

## WATER-ROCK INTERACTIONS AND GEOCHEMISTRY OF GROUNDWATER OF A COASTAL CARBONATE AQUIFER, NORTHWEST EGYPT

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### ABSTRACT

The geochemical evolution of groundwater and porosity development of a coastal carbonate aquifer due to mixing of freshwater and saline water were investigated to reveal that this geochemical mixing results in a chemically active environment where carbonate mineral diagenesis occurs. The study area is located along the northwestern coastal zone of Egypt at the Umm El Rakhm area to the west of Mersa Matruh City. The Pleistocene oolitic limestone aquifer is the main source of groundwater in this area, where a shallow thin freshwater layer floats over dense seawater. Groundwater salinization is expected in such area as a result of over-exploitation that leads to salt-water intrusion. Origin of salinity and the development of the aquifer porosity were assessed by the integrated use of chemical and petrographic parameters. The problem of groundwater salinization in coastal aquifers, besides active seawater intrusion, may be affected by several human activities that accelerate the progressive deterioration of water quality, such as concentrated pumping, intensive agricultural practices including return flows. The high salinity zone may be developed due to mixing with the underlying salt water. Generally, the groundwater salinity increases from the southern part of the area towards northeast and northwest. The chemical composition of groundwater in the study area shows predominance of Na, Mg, Cl and SO<sub>4</sub>. High salinity values and the appearance of Na-Cl water strongly suggest mixing with sea water. The application of several hydrochemical techniques (Piper diagram, Schoeller diagram, binary relations, ionic ratios) combined with field observations, may lead to a better explanation of the origin of the saline groundwater. The high boron content reveals that seawater contributes these high concentrations and it coincides with high salinity values at this part. The high Sr contents in groundwater samples may be attributed to dissolution of the Pleistocene carbonate minerals of the coastal aquifer where aragonite is the main carbonate species. Petrographic investigation of the aquifer rock samples of the study area indicates those aragonite and low-Mg calcites are the two carbonate minerals present. Groundwater from the carbonate coastal aquifer of Umm El Rakhm area shows varying values of the saturation indices with respect to calcite and aragonite. All of the groundwater samples are oversaturated with respect to dolomite and are strongly undersaturated with respect to gypsum.

### 1. INTRODUCTION

In coastal carbonate aquifers, the saline-fresh water mixing zone is an area of enhanced calcite dissolution (Back *et al.*, 1979, 1986), aragonite neomorphism (Smart

*et al.*, 1988), and dolomitization (Randazzo and Cook, 1987). The water-rock interactions that occur in these mixing zones are the main cause of changes in the groundwater chemical composition, the mineralogical composition of the aquifer, and the porosity

and permeability of the aquifer. Hanshaw and Back (1980) revealed that dissolution and precipitation of minerals in the mixing zone could enhance, or at least redistribute, porosity and permeability. Diagenetic studies of aquifer rocks in the mixing zone have focused on porosity development as related to calcite or aragonite dissolution (James and Choquette, 1984).

Seawater intrusion into coastal aquifers is usually assumed when an increase in total dissolved solids (TDS) or electrical conductivity of the extracted groundwater is observed. Seawater encroachment is the most common mechanism operating in water points located at short distances from the coastline, mainly due to overpumping in selected sites. The magnitude of seawater intrusion is controlled by the geological characteristics of the aquifers and the particular hydrogeological and hydraulic setting around each particular observation point. The most common sources of salinization in coastal aquifers are: 1) Present day (active) seawater intrusion due to overpumping and upward displacement of the freshwater/saline water interface, 2) Irrigation return flow or infiltration of sewage, and 3) Incorporation of sea salt spray into infiltrating water in the soil zone after rainfall events and irrigation practices. In the simple case of direct seawater intrusion or simple mixing of the two water types (fresh groundwater and seawater), the mixing proportions of the two end-members can be obtained from a simple linear relationships between the constituting ions, especially conservative ones. Conservative mixing refers to the simple mixing of waters without chemical reactions, such as mineral precipitation or adsorption, which could alter the concentrations of one or both of the constituents.

Understanding of mixing zone diagnosis is impossible without association of groundwater geochemistry with the aquifer rock characteristics.

The present work deals with integrated investigation of the aqueous geochemistry

and carbonate petrology of a coastal Pleistocene oolitic limestone aquifer of the Umm El Rakhm area (~ 130 km<sup>2</sup>) at the northwestern coastal zone of Egypt, directly to the west of Mersa Matruh (Fig. 1). The main objectives of this study were to: (1) describe the petrology of a coastal carbonate aquifer showing mixing phenomenon, (2) evaluate the geochemical reactions (water/rock interactions) that yield the current groundwater composition, and (3) relate water/rock interactions to porosity development of a coastal carbonate aquifer.

## 2. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Umm El Rakhm area is characterized by a mild relief with a general slope towards north (Fig. 1). The area can be differentiated into two physiographic provinces (El-Senussi and Shata, 1969), from coast southward; the coastal plain and the southern tableland. The coastal plain is distinguished by the presence of an elongate medium hard snow white oolitic limestone ridge running in an E-W direction (foreshore ridge ~ +18 m). To the south of this ridge, a low depression area (Umm El Rakhm Depression ~ +5m) with reddish brown alluvial deposits, composed of calcareous loam, extends southwards to the foot of the escarpment of the southern tableland. The alluvial deposits are underlain by oolitic limestone, where this area has high groundwater potential. The southern tableland (~ 80 m high) is formed mainly of fissured and jointed limestone, the top portion of which is highly weathered and is developed into a hard pink crust. Its northern portion is characterized by a number of wadis that are responsible for its drainage.

The Umm El Rakhm area is entirely composed of sedimentary rocks belonging to Quaternary and Late Tertiary. The Quaternary rocks have a thickness of about 65 m and are represented by both Holocene (beach deposits, dune sand accumulations, and alluvial deposits) and Pleistocene (oolitic

limestone). The Tertiary rocks belong mainly to Middle Miocene (Vindobonian) and have a thickness of about 85 m. These rocks are developed essentially into shallow marine limestone, which is rich in its faunal content.

