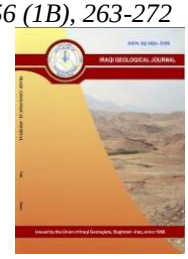
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Salt Crystallization and Mineralogy of Sabkhas in Abu Ghraib, Western Baghdad, Abu Graib, Iraq

Yaser B. Mohammad[1,*] and Salih M. Awadh[1,*]

[1] Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

[*] **Correspondence**: salih.awadh@sc.uobaghdad.edu.iq; Yasrbshyraltmymy@gmail.com

Received:
21 November 2022

Accepted:
23 December 2022

Published:
28 February 2023

Abstract

The research aims to study Sabkha mineralogy to determine the mineral types, the nature of the precipitation, and the patterns of salt crystallization. Two Sabkhas in Abu Ghraib, west of Baghdad, were studied. It was found that the Sabkhas were formed in flat ponds from saturated solutions in a semi-arid to arid climate. Halite predominates, followed by anhydrite and gypsum as evaporite minerals. As for the minerals of the Sabkha soil, it consisted of feldspar, calcite, quartz, and dolomite, in addition to the clay minerals represented by kaolinite, illite, and chlorite. Needle forms, hopper shapes, dendritic crystals, and polygon shapes are the main crystallization patterns dominantly found in the Sabkhas. All these types of crystallization occurre under normal temperatures.

Keywords: Sabkha; Crystallization; Mineralogy; Salts; Evaporite; Dry arid

1. Introduction

Water flow is important for water resource planning and management, especially for assessing water availability and drought identifiers; Therefore, the presence of Sabkhas is an indication of severe drought (Yaseen et al., 2018; Khosravi et al., 2019). Sabkhas are low-lying areas that collect water in arid and semi-arid climates (Awadh et al., 2021). The word Sabkha is of Arabic origin. In Central Asia, it is called "Noor"; in North Africa, it is known as “Sabkha” and in North America “Playa” (Hamdona and Al Hadad, 2008; Briere, 2000). There are two types of Sabkha, continental and coastal. The continental Sabkha is a sedimentary basin with internal drainage in which salts accumulate, due to the proximity of groundwater to the surface (Hsü, 2013; Friedman, 1978). Soil salinization occurs as a result of the shallow groundwater level rise (Quraishi et al., 2013). The report conducted by the USAID (2004) states that the rising groundwater table and the consequent problems of soil salinity lead to land degradation and destroys 5% of the cultivated land annually. Poorly permeable soils do not allow water to penetrate during conventional irrigation and therefore are not washed away (Awadh and Al-Hamdani, 2019). Excess water evaporates due to higher temperatures in dry and semi-arid climates, and salts precipitate over time, causing a large amount of salt to accumulate on the soil surface (Awadh et al., 2022; Boschetti et al., 2020; Awadh, 2018; Al-Hamdani et al., 2016). The sources of salts and their mineral components in Iraq were determined with an estimate of the salt reserves (Jassim and Al-Badri, 2019). Many lakes formed due to structural depression defined as a sag pond (Awadh and Muslim, 2014; Awadh. 2016; Boschetti et al., 2020). One of the large and well-known Sabkhas in Iraq is the Sunaisla Sabkha, which represents a closed continental Sabkha in western Iraq in which rainwater collects, washing the surrounding soil and some of the outcrops of the Fatha and Injana formations,

DOI: 10.46717/igj.56.1B.19ms-2023-2-27

which recently mixed with the groundwater (Abdul Amir, 2005; Awadh and Ahmed, 2013). The Sunaisla Sabkha is mainly composed of halite in an amount of 97%. Some Sabkhas may concentrate elements after the evaporation of water during several cycles of evaporation, which makes them economically valuable or at least pay attention as an area of interest (Bhagat et al., 2021). The study area is located in Abu-Ghraib, western Baghdad, Iraq (Fig. 1). This research is going to identify and discuss the Sabkha mineralogy using XRD and a polarized transmitted microscope to further understand the mineral component of both Sabkha salt and Sabkha soil in addition to a diagnosis of the crystallization patterns.

