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Research Article

The Depositional Environment: Diagenetic and Depositional Settings of Gypsum Deposits from Bi'r El Ghanem, NW Libya

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ABSTRACT

This study considers the diagenetic processes and the depositional setting of the Bi'r Elghanem evaporates in the northwestern of Libya. The deposition environment has revealed a variety of ranging from lagoonal to fluvial deposit pools and evaporitic basins, which become intensely saline as a result of evaporation of fluvial freshwater (semi-) arid environments. The results indicate that gypsum has evidence of mineral substitutions and displacement, suggesting a homologous mechanism for lithofacies and subsequent textural change. As part of this study, samples were analyzed using elemental analysis, statistical evaluation such as Multiple Correlations, Principal Component Analysis, and mineralogical evidence to determine their mode of environmental deposition, mineralogical and geochemical composition. The development of gypsum minerals in a variety of lithologies and textures is aided by eustatic fluctuations in Lake water level due to regional tectonism and climate.

Keywords: Sabkha; Bi'r El ghanem formation; Wadis; Jifarah plain

INTRODUCTION

One of the large deposits of gypsum and anhydrite in Libya has been discovered in the Bi'r El Ghanem area at various sites in the Jifarah plain province in northwestern Libya. The other areas surrounding Nalut, Mizda and Bu Ngem, on the other hand, are uninteresting due to their lower valuations. Numerous previous researches have been conducted [1-5]. However, these previous studies only provide a restricted data set on mineralogical and geochemical behavior. The gypsum and anhydrite deposits are exposed almost continuously along the Jabal escarpment for a distance of about 60 km, from 4 km west of Gharyan to about 14 km west of Yefren (Figure 1). The maximum exposed width of the deposite is about 25 km. Access to the deposits is over 94 km along the Tripoli-Jefren high way. The highest recorded thickness of the deposit is 350 m on the western side of the area. The Libyan authority for mining published data from geological work in the study area, estimating it to be 8.403 million tons (LAM 2010). Therefore, the Bi'r El Ghanem formation provides an excellent opportunity to study this mineralization to infer the depositional and diagenetic history. It is located in the northwest of Libya and is an example of a shallow evaporitic lake with lagoonal deposits (Figure 1). The investigated area is related to tectonic history during the upper Jurassic to lower Jurassic, climate and regional uplift were the primary determinants of evaporation accumulation in the basin. These occurrences are connected with Throughout the Cretaceous period through the end of the Early Cretaceous period; shallow marine deposits were deposited in this region (Figure 2). The emphasis of this study was to use diagenetic criteria to identify the environment of deposition of gypsum and focused on field investigations and studying the petrography of the outcrops to understand the diagenetic alteration of deposits and the depositional settings of gypsum and anhydrite.

Geological setting

The study area is located on the Jifarah plain and consists of alternating evaporate and shale with intervals of clastic deposits deposited on a shallow platform in sabkha and lagoonal environments due to aeolian and fluvial environments. It is bounded by longitudes 12'25 E to 12'55 E and longitudes 32'05 N to 32'20 N (Figure 1). The evaporate basin formed in the late Jurassic – early Cretaceous period [4] and is extensively exposed

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in the scarp between Bi'r El Ghanem town and Bi'r Eyad. The stratigraphy of Bi'r El Ghanem exhibits many significant sequences (Figure 2), which are mainly characterized by mostly carbonate-evaporate succession. The upper part of the Bi'r El Ghanem formation consists of an alternation of massive gypsum, occasionally gypsiferous shale, and gypsum (Figures 3a-3e). In many places, gypsum deposits form as a result of sluggish evaporation, it is particularly prevalent in the center of an evaporitic basin, and is characterized by a wide variety in thickness, most likely due to the basin's tectonics. The middle and the lower part of the formation contain a sequence of gypsiferous clay and other circumstances, the contact of gypsum with shale is gradational in some cases, as shown by gypsiferous clay and dolomite. Gypsum is represented by both massive and laminated gypsum with lamina thickness ranging from a few milimeters to 1-2 cm (Figures 3a-3e).

