium values in the Bed vary from 511 to 674 ppm and show no obvious trend with depth. It is noted that the strontium values in the Bed are relatively lower than those in the Basal Anhydrite Bed. The average values of strontium for anhydrite in evaporite rock can be up to 800 ppm (Stewart, 1963). Therefore, it is apparent that the



(a)



(b)

Figure 3.2.7.2 Photomicrographs of Basal Cap Anhydrite Bed showing fine-grained anhydrite and acicular anhydrite textures. Note subhedral dolomite crystals replaced by acicular anhydrite. An-anhydrite, Do-dolomite.

(a) from drilled hole no. RS-2.21, at depth 67.02 m. (crossed nicols, approx. x 35).

(b) from drilled hole no. RS-2.21, at depth 66.06 m. (crossed nicols, approx. x 85).

average values of strontium content in Basal Cap Anhydrite Bed in this study are much lower than normal values.

Manganese values in the Bed vary from 8 to 55 ppm and show no obvious trend with depth. It is noted that manganese values in the Bed are lower than average values of 120 ppm manganese in 80 anhydrite rocks (Stewart, 1963).

Barium values in the Basal Cap Anhydrite Bed and the Basal Anhydrite Bed are generally below 50 ppm. Besides, iron values very from 72 to 206 ppm in the Bed with no obvious trend with depth.

The chemical data of some water soluble components of representative samples of the Bed are summarized and presented Appendix 1-C. The weight percent of the total soluble components in the Basal Cap Anhydrite Bed varies in the range of 69.32-70.12 that is relatively higher than the weight percent of the total soluble components in the Basal Anhydrite Bed.

3.3 Lower Clastics Member

The Lower Clastics Member is generally subdivided into two parts, notably, the lower and the upper parts. The lower part of the Member consists of the dark grey semi-consolidated clay to claystone/mudstone that is upwardly graded to greenish grey semi-consolidated clay to claystone/mudstone. The thickness of this part is about one-fourth of the total thickness of the Member. Generally, this part is mainly semi-consolidated, plastic, sticky and very well compacted, massive and nearly horizontally laminated in some intervals. Besides, numerous halite crystals are associated with dark grey semi-consolidated clay to claystone/mudstone as chaotic mudstone-halite texture, crystals of halite floating in mudstone-matrix. These halite crystals increase upto 50% in content downward to the bottom part of the Member. In addition, some clear, pale orange, yellowish brown halite and orange-red carnallite are associated as veins and veinlets along the steep to nearly vertical dipping fractures. It is noted that there are some white-grey anhydrite spots and/or layers disseminated throughout the greenish grey semi-consolidated clay to claystone/mudstone.

The upper part, the major part of the Member, is characterized by the reddish brown semi-consolidated clay to claystone/mudstone. Some associated greenish grey semi-consolidated clay to claystone/mudstone is mottled and interbedded, especially in the lower interval of this upper part of the Lower Clastics Member. The other lithological characteristics are generally similar to those of the lower part of this Member. However, the amount of halite crystals associated with this upper part are less abundant. In contrast, the amount of anhydrite grains and/or layers are relatively more abundant in the upper part than the lower part of the Member.

It is noted that the lower part is graded into the upper part of this member indicating by the interbedding of the greenish grey and the reddish brown semi-consolidated clay to claystones/mudstones. Besides, the contact with the overlying Middle Salt Member is of nearly horizontal gradational type.

From the x-ray diffractogrammes of this Member (Appendix 1-D), mineral composition of the lower part of this Member is quartz, halite, anhydrite, kaolinite, illite, chlorite (?), hematite (?), etc. However, mineral composition of the upper part of this Member is characterized by quartz, anhydrite, halite, illite, kaolinite, chlorite, hematite (?), etc. Therefore, mineral compositions in both parts of this Member are generally similar in nature with only slight variation in their abundances. It is interesting to note that the chemical content of some water soluble components of representative samples of the Lower Clastics Member (Appendix 1-C) indicates that the weight percent of soluble components in this Member increase downward from 11.32 to 32.32 at the bottom of this Member. Besides, the weight percents of soluble alkaline oxides (Na_2O, K_2O, CaO and MgO) generally increase downward to the bottom part of this Member too (Appendix 1-C). It is noted that the content of soluble MgO in the Lower Clastics Member is in the range of 0.26-0.58 wt.%.