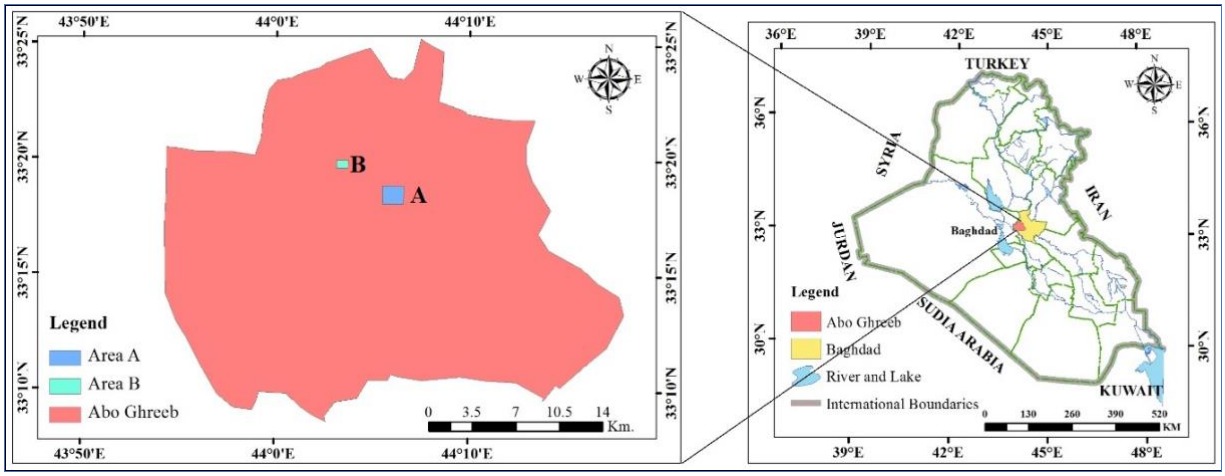


Fig. 1. Location map of the study area; A) is the Shiaa village; B) is the Kadim Alaa'ab village.

2. Materials and Methods

2.1. Sampling

The fieldwork included an exploratory trip in which the locations of the Sabkhas were selected in two areas, the village of Haj Shiaa and the village of Kadim Alaa'ab (Fig. 2). A detailed trip was conducted during which thirty soil samples were collected, twenty from the village of Haj Shiaa (A) and the remaining ten from the village of Kadim Alaa'ab (B). The systematic sampling procedure was applied, in which, samples were collected from a depth of 1-30 cm with an interval of 100 m. The samples were placed in nylon bags and then transported to the laboratory to be prepared for the analysis required. All sample locations were determined using GPS (Table 1).

2.2. Thin Section Preparation

Thin sections (31 slides) were made for each sample without using water during the cutting process to avoid salt dissolving. Also, the heat was not used during the preparation and drying of the slides to keep the crystalline shape. The adhesive consists of two parts, Sikadur 52 LP with hardener, which were used to stick the soil samples onto the glass slide. They are mixed in certain proportions (2:1) to ensure good hardening. The sample was left for 24 hours to dry. The cutting machine was used for cutting slides, and then the cut face was smoothed with a smoothing device until it reached 0.3 mm thick. Minerals were diagnosed using a polarizing transmission microscope.

2.3. Clay Mineral Separation

Clay minerals and non-clay minerals were examined by Shimadzu 6000 XRD device, a Japanese manufacturer. The samples were dried in an oven at 500 °C. Thirty grams were treated with 15% H_2O_2 to dissolve the organic matter (Muller, 1967). Then it was washed with distilled water to get rid of the

salt. This process was repeated five times to ensure that the salts were removed. The clay was separated from the silt using the wet sieving method.