Pliocene rocks are not exposed, but are expected in the subsurface of the foreshore part of the Umm El Rakham area (El Senussi and Shata, 1969).

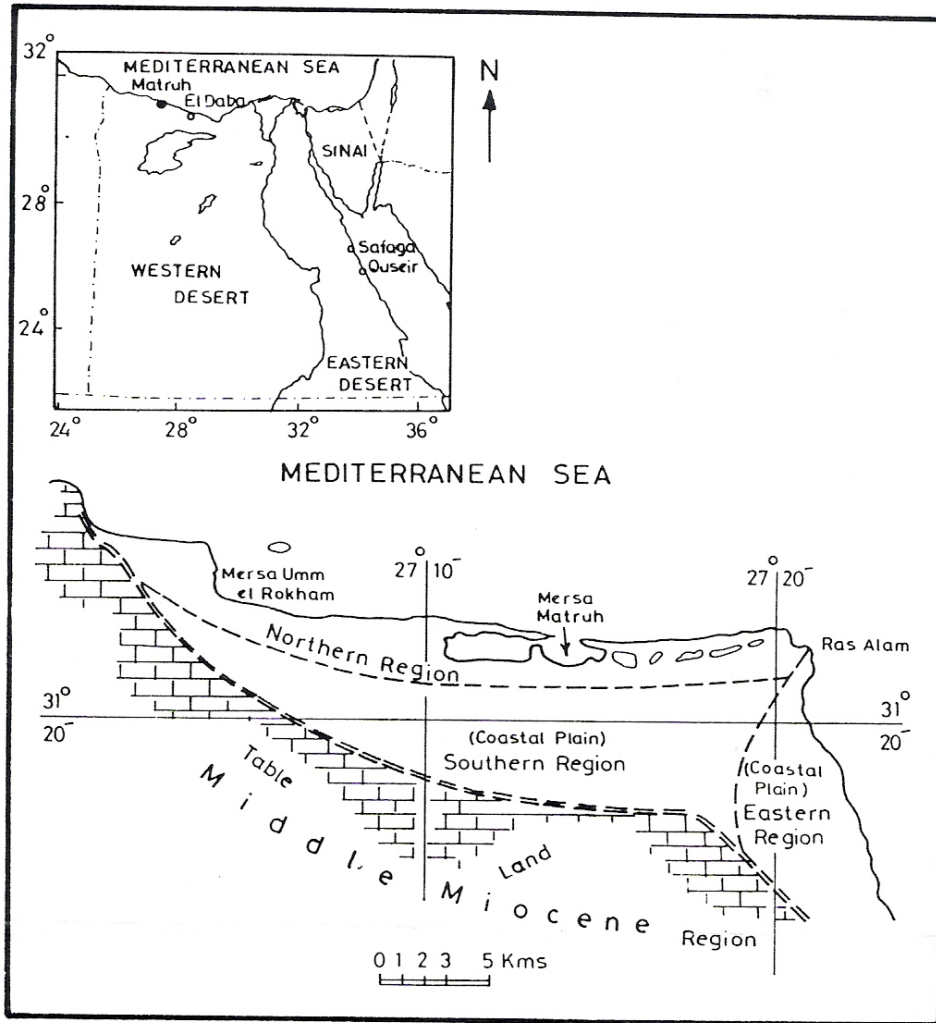


Fig. (1): Generalized geologic map of Mersa Matruh-Umm El Rakham area, Egypt (after Holail, 1993).

The structure of the northern coast of the Western Desert is associated with epeirogenic rising during Late Tertiary and continued throughout the Quaternary.

The surface of the study area is characterized by numerous drainage lines sloping northward and end either into the inland depressions or to the sea. The watershed area of such drainage lines is located mainly in the southern tableland.

The main water-bearing formations in the Umm El Rakham area are the coastal and inland sand dunes of Holocene age; the Pleistocene oolitic limestone and the Middle Miocene fissured limestone.

The Pleistocene aquifer occupies the ridges and the base of the depressions. It extends from the escarpment of the tableland in the south to the shoreline in the north with a thickness ranges from 10 to 75 m. The oolitic limestone of Umm El Rakham has porosity of about 36% (El Fiky, 1996). The depth to the water table depends on topography, annual rainfall (about 150 mm), and discharge rates. The groundwater flow is mainly towards north (El Fiky, 1996). The groundwater of this aquifer exists under free conditions. This groundwater is recharged by the infiltrated rain water. The water obtained from this aquifer is of limited quantities and has a very low salinity unless contaminated with sea water due to excessive pumping and is used for domestic and irrigation purposes (El Shazly *et al.*, 1975).

### 3. MATERIALS AND METHODS

Twelve groundwater samples were collected from the coastal Pleistocene carbonate aquifer of the Umm El Rakham area in August 2005. Measurements for water temperature, electrical conductivity and pH were made in situ. Each water sample was filtered through 0.45  $\mu\text{m}$  membrane filter (cellulose acetate) then divided into two parts. The first part was acidified to  $\text{pH} < 2$  with ultra pure  $\text{HNO}_3$  for determination of

major cations, boron and strontium; the second unacidified part was reserved for the analysis of major anions. The water samples were collected in polyethylene bottles, which were soaked in 10%  $\text{HNO}_3$  for 24h and rinsed several times with deionized water prior to use. Water points were chosen in order to achieve a relatively uniform distribution of the samples within the study area.

