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MINERAL RESOURCES AND OCCURRENCES OF SODIUM CHLORIDE IN IRAQ: AN OVERVIEW

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ABSTRACT

Sodium chloride salt deposits in Iraq are found in many forms. It is found as beds of rock salt and in the Quaternary inland salterns and sabkhas. The rock salt layers were deposited in closed basins in various geological times and found in Kurra Chine, Butmah, Adaiyah, Alan, Gotnia, Dhiban and Fatha formations. Another form of the rock salt is the salt plug at Jabal Sanam in southern Iraq, derived from the evaporites of the Hormuz Series and formed by the upward movement of the salt due to pressure of the overlying sediments and low density of the salt. On the other hand, the inland salterns are of Quaternary (Holocene) age and formed by the accumulation of salt derived from salt-bearing beds at depth, such as those in the Fatha formation, seeping upward through fault planes or washed from surrounding salt-bearing formations or saline soils and precipitated by evaporation in local depressions. The main inland salterns are those found in Bowara, Albu-Gharis, Snaisla, Ashgar, Umm Dhiyaba, Al-Tawila and Gzaiz in the Jazera area; Hawija Saltern NE of the Fatha gorge; Shari Saltern near Samarra Khalifa Saltern near Hemrin Mountain, Douz Saltern north of Duz Khurmatu town, Samawa and Umm Al-Tigan salterns in southern Iraq. Sea water of the Arabian Gulf represents another source of sodium chloride in Iraq. The Basrah salt plant is constructed to produce sodium salts from seawater and includes a number of artificial basins, some of them are for increasing the salt concentration by solar evaporation of the seawater and the others for salt precipitation. Sodium chloride is produced by the Ministry of Industry and Minerals for industrial and domestic uses mainly from the Samawa Saltern and from the Basra salt plant. In addition, numerous small-scale salterns are being exploited for this purpose by the private sector. The total reserves of sodium chloride have been estimated in the inland salterns by about 50 m.t., but the potential resources are much larger, especially in the rock-salt deposits.

المصادر المعدنية لكلوريد الصوديوم في العراق: نظرة شاملة

رافع زائر جاسم و عباس صالح البدري

المستخلص

توجد ترسبات ملح كلوريد الصوديوم في العراق بعدة اشكال منها ما يكون على شكل طبقات ملحية صخرية ومنها مايكون على شكل ممالح وسباخ قارية وكذلك على شكل سدادات ملحية. تكونت طبقات الملح الصخري في احواض بحرية مغلقة خلال عصور جيولوجية مختلفة وتوجد في تكوينات قورة چيني، بطمة، عظاية، القطنية، الذبان والفتحة. من الأشكال الأخرى للملح الصخري في العراق هي السدادات الملحية التي تندفع الى الأعلى بسبب ضغط الطبقات التي فوقها وتدني كثافتها النوعية مقارنة بالصخور المحيطة بها كما هو الحال في جبل سنام في جنوب العراق. تكونت الممالح السطحية خلال

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العصر الرباعي (الهولوسين) وأغلبها نشأت من محاليل غسلت الطبقات الملحية في التكوينات الحاملة للاملاح في العمق مثل تكوين الفتحة وهاجرت الى السطح عن طريق الفوالق مكونة نضوحات سطحية فضلا عن الاملاح التي يتم غسلها من المكاشف الصخرية والتربة في المناطق التي تحيطها بواسطة مياه الامطار التي تسيل عبر الوديان المؤدية اليها. من اهم هذه الممالح هي البوارة والبوغارس وصنيصلة وأشقر وأم الذيابة والطويلة وأم دلي وكزيز في منطقة الجزيرة ومملحة الحويجة شمال شرق مضيق الفتحة ومملحة الحويجة قرب جبل حمرين ومملحة الدوز شمال مدينة دوز خرماتو ومملحة الشاري قرب سامراء وممالح السماوه وأم طيكان في جنوب العراق. هناك ايضا مجموعة من السباخ تقع في السهل الرسوبي جنوب بغداد تكونت نتيجة تجمع مياه الأمطار التي تغسل الأملاح وتتجمع في المنخفضات وتتبخر مرسبة الأملاح على السطح. أما مملحة البصرة فتتكون من مجموعة من الأحواض الاصطناعية بعضها لزيادة لتركيز مياه البحر بالتبخير الشمسي والأخرى لترسيب الاملاح. يتم الانتاج الرئيسي لملح كلوريد الصوديوم من مملحتي السماوة والبصرة من قبل وزارة الصناعة والمعادن فضلا عن العديد من الممالح الصغيرة التي يقوم باستثمارها القطاع الخاص. يبلغ احتياطي الملح في العراق حوالي 50 مليون طن غير ان المصادر الملحية المعدنية اكبر من ذلك بكثير وخاصة في رواسب الملح الصخري.

INTRODUCTION

Halite is the natural mineral name for sodium chloride which is a white crystalline solid mineral, deposited in the marine environment, as salt beds, by slow evaporation of ancient seawater, and in the continental environment by evaporation of brines and saline water in depressions forming inland salterns. Seawater contains various concentrations of salt, the actual concentration ranges from about 1% (in the polar seas) to 5%, and on the average it contains about 3% salt. Some enclosed seas and gulfs, such as the Mediterranean and Red seas, contain higher proportions of salt than the open sea at the same latitude. Salt obtained by the evaporation of seawater has sodium chloride (77.76%), magnesium chloride (10.88%), magnesium sulfate (4.74%), calcium sulfate (3.60%), potassium chloride (2.46%), calcium carbonate (0.34%) and magnesium bromide (0.22%) (Suckow *et al*., 1995).

Rock salt (lithified crystalline sodium chloride) is precipitated after evaporation of about nine-tenths of the seawater volume. The thickness of the rock salt beds in the geologic formations through geologic time ranges from a few meters to hundreds of meters. A large quantity of sea water when evaporated leaves small amount of rock salt, therefore to maintain such a huge thickness of rock salt the basin should be partly linked to the sea and they are separated partially by barrier (forming lagoon) where the evaporation is greater than the supply. Salts are also precipitated in coastal and inland sabkhas. The former is supplied by the brines from the sea, whereas in the latter the salt is either accumulated in depressions by washout from the surroundings or by brine ascending from beneath through springs or seepages. Salt domes are another form of rock salt which bulge from great depths as plugs due to the pressure subjected on the rock salt beds at depth and its low specific gravity.

Salt is considered to be one of the oldest and most everywhere food seasonings, while salting is an important method of preservation. Salt occurs naturally in most parts of the world in mineral form and has been collected for thousands of years in ancient Iraqi civilization. The earliest evidence of salt processing in Iraq dates to around 7,000 years B.P. by ancient civilizations of the Mesopotamia. Salt became an important article of trade and was transported by boat across the two rivers and Arabian Gulf, as well as, across the Sahara on camel caravans. Several laws and legislations concerning salt trade, like those assigned by Hammurabi, were found during the archaeological investigation in southern and northern Iraq. The scarcity and universal need for salt have led ancient nations to go to war over it and use it to raise tax revenues. It was used in religious ceremonies and other cultural and traditional events of significance.

Various forms of sodium chloride salt are present in Iraq; rock salt deposits are present in the Dhiban Formation (Lower Miocene); the Fatha Formation (Middle Miocene); the Rus Formation (Lower Eocene) and the Gotnia Formation (Upper Jurassic) (Buday, 1980; Jassim, 2006; Jassim and Buday, 2006a, b and c). Sodium chloride is also present as salt crust precipitated in the top layer of sabkhas, salterns and playas. Some salts are precipitated from brine springs which are originated by the dissolution of the salt layers in the geologic formations like Khalifa spring. Thirty surface salt lakes, salterns and playas of different sizes are known in Iraq (Fig.1). The Fao and Basrah salt plants, on the Arabian Gulf coast, enabled the production of salt directly by solar evaporation of seawater in artificially prepared salt pools.