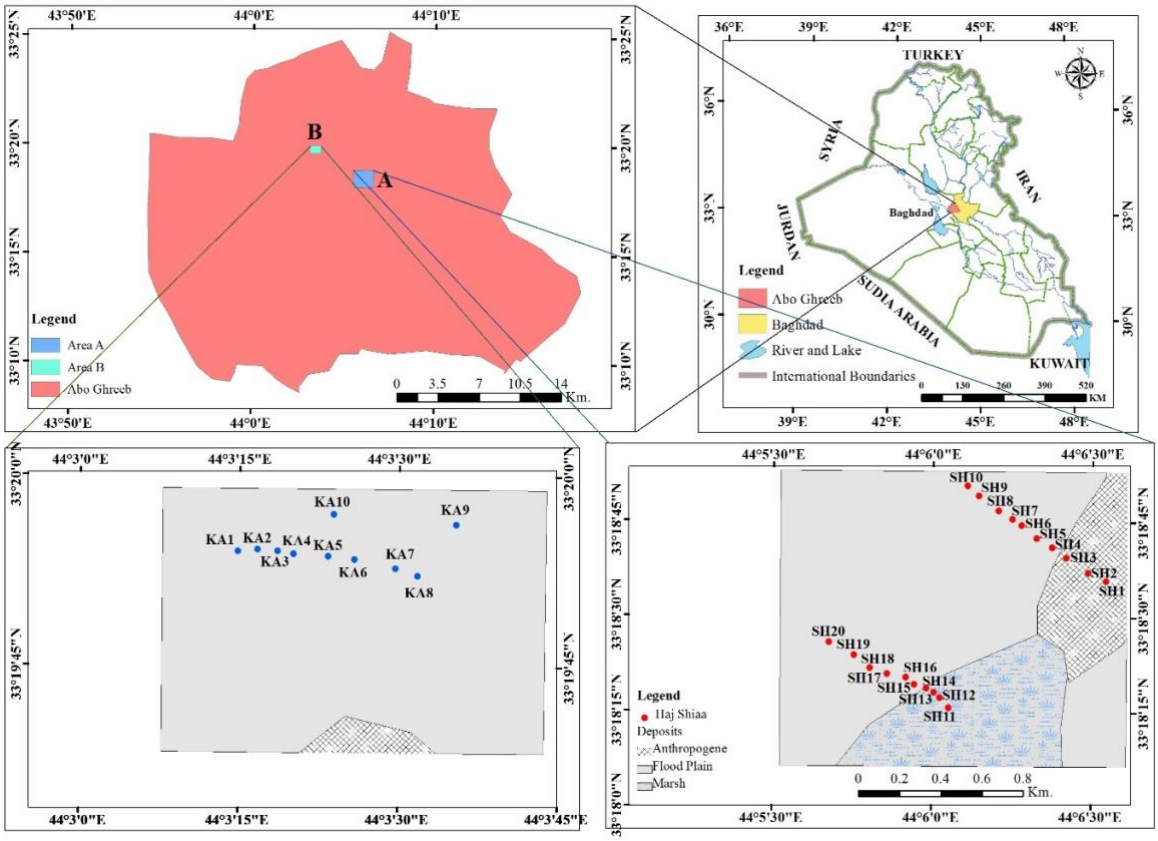


Fig. 2. Sampling sites in the studied areas; the blue circles are the location samples in the Shiaa village (A); the red circles are the location of the samples in the Kadim Alaa'ab village (B) in Abu Ghraib, western Baghdad.

Table 1. Coordinates and summarized methodology done on samples that have been collected from the village of Haj Shiaa and Kadim Alaa'ab. The x is the type of analysis performed on the samples

S. No	Area	UTM easting	UTM northing	XRD		Thin section	
				Bulk	Clay mineral	Bulk	Salt
1 SH	Haj Shiaa	44.10873	33.30968	X		X	X
2 SH		44.10854	33.31007			X	X
2 ASH		44.10854	33.31007	X	X	X	X
3 SH		44.10824	33.31041			X	X
4 SH		44.10800	33.31071			X	X
5 SH		44.10782	33.31114			X	X
6 SH		44.10752	33.31147	X		X	X
7 SH		44.10722	33.31187			X	X
8 SH		44.10722	33.31227			X	X
9 SH		44.10677	33.31228			X	X
10 SH		44.10622	33.31229			X	X
11 SH		44.10736	33.30916	X		X	X
12 SH		44.10724	33.30940			X	X
13 SH		44.10755	33.30961			X	X
14 SH		44.10615	33.30982	X		X	X
15 SH		44.10580	33.31003			X	X
16 SH		44.10540	33.31044			X	X
17 SH		44.10497	33.31067	X		X	X
18 SH		44.10454	33.31067			X	X
19 SH		44.10302	33.31089			X	X

S. No	Area	UTM easting	UTM northing	XRD		Thin section	
				Bulk	Clay mineral	Bulk	Salt
20 SH	Kadim Alaa'ab	44.10354	33.31110	X		X	X
1 KA		44.05442	33.33092			X	X
2 KA		44.05444	33.33091			X	X
3 KA		44.05545	33.33105			X	X
4 KA		44.05589	33.33109			X	X
5 KA		44.05638	33.33112	X		X	X
6 KA		44.05701	33.33117			X	X
7 KA		44.05758	33.33119			X	X
8 KA		44.05818	33.33127			X	X
9 KA		44.05853	33.33129			X	X
10 KA		44.05900	33.33136	X		X	X

Volume less than 63 µm was collected in a container and transferred to a 1000 ml. cylinder. Ten ml. of sodium hexametaphosphate was added as a dispersant to prevent agglomeration of fine particles, according to Folk (1974, 1980), and Folk et al. (1970). A sample of 20 ml was withdrawn from the cylinder at a depth of 5 cm after 4 h. The clay fraction was distributed on three glass slides and left to dry at room temperature. Samples were examined based on the procedures of Stixrude and Peacor (2002); Banat (1980), and Thorez (1976) as follows:

- An untreated sample with 2θ angle 2-16 where most of the basic reflections of clay minerals can be identified.
- The sample treated with ethylene glycol, the sample was tested by XRD after exposure to ethylene glycol vapor for 24 h at a temperature of 60 °C, to distinguish between chlorite and montmorillonite, in which the basal space expands due to the entry of ethylene glycol into the internal structure (Brown, 1961).
- The sample was treated by heating for 2 hours at a temperature of 550 °C, as the structure of kaolin is destroyed at this temperature (Thorez, 1976).