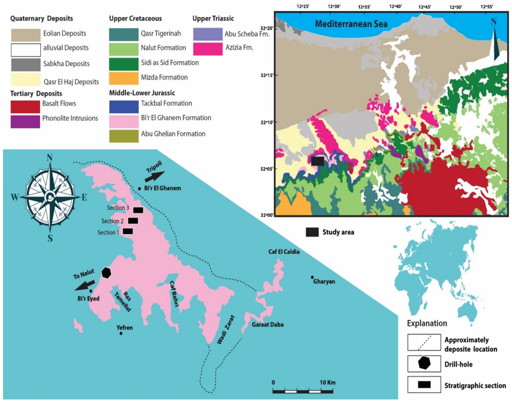


Figure 1: A map of the study area showing the distribution of outcrops [9].

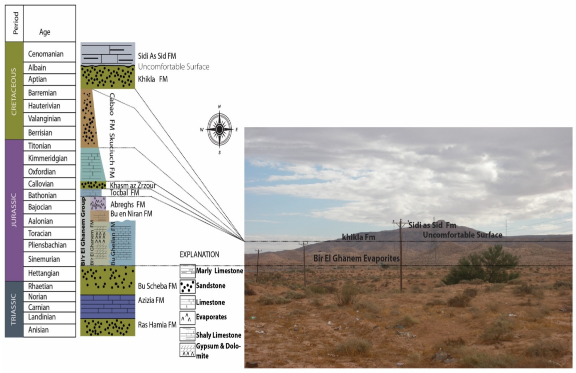


Figure 2: Representative the stratigraphic column of Bi'r El Ghanem formation.

METHODOLOGY

Elemental analysis was performed on 10 evaporite samples using an XRF (X-ray Fluorescence Spectroscopy) instrument. In this method, the samples are crushed and powdered by grinding processes. Major elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, SO_3 etc.) were analyzed in terms of weight level (percent).

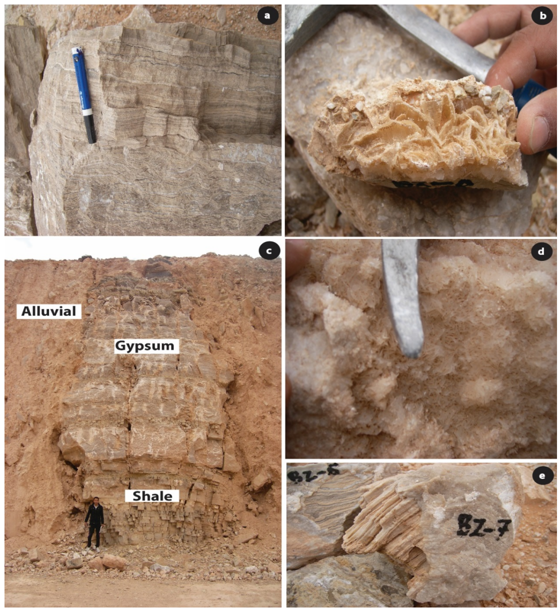
Petrographic analysis

Sedimentary structures, textures, and stratigraphic sections were measured in the field to collect systematic samples from the study area. Identifying gypsum types (massive, stainspar and laminated), as well as various minerals (dolomite, clay and other detritus) are the target of these analyses.

RESULTS

Geochemisrty

Various gypsum lithofacies samples were analyzed for geochemical elements, and the results are shown in Table 1. The major oxides Mg^{2+}, Ca^{2+}, S^{2-}, and Si^{4+} have relative concentrations in the evaporite samples (Figure 4). However, these major elements (such as Mg^{2+} and Ca^{2+}) exhibit a strong negative trend with SO_3. The reason behind this relationship might be explained by decreases in Mg^{2+}/Ca^{2+} amounts due to temperature and pressure conditions during diagenesis [6]. Dolomitization causes the precipitation of calcium sulfate by increasing the Ca^{2+} content in salt water [7]. Later, a possible increase in sulfate-rich solutions disrupted the neutral balance, resulting in the replacement of calcites and dolomite with sulfate minerals [8]. By releasing water during dolomitization of minerals (Mg^{2+}, Ca^{2+}), diagenetic carbonate (calcite and dolomite) and celestine minerals (new mineral formations) were formed as a result of this process. In elemental analysis, the increase in MgO content in gypsum lithofacies samples is related to the increase in dolomite content (Table 1).



