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Petrography and Mineralogy of Gercus and Fat'ha Formations Gypsum: A Comparative Study

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ABSTRACT

The petrography and mineralogy of the gypsums from the Gercus (Lower Eocene) and Fat'ha (Middle Miocene) formations were investigated. Petrographically, the gypsums of both formations consist of two main textures: porphyroblastic of minimal extent and alabastrine of very wide distribution. Alabastrine texture could be divided according to shape, size and outlines of crystals into three hydration stages. The first stage texture consists of composite crystals and feathery texture, where in the Fat'ha Formation, they have about equal distribution of this stage and (87%) of the first and second hydration stages. The third Stage is absent from the gypsum of the Fat'ha Formation. Feathery texture is absent from gypsum of the Gercus Formation, and the composite crystals of stage one make up only about 12% of the three stages, except in the massive gypsum of Duhok Dam, where they make up 50%. X-ray diffraction study revealed that massive gypsum of Duhok Dam (Gercus Formation) and nodular gypsum of Baashiqa area (Fat'ha Formation) have very similar intensities for the three secondary characteristic peaks at d-spacings of (4.27 Å, 3.79 Å and 3.06 respectively and higher than that of nodular gypsum of Duhok Dam and Zawita junction (Gercus Formation). The presence of relatively large proportions of composite crystals in massive gypsum of Duhok Dam and nodular gypsum of Baashiqa area could be the cause for these high intensities.

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بتروغرافية ومعدنية جبسوم تكويني جركس والفتحة: دراسة مقارنة

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الملخص

تم إجراء دراسة بتروغرافية ومعدنية على جبسوم تكوين جركس وجبسوم تكوين فتحة بهدف المقارنة بينهما. يتألف الجبسوم في كلا التكوينين من نسيجين رئيسيين: البورفيروبلاستي ذو الانتشار المحدود والألباستري ذو الانتشار الواسع. وبناءً على شكل وحجم البلورات وتداخل حوافها، يُقسم النسيج الألباستري إلى ثلاث مراحل تمييزية. المرحلة الأولى تشمل البلورات المركبة والنسيج الريشي، حيث يشكلان نسبة متساوية ويبلغان 87% من المرحلتين الأولى والثانية في جبسوم تكوين فتحة، بينما لا يوجد نسيج المرحلة الثالثة فيه. أما في تكوين جركس، فلا يوجد نسيج ريشي، وتبلغ نسبة البلورات المركبة في المرحلة الأولى 12% فقط، ما عدا الجبسوم الكتلي في سد دهوك الذي تصل فيه إلى حوالي 50%. أظهرت تحاليل الأشعة السينية الحائدة تشابهًا كبيرًا في شدة الذروات الثانوية الثلاث للجبسوم بين الجبسوم الكتلي لتكوين جركس في منطقة سد دهوك والجبسوم العقدي لتكوين فتحة في بعشيقة، مع زيادة في الشدة في الجبسوم العقدي لتكوين جركس في منطقتي سد دهوك ومفرق زاويتة، ويُعزى ذلك إلى وفرة البلورات المركبة التي تعزز الشدة في هذه العينات.

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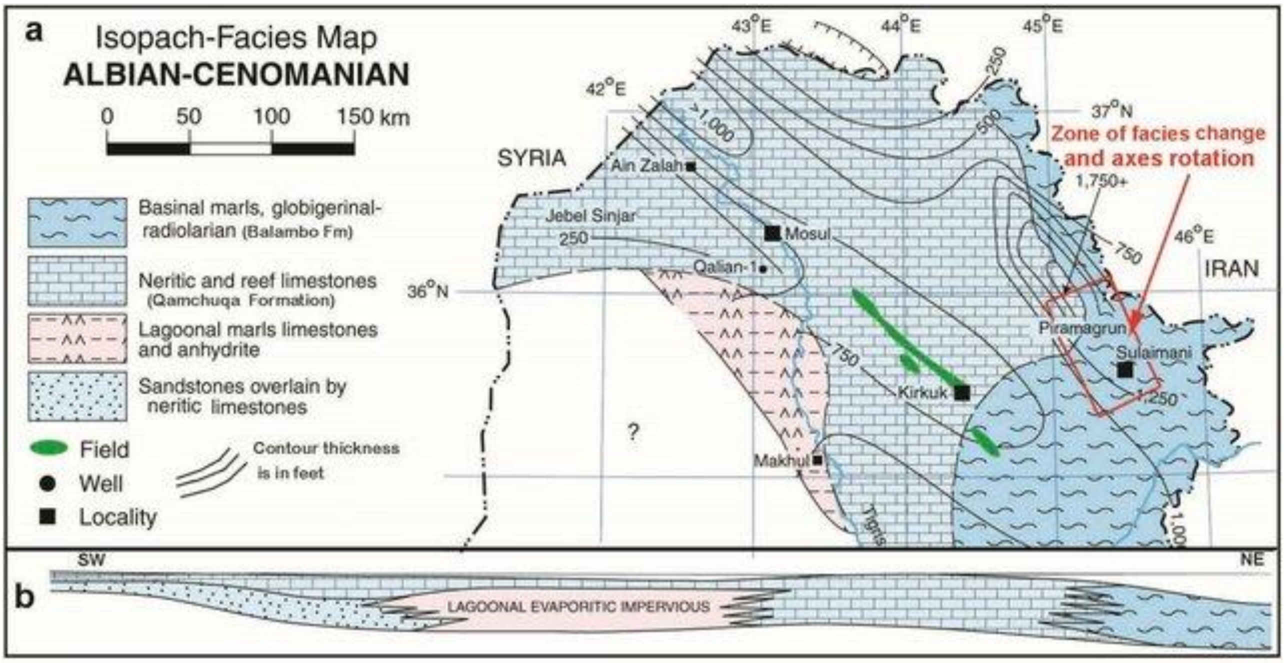
Introduction

A total of 34 gypsum samples were collected from three localities in northern Iraq (Fig. 1). The first is at Duhok Dam (6 km NNE of Duhok), collecting 12 samples, the second is at Zawita junction (8 km NE of Duhok) belongs to the Gercus Formation (Lower Eocene), collecting 1 sample from it. The third location is at Baashiqa locality (24 km NE of Mosul) belongs to the Fat'ha FormatiMiddleiddl Miocene) (11) samples were taken there (Map 1).



Map 1. Fat'ha Formation (Dunnington, 1958).

Duhok Dam section has a total thickness of about 60 m; however, the upper (21 m), which consists of marl, is very steep and could not be reached and described. The remaining (29 m) consists of alternations of mostly red and occasionally green marl, with thin beds of gypsum which have a thickness ranging from 20 cm to 1.5 m. Only the lowermost bed consists of massive gypsum, and the remaining 7 beds are nodular. The nodules are elongated and range in size from 1-5 cm. There are a few bands of fibrous gypsum, either surrounding gypsum beds or within the marl. Gypsum makes up about 22% of the total thickness of the section, while the marl makes up the remaining 78%. Figure 1 shows the lithology and sample distributions within the Duhok Dam section. Zawita junction section has a thickness of (24 m) and consists of red sandstone, red marl (both making up (91.5 %) of total thickness) and four thin beds of nodular gypsum with thickness ranging from (20 cm) to (1 m) and making up (8.5%) of total thickness. There are a few thin bands of fibrous gypsum within the marl Figure 2. The Baashiqa section has a thickness of about 52 m and consists of nodular gypsum and red and green marl. There are only three beds of nodular gypsum; however, the top bed is rather thick, with a thickness of about 25 m. The other two have thicknesses of 50 and 80 cm only. Gypsum comprises about 52.5% of the total thickness, and the rest (47.5%) is made up of red and green marl. There are a few bands of fibrous gypsum within the marl or surrounding gypsum nodules. Figure 3 shows the lithology and sample distributions within the Baashiqa section.

