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Hydrogeochemical Characteristics of Brines in the Western Coast of the Gulf of Suez

(5 text—fig., 2 tab.)

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Abstract. Brines of the western coast of the Gulf of Suez belong to: the Nubian sandstones; Cretaceous; Eocene; Miocene; Pliocene and Recent formations. Salinities reach 222.4, 288, 253, 352, and 73 g/l respectively. Generally, salinity increases towards the south-east direction. Stronger brines occupy deeper parts of the geological section, which are schematically divided into zones ranging from less than 50 to 300 g/l and more. From the hydrogeochemical graphical representation, they are only of the sodium chloride type. Bromine and boron concentrations in these waters are high, but those of iodine and lithium show also some increase.

The study of different hydrogeochemical coefficients showed that brines of this type are somewhat metamorphosed, i. e. they accuse an enrichment in calcium, denitrification and desulphatisation. The $rSO_4/rCl \cdot 100$ coefficient is low and generally decreases with depth and salinity. The rNa/rCl ratio is less than one and depends on the degree of metamorphisation. The Cl/Br and Br/I ratios are less than that of sea water.

The reserves of microelements in brines, i. e. Br, I and B are high and can be used for industrial application. These brines can also be used as criteria for searching other mineral deposits and for therapeutic treatment of various ailments.

Introduction

Iodine-bromine water, especially bromine water, is often of very high salinity, i. e. brine (more than 50 g/l). Such brines in the studied area are mainly found in the earth's crust at considerable depths. However, it must be noted that salinity of water some lakes also reaches sometimes more than 50 g/l. Such water in many cases contains bromine in high concentrations. Iodine is often associated with oil-water, but not necessarily always. Iodine-bromine brines also contain boron, lithium, potassium, radioactive elements and some others.

Therefore, underground brines can be considered as a mineral deposit and as criteria for searching other mineral deposits, e. g. oil and gas deposits.

To evaluate the perspective utilization of underground brines, the study of changes in chemical composition, horizontal and vertical on a regional scale, covering also different areas, is of great importance.

The aim of this work is to elucidate the hydrochemical characteristics, distribution of iodine-bromine brines in the western coast of the Gulf of Suez, their chemical changes with depth and direction from north-west to south-east, their application in industry.

The study includes deep wells drilled for exploring oil in the area (Fig. 1) as well as oilfields up to Hurghada (on the Red Sea northern coast).

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Hydrostratigraphical units

Artesian basin of the Gulf of Suez, according to Ovčinikov's scheme (1961) can be considered as a medium basin. It is bordered on both sides by the chain of mountains formed as a result of the two major clismic faults and others serie of minor faults. Along the western coast of the Gulf of Suez, on the basis of geologic age, the water-bearing formations (sometimes oil-water bearing) belong to: Pliocene-Recent (only water bearing); middle and lower Miocene; Eocene and Paleocene; Cretaceous and Nubian sandstone formations. Oligocene deposits are not represented in wells from Rahmi to Hurghada.

FIG.1.

Hydrogeologically the basin is characterized by the presence ofhit ck deposits of impermeable anhydrites and shales of middle Miocene covering more older deposits (Fig. 2). Such thick deposits of anhydrites and gypsum provide good conditions for the closure of the structure, causing the prevailance of highly reducing conditions favourable for the formation and preservation of oiln ad gas deposits in the area.

Pliocene-Recent water bearing formations: These lie unconformably on the evaporite series of the middle Miocene and are of wide distribution, but in some places they are not represented, consist mainly of gravels, sands and some limestones and sandstones which contain sometimes tar impregnations. The thickness of these formations varies, for example in Ras-Bakr it reaches 490 m and in Ras El-Bihar only 31 m. There is no definite sharp line between Pliocene and Miocene deposits, but the appearance of gypsum and anhydrite (sometimes with rock salt) is considered as its lower boundary. Likewise, there is no sharp line between Pliocene and Recent formations.

Miocene water-bearing formations: Upper Miocene deposits are not represented in the area. The formations of the middle Miocene section are the most widely represented in the area. They consist mainly of impermeable layers of gypsum, anhydrites, rock salt and shales. Permeable water oil-bearing layers of limestones, sandstones and conglomerates are found in oil-fields, for example Nullipore rocks which consist of reefy limestones of very high porosities and basal beds which consist of conglomerates of different lithological facies in Ras-Gharib. These permeable layers are of local distribution. Middle Miocene deposits outcrop sometimes at the surface in some places. The Middle Miocene section, in its upper part consists of lithothaminum limestone of the Ras-Malaab (evaporite) group formatoins which consist of alternations of shales and anhydrites containing rock salt. The thickness of this formation reaches some thousands of meters in the south-east part. Rock salt represents more than 70 % of the evaporites (in Ras El-Bihar, Gebel El-Zeit).

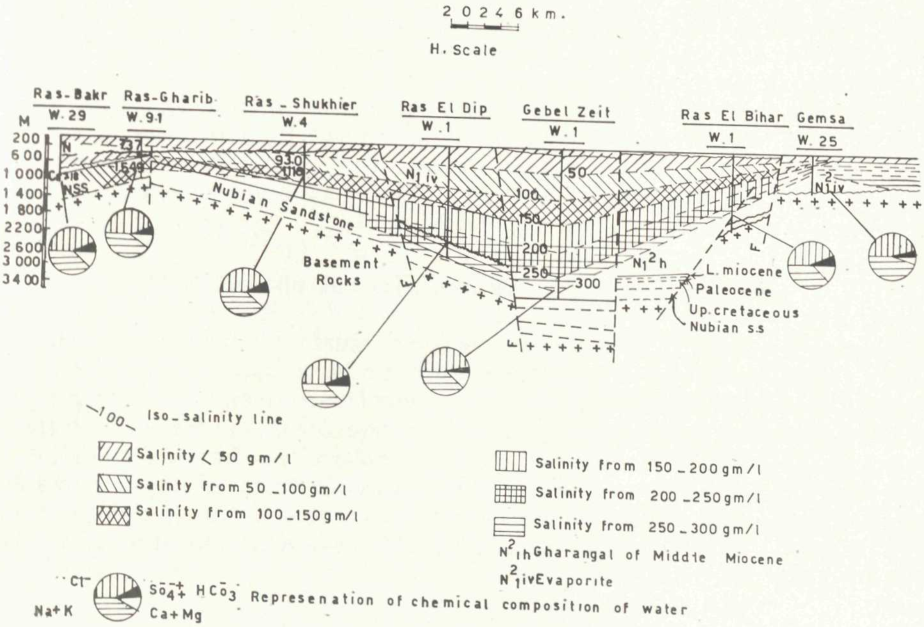

Fig. 2. Schematic Hydrogeochemical Section of the Western Coast of the Gulf of Suez from Ras — Bakr to Gemsa.

Fig. 2 shows the distribution of brines which can be schematically divided vertically into zones ranging from less than 50 to more than 300 g/l. Of course there is no sharp line between these zones. It is observed that strong brines occupy deeper parts of the areas of Gabel El-Zeit, Ras El-Bihar and Ras El-Dib. In this Figure also the chemical composition of water is represented by the cirle method and it is only of the sodium chloride type.

