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GYPSUM DEPOSITS IN IRAQ: AN OVERVIEW

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Key words: Gypsum; Gypcrete; Gypsiferous soil; Miocene; Iraq

ABSTRACT

Gypsum deposits in Iraq are either primary or secondary in origin. The primary deposits were deposited in different geological periods in semi restricted basins, of which, only the gypsum and anhydrite deposits of the Fatha and occasionally the Dhiban formations are exposed on the surface in the areas of Nineva, Kirkuk, Erbil, Sulaimaniyah, Diyala, Wasit and Anbar governorates, forming important resources for cement and plaster industries. The total reserve of the primary gypsum is estimated to be 142 million tons. The secondary gypsum deposits, present as gypcrete or gypsiferous soil, are developed in the upper few meters of the soil cover by different processes leading to enrichment of calcium sulfate in the soil, mainly by the upward migration of the sulfate-rich water by capillary action. The gypsiferous soil is of low gypsum content in the depth of (0 – 25) cm and covers about 39% of Iraqi soil; while at the depth (25 – 150) cm it is of medium gypsum content and covers about 53% of the Iraqi soil. The reserve of the gypsiferous soil is estimated to be 6 million tons. Primary gypsum and gypsiferous soil have produced many problems in Iraq and are potential hazard to the constructions due to possible settlement of the foundations, as well as degrading the agricultural lands in reducing the productivity of the soils and limit the crop types.

رواسب الجبسم في العراق: نظرة شاملة

رافع زائر جاسم

المستخلص

يوجد نوعان من رواسب الجبسم في العراق، رواسب أولية ورواسب ثانوية. ترسبت الأولية منها في عصور جيولوجية مختلفة في أحواض مغلقة أو شبه مغلقة وتوجد في العديد من التكاوين الجيولوجية في العراق. معظم ترسبات الجبس والأنهيدرايت تحت سطحية باستثناء تلك العائدة لتكويني الفتحة والذبان، حيث تتكشف صخور الجبس والأنهايدرايت في تكوين الفتحة وأحيانا تكوين الذبان في محافظات نينوى وكركوك وأربيل والسليمانية وديالى وواسط والأنبار وهي مصدر جيد لصناعات السمنت والبورك وبلغ الاحتياطي المقدر للجبسم الأولي حوالي 142 مليون طن. أما الجبسم الثانوي فيتكون في الأمتار القليلة العليا من التربة بعدة طرق تؤدي الى إغناء التربة بكبريتات الكالسيوم ومن أهم هذه الطرق هي صعود المياه الحاوية على كبريتات الكالسيوم الى الأجزاء العلوية من التربة بواسطة الخاصية الشعرية. بينت الدراسات أن الجزء العلوي من التربة الممتد من السطح الى عمق 25 سم يحوي على كمية قليلة من الجبس وهذه الطبقة تغطي 39% من سطح تربة العراق، بينما للعمق الذي يتراوح بين 25 سم و 150 سم يحتوي على كمية متوسطة من الجبس ويوجد في حوالي 53% من تربة العراق. قدر إحتياطي الترب الجبسية أو الجبكريت الصالح لصناعة الجص (الملاط) حوالي ستة ملايين طن. ان الجبس والترب الجبسية ممكن ان تلحق الضرر بالمنشآت الهندسية فقد تؤدي الى تجلسها أو حتى الى إنهيارها، بينما تؤدي في الزراعة الى تقليل خصوبة التربة وخفض انتاجيتها وتقليص أنواع المحاصيل الزراعية التي من الممكن زراعتها فيها.

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INTRODUCTION

Calcium sulfate is the inorganic compound with the formula $CaSO_4$ and related hydrates. Anhydrite is anhydrous ($CaSO_4$), gypsum is the dihydrate ($CaSO_4.2\ H_2O$) and bassanite is the hemihydrate ($CaSO_4.0.5\ H_2O$). Anhydrite is somewhat harder and heavier than gypsum. Gypsum has four different cleavage surfaces, and its crystals display a variety of forms, the most common are granular, massive rock (alabaster), transparent crystalline material that forms large, well-developed crystals (selenite), rose-like and aggregates of fibrous gypsum (satin spar). Gypsum precipitates at temperatures lower than 25 °C while anhydrite precipitates in temperatures above than 25 °C in closed basins. Gypsum transfers to anhydrite upon burial or by heating to 200 °C and anhydrite transfers to gypsum by hydration or weathering (Warren, 2016). Pure gypsum contains 20.9% combined water, 46.6% sulfur trioxide (SO_3) and 32.5% lime (CaO). The minimum for a material to be called gypsum is 70% $CaSO_4.2H_2O$. Gypcrete (also called gypcrust) is an indurated or hardened, layer of secondary gypsum cemented duricrust, formed on the surface or within the soil. It is a weakly consolidated earthy mixture of gypsum and clay or silt. It is a surficial material that forms as an efflorescent crust in the hot, arid or semiarid climate regions of little rain and rapid evaporation (Warren, 2016).

Gypsum is the source material for Juss and plaster industries in Iraq and it is used as a retarder in the cement industry. Anhydrite was used in the sculptures of the ancient civilizations in Mosul vicinity like those found in the Assyrian ruins of Namroud. The anhydrite of the Fatha Formation is also used as a decorative building material, especially in Mosul and Kirkuk cities. Moreover, gypsum of the Fatha Formation is considered as the parent material of native sulfur in the Mishrak deposits (Jassim and Al-Murib, 1989 and Jassim and Gulam, 1991).

PREVIOUS WORK

Macfayden (1944) is one of the pioneer geologists who mentioned that gypsum for plaster of Paris is of three types, the sedimentary one of Miocene age and the more powdery represented by the gypcrete of Plio-Pleistocene age and that mixed with the clays and marl. Since then geological investigations and reserve estimation projects of gypsum and anhydrite in Iraq continued for more than sixty years and were carried out mainly by Iraq Geological Survey:

El-Sabti and El-Mehedi (1967), El-Sabti (1970), Al-Mubarak and Al-Rufai (1971), Mansour (1972), Semchinov (1973), Al-Kaaby (1974), Al-Kaaby (1975), Jabur and Mustafa (1976), Mohammed *et al*. (1976), Mustafa and Abdul Ghani (1977), Al-Kaaby (1977), Ashoor and Mehdi (1976), Abdul Husain and Jirgees (1977), Jirgees (1978), Mustafa and Mekho (1978), Saad (1979), Jirgees and Ali (1979), Abdul Husain (1979), Abdul Husain *et al*. (1980), Saad (1980), Ghalib (1980), Toma (1980), Leitch (1980), Abdul Husain (1981), Mehdi (1981), Al-Sharbati and Ma'ala (1983a), Al-Sharbati and Ma'ala (1983b), Al-Ani and Ma'ala (1984), Jassim *et al*. (1984), Maiqil (1986), Mansour and Toma (1983), Mehdi (1992), Deikran and Yacoub (1993), Deikran and Mahdi (1994), Al-Bassam and Dawood (2002), Hussain *et al*. (2006), Yaqub and Abdul Jabar (2007), Al-Kaabi (2007) and Hussain *et al*. (2011).