The laboratory analysis program was carried out in the Department of Environmental Sciences, Faculty of Science, Alexandria University and comprised the determination of carbonate and bicarbonate by titration against 0.01N  $\text{H}_2\text{SO}_4$  in less than 12h after sampling, whereas calcium and magnesium were determined by titration against 0.01 M  $\text{Na}_2\text{EDTA}$  solution. Chloride was determined by titration against 0.02 N  $\text{Hg}(\text{NO}_3)_2$ , and sulfate was determined turbidimetrically using  $\text{BaCl}_2$ . Sodium and potassium were measured using flame photometer (Corning 410C), and boron was determined spectrophotometrically using carmine method. Strontium was measured using AAS in the National Research Center, Cairo, Egypt. Saturation indices with respect to calcite, aragonite, dolomite and gypsum were calculated for each groundwater sample using the geochemical program NETPATH (Plummer *et al.*, 1994)

Twelve carbonate rock samples were collected from the groundwater open trenches dug in the coastal plain of the study area in order to investigate water-rock interaction. Thin sections were made in Geology Department, Faculty of Science, Alexandria University for petrographic description using polarizing microscope.

### 4. RESULTS AND DISCUSSION

#### 4.1. HYDROCHEMISTRY

The chemical composition of the groundwater in the Umm El Rakham area is variable, which ranges from fresh to brackish

water (Table 1). Groundwater temperature ranged from 26 to 29°C. The specific electrical conductance ranged from 1300 to 9500  $\mu\text{S}/\text{cm}$ . The pH values ranged from 7.6 to 9.09, indicating alkaline nature of groundwater. In coastal areas, two fundamental processes dominate, which are the leaching of recent marine sediments by infiltrated rain water and sea-water intrusion caused by the decline of freshwater head. These processes result in an increase in groundwater salinity. In addition, during groundwater flow, groundwater dissolves minerals from the rock units, resulting in an increase in total dissolved solids.

The salinity values of the collected groundwater samples from the Pleistocene aquifer varied spatially from 843 mg/l at water point no. 2 to 5747 mg/l at water point no. 12 (Fig. 2). This figure shows the presence of high salinity zone around water point no. 12. This high salinity zone may be developed due to mixing with the dense underlying salt water during upcoming resulted from high rate of discharge in this zone. Generally, the groundwater salinity increases from the southern part of the area towards northeast and northwest.

Chloride is the major solute in the composition of seawater, its predominance in the coastal aquifer can normally be related to the presence of salt-water intrusion. An increase in the concentration of chloride helps to determine the position of an advancing front of intruding seawater. The chemical composition of groundwater in the study area shows predominance of Na, Mg, Cl and  $\text{SO}_4$ , where three water types with varying dominance of major ions were recognized. Most of the groundwater samples exhibit Na-Mg-Cl- $\text{SO}_4$  water type (7 samples), whereas the remaining samples are of Na-Mg-Cl (4 samples) and Na-Cl- $\text{SO}_4$  types (one sample).

Dissolution of carbonate minerals is the main source of Ca, Mg,  $\text{CO}_3$  and  $\text{HCO}_3$  in groundwater. Ca and Mg from carbonate minerals are removed from solution by

cation-exchange and replaced by Na. The sodium that occurs on cation-exchange minerals (primarily clay minerals) probably originates from salt water or from weathered sodium-rich clay (Petalas and Diamantis, 1999).

Cation exchange of  $\text{Ca}^{2+}$  for  $\text{Na}^+$  on Na-rich minerals results when excess  $\text{Ca}^{2+}$  from aragonite dissolution is available in infiltrating water. Exchange of  $\text{Ca}^{2+}$  for  $\text{Na}^+$  results in an increase in dissolved  $\text{Na}^+$  and further dissolution of aragonite. Through the mechanism of cation exchange, high concentrations of  $\text{Na}^+$  are generated in groundwater.

On the other hand, dominance of Na and Mg in a carbonate coastal aquifer is mainly caused by mixing with sea water, where these cations are the most dominant in sea water. High salinity values and the appearance of Na-Cl water, which represents an advanced stage of geochemical evolution, strongly suggest mixing with sea water at the coastal plain of the study area.

Plots of groundwater samples on Piper diagram (Fig. 3) shows that the groundwater of the Pleistocene coastal aquifer of the Umm El Rakhm area is characterized by predominance of Na over Ca and Mg, and predominance of Cl and  $\text{SO}_4$  over  $\text{HCO}_3$ . Therefore, the groundwater is characterized by primary salinity (Cl+ $\text{SO}_4$ ) that does not exceed twice the alkalies (Na+K), where chemical properties are dominated by alkalies and strong acids (sea water and many brines plot in this subarea).

Plotting the results of groundwater chemical analysis and sea water (El Fiky, 1996) on Schoeller's diagram (Fig. 4) shows that the groundwater samples nearly have the same trend of increase and decrease of major ions as sea water, which indicates the effect of mixing with sea water.

Boron was detected in groundwater samples of the study area; it ranges from 0.80 to 5.40 mg/l (Table 1). The relatively high concentration of boron in seawater leads to consider it as an indicator of marine intrusion (Martos *et al.*, 1999). High concentration

values of boron are present at the central part of the study area (water point no. 12), supporting that seawater contributes these high concentrations of boron and it coincides with high salinity values at this part.

The measured Sr contents in groundwater samples are relatively high, which may be attributed to dissolution of the Pleistocene carbonate minerals of this coastal aquifer where aragonite is the main carbonate species. Sr concentrations in groundwater ranged between 3.41 and 30.56 mg/l (Table 1). However, Sr concentrations increase sharply when the water comes into contact with evaporates (Hidalgo and Cruz-Sanjuliàn, 2001).

The hydrogeochemical evolution of groundwater in the study area takes place from the least saline meteoric water (recharge water) to the most saline groundwater by mixing with seawater as illustrated by the binary relations between Cl and major ions (Fig. 5). Plot of seawater in these binary relations clarify the main hydrogeochemical processes including simple mixing with seawater and enrichment or depletion of the major ions caused by the active water/rock interactions.

Figure (5) shows that binary relations between Cl and major ions are strongly positively correlated. Mixing line was drawn between seawater and water point no. 6 (lowest chloride content) through the plotted points to show whether the ionic composition of groundwater is the result of simple mixing with seawater or further modified by dissolution and/or precipitation reactions.