However, this Member is composed mainly of fine-grained clastic sediments with some NaCl and $CaSO_4$ orders of evaporites. Besides, traces of potassium and magnesium salts are disseminated in this Member too.

3.4 Middle Salt Member

The Middle Salt Member is generally subdivided into four Beds, namely, Lower Middle Halite, Middle Anhydrite, Upper Middle Halite, and Middle Cap Anhydrite in their decreasing depth order respectively. Besides, these Beds have nearly horizontal gradational contacts with each other, and conformable with the overlying Middle Clastics Member. The detailed mineralogy and petrography of these Beds in the Middle Salt Member are described below.

3.4.1 Lower Middle Halite Bed

The Lower Middle Halite Bed is subdivided into three parts with gradational contacts to each other, notably, the lower, the middle and the upper parts.

The lower part of the Bed consists mainly of dark honey fine-grained halite interbedded with smoky dark halite beds, 1-5 centimeters thick (Figure 3.4.1.1). Besides, same pale orange, light yellowish brown halite grains and traces of orange-red carnallite and/or cloudy white sylvite grains/layers are scatteringly present.

The middle part of the Bed is characterized by honey brown, pale orange, light yellowish brown fine-to medium-grained halite interbedded with some smoky dark halite bands.

The upper part of the Bed is composed mainly of dirty honey, dark yellowish brown fine-grained halite interbedded with smoky dark halite bands (Figure 3.4.1.2). Locally, some clear, light brown, orange and grey coarse-grained halite are disseminated.

It is noted that the anhydrite layers are less abundant in the Lower Middle Halite Bed. Furthermore, fractures developed along the bedding plane are dominant.

In addition, mineral composition of the Bed, determined from x-ray diffractogramme (Appendix 1-D), is mainly halite, anhydrite, gypsum (?), etc. Traces of carnallite and sylvite grains/layers associated in the Bed are also noted.

The chemical data of some water soluble components of representative samples of the Lower Middle Halite Bed are summarized and tabulated in Appendix 1-C.

3.4.2 Middle Anhydrite Bed

The Middle Anhydrite Bed has dark grey to light grey colour, and is generally subdivided into two parts, notably, the lower part and the upper part.

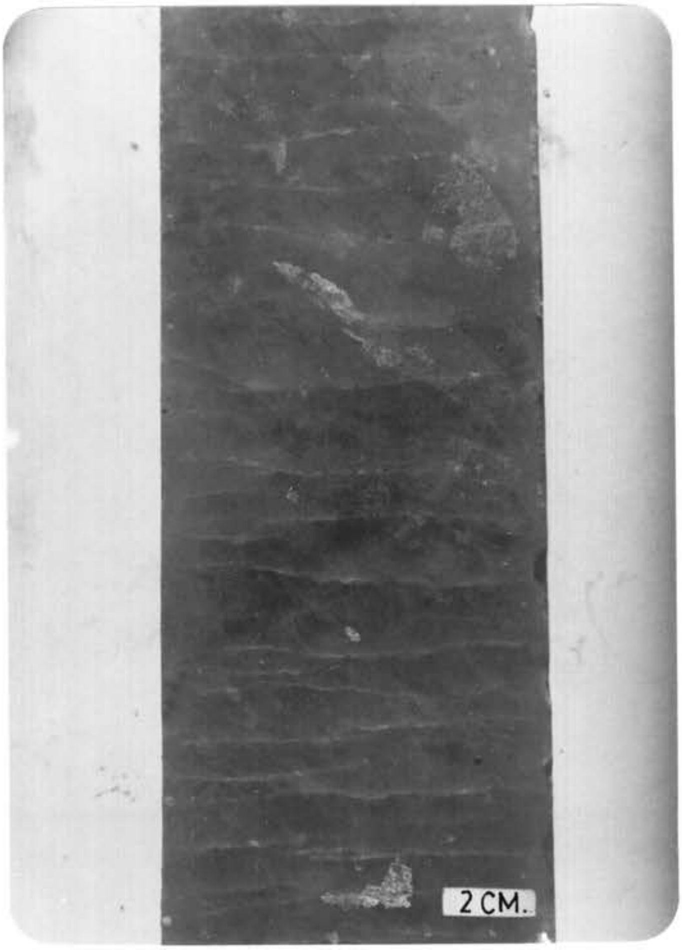


Figure 3.4.1.1 Photograph of the core-slab of the lower part of Lower Middle Halite Bed showing its general appearances. (from drilled hole no. KB-2, at depth 121.05-121.27 m.)