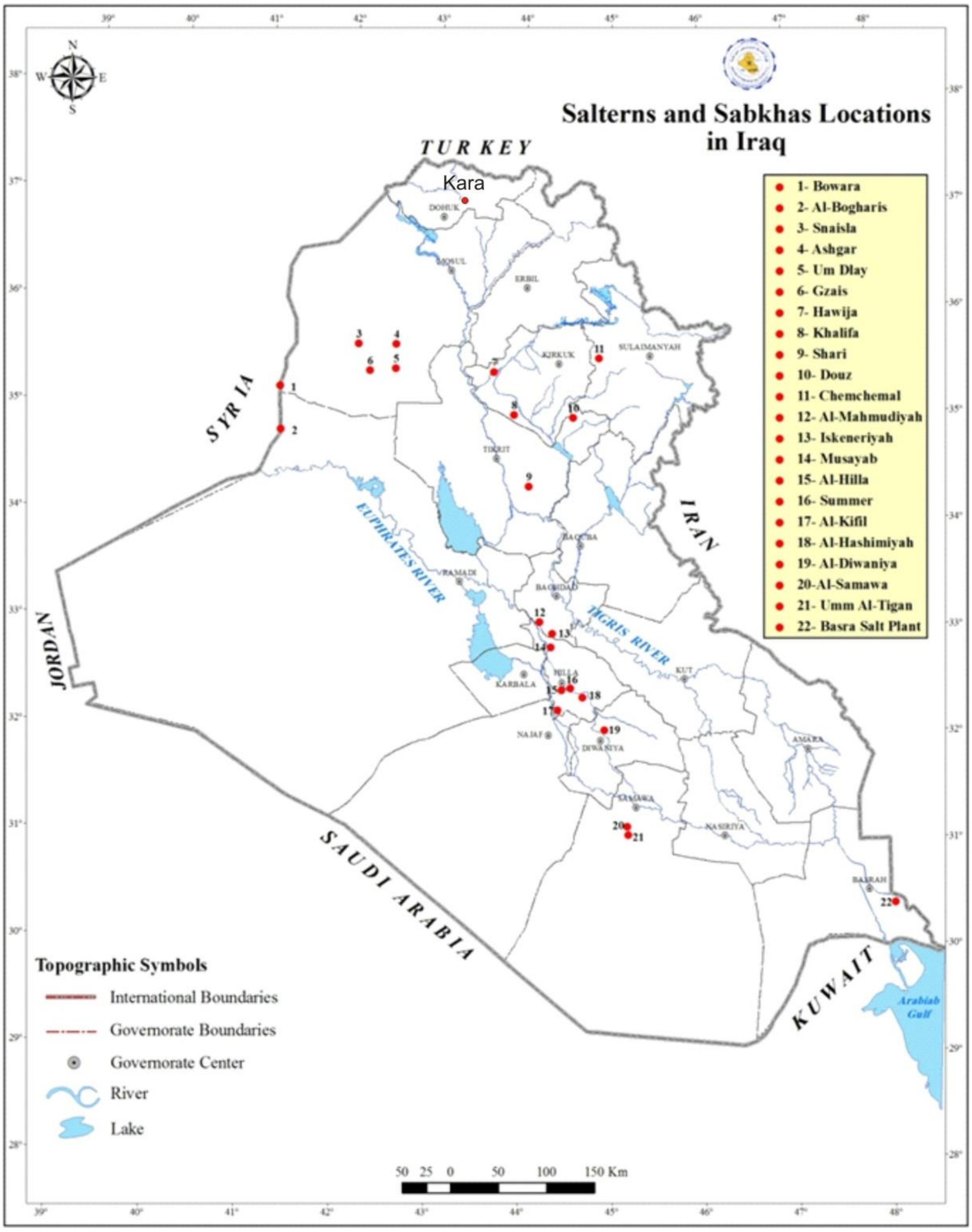

Fig.1: Location of salt deposits and occurrences in Iraq (Archives of GEOSURV-Iraq)

At the present time, Iraq consumes more than half a million tons of salt/ year. This includes table salt, petrochemicals, food canning, dairy, tanning, agriculture, electricity, textile and many more. In this article many expressions have been used, so it is useful to define them here. The term saltern means salt pools or natural depressions in which water is evaporated to leave salt. Playa means an area of flat, dried-up land, especially found in desert basins, which forms as water evaporates quickly to get salt. Salt pans mean shallow morphological surface depressions in which water evaporates to leave behind salt deposits. A salt lake means a lake of salt water which can evaporate or dried to leave salt precipitates. A salt pond is smaller than salt lake in size.

PREVIOS WORK

Many studies on the salt occurrences have been executed by Iraq Geological Survey and foreign companies. Dunnington (1953) recorded the subsurface salt-bearing formations of north Iraq. The Site Investigation Co. (1956) described many of the big and small salt occurrences in Iraq and the type of salt present in them including Samawa, Shari and Salman-Pak Salterns. Al-Mhaidi (1968) studied Duz and Hawija salterns and defined their origin, reserves and salt production. Al-Rawi (1968) studied the salterns in the Jazera area. The study included Snaisla, Bowara, Ashgar, Umdlay, Gattar Al-Tawila and Albu-Gharis Salterns. Chemical analyses of samples from these salterns were made together with geological estimation of their reserves and the origin of the salt deposits was discussed. Al-Rawi (1970) continued his efforts and studied Bowara, Al-Tawila, Al-Khalifa, Chemchemal, Hawija, Shari, Tuz and Samawa inland salterns and Fao Saltern (sea water evaporation). He also studied Jabal Sanam and suggested that it is a salt dome.

Al-Badri (1984 and 1985) studied in detail the Samawa salt deposit, made a detailed geochemical analysis of its brine and re-evaluated its salt reserves. Al-Hadithi *et al*. (1986) located and mapped the salt lakes in the Jazera area using aerial photographs and Landsat imageries. Al-Badri *et al*. (1986) studied in detail the salt lakes present in Jazera area, determined the type of salts and estimated their reserves. Al-Ani (1986) studied the geochemistry and sedimentology of sabkha regions in middle and southern Iraq. Al-Badri *et al*. (1988) made a preliminary study on the possibility of exploiting the bittern in the Samawa saltern. Al-Badri and Mohammed (1988) further studied the salt types and origin of salt deposits in Bowara and Albu-Gharis Salterns at the Iraqi – Syrian border, north of Hussaiba town (Fig.1). Al-Baidari (1988) continued the study of the Bowara and Albu-Gharis Salterns, in addition to the subsurface rock salt beds in Sinjar and Kirkuk vicinities.

Jassim (1992) studied the Shari salt lake and the sodium chloride salt present in the salt crust and brines. Tobia (1996) studied the Snaisla Saltern in the Jazira area and estimated its reserve. Jassim (1999) reevaluated the salts present in Snaisla Saltern described in the study of Tobia (1996). Mustafa *et al*. (2011) reported about the salt occurrences in Iraq and the salt layers in the geological formations and the salt plug of Jabal Sanam. Al-Bassam and Hak (2006 in Jassim and Goff, 2006) reviewed the salt occurrences in Iraq and their reserves. This study is an overview of previous work based on internal reports of the Iraq Geological Survey, published papers and postgraduate research work of Iraqi universities.

SALT LOCALITIES AND DETAILS

- **High Folded Zone Salterns**

– **Kara Saltren:** It is located in Dohuk Governorate and considered one of the main sources of NaCl salt in the farther north of Iraq and the only one where rock salt is used. Its production is estimated to be more than 20,000 ton/year. Kara Village is located in the vicinity of the Amadiya town, on the Greater Zab River. The origin of the salt is brines derived from the saliferous beds of the Fatha Formation. Local people dig by hands deep wide wells down to the salty beds. The depth of the wells ranges between 10 to 25 meters. The local inhabitants fill the holes with water, leave it a few days to dissolve the salt bed, then direct the brine water from the wells to open air small pans (2 – 4 meters in diameter), and leave it for complete solar evaporation, crystallization and harvesting. In winter, they do the same but evaporation is induced by applying external heat and fire to boil brines till complete dryness using simple available home vessels. The average chemical composition of the brine shows that NaCl=95.49%, $CaSO_4$=1.06% and Na_2SO_4= 0.5% (Abbas Al-Badri, personal data).

- **The Jazera Salterns**

The geological formations exposed in the Jazera area, northwestern Iraq, are Fatha, Injana and Quaternary deposits. The Euphrates Formation is exposed at the southern part near the Euphrates River. Structurally, this region represents the northeastern boundary of the Arabian – Nubian Platform. It is located within the Rutba – Jezira and Salman zones of the Stable Shelf of Jassim and Buday (2006d) and according to recent tectonic subdivisions of Fouad (2012) it lies in the Outer Platform of the Arabian Shelf. The structures present in the area are: Al-Tharthar, which is a NE – SW longitudinal structure located 2Km East of Hatra (Hader) town; Mityaha which is a wide structure composed of two parts, the first includes the salt depressions and contains many high hills and dense drainage system, while the second represent the area extending from the north to the southwest; Tayarat anticline which extends about 20 Km in a NE – SW direction with a height of about 50 m above the surroundings and Abu Rasain structure, which is also called the Khlaisiya High, is located south of Ash Shaabani area and extends about 60 km in a WNW direction (Al-Jumily *et al*., 1976; Ma'ala and Hetzer, 1976; Al-Mubarak and Youkhana, 1976 and Al-Badri and Mohammed, 1988). The Quaternary cover made most of the faults untraceable, while the lineament map of Al-Amiri (1982) and Jassim (1999) indicates the presence of many faults in the area directed NW – SE in addition to the proved faults in the same direction and other directions. The presence of such faults increases the possibility of being a passage way for the brines to move to the surface as salty seepages and springs (Al-Badri *et al*., 1986). The climate in the Jazera area is in general arid to semi-arid, mostly dry with average precipitation of (200 – 300) mm/year (I.M.O., 1989).

