

## CHEMISTRY, MINERALOGY AND MATURITY STATUS OF OBHOR SABKHA, SAUDI ARABIA

CARACTÉRISTIQUES CHIMIQUES, MINÉRALOGIQUES ET STADE D'ÉVOLUTION  
DE LA SEBKHA D'OBHOR (ARABIE SÉOUDITE)

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## Abstract

The mineralogy and pore water chemistry of subsoil of the relatively stronger crustal layer above the watertable and the ground water chemistry at two locations in the coastal clayey sabkha areas of Obhor, Saudi Arabia confirm the predominance of evaporites like halite, gypsum, aragonite and calcite and the trend of progressive sabkhaization from top downwards. Of the two locations studied, Station 1 with higher soluble salts contents (TSS up to 28 %) in soil and interstitial water salinity (up to 384,200 mg/l) is in a well developed sabkha and Station 2 with lower TSS and salinity is in a slightly developed sabkha as per the classification of Bahafzallah *et al.* (1993). Clay mineral montmorillonite was identified as a trace (in bulk powder sample) at 45 cm depth at Station 1 and illite at same depth at Station 2 and further work for clay mineral identification is suggested.

## Résumé

Dans les secteurs côtiers argileux de la sebkha d'Obhor (Arabie Séoudite), l'étude minéralogique de la couche située sous la croûte durcie, ainsi que la composition chimique de l'eau intersticielle qui y est incluse, de même que la chimie de la nappe elle-même confirment la prédominance des évaporites, telles que l'halite, le gypse, l'aragonite et la calcite et la tendance à «sébkhaisation» progressive du haut vers le bas. Sur les deux sites étudiés, le premier contenant un pourcentage de sels solubles plus élevé dans le sol (jusqu'à 28 %) et une salinité de l'eau intersticielle également plus forte (jusqu'à 384,2 mg/l) est situé dans une sebkha déjà bien développée, alors que le second, contenant moins de sels solubles et une eau à salinité plus faible, correspond à une sebkha peu développée d'après la classification de Bahafzallah *et al.* (1993). De la montmorillonite a été identifiée en traces à 45 cm de profondeur dans le premier site et de l'illite à la même profondeur dans le second. L'auteur suggère de poursuivre dans la voie de l'identification des argiles dans le contexte des sebkhas.

## 1. Introduction

The presence and the geotechnically problematic nature of the Red Sea coastal sabkhas of Saudi Arabia have been reported in a number of recent studies (Sabtan and Shehata, 1982; Ali, Kazi & Al-Quhtani, 1985; Ghazali, Fatani and Khan, 1985; Dhowian, Erol and Sultan, 1987; Hossain & Ali, 1988, 1990, etc.). In common with other sabkhas (e.g. Sabkha Abu Dhabi, reported by Bush, 1973), the high salt content of the sub-soil in these sabkhas and the high salinity of their groundwater is also generally recognized. For example, Hossain and Ali (1988) noted a total soluble salt content (TSS) up to 25 % in soil and a total dissolved solids content (TDS) (also termed 'salinity') in groundwater in the range 50,000 to 155,000 mg/l in Obhor Sabkha, located some 40 km north of the port City of Jeddah. Further, Bahafzallah *et al.* (1993) proposed a classification of sabkhas on the basis of sediment composition and the associated groundwater salinity of Dahban Sabkha located north of Obhor, while Sabtan, Al-Saify and Kazi (1995) investigated the effect of salinity on moisture retention characteristics of artificial sabkhas.