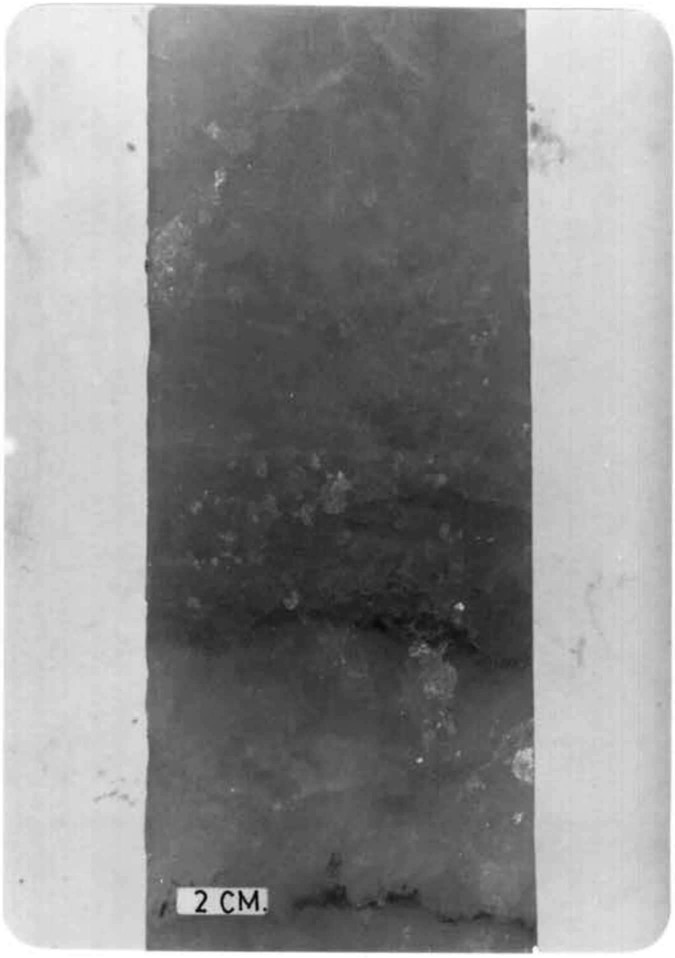


Figure 3.4.1.2 Photograph of the core-slab of the upper part of Lower Middle Halite Bed showing its general appearances. (from drilled hole no. KB-2, at depth 104.16-104.38 m.)

The lower part, the main part of the Bed, consists of massive and dense nodular anhydrite associated with swallow-tail halite grains, and halite layers (Figures 3.4.2.1 and 3.4.2.2). The swallow-tail texture was originated by the slow evaporation of calcium sulphate-saturated NaCl solution (Ogniben, 1957). Besides, some carbonaceous layers are commonly interlaminated in the lower part of the Bed.

The upper part of the Bed is characterized by laminated anhydrite associated with carbonaceous layers, 0.1-0.5 centimeter thick. It is noted that a few massive nodular anhydrite are associated within this zone.

In general, the Middle Anhydrite Bed is partly massive anhydrite interbedded with partly laminated anhydrite throughout its sequence. From x-ray diffractogramme of the Bed (Appendix 1-D), mineral composition is mainly anhydrite, gypsum (?), carbon (?), etc.

In addition, some trace or minor elements (Mn, Fe, Sr, Ba) in Middle Anhydrite Bed are analysed and presented in Appendix 1-E.

Strontium values in the Bed vary from 495 to 629 ppm and show no obvious trend with depth. These values are lower than average values, up to 800 ppm, for anhydrite in evaporite rock (Stewart, 1963).