Some of the results achieved by previous workers are outlined below:

Al-Barzanji (1973) studied gypsiferous soil in several localities in Iraq. Al-Hassani (1984) studied the characteristics of sabkha soil in some Iraqi regions. Al-Ani (1986) studied some sabkha sediments in western Mesopotamia. Al-Maroof (1986) studied the gypsiferous sandstones of the Injana Formation in the Habbaniya – Razzaza area. Saeed (1994) studied the distribution of gypsiferous soil in Iraq. Razouki *et al*. (1994) studied the structural failure caused by gypsiferous soil in Iraq. Al-Jumaily (1994) studied the influence of gypsum on the engineering properties of soil. Ismail (1994) studied the agricultural exploitation of gypsiferous soils and the crops suitable for various types of these soils according to their gypsum content. Al-Baidari (1996) studied the sedimentology and geochemistry of the Injana Formation in the Najaf – Kerbala area and described the gypsiferous horizons as paleogypcrete. Sissakian and Salih (1999) and Sissakian and Abdul Jab'bar (2002) studied the distribution and thickness variation of the Fatha Formation in Iraq and found that the maximum thickness of the gypsum beds is recorded west of Kifri town, within the Pulkhana anticline, were it reaches 40 m. Sissakian (2000a) studied the geographical distribution of the Dhiban Formation in surface and subsurface sections and provided details on thickness variation.

Sissakian (2000b) studied the potential hazards caused by some geological criteria and he outlined that one of the main geological hazards in Iraq is caused by gypsum exposures expressed, as an example, in the Mosul Dam which suffers from severe karstification problems in the foundations, abutments and reservoir area. The Al-Fatha alluvial fan of northern Mesopotamia contains channels truncated by a younger channel system (up to 10 m thick) probably of Middle to Late Pleistocene age, forming isolated shallow gravel bodies. The younger system is rich in gypsum and is often described as gypcrete. The central belt of the aeolian deposits lies between the Tigris and Euphrates Rivers is generally rich in gypsum and clayey-crusted grains derived from the sabkhas and depression deposits on which they are often located (Aqrawi *et al*., 2006).

PRIMARY GYPSUM DEPOSITS AND OCCURRENCES

Gypsum and anhydrite may be of marine or continental origin. Primary gypsum and anhydrite deposits are found in many geological formations and in many localities in Iraq (Fig.1). They are found in formations ranging in age from Triassic to Neogene either as the main constituent or as subordinate (Bellen *et al*., 1959 and Jassim *et al*., 2006; in Jassim and Goff, 2006). Although the gypsum and anhydrite beds of most of these formations are not important from economic point of view (except the Dhiban and Fatha formations), but some of them are important for the oil industry forming the cap rocks for the oil accumulation in the oil reservoir (Jassim and Al-Gailani, 2006; in Jassim and Goff, 2006).

The gypsum and anhydrite-bearing formations in Iraq are Geli Khana (Middle Triassic), Zor Hauran, Kurra China, Butmah and Baluti (Upper Triassic), Gotnia (mid-Upper Jurassic), Amij (Liassic), Sarki (Lower Liassic), Barsarin (Kimmeridgian – Lower Tithonian), Jawan (Albian), Sa'di (Upper Cretaceous), Umm Er Radhuma (Paleocene), Khurmala (Paleocene – Lower Eocene), Rus (Lower Eocene), Jeribe (Lower Miocene), Ghar (Lower Miocene), Dhiban (Lower Miocene) and the Fatha (Middle Miocene).

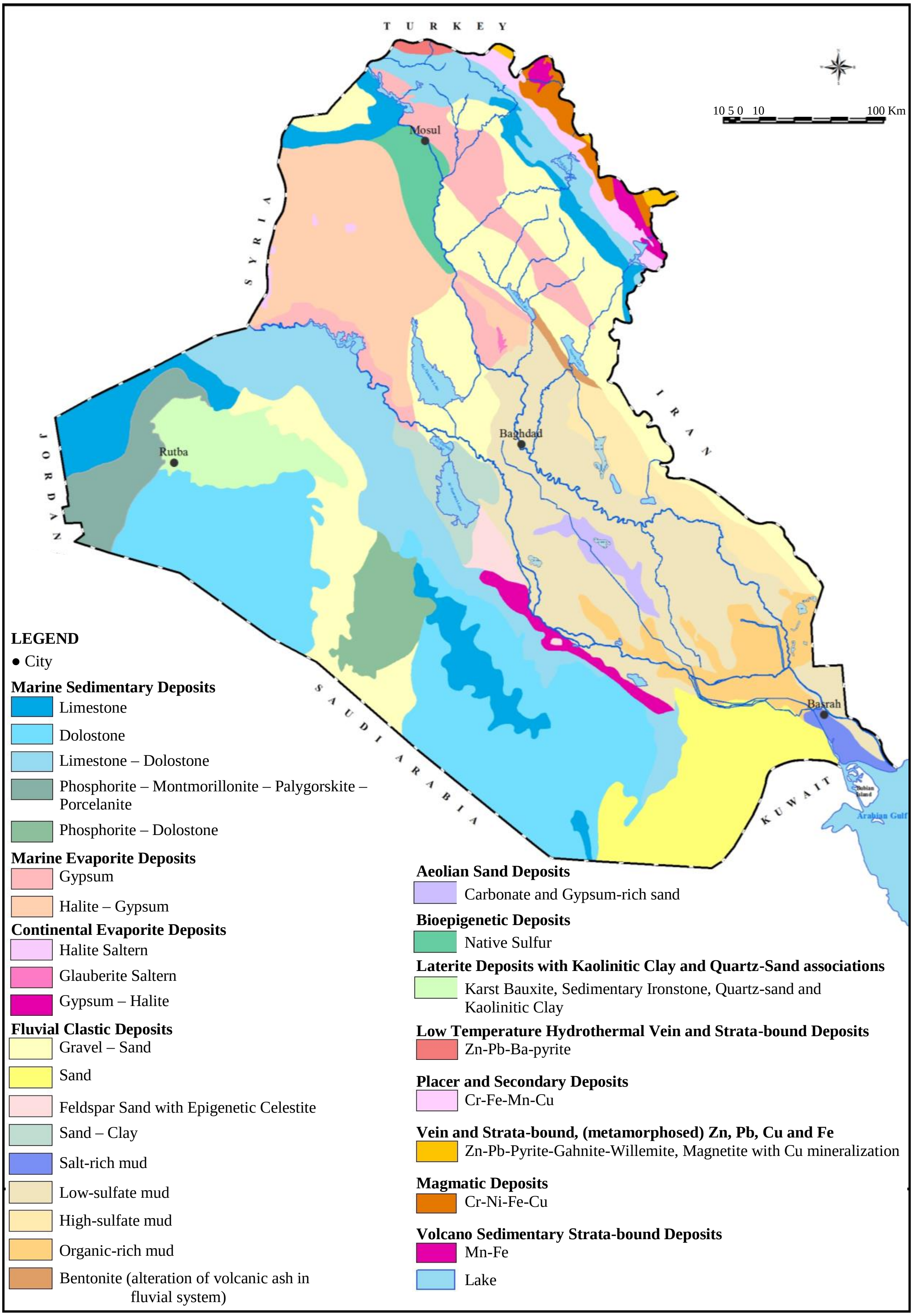


Fig.1: Minerogenic map of Iraq scale 1: 1000 000 (after Al-Bassam, 2007)