Methodology

The purpose of this work is to study and compare the petrography and mineralogy of the Gercus and Fat'ha formations. The petrography includes the study of the types of nodular gypsum textures revealed by thin sections and the possible presence of secondary minerals like anhydrite, dolomite and celestite. The mineralogy includes the differences in peak intensities revealed by X-ray diffraction (XRD) analyses of gypsum of the two formations and the possible presence of secondary minerals identified by the petrographical study.

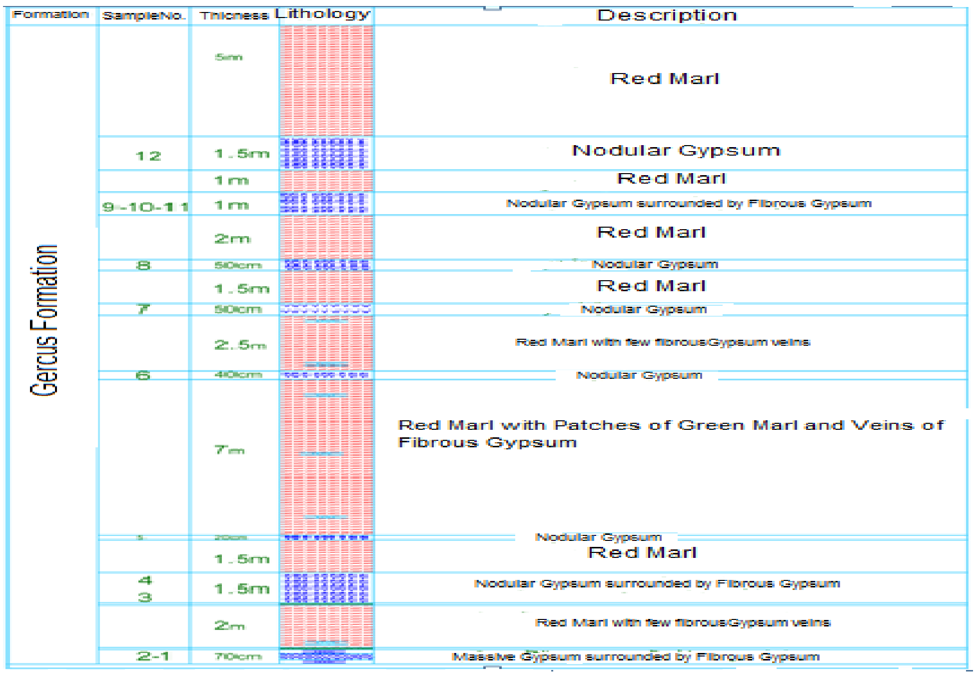


Fig. 1. Stratigraphical Section of Gypsum Formation at Duhok Dam Locality.

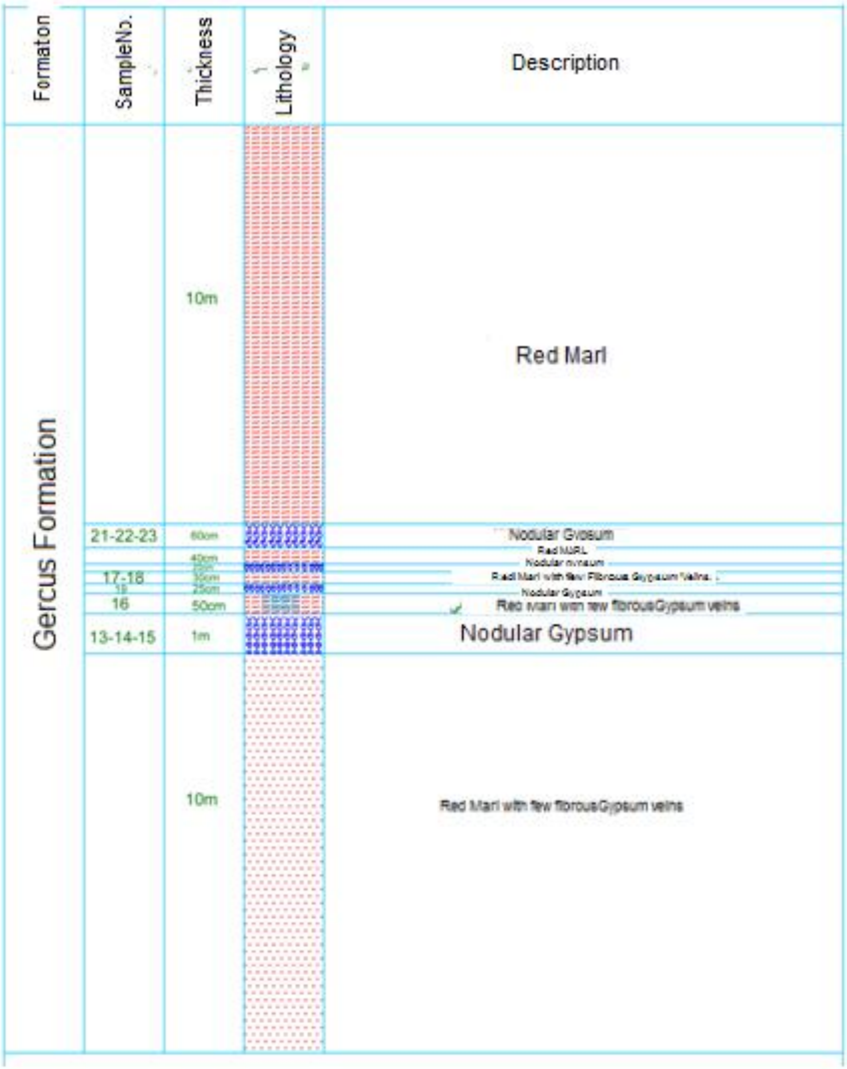


Fig. 2. Stratigraphical Section of Gypsum Formation at Zawita Junction Locality.