In Obhor, there are areas with clayey sabkhas and those with sandy sabkhas (Hossain and Ali, 1988). In the areas with the clayey sabkha a relatively stronger top crust 0.6 to 0.9 m thick occurs above the watertable. Fig. 1 shows the pattern of undrained shear strength variation with depth in the crustal layer and the underlying very soft layer. The crustal part is the product of a combination of geological processes like desiccation, weathering and, above all, cementation of the salts precipitated through evaporation of highly saline groundwater. Khedr (1989) terms such a growth or development of sabkhas through this latter process as "sabkhaization". The presence of such a salt-cemented crustal part is also recognized in other sabkhas (e.g. Arabian Gulf coast sabkhas reported by Kinsman, 1969; Sinai coast Sabkha reported by Gavish 1974). It is expected that the strength of this crustal part will depend, among other factors, on the sediment mineralogy and the type and amount of different salts present therein. However, there are no published quantitative data on the mineralogy and geochemistry of the sub-soil of Obhor and other sabkhas along the Red Sea coast and on the geochemistry of their interstitial water except a few compositional data for Obhor

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boiled for five minutes and then filtered. The filtrate was put in a 500 ml volumetric flask, which was then filled by adding distilled water. This solution was then used to determine carbonate ( $\text{CO}_3$ ), bicarbonate ( $\text{HCO}_3$ ) chloride ( $\text{Cl}$ ), sodium ( $\text{Na}$ ), potassium ( $\text{K}$ ) total soluble salts in water (TSS), and  $\text{p}^{\text{H}}$ .

The same quantity of soil from the selected sample was placed in 75 ml of (30%) hydrochloric acid ( $\text{HCl}$ ) and boiled for ten minutes and then filtered. The filtrate was put in a 250 ml volumetric flask which was filled by adding distilled water. This solution was used for measurement of sulphate ( $\text{SO}_4$ ), calcium ( $\text{Ca}$ ), magnesium ( $\text{Mg}$ ), sodium ( $\text{Na}$ ), potassium ( $\text{K}$ ) and total soluble salts in  $\text{HCl}$  (TSS).

#### ii) Soil specimen for XRD

Bulk powder specimens were prepared for XRD by drying the soil samples in the oven and crushing in a mortar.

#### iii) Pore water specimens

The pore water specimens were extracted by squeezing each bulk sample (having a mass of a few kg) held in a 102 mm diameter standard compaction mold by a piston using a compression machine and following the procedure of Bahafzallah *et al.* (1993) and then filtering.

### 3. Method of analysis

#### A - Chemical analysis

After preparing solutions of soil samples, and pore water samples, the procedures described by Vogel (1978) were followed in the subsequent steps of analyses as detailed by Al-Ghamdi (1993).

#### B - XRD analysis

A Phillips X-Ray diffractometer of the United States Geological Survey (USGS), Jeddah (who work as consultants to the Deputy Ministry of Mineral Resources, of the Govt. of the Kingdom of Saudi Arabia) was used for these analyses. This follows a standard computerized procedure used for XRD analysis of powder samples. Its generator settings are 45 kV, 35 mA, while its step size and count time are 0.1 degree and 1.00 second respectively. A 2-theta range from 5.05 to 84.95 degree was used in this work.

Table 2 : Soil chemical analysis.

Station	Depth (cm)	TSS (%) in		$\text{Cl}^-$	$\text{HCO}_3^-$	$\text{SO}_4^{2-}$	CaO	MgO	$\text{Na}_2\text{O}$ (%) in		$\text{K}_2\text{O}$ (%) in	
		HCL	Water						HCL	Water	HCL	Water
1	7.5	94.40	27.75	11.88	0.16	28.79	18.64	5.59	8.06	8.78	0.19	0.16
	22	95.20	14.33	3.33	0.22	27.47	18.12	4.09	12.40	1.91	0.13	0.14
	45	97.10	15.39	4.00	0.19	27.67	21.48	6.68	2.86	2.90	0.19	0.11
	66	100	13.25	7.19	0.33	0.57	18.96	7.48	5.58	5.63	0.57	0.22
	100	100	13.83	5.94	0.18	7.86	33.26	5.95	4.07	4.74	0.20	0.16
2	5	100	20.28	5.42	0.26	22.48	24.80	6.86	7.43	4.21	0.16	0.09
	45	90.47	7.42	4.27	0.43	0.51	10.11	8.22	3.33	3.55	0.67	0.18
	75	100	4.47	2.60	0.32	0.48	40.68	3.89	1.90	2.05	0.20	0.11
3	1	20.65	0.37	0.38	0.20	0.29	0.87	3.02	0.12	0.09	0.06	0.01
4	1	49.25	16.47	2.92	0.21	11.19	9.27	3.63	1.89	0.18	0.10	0.04