Ionic ratios clarify changes in water quality and can aid in identifying any dominant groundwater influences. Ionic ratios can provide useful information about

aquifer characteristics. These ratios can indicate the degree of mixing of waters, whether minerals are dissolving or precipitating, if ion exchange is occurring and if there is active recharge (Mandel and Shiftan, 1981).

The ionic molar ratios of groundwater samples were compared to those of seawater in order to trace the extent of mixing with seawater.

In salinization processes, the Na/Cl ratio value may indicate the chemical composition of the saline end member (Vengosh and Rosenthal, 1994). Na/Cl ratio of the groundwater varies from 1.44 to 0.75 (Table 1), where 6 water samples have values approaching that of sea water (0.86) indicating possible mixing between groundwater and marine water.

In the coastal aquifer, when the Mg/Ca molar ratio is greater than 5, it indicates that seawater intrusion is the effective process in the groundwater system (Montenegro, *et al.*, 2003 and Ghabayen *et al.*, 2006). The calculated Mg/Ca ratio of the groundwater of the study area shows that most of the samples have values greater than 5 (Table 1), indicating that the area is affected by seawater intrusion.

The Sr/Ca ratio ranges from 1.90 to 0.19 (Table 1). The increase in Sr/Ca ratio can be attributed to dissolution of the main carbonate mineral (aragonite) forming the Pleistocene aquifer matrix that results in release of Sr. Also, the requirement that Sr<sup>2+</sup> does not undergo ion exchange during Ca<sup>2+</sup>/Na<sup>+</sup> exchange runs counter to the general adsorption affinity of Sr > Ca, which predicts that the cation with smaller hydrated radius of equal charge should be preferentially adsorbed.

Table (1): Results of chemical analyses of groundwater samples of Umm El Rakham area (concentrations are in mg/l)

Well #	pH	T <sup>o</sup> C	EC	TDS (mg/l)	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Cl <sup>-</sup>	B	Sr	Na/Cl	Mg/Ca	Sr/Ca
1	7.84	28	7000	4471	20.04	226.04	1180.00	78.00	0.00	325.44	640.00	1971.17	4.10	26.57	0.92	18.58	0.61
2	9.09	28	1300	843	8.02	51.04	190.00	22.00	11.64	118.34	90.00	347.44	0.80	3.41	0.84	10.62	0.19
3	7.8	28	4350	2845	28.05	187.15	665.00	38.00	0.00	301.77	370.00	1237.30	1.30	16.75	0.83	11.13	0.27
4	8.2	28	4250	2799	8.02	106.94	810.00	78.00	0.00	142.01	530.00	1113.21	1.30	10.28	1.12	22.25	0.59
5	7.6	27	2700	1810	12.02	119.09	407.00	30.00	0.00	224.85	565.00	432.52	3.20	15.90	1.45	16.53	0.60
6	8.0	26	1650	1090	4.01	75.35	230.00	26.00	0.00	183.43	295.00	262.35	1.90	12.05	1.35	31.35	1.37
7	7.8	28	2850	1872	4.01	99.65	430.00	56.00	0.00	242.60	450.00	567.24	5.40	16.70	1.17	41.46	1.90
8	8.7	29	4000	2538	8.02	179.86	580.00	62.00	8.73	118.34	375.00	1180.57	1.90	23.95	0.76	37.41	1.36
9	7.8	29	2950	1879	8.02	123.96	430.00	35.00	0.00	242.60	470.00	549.52	2.60	17.34	1.21	25.79	0.99
10	8.0	29	4750	3088	8.02	160.41	730.00	81.00	0.00	213.01	1050.00	826.05	5.00	14.47	1.36	33.37	0.82
11	8.1	27	3550	2307	32.06	94.79	605.00	54.00	0.00	224.85	500.00	776.41	3.70	16.26	1.20	4.93	0.23
12	8.0	28	9000	5747	56.11	286.80	1460.00	95.00	0.00	213.01	1260.00	2339.88	5.40	30.56	0.96	8.53	0.25
S.W.				35075	411.00	1290.00	10760.00	399.00	0.00	142.00	2710.00	19350.00	4.50	8.00	0.86	5.24	0.01