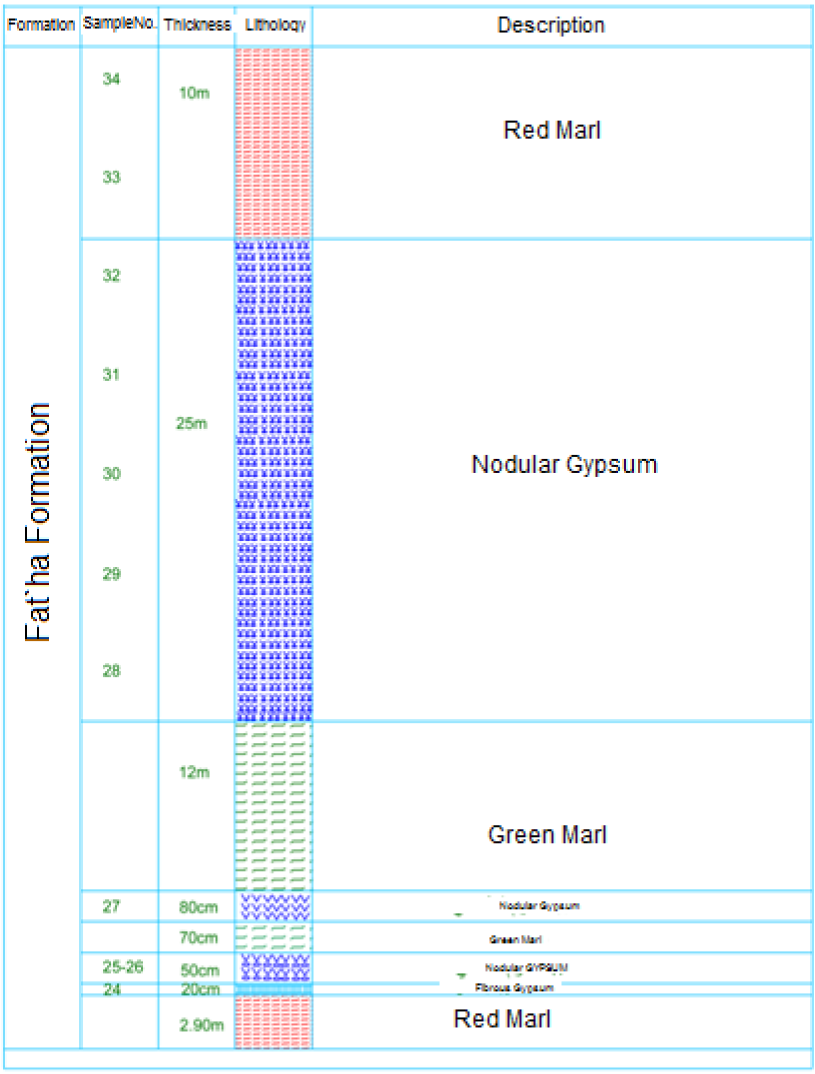


Fig. 3. Stratigraphical Section of Fat`ha Formation at Baashiqa Locality.

Analytical techniques

Petrographical examinations were carried out using a polarizing microscope, British-made, type (Swift, M.P. 1020), at the Department of Geology, University of Mosul, Iraq. Photographs (plates) were taken using a "Canon Digital Camera" attached to the eyepiece of the microscope. The mineralogy was studied by an X-ray diffraction spectrometer at the "Mining Research Institute, MTA", Ankara, Turkey. The spectrometer used was of the type (XE PERT-PRO), using (Cu-Kα) radiation and a (Ni) filter. For further details of the analyses, see Alhadeedi (2010).

Results and Discussion

Petrography

From the study of (30) thin sections of gypsum in the studied sections of Duhok Dam, Zawita junction and Baashiqa localities (ten thin sections each), it was possible to identify the type of textures in these gypsum rocks. Ogniben (1957) divided massive and nodular gypsum into two main textures: porphyroblastic and alabastrine. This division was approved by several authors like West (1964), Holliday (1967, 1970), Aljubouri (1972, 1993), Mossop and Shearman (1973), Sulayman (1990) and by many others. In gypsum of the present study (Gercus and Fat'ha formations), both of these textures were diagnosed.

1. Porphoblast Texture:

This texture is characterized by its very large, bladed crystals having a length of more than 2 mm and a width of about 0.4 mm (Sulayman, 1990). However, in the present study, a porphyroblastic crystal of about 1.6 mm) was observed in nodular gypsum of the Baashiqa area (Plate 1). The small crystals of the groundmass penetrate the long edge of the porphyroblast, indicating that the latter is earlier in crystallization than the groundmass. This is in full agreement with the findings of previous authors like Holliday (1970), Aljubouri (1972), and Mohammed Ali (2009). The porphyroblasts were formed at depth with a slow rate of crystallization where gypsum and anhydrite were under equilibrium with dispersed centres of growth, and this allowed for the growth of relatively large crystals (Holliday, 1970).

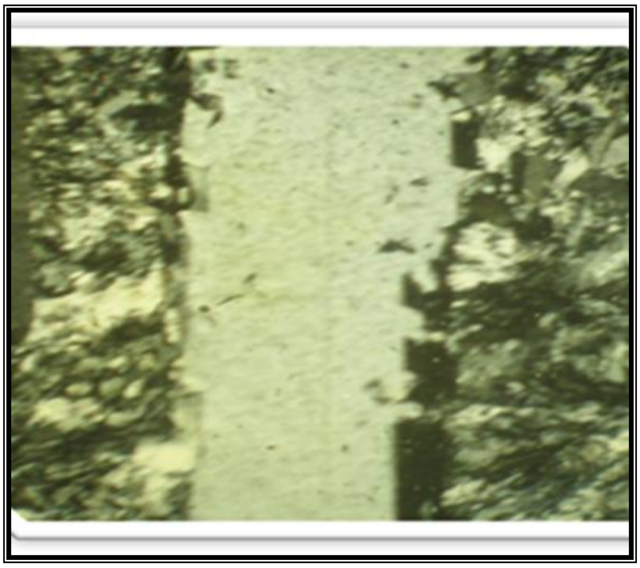


Plate 1. Porpheroblast crystal. Gypsum of Fat'ha Formation, Baashiqa Area.X200.Crossed polars. (Sample 28).

2. Alabastrine Texture:

This texture is characteristic of nearly all massive and nodular gypsum throughout the world of different ages (Orti and Rassel, 1977; Orti and Salvany, 1997; Veigas, 1997). Holliday (1967, 1970) divided this texture into three stages depending on the degree of crystallisation: stage one, stage two and stage three alabastrine texture. These three stages were diagnosed by Aljubouri (1972) in the Triassic gypsum of East-Midlands, England and by Sulayman (1990), Aljubouri (1993) and Mohammed-Ali (2009) in the gypsum of Fat'ha Formation, northern Iraq. The stages have also been diagnosed in gypsum of the present study.

2.1. Stage One Alabastrine Texture:

There are four characteristic properties for this texture: indistinct crystals, the absence of crystal edges, wavy extinction and the presence of superindividuals or composite crystals, with or without the "Feathery Texture" (Ogniben, 1957). The composite crystals are fairly large, up to one millimetre in size, with no distinct edges and interlocking with each other, giving a kind of mosaic texture. When the stage is rotated about (30°), the large composite crystal splits up into several small crystals (Plates 2A and B). The feathery texture was first suggested by Richardson (1920); it consists of irregular bands of gypsum crystals, which look like a bunch of bird feathers but without the middle stem. Sometimes, the bands are arranged in a radiating fashion or simple folds (Plates 3 and 4).