The lower part consists of the Gharandal group formations comprising mainly shales, sands and marls. The Gharandal group formations are less distributed than the Ras-Malaab group. The geologists of the General Petroleum Company attained lower Miocene for the lower part ov the Ras Malaab group (M. Safi, 1968). The thickness of the Gharandal group varies and increases also towards the south-east direction where it reaches more than 1000 m.

Eocene and Paleocene water-bearing formations: These formations are locally represented. Paleocene formations are less distributed than those of Eocene. Eocene deposits consists of brownish limestones containing shales. These deposits are oil-bearing, for example in Ras-Bakr and Kareem oil-fields and in others they are completely missing in the geological section. Thickness of Eocene deposits reaches 200 m, for example in Rahmi.

Paleocene consists of limestones containing some shales in its upper and lower parts, its thickness reaches 66 m.

Cretaceous water-bearing formations: The Cretaceous deposits are represented by senonian, turonian and cenomanian in its upper part. These formations consist of shales in its upper part, sandstones, sands and calcareous sands in its lower part. Thickness varies from 45 in Hurghada oil-field to 829 m in Ras Bakr field.

Nubian sandstones water-bearing formations: Sandstones lying on the basement rocks up to cenomanian are considered as sandstones of the Nubian type; these consist of alternating sandstones and shales which contain sands. Their thickness varies from 860 m (A, B, C and D series of Ras-Gharib) to 125 m in Hurghada. In some areas these deposits are not reached by deep wells and in others they are of about 420 m deep as in Gharib.

Structurally the Gulf of Suez was originated as a result of a system of parallel faults of tensional forces that have been active since the early geological times. According to R. Said (1962) the Gulf of Suez is considered as a series of sinking and rising of a large number of blocks that border or build the gulf, resulting in the formation of step blocks of different sizes.

Hydrogeochemical characteristics and distribution

Brines of the Nubian sandstones have high values of salinity (Table 1). Their salinity ranges from 148.8 to 222.4 g/l. Only one sample from El-Wadly has a lower salinity — 112.5 g/l. Brines of Hurghada oil-field (south-east), generally have a higher salinity and its mean value reaches more than 200 g/l. In Ras-Gharib (north-west), maximum salinity reaches 171 g/l. pH value varies from 5.5 to 7.3.

As shown in table 1 according to Kurlov's formula these brines are only of the sodium-chloride type (calcium chloride by Sulin's classification). Chlorine forms more than 95 % equivalent and reaches 99.9 % equivalent. Sulphate and bicarbonates form the rest. Nitrates and nitrites are not represented in the chemical composition of such brines. Sodium is the dominant cation and its concentration ranges from 64 % equivalent to 82 % equivalent. Calcium and magnesium form the rest and their distribution is more or less equal.

The concentration of microelements are high, especially that of bromine and boron. Iodine shows some increase. Bromine, boron (HBO_2) and iodine reach 785.9, 411.8 and 14.2 mg/l in Ras-Gharib respectively, while in Hurghada these values are 745.9, 170.4 and 5.7 mg/l respectively.

Lithium concentration is of 1.8 to 6.9 mg/l and that of NH_4 varies from 100.8 to 462.4 mg/l.

The composition of free gases accompanying oil and water are mainly of the methane type, where methane consists from 45 to 60 % by volume, the heavier hydrocarbons form the rest. H_2S, O_2, CO, CO_2 are of very low values.

Hydrochemical coefficients for the Nubian sandstones brines are given in table 2. Degree of metamorphisation rCl — rNa/rMg reaches 3.5 and only in one sample is less than one which according to Sulin's classification, this type of water is considered as magnesium chloride. The mean value of this coefficient is about 2. The concentration of calcium is more than 2.5 times that of magnesium, this gives an indication of a high degree of metamorphisation.

The sulphate coefficient $rSO_4/rCl \cdot 100$, is generally very low, but in one or two samples it shows some increase.

Cl/Br ratio varies from 124.9 to 248.9. For Ras-Gharib it is observed that the lowest value 124.9 corresponds to the highest value of salinity 159.2 g/l, also the same in Hurghada where the lowest value 182.3 corresponds to 222.6 g/l, i. e. concentration of bromine increases with the increase in salinity (in some samples this relation is not observed).

Br/I ratio ranges from 55.3 to 128.7. For Ras-Gharib this value does not increase more than 77.3, but for Hurghada is more than 100. This ratio as well as Cl/Br ratio as shown in table 2 in Ras-Gharib (north-west) are less than that of Hurghada (south-east).

rNa/rCl ratio is always less than one. For Gharib its mean value is about 0.7 and only in one sample is 0.8, but in Hurghada it is more than 0.8 and reaches 0.9. This can be attributed to leaching and dissolving of rock salt layer of the middle Miocene in Hurghada. rNa/rCl ratio for a solution of a rock salt is equal to one, hence the increase of this value for brines in Hurghada.

Ca/Sr ratio varies from 26.9 to 55.2. This ratio does not show any obvious trend. rCa/rMg ratio is somewhat more than one and in one or two cases it is higher or lower than this value.

B/Cl ratio is of $1.1 \cdot 10^{-3}$ to $2.8 \cdot 10^{-4}$.

For Cretaceous brines, salinity is higher than that of Nubian sandstones and reaches 288 g/l in Ras El Dib area (tab. 1) Generally, salinity increases with depth, but there are some exceptions. pH value varies from 5.5 to 6.7.

These brines are also of the sodium chloride type. Chlorine forms more than 96 % equivalent, sulphates and to a little extent bicarbonates forms the rest. Nitrates and nitrites also are not represented. Sodium is the dominant cation and forms more than 60 % equivalent and reaches 78 %. Calcium in such brines is somewhat higher than magnesium and of 28, 19 % equivalent respectively. It is observed that calcium increases with salinity increase.

Microelements were determined in one sample only. Bromine iodine and boron (HBO_2) concentrations are of 586.1, 5.9 and 383.4 mg/l respectively.

Lithium is of 4.8 mg/l and NH_4 is of 234 mg/l.

Free gas composition also mainly of methane 46 % by volume and other heavier hydrocarbons 53 % CO, O_2, CO_2 and H_2S are of less than 0.5 %.

Hydrochemical coefficients for Cretaceous brines are given in table 2. Degree of metamorphisation of rCl—rNa/rMg ranges from 1.6 to 3.8. Higher coefficients are observed in brines of Ras-Bakr oil-field, where this value is more than 3. Higher value (3.8) corresponds to higher salinity (218 g/l).

Sulphate coefficient rSO_4/rCl — 100, is very low and does not exceed 3.1, which corresponds to a low value of salinity (52 g/l).

Cl/Br ratio is less than 150, and that of Br/I less than 100.

rNa/rCl ratio ranges from 0.6 to 0.79. This is similar to that of the Nubian sandstones which means that sodium sulphate or sodium carbonate salts are not represented, while magnesium and calcium chloride salts are more represented than those of magnesium and calcium sulphates or carbonates (less than sulphates) are represented. The lower values of this ratio generally corresponds to brines of higher salinity.