### 4. Geochemical results

Chemical results of the major oxides and important anions in the analyzed soil samples are presented in Table 2 and illustrated in Figs. 2 to 4. The chemical contents shown are in terms of percentages of dry weight of soil used. The plots of anions contents (i.e.  $\text{SO}_4$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ) and the oxides of the major cations (i.e.  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ ) against depth for Stations 1 & 2 in Figs. 2 and 3 show that every two or three ion types form a group with comparable values and similar pattern of variations with depth at both stations. Thus  $\text{CaO}$  and  $\text{SO}_4$  represent the major group with values in the range of 18 to 28% near surface at the two stations. At Station 1,  $\text{CaO}$  tends to increase slightly with depth below ground surface reaching a value of about 33% at 100 cm depth, but at Station 2, it decreases to 10.1% at 45 cm depth and then increases to 41% at 75 cm depth. However, the  $\text{SO}_4^{2-}$  content at Station 1 remains high at around 28% within the top 45 cm depth and then decreases abruptly to 0.6% at 66 cm depth and then increases to 8% at 100 cm. In contrast, at Station 2, the  $\text{SO}_4^{2-}$  content decreases from 22% at 5 cm depth to 0.51% at 45 cm and remains almost unchanged at 75 cm depth.  $\text{Na}_2\text{O}$ ,  $\text{Cl}^-$  and  $\text{MgO}$  represent the minor group with values in the range of 2 to 12.4% in crust that decrease to values in the range of 1.9 to 8.2% at greater depths at Station 1 and in the range