In the present study, stage one alabastrine texture is present in gypsum of both the Gercus and Fat'ha formations. However, in gypsum of the Gercus Formation, the feathery texture is absent and composite crystals make up only about 12% of the three stages and one range. In the lowermost bed, which consists of massive gypsum of the Duhok Dam section (Fig. 2), composite crystals make up about 50% of the three textures. On the other hand, in gypsum of the Fat'ha Formation, Baashiqa area, stage one alabastrine texture is very dominant and makes up about 87% of stages one and two, where stage three is absent. Composite crystals and feathery texture are present in about equal amounts in stage one. It is believed by many authors, including the present study, that the radiating and simple folding feathery texture in gypsum is inherited from primary anhydrite; that is, gypsum is secondary. Stage one alabastrine texture represents the starting of hydration of anhydrite with conservation of anhydrite texture. This stage is followed by recrystallisation into composite crystals, which later on and with the remaining feathery texture, and by another recrystallisation and change into the second-stage alabastrine texture. The observation in gypsum mines of the gradual transformation of gypsum into anhydrite with depth and the presence of anhydrite remnants within gypsum texture leaves no doubt that gypsum is of secondary origin, derived from primary anhydrite (West, 1964; Aljubouri, 1972, 1993, 2011; Alhadeedi, 2010).

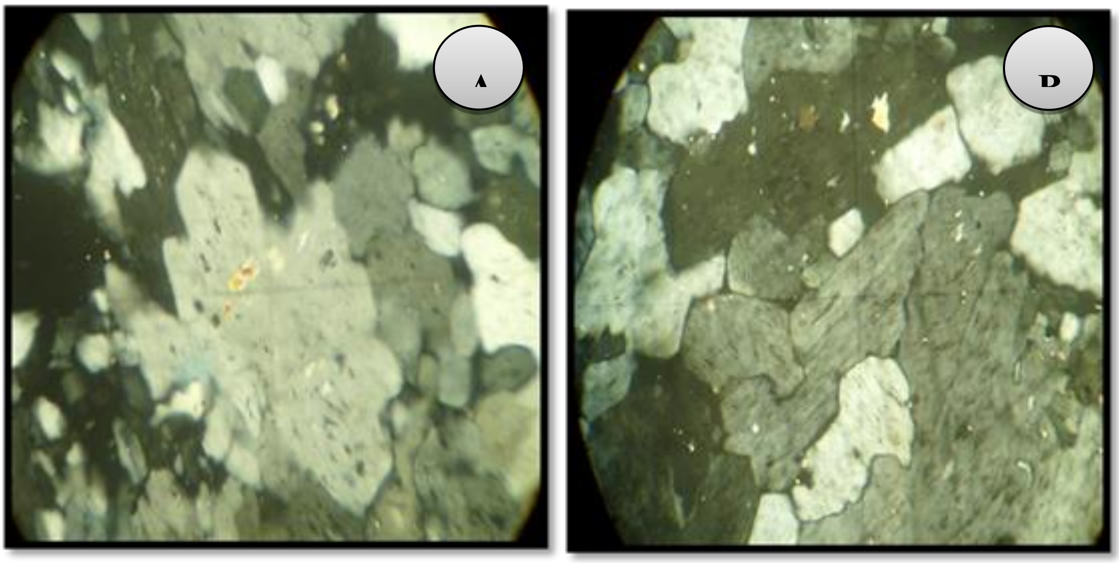


Plate 2. Composite crystal of stage one Alabastrian Texture B-on(30̊)Stage Rotation, The large crystal Gypsum of Fat'ha Formation, Baashiqa area .X200.Crossed Nicols (Sample32).

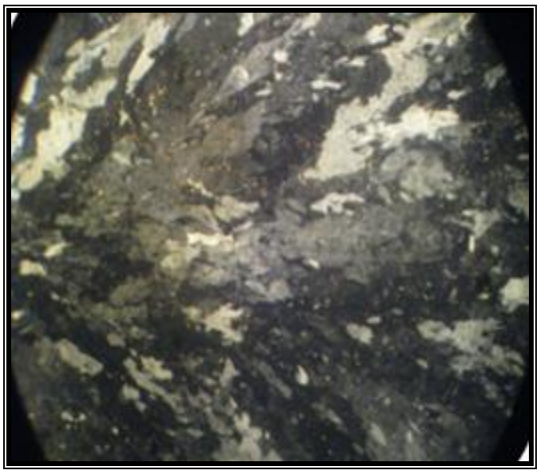


Plate 3. Feathery Texture with radiating irregular crystals.Gypsum of Fat'ha Formation, Baashiqa Area .X200.Crossed polars (Sample34).

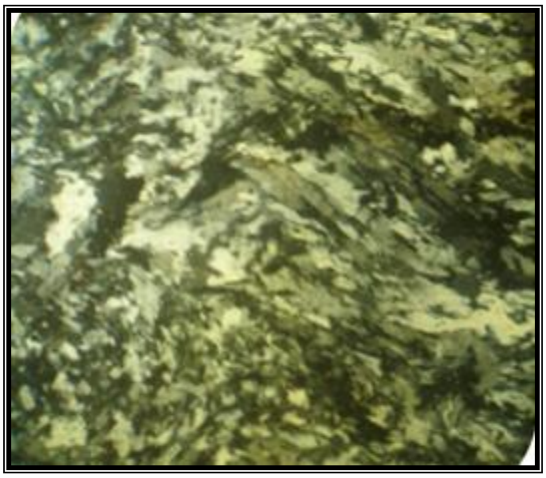


Plate 4. Feathery Texture with a simple fold.Gypsum of Fatha Formation.Baashiqa Area .X200.Crossed polars (Sample 26).

2.2. Stage Two Alabastrine Texture:

This texture is characterized by clear, well-developed, subhedral to anhedral crystals with a size ranging from 20 to 200µ). This is the same range as that stated by Aljubouri (1993) for gypsum of the Fat'ha Formation below Mosul Dam base and close to that stated by Mohammed Ali (2009) (40-185µ) for gypsum of the Fat'ha Formation (Plate 5).In the present study, this texture makes up only about 13% of the first and second stages in gypsum of the Fat'ha Formation, Baashiqa area, whereas it makes up about 88% of the onerage in gypsum of the Gercus Formation of Duhok Dam and Zawita junction area. The remaining (12%) is made up of composite crystals. However, in the lowermost (20 cm) bed of massive gypsum (Fig. 2A), the composite crystals make up about 50% of the total three textures, as stated earlier. Feathery texture is absent, and hence gypsum of the Gercus Formation represents an advanced stage of recrystallization compared with gypsum of the Fat'ha Formation.

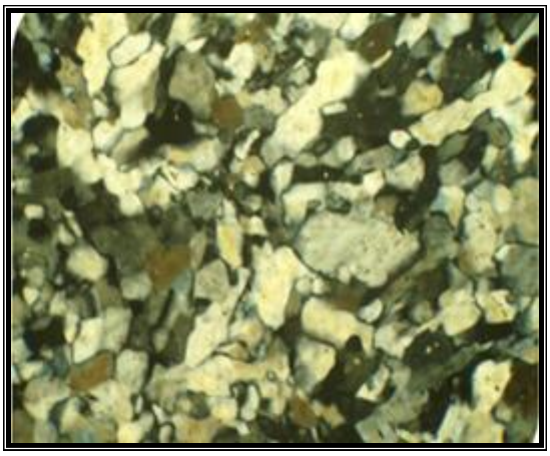


Plate 5. Stage Two Alabastrian Texture.Duhok Dam Gypsum .X100.Crossed polars (Sample 7).