The Miocene formations are the most prominent primary gypsum- and anhydrite-bearing rock units in Iraq. The Dhiban Formation (Lower Miocene) and the Fatha Formation (Middle Miocene) are comprised of anhydrite, gypsum, and salt, interbedded with limestone and marl. The Dhiban Formation (Lower Miocene) contains thick beds of gypsum in outcrops and anhydrite in the subsurface. Its thickness is (5 – 40) m and reaches up to (65.1) m in Jabal Sinjar. It crops out at the core of Jebel Jeribe also. The gypsum beds of the Fatha Formation were deposited during the Middle Miocene time when the Tethys Ocean was closed or semi closed (Fig.2). The gypsum beds of the Fatha Formation are exposed in two NW – SE belts in the Low Folded Zone of Iraq (Fig.1), having the main trend of the Middle Miocene depositional basin in Iraq (Figs.2 and 3). The Fatha Formation is aerially widespread and economically important formation. It is of Tortonian age (Middle Miocene) and divided into the Lower and Upper members. Primary gypsum deposits are found in the two members of the Fatha Formation with total thickness exceeding 650 m (Table 1 and Figs.4 and 5). They are composed of almost pure gypsum (Table 2). The basal unit of the Injana Formation (Upper Miocene) contains thin gypsum and anhydrite beds. (Jassim and Buday, 2006; in Jassim and Goff, 2006).

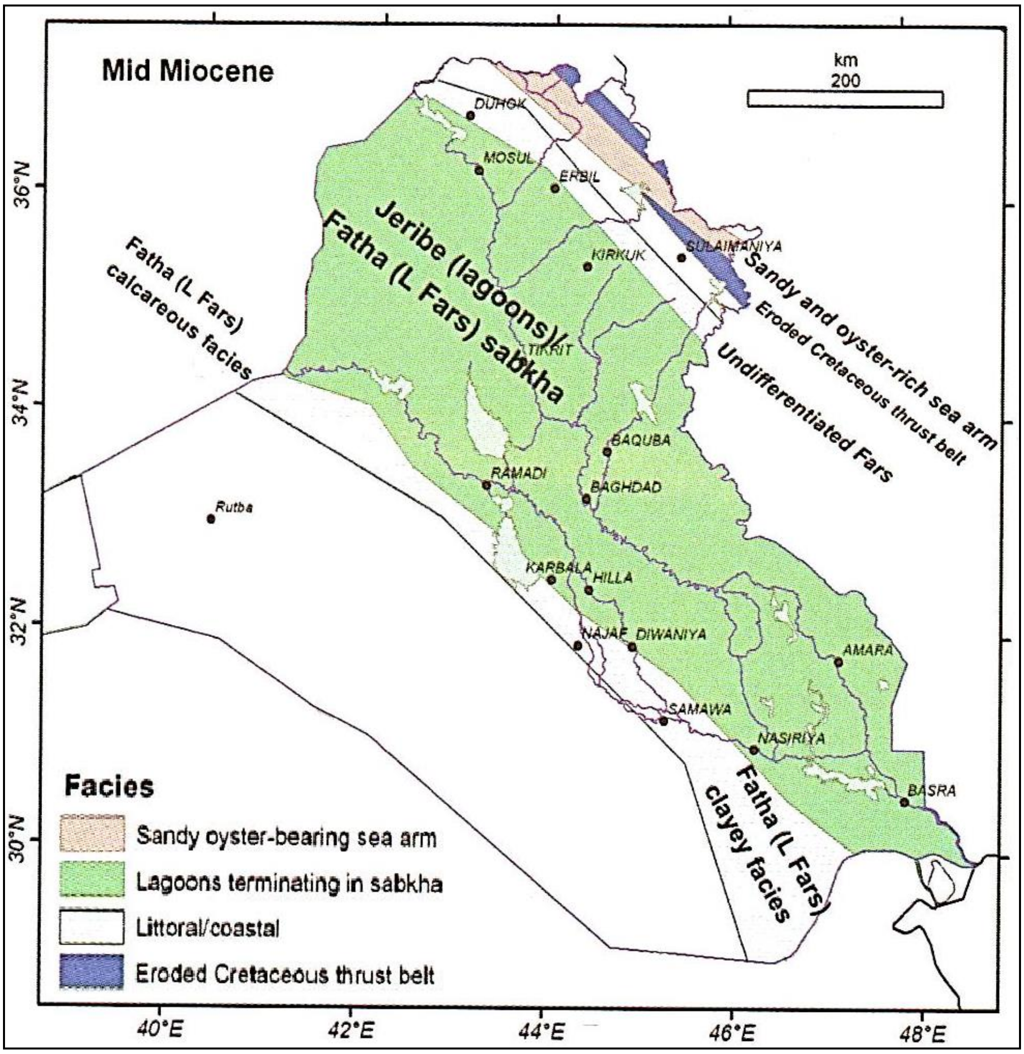


Fig.2: Middle Miocene Paleogeography (after Jassim and Buday, 2006; in Jassim and Goff, 2006). Note: The region named “Fatha clayey facies” and “Fatha calcareous facies” are recognized now as the Nfayil Formation by GEOSURV