Ca/Sr ratio is of 55.2 and that of rCa/rMg varies from 0.6 to 2.7. B/Cl ratio is $1.8 \cdot 10^{-3}$.

Salinity of Eocene brines reaches 253 g/l (table 1). pH value varies from 6 to 7.3. Chemical composition of brines is similar to that of Nubian and Cretaceous brines. They also are of sodium chloride type. Chlorine and sodium are the dominant ions. Sulphate, bicarbonates, calcium and magnesium are of minor values, but sometimes show some increase. The highest value of sulphates (7 % equivalent) correspond to the lowest value of salinity (71.5 g/l).

Bromine reaches 1250 mg/l and iodine 8 mg/l.

Hydrogeochemical coefficients for Eocene brines are indicated in table 2. Degree of metamorphisation reaches 4.4 and corresponds to the higher value of salinity and vice versa, its mean value is less than 2.

Cl/Br and Br/I are of 116 and 156.3 respectively.

rNa/rCl ranges between 0.64 and 0.88. This value is reversibly proportional to salinity.

rCa/rMg is high in east Gharib, where it reaches 3.5. The increase of calcium with the increase of salinity is aslo observed, the less values are for Bakr oil-field (0.7 to 0.9).

Eocene brines need more detailed study, since samples from this formation are few.

Miocene brines have the highest salinities and reach 352 g/l in Ras El-Bihar (table 1). In the area of Gebel El-Zeit, Ras El-Bihar and Gemsa (south-east), the mean salinity is more than 250 g/l while, those in Kareem and Ras-Gharib (north-west) have less salinities and its mean value (in Gharib) is about 140 g/l. pH value for such brines ranges from 4.5 to 7.6.

Sodium chloride type is the only type for Miocene brines. Chlorine forms up to 99.9 % equivalent, sulphates sometimes reach 14 % equivalent, but its normal concentration is 2 % equivalent and sometimes decreases to less than 0.2 % equivalent. Generally sulphate concentrations increase in brines where they are not associated with oil and decrease in the areas of oil-fields. Bicarbonates and carbonates are low. Nitrates and nitrites are undetected.

Sodium forms not less than 56 % equivalent and reaches more than 90 % equivalent. Calcium and magnesium form the rest. Calcium and magnesium reach 35 and 19 % equivalent respectively and sometimes decrease to very low concentrations.

Concentrations of bromine, iodine and boron (HBO_2) reach 638.4, 10 and 326.6 mg/l respectively.

Lithium is of 5 to 7.6 mg/l and NH_4 is of 93.6 to 204.8 mg/l.

Free gases consist mainly of methane which forms 35.4 to 71.6 by volume percent, C_2H_6 in Ras Gharib consists of 15.2 to 37.6 %. H_2, CO_2, Co, O_2, N_2 and H_2S are low, but H_2S cometimes forms 7 % in Gharib.

Hydrogeochemical coefficients for Miocene brines are also given in table 2. Metamorphisation coefficient ranges from 0.34 to 8.0. Sulphate coefficient of rSO_4/ /rCl . 100 varies from 0.1 to 16.93. Generally, this ratio is reversibly proportional to that of metamorphisation coefficient, but there are some exceptions.

Cl/Br ratio is less than 200 and reaches 182.6, Br/I ratio is of 137.1 to 111.5.

rNa/rCl ratio is less than 1, only in one case it is more than one and ranges from 0.57 to 1.01. It is similar to that of Eocene, Cretaceous and Nubian sandstone brines. This ratio is also reversible with the coefficient of metamorphisation, i. e. higher values of rNa/rCl correspond to lower values of rCl—rNa/rMg.

Ca/Sr ratio is similar to that of other brines and ranges from 23.2 to 38.2.

rCa/rMg ratio reaches 6.8 and decreases to 0.11. B/Cl ratio is of $3.4 \cdot 10^{-4}$ to $9.3 \cdot 10^{-4}$.

The salinity of brines of Pliocene-Recent reaches 73 g/l in Gharib at a depth of more than 200 m. These brines are also of sodium chloride type (Table 1), lower salinities are found in some shallow wells, but of little interest as iodine bromine brines.

Hydrogeochemical coefficients (Table 2) show that coefficient of metamorphisation is less than one and high rSO_4/rCl . 100 . rNa/rCl is of 0.84 and that of rCa/ /rMg is of 0.35.

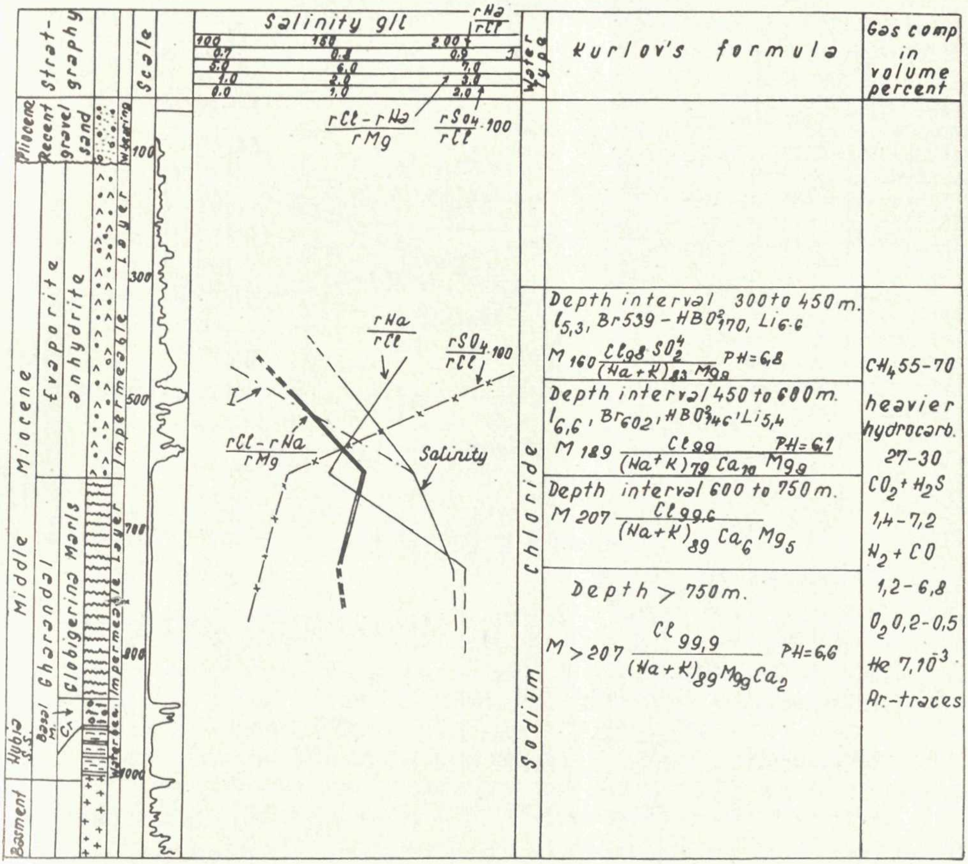

Fig. 3. Change in Salinity, Cl^-, Ca^{++}, Mg^{++}, $\frac{r\,Na}{r\,Cl}$, $\frac{r\,Cl - r\,Na}{r\,Mg}$ and $\frac{r\,SO_4}{r\,Cl} \cdot 100$ in Underground Water of the Western Coast of the Gulf of Suez from NW to SE Direction.