Manganese values in the Bed are fairly low at about 5-12 ppm and show no obvious trend with depth. This may explain the very low values of manganese in the Bed differ from the average values of 120 ppm manganese in 80 anhydrite rocks (Stewart, 1963).

Barium values in the Bed are generally below 50 ppm. Besides, iron values vary from 75 to 240 ppm and show no obvious trend with depth.

Figure 3.4.2.1 Photograph of the core-slab of the lower part of Middle Anhydrite Bed (contact with the underlying Lower Middle Halite Bed) showing laminated and massive nodular textures.
(from drilled hole no. KB-2, at depth 100.87-101.06 m.)

Figure 3.4.2.2 Photograph of core-slab of Middle Anhydrite Bed showing laminated anhydrite and swallow-tail texture of halite associated with anhydrite.
(from drilled hole no. KB-2, at depth 100.66-100.85 m.)

The chemical data of some water soluble components of some representative sample of the Bed are summarized and tabulated in Appendix 1-C.

3.4.3 Upper Middle Halite Bed

The Upper Middle Halite Bed is subdivided very generally into two parts, namely, the lower part and the upper part. The lower part of the Bed consists of grey, dark grey medium-grained halite interbedded with smoky dark halite bands (Figure 3.4.3.1). Besides, there are some anhydrite layers associated with the smoky dark halite bands. Locally, traces of orange-red carnallite and/or cloudy white sylvite grains are present.

The upper part, the main part of the Bed, is characterized by clear fine-to medium-grained halite, and smoky dark halite bands. The anhydrite layers, 0.5-5.0 centimeters thick, are interbedded at every 0.10-0.60 meter interval (Figure 3.4.3.2). Besides, some milky white medium-grained halite are disseminated locally. In the uppermost interval, some grey, pale orange fine-to coarsed-grained halite are present. It is noted that anhydrite layers interbedded with smoky dark halite bands generally increase in their abundances and thicknesses downward to the bottom of this Bed.

The mineral composition determined from x-ray diffractogramme of the Bed (Appendix 1-B) is mainly halite, anhydrite, gypsum (?), etc. The chemical data of some water soluble components of representative samples of the Upper Middle Halite Bed are summarized and tabulated in Appendix 1-C.

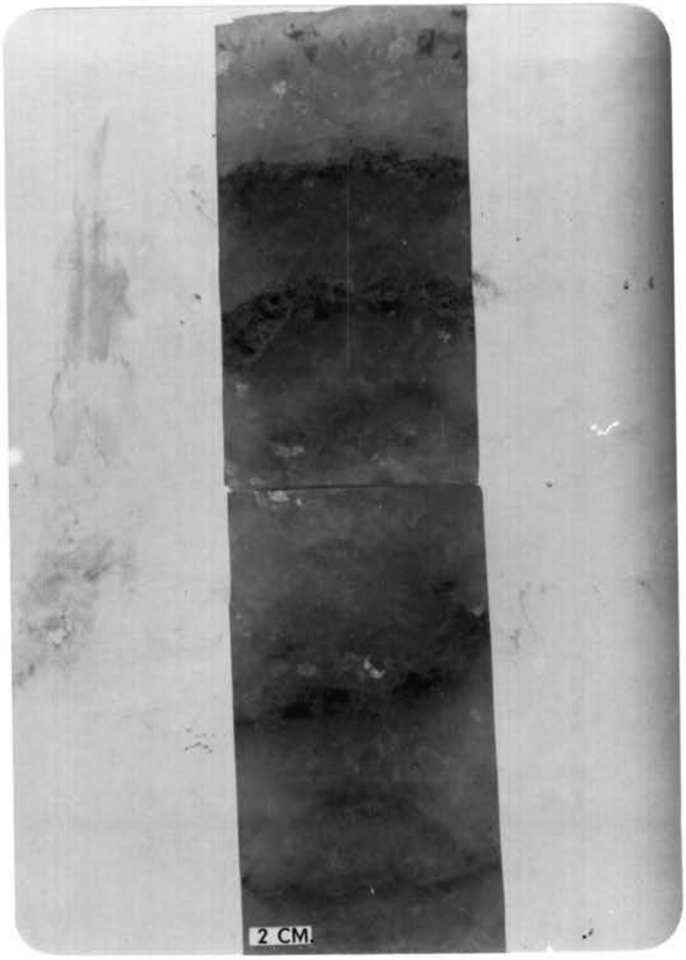


Figure 3.4.3.1 Photograph of the core-slab of the lower part of Upper Middle halite bed showing halite interbedded with anhydrite layers.
(from drilled hole no. KB-2, at depth 89.45-89.70 m.)