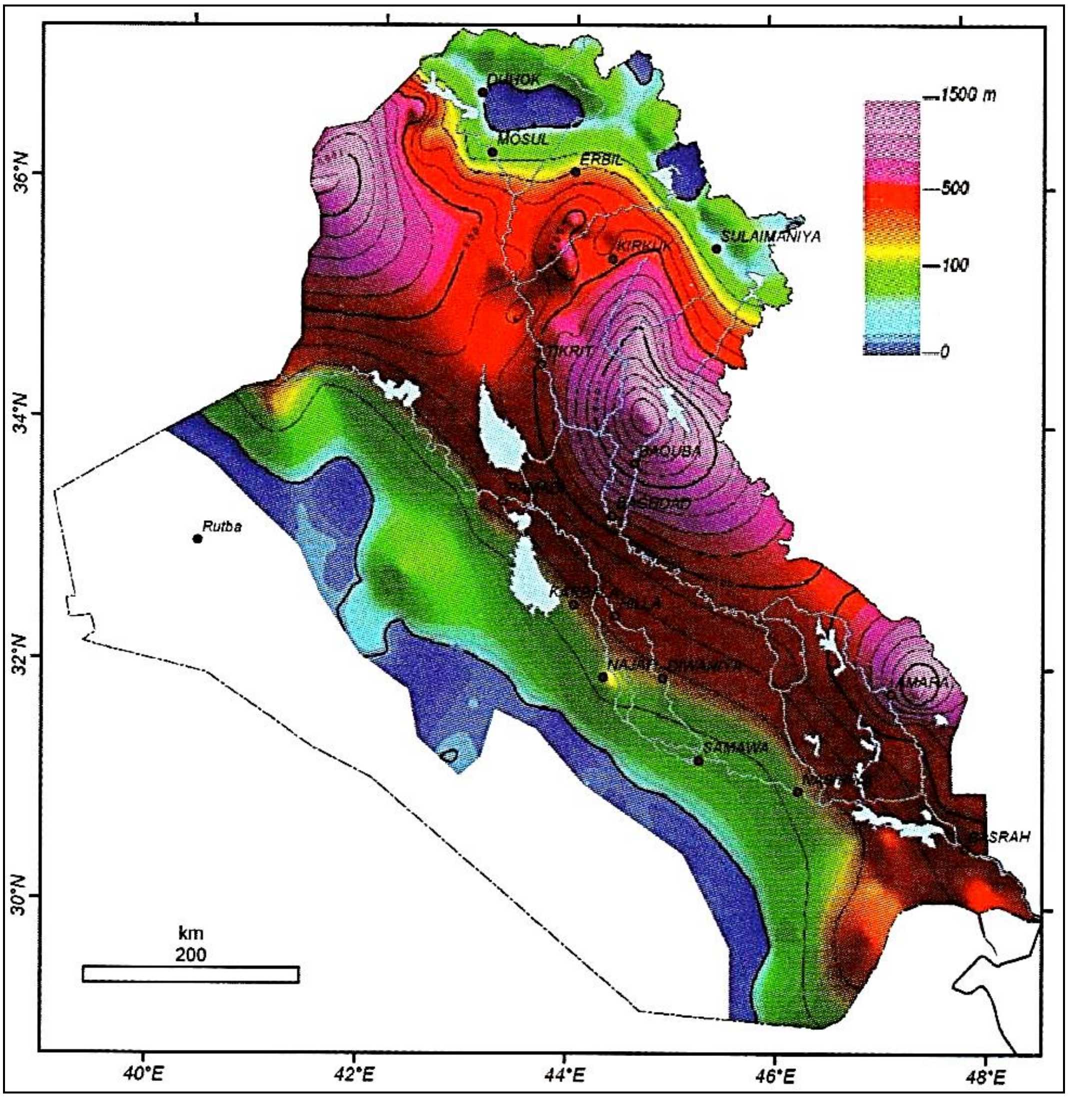


Fig.3: Thickness of the early Middle Miocene sequence (after Jassim and Buday, 2006 in Jassim and Goff, 2006)

Table 1: Thickness of the two members of the Fatha Formation (Middle Miocene) in northern Iraq (after Mansour and Toma, 1983)

Place	**Lower Member**	**Upper Member**	**Total thickness of the Fatha Formation**
Sinjar	405 m	260 m	665 m
Mosul Tel-Afer	110 – 170 m	110 – 180 m	220 – 350 m
Al-Fatha – Mosul	31 – 95 m	100 – 187 m	220 – 350 m
Hadhar	Not exposed	63 m	63 m
Dohuk – Ain Zala	358 m	155 m	513 m
Al-Jazera	99 m (north of Anah)	89 m	188 m
Khabour	--	--	32 m
Mosul – Erbil	--	--	300 m
Khanaqin	--	--	670 m

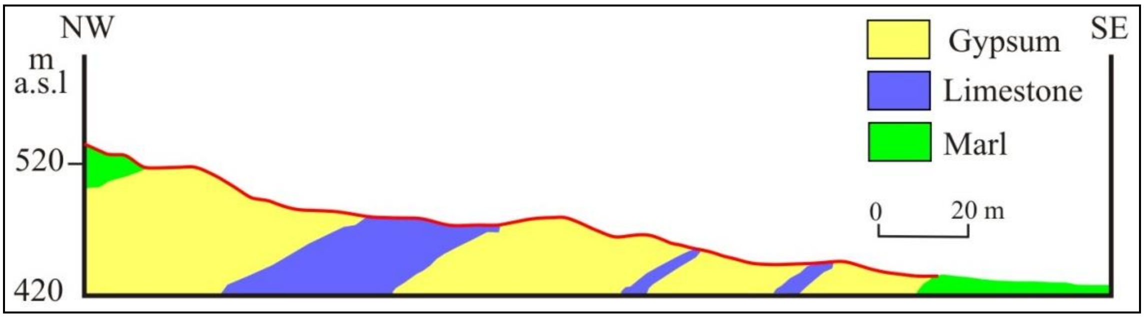


Fig.4: Geological cross section in Qara Walli gypsum deposit
(from Al-Ka'aby and Mohammad, 1976; in: Al-Bassam, 2012)

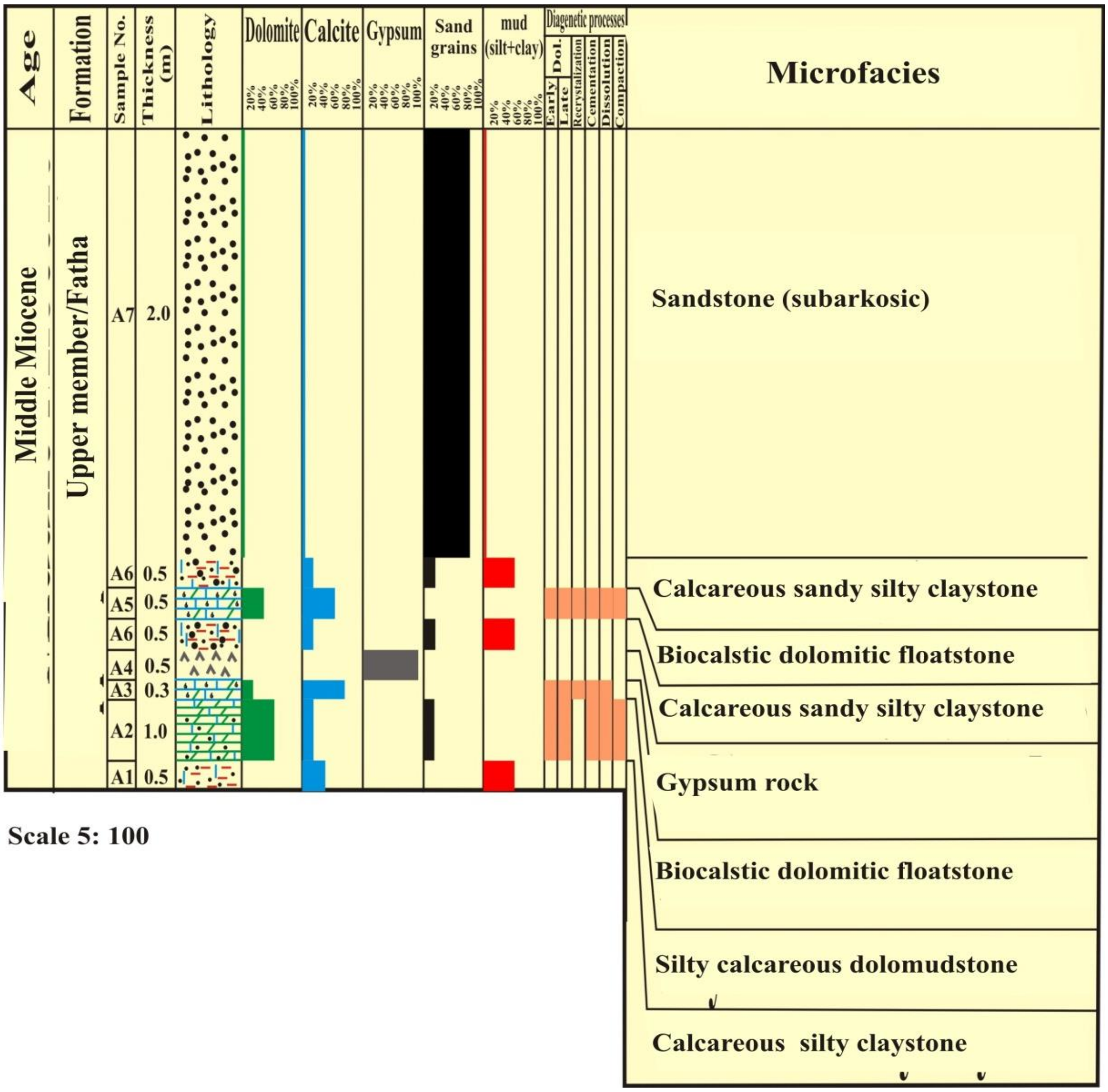


Fig.5: Lithologic columnar section of the upper part of the Fatha Formation in Zurbatyah area (after Mahmuod *et al*., 2017)