3. Results and Discussion

3.1. Shapes of Sabkha Salt Crystals

Continental Sabkhas consist of a thin white saline soil layer in which halite (NaCl) predominates as the main mineral that crystallizes in the cubic system. The sodium chloride ions are arranged so that each ion is surrounded by six sodium ions, and the sodium ions are surrounded by six chloride ions. The shape and size of the cubic halite crystal depend mainly on the saturation state of the solution, and the concentration of some common elements. Several shapes of salt crystals were identified in the study. Needle form is a type of crystallization consisting of the growth of salt crystals in one direction, which makes it longitudinal needle shapes (Fig. 3). This type of crystallization is found in the Sabkha area of Haj Shiaa. The Hopper shape is another crystalline shape that was recorded which occurs as inverted pyramidal crystals (Fig. 4), and is formed due to rapid crystal growth from a supersaturated solution. Crystals accumulate more at the crystal corners than at the center of the crystal (Gorniz and Schreiber, 1981). Crystallization in the area of Hajj Shia, A dendritic shape is also noticed which arises in the form of a salt crust, which varies between 4 to 12 cm thick. It is formed in a stagnant brine solution in which no water currents. If the water is moving, this type is not formed because moving causes homogeneous concentrations (Buckley, 1951) (Fig. 5). Polygonal crystals are crystallized after the surface of the Sabkha dries up, while halite crystals continue to grow from the brine solutions underneath, leading to the rise of the edges of the salt surface that intersect, forming a network of polygonal halite crystals (Fig. 6).

Fig. 3. Salt crystals of longitudinal needle shape

Fig. 4. Hopper-shaped salt crystals

Fig. 5. Dendritic salt crystals

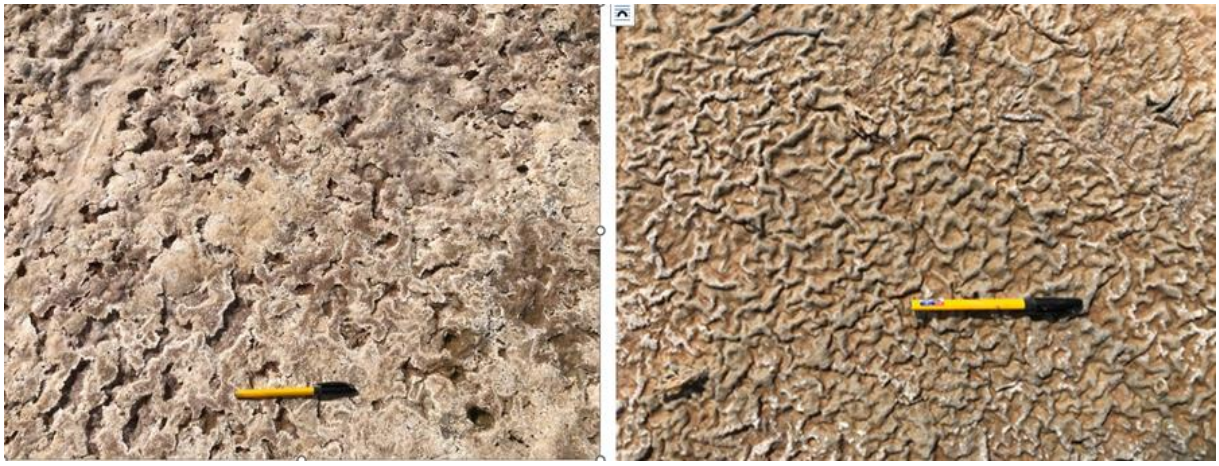


Fig. 6. Polygonal Sabkha crystals

3.2. Growth of Sabkha Salt Crystals

In regions with arid or semi-arid climates, the Sabkha covers a salt crust consisting mostly of halite. High temperatures cause evaporation and an increase in the concentration of salts, so the process of crystal growth begins after the concentration of the solution. Crystallization takes place at different temperatures ranging from 5 to 30 °C. Crystal forms vary with different temperatures. Some crystals appear on the surface of the solution in the daytime when the temperatures are high. Others arise at the bottom of the pelvis during the night when temperatures are low (Arthurten, 1973). The crystals that arise on the surface of the solution consist of a thin film consisting of one face of the halite crystal. Then the crystal growth continues towards the top outward, forming a hollow pyramid shape and its top towards the bottom. The crystals converge and connect, forming a layer, and then sink to the bottom of the solution when their weight is higher than the surface tension force (Arthurton, 1973). As for the crystals that grow at the bottom of the basin, they are the result of the subsidence of the salt layers that formed during the day. There are five crystal forms as shown in Fig. 7, four types arise on the surface of the solution (A, B, C, D) and only one of them arises at the bottom of the basin E.