– **Bowara Saltern:** This saltern is located about 90 Km north of Al-Qaim town (Fig.1) at the Iraqi – Syrian border and extends in both countries. It is 12 Km long (6 Km in Iraq and 6 Km in Syria) and 1.5 – 3.5 Km (average 2 Km) wide with an area of about 19 Km^2 (11 Km^2 inside Iraq). The chemical analyses of the salt samples and the calculated salts are shown in Table (1). The Bowara Saltern is located in the area where the Fatha Formation is exposed, surrounded by the exposures of the Injana Formation. The salt crust is about 2 mm at the periphery and reaches more than 20 cm in the center (Fig.2) where the thickness increases near the springs (Fig.3). The brine evaporates at the surface leaving salt cones on the surface. The salt minerals detected by X-ray diffraction are: halite, bassanite, gypsum, anhydrite, sylvite and polyhalite. While the clay minerals in the clayey sediments are: palygorskite, kaolinite, illite, montmorillonite and chlorite. The detrital non-clay minerals are: quartz, calcite, dolomite, gypsum, plagioclase and mica. The salt reserve was estimated by about 2,953,000 ton (Al-Badri and Mohammed, 1988).

The geochemical indices of (Cl-Na)/Mg, Na/Cl and SO_4/Cl of the brines in the Bowara Saltern suggest that the salt is of deep oceanic origin diluted by recent rain water and rising to the surface through faults and fissures, indicated by the linear arrangement of these springs (Al-Badri and Mohammed, 1988). The brines may have originated from the salt beds of the Dhiban and Fatha formations. The presence of salt beds of the Dhiban and Fatha formations is proved by the drillings of oil companies in Khlaisia, Mityaha, Ain Gazal, Sfeya and Tel Hajar structures and said to extend to Hermishiya in Syria in addition to that present in south of Kirkuk (Ponikarov *et al*., 1967).

Table 1: Chemical analyses of salts and salts contents from the Bowara Saltern

Constituents	**Concentration %**			**Minerals**	**Calculated Salts %**		
	(Al-Rawi, 1970)	(Al-Badri and Mohammed, 1988)			(Al-Rawi, 1970)	(Al-Badri and Mohammed, 1988)	
		Average	**Range**			**Average**	**Range**
Cl	59.28	49.34	6.75 – 60.77	NaCl	90.17	27.3	8.19 – 94.82
SO_3	0.76	4.41	0.8 – 26.4	$CaSO_4$	0.94	28.28	2.45 – 58.1
NO_3	0.02	--	--	KCl	0.38	0.53	0.09 – 1.09
Na	35.5	15.43	7.04 – 19.24	KNO_3	0.03	--	--
K	0.23	0.227	0.042 – 0.55				
CaO	0.39	2.68	0.56 – 16.26				
MgO	0.12	0.2	0.04 – 0.77				
Fe_2O_3	0.02	--	--				
Al_2O_3	0.18	--	--				
I.R.	--	35.78	1.6 – 74.2				

Fig.2: Salt crust in the Bowara Saltern showing polygonal shapes

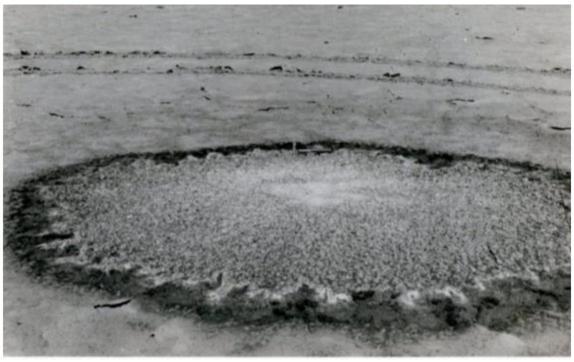

Fig.3: Spring in the Bowara Saltern

The minor and trace elements concentrations of Bowara saltern are: SrO = 573 ppm, MnO = 114 ppm, Rb = 10 ppm, Cd = 3 ppm, Cu = 5 ppm, B<5 ppm, Ni = 52 ppm, Pb = 10 ppm, Zn = 15 ppm, Li = 3 ppm and Co = 6 ppm.

The brine of the Bowara saltern contains chlorides and sulfates of sodium, potassium and magnesium (Table 2). The study of Al-Ajeel *et al*. (1989) to extract some valuable salts from the brine followed two routes, the first by precipitating potassium chloride (96% purity) and sodium sulfate with magnesium sulfate as a by-product by evaporation and cooling, while the second rote considered precipitating potassium sulfate instead of potassium chloride.

Table 2: Chemical constituents of the Bowara salt

Ions	Concentration in ppm at (Specific gravity 28.7 Bome´)
Na^{+}	100202 mg/L
K^{+}	14900 mg/L
Mg^{2+}	20412 mg/L
Ca^{2+}	206 mg/L
SO_4^{2-}	40800 mg/L
Cl^{-}	198800 mg/L

– **Albu-Gharis Saltern:** This saltern is located about 20 Km north of Al-Qaim town on the border line between Iraq and Syria (Fig.1). It is an elongated depression 23 Km long and 1 – 4.5 Km wide with NE – SW direction. It is linked at the southern part with Al-Twailla Saltern and the total length together will be 40 Km. The total area of the saltern is about 88 Km^2 and the area covered by salt is about 70 Km^2. Like Bowara saltern, Albu-Gharis and Al-Tawila salterns are developed within the exposures of the Fatha Formation and surrounded by the exposures of the Injana Formation (Al-Badri and Mohammed, 1988).

The salt is present in the salt crust which is a few millimeters at the periphery and reaches about 20 cm in the middle part. Underneath the crust, brines and crystalline salt is present in the first meter of the sediments which contains salt crystals and silty sediments. The second salt bed lies underneath and continues beyond the maximum digging depth of (170 cm). The salt minerals detected by X-ray diffraction are: halite, bassanite, anhydrite, gypsum, bischofite and sylvite. While the clay minerals in the clayey sediments are palygorskite, kaolinite, montmorillonite and chlorite. The detrital non-clay minerals are quartz, calcite, dolomite, gypsum, plagioclase and mica. The chemical analyses of salts from Albu-Gharis Saltern are listed in Table (3). The origin of salts and brine in this saltern is similar to that of the Bowara Saltern. The minor and trace elements concentrations are: SrO = 176 ppm, MnO = 7.89 ppm, Rb = 16 ppm, Cd = 2 ppm, Cu = 10.8 ppm, B = 7 ppm, Ni = 30 ppm, Pb = 4 ppm, Zn = 30 ppm and Co not detected. The salt reserve is about 13,450,000 tons (Al-Badri and Mohammed, 1988).

It is worth mentioning that Albu-Gharis Saltern contains KCl salt in addition to the NaCl salts. Al-Bassam (2002 and 2012) carried out mineral investigation for potassium salts in the Albu-Gharis Saltern and found that the potassium concentration in the salt crust ranges between: (0.3 – 3.0) % (mean = 1.16%), sodium: (17.44 – 37.76) % (mean 32.89%), chloride: (27.89 – 59.82) % (mean = 52.97%), KCl: (0.57 – 5.7) % (mean = 2.20%) and I.R.: (0 – 49.58) % (mean = 8.86%). The X-ray diffraction (XRD) analysis revealed the dominance of halite and the presence of sylvite in all samples. The chemical analysis of the brines from this saltern showed that the T.D.S. ranges from 325576 ppm to 332744 ppm and the potassium concentration ranges from 5464 ppm to 7948 ppm. Two types of salts are reported in the saltern, the older salts which have sylvite content of 1.63% and the recent salts with sylvite content of 3.52%.

Table 3: Chemical analyses of salts and salts contents from Albu-Gharis Saltern

Constituents	Concentration %			Minerals	Calculated Salts %		
	(Al-Rawi, 1970) for Al-Tawila only	(Al-Badri and Mohammed, 1988)			(Al-Rawi, 1970) for Al-Tawila only	(Al-Badri and Mohammed, 1988) Albu-Gharis and Al-Tawila	
		Average	**Range**			**Average**	**Range**
Cl	58.85	37.74	5.32 – 60.35	NaCl	95.61	90.91	25.27 – 94.3
SO_3	1.08	4.68	0.9 – 49	$CaSO_4$	1.94	18.12	1.05 – 63.79
NO_3	0.09	--	--	KCl	1.53	2.68	0.25 – 6.65
Na	37.6	11.87	2.29 – 20.02	KNO_3	0.15	--	--
K	0.86	0.51	0.05 – 1.53				
CaO	0.8	3.42	0.84 – 33.88				
MgO	--	0.28	0.04 – 0.69				
Fe_2O_3	--	--	--				
Al_2O_3	--	--	--				
I.R.	--	20.53	6.2 – 54.11				

Al-Ajeel *et al*. (1989) executed experiments to separate potassium and magnesium salts from the brine of Albu-Gharis Saltern (Table 4). The main salt in Albu-Gharis saltern is sodium chloride and potassium is one of the secondary salts; therefore, they separated the highest possible amount of sodium chloride to concentrate the potassium salt in the remaining solution. They found out that the best concentration (specific gravity) to precipitate sodium chloride is between 27 and 27.7 Bome´ and the remaining bittern brine is separated by filtration. Since the bittern is a mixture of sodium, magnesium and potassium salts, it was evaporated to increase its concentration between 27 and 39.4 Bome´ to precipitate these salts which include potassium chloride (Table 5). The precipitated salts were washed with hot water to wash the sodium and potassium salts then cooling the brine to separate potassium chloride which was later on precipitated by cooling. The purity of the separated potassium chloride was 90%.