Table 2: Chemical composition of some gypsum deposits in the Fatha Formation from the Low Folded Zone (compiled by Al-Bassam, 2012 from GEOSURV archives)

Deposit	Formation	SO_3 (%)	CaO (%)	IR (%)	H_2O^+ (%)
Qara Walli	Fatha	45.5	31.4	1.2	20.0
Al-Qausiyat	Fatha	45.1	32.3	1.2	18.7
Makhmour	Fatha	44.5	32.2	2.0	18.1
Derbandi Bazian	Fatha	44.9	32.2	1.8	17.7
Ain Al-Nukhaila	Fatha	44.4	32.8	2.5	18.0
Sulaiman Beg	Fatha	44.9	32.4	0.8	18.8
Tarjil	Fatha	44.8	32.2	2.0	18.5
Al-Heshaimia	Fatha	44.7	32.2	n.a.	20.5
Al-Jabal	Fatha	44.2	32.1	n.a.	20.8

GYPCRETE AND GYPSIFEROUS SOIL

- **Definition and origin**

Gypsiferous soil is the soil that contains gypsum >2% according to Van Alpen and Romero (1971) or 3% or more according to Barzanji (1973). It is the product of precipitation of secondary gypsum in the soil from sulfate-rich water originating from the dissolution of primary gypsum beds (Barzanji, 1973). Hussin (2005) described gypcrete as soil which mainly contains secondary gypsum at or near ground surface. Secondary gypsum forms either by upward movement of sulfate- and calcium- rich water by capillary action and evaporation at the surface, or by direct precipitation from the groundwater or surface water (Van Alpen and Romero, 1971). The gypcrete can also form by the dissolution of the soluble salts, like NaCl, from the soil by surface water leaving the soil rich with gypsum (FAO, 1990). Soil Investigations (2002) suggested that secondary gypsum may originate from sea water or from the dissolution of sulfate-bearing rocks and oxidation of sulfur present in the rocks. It can be also formed by the wind transportation of primary and secondary gypsum to be deposited in other places and mixed with the soil or forming gypsum dunes (Mulders, 1969 and Al-Kaabi, 2007). The secondary gypsum is formed in regions with < 400 mm precipitation annually and the soils with groundwater depth <5m (FAO, 1990). Gypsiferous soil reduces the fertility of the agricultural land and hence reduces the crops productivity. It can also create many engineering problems to the constructions, represented by the dissolution of gypsum from the soil leading to settlement or even the collapse of constructions (Clemence and Finbar, 1981; and Razouki *et al*., 1994).

- **Classification**

Many classifications were applied in the gypsiferous soils studies among them the American, the French, the Australian, the Russian and the Iraqi classifications. The classification used in the Iraqi studies is that of Barazanji (1973) which depends on the gypsum concentration in the soil (Table 3). Another classification was proposed for construction purposes by the National Center for the Constructions Laboratories (NCCL) which considers the gypsum content in soils (Nashat, 1990) (Table 4), whereas, Gibb *et al*. (1967) proposed a special classification for the gypsiferous soils for agriculture (Table 5).

Table 3: General classification of Iraqi gypsiferous soils (Barazanji, 1973)

Gypsum content	Classification
0 – 0.3 %	Non gypsiferous
0.3 – 3 %	Very low gypsiferous
3 – 10 %	Low gypsiferous
10 – 25 %	Medium gypsiferous
25 – 50 %	Highly gypsiferous
>50%	Very Highly gypsiferous

Table 4: Classification of Iraqi gypsiferous soils for construction purposes (Nashat, 1990)

Gypsum content	Classification
0 – 10 %	Low gypsiferous
10 – 25 %	Medium gypsiferous
25 – 50 %	Highly gypsiferous
>50%	Gypcrete

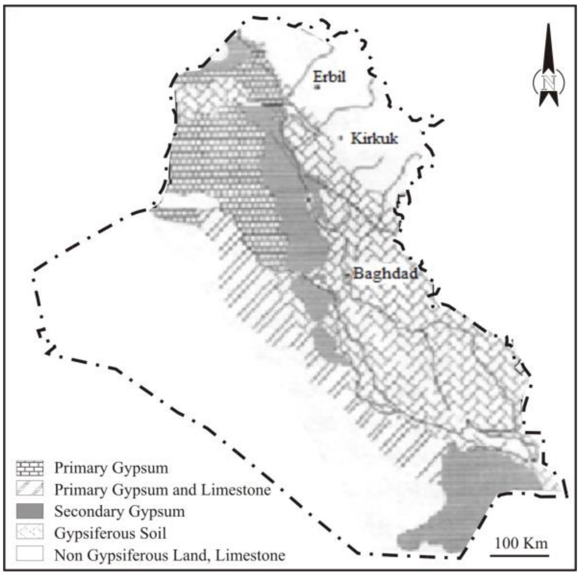
Table 5: Classification of gypsiferous soils for agricultural purposes (Gibb *et al*., 1967)

Gypsum content	Classification
<10%	Suitable for all crops
10 – 50 %	Suitable for certain crops
>50 %	Not Suitable for ordinary irrigation

- **Distribution**

The first study on the distribution of the gypsiferous soils in Iraq was by Buringh (1960) who mentioned that the gypsiferous soils cover about 20% of the Iraqi territory and he compiled a map for the gypsiferous soils in Iraq (Fig.6). Barazanji (1973) assumed that the gypsiferous soils covers about 12.2% of the Iraqi territory (Fig.7), while Mansour and Toma (1983) constructed a map for the distribution of the gypsiferous soil in Iraq, which is used by Nafie (1989) to estimate the area covered by gypsiferous soils in Iraq by about 50% of the total area, which is in agreement with the area previously estimated by Al-Mukhtar (1987). The area covered by gypsiferous soil in Iraq represents 7.3% of the world's gypsiferous soils areas and about 16.1 of the gypsiferous soils in Asia (FAO, 1990). Lower estimations of gypsiferous soils coverage in Iraq were forwarded by other workers (Nashat, 1990 as 33%; Ismail, 1994 as 31.7%). In more recent studies, Jafarzaden and Zinck (2000) mentioned that the area covered by gypsiferous soil in Iraq is 28.6% which is equal to 125000 Km^2 (Al-Kaabi, 2007). This area is increasing with time due to climate change and salinization of the soil and it represents a very serious factor in land degradation (desertification) and soil fertility.