By studying the thin section of the manure samples, it was found that halite is a common salt, which was distinguished by its cubic crystals of various shapes (Fig. 8).

3.3. Mineral composition of Sabkha

The XRD results showed that halite is the most common mineral in the Sabkha, with few crystals of gypsum. The Sabkha soil contains a lot of calcite, quartz, dolomite, and feldspar in minor quantities (Fig 9). As for the clay minerals, they included kaolinite, illite, and chlorite (Fig. 10).

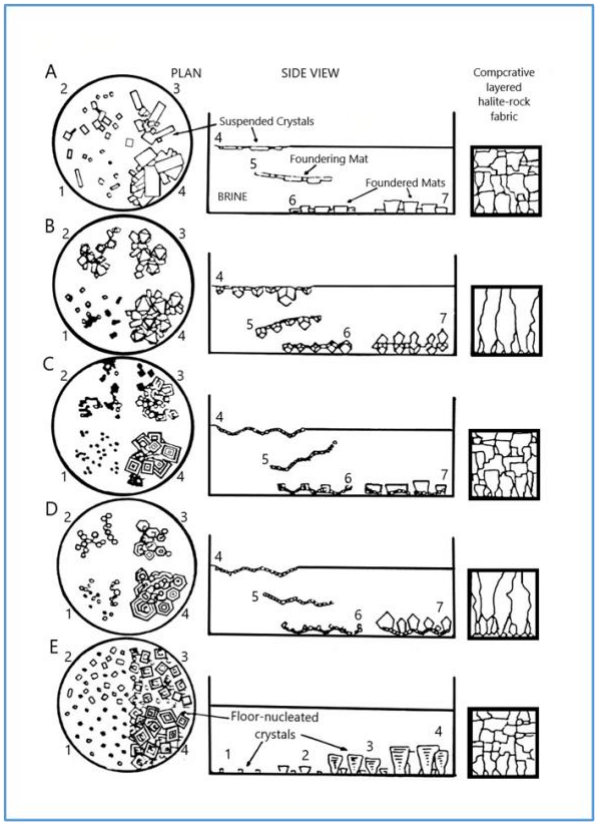


Fig. 7. The growth phases and shapes of salt crystals. A) Horizontally suspended rectangular crystal sheets growing on the surface of the solution at a temperature of 5-25°C; B) Cubic crystals with angles pointing downward, hanging from one of its corners and then dropping to the bottom when their weight increases; C) Four pyramidal faces; D) Six hollow and inverted pyramidal faces. B, C, and D crystals are formed at a temperature of 15-25°C; E is the phase of salt crystals forming at the bottom of the basin (Arthurton, 1973).