Table 4: Chemical constituents of Albu-Gharis Saltern
(After Al-Ajeel *et al*., 1989)

Ions	**Concentration in ppm at specific gravity 25.5 Bome´**
Na^+	106458
K^+	20800
Mg^{2+}	5943
Ca^{2+}	3758
SO_4^{2-}	2160
Cl^-	205200

Table 5: Salts concentrations separated between 27.4 – 39.4 Bome´
from Albu-Gharis Saltern (After Al-Ajeel *et al*., 1989)

Compounds	Concentration (%)
NaCl	54.5
KCl	27.8
$MgCl_2$	7.1
$CaCl_2$	1.72
$CaSO_4$	0.3

– **Snaisla Saltern:** This saltern is located in the central part of the Jazera area (Fig.1). Its area is 44 Km^2 (Al-Badri *et al.*, 1986). The chemical analysis of the salt from salt crust in the Snaisla saltern is listed in Table (6).

Table 6: Chemical analyses of salts and salts contents from Snaisla Saltern

Constituents	Concentration %			Minerals	Calculated Salts %		
	(Al-Rawi, 1968)	(Al-Badri *et al*., 1986) Average	(Al-Badri *et al*., 1986) Range		(Al-Rawi, 1968)	(Al-Badri *et al*., 1986) Average	(Al-Badri *et al*., 1986) Range
Cl	57.28	46.75	26.62 – 60.04	NaCl	94.38	80.15	43.78 – 98.9
SO_3	1.83	10.94	0.3 – 28.5	$CaSO_4$	2.5	14.68	0.49 – 37.4
NO_3	0.08	--	--	KCl	0.18	0.104	0.052 – 0.38
Na	38	31.5	2 – 38.9	KNO_3	0.13	--	--
K	0.1	0.055	0.029 – 0.11	$CaCO_3$	--	0.072	0.05 – 0.25
CaO	1.03	6.036	0.28 – 16.24				
MgO	0.16	0.23	0.78 – 1.26				
Fe_2O_3	0.1	--	--				
Al_2O_3	0.01	--	--				

The origin of salt in Snaisla Saltern according to Al-Rawi (1968) is the ascending brines through fissures originated from the dissolution of salt from the saliferous beds of the Fatha Formation. According to Al-Badri *et al.* (1986) the origin of the salts, based on the hydrochemical study for the brines, is ancient interstitial sea water mixed with recent connate water (rain). The groundwater dissolves the salts from the saliferous beds of the Fatha and Dhiban formations ascending to the surface through fissures and faults forming seepages and springs inside the saltern. In addition, salts washed by rain water from the surrounding rocks of the Fatha Formation and draining them into the depression are another source for salts in the saltern. The minor and trace elements concentrations of Snaisla Saltern are: Sr = 537 ppm, Zn = 6.4 ppm, Cd = 3.6 ppm, Cu = 7 ppm and Pb = 13.9 ppm.

The salts of this saltern were found to be unsuitable, neither for food nor for industrial purposes, because of a considerable amount of insoluble residue content represented by dust and clay. The salt reserve according to Al-Rawi (1968) is estimated to be about 1000000 ton and according to Al-Badri *et al.* (1986) calculated to be 1,895,290 ton in addition to the amount present in the brine.

Ashgar Saltern: It is the second saltern in size, located in the middle of Jazera area (Fig.1). Its area is 37.5 Km^2 (Al-Badri *et al*., 1986). The area covered by salt is about 1.5 Km^2 with salt thickness of about 1 cm. The origin of salts in this saltern is the same as that of Snaisla Saltern. The chemical analyses and the calculated theoretical salts of salt samples from Ashgar Saltern are listed in Table (7). Minor and trace elements concentrations were: Sr = 132.2 ppm, Zn = 9.9 ppm, Cd = 6.1 ppm, Cu = 7.2 ppm and Pb = 11 ppm. The salt reserve is about 125000 ton, but the salt is unsuitable neither for food nor for industrial purposes.

Table 7: Chemical analyses of salts and salts contents from Ashgar Saltern

Constituents	**Concentration %**			**Minerals**	**Calculated Salts %**		
	(Al-Rawi, 1968)	(Al-Badri *et al*., 1986)			(Al-Rawi, 1968)	(Al-Badri *et al*., 1986)	
		Average	**Range**			**Average**	**Range**
Cl	57.28	53.35	25.9 – 60.09	NaCl	94.3	90.085	42.46 – 99.58
SO_3	0.75	2.83	0.37 – 16.95	$CaSO_4$	1.38	3.439	0.55 – 22.33
NO_3	0.02	--	--	KCl	0.24	0.114	0.03 – 0.28
Na	40	32.49	18.69 – 39.22	KNO_3	0.03	--	--
K	0.14	0.052	0.029 – 0.145	$CaCO_3$	--	0.064	0.05 – 0.09
CaO	0.63	1.36	0.28 – 9.24				
MgO	0.23	0.124	0.046 – 0.218				
Fe_2O_3	0.13	--	--				
Al_2O_3	0.42	--	--				

There are other small salterns in the middle of the Jazera area with small areas and small salt reserves. They are: Um Dlay (4.5 Km^2 and 80,124 ton), Gattar (1.2 Km^2 and 46,472 ton) and Gzaiz (3.9 Km^2 and 130,749 ton).

- **The Low Folded Zone Salterns**

– **Hawija Saltern:** This saltern is located about 18 Km to the northeast of Al-Fatha gorge in Salahdin Governorate (Fig.1). It is 2 Km long and 1Km wide valley descending from Hemrin Mountain. The source of the salts is springs and seepages inside the saltern depression, originating from the dissolution of the salt from the saliferous beds of the Fatha Formation (Al-Rawi, 1968). The chemical analyses of three salt samples showed the followings: Cl^- = 54.26%, 54.26%, 47.33%; SO_3^- = 0.13%, 5.7%, 7.1%; NO_3^- = 0.05%, 0.1%, 0.03%; Na^+ = 42.5%, 38.0%, 35.5%; K^+ = 0.16%, 0.17%, 0.05%; CaO and MgO contents are Trace. The calculated salts for these samples are: NaCl = 89.45%, 89.45%, 78.3%; Na_2SO_4 = 0.23%, 8.64%, 12.34%; KCl = Trace and $CaSO_4$ = Trace (Al-Mhaidi, 1968).

– **Khalifa Saltern:** This saltern is located about 41 Km NE of Tikrit City, Salahdin Governorate (Fig.1). It is a spring which rises from the Fatha Formation where the groundwater dissolves salt from the saliferous beds. Part of the brine is directed to a number of ditches for evaporation and salt precipitation. The brine contains 96.77% NaCl and 1.48% Na_2SO_4. The chemical analysis is as follows: Cl^- = 58.70%, SO_3^{2-} = 0.48%, NO_3^- = Nil, Na^+ = 42.5%, K^+ = 0.04%, CaO = 0.55%, MgO = 0.09% (Al-Rawi, 1970).

– **Shari Saltern:** The Shari Saltern is located about 35 Km to the northeast of Samarra town (Fig.1). Although this saltern is characterized by the dominance of sodium sulfate, but sodium chloride is also present in the salt crust and the brine. The chemical analyses of the saltern brine in different times are shown in Table (8). Sodium chloride concentration in the salt crust is about 22% (Table 9). The locals are used to extract sodium chloride salt and use it or sell it as a table salt despite of the presence of other impurities like sodium sulfate. The maximum concentration of NaCl is present near the peripheries, and the minimum is in the central part where sodium sulfate has its maximum concentration (Fig.4) (Jassim, 1997). The lake brine analyses are shown in Table (8).

– **Douz Saltern:** It is located about 35 Km southeast of Kirkuk City and 2 Km east of Douz Khormato town. It is a salty spring with brines derived from the saliferous beds of the Fatha Formation. The chemical analyses of two brine samples are: Cl^- = 55.7%, 60.25%; SO_3^- = 0.5%, 0.44%; Na^+ = 38.0%, 39.0%; K = 0.18%, 0.3%; CaO = 0.49%, 0.54% and MgO = 0.16%, 0.2%. The calculated salts for these two samples are: NaCl = 96.88%, 98.90%; KCl = 0.4%, 0.5%; $CaSO_4$ = 0.75%, 0.68% and Na_2SO_4 is Nil. The production depends on the capacity of the artificial basins made by investors (Al-Mhaidi, 1968).

– **Chemchemal Saltern:** It is located about 44 Km east of Chemchemal town (Fig.1). The origin of the salt is a brine spring. The brine is directed to ponds for solar evaporation, then salt precipitation and harvesting. The salt contains are: 97.31% NaCl and the impurities are: CaO = 0.27%, K^+ = Nil, Mg = 0.05%, SO_4^{2-} = 0.6%, NO_3^- = 0.02%, Fe = 0.003%, Cu = 0.001% and Pb = 0.003% (Al-Rawi, 1970).