In Fig. 3 the mean change of chemical composition of brines for different oil-water bearing formations are presented. It can be observed that salinity generally increases towards the south-east direction. The Figure also shows the relation between different coefficients and salinity.

Fig. 4 shows vertical hydrochemical changes for brines of Hurghada Oil-field. At a depth of 300 to 450 m, the mean salinity is about 160 g/l with somewhat high sulphate concentration. At a depth interval between 450 and 600 m the mean salinity increases to about 190 g/l and sulphate concentration comparatively decreases. At a depth of 600 to 750 m the salinity increases to 207 g/l. At greater depth the salinity increases with the decrease in sulphates. Also bromine content increases with salinity and depth, the lowest amount of bromine is 522.8 mg/l at a depth of 500 m and the highest amount is 745 mg/l at a depth of 600 m. This was also observed for Ras Gharib oil-field (N. Z. Bishay 1971).

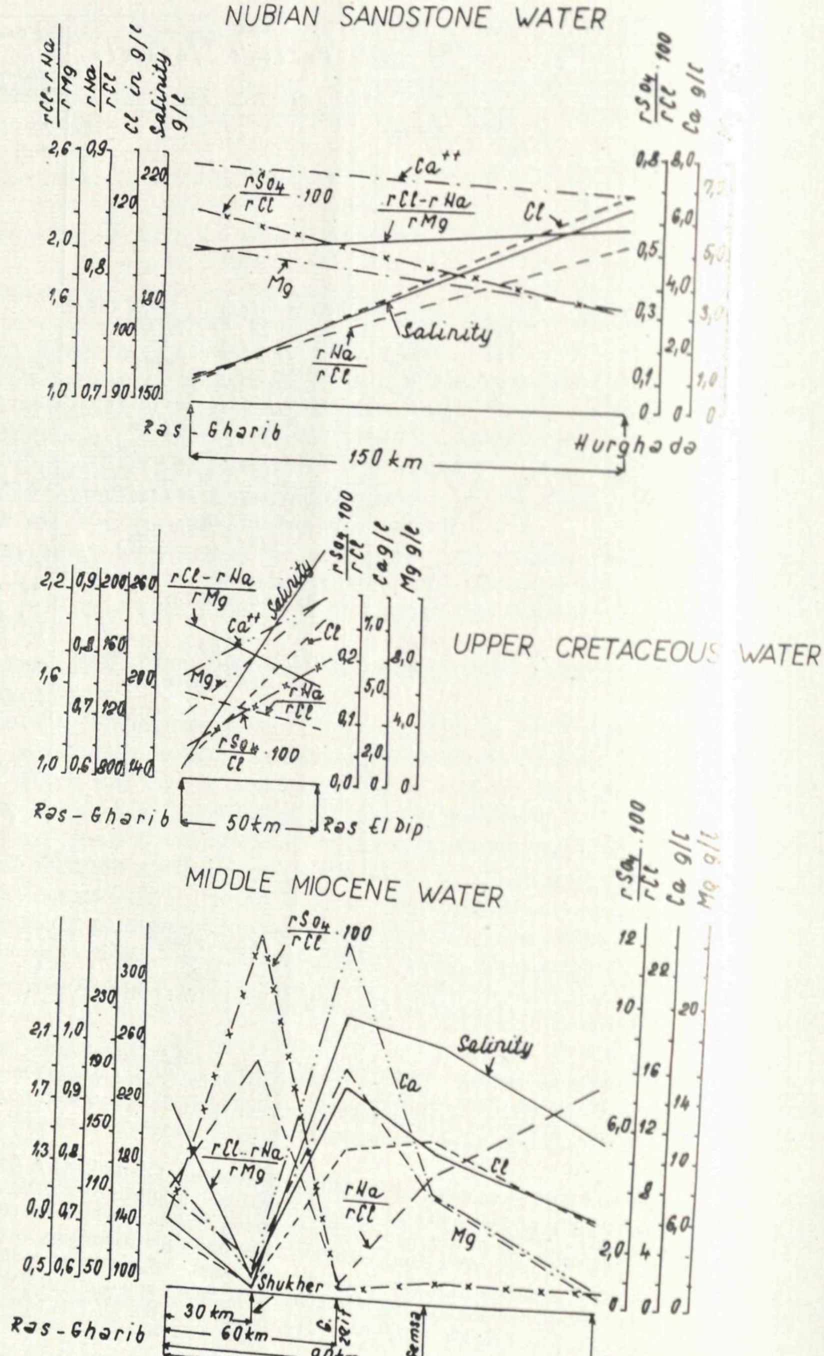

Fig. 4. Geological and Hydrochemical Section of Hurghada Oil Field

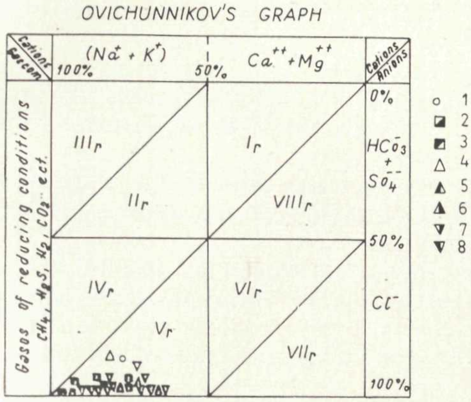

Fig. 5. Hydrogeochemical Graph for Representation of Water of Western Coast of the Gulf of Suez

1 — Pliocene water, 2 — Middle Miocene water of Ras-Gharib, 3 — Middle Miocene water of Hurghada, 4 — Eocene water of Ras-Bakr, 5 — Upper Cretaceous water of Ras-Gharib, 6 — Upper Cretaceous water of Ras El-Dip, 7 — Nubian S. S. water of Ras-Gharib, 8 — Nubian S. S. water of Hurghada.

Fig. 5 shows the graphical representation of brines by Ovčinikov's graph characterizing reducing conditions resulting from the presence of methane gas ando ther heavier hydrocarbons. Brines from different formations lie in one zone of the sodium chloride type.

Application in industry

Brines contain not only rock salt, but also they contain in great quantities bromine. Industrial lower limit for bromine is 250 mg/l (N.A. Plotnikov 1959). Along the western coast bromine content is much higher than this limit and reaches 1250 mg/l in Ras-Bakr. In stronger brines (more than 250 g/l) bromine concentration may reach more than 2.0 g/l. It can be said that the reserve of bromine in brines can be calculated in millions of tones.

Besides rock salt and bromine, iodine and boron can be extracted. Magnesium chloride, calcium chloride and in some few cases other elements such as lithium and potassium can be extracted as a by-product.

Brines can also be considered as valuable mineral deposits in relation to the possibility that they may contain gases as hydrogen sulphide, iodine and radioactive elements which can be used as therapy for different ailments.