E.C. in  $\mu\text{S}/\text{cm}$  at 25<sup>o</sup>C  
S.W. is Sea Water

WATER-ROCK INTERACTIONS AND GEOCHEMISTRY OF GROUNDWATER OF A COASTAL CARBONATE AQUIFER, NORTHWEST EGYPT

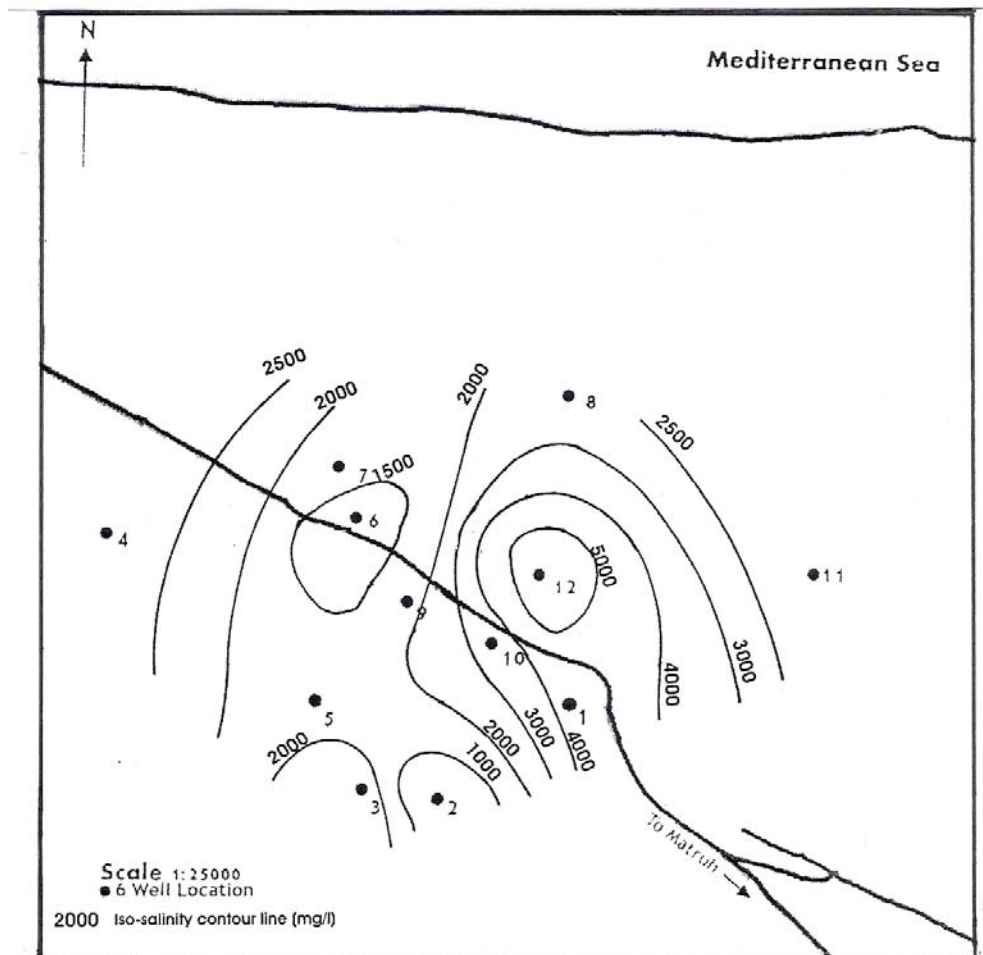
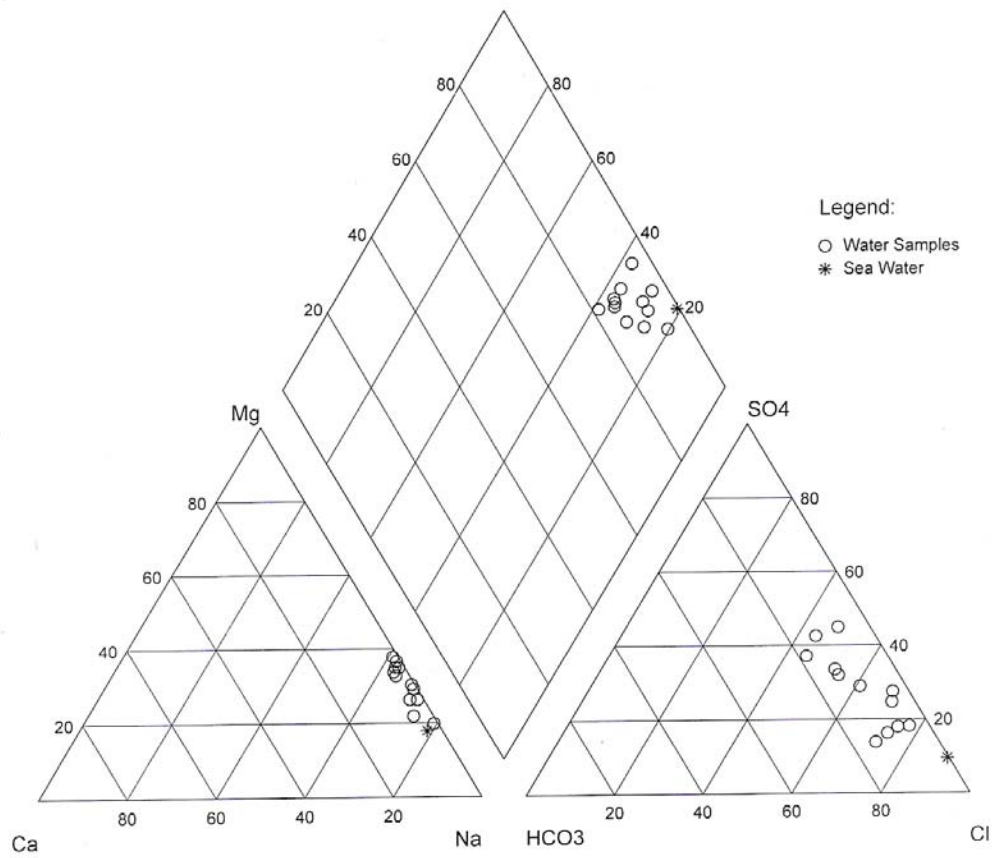


Fig. (2): Well location and iso-salinity contour map of the Umm El Rakhm area, Egypt.