2.3. Stage Three Alabastrine Texture:

This texture is characterized by the relatively large crystals with a size ranging from 400 to 700μ. Most crystals are euhedral. In gypsum of the Fat'ha Formation, this stage is absent. On the other hand, a few thin sections (e.g. sample 24) of gypsum of the Gercus Formation, Zawita junction, contain euhedral crystals similar to stage three texture but with a smaller size (about 300μ) (Plate 6).

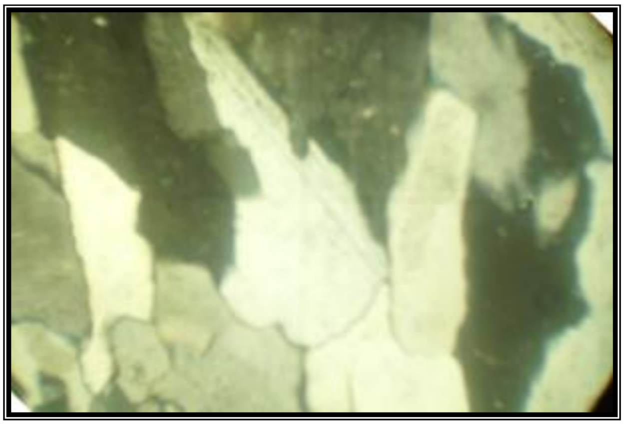


Plate 6. Stage Three Alabastrian Texture.Zawita Junction Gypsum .X200.Crossed polars (Sample 24).

3. Interference colours

Interference colours cover all range of first order for gypsum from pale yellow to grey. From the optic orientation diagram (Fig. 5), it is possible to relate interference colours and birefringence of gypsum to their most likely faces or forms in the crystals (Bloss, 1961; Aljubouri, 1989). Grains and crystals, including all of stage one composite crystals, exhibiting first order pale yellow to white interference colours represent the side or (b) pinacoid which is perpendicular to (y) vibration direction and parallels (x and z) and therefore it is a principal section having maximum birefringence (γ-α) in the range of (0.009-0.01). Other gypsum grains and crystals exhibiting first-order pale grey to grey interference colours represent prisms of first, third and fourth order (okl, hko and hkl). They are random sections, i.e. sections which cut the three vibration directions (x, y and z) and therefore have moderate to weak birefringence in the range of (0.007-0.003), Figure 4.

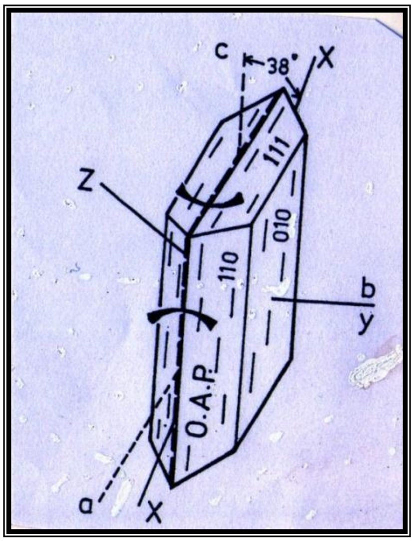


Fig. 4. Optic Orientation Diagram for Gypsum. (a, b, c) Crystallographic Axes; (X, Y, Z) Vibration Directions: (O, A, P) Optic Axial Plane. (Phillips and Griffen, 1981).

4. Secondary Minerals

In gypsum of the present study, there are three secondary minerals identified under the polarizing microscope, which are nearly always associated with nodular or massive gypsum; these are anhydrite, dolomite and celestite.

4.1. Anhydrite $CaSO_4$:

This mineral is present in gypsum of both Gercus and Fat'ha formations and throughout the three stages of crystallization. It is characterized by the moderate relief, rectangular, euhedral to subhedral crystals, second-order red and purple and third-order blue and green bright interference colours (Phillips and Griffen, 1981; Aljubouri, 1989) (Plate 7). These crystals are cleavage remnants of anhydrite, which did not hydrate to gypsum and are an indication of the secondary origin of gypsum. In the present study, about 50% of the thin sections of gypsum of both formations contain anhydrite.

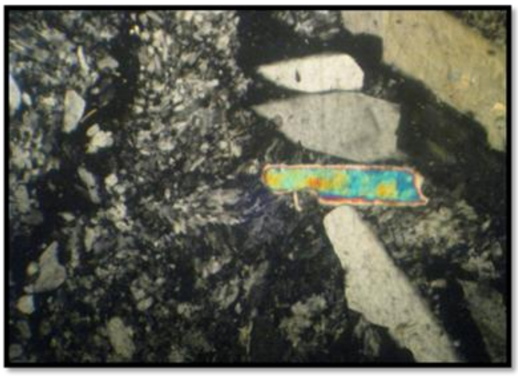


Plate 7. Anhydrite crestel, Brillion Interference colours.Duhok Dam Gypsum .X400.Crossed polars (Sample 2).

4.2. Dolomite CaMg (CO_3):

This mineral is present in gypsum of both Gercus and Fat'ha formations in the same proportion as that of anhydrite, that is, in about 50% of thin sections. Crystals are either anhydrite, irregular grains or subhedral, rhombic in shape. Dolomite is characterized by twinkling, the well-known optical phenomenon in carbonates (Aljubouri, 1993; Alhadeedi, 2010 (Plate 8 A and B).

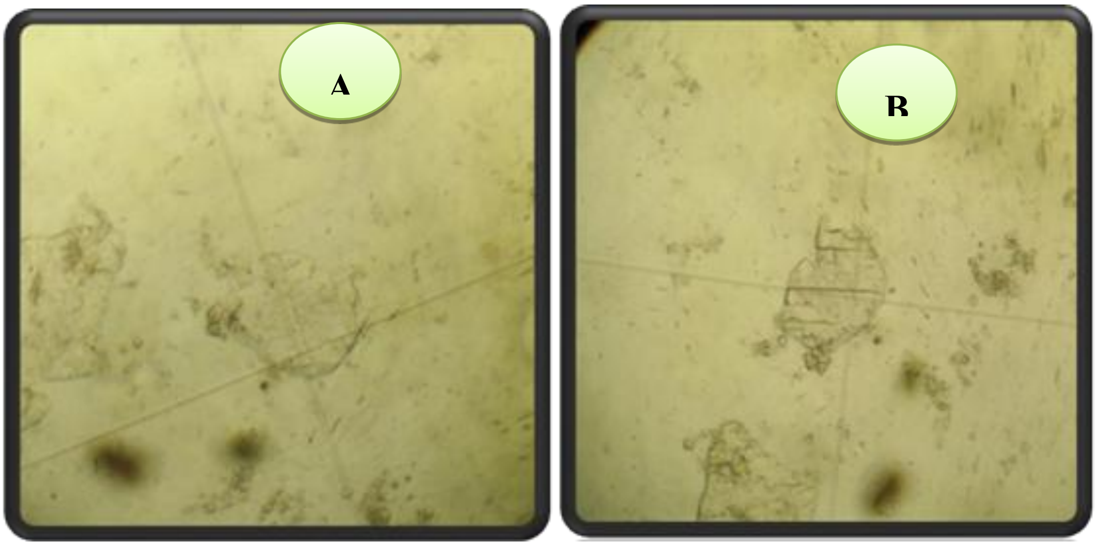


Plate 8. Dolomite crystal showing twinning. A- High Relief. B-Low Relief.