Figures 3a-3e: a) Laminated gypsum with lamina ranges from a few millimeters to 1-2 cm. b) Stainspar gypsum at the base is composed of coarse lamina at the base and finely laminated at the top, underlain and overlain by sharp contact with anhydrite. c) Gypsum and anhydrite deposits are commonly interbedded with, or rest upon, shale. d) Fissures and cavities are frequently associated with gypsum in the form of selenite. e) Massive Anhydrite with grey-to-brown laminitic shale intercalations.

Towards this ($Mg^{2+}+Ca^{2+}$) is a reasonable proxy for tracing these processes in carbonate system (Figure 4a). The results indicate that (Mg^{2+}/Ca^{2+}) in gypsum is very low (Figure 4b). This demonstates that gypsum does not include magnesium in its crystal structure. In contrast, the Ca^{2+}/Al^{3+} ratio in gypsum is rather high, indicating that gypsum contains calcium in its crystal lattice (Figure 4c). Similarly, iron is present in gypsum in relative low concentrations in gypsum when compared to adjacent rock (Figure 4d). However, sulphur may be associated with gypsum the lattice in rather stable constant quantities, as evident in Figure 4a.

Sample	BG-1	BG-2	BG-3	BG-4	BG-5	BG-6	BG-7	BG-8	BG-9	BG-10
SiO_2	2.49	5.12	23.86	1.96	2.57	9.22	49.47	0.5	4	0.74
Al_2O_3	0.31	0.48	1.33	0.23	0.41	0.67	5.26	0.19	0.5	0.41
Fe_2O_3	1.32	1.45	0.76	1.5	0.12	0.47	1.6	1.72	0.76	0.23
FeO	0.24	0.31	0.83	0.02	0.43	0.02	0.34	0.06	0.43	0.04
TiO_2	0.01	0.02	0.08	0.08	0.03	0.03	0.28	0.01	0.01	0.01
CaO	33.49	32	24.54	34.11	31.9	30.39	12.07	33.78	33.75	35.08
MgO	1.36	0.59	0.72	1.05	1.42	1.2	4.3	0.54	0.43	5.47
MnO	0.001	0.021	0.022	0.004	0.003	0.004	0.003	0.001	0.002	0.004
SO_3	40.87	38.62	29.1	37.97	40.29	31.45	34.66	41.01	37.95	27.65
CL	0.05	0.07	0.23	0.02	0.09	0.08	0.04	0.06	0.05	0.12
Na_2O	0.04	0.05	0.26	0.1	0.12	0.16	3.52	0.03	0.05	0.027
K_2O	0.08	0.11	0.3	0.036	0.064	0.19	1.16	0.04	0.1	0.044
CO_2	3.45	3.56	4.62	4.76	5.09	4.09	5.67	3.87	2.78	1.89
Si	5.33	10.95	51.05	4.19	5.50	19.73	105.8	1.07	8.56	1.58
Al	0.59	0.91	2.51	0.43	0.77	1.27	9.94	0.36	0.94	0.77
Fe	0.92	1.01	0.53	1.05	0.08	0.33	1.12	1.20	0.53	0.16
Mg	0.82	0.36	0.43	0.63	0.85	0.72	2.59	0.33	0.26	3.46
Ca	23.59	22.88	17.55	24.39	22.81	21.73	8.63	24.15	24.13	25.08
Mn	0.0013	0.0271	0.0284	0.0052	0.0039	0.0052	0.0041	0.0013	0.0026	0.0052
S	16.35	15.45	11.64	15.19	16.12	12.58	13.86	16.4	15.18	11.02
Na	0.03	0.04	0.19	0.07	0.09	0.12	2.61	0.02	0.04	0.02
K	0.07	0.09	0.25	0.02	0.05	0.16	0.96	0.03	0.08	0.03
Mg/Ca	0.035	0.016	0.025	0.026	0.037	0.033	0.300	0.014	0.011	0.138
Mg+Ca	24.41	23.24	17.98	25.02	23.66	22.45	11.22	24.48	24.39	28.54
Ca/Al	40.28	25.23	6.98	56.13	29.45	17.17	0.87	67.28	25.54	32.38
Fe/Al	1.58	1.12	0.21	2.41	0.11	0.26	0.11	3.35	0.56	0.21

Table 1: Major Values (%) of Bi'r El Ghanem formation.