The brines can serve as analogic criteria for the investigation of other mineral deposits which depend to a great extent on the determination of their origin. The abundance of very strong brines (more than 250 g/l) with high content of calcium chloride and bromine show that in the area in the previous geologic time when lagoons were formed, not only halites can be deposited but also potassium salts. Therefore, the presence of potassium salts can be expected in the area of the Gulf of Suez.

Brines enriched in calcium chloride, bromine, biochemical gases (methane, heavier hydrocarbons and others) or other components can be used as a good indicator of the presence of weakly washed deposits and highly reducing conditions. This geochemical medium represents favourable conditions for accumulation and preservation of liquid and gases of hydrocarbons, therefore, such brines with such specific components can be considered as an indirect indicator for the investigation of oil and or gas deposits.

Conclusion

From the previous study, the general hydrogeochemical characteristics and distribution of brines in the western coast of the Gulf of Suez can be summarized in the following points:

1. Brines reach very high values of salinity (350 g/l) which increases with depth. Salinity of brines increases from North-West to South-East and reaches its maximum in the areas of Gebel El-Zeit, Ras El-Dib and Ras El-Bihar, farther to the South in Hurghada salinity somewhat decreases.

2. Concentration of sulphates, bicarbonates decreases with depth in general. This is also observed in oil-fields. Nitrates and nitrites are not represented. Calcium generally increases with the increase in salinity.

3. Brines are of the sodium chloride type and are accompanied in oil-fields by free gases consisting of methane and other heavier hydrocarbons. Such strong brines of characteristic components characterize highly reducing conditions and weakly washed deposits favourable for formation and preservation of oil and gas deposits.

4. Bromine, iodine and boron are detected in all samples and of high concentrations. Bromine, iodine and boron (HBO_2) reach 1250, 14.2 and 411.8 mg/l respectively. Generally their concentration increases with the increase in salinity.

5. Cl/Br ratio is less than 300 (for sea water this ratio is of about 300) for brines from different formations. rNa/rCl is less than one and generally decreases with the increase in salinity and with the increase of coefficient of metamorphisation rCl—rNa/rMg.

6. Brines can be used for extraction of bromine, iodine and boron. Lithium, potassium salts magnesium chloride, calcium chloride and sodium chloride (rock salt) can be extracted as a by-product. Brines also can be used for some medical treatments of different ailments. Also they can be used as criteria for searching other mineral deposits, i. e. oil and gas fields.

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Tab. 1

Chemical analyses of brines

No of well	Absolute level of well in m	Dept interval of sampling in m	Geologic age	Area	Kurlov's Formula
54	+ 39.0	496.2 — 513.5	Nubian S. S.	Ras-Gharib	$Br_{373}\ H\ B\ O^2_{85.2}\ Li_{1.8}\ NH^4_{288.0}$ $M_{157.7} \frac{Cl_{96} . SO^4_4}{(Na + K)_{78}\ Mg_{16}\ Ca_4}$ PH = 7.3
60	+ 42.7	519.7 — 573.6	Nubian S. S.	Ras-Gharib	$I_{10.4}\ Br_{759.2}\ HBO^2_{411.8}\ Li_{5.2}\ NH^4_{292}\ H_2S_{170.0}$ $M_{157.0} \frac{Cl_{99}}{(Na + K)_{68}\ Ca_{15}\ Mg_{14}}$ PH = 6.0
12	+ 17.7	607.8 — 645.3	Nubian	Ras-Gharib	$I_{11.0}\ Br_{732.6}\ HBO^2_{355.0}\ Li_{5.2}\ NH^4_{73.6}$ $M_{150.0} \frac{Cl_{99}}{(Na + K)_{68}\ Ca_{15}\ Mg_{14}}$ PH = 6.8
164	+ 10.9	700.9 — 741.8	Nubian	Ras-Gharib	$I_{10.2}\ Br_{.652.7}\ HBO^2_{355.0}\ Li_{511}\ NH^4_{259}$ $M_{148} \frac{Cl_{99}}{(Na + K)_{70}\ Ca_{14}\ Mg_{13}}$ PH = 6.1
67	+ 5.8	660.5 — 701.0	Nubian S. S.	Ras-Gharib	$I_{8.9}\ Br_{666.0}\ HBO^2_{355.0}\ Li_{4.6}\ NH^4_{209}$ $M_{148.8} \frac{Cl_{99}}{(Na + K)_{70}\ Ca_{15}\ Mg_{13}}$ PH = 6.0
29	+ 14.1	681.5 — 728.4	Nubian S. S.	Ras-Gharib	$I_{14.2}\ Br_{785.9}\ HBO^2_{397.6}\ Li_{5.4}\ NH^4_{462}$ $M_{159.2} \frac{Cl_{99}}{(Na + K)_{67}\ Ca_{16}\ Mg_{15}}$ PH = 6.6
28	+ 47.5	707.7 — 733.3	Nubian S. S.	Ras-Gharib	$I_{9.3}\ Br_{719.3}\ HBO^2_{373.2}\ Li_{5.6}\ NH^4_{256}$ $M_{151} \frac{Cl_{99}}{(Na + K)_{69}\ Ca_{14}\ Mg_{14}}$ PH = 7.2
106	+ 14.0	664.4 — 683.3	Nubian S. S.	Ras-Gharib	$M_{157.0} \frac{Cl_{99.9}}{(Na + K)_{75}\ Ca_{14}\ Mg_{11}}$ PH = 5.9
18	+ 44.3	554.4 — 579.4	Nubian S. S	Ras-Gharib	$M_{162} \frac{Cl_{98}}{(Na + K)_{71}\ Mg_{15}\ Ca_{13}}$ PH = 7.3

No of well	Absolute level of well in m	Depth interval of sampling in m	Geologic age	Area	Kurlov s Formula
20	+ 49.4	463.2 — 475.4	Nubían S. S.	Ras-Gharib	$M_{171} \frac{Cl_{95}\, SO^4_{4}}{(Na + K)_{72}\, Mg_{24}\, Ca_{4}}$ PH = 6.9
1	+ 118.9	1820 — 1834	Nubian S. S.	El-Wady	$M_{112.5} \frac{Cl_{99.0}\, SO^4_{0.9}}{(Na + K)_{64}\, Ca_{26}\, Mg_{10}}$
8		613.8 — 616.2	Nubian S. S.Ř	Hurgh-ada	$M_{212} \frac{Cl_{99.8}}{(Na + K)_{81}\, Ca_{12}\, Mg_{7}}$
16	+ 9.1	473.9 — 523.9	Nubían S. S.	Hurgh-ada	$I_{5.7}\, Br_{572.8}\, HBO^2_{170.4}\, Li_{5.8}\, NH_{100.3}$ $M_{207.3} \frac{Cl_{99}\, SO^4_{0.5}}{(Na + K)_{82}\, Ca_{9}\, Mg_{8}}$ PH = 6.
125	+ 6.1	595 — 596.1	Nubían S. S.	Hurgh-ada	$I_{6.6}\, Br_{745.9}\, HBO^2_{156.2}\, Li_{6.9}\, NH^4_{1[illegible].4}$ $M_{222.4} \frac{Cl_{99}\, SO^4_{0.5}}{(Na + K)_{78}\, Ca_{12}\, Mg_{8}}$ PH = 5.5
61	+ 7.6	513.2 — 581.5	Nubían S. S.	Hurgh-ada	$I_{4.4}\, Br_{566.1}\, HBO^2_{156.2}\, Li_{5.4}\, NH^4_{1[illegible].7}$ $M_{193} \frac{Cl_{99}\, SO^4_{0.5}}{(Na + K)_{82}\, Ca_{9}\, Mg_{8}}$ PH = 6.1
129	+ 7.0	383.4 — 435.2	Nubían S. S.	Hurgh-ada	$M_{220} \frac{Cl_{99.9}}{(Na + K)_{86}\, Mg_{8}\, Ca_{6}}$
16	+ 1.0	981 — 1000	Cretaceous eous	Ras-Bakr Bakr	$M_{199} \frac{Cl_{99.9}}{(MNa + K)_{65}\, Ca_{25}\, Mg_{10}}$
35	+ 4.7	1182 — 1234	Cretaceous	Ras-Bakr	$M_{204} \frac{Cl_{99.8}}{(Na + K)_{61}\, Ca_{26}\, Mg_{13}}$
39	+ 0.2	1192 — 1231	Cretaceous	Ras-Bakr	$M_{189} \frac{Cl_{99.6}}{(Na + K)_{60}\, Ca_{28}\, Mg_{12}}$