4.3. Celestite $SrSO_4$:

This mineral is present in a few gypsum samples, which have relatively high strontium content in the three studied areas (Duhok Dam and Zawita junction, both of the Gercus Formation and Baashiqa of the Fat'ha Formation). Nine samples, three from each locality, contain celestite. Crystals are either very small grains with a size less than 20 µm or euhedral elongated, six-sided, with up (100 µ (Plates 9 and 10). The optical properties are high relief, colourless, prismatic, euhedral, parallel extinction, low interference colours of first order grey and white and length slow positive. These properties are similar to those for (Barite, BaSO4);

however, the relatively very high concentration of strontium compared with barite (x 50 as much) leaves no doubt that the mineral is celestite and not barite.

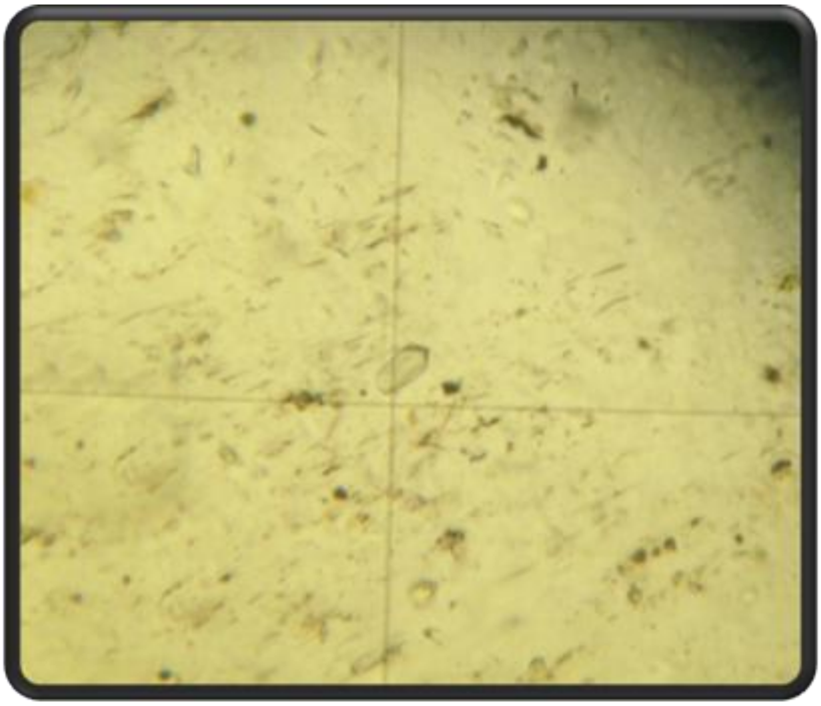


Plate 9. Euhedral Celestite, near centre, in a groundmass of Gypsum, Baashiqa Section.X400.PPL. (Sample 3).

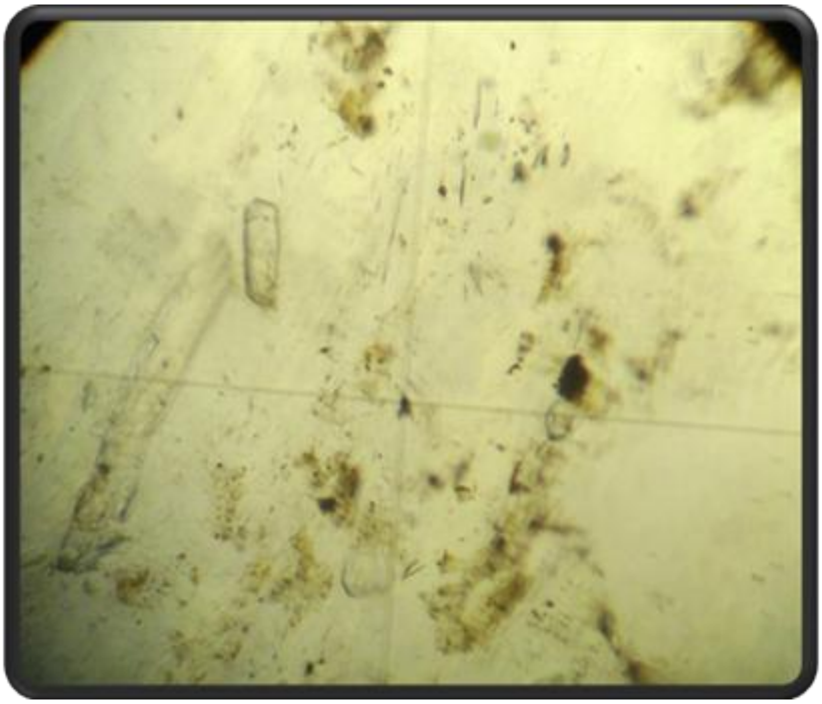


Plate 10. Euhedral Celestite, in a groundmass of Gypsum.Zawita Junction section.X400.PPL (Sample 14).

Mineralogy

Gypsum belongs to the monoclinic system, prismatic class (2/m). This class has only two types of forms, the side pinacoid (two-faced form) and the prism (four-faced form). Ordinary gypsum crystals consist of either (10) faces (side pinacoid 010, fourth order prism 111 and third order prism 110) (Fig. 5) or sometimes (14) faces with additional first order prism (011) (Hurlbut and Klein, 1977; Berry et al., 1983).

The most characteristic peak with (100%) intensity, (d) spacing of (7.56 Å) and (2θ) of (11.70°), which belongs to the side pinacoid (020) for gypsum standard, appears at all types of gypsum of the present study. The other three secondary characteristic peaks corresponding to fourth-order prisms ($12\bar{1}$) and ($14\bar{1}$) and other secondary pinacoids (040 and 030), all have lower peak intensities compared with the gypsum standard (Table 1 and Figures 5 to 8.

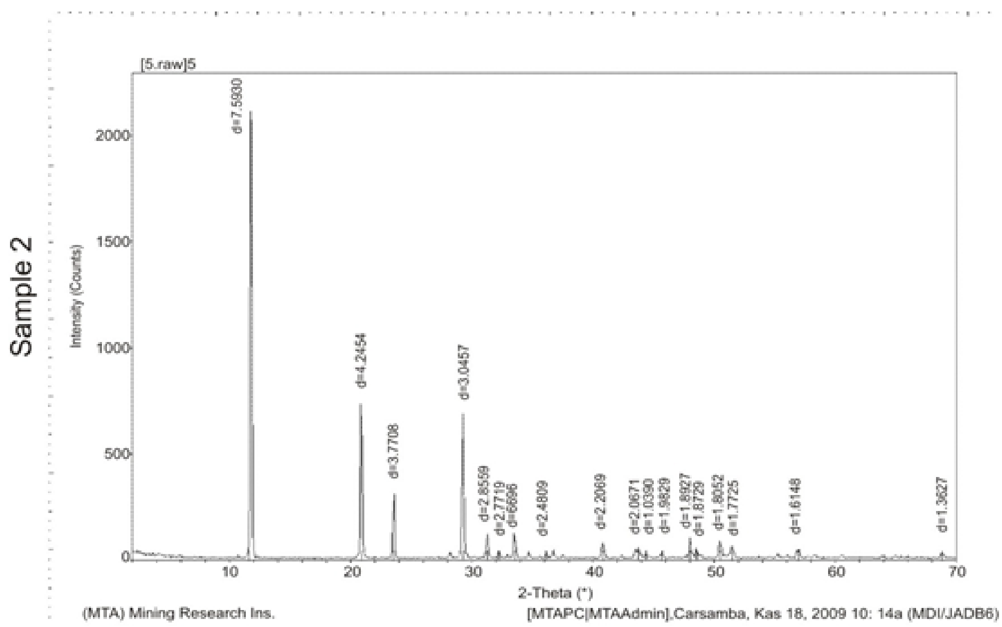


Fig. 5. X-Ray Difraction Peaks for Massive Gypsum, Duhok Dam .Gercus Formation.