Statistical analysis

The various diagonally symmetrical linear correlation matrices of Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{3+} and S^{2-} of the study area samples are shown in Table 2a. The bivariate relationship between the variables is often characterized by a negative correlation. Except for Ca^{2+}, Mg^{2+} and S^{2-}, which show a very low degree of inconsequential negative correlation, the association of the above variables in the study shows the same positive correlation.

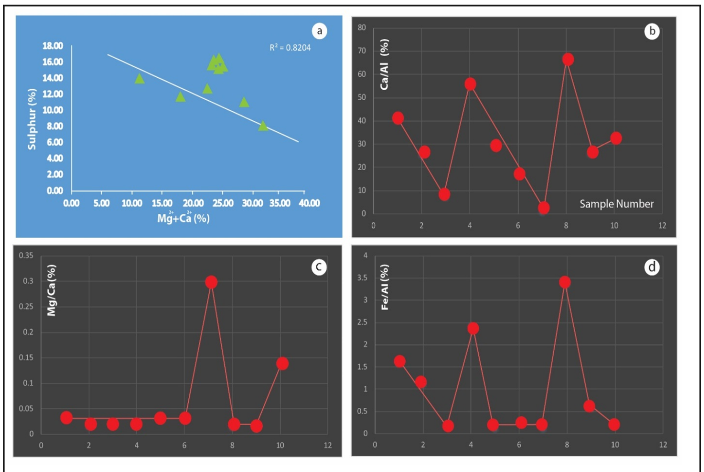


Figure 4: Shows the variation in ratio of (a) Sulphur vs. (Ca +Mg) (b) Ca/Al (c) Mg/Ca (d) Fe/Al.

The Principle Components Analysis (PCA) is useful for calculating the Eigen values, percentage of cumulative variance, and component loading scores. The Principle Components

Analysis (PCA) has been performed by using the basic computer programme "SPSS". The Eigen value of total variance of cumulative variance as well as three principal component loading scores values of studied area parameter given in Table 2b. The Tables 2a and 2b shows that the three PCA components vary between 58.12%, 20.00% and 14.23%, respectively (Figure 5). The principal component factors are chosen as close approximation to the value of 1.0 Eigen values as possible. The three PCA components account for 92.35% of total variance. According to the component loading on the parameter (Table 2b), each component is predominantly related with only a few parameters, which are as follows; Component (I) consists of Si, Al, K and Na; Component (II) consists of

Fe, S; Component (III) consists of Mn. The first principal component had a positive loading score of 5.23 and 1.28 and was weighted on the positive direction of the variable axis. This accounts for up to 47.13% of the overall variance between the parameters. The second PCA component accounts for 20.00% of the variance, while the third PCA components contribute 14.23%.

Si	Al	Fe	Mg	Ca	Mn	S	Na	K
1.000								
.966	1.000							
.246	.281	1.000						
.342	.465	-.233	1.000					
-.994	-.968	-.254	-.323	1.000				
.185	.003	.030	-.249	-.162	1.000			
-.322	-.223	.480	-.544	.254	-.321	1.000		
.920	.988	.336	.484	-.929	-.111	-.123	1.000	
.973	.997	.295	.421	-.976	.018	-.217	.981	1.000

Table 2a: Correlation matrix of Bi'r El Ghanem's major elements.

Initial Eigen values			Extra. sums of squared loadings			Descriptive statistics	
Total	%of variance	Cumulat.%	Total	%of Varia.	Cumulat.%	Mean	Std. Devia.
5.231	58.124	58.124	5.231	58.124	58.124	21.37	33.16
1.801	20.007	78.131	1.801	20.007	78.131	1.84	2.90
1.281	14.235	92.366	1.281	14.235	92.366	0.69	0.41
0.467	5.185	97.551				1.04	1.08
0.199	2.210	99.761				21.49	4.99
0.016	.175	99.936				0.0084	0.010
0.003	.032	99.968				14.37	1.99
0.003	.030	99.998				0.3230	0.80
0.000	.002	100.000				0.1740	0.28

Table 2b: Principal component analysis of Bi'r El Ghanem.