53	+ 1.1	926 — 992	Cretaceous	Ras-Bakr	$M_{218} \frac{Cl_{99.9}}{(Na + K)_{62}\, Ca_{28}\, Mg_{10}}$
85	+ 8.2	632.6 — 691.8	Cretaceous	Ras-Gharib	$I_{5.9}\, Br_{586.1}\, HBO^{2}{}_{383.4}\, Li_{4.8}\, NH^{4}{}_{234.0}$ $M_{141.4} \frac{Cl_{99.6}}{(Na + K)_{71}\, Ca_{14}\, Mg_{14}}$ PH = 6.7
163	+ 16.5	735.1 — 750.3	Cretaceous	Ras-Gharib	$M_{146} \frac{Cl_{99.8}}{(Na + K)_{76}\, Mg_{13}\, Ca_{10}}$ PH = 6.2
93	+ 6.4	647.7 — 678.1	Cretaceous	Ras-Gharib	$M_{152} \frac{Cl_{99.9}}{(Na + K)_{75}\, Ca_{13}\, Mg_{11}}$ PH = 6.2
4	+ 122.2	904.4 — 915.6	Cretaceous	Kareem	$M_{52} \frac{Cl_{96}\, SO^{4}{}_{4}}{(Na + K)_{78}\, Ca_{16}\, Mg_{6}}$ PH = 6.5
1	+ 4.3	2062.1 — 2075	Cretaceous	East-Shukeir	$M_{147} \frac{Cl_{96}\, SO^{4}{}_{4}}{(Na + K)_{76}\, Ca_{14}\, Mg_{10}}$
11		1445 — 1467	Cretaceous	Um El-Yusr	$M_{111} \frac{Cl_{98}\, SO^{4}{}_{1.7}}{(Na - K)_{7}\, Ca_{21}\, Mg_{9}}$ PH = 6.0
1	+ 68.4	1437 — 1459	Cretaceous	Ayun	$M_{72} \frac{Cl_{99}\, SO^{4}{}_{0.9}}{(Na + K)_{67}\, Ca_{24}\, Mg_{9}}$ PH = 5.9
1	+ 3.5	2572.4 — 2580	Cretaceous	Ras El-Dib	$M_{288} \frac{Cl_{99.7}}{(Na + K)_{69}\, Mg_{19}\, Ca_{12}}$ PH = 5.5
69	+ 2.3	1035 — 1150	Eocene	Ras-Baker	$M_{156} \frac{Cl_{99}}{(Na + K)_{77}\, Mg_{13}\, Ca_{9}}$ PH = 6.0
66	0.0	849 — 1134	Eocene	North Bakr	$M_{150} \frac{Cl_{99}\, SO^{4}{}_{4}}{(Na + K)_{67}\, Mg_{17}\, Ca_{15}}$ PH = 6.0
7*	+ 3.1	806.4 — 992.3	Eocene	Bakr	$M_{161} \frac{Cl_{99}\, SO^{4}{}_{1}}{(Na + K)_{78}\, Mg_{13}\, Ca_{9}}$

19*	+ 124.5	655 700	Miocene	Kareem	$M_{103}\dfrac{Cl_{99.9}}{(Na+K)_{61}\,Ca_{27}\,Mg_{12}}$	
9*	+ 2.7	250	Miocene	Um El- Yusf	$M_{113}\dfrac{Cl_{99.7}\,So^4_{0.2}}{(Na+K)_{68}\,Ca_{23}\,Mg_{9}}$	PH = 4.5
18*	+ 15.0	1382	Miocene	Um El Yusr	$M_{82}\dfrac{Cl_{99.6}\,So^4_{0.2}}{(Na+K)_{70}\,Ca_{22}\,Mg_{8}}$	PH = 7.2
1*	+ 3.5	3188 3208.5	Miocene	Gebel El-Zeit	$M_{285}\dfrac{Cl_{99}}{(Na+K)_{63}\,Mg_{19}\,Ca_{18}}$	
1*	+ 2.9	1515.5 — 1518.5	Miocene Bihar	Ras El- Bihar	$M_{252}\dfrac{Cl_{99}}{(Na+K)_{71}\,Ca_{21}\,Mg_{8}}$	PH = 7.5
2*		2433 — 2446	Miocene	Ras El- Bihar	$M_{286}\dfrac{Cl_{99}}{(Na+K)_{68}\,Ca_{22}\,Mg_{10}}$	PH = 5.0
4*	1987.2	Miocene 2004	Ras El-	M_{352} Bihar	$Cl_{99}\dfrac{So_{1}}{(Na+K)_{62}\,Ca_{32}\,Mg_{6}}$	
4*			Miocene	Ras El- Bihar	$M_{280}\dfrac{Cl_{98}\,So^4_{1.5}}{(Na+K)_{56}\,Ca_{35}\,Mg_{9}}$	PH = 5.0
5*		1975.6	Miocene	Ras El- Bihar	$M_{322}\dfrac{Cl_{99.9}\,So_0{}^4{}_{.1}}{(Na+K)_{61.0}\,Ca_{34}\,Mg_{5}}$	
24*	+ 3.5	364.5 457.0	Miocene	Gemsa	$M_{270}\dfrac{Cl_{99}\,So^4_{0.7}}{(Na+K)_{81}\,Mg_{12}\,Ca_{7}}$	PH = 7.0
136*	+ 2.7	880.8	Miocene	Hurgh- ada	$M_{193}\dfrac{Cl_{99}}{(Na+K)_{97}\,Mg_{2}\,Ca_{1}}$	PH = 6.3
144*	+ 2.7	728.1 742.7	Miocene	Hurgh- ada	$M_{201}\dfrac{Cl_{99}\,So^4_{0.7}}{(Na+K)_{81}\,Mg_{12}\,Ca_{1}}$	PH = 4.9
85	+ 7.6	395.0 — 448.0	Miocene	Hurgh- ada ada	$I_{5.3}\,Br_{639.4}\,HBO^4_{170.4}\,Li_{6.6}\,NH^4_{94}$ $M_{221.6}\dfrac{Cl_{99}\,SO^4_{0.7}}{(Na+K)_{81}\,Ca_{9}\,Mg_{29}}$	PH = 6.0
59*		243.8	Pliocene	Ras- Gharib	$M_{73}\dfrac{Cl_{91}\,So^4_{6}\,HCO^3_{2}}{(Na+K)_{77}\,Mg_{17}\,Ca_{6}}$	PH = 7.1

* Samples analized by Chemists of the General Petr. Company.