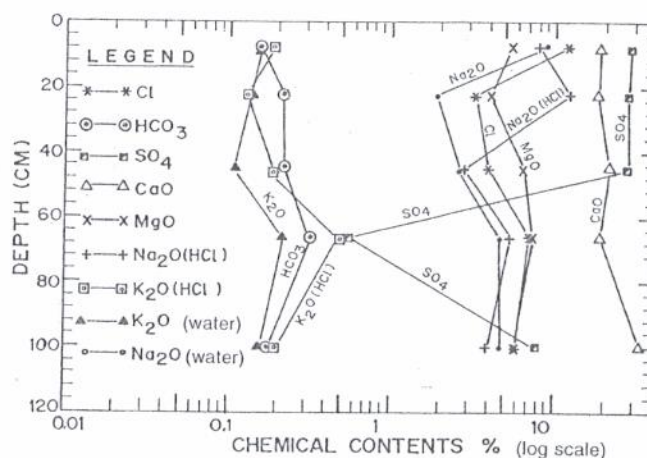


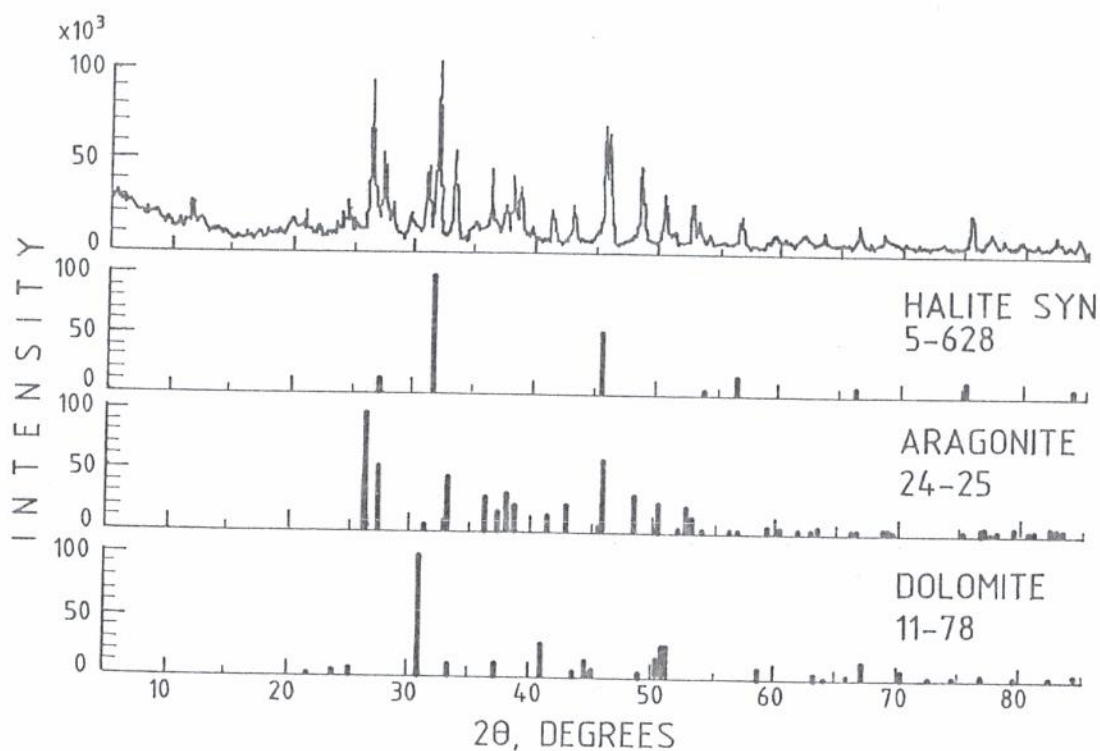
Fig. 2 : Plot of chemical contents of soluble soil matter versus depth for Station 1.

Table 3 : XRD results.

Lithology	station No.	Sample No.	Sample Depth, cm	Minerals		
				Major	Minor	Trace
Sabkha	1	1.1	7	Gy	*	Ha, Qu
		1.2	22	Gy	Ha	Ba, Qu, Al
		1.3	45	Gy	Ha	Ar, Al, Ha, Mo
		1.7	66	Ha	Ar, Do, Ca, Al	Na, Gy, CC, No
		1.9	95	Ha, Do, Ar	Us, Cl, Qu, Di, Hp	Hd, Ba
	2	2.1	5	Gy	Ha	Do, Di
		2.2	45 natural	Qu, Do	Ha, Ca, Al	Ko, Ri, CC, Re
		W2.2	45 washed	Qu, Do	Ca, Al	Ma, Ra, CC, Il, CH
		2.3	75	Ca, KCa	Ne, Ar, Qu, Or, Ha	Al, CC, Zi, No
Sand	3	3.1	5	Qu	Al	Mi, CC, Ma, No
	4	4.1	5	Qu	Mi, Al, An	Ha, Gy, CC, Re

Al : Albite	Di : Diopside	Ko : Korzhinskite	Or : Orthoclase
An : Anhydrite	Do : Dolomite	Ma : Magnesioriebeckite	Qu : Quartz
Ar : Aragonite	Gy : Gypsum	Mi : Microcline	Ra : Ramsdellite
Ba : Bassanite	Ha : Halite	Mj : Majorite	Re : Rectorite
Ca : Calcite	Hd : Hydromolysite	Mo : Montmoril	Ri : Richterite
CC : Clinoclore	Hp : Hypersthene	Na : Natrophilite	Us : Usovite
CH : Chamosite	Il : Illite	Ne : Nepheline	Zi : Zincite
Cl : Clintonite	KCa : Kutnohrite calcite	No : Nontronite	

Fig. 5 : Typical diffractogram of XRD of halite and aragonite rich sample from Station 1 scanned in the  $2\theta$  range of  $5^\circ$  to  $85^\circ$ .