Al-Kaabi (2007) collected the available data about the Iraqi soils and constructed two maps, one for the depth (0 – 25) cm (Fig.8) and the other for the depth 25 – 150 cm (Fig.9). He related the gypsiferous soils distribution in Iraq with the climate, depth, geological formations, availability of calcium and sulfate ions, geological environment, groundwater, geomorphology and structure. Al-Kaabi (2007) concluded, from the gypsiferous soil distribution maps, that the gypsum content at the depth (0 – 25) cm (Fig.8) ranges between 0 and 87% (mean = 6.3%), covering 39% of the total area investigated. Whereas, for the depth (25 – 150) cm he found that the gypsum content is (0 – 94%) (mean = 11.33%), covering 53% of the studied area (Fig.9). Al-Kaabi (2007) indicated that gypsum content increases with depth in general, with maximum increase at the depth of 40 cm, with some exceptions. The study also indicated that the area covered by gypsiferous soil is characterized by <400 mm/year mean precipitation and 2400 mm/year mean evaporation, but he found no relation between the rate of precipitation and the depth of gypsiferous soils. He also found that the gypsiferous soils have inverse relation with calcic soils.



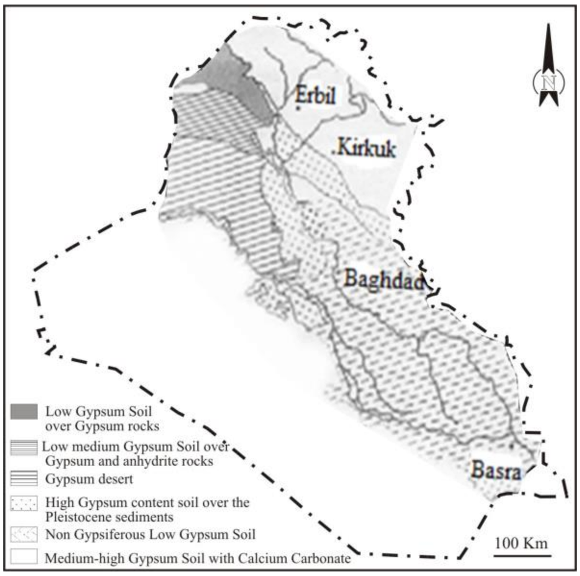
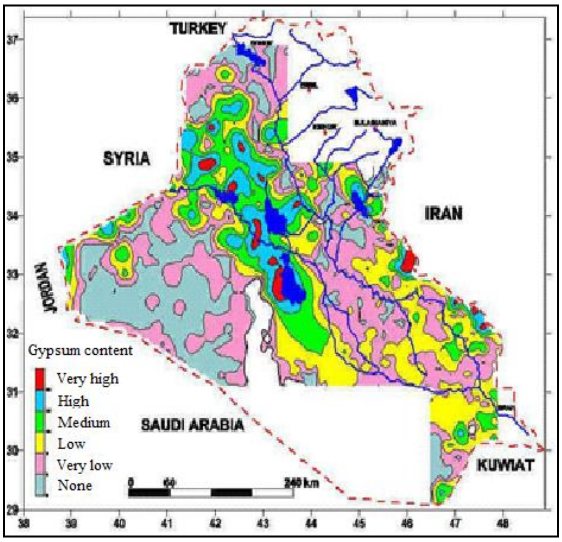


Fig.6: Soil map of Iraq (Buringh, 1960)

Fig.7: Soil map of Iraq (Barzanji, 1973)



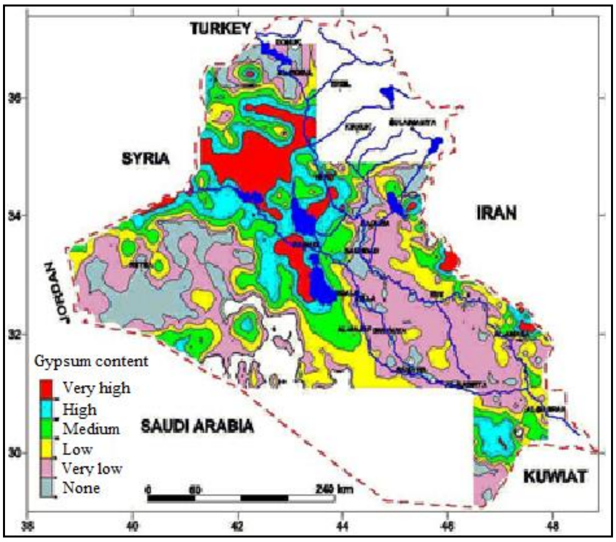


Fig.8: Gypsiferous soil map of Iraq (depth 0 – 25 cm) (Al-Kaabi, 2007)

Fig.9: Gypsiferous soil map of Iraq (depth 25 – 150 cm) (Al-Kaabi, (2007)

GYPSUM RESOURCES OF IRAQ

The reserves of the gypsum deposits in Iraq have been estimated in numerous localities and include primary and secondary gypsum deposits. The proved reserves of the former are estimated by 142 m.t. and the later by 6 m.t. (Table 6). However, the gypsum resources of Iraq are believed to be much larger than this, especially in the primary gypsum deposits of the Fatha Formation (Middle Miocene), which is widely exposed in the Low Folded Zone of Iraq. Most of the gypsum deposits are extracted from small to medium size quarries licensed to the private sector and used primarily for construction purposes as well as a retarder in cement industry.

Table 6: The surveyed gypsum deposits in Iraq

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
El-Sabti and El-Mehedi (1967); 323	Aquba	between Ramadi and Hit in Al-Anbar Governorate	Fatha (Lower Fars Formation)	Upper: 1.28 m in the southern part and 4.32 m in the northern part. Lower: 2.85 m at the southern part to 4.40 m at the northeastern part of the area.	Compact, laminated fibrous, fractured and selinitic. chemical analyses of the gypsum samples shows that CaO is ranging 31.07% - 45.67%, SO_3 38.60% – 46.41%,	157841	Good for ceramic and fine Juss industries
El-Sabti (1970); 92	Aquba	between Ramadi and Hit in Al-Anbar Governorate	Fatha (Lower Fars Formation)	Upper: 1.28 – 4.32 m Lower: 2.8 – 5.4 m	Gypsum exposures	157841	Reserved for ceramic industry
El-Sabti (1970); 423	Al-Fatha	on Tigris River near Baiji Town	Fatha (Lower Fars Formation)	Not specified	Gypsum exposures are weathered and turned to powder. On fresh sample, gypsum is compacted, massive and partly crystallized.	Not specified	Not specified
El-Sabti (1970); 423	Jabal Najma, Jabal Jawan, Adaiyh, Ibrahim and Qaiyarah	within Neineva Governorate extending from south to southeast of Mosul City	Fatha (Lower Fars Formation)	Not specified	Not specified	Not specified	Not specified
El-Sabti (1970); 423	Mishraq	45 km southeast of Mosul City at the right bank of Tigris River	Fatha (Lower Fars Formation)	Not specified	gypsum is massive, compact and recrystallized	Not specified	Not specified
El-Sabti (1970); 423	Lizaga	located on the right bank of Tigris River about 15 km south of Mosul City	Fatha (Lower Fars Formation)	3 – 7.10 m	massive semitransparent and partly crystallized	Not specified	Not specified
El-Sabti (1970); 423	Rawa near Anah	located at the left bank of Euphrates River opposite to Anah Town	Fatha (Lower Fars Formation)	Not specified	powdery on the surface exposure while in the fresh fracture is massive, partly recrystallizing and semitransparent	Not specified	Used for Juss industry
El-Sabti (1970); 423	Kirkuk oil field belt	from Tuz Khurmatue to the Kura Chai area	Fatha (Lower Fars Formation)	Not specified	Not specified	Not specified	Not specified
El-Sabti (1970); 423	Khashm Al-Ahmar and Injana area	within Al-Tameem (Kirkuk) Governorate	Fatha (Lower Fars Formation)	about 4 m of three gypsum beds are exposed for about 750 m	Not specified	Not specified	Not specified