Continuation Tab. 1

1*		2295 — 2332	Eocene	East Gharib	$I_{8.0}\,Br_{1251}\,M_{253}\,\frac{Cl_{99}\,So^{4}_{0.5}}{(Na+K)_{64}\,Ca_{28}\,Mg_{8}}$ PH = 6.5
15*	+ 15.8	1229 — 1250	Eocene	Um El-Yusr	$M_{71.5}\,\frac{Cl_{92}\,SO^{4}_{7}}{(Na+K)_{86}\,Ca_{9}\,Mg_{5}}$ PH = 7.3
83	+ 5.8	346.8 — 365.5	Miocene	Ras-Gharib	$I_{3.4}\,Br_{466.2}\,HB^{2}O_{241.4}\,Li_{7.6}\,NH^{4}_{108.7}$ $M_{141.6}\,\frac{Cl_{97}\,SO^{4}_{2}}{(Na+K)_{73}\,Mg_{16}\,Ca_{8}}$ PH = 7.5
157	+ 3.6	675.7 — 690.3	Miocene	Ras-Gharib	$I_{4.9}\,Br_{546.1}\,HBO^{2}_{326.6}\,Li_{5.0}\,NH^{4}_{205}$ $M_{142}\,\frac{Cl_{99}}{(Na+K)_{71}\,Mg_{15}\,Ca_{12}}$
114*	+ 3.7	421.5 — 637.0	Miocene	Ras-Gharib	$M_{140.7}\,\frac{Cl_{97}\,SO^{4}_{3}}{(Na+K)_{82}\,Ca_{10}\,Mg_{8}}$ PH = 6.3
4*	+ 4.3	594 — 606	Miocene Shukeir	Ras-	$M_{93}\,\frac{Cl_{94}\,SO^{4}_{6}}{(Na+K)_{89}\,Mg_{9}\,Ca_{2}}$ PH = 6.5
4*	+ 4.3	625 643 643	Miocene	Ras-Shukeir	$M_{111.8}\,\frac{Cl_{85}\,SO^{4}_{14}}{(Na+K)_{86}\,Mg_{10}\,Ca_{4}}$ PH = 6.5
2*	+ 0.3	764 — 768	Miocene	Ras-Shukeir	$M_{252}\,\frac{Cl_{98}\,SO^{4}_{2}}{(Na+K)_{97}\,Ca_{1.5}\,Mg_{1.5}}$ PH = 7.1
1*	+ 4.3	819.6 — 831.5	Miocene	East Shukeir	$M_{277}\,\frac{Cl_{99}}{(Na+K)_{96}\,Mg_{2.5}\,Ca_{1.5}}$
1*	+ 4.3	1074.8 1088.8	Miocene	East Shukeir	$M_{201}\,\frac{Cl_{99}}{(Na+K)_{94}\,Ca_{3.8}\,Mg_{2}}$
1*	+ 4.3	771.6 — 783	Miocene	East Shukeir	$M_{296}\,\frac{Cl_{98}\,SO^{4}_{1.7}}{(Na+K)_{97.5}\,Mg_{1.5}\,Ca_{1}}$ $I_{19}\,H_{2}\,S_{71}$
3*	+ 139.3	756.1 828.3	Miocene	Kareem	$M_{74}\,\frac{Cl_{98.5}}{(Na+K)_{62}\,Ca_{27}\,Mg_{11}}$ PH = 6.7

Table 2

Degree of metamorphisation, sulphate coefficient and some hydrogeochemical coefficients of brines

No of Well	Geologic age	Area	$\frac{rCl-rNa}{r\,Mg}$	$\frac{r\,SO_4}{r\,Cl}\cdot 100$	$\frac{Cl}{Br}$	$\frac{Br}{I}$	$\frac{rNa}{rCl}$	Ca/Sr	$\frac{rCa}{rMg}$	B/Cl	Salinity in g/l
54	Nubians S. S.	Ras Gharib	1.12	4.29	248.9	—	0,81	55.2	0.25	$2.2.10^{-4}$	157.7
60	Nubians S. S.	Ras Gharib	2.14	0,47	127.5	73.0	0.70	49.2	1.07	$1.1.10^{-3}$	157.7
12	Nubians S. S.	Ras Gharib	2.14	0.04	126.9	66.6	0.68	37.9	1.07	$9.4.10^{-4}$	150.0
164	Nubians S. S.	Ras Gharib	2.23	0.03	155.7	64.0	0.71	54.1	1.08	$9.5.10^{-4}$	148.0
67	Nubians S. S.	Ras Gharib	2.23	0.02	138.0	74.6	0.71	40.0	1.15	$9.5.10^{-4}$	148.8
29	Nubians S. S.	Ras Gharib	2.13	0.59	124.9	55.3	0.68	42.2	1.07	$1.0.10^{-3}$	159.2
286	Nubians S. S.	Ras Gharib	2.14	0.60	129.3	77.3	0.69	26.9	1.00	$9.9.10^{-4}$	151.0
10	Nubians S. S.	Ras Gharib	2.27	0.02	—	—	0.75	—	1.27	—	157.0
18	Nubians S.S.	Ras Gharib	1.73	1.32	—	—	—	0.72	—	—	162.0
20	Nubians S.S.	Ras Gharib	0.96	0.46	—	—	—	0.73	—	0.17	171.0
1	Nubians S.S	El Wady	3.5	1.0	—	—	0.65	—	2.6	—	112.5
8	Nubians S.S	Hurghada	2.70	0.20	—	—	—	0.81	—	—	212.1
16	Nubians S.S	Hurghada	2.13	0.53	220.6	100.4	0.83	45.4	1.12	$3.3.10^{-4}$	207.4
125	Nubians S.S	Hurghada	2.62	0.45	182.3	113.0	0.79	38.9	1.50	$2.8.10^{-4}$	222.6
61	Nubians S.S.	Hurghada	2.13	0.42	209.1	128.7	0.83	30.4	1.12	$3.2.10^{-4}$	193.9
129	Nubians S.S.	Hurghada	1.70	0.10	—	—	0.86	—	0.75	—	220.2
16	Cretaceous	Bakr	3.5	0.1	—	—	0.65	—	2.5	—	199.0
35	Cretaceous	Bakr	3.0	0.2	—	—	0.61	—	2.0	—	204.0
39	Cretaceous	Bakr	3,3	0.4	—	—	0.60	—	2.3	—	189.0
53	Cretaceous	Bakr	3.8	0.1	—	—	0.62	—	2.8	—	218.0
85	Cretaceous	Ras Gharib	2.0	0.4	149.3	99.3	0.71	55.2	1.0	$1.8.10^{-3}$	141.4
168	Cretaceous	Ras Gharib	2.4	0.2	—	—	0.76	—	0.8	—	146.0
93	Cretaceous	Ras Gharib	2.2	0.1	—	—	0.75	—	1.2	—	152.0
4	Cretaceous	Kareem	3.0	3.1	—	—	0.79	—	2.7	—	52.0
1	Cretaceous	East Shukeir	2.0	0.4	—	—	0.77	—	1.4	—	147.0
11	Cretaceous	Um El-Yosr	3.1	1.8	—	—	0.71	—	2.3	—	111.0
1	Cretaceous	Ayun	3.5	1.0	—	—	0.67	—	2.7	—	72.0
1	Cretaceous	Ras El-Dib	1.6	0.3	—	—	0.69	—	0.6	—	288.0
69	Eocene	Bakr	1.7	1.0	—	—	0.77	—	0.7	—	156.0
66	Eocene	Bakr	1.9	[illegible]	—	—	[illegible]	—	[illegible]	—	[illegible]
7	Eocene	Bakr	1.6	1.0	—	—	0.78	—	0.7	—	161.0
1	Eocene	East Gharib	4.4	0.5	116.0	156.3	0.64	—	3.5	—	253.0
15	Eocene	Um El-Yusr	1.2	8.0	—	—	0.88	—	1.8	—	71.5