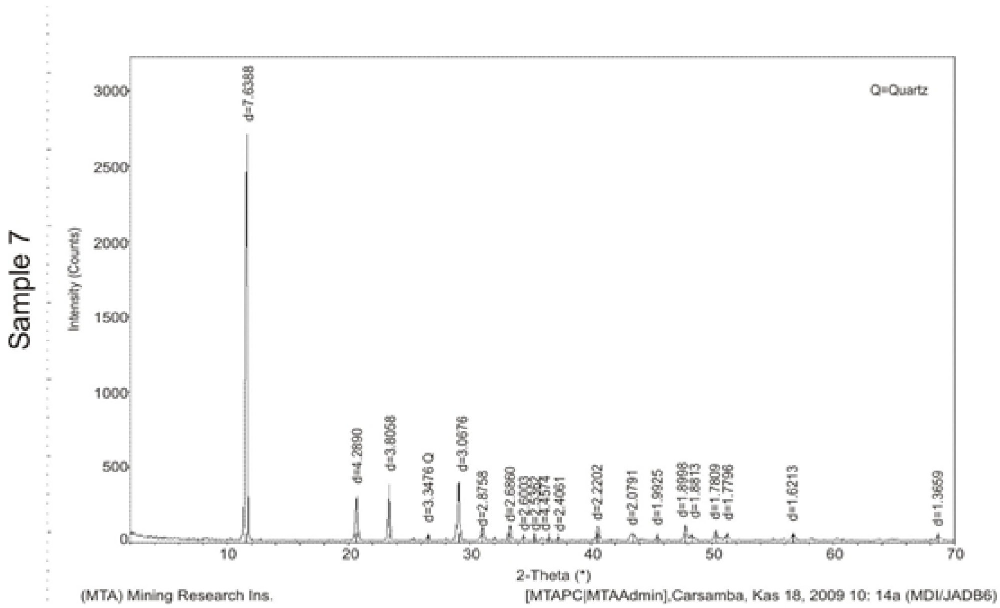


Fig. 6. X-Ray Difraction Peaks for nodularGypsum, Duhok Dam .Gercus Formation.

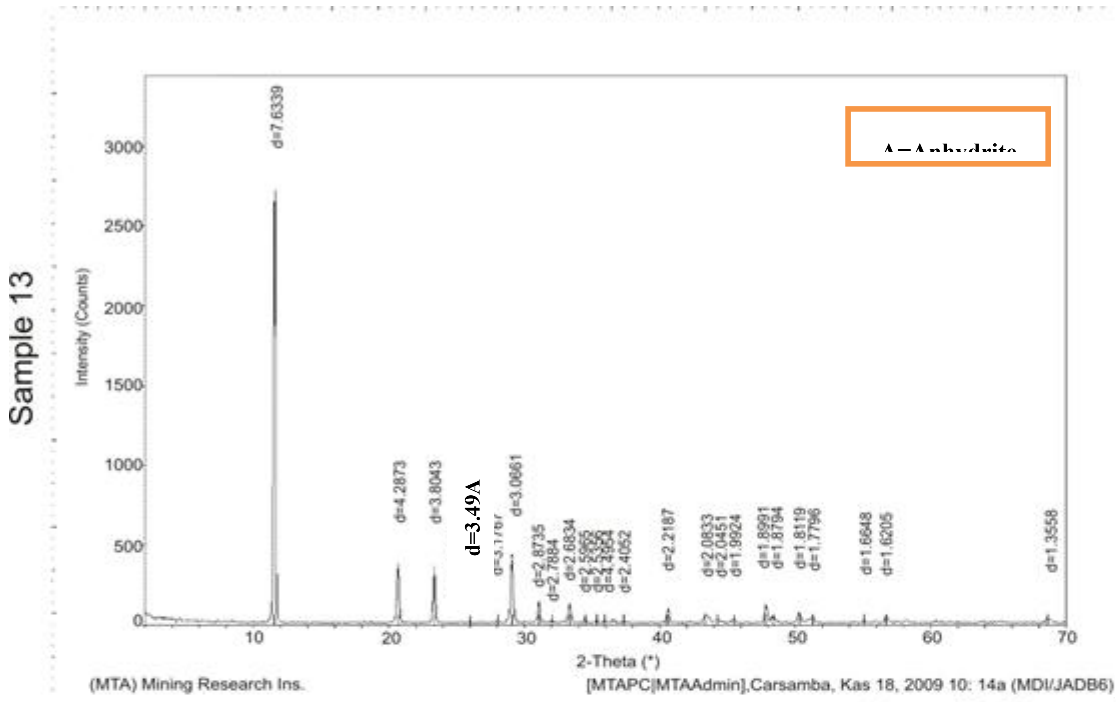


Fig. 7. X-Ray Difraction Peaks for nodular Gypsum, Zawita Junction .Gercus Formation.

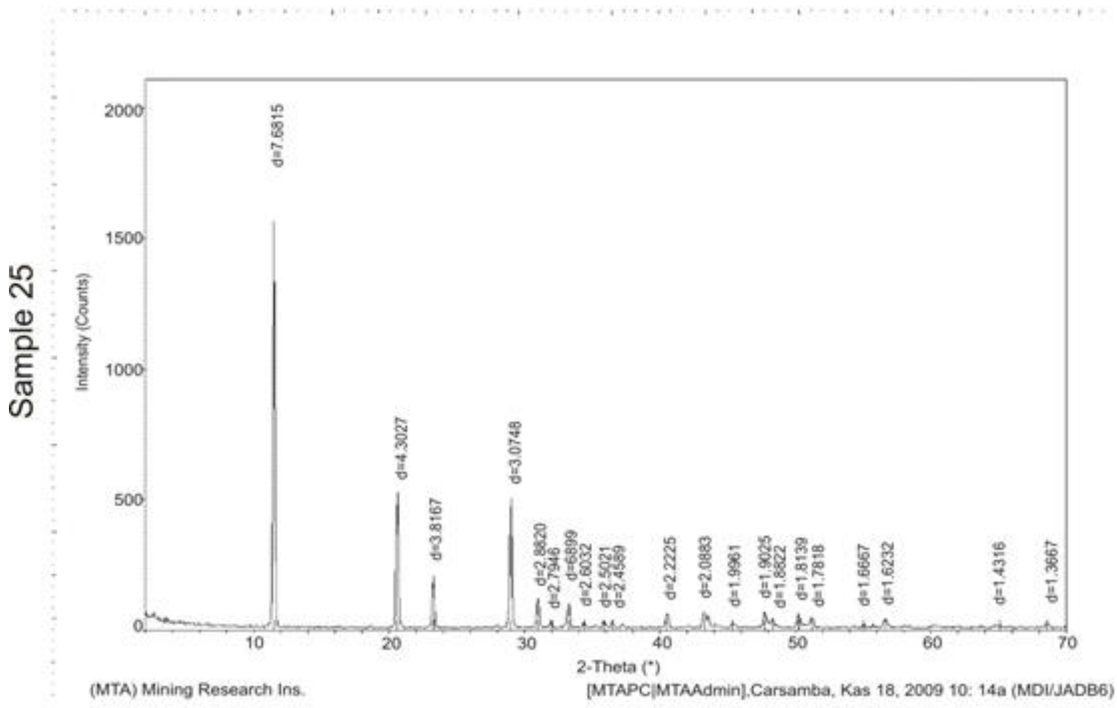


Fig. 8. X-Ray Difraction Peaks for nodular Gypsum, Baashiqa Area .Gercus Formation.