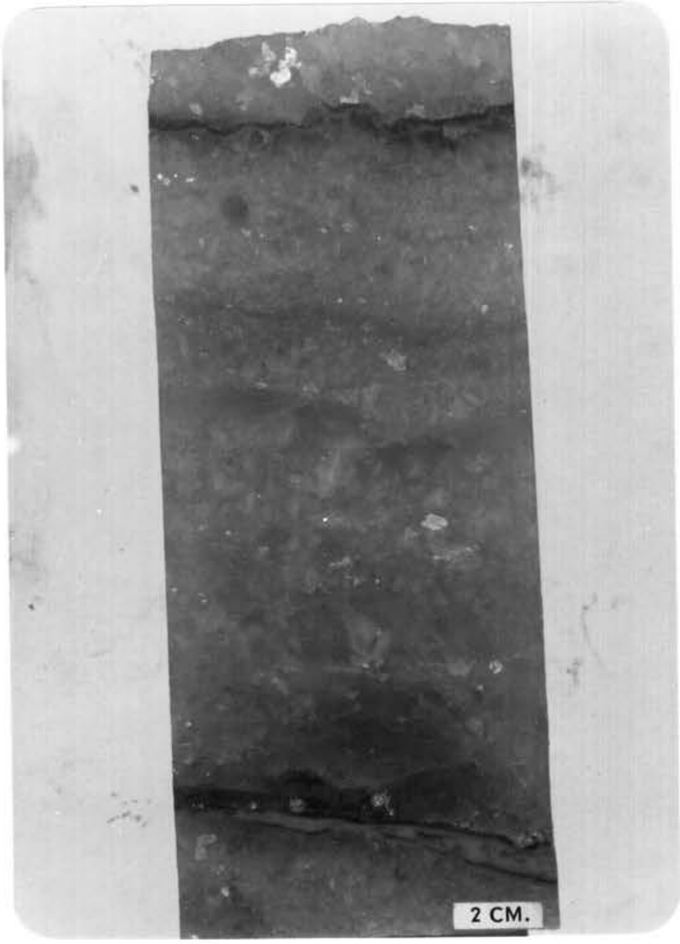


Figure 3.4.3.2 Photograph of the core-slab of the upper part of Upper Middle halite bed showing the general appearances of halite and anhydrite layers interbedded.
(from drilled hole no. KB-2, at depth 55.92-56.14 m.)

3.4.4 Middle Cap Anhydrite Bed

The Middle Cap Anhydrite Bed is generally mottled light grey, massive with some carbonaceous layers. From the x-ray diffractogramme of the Bed (Appendix 1-D), mineral composition is characterized by anhydrite, gypsum, etc.

From thin-sections, mineral composition is generally composed of very fine-grained anhydrite, some acicular anhydrite, and a few euhedral to subeuhedral gypsum crystals (Figure 3.4.4). Locally, some dark brown thin layers are present. It is noted that acicular anhydrite generally shows fibrous and fibroradiated texture. Besides, most of the anhydrite grains are very fine grained anhedral.

Generally, anhydrite grains in the Middle Cap Anhydrite Bed are relatively finer than those of in the Basal Cap Anhydrite Bed of the incomplete sequences of the Basal Salt Member.

In addition, geochemistry of some trace or minor elements (Mn, Fe, Sr, Ba) in Middle Cap Anhydrite Bed are studied and presented in Appendix 1-E.

Strontium values vary from 328 to 671 ppm and generally increase towards the base of the Bed. These values are lower than average values, up to 800 ppm for anhydrite in evaporite rock (Stewart, 1963).

Manganese values vary from 11 to 37 ppm and generally high towards the base of the bed. These values are lower than the average values of 120 ppm manganese in 80 anhydrite rocks (Stewart, 1963).