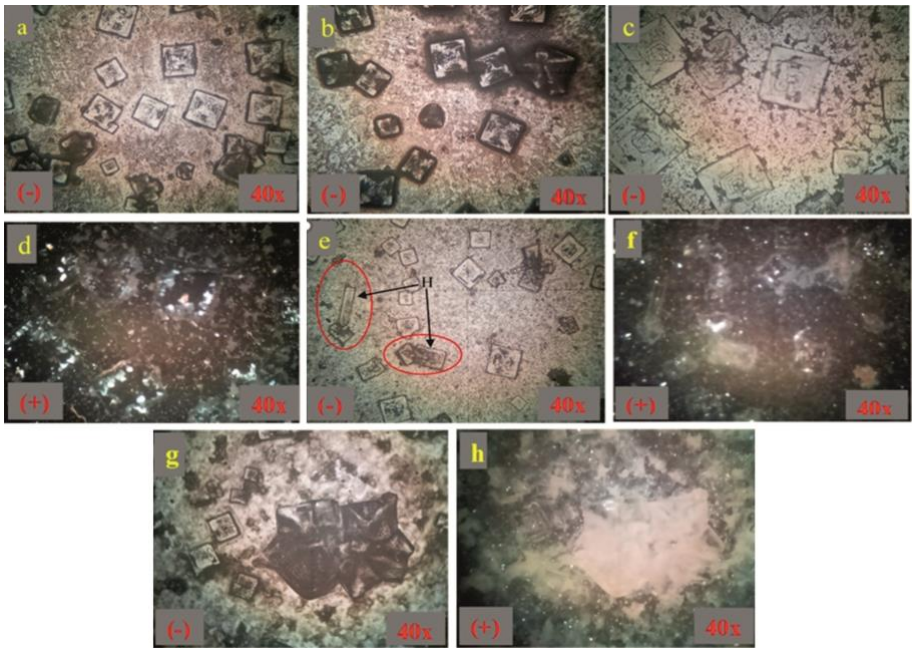


Fig. 8. Different halite crystals are found in the Sabkha

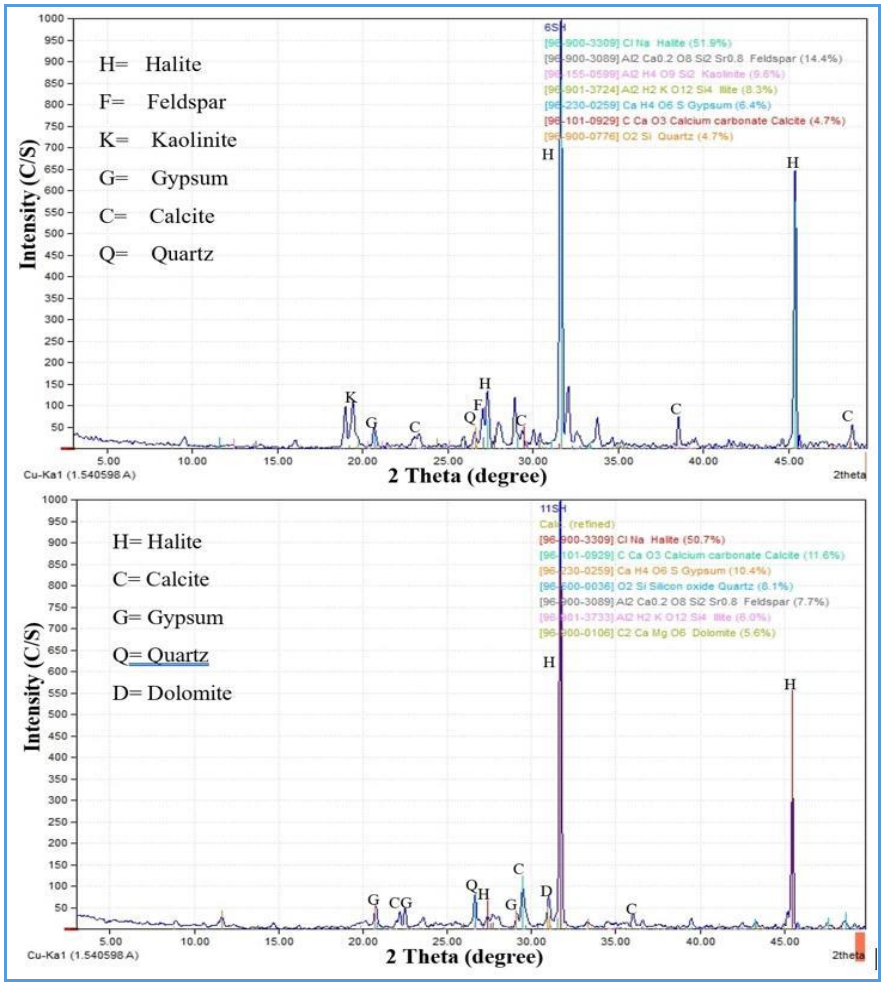


Fig. 9. XRD diffractogram of the Sabkha mineralogy in samples 6SH and11SH as whole samples

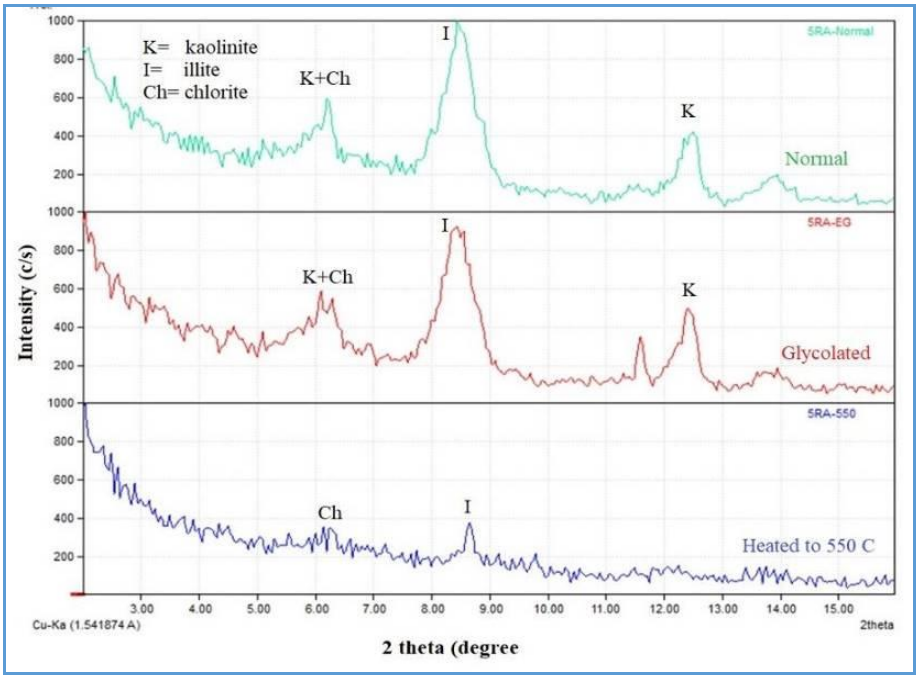


Fig. 10. XRD diffractogram displays the clay minerals in the Sabkha soil, sample No. 2A SH