**Fig. (3): Piper trilinear diagram for the groundwater samples in the Umm El Rakham area, Northwest Egypt.**

WATER-ROCK INTERACTIONS AND GEOCHEMISTRY OF GROUNDWATER OF A COASTAL CARBONATE AQUIFER, NORTHWEST EGYPT

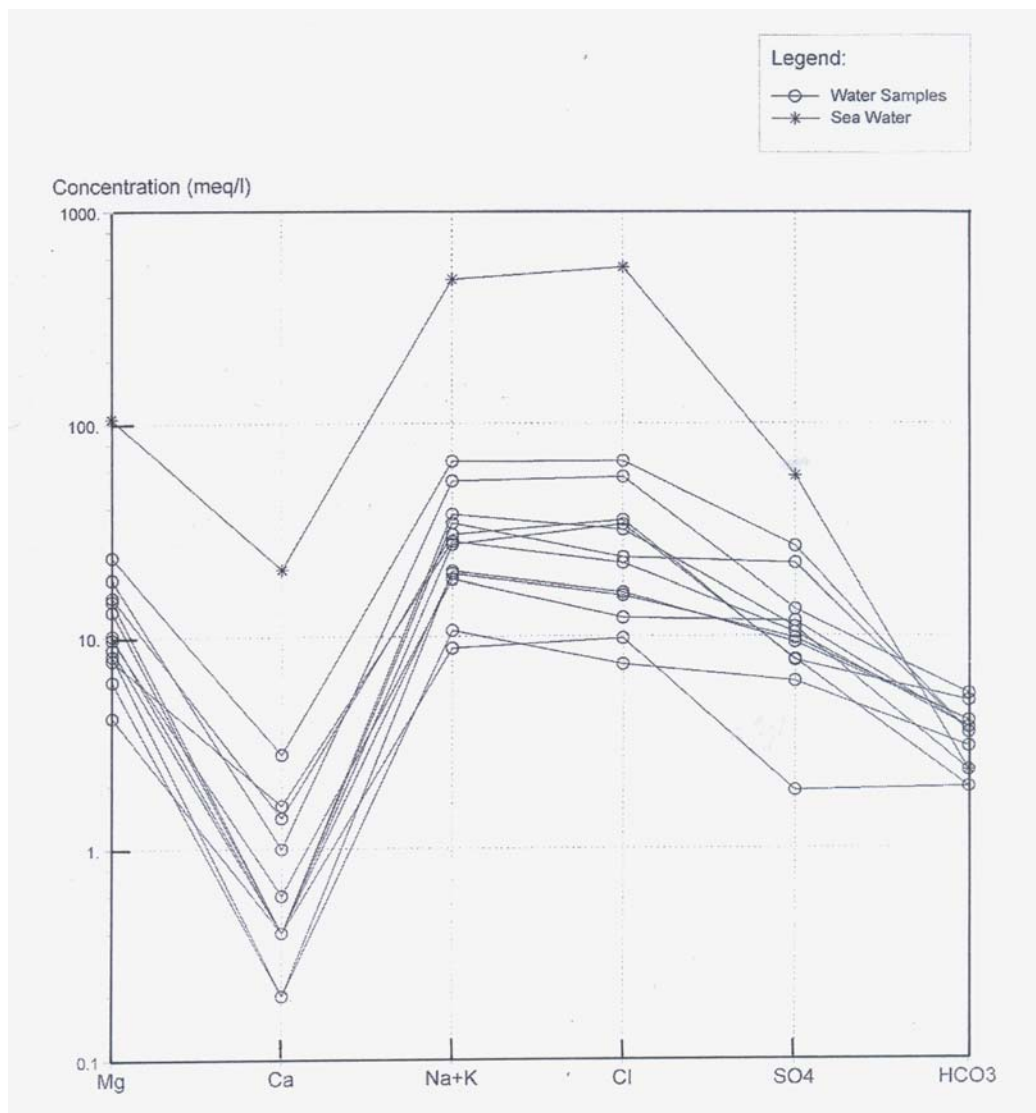


Fig. (4): Schoeller diagram of the groundwater samples of the study area.

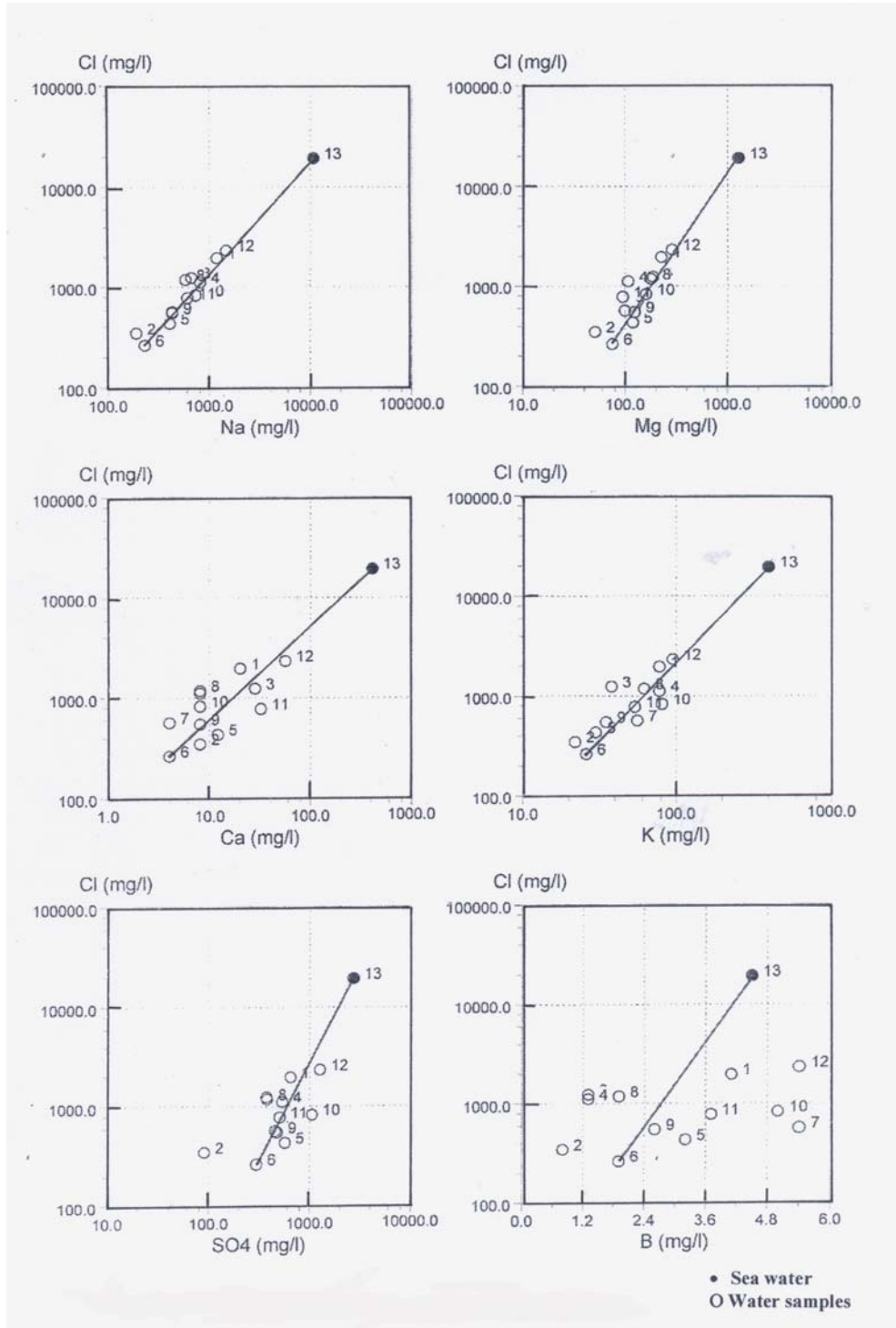


Fig. (5): Binary relations between Cl and major ions.