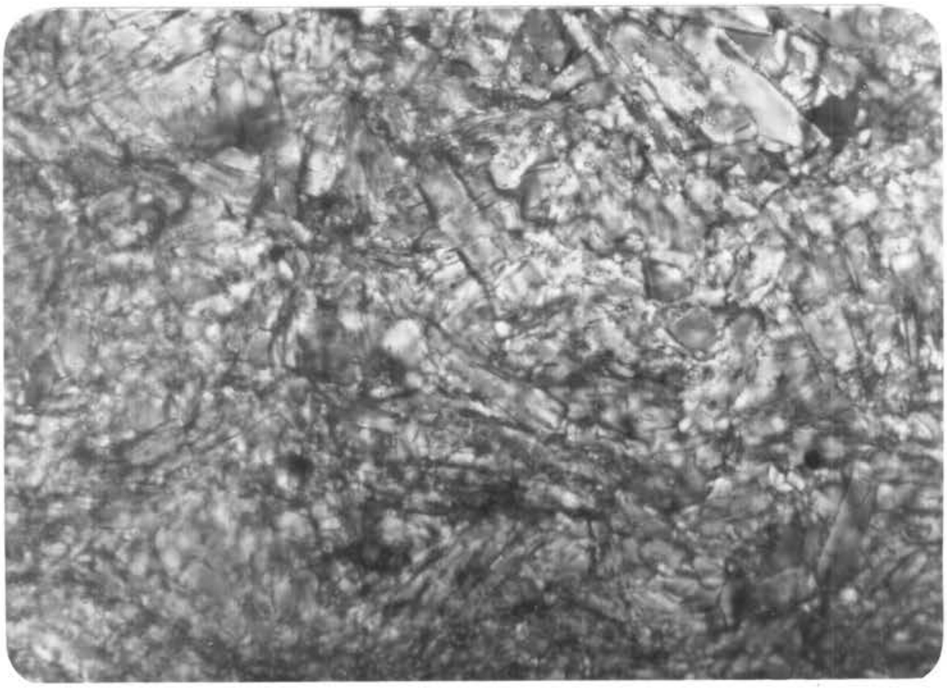


Figure 3.4.4 Photomicrograph of Middle Cap Anhydrite Bed showing fine-grained anhydrite and some acicular anhydrite associated. (crossed nicols, approx. x 175). (from drilled hole no. KB-8, at depth 55.19 m.)

Barium values in the Bed are generally below 50 ppm. Besides, iron values vary from 101 to 811 ppm.

Besides, the chemical data of some water soluble components of representative samples of the Bed are summarized and tabulated in Appendix 1-C.

From the typical bromine profiles of the halite zones in the Middle Salt Member (Figure 3.1.1), the KBr content progressively increases from the lower part of approximately 200 ppm KBr to the uppermost part of 450 ppm KBr.

However, it is interesting to note that the Middle Salt Member generally falls in NaCl zone of the theoretical evaporitic sequences with thin $CaSO_4$ zone associated in the middle and uppermost parts. The potassium and magnesium salts of higher order of evaporites in the Member are only traces, locally.

3.5 Middle Clastics Member

Generally, the lithology of the Middle Clastics Member is similar to the Lower Clastics Member except the absence of orange-red carnallite veins and veinlets. This Member is subdivided into two parts, notably, the lower and the upper parts. The lower part of the Member consists of the dark grey to greenish grey semi-consolidated clay to claystone/mudstone. The thickness of this part is about one-seventh of the total thickness of the Member. Besides, this part has the gradational contact with the upper part of this Member.

The upper part, the major part of the Member, is characterized by the reddish brown semi-consolidated clay to claystone/mudstone with the greenish grey semi-consolidated clay to claystone/mudstone mottling and interbedding. The general lithology is similar to the upper part of the Lower Clastics Member.

From x-ray diffractogrammes of Middle Clastics Member (Appendix 1-D), the minerals composition of the lower part of the Member is quartz, halite, illite, kaolinite, anhydrite (?), etc. Besides, the mineral composition in the upper part is quartz, anhydrite, halite, illite, kaolinite, hematite, etc. However, mineral compositions in both parts of the Member are generally similar in characteristics, except differences in their abundances. In addition, the mineral composition in Middle Clastics Member is generally similar to that of the Lower Clastics Member.