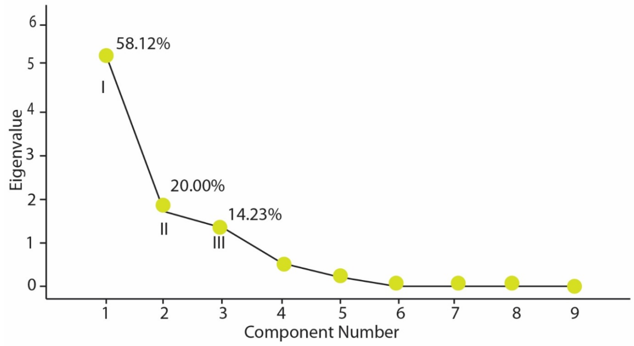


Figure 5: Principle components analysis scree plot.

DISCUSSION

Depositional environments and lithofacies

The progression of uplift in the Jifarah plain region generated several closed basins. At the same time, the Jurassic period is associated with dramatic changes has a significant impact on global climate change (warming trend) [10-12]. Due to the arid environment and tectonism, the effect of changing basin drainage and depth caused gypsum lithofacies to repeatand change vertically and laterally within the sequence of the Bi'r El Ghanem formation. The evaporite deposits in the study area have been affected by depositional changes and large-scale evaporite dissolution, preventing a satisfactory reconstruction of the deposition environment. The sedimentological analysis of outcropping evaporitic material suggests that the Bi'r El Ghanem Formation originated through lateral and vertical accretion within a depositional environment analogous to those of the present time, in supratidal flats and lagoons (Figure 6).

In most areas, the lagoonal facies is comprised of white, medium hard, crystalline, and amorphous anhydrite and gypsum with dark grey and cream gypisferous marl. Tectonic activity influenced local thickness and facies variation. The low overall thickness of the deposits can be attributed to the pre-existing depositional and tectonic setting [13]. In the study area, the thick evaporate deposits accumulated in the deeper basin

(Figure 7). Dry subtropical lithological indicators low, or seasonal, rainfall and warm temperatures in the Bi'r El Ghanem arid subtropics cause net evaporation of water bodies and the deposition of evaporitic deposits.

5.2 Diagenetic evolution

The gypsum at Bi'r El Ghanem's has spherical or roughly tabular crystals with a smooth shape that are generally dark brown (Figure 3) and are distorted by bedding visible in the gypsum unit, as well as the adjacent thin claystone. However, they are also associated with clastic deposits and shale. In most cases, clastic deposits are interbedded with gypsum and anhydrite. Furthermore, the most important commercial sources of gypsum are bedded deposits. Massive gypsum occurs in a stratified sequence with shale in bedded deposits. The gypsum beds are likely to be permanent and often conform to adjacent rocks in their structure. Massive gypsum facies is distinguished by its gray-beige color; unbedded forms, fine-grained gypsum clusters, anhydrite interbands and clay intercalations are the main characteristic features. Small fissures and cavities are commonly associated with carbonaceous material (Figure 3), which favors the development of a reducing environment as evidenced by the presence of euhedral to subhedral crystals. Diagnostic analysis evidences that Bi'r El Ghanem's gypsum is characterized by the same petrofacies with a variety of textures arising from the hydration of anhydrite. Except for relatively extreme environmental conditions restricted to high temperatures and salinities such as those of sabkhas, experimental studies and current sedimentary analogues show that primary gypsum more commonly precipitates more than anhydrite [14]. For these reasons, the anhydrite, the precursor of microcrystalline gypsum, could be interpreted as a diagenetic product, derived from dehydration of a primary gypsum deposit [15].

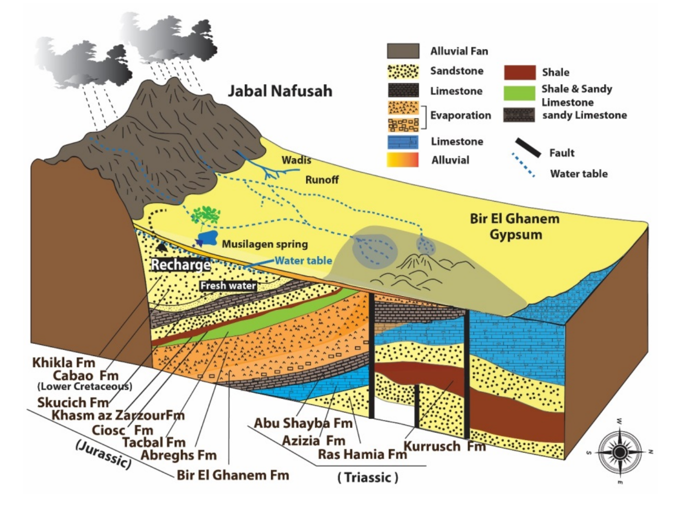


Figure 6: Precession of climatic change in the studied area during the Lower Cretaceous-Upper Jurassic succession. Evaporatic environments, in which is gypsum deposited and an influx of hydration to the closed lagoon in the Jifarah plain.