Table 8: Chemical analyses of the lake brines at the Shari Lake (after Jassim, 1997)

Early lake brine				**Late lake brine**			
Main Constituents	**ppm**	**Trace Elements**	**ppm**	**Main Constituents**	**ppm**	**Trace Elements**	**ppm**
Na^+	22663	Ni	2.48	Na^+	65540	Ni	4.54
Ca^{2+}	589	Cu	0.30	Ca^{2+}	641	Cu	0.34
Mg^{2+}	69.3	Zn	0.19	Mg^{2+}	775	Zn	o.18
K^+	91.8	Cd	0.27	K^+	349	Cd	0.43
SO_4^{2-}	28818	Pb	0.92	SO_4^{2-}	69643	Pb	2.10
Cl^-	14889	Li	0.04	Cl^-	53174	Li	0.10
NO_3^-	--	Br	10.80	NO_3^-	--	Br	113.60
CO_3^{2-}	24			CO_3^{2-}	54		
HCO_3^-	122			HCO_3^-	152		
T.D.S.	67250			T.D.S.	197790		

Table 9: Chemical analysis and mineral constituents of the salt from the salt crust at 1 km inside the Shari Saltern (after Jassim, 1997)

Main Constituents	**%**	**Compounds**	**%**
Na^+	28.67	NaCl (Halite)	20.29
Ca^{2+}	1.47	Na_2SO_4 (Thenardite)	67.75
Mg^{2+}	0.096	$Na_2Ca(SO_4)_2$ Glauberite	11.95
K^+	0.11		
SO_4^{2-}	48.06		
Cl^-	11.07		

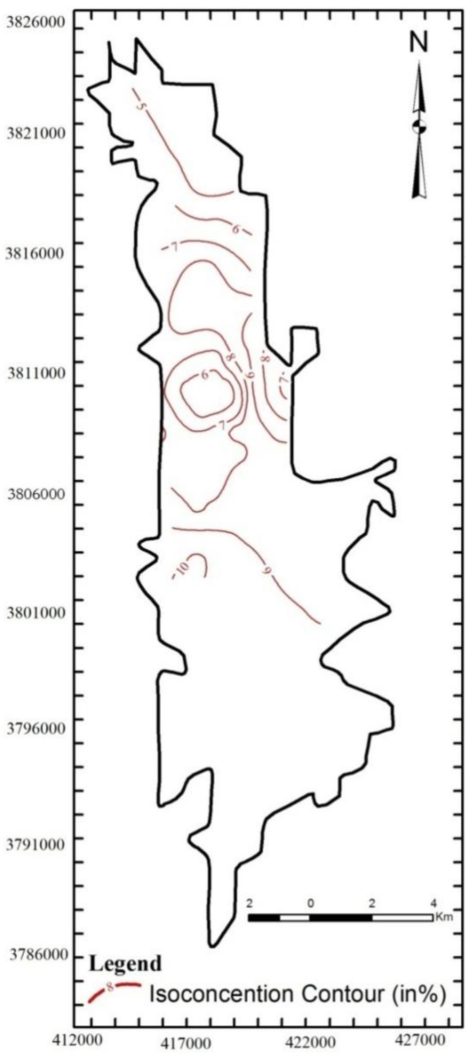

Fig.4: Isoconcentration map of sodium chloride salt in the Shari Saltern (after Jassim, 1997)

- **Mesopotamian Plain Salterns and Sabkhas**

The Mesopotamian Plain is a low land as compared with other surrounding parts of Iraq. The sediments are mainly of fluvial origin composed mainly of detrital clay, silt and sand which are the erosion products of rocks and sediments along the course of the Tigris and Euphrates rivers and their tributaries. It is a dumping area of the sediments brought to this part by the Tigris and Euphrates rivers and the ephemeral streams from the surroundings (Buday and Jassim, 1987; Aqrawi *et al*., 2006 in Jassim and Goff, 2006). The western boundaries of the Mesopotamian Plain are sharply marked by the NW – SE trending Abu Jir – Euphrates Active Fault Zone where several saline seepages, springs and salt deposits are located.

– **Al-Samawa Saltern:** This saltern has been the main source of salt in Iraq for several decades. It is located about 35 Km south of Al-Samawa City (Fig.1) at the boundary between the Stable Shelf and the Mesopotamian Zone of Iraq, to the west of the Abu Jir – Euphrates Active Fault Zone (Sissakian and Fouad, 2012). The saltern is developed in a depression, about 3.5 Km long and 1.5 Km wide and the area is covered by a few meters of Quaternary alluvial sediments, composed of silty gypseous sediments and white salts underlain by rocks of the Euphrates Formation (Al-Hashimi, 1974; Jassim and Buday, 2006b).

Al-Samawa salt deposit was studied in the beginning by Al-Rawi (1970), Al-Badri (1984) and Al-Ani (1986). Four salt layers have been identified and the salt contents of these layers are shown in Table (10). The minor and trace elements concentrations of Al-Samawa salt deposits are: Fe = 13 ppm, Mn = Nil, Cu = 5 ppm, Zn = 7 ppm, Co = 4 ppm, Cd = 3.6 ppm, Cr = Nil, Ni = 11 ppm and Pb = 25 ppm. The reserve was estimated in the earlier investigations by 4300000 tons.

Table 10: Types and contents of salts in the salt layers of Al-Samawa Saltern (Al-Rawi, 1970)

Salt %	First layer (A)	First layer (B)	Second layer	Third layer	Fourth layer
NaCl	94.88	78.94	89.23	86.71	88.67
KCl	0.39	5.70	0.41	Nil	0.20
$CaSO_4$	2.11	1.25	4.48	5.24	4.91
KNO_3	Trace	0.26	Trace	Trace	Trace

Al-Samawa Saltern was studied in more detail by Al-Badri *et al*. (1988), who confirmed the presence of the four main salt layers with chemical composition similar to that shown in Table (10). The main salt layer is very tough with a thickness of about 7 meters in the central area and about (1 – 2) meters at the periphery extending over an area 450 m long and 1500 m wide (Fig.5) containing halite crystals of different sizes (few millimeters to 30 cm). Crystals of other salts are found between the halite crystals, like gypsum, glauberite, borite and polyhalite. The chemical composition of the main salt layer in different parts of the saltern is shown in Table (11). The study of salt in the main salt layer revealed that the NaCl concentration ranges between 71.82% and 99.56% (Table 12). The chemical analysis of the salts revealed the following average concentrations: Na^+ = 36.6%, Cl^- = 56.00%, Mg^{2+} = 0.90%, K^+ = 0.13%, SO_4^{2-} = 0.24% and the compounds NaCl = 93.87%, $CaSO_4$ = 2.76%, KCl = 0.09%, $CaCO_3$ = 2.02%, Fe_2O_3 = 0.02% and I.R. = 1.24%. The minor and trace elements concentrations are: Fe = 27 ppm, Mn = 1.55 ppm, Cu = 5 ppm, Zn = 23 ppm, Co = 11 ppm, Cd = 3 ppm, Cr = Nil, Ni = 18 ppm and Pb = 12.5 ppm.

The work of Al-Badri *et al*. (1988) included reserve estimation of the salt deposits of the saltern based upon information gathered from detailed exploration work which included about 200 ditches, 110 vertical trenches, 33 shallow boreholes and one deep borehole. In addition, bout 60 geological sections in the surrounding area were documented, 600 samples of rocks, salts and brines were collected and about 11000 field and laboratory tests were performed. The salt reserves were estimated in category C1 and part of it in category B. The salt deposit reserve was calculated to be 41 million tons.

The detailed investigations of Al-Badri *et al*. (1988) covered brines in the Samawa saltern and surrounding areas which revealed that most of the brines in the saltern are of high salts concentration and sometimes approaches the saturation level in NaCl (Table 13). The first rain washout in the season shows T.D.S. concentration up to 4232 ppm despite the absence of any salt layer in the sections of the valleys that bring the rain washout to the saltern depression. Some believe that these amounts of solutes were concentrated by evaporation in the arid condition of the area for very long time and accumulated in the depression leading to precipitation of salts. The T.D.S. of the underground water increased in E–W direction near the Samawa Saltern to be salty water, especially with sodium chloride, in most of the aquifers in the Euphrates and Dammam formations. The underground water turns to be of sulfate-type with moderate salinity south from the Samawa Saltern, near Nugrat Al-Salman area and surroundings.