The chemical data of some water soluble components of representative samples of the Member are summarized and tabulated in Appendix 1-C.

3.6 Upper Salt Member

The Upper Salt Member has the nearly horizontal gradational contacts with both the underlying Middle Clastics and the overlying Upper Clastics Members. Generally, the lithology of Upper Salt Member is similar to the Middle Salt Member. The Upper Salt Member is subdivided into four Beds, namely, Lower Upper Halite, Upper Anhydrite, Upper Upper Halite, and Upper Cap Anhydrite, as described below.

3.6.1 Lower Upper Halite Bed

General lithology of the Bed consists mainly of clear medium-grained halite interbedded with smoky dark halite bands (1-5 centimeters thick). Besides, some pale-honey to orange medium-grained halite are associated in the lower part.

3.6.2 Upper Anhydrite Bed

The lithology of the Upper Anhydrite Bed is generally similar to the Middle Anhydrite Bed of the Middle Salt Member. The lower part of the Upper Anhydrite Bed consists of massive nodular anhydrite associated with swallow-tail halite grains and halite layers. Furthermore, the upper part is commonly characterized by laminated anhydrite with carbonaceous layers.

3.6.3 Upper Upper Halite Bed

The general lithology of the Bed is relatively similar to the Upper Middle Halite bed of the Middle Salt Member. The Upper Upper Halite Bed consists mainly of clear, milky white medium-grained halite, and smoky dark halite bands with anhydrite layers. The anhydrite layers (1-5 centimeters thick) are interbedded with the smoky dark halite bands at every 15-30 centimeters interval. Besides, the milky white halite grains decrease downward from the middle part to the lower part of the Bed.

From x-ray diffractogramme of the Bed (Appendix 1-D), the mineral composition is halite, anhydrite, gypsum (?), etc.

It is interesting to note that potassium and magnesium salts are absent in both Lower Upper Halite and Upper Upper Halite Beds of Upper Salt Member.

From the typical bromine profiles of the halite zone in the Upper Salt Member (Figure 3.1.1), the KBr content progressively increases in the narrow range from the lower part of approximately 200 ppm KBr to the uppermost part of 300 ppm KBr.

3.6.4 Upper Cap Anhydrite Bed

The general lithology of the Upper Cap Anhydrite Bed is composed mainly of massive mottled dark to light grey anhydrite with some carbonaceous layers. Locally, some dark grey or reddish brown semi-consolidated clay to claystone/mudstone layers are interbedded.

From thin-sections, the mineral composition of the Bed consists mainly of fine-grained anhydrite and acicular anhydrite crystals (Figure 3.6.4). Besides, some gypsum crystals and dolomite (?)/calcite (?) are aggregated and disseminated in the Bed. The acicular anhydrite crystals commonly show the fibrous to fibroradiated texture. Some gypsum crystals pseudomorph after the anhydrite crystals.

From x-ray diffractogramme (Appendix 1-D), the mineral composition of the Bed is mainly anhydrite, gypsum, etc.

In addition, the geochemistry of some trace or minor elements (Mn, Fe, Sr, Ba) in Upper Cap Anhydrite Bed are studied and presented in Appendix 1-E.

Strontium values in the Bed are fairly consistent at about 514-540 ppm and are generally lowered towards the base of the Bed. These values are relatively lower than average values (up to 800 ppm) for anhydrite in evaporite rock (Stewart, 1963).

Manganese values in the Bed are fairly consistent at about 61-68 ppm and show no obvious trend with depth. These values are lower than the average values of 120 ppm manganese in 80 anhydrite rocks (Stewart, 1963).