## 4.2. PETROGRAPHY

Petrographically, the examined rocks are mainly grainstones, which are composed of ooids with some skeletal particles and intraclasts (Fig. 6). Ooids display noticeable variability among their sizes, nucleus (detrital quartz and skeletal particles are dominant) and thickness of their cortex (20-40 layers). However, all recorded ooids are made up of aragonite and exhibit concentric fabric and no radial fabric is observed. Skeletal particles are mainly bivalves, benthic forams and echinoderms. The recorded intraclasts are made up of fine-grained carbonates. Micritization of some ooids and bivalves is a noticeable criterion in some samples where dark micrite envelopes may develop surrounding their grains. Neomorphic alteration of some grains is not uncommon.

Primary porosity is represented by the intergranular type, which shows wide variations (15-25%) among the studied rocks. Secondary porosity may develop due to partial dissolution of carbonate particles thus forming intragranular porosity. Oomoldic porosity may result from the complete dissolution of some aragonitic ooids.

The recorded cements display two characteristic fabrics. The first fabric comprises thin fringes of aragonite needles that surround the grain and form isopachous crusts. Aragonite needles around 10 $\mu$  length and their long axes are oriented normal to grain substrate. The second fabric of cement is made up of low-Mg calcite equant drusy mosaics that partly, or completely in some instances, fill the intergranular pores.

Regarding the volumetric distribution of cements, it is apparent that samples taken from the northern area (wells no. 6, 7, 8) are weakly cemented compared to those of the southern area (wells no. 1, 2, 3, 5). An expected antipathetic relationship exists between the volume of cement and porosity percent is observed (Fig. 6).

## 4.3. WATER-ROCK INTERACTIONS

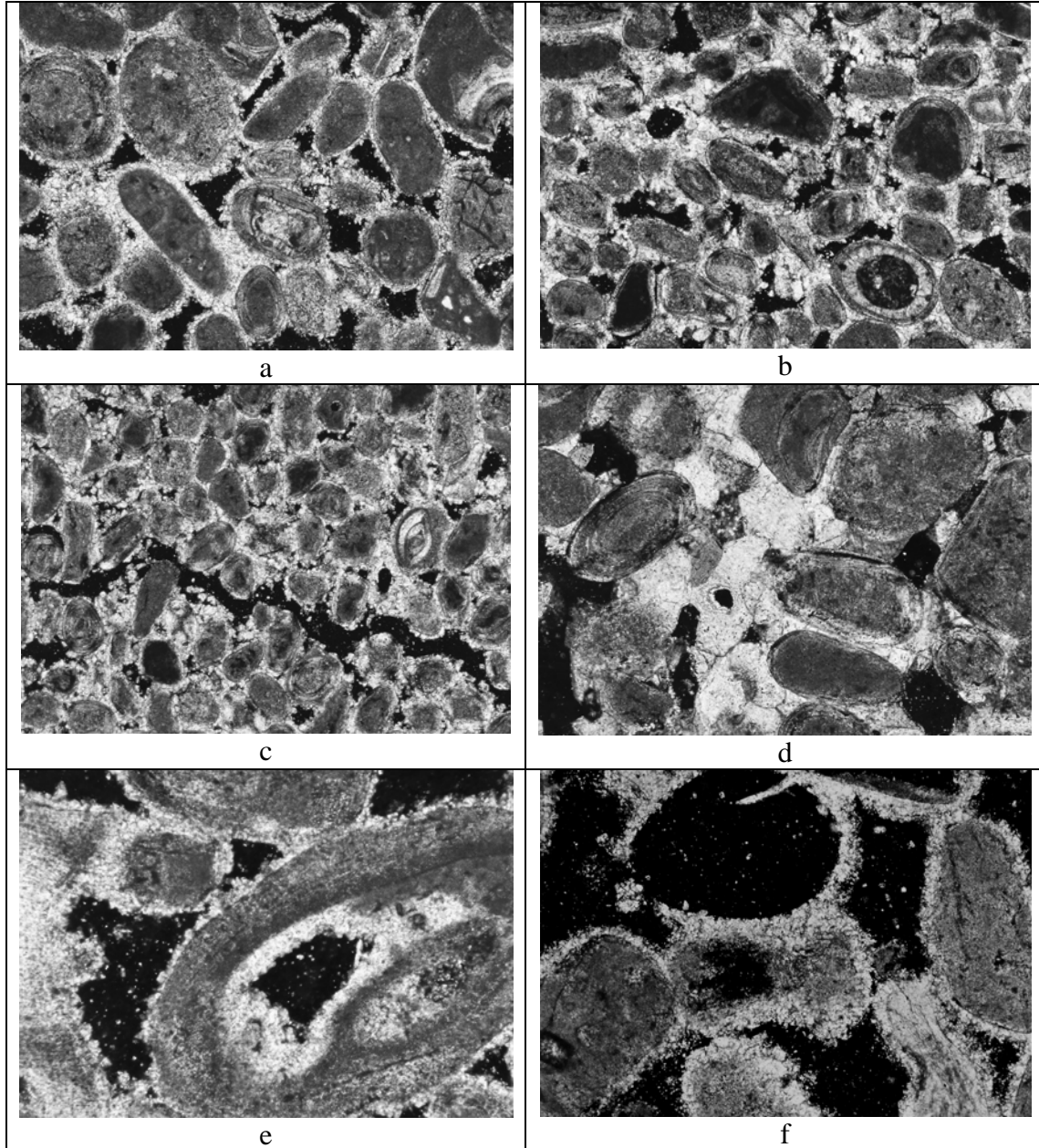
Most modern marine ooids are composed of aragonite (Newell *et al.*, 1960; Purdy, 1963; Friedman *et al.*, 1973); calcite ooids are much less abundant in modern environments (Popp and Wilkinson, 1983).