The mineralogical composition of both non-clay and clay minerals is presented in Table 2. Halite formed 48.1 to 80.2% with an average of 63.4% of the total mineralogical composition of the Sabkha. The average (%) of feldspar (7.0), quartz (5.7), calcite (6.5), gypsum (5.8), anhydrite (7.6), dolomite (2.3), chlorite (4.8), illite (6.2) and Kaolinite (7.9) indicate saturation solution precipitated salts, particularly halite, gypsum and anhydrite.

Table 2. Mineral components (%) of non-clay and clay minerals in the Sabkha

S. No	Non-clay minerals							Clay minerals			Total
	*Hal.	Feld.	Qtz.	Cal.	Gyp.	Anh.	Dol.	Chl.	Ili.	Kaol.	
1 SH	80.2	1.4	7.3	7.1	3.3	nil	0.5	nil	nil	nil	99.8
2 A SH	72.3	6.6	5.2	5.5	0.1	nil	nil	4.8	3.3	2.2	100
6 SH	51.9	14	4.7	4.7	6.4	nil	nil	nil	8.3	9.6	99.7
11 SH	50.7	7.7	7.6	12	10.4	nil	5.6	nil	6	nil	99.6
14 SH	73.8	5.3	2.2	6.9	4.5	nil	nil	nil	7.3	nil	100
17 SH	64.2	7.4	1.1	1.4	3.7	10.7	nil	nil	nil	11	99.6
20 SH	66	9.1	5.8	1.8	4.3	2.5	nil	nil	nil	8.6	98.1
5 KA	48.1	4.1	8.7	13	14.7	nil	0.7	nil	nil	nil	89.1
10 KA	63.1	6.9	8.5	7	4.9	9.5	nil	nil	nil	nil	99.9
Min	48.1	1.4	1.1	1.4	0.1	2.5	0.5	4.8	3.3	2.2	
Max	80.2	14	8.7	13	14.7	10.7	5.6	4.8	8.3	11	
Av	63.4	7.0	5.7	6.5	5.8	7.6	2.3	4.8	6.2	7.9	

*Hal= halite; Feld=feldspar; Qtz= quartz; Cal= Calcite; Gyp= gypsum; Anh=anhydrite; Dol= dolomite; Chl= chlorite; Ili= illite; Kao= kaolinite

4. Conclusions

In this research, two continental Sabkhas in the Abu Ghraib region, in western Iraq, were studied. The Sabkhas were formed in low basins that suffer from drought and intense evaporation, as well as high subsurface water levels in a semi-arid-arid climate. Halite is the predominant mineral, followed by anhydrite, and gypsum is an evaporite. The Sabkha soils consist of feldspar, calcite, quartz, dolomite, and clay minerals (kaolinite, illite, and chlorite). The salts crystallized under normal thermal conditions in various patterns. Needle form was formed as the salt crystals grew in one direction, making longitudinal needle shapes. Another type is the Hopper shape a crystalline shape formed from inverted pyramidal crystals. A dendritic shape was also noticed in the Sabkhas forming a salt crust 4 to 12 cm thick. Polygonal halite crystals grow after the Sabkha's surface dries out, they are continued to grow from the brine solutions below, generating a network of polygonal halite crystals.

Acknowledgements: The authors are grateful to the Department of Geology that provides laboratory facilities for doing mineralogy diagnosis, particularly the workshop and geochemistry laboratory.

References

Abdul Ameer, I.A., 2005. Sedimentological and Hydrochemistry study of Sunaisla Sabkha N-W Iraq. MSc Thesis, University of Baghdad, 105.

Al-Hamdani, J.A.J., Awadh, S.M., Ibrahim, O.S., 2016. Geochemical partitioning of heavy metals in the urban soil, Kirkuk, Iraq. Iraqi Geological Journal, 39–49(1), 1-24.

Arthurton, R.S..1973. Experimentally produced halite compared with Triassic layered halite rock from Cheshire, England: Sedimentology, 20, 145-160.

Awadh, S.M., 2016. Outstanding universal values of the Sawa Lake as a world natural heritage. Bulletin of the Iraq Natural History Museum, 14(1), 1-11.