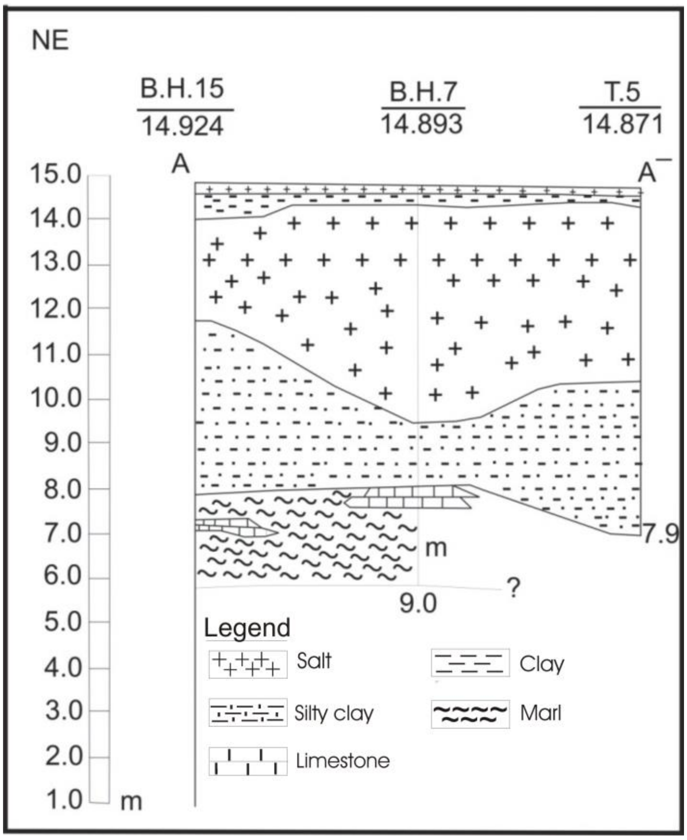

Fig.5: Schematic cross section in the Samawa Saltern (After Al-Badri *et al*., 1985)

Table 11: Chemical and salt composition (%) of the main salt layer in different parts of the saltern (after Al-Badri *et al*., 1985)

Position	**Number of Samples**	**Na^+**	**Cl^-**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**NaCl**	**KCl**	**$MgCl_2$**	**$CaSO_4$**
Central part	100	32.6	55.0	4.5	0.9	0.13	88.0	0.12	1.8	3.7
Northern Part	30	34.6	52.6	2.9	1.2	0.09	82.5	0.15	3.2	5.0
Southern Part	55	31.6	51.7	2.8	0.8	0.12	83.8	0.18	2.7	6.8
Eastern Part	88	30.2	50.9	2.6	1.0	0.1	86.25	0.2	2.2	3.1
Western Part	93	34.4	53.9	1.8	0.5	0.08	83.3	0.2	2.9	5.2

Table 12: Chemical composition of the main salt layer (after Al-Badri *et al*., 1985)

Component	**Average (%)**	**Range (%)**
I.R	1.31	0.11 – 4.17
Na^+	36.06	27.85 – 38.75
Cl^-	58.96	49.76 – 60.55
NaCl	91.87	71.82 – 99.56
$CaCO_3$	0.32	0.03 – 0.83
$CaSO_4$	2.76	0.26 – 9.84
$CaCl_2$	0.92	0.027 – 5.95
$MgCl_2$	1.15	0.01 – 5.71
KCl	0.04	0.04 – 0.11

Table 13: Salt constituents of the Samawa Saltern brine (after Al-Badri, 1984)

Salt constituents	Concentration (%)
NaCl	24.9
$NaNO_3$	0.447
KNO_3	0.583
$MgCl_2$	o.30
$MgSO_4$	0.58
$CaSO_4$	0.25

Al-Badri *et al*. (1988) suggested the presence of some evaporite beds at depth in the saltern area. These evaporite beds most probably belong to the Rus Formation and dissolved by the ground water that migrated upward through the faults (or step faults) in the area. Tens of faults are observed on the northern and southern peripheries of the saltern and ten salty springs are observed inside the saltern. In order to prove this suggestion a deep borehole was drilled to pass Rus Formation layers, and it was found that the Rus Formation is composed of gypsum, anhydrite and claystones which eliminate the possibility of being the origin of salts in the saltern. The drilling of the Iraqi National Oil Company in the area (Borehole Samawa-1) proved that there are very salty brines from the Gotnia and Shiranish formations.

Al-Ajeel *et al*. (1989) studied the bittern brine left after the precipitation of sodium chloride from the Samawa salt plant in order to extract potassium chloride. The bittern (Table 14) was treated with CaO at pH = 11 to precipitate magnesium hydroxide and calcium sulfate as in the equations (1) and (2), then the precipitate was rinsed with water. The remaining brine was evaporated till the saturation point and then cooling to crystallize potassium salts.

$$MgSO_4 + CaO + H_2O \rightarrow Mg(OH)_2 + CaSO_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

$$MgCl_2 + CaO + H_2O \rightarrow Mg(OH)_2 + CaCl_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Table 14: Chemical analysis of the Samawa bittern brine (Al-Ajeel *et al*., 1989)

Ions	Concentration (ppm)	Compounds	Concentration %
Na+	122745.97	$CaSO_4$	0.0667
K^+	14600	$MgSO_4$	5.641
Mg^{2+}	20496	$MgCl_2$	3.6471
Ca^{2+}	196.4	KNO_3	3.781
Cl^-	213000	$NaNO_3$	0.8891
SO_4^{2-}	45600	NaCl	30.61
NO_3^-	27000		
NO_2^{2-}	2000		

– **Umm Al-Tigan Saltern:** This saltern is considered the southern extension of the Samawa Saltern. Al-Badri (1984) studied the geology of the saltern and carried out detailed exploration in 1989 (Al-Badri, 1989). He made 90 trenches and chemically analysed more than 400 salt, brine and sediment samples. The study revealed that the salt reserve of the salt crust is about 2.16 million tons. The salt crust has variable thickness ranging from few millimeters near the periphery and about 10 cm in the middle. Al-Badri (1989) found that the average concentration of Na^+ and Cl^- in the salt crust are 36% and 58% respectively. The sulfate and I.R. concentrations in the salt samples near the periphery of the saltern are 20% and 16% respectively, which are higher than those in the middle part of the saltern of 0.5% and 6% respectively. The salt minerals identified in the salt crust are mainly halite with small amount of polyhalite, sylvite and gypsum. The chemical composition of salt sample from this salt pan is as follows: Na^+ = 32.6%, Cl^- = 50.58%, CaO = 1.08%, MgO = 0.16%, K_2O = 0.14%, SO_3^- = 1.65%, CO_3^{2-} = 0.21%, NO_3^- = Trace, I.R. = 14.08%, SrO = 172 ppm, MnO = 196 ppm and Cd = Trace.

- **Mesopotamian Plain Sabkhas**

Some shallow depressions in the Mesopotamian Plain, where the groundwater is near to the surface, are characterized by accumulation of salty brine forming salt precipitates called sabkhas. It is worth mentioning that the marshes of south Iraq affect the groundwater and the salt accumulation in the region. There are many of these sabkhas in the Mesopotamian Plain, but only the big ones have been studied. The origin of salts in these sabkhas is from the shallow (near-surface) groundwater feeding the depressions from beneath. Salts can also accumulate in these depressions from the washout of the surrounding sediments (Al-Ani, 1986).

– **Al-Mahmudiyah Sabkha:** It is a small sabkha located about 32 Km south of Baghdad (Fig.1). The salt crust does not exceed 7 cm in the deepest part of the depression. It is composed of halite (NaCl), thenerdite (Na_2SO_4) and bischofite ($MgCl_2.6H_2O$). The salts are more concentrated at the depth (0 – 10 cm) than at deeper depth due to the presence of high percentage of fine materials which reduces the permeability of the surface soil. The concentration of sodium chloride salt in this sabkha ranges between (46.2% – 70.2)%, whereas sodium sulfate ranges between (1.9% – 37.7)%, and calcium sulfate concentration is (17.2)%. The minor and trace elements concentrations are: Fe = 8 ppm, Mn = 3.4 ppm, Cu = 6 ppm, Zn = 9 ppm, Co = 8 ppm, Cd = 3 ppm, Cr = Nil, Ni = 18 ppm and Pb = 15 ppm (Al-Ani, 1986).

– **Iskenderiyah Sabkha:** It is a small sabkha located about 55Km south of Baghdad (Fig.1).The dominant anions are chloride and sulfate which reflects the presence of halite (NaCl) and thenerdite (Na_2SO_4) as main salts of the sabkha. Sodium chloride reaches up to (60.2)%, sodium sulfate varies in the salt crust and the underlying sediments between (41.6)% and (11.6)% respectively and calcium sulfate concentration in the salt crust and the underlying sediments is (23.5)% and (10.36)% respectively. The top layer of the salt crust is of higher purity in sodium chloride due to the precipitation of sulfate minerals before the chloride minerals. The minor and trace elements concentrations are: Fe = 6 ppm, Mn = 1.0 ppm, Cu = 5 ppm, Zn = 7.5 ppm, Co = 4 ppm, Cd = 2.6 ppm, Cr = Nil, Ni = 10 ppm and Pb = 22.5 ppm. Loeweite [$Na_{12}Mg_7(SO_4)_3$] was also detected in the XRD examination of the salt precipitates (Al-Ani, 1986).

– **Al-Musayab Sabkha:** It is a small sabkha located about 74 Km south of Baghdad (Fig.1). Although sodium and chloride are dominant in the sediments, but they increase upward and reach the highest concentration at depth (0 – 20 cm)., where sodium chloride content reaches up to (61.91)%. Magnesium chloride varies in the salt crust and the underlying sediments between (25.86% – 8.3) % respectively and calcium chloride concentration in the salt crust is (5.6)%. The minor and trace elements concentrations are: Fe = 12 ppm, Mn = Nil, Cu = 8 ppm, Zn = 8 ppm, Co = 4 ppm, Cd = 4.3 ppm, Cr = Nil, Ni = 13 ppm and Pb = 25 ppm. The salts present in the harvested products are halite and bischofite (Al-Ani, 1986).