Table (1): X-ray Diffraction Data for (JCPDS, 1974) Standard Gypsum, Massive Gypsum and Nodular Gypsum, Duhok Dam; Nodular Gypsum, Zawita Junction (Gercus Formation) and Nodular Gypsum, Baashiqa Area (Fat'ha Formation).

Gypsum, JCPDS, 1974, (Card No. 6-0046)				Massive gypsum, Duhok Dam, Gercus Formation			Nodular gypsum, Duhok Dam, Gercus Formation			Nodular gypsum, Zawita junction, Gercus Formation			Nodular gypsum, Baashiqa Area, Fat'ha Formation		
d (Å)	I/I_0 %	hkl	2θ°	d (Å)	I/I_0 %	2θ°	d (Å)	I/I_0 %	2θ°	d (Å)	I/I_0 %	2θ°	d (Å)	I/I_0 %	2θ°
7.56	100	020	11.70	7.59	100	11.66	7.64	100	11.58	7.63	100	11.63	7.68	100	11.52
4.27	50	$12\bar{1}$	20.80	4.25	38	20.90	4.29	14	20.70	4.29	17	20.70	4.30	33	20.65
3.79	20	040, 030	23.45	3.77	15	23.60	3.81	14	23.35	3.80	13	23.41	3.82	13	23.30
3.06	55	$14\bar{1}$	29.15	3.05	32	29.25	3.07	19	29.05	3.07	19	29.05	3.08	32	28.95
2.87	25	002	31.20	2.86	5	31.25	2.88	4	31.05	2.88	5	31.05	2.88	7	31.05
2.79	6	211	32.05	2.77	2	32.30	--	--	--	2.79	2	32.05	2.79	2	32.05
2.68	23	051, 022	32.45	2.67	6	33.55	2.69	2	33.30	2.68	5	32.45	2.69	7	32.35
2.50	6	200	36.00	2.48	2	36.20	2.46	2	36.55	2.50	2	36.00	2.46	2	36.55
2.22	6	$15\bar{2}$	40.70	2.21	4	40.80	2.22	4	40.70	2.22	4	40.70	2.22	4	40.70
2.08	10	$12\bar{3}$	43.50	2.07	3	43.70	2.08	2	43.50	2.08	3	43.50	2.09	4	43.30
1.99	4	170	45.60	1.98	2	45.80	1.99	2	45.60	1.99	2	45.60	1.99	2	45.60
1.90	16	080, 062	47.95	1.89	5	48.15	1.90	4	47.95	1.90	5	47.95	1.90	5	47.95
1.88	10	$14\bar{3}$	48.45	1.87	3	48.70	1.88	2	48.45	1.88	2	48.45	1.88	2	48.45
1.81	10	$26\bar{2}$	50.42	1.81	5	50.42	1.81	3	50.42	1.81	3	50.42	1.81	4	50.42
1.78	10	260	51.33	1.77	3	51.64	1.78	2	51.33	1.78	2	51.33	1.78	3	51.33

For the same mineral, the decisive factor for the diffraction of x-rays is the "multiplicity factor" (Cullity, 1978), which is the number of faces in a crystal form having the same (d-spacing). The higher the number of faces in the form, the higher the chances of diffraction of x-rays from these faces and consequently the higher the intensity. This means that the intensity of the fourth-faced prisms is expected to be higher than that of the two-faced pinacoid. However, in gypsum, this rule does not hold, and the very strong preferred orientation of the two-faced side pinacoid (010) results in greatly enhanced intensity of the (020) reflection observed in all gypsum diffractograms (Grattan-Bellew, 1975). It is interesting to note that the common faces of gypsum crystal, the side pinacoid (010), third order prism (110) and fourth order prism (111) (Fig. 5) do not have diffraction peak intensities. This is because their reflected waves from their respective atomic planes do not have a whole number of wavelengths, i.e. (nd) phase difference, and therefore the Bragg equation ($n\lambda=2d\sin\theta$) is not satisfied (Hurlbut and Klein, 1977; Berry et al., 1983). Instead, their other respective family planes (020, $12\bar{1}$ and $14\bar{1}$) have satisfied the equation and exhibited the observed diffraction peak intensities in Figures (6 to 9). Secondary minerals identified by x-ray diffraction study were quartz in the nodular gypsum of Duhok Dam and anhydrite in the nodular gypsum of Zawita junction, where both gypsums are of the Gercus Formation. The two minerals appear at their characteristic peaks of (3.45 and 3.49 Å) d-spacings respectively, but with very low intensity of not more than 3%

(Figures 4 and 5). Anhydrite was identified under the polarizing microscope in nodular gypsum of Duhok Dam (Plate 7). The presence of quartz in gypsum of the Gercus Formation is possibly due to the higher proportions of insoluble residue (I.R.) of (1.27%) compared with (1.17%) for the Baashiqa area, Fat'ha Formation (Aljubouri, 2010). Insoluble residue consists mainly of clay minerals and quartz in the ratio of roughly 2:1 (Aljubouri and Al-Kawaz, 2008). The presence of anhydrite in gypsum of the Gercus Formation could be due to its lower content of (H2O+) of (19.92%) compared with (20.22%) for gypsums of the Baashiqa area, Fat'ha Formation, which makes it more possible for the appearance of anhydrite in gypsum of the Gercus Formation. The amount of anhydrite is inversely proportional to (H2O+) content of gypsum (Aljubouri, 1972, 1993; Alhadeedi, 2010).

CONCLUSIONS

The present study concludes that:

1. Petrographically, gypsums of Gercus and Fat'ha formation consist of two main textures: porphyroblastic of minimal extent and alabastrine of very wide distribution. According to shape, size and outline of crystals, the alabastrine texture could be divided into three hydration stages of unequal distribution in gypsums of Gercus and Fat'ha formations.
2. Secondary minerals identified under the polarizing microscope in gypsums of both Gercus and Fat'ha formations were anhydrite, dolomite and celestite. Anhydrite represents the primary phase, which was not hydrated to the secondary gypsum.
3. X-ray diffraction study shows that massive gypsum of Duhok Dam (Gercus Formation) and nodular gypsum of Baashiqa area (Fat'ha Formation) have very similar intensities for the three secondary characteristic peaks at d-spacings of (4.27, 3.74 and 3.06) and higher than that of nodular gypsum of Duhok Dam and Zawita junction (Gercus Formation). The presence of relatively large proportions of composite crystals could be the cause for these high intensities in these gypsums.

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