Awadh, S.M., 2018. A preliminary assessment of the geochemical factors affecting groundwater and surface water quality around the rural communities in Al-Anbar, Western Desert of Iraq. Environmental Earth Sciences, 77(3), 1-18.

Awadh, S.M., Al-Mimar, H., Yaseen, Z.M., 2021. Groundwater availability and water demand sustainability over the upper mega aquifers of Arabian Peninsula and west region of Iraq. Environment, Development and Sustainability, 23(1), 1-21.

Awadh, S.M., Al-Sulttani, A.H., Yaseen, Z.M., 2022. Temporal dynamic drought interpretation of Sawa Lake: case study located at the Southern Iraqi region. Natural Hazards, 112(1), 619-638.

Awadh, S.M., Ahmed, R.M., 2013. Hydrochemistry and pollution probability of selected sites along the Euphrates River, Western Iraq. Arabian Journal of Geosciences, 6(7), 2501-2518.

Awadh, S.M., Al-Hamdani, J.A.M.Z., 2019. Urban geochemistry assessment using pollution indices: a case study of urban soil in Kirkuk, Iraq. Environmental Earth Sciences, 78(20), 1-12.

Awadh, S.M., Muslim, R., 2014. The formation models of gypsum barrier, chemical temporal changes and assessments the water quality of Sawa Lake, Southern Iraq. Iraqi Journal of Science, 55(1), 161-173.

Banat, K.M., 1980. Principles of Clay Mineralogy, Baghdad University. Press, Baghdad, 138.

Bhagat, S.K., Tiyasha, T., Awadh, S.M., Tung, T.M., Jawad, A.H., Yaseen, Z.M., 2021. Prediction of sediment heavy metal at the Australian Bays using newly developed hybrid artificial intelligence models. Environmental Pollution, 268, 115663.

Boschetti, T., Awadh, S.M., Al-Mimar, H.S., Iacumin, P., Toscani, L., Selmo, E., Yaseen, Z.M., 2020. Chemical and isotope composition of the oilfield brines from Mishrif Formation (southern Iraq): Diagenesis and geothermometry. Marine and Petroleum Geology, 122, 104637.

Briere, P.R., 2000. Playa, playa lake, Sabkha: Proposed definitions for old terms. Journal of Arid Environments, 45(1), 1-7.

Brown, G., 1961. The x-ray identification and crystal structures of clay minerals. Journal of Sedimentary Petrology. 40,855-863.

Folk, R.L., 1974. Petrology of Sedimentary Rocks. Hemphill, Austin, 182.

Folk, R.L., 1980. Petrology of sedimentary rocks. Hemphill publishing company.

Folk, R.L., Andrews, P.B., Lewis, D.W., 1970. Detrital sedimentary rock classification and nomenclature for use in New Zealand. New Zealand Journal of Geology and Geophysics, 13(4), 937-968.

Friedman, G.M., 1978. Principle of sedimentology. John Wiley, New York, 792.

Hamdona, S.K., Al Hadad, O.A., 2008. Influence of additives on the precipitation of gypsum in sodium chloride solutions. Desalination, 228(1-3), 277-286.

Hsü, K.J., 2013. Physical principles of sedimentology: a readable textbook for beginners and experts. Springer Science & Business Media.

Jassim, R.Z., Al-Badri, A.S., 2019. Mineral resources and occurrences of sodium chloride in Iraq: an overview. Iraqi Bulletin of Geology and Mining, (8), 263-287.

Khosravi, K., Daggupati, P., Alami, M.T., Awadh, S.M., Ghareb, M.I., Panahi, M., Pham, B.T., Rezaie, F., Qi, C. Yaseen, Z.M., 2019. Meteorological data mining and hybrid data-intelligence models for reference evaporation simulation: A case study in Iraq. Computers and Electronics in Agriculture, 167, 105041.

Muller, G., 1967. Methods in Sedimentary Petrology. E. Schweizerbart, Sche verlegs bnchhundlung (Nagele V. Obermiller), Stuttgart, 283.

Qureshi, A. S., Ahmad, W., Ahmad, A. F. A. 2013. Optimum groundwater table depth and irrigation schedules for controlling soil salinity in central Iraq. Irrigation and Drainage. 62 (4),414-424

Stixrude, L., Peacor, D.R., 2002. First-principles study of illite–smectite and implications for clay mineral systems. Nature, 420(6912), 165-168.

Thorez, J., 1976. practical identification of Clay Minerals G. Lellotte (ed.), Dison (Belgium), 89 .

USAID, 2004. Agriculture Reconstruction and Development Program for Iraq: Irrigation water management assessment and priorities for Iraq. USAID.

Yaseen, Z.M., Awadh, S.M., Sharafati, A., Shahid, S., 2018. Complementary data-intelligence model for river flow simulation. Journal of Hydrology, 567, 180-190.