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
El-Sabti (1970); 423	JabalSanam	about 45 Km south of Basrah and about 150 m high	Infra Cambrian age.	Not specified	salt plug and the core of this mountain consist mainly of massive gypsum	Not specified	Many gypsum quarries were opened
Mansour (1972); 539	Al-Mawan	North of Erbil and Koisanjak	Fatha (Lower Fars Formation)	4.0 m	fine to coarse crystalline whitish massive gypsum with fractures filled with greenish gray calcareous clay	512000	Juss making kilns and quarries are present in the area
Semchinov (1973); 589	Aquba	As inEl-Sabti and El-Mehedi (1967)	As inEl-Sabti and El-Mehedi (1967)	As inEl-Sabti and El-Mehedi (1967)	As inEl-Sabti and El-Mehedi (1967)	A_1 = 2063090 A_2 = 485440 C_1 = 30229870	
Al-Kaaby (1974); 636	Al-Teeb	1 km from the Iranian border, Wasit Governorate	Fatha (Lower Fars Formation)	2.5 m extends over 1 Km^2	Friable to moderately hard: white to whitish gray. The Juss product solidifies quickly and not preferred	--	Not recommended for investment
	Zurbatyah	11 Km north of Zurbatyah Village	Recent sediments	1.5 m covers about 2 Km^2	White friable gypcrete become solid and less polluted with clay and sand at depth	--	Recommended for investment
Al-Kaaby (1975); 927	Balad	Saladin Governorate	Recent	0.5 – 1.7 m	Sand and gravel with gypcrete	>30% SO_3 = 1,205,000 <30% SO_3 = 1,384,000	Needs further investigation to assess the gypsum deposits for Juss industry
Jabur and Mustafa (1976); 702	They studied the gypsum deposits in Iraq.	--	--	--	They classified it into three types: Sedimentary, residual and infiltration deposits and specified the localities depending on the previous surveys without mentioning the reserves	--	--

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)		Type of deposit	Category &Reserve (Ton)	Remarks
Ashoor and Mehdi (1976); 804	Qara Weli	in Tel-Afer, Neneva Governorate	Fatha (Lower Fars Formation)	1st	Upper 4 m	yellow, porous, friable to moderately hard marly gypsum	More than 100 million tons: B = 39 m.t. C_2 = 34 m.t. Geological = 37 m.t. The second bed: 6 m.t	Good for Juss industry. The second gypsum bed is the best to start wit for investment due to the lack of over and inner burden
					Middle 9 m	White turning to gray coarse granular hard gypsum with some green marl		
					Lower 15.6 m	Upper part containing considerable amount of marl		
				2nd	22.5 m	White to grey hard coarse grained gypsum containing some marl		
				3rd	10 m	Gray coarse grained tough gypsum containing some marl turning to gray anhydrite		
				4th	9.8 m	Dark gray changing to white fine to coarse hard gypsum		
Mohammed *et al.* (1976); 781	Southern Governorates	Ameed in Samawa	Recent	1 m		Gypcrete lenses	600,000	Not suitable for Juss industry
		Haswat Al-Khawarnaq in Najaf,		0.5 – 1 m			210,000	
		Tel Al-Laham in Thi Qar		1 m			600,000	
		Juaibda, Zubair, Basrah		0.6 m			540, 000	
		Al-Teeb, Missan		1 m			675,000	Near to besuitable for Juss industry
		Zurbatyah, Badra, Wasit		1.2 m			1,620,000	Suitable for Juss industry

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
Mustafa and Abdul Ghani (1977); 770	Wisheil area	in Karbala Governorate	Recent	0.8 – 2.1 m	Gypcrete lenses bellow sand gravel sheet. Three types were found: fibrous, filling polygonal fractures and granular	B1= 150,000	Suitable for Juss industry
	Quaries area			0.4 – 1.6 m	--	--	Not suitable for Juss industry
	Strategic line area			0.5 – 1.6 m			
	Al-Razaza area			0.9 m			
	Area 31			0.45 – 1.2 m			
	Awaina area			0.5 – 1.35 m			
Abdul Husain and Jirgees (1977); 805	Kani Sekht	Zurbatyah – Bedra in Wasit Governorate	Fatha (Lower Fars Formation)	5 beds: 5, 6, 18, 10 m	Suitable for Juss industry	B = 6,018,383 Geology: 15,178,756	Suitable for Juss industry
Jirgees (1978); 891	Bayadir	In Al-Baghdadi, Hit, Anbar Governorate	Fatha (Lower Fars Formation)	Area 1: 4 m	Hard gypsum contains 85.05% $CaSO_4.2H_2O$	B = 3,040,000	Suitable for industrial uses
				Area 2: 4.5 m	Hard gypsum contains 87.44% $CaSO_4.2H_2O$	C_2 = 11,632,725	
Mustafa and Mekho (1978); 909	Al-Teeb	Wasit Governorate	Recent	Area A: 1.01 m	Fibrous gypcrete with gravel, contains 51.64% $CaSO_4.2H_2O$	315,000	not good for Juss industry
				Area B: 1.15 m	Hard gypcrete with gravel, contains 51.64% $CaSO_4.2H_2O$		Not feasible
Al-Kaaby (1977); 928	Makhmour	Erbil Governorate	Fatha (Lower Fars Formation)	Three beds: 141.1, 113.8 and 121.9 m	White to gray in color, coarse grained hard gypsum	C_1 = 3,369,000	Suitable for Juss industry
				Four beds: 94.3, 1.9, 4.25 and 1.5 m	White to gray in color, coarse grained hard gypsum	C_2 = 3,640,000	
Saad (1979); 955	Derbendkhan	Chamchamal, Sulaimaniyah Governorate	Fatha (Lower Fars Formation)	Three beds 10 – 20 m	Massive gypsum	C_1 = 6,096,000 C_2 = 3,297,000	Suitable for industrial uses

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
Jirgees and Ali (1979); 974	Qausiyat	Tel Kaif, Neneva Governorate	Fatha (Lower Fars Formation)	12 m	White massive gypsum	B = 9,495,551	Suitable for industrial uses
				7 m	Gray very hard fractured gypsum		
Abdul Husain (1979); 978	Deposits of gypsum in Iraq	--	--	--	Classified the gypsum into primary and secondary with description of their mechanism of formation with locating their occurrences and assessing the quality and reserves in Iraq depending on the previous surveys	--	--
Saad (1980); 1011	Sulaiman Beg	Al-Tameem Governorate	Fatha (Lower Fars Formation)	3 – 20 m with an average of 10 m	White, gray and whitish gray hard massive gypsum with average of $CaSO_4.2H_2O$ = 90.05	B = 15,181,881 C_2 = 6,455,163	Suitable for all industrial purposes
Abdul Husain *et al*. (1980); 1024	Haditha	Al Anbar Governorate	Fatha (Lower Fars Formation)	Upper bed = 0.5 – 4.6 m	White and gray massive fine grained with low hardness gypsum with average of $CaSO_4.2H_2O$ = 93.3	B = 5,707,571 C_1 = 6,722,624	Suitable for industrial uses
				Lower bed = 0.7 – 12.6 m with an average of 6.8 m	White and gray massive fine grained with low hardness gypsum with average of $CaSO_4.2H_2O$ = 93.3		
Abdul Husain (1981); 1112	Wadi Mailan	North of Rawa, in Al-Anbar Governorate	Fatha (Lower Fars Formation)	1 – 9 m	Massive gypsum	B = 5,963,885 C_1 = 9,127,847 C_2 = 4,973,414	Suitable for Juss industry
Mehdi (1981); 1117	Al-Falluja	Al-Anbar Governorate	Recent deposits	1.06 m	Fibrous, massive and powder like gypcrete with average of SO_3 = 35.79	646780	Not suitable for industrial uses