– **Al-Hillah Sabkha:** It is a small sabkha located about 97 Km south of Baghdad City (Fig.1). Sodium and chloride ions concentration in sediments are the dominant, and they increase upward. Calcium, magnesium and sulfate increase downward in the sediments. Sodium chloride ranges between (29.2% – 70.8)%, sodium sulfate varies in the salt crust and the underlying sediments between 0% and 14.1%, magnesium sulfate ranges between (0.5% – 20.5)% and calcium sulfate is present in the salt crust (35.8)% and in the underlying sediments (11.7)%. The minor and trace elements concentrations are: Fe = 15 ppm, Mn = 5 ppm, Cu = 5 ppm, Zn = 12 ppm, Co = 8 ppm, Cd = 2 ppm, Cr = Nil, Ni = 21 ppm and Pb = 15 ppm. The dominant salts in the salt crust are halite and bischofite (Al-Ani, 1986).

– **Al-Kifil Sabkha:** It is a small sabkha located about 140 Km south of Baghdad City (Fig.1). Sodium, magnesium and chloride increase upward in the sediments, while sulfate increases downward due to the precipitation of calcium sulfate (gypsum) during the movement of the shallow groundwater upwards by capillary action or what is called evaporation pumping. Calcium sulfate, magnesium sulfate then sodium sulfate precipitate first before sodium chloride precipitation. Sodium chloride reaches up to 66.9%, sodium sulfate varies between (29.8% – 6.1)% in the salt crust and the underlying sediments respectively and calcium sulfate is present in the salt crust (34.0)% and the underlying sediments (11.4)%, whereas magnesium sulfate ranges between (25.2% – 7.8)%. The minor and trace elements concentrations are: Fe = 14 ppm, Mn = Nil, Cu = 4 ppm, Zn = 10 ppm, Co = 7 ppm, Cd = 6.6 ppm, Cr = Nil, Ni = 10 ppm and Pb = 25 ppm. Halite is the only salt mineral detected by XRD in the salts of the salt crust (Al-Ani, 1986).

– **Al-Hashimiyah Sabkha:** It is a small sabkha located about 55 Km southeast of the Hillah City (Fig.1). The positive and negative ions decrease downwards due to the sandy composition of the underlying sediments (190 – 290 cm depth) which allow the water to penetrate downwards washing the main ions. The increase in the main elements at and near the surface is due to evaporation, which increases the brine concentration. Sodium chloride ranges between (35.5% – 64.1)%, magnesium chloride reaches (20.9)%, sodium sulfate (21.4)%, calcium sulfate is present in the salt crust (38.5)% and the underlying sediments and (4.26)% and magnesium sulfate ranges between (2.4% – 25)%. The minor and trace elements concentrations are: Fe = 13 ppm, Mn = 5.3 ppm, Cu = 5 ppm, Zn = 10 ppm, Co = 8 ppm, Cd = 2 ppm, Cr = Nil, Ni = 22 ppm and Pb = 15 ppm. The XRD analysis revealed the presence of halite and bischofite salt minerals (Al-Ani, 1986).

– **Summer Sabkha:** It is a small sabkha located about 105 Km southeast of Hillah City (Fig.1). Al-Ani (1986) noticed that the concentration of the soluble salts in the sediment interval (0 – 40) cm is less than that in the depth interval (40 – 60) cm due to the coarse texture of the sediments near the surface which facilitated leaching of the salts towards the subsurface. The salts precipitated in the subsurface finer sediment, and led to an increase in the salts concentration. Sodium chloride ranges between (36.2 – 68.5) %, sodium sulfate varies between (5.0)% and (2.2)% in the salt crust and the underlying sediments respectively, magnesium chloride varies between (0.1 – 7) %, magnesium sulfate ranges between (4.6 – 49.8) % and calcium sulfate is present in the salt crust (34.3)% and the underlying sediments (5.5)%. The minor and trace elements concentrations are: Fe = 13 ppm, Mn = 0.8 ppm, Cu = 4 ppm, Zn = 10 ppm, Co = 10 ppm, Cd = 2 ppm, Cr = Nil, Ni = 18 ppm and Pb = 12.5 ppm (Al-Ani, 1986).

– **Al-Diwaniya Sabkha:** It is small sabkha located about 15 Km north east of Al-Diwaniya City (Fig.1). Sodium increases upward in the sediments forming sodium chloride on the surface and calcium increases downwards forming gypsum which is the first evaporate mineral to precipitate during the concentration and crystallization process. The sulfate ions have excess concentration over that needed for the gypsum formation leading to its movement to the surface forming thenerdite by combination with sodium, and the rest of sodium is combined with the chloride forming halite. Sodium chloride reaches up to (60.4)%, sodium sulfate varies between (44.0)% and (28.0)% in the salt crust and the underlying sediments respectively and calcium sulfate is present in the salt crust (43.1)% and the underlying sediments (1.8)%, whereas magnesium sulfate ranges between (22.0% – 5.9)%. The minor and trace elements concentrations are: Fe = 15 ppm, Mn = Nil, Cu = 4 ppm, Zn = 9 ppm, Co = 4 ppm, Cd = 4 ppm, Cr = Nil, Ni = 8.3 ppm and Pb = 30 ppm. The salt minerals detected by XRD in the salt crust are halite and thenerdite (Al-Ani, 1986).

There are other sabkhas which are not mentioned in this overview due to lack of information, such as Numaniyah and Zurbatyah. Both of them are located in Wasit Governorate and provide Kut Textile Plant with salt.

SEAWATER SALT PLANTS

- **Basrah Salt Plant**

In1990, the Iraqi Government planned for a new saltern based on the Arabian Gulf water and solar evaporation energy, called Basrah Salt Plant. In 1990, a French company called Saline de Mede, supported by other companies (Angico from Italy and Acajico from Japan), was contracted to build the plant. The contract covered the implementation of a new saltern, including construction of salt-pans, basins as well as pumps, roads and other civil facilities. The saltern is located 60 Km south of Basra City, and covers an area of 50 square kilometers. Its design capacity is to produce half a million tons of salt annually.

The Gulf water reaches the pans through pumps from Khor Abdullah with a three kilometers long canal, and another secondary canal of 1 Km long. The water flows through a canal, passing into the intake salt-pans with the composition listed in Table (15). The salt-pans are provided with large flood gates with hand adjustment to open the gates allowing the tide water to run in, and close them when the tide begins to retreat. The salt water remains in the intake salt-pans for few days, in the meanwhile evaporating. The salt-pans have mud floors and they are separated from each other by low embankments (dikes), range in height from 20 to 60 cm. Some dikes are narrow, others, especially the outside dikes, are wide enough to be used as roadways over which tractors and cars may be driven. When enough halite salt crystallizes in the salt-pans, the hand gates are re-opened to let the bitter solution to return back to the gulf.

This Basra Salt Plant worked for a few years and was completely destroyed and vandalized by the 2003 war and ensuing events. Considering the demand for salt in food and many other industries, Iraq has partly rehabilitated, renovated and rebuilt some necessary pans of the Basra Salt Plant in 2013. It started working with a capacity of 200,000 tons annually. Later, in 2017 the Iraqi Government submitted the Basrah Salt Plant as an international investment project to bring the production back to the full designed capacity of 500,000 tons salt per year. At present, the salt plant works with low capacity. The composition of the precipitated salt is shown in Table (16). The salt is harvested and washed to increase the NaCl concentration and reduce the impurities (Table 17).

Table 15: Arabian Gulf water composition at the pumping station of Basrah Salt Plant (Data from the State Company for Mining Industries)

Parameters	**Composition**
pH (at 25 °C)	7.9
Electrical Conductivity (μv at 25 °C)	56000
Turbidity (ppm as kaolin)	160
Total Hardness (ppm as $CaCO_3$)	7400
Calcium Hardness (ppm as $CaCO_3$)	1350
Magnesium hardness (ppm as $CaCO_3$)	6050
M-Alkalinity (ppm as $CaCO_3$)	150
Chloride (ppm as $CaCO_3$)	28700
Sulfate (ppm as $CaCO_3$)	3250
Total Dissolved Solids (mg/l)	40800
Iron (ppm as Fe_2O_3)	0.15
Silica (ppm as SiO_2)	3.0

Table 16: Harvested salt composition (Data from the State Company for Mining Industries)

Parameter	**Concentration**
NaCl (%)	93 -96
Insoluble of water (%)	1 – 2
Ca (%)	0.5 – 1.0
Mg (%)	0.1 – 0.9
SO_4 (%)	0.5 – 1.5
CO_3 (%)	0.5 – 1.0
Fe_2O_3 (ppm)	< 50
Moisture (%)	5 – 15

Table 17: Washed salt composition (Data from the State Company for Mining Industries)

Parameter	**Concentration**
NaCl (%)	98 -99
Insoluble in water (%)	0.05 max
Ca (%)	0.05 max
Mg (%)	0.07 max
SO_4 (%)	0.3 max

- **Fao Salt Plant**

The Fao Salt plant is located near the Fao town south of Basrah City. It is a large saltern, consists of tens of salt ponds. The gulf water is pumped through a feeding canal for about 4 Km. to the salt ponds, where concentration and crystallization of the salt takes place. There are many types of ponds (salt-pands) in the plant: settling ponds, evaporating ponds, crystallizing and harvesting ponds. The brine is passed from one pond to the other by gravity, the flow being controlled by means of small gates. The ponds are separated from each other by clay embankments. Evaporation goes on approximately at the same rate as pumping. Pumping is regulated so as to maintain the level of the brine in the ponds. In the harvesting ponds, evaporation is carried out to the point where all the salt separates out. In the final stages, after deposition and crystallization of salt, the remaining bitter solution is pumped back from the harvesting ponds to the Gulf again, while logically must be used to extract the rest of the other important salts, such as KNO_3, KCl, $MgCl_2$, Br, etc.. Unfortunately, this saltern was completely destroyed during the first gulf war (1980 – 1988).