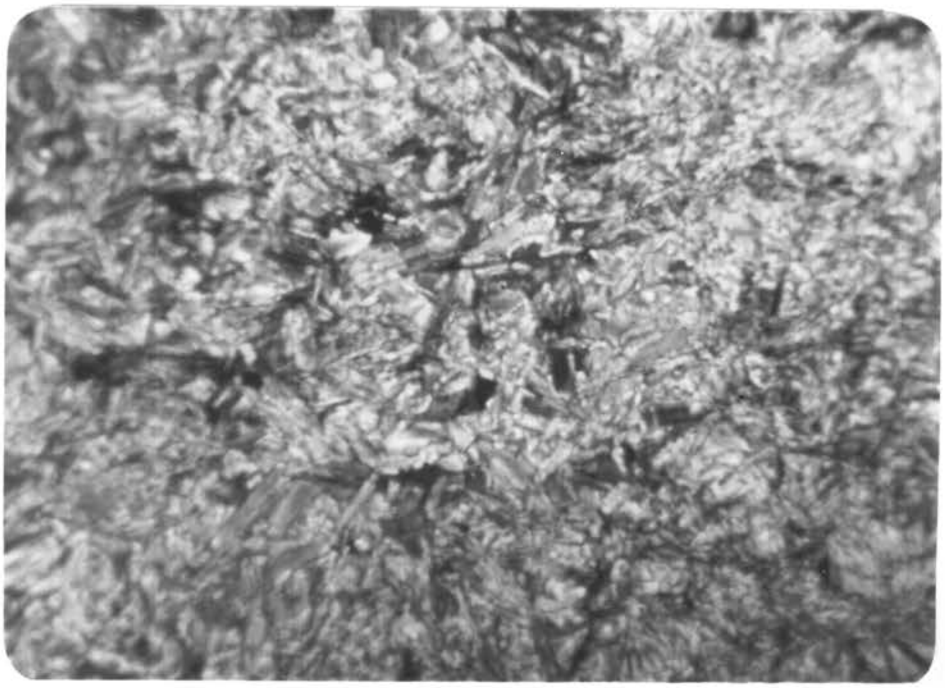


Figure 3.6.4 Photomicrograph of Upper Cap Anhydrite bed showing acicular and fine-grained anhydrite textures (crossed-nicols, approx. x 35).
(from drilled hole no. KB-21, at depth 149.76 m.)

Barium values in the Bed are generally below 50 ppm. Besides, iron values vary from 75 to 115 ppm and show no obvious trend with depth.

The chemical data of some water soluble components of representative samples of the Upper Salt Member are summarized and tabulated in Appendix 1-C.

3.7 Upper Clastics Member

The general lithology of the Upper Clastics Member is the reddish brown and greenish grey semi-consolidated clay to claystone/mudstone interbedded with the calcareous claystone/mudstone and siltstone/sandstone. The greenish grey semi-consolidated clay to claystone/mudstone is commonly associated with the reddish brown clay to claystone/mudstone as mottling and layering. Besides, gypsum veins and veinlets, as well as gypsum/anhydrite layers, and pods are scatteringly present in this Member.

It is noted that the mineral composition of the Member determined from x-ray diffractogramme (Appendix 1-D) is quartz, anhydrite, albite, calcite, illite, kaolinite, halite, hematite, etc. The differences in mineral compositions between this Member and the Middle & Lower Clastics Members are their abundances and the presence of calcite and albite in the Upper Clastics Member.

Besides, the undifferentiated overlying Clastics Members of the salt anticlinal areas sometimes have white to dark grey Anhydrite/Gypsum Bed (0-10.77 meters thick) associated in the lower part (Figure 2.2.2). The general lithology of the upper part of this Clastics Members, 12.19-53.96 meters thick, consists of reddish brown and greenish grey semi-consolidated clay to claystone/mudstone interbedded with the calcareous claystone/mudstone, and siltstone/sandstone. In the lower part of the Members, 5.06-17.90 meters thick, the general lithology is similar to that of the upper part of the Member. However, the reddish brown and greenish grey siltstone/sandstone is absent.

In addition, the chemical data of some water soluble components of representative samples of the Upper Clastics Member are summarized and tabulated in Appendix 1-C.

3.8 Alluvium Member

The general lithology of the Alluvium Member consists mainly of yellowish grey to brown unconsolidated clays, sands, and some gravels.

Besides, this Member that overlies the undifferentiated Clastics Member of the salt anticlinal zones of the area shows only a slight difference in lithology from the Alluvium Member elsewhere in the study area. The lithology of the Alluvium Member in the salt anticlinal areas is yellowish brown and grey unconsolidated to semi-consolidated sands, clayey sands, gravels and some clays (Figure 2.2.2).