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
Ghalib (1980); 1118	Ain Al-Nikhaila	Saladin Governorate	Fatha (Lower Fars Formation)	1st bed = 5.6 m	Whitish gray hard gypsum	$B+C_1$ = 4,084,896	Suitable for Juss industry
				2nd bed = 7.6 m	Whit to light gray massive gypsum containing some small marl and limestone lenses	$B+C_1$ = 4,671,769	
Toma (1980); 1119	Tel Al-Laham	Souq Al-Shiyoukh, Thi Qar Governorate	Recent	0.6 – 1.2 m	Granular and fibrous gypsum		Not suitable for industrial uses
Leitch (1980); 1130	Hammam Ali	Neneva Governorate	Fatha (Lower Fars Formation)	Extensive gypsum bed, no thickness mentioned	Massive gypsum	Not mentioned	Suitable for cement industry
Al-Mubarak, Q. and Al-Rufai, A., 1971; 1159	Tel-Afer	Neneva Governorate	Fatha (Lower Fars Formation)	Upper bed: 2 m	White to gray massive hard gypsum	Large amount	Suitable for Juss industry
				Lower bed: 5 – 20 m	White grayish massive hard anhydrite		
Al-Sharbati and Ma'ala (1983a); 1345	JabalSanam, West of Zubair	Basrah Governorate	Unknown	80 m	Massive highly faulted gypsum with thin beds of limestone	Not mentioned	Not mentioned
Al-Sharbati and Ma'ala (1983b); 1347	South of Busaya	Thi Qar Governorate	Recent	The maximum thickness reaches up to 1 m	White to yellowish fine to granular gypcrete	Not mentioned	Not mentioned
1349 Al-Ani and Ma'ala (1984)	North of Busaiya	Thi Qar Governorate	Recent	1 m	Gypcrete with carbonate gravels	Not mentioned	Not mentioned
Mmansour and Toma (1983); 1429	Iraq		Fatha (Lower Fars Formation)	--	Primary	142 m.t.	For cement and Juss industries
			Recent		Secondary	6 m.t.	Juss industry
Maiqil (1986); 1520	Sinjar	Mosul Governorate	Fatha (Lower Fars) Formation	3 – 10 m	White turns to gray or red depending on the impurities	951666	Suitable for cement industry
Mehdi (1992); 2006	Iraq	This report summarizes the results of works of the mineral investigation Directorate over Iraq since 1956 till 1990. The total reserve was 142 million tons of primary gypsum and 6 million tons of secondary gypsum. This report summarizes the recommendations to extend the works to increase the reserve.					

Cont. Table 6:

Author and Rep. No.	Area	Location	Formation	Thickness (m)	Type of deposit	Category &Reserve (Ton)	Remarks
Deikran and Yacoub (1993); 2255	Baghdad	Iraq	Recent gypcrete	0.5 – 2 m	It is either pure gypcrete or with 20 – 25 % clay and fine to coarse sand. It occurs as fibrous, powder like or massive form.	--	--
Deikran and Mahdi (1994); 2258	around Sawa Lake	Al-Muthana Governorate	Recent forming the bank of the lake	--	Gypcrete and gypsiferous soil	--	--
Al-Bassam and Dawood (2002); 2789	Dour and Falluja	Saladin and Al-Anbar Governorate	They studied the lithology, mineralogy and geochemistry of the Quaternary and Neogene gypcrete and gypsiferous soils in Al-Dour and Falluja areas. Most of these gypsum rich soils are related to in-site SO_4 enrichment from groundwater sources and some are of aeolian origin and mechanically transported.				
Hussain*et al*. (2006); 3025	Badush	Neneva	Fatha (Lower Fars Formation)	13 m	Greyish White coarse grained hard gypsum with no impurities	2,100,000	Suitable for cement industry
Al-Kaabi (2007); 3044	Iraq	Two contour maps scale 1:1000000 for the gypsiferous soil at depths 20 – 25 cm and 25 – 150 cm using GIS were constructed.					
Yaqub and Abdul Jabar (2007); 3060	Iraq	The study separated the gypsiferous soils all over Iraq from the other soils and rocks using GIS technique. Visual interpretation for the visible spectral bands, the digital processing for the spectral reflection of the satellite images to locate the mineral deposits and other enhancements were used to locate the gypsiferous soils distribution.					
Hussain *et al*. (2011); 3325	Al-Teeb	Missan Governorate	Recent gypcrete	0.9 m	White to light gray medium tough fibrous secondary gypsum	C_2+ C_1 = 2,499,800 C_2 = 2,227,853	Suitable for Juss industry

CONCLUSIONS

- Eighteen geological formations, extending in age from Middle Triassic to Middle Miocene, contain primary gypsum and anhydrite deposits in Iraq, most of them are found in subsurface, except the Fatha Formation (Middle Miocene) and the Dhiban Formation (Lower Miocene) which are exposed and can be used in the industry. Gypsiferous soils and gypcrete represent other gypsum deposits of secondary origin formed by upward migration of the sulfate underground water by capillary action. Gypsum of primary and secondary origins is widely used in Iraq as a building material in various applications and as a retarder in cement industry.
- The most important and promising primary gypsum deposits are present in the following localities: Qara Welli (Tel-Afer, Neneva Governorate); Mishrak Anticline South of Mosul); Al-Qausiyat (Tel Kaif, Neneva Governorate); Darbendikhan – Bazyan – Asker area (Sulaimaniyah Governorate); Ain Al-Nukhaila (Salahidin Governorate); Makhmur (Erbil Governorate); Aquba (Hit, Al-Anbar Governorate); Kani Sekht (Zurbatyah, Wasit Governorate) and Al-Bayadir area (Al-Baghdadi, Hit, Anbar Governorate). The proved reserves of the primary gypsum deposits are 142 million tons.
- The secondary gypsum in soil is investigated in two depth intervals; (0 – 25) cm and (25 – 150) cm and the latter is dominant. For the depth interval (0 – 25) cm, the gypsum content is generally low and ranges between (0 and 87) % (mean = 6.3%) and the area covered by gypsiferous soils at this depth interval represents 39 %. Whereas, for the depth of (25 – 150) cm, the gypsum content ranges between (0 and 94) % (mean = 11.33%) which reflects medium gypsum content and the area covered by gypsiferous soil for this depth interval is 53%. The proved reserves of secondary gypsum deposits are 6 million tons.

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