The water-rock interactions potentially control dissolution of aragonite (ooids) and precipitation of low-Mg calcite cements (Holail, 1993).

The present hydrologic regime of the study area consists of thin freshwater layer underlain by a brackish transitional zone which varies in salinity and extent in response to freshwater recharge and discharge rates of groundwater. Saturation indices of the most common minerals forming the carbonate aquifer of the study area are given in Table (2).

Petrographic investigation of the aquifer rock samples of the study area indicates that aragonite and low-Mg calcite are the two carbonate minerals present. All ooids are composed of aragonite and cements of low-Mg calcite. Thus the pore spaces between the ooid grains are partially occluded. The amount of cement increases landward (Holail, 1993). The porosity decreases in percent landward due to increasing diagenesis processes.

Groundwater from the carbonate coastal aquifer of Umm El Rakhm area shows varying values of the saturation indices with respect to calcite and aragonite. This reflects that their dissolution and precipitation in the aquifer matrix are the main processes controlling porosity of the water-bearing formation. Dissolution of aragonite is also consistent with groundwater enrichment with strontium. Calcite precipitation is observed in the examined rock samples as cement between the aragonite ooids.



**Figure 6. Illustrates photomicrographs of the studied rocks showing ooidal grainstone. (a) Ooids display various sizes and shapes and degree of alteration. Notice that intergranular pores are partly filled with two types of cement: isopachous crust and medium to fine drusy mosaics. (b) In this rock sample, most of intergranular pores are filled. (c) Another type of porosity is noticed in this sample, which is fracture porosity. (d) Drusy mosaics exhibit coarser crystal sizes and non planar crystal boundaries. (e) In addition to intergranular porosity, intragranular porosity is another type of porosity. (f) The complete dissolution of ooids led to the formation of oomolds.**

**Table (2): Saturation indices of some common minerals.**

Well No.	Calcite	Aragonite	Dolomite	Gypsum
1	-0.14	-0.28	1.16	-1.92
2	0.40	0.26	2.00	-2.72
3	0.02	-0.13	1.24	-1.90
4	-0.47	-0.61	0.57	-2.24
5	-0.66	-0.80	0.04	-1.97
6	-0.75	-0.90	0.12	-2.58
7	-0.88	-1.02	0.02	-2.52
8	-0.08	-0.22	1.60	-2.42
9	-0.57	-0.71	0.43	-2.23
10	-0.54	-0.68	0.60	-2.03
11	0.24	0.10	1.33	-1.63
12	0.21	0.06	1.50	-1.29

Geochemical mixing theory suggests that the mixing of seawater and aragonite-saturated fresh groundwater can result in a solution that is undersaturated with respect to aragonite (Stanford and Konikow, 1989).

All of the groundwater samples are oversaturated with respect to dolomite. However, dolomite is not observed in the examined rock samples because it is evident that the degree of oversaturation is not the sole factor that influences the precipitation of dolomites from natural fluids. Kinetic (e.g. ion hydration behavior, rate of diffusion, ion pairs) and thermodynamic (e.g. Ca/Mg ratio, nature of stoichiometric reaction) factors are of crucial importance in controlling the dolomitization process (Morrow, 1982; Hardie, 1987; Shaaban *et al.*, 1997 and Shaaban *et al.*, 2005). The analyzed groundwater in contact with the examined rocks is, theoretically, supersaturated with respect to dolomite (SI: 0.02-2.00). However, no dolomite exists with these rocks. This can be related to insufficient time, which is a critical kinetic constraint that may impede dolomitization. Hardie (1987) stated that dolomite needs at least 10,000 years to be found with dolomitization fluids in direct contact with sediments. The apparent intensive dolomitization in the older ridges, which are located south of the study area (Holail, 1993) supports this interpretation.

Groundwater is strongly undersaturated with respect to gypsum where its dissolution is the active process. This is also revealed from the investigated rock samples where gypsum is not recorded.

## 5. CONCLUSIONS

The mixing of freshwater and saline water was investigated to reveal that this geochemical mixing results in a chemically active environment where carbonate mineral diagenesis occurs. A thin fresh groundwater layer in the study area floats over dense seawater in the Pleistocene oolitic limestone aquifer. Salinization of groundwater in the study area is due to over-exploitation. Origin of salinity and the development of the aquifer porosity were assessed by the integrated use of chemical and petrographic parameters. In the study area, the groundwater salinity increases from the southern part of the area towards northeast and northwest. Na, Mg, Cl and SO<sub>4</sub> in the area of study were the predominant ions. High salinity values and the appearance of Na-Cl water strongly suggest mixing with sea water. The application of Piper diagram, Schoeller diagram, binary relations, ionic ratios combined with field observations, may lead to a better explanation of the origin of the saline groundwater. The high boron content reveals that seawater contributes these high

concentrations. The high Sr contents in groundwater samples may be attributed to dissolution of the Pleistocene carbonate minerals of the coastal aquifer where aragonite is the main carbonate species. Petrographic investigation of the aquifer rock samples of the study area indicates that aragonite and low-Mg calcite is the two carbonate minerals present. Groundwater from the carbonate coastal aquifer of Umm El Rakham area shows varying values of the saturation indices with respect to calcite and aragonite. All the groundwater samples are oversaturated with respect to dolomite and strongly undersaturated with respect to gypsum.

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