As a result, massive gypsum and gypsum laminites have undergone through a dehydration–hydration cycle (Figure 8). On the other hand, the massive gypsum was deposited in more basinal areas and buried beneath a much thicker succession below the transition level. All of them cover almost the same depositional time interval since they all represent the bottom and top of the formation (Figures 7 and 8). All of these sections have primary and secondary gypsum lithofacies. The primary facies include massive gypsum and Anhydrite. The secondary facies comprise stainspar and laminated-banded gypsum facies (Figure 8). In addition to these facies, clastic and carbonate layers are observed along the sections as interbands or intercalations between and at the bottom of the formation facies (Figure 8). Due to an increase in salinity and temperature in the system, dolomite was eventually, replaced by the secondary gypsums during the late diagenesis period (Figure 8) according to [16,17].

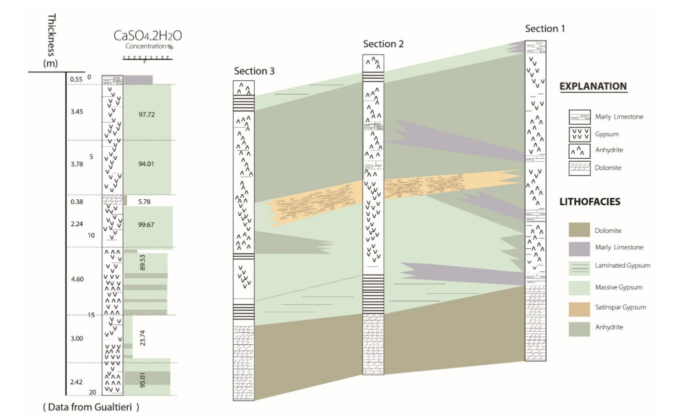


Figure 7: Shows stratigraphic sections of study area.

The late diagenesis stages were observed as result of succession transformations between gypsum and anhydrites and decreases in the sedimentation load, which resulted in the development of some fissures and cracks.

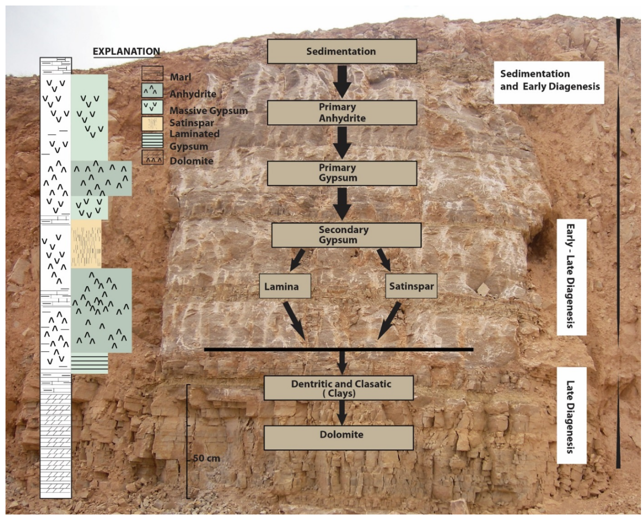


Figure 8: Diagenetic evolution of Bi'r El Ghanem Gypsum.

CONCLUSION

The study area is a terrain which consists of gypsiferous shale, claystone with massive gypsum and carbonate rocks such as dolomite. The deposition environment of B'ir El Ghanem ranges from lagoonal to fluvial deposits pools. According to sedimentological, petrographic, and mineralogical studies, the secondary gypsums are derived from both primary gypsums and primary anhydrite. During the early and late diagenetic process, factors such as the conversion of minerals to each other and increased salinity, temperature, and diagenetic fluids played a major role in the diagenesis of Bi'r El Ghanem's gypsum deposits. Finally, the climate and regional tectonism contribute to the development of gypsum minerals in different lithology and textures by bringing eustatic movements in the lake water level.

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