ROCK SALT

Rock salt is the precipitated salts from concentrated seawater in the shallow embayment water by evaporation during the long isolation from the open ocean by sill or reef. Some sedimentary basins may contain salt beds hundreds of meters thick. The thickness of the salt layers or evaporite beds increases when the basin undergoes subsidence simultaneously with the evaporites precipitation (Warren, 2016). The formations that contain salt beds in their successions in Iraq are Kurra Chine (Upper Triassic), Butma (Lower Jurassic), Adaiyah (Lower Jurassic), Allan (Lower Jurassic), Gotnia (Upper Jurassic), Dhiban (Lower Miocene) and Fatha (Middle Miocene) formations (Jassim and Buday, 2006a, b, c; Jassim *et al*., 2006 and Mustafa *et al*., 2011). Mustafa *et al*. (2011) mentioned that the rock salt is present in three ages; the pre-Paleozoic, the Upper Triassic to Lower – Upper Jurassic and the Lower – Middle Miocene ages.

- **The Pre-Paleozoic Salt**

This is represented by the salt plug of Jabal Sanam, which is an isolated hill located about 50 Km southwest of Basrah City (Fig.6). It is about 2 km in diameter and reaches a maximum elevation of 153.3 m above sea level. This uplifted area was suggested to be underlain by Infra Cambrian salt due to the negative gravity residuals. Piercing of the Infra Cambrian salt to the overlying rock beds is due to its lower specific gravity. The salt plug pushes the beds upwards and resulted in the appearance of vertical beds of the Dibdibba Formation over an area of 5 kilometers, forming the periphery of the isolated Jabal Sanam. As noted in the quarries sections, the Jabal Sanam uplifted area is composed of variably dipping cross slope sediments containing a mixture of rocks passing into a gently inclined pediment radiating and extends a few kilometers from it. This rock accumulation is underlain by black algal dolomite which is similar to that found over the salt domes of SW Iran (Jassim, 2006). Buday and Jassim (1987) sampled and dated two dolerite samples from Jabal Sanam and were dated as 570±10Ma and 580±10 Ma old. Mustafa *et al*. (2011) suggested that this salt plug can be a good source for sodium chloride and recommended drilling a deep borehole in the area.

Fig.6: Jabal Sanam

- **Mesozoic Formations**

– **Kurra China Formation (Upper Triassic):** It contains some salt layers in its middle part of the sequence. It is well observed in the subsurface sections of the Tharthar and Sinjar regions, west of Iraq. It also extends to the Mesopotamian Zone and part of the Foothill Zone (Hay and Algawi, 1958; Jassim *et al*., 2006). The thickness of the salt layers is recorded in the wells Kifil-3 (18 m), Melih Tharthar (30 m), Metyaha-1 (70 m), Qara Chough-2 (135 m) and Deep Kuwait (45 m) (Mustafa *et al*., 2011).

– **Butmah Formation (Lower Jurassic):** It was deposited in a shallow water lagoonal and sabkha environment. The bedded salt has been recorded in the middle part of the formation (Hay and Algawi, 1958; Jassim *et al*., 2006).

– **Adaiyah Formation (Lower Jurassic)**: The Adaiyah Formation is composed of bedded anhydrites with subordinate beds of brownish limestone, black calcareous shale and greenish marls, both with anhydrite nodules (Jassim *et al*., 2006). In some wells, such as Makhul-2, salt beds occur (Ditmar and the Iraqi-Soviet Team, 1971). The thickness of the formation ranges from 30 – 100 m depending on the well location (Bellen *et al*., 1959; Mustafa *et al*., 2011).

– **Allan Formation (Lower Jurassic):** It was deposited in a basin-centered sabkha environment. The thickness of the formation is 87 m, composed of bedded anhydrites with subordinate pseudo oolitic limestone. Lateral changes, i.e. the frequent wedging out by the anhydrites, are typical for the formation and greatly affect its thickness. In well Makhul-2, halite is present. The maximum thickness is reached in well Makhul-2 (199 m) (Dunnington, 1953).The salt layer is also present in wells Rumaila 172 with thickness of 2 m and in Khedir AlMa´ai 1 with thickness of the 20 m (Mustafa *et al*., 2011).

– **Gotnia Formation (Upper Jurassic):** It is comprised of anhydrite with subordinate beds of calcareous shale, thin black bituminous shale and recrystallized oolitic limestone (Bellen *et al*., 1959). Exploration drilling of the Iraqi National Oil Company (wells Kifil-1, Diwan-1 and Khedir Al-Ma´ai 1) recorded that this formation contains salt layers which proved to be deposited over the whole of Salman Zone in Central and Southern Iraq (Jassim *et al*., 2006c).The salt layers are recorded in the wells Rumaila-172 (154 m), Abu Amood-1 (47 m), Khedir Al-Ma´ai-1 (290 m), Ratawi-3 (266 m) (Mustafa *et al*., 2011).

- **Miocene Formations**

– **Dhiban Formation (Lower Miocene):** It is comprised of gypsum, thin beds of marl and brecciated recrystallized limestone (Bellen *et al*., 1959) with salt beds recorded in well Injana 5 (Bray, 1960). Salt is also discovered in the exploration wells east of Syria and south of Sinjar in Tel Hajar structure (Ponikarov *et al*., 1967 mentioned in Jassim and Buday, 2006b). The salt beds are also present in Dhiban Formation south of Kirkuk (Jassim and Buday, 2006b). The thickness of the salt in the Dhiban Formation is recorded in wells Badra-1 (68 m), Qumer-1 (60 m), Khashim Al-Ahmer-2 (16 m), Metyaha-1 (20 m), Tel Hajar-1 (240 m) and Abtekh-1 (119 m) (Mustafa *et al*., 2011).

– **Fatha Formation (Middle Miocene):** It was deposited in lagoonal evaporitic environment. The basin extended in a NW – SE direction over an area 1200 Km long and 250 – 300 Km wide. Three main areas in Iraq were reported to contain rock salt deposits located south of Sinjar, south of Kirkuk and between Amara and Kut. They occur in the lower and middle parts of the Fatha Formation (Mustafa *et al*., 2011). The thickness of the salt layers of the Fatha Formation was recorded in the wells Ajil-1 (80 m), Juraida-1 (115 m), Hemrin-2 (80 m), Jambour-15 (135 m), Bi-Hassan-52 (70 m), Kirkuk-211 (16 m), Chemchemal-2 (25 m), Taq Taq-3 (18 m), Khabaz-1 (30 m), Qara Chough-1 (36 m), Makhmour-1 (40 m), Habara-1 (7.5 m), Tel Hajar-1 (153 m)and Abtakh-1 (85 m) (Mustafa *et al*., 2011).

SALT PRODUCTION IN IRAQ

At the present time the processes employed in the production of salt in Iraq are based mainly on solar evaporation in open air in wide artificial salt-pans. Salt is mainly produced in from the Arabian Gulf water in the Basra Plant and from the Samawa inland saltern. The production in the Samawa Salt Plant is by harvesting the salt precipitated in the ponds by evaporation (Fig.7) then washed by saturated brine in the salt washer machine (Fig.8) and finally transported for stacking by a conveyor belt (Fig.9). The plant is designed to produce 300000 tons/year. Local contractors produce limited amounts of salt by direct harvesting from several salterns in the Jazera area. Primitive solar evaporation methods of brines from Sabkhas are commonly used by local people in the Mesopotamia to produce impure salt for local domestic use. The rock-salt deposits, encountered in several subsurface formations in Iraq, represent a very potential salt resource for the country in the future.

Fig.7: Salt harvesting at the Samawa Salt Plant

Fig.8: Salt washing at the Samawa Salt Plant

Fig.9: Salt transport by conveyor belt for stacking at the Samawa Salt Plant

CONCLUSIONS

- Most of the salterns and salt pans in the Jazera area are developed due to the presence of faults and fractures through which the salt brines are migrating from the underlying saliferous beds of the Fatha Formation to the surface. Similarly, the salterns present on both sides of Hemrin Mountain, like Khalifa and Duz, are formed by salty brines originating from the saliferous beds of the Fatha Formation (Middle Miocene). On the other hand, the Samawa salt deposits may have been derived from the dissolution and upward migration of brines originating from older subsurface saliferous beds, seeping to the surface through fault plains.
- The sabkhas present in the Mesopotamian Plain are formed by upward migration of the leached salts by underground water to the surface by evaporation pumping and precipitation of salt crusts on the surface due to high evaporation rate.
- The Basrah Salt Plant produces high quality sodium chloride salt, but it needs maintenances and dredging of the sea canal to allow sea water to reach the pumps.
- The numerous rock salt beds in various geologic formations are promising source for sodium chloride in Iraq but needs drilling and water injection for production.

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