Continuation Tab. 2

No of well	Geologic age	Area	$\frac{rCl-rNa}{r\ Mg}$	$\frac{r\ SO_4}{r\ Cl}.100$	$\frac{Cl}{Br}$	$\frac{Br}{I}$	$\frac{rNa}{rCl}$	Ca/Sr	$\frac{rCa}{rMg}$	B/Cl	Salinity in gm/1
83	Middle Miocene	Ras Gharib	1.45	2.24	182.6	137.1	0.75	33.9	0.5	$6.1.10^{-4}$	141.6
157	Middle Miocene	Ras Gharib	1.80	1.28	158.4	111.5	0.72	38.2	0.8	$9.3.10^{-4}$	142.2
114	Middle Miocene	Ras Gharib	1.90	3.20	—	—	0.84	—	1.25	—	140.7
4	Middle Miocene	Ras Shukeir	0.55	6.17	—	—	0.95	0.95	—	0.22	92.9
4	Middle Miocene	Ras Shukehir	—	1.93	—	—	1.01	—	0.4	—	111.8
2	Middle Miocene	Ras Shukehir	0.7	2.0	—	—	1.0	—	1.0	—	252.0
	Middle Miocene	East Shukehir	1.2	1.0	—	—	0.97	—	0.60	—	277.0
1	Middle Miocene	East Shukehir	2.5	1.0	—	—	0.96	—	1.9	—	201.0
1	Middle Miocene	East Shukehir	0.34	1.8	—	—	1.0	—	0.67	—	296.0
3	Middle Miocene	Kareem	3.3	1.1	—	—	0.63	—	2.4	—	74.0
19	Middle Miocene	Kareem	3.3	0.1	—	—	0.61	—	2.3	—	103.0
9	Middle Miocene	Um El-Yusr	3.4	0.2	—	—	0.69	—	2.5	—	113.0
18	Middle Miocene	Um El-Yusr	3.7	0.2	—	—	0.70	—	2.75	—	82.0
1	Middle Miocene	G. El-Zeit	1.90	0.32	—	—	0.64	—	1.0	—	285.1
1	Middle Miocene	Ras El-Bihar	3.5	1.0	—	—	0.71	—	2.6	—	252.0
2	Middle Miocene	Ras El-Bihar	3.1	1.0	—	—	0.68	—	2.2	—	286.0
4	Middle Miocene	Ras El-Bihar	6.1	1.0	—	—	0.62	—	5.3	—	352.0
4	Middle Miocene	Ras El-Bihar	4.7	1.0	—	—	0.57	—	4.0	—	290.0
5	Middle Miocene	Ras El-Bihar	8.6	0.1	—	—	0.61	—	6.8	—	322.0
24	Middle Miocene	Gemsa	1.5	0.7	—	—	0.82	—	0.59	—	269.8
136	Middle Miocene	Hurghada	1.1	0.6	—	—	0.98	—	0.5	—	192.8
144	Middle Miocene	Hurghada	1.0	0.5	—	—	0.95	—	0.36	—	201.6
85	Middle Miocene	Hurghada	2.0	0.67	182.3	113.0	0.82	23.2	1.00	$3.4.10^{-4}$	221.6
59	Middle Miocene	Ras Gharib	0.82	6.6	—	—	0.84	—	0.35	—	73.0

Hydrogeochemická charakteristika slaných vôd západného pobrežia Suezského zálivu

NASRY ZAKY BISHAY

Autor študoval rozšírenie a chemizmus slaných vôd v oblasti západného pobrežia Suezského zálivu.

V prvej časti práce autor stručne opisuje geologické aj tektonické pomery artézskej panvy Suezského zálivu. Všíma si hydrostratigrafické jednotky územia. Pre artézsku nádrž je charakteristická prítomnosť nepriepustných bridlíc a anhydritov stredného miocénu, ktoré dosahujú značné mocnosti a prikrývajú staršie sedimenty. V takejto štruktúre sú priaznivé podmienky na udržanie nafty a plynu.

V druhej časti štúdie autor rozvádza hydrogeochemické charakteristiky podzemných vôd a ich rozdelenie.

Slané vody západného pobrežia strednej artézskej panvy Suezského zálivu sú viazané na núbijské pieskovce, kriedu, miocén, pliocén; sedimenty kvartéru v nich dosahuje 222,4 — 28[illegible] — 253 — 252 a 73 g/l. Vo všeobecnosti sa obsah solí zvyšuje juhovýchodným smerom a do hĺbky. Z grafického znázornenia chemizmu vôd vidieť, že sú to vody chlorido-sodného typu s vysokými koncentráciami brómu (1 250 mg/l) a bóru (411,8 mg/l HBO_2) a zvýšenými koncentráciami jódu a lítia.

Z hydrogeochemických koeficientov je zrejmé, že tieto slané vody sú do určitej miery metamorfované. Je zjavná ich denitrifikácia a desulfatácia. Okrem toho sú tieto vody obohatené vápnikom. Koeficient $\frac{r\,SO_4}{r\,Cl} \cdot 100$ je nízky a klesá s hĺbkou a slanosťou. Pomer r na r Cl je 1, jeho hodnota závisí od stupňa metamorfózy.

Pomery Cl (Br a Be) J sú nižšie ako v morskej vode.

Študovala sa aj možnosť využiť tieto vody na získanie niektorých prvkov a zlúčenín pre priemyselné využitie. Bolo by možné získať bróm, jód a bór a ako vedľajšie produkty aj chlorid horečnatý, chlorid vápenatý, chlorid sodný a draselné soli. Okrem toho možno používať tieto vody aj na balneoterapeutické ciele.