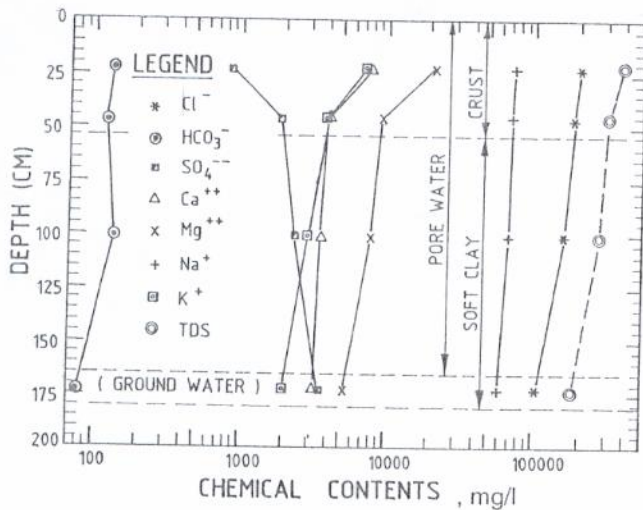


Fig. 7: Chemical characteristics of pore water and groundwater for Station 1.

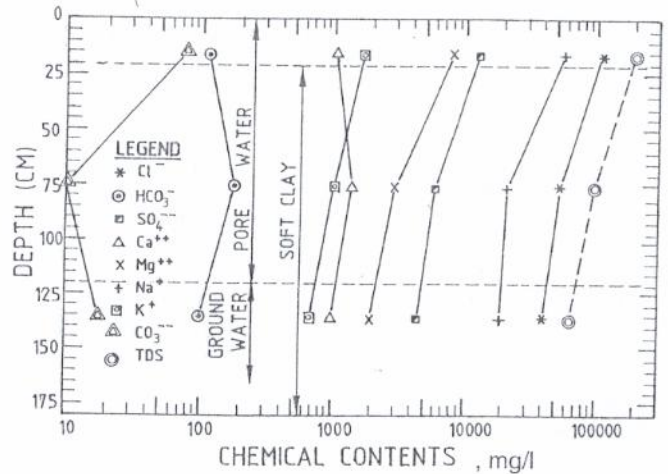


Fig. 8: Chemical characteristics of pore water and groundwater for Station 2.

the contents of  $\text{HCO}_3^-$  at Station 1 and those of  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  at Station 2 are in the range of 18 to 183 mg/l.

The observed values of cation and anion contents of pore water are generally higher than those of groundwater except for  $\text{SO}_4^{2-}$  at Station 1, whose concentration in groundwater (i.e. 3600 mg/l) is more than that in pore water (800 to 2400 mg/l). The pattern of  $\text{SO}_4^{2-}$  concentration variation between the crustal pore water and the underlying groundwater at Station 1 agrees with the finding of Bahafzallah *et al.* (1993) but that at Station 2 appears to be at variance; this needs further verification.

## 7. Discussion

Investigations into the various aspects of the Red Sea coastal sabkhas of Saudi Arabia is the subject of continuing research in the Faculty of Earth Sciences in the King Abdulaziz University and the understanding of the full implication of the observed pattern of soil mineralogy and soil and pore water chemistry including their expected geotechnical behaviour is still incomplete. However, the predominance of evaporites like halite, gypsum, aragonite and calcite in the studied crustal parts at Stations 1 and 2 and their absence in the surface samples of non-sabkha areas confirm the existence of the sabkhaization process at these two stations. Further, these results shed light on the maturity status of the Obhor Sabkha areas in which these two stations are located. Thus the observed higher TDS in both the pore water and groundwater at Station 1 compared to the corresponding ones at Station 2 confirms the well developed nature of sabkha at Station 1 vis-a-vis the slightly developed nature at Station 2 as per the classification of Bahafzallah *et al.* (1993) who specifies groundwater salinity of > 120,000 mg/l and 30,000-45,000 mg/l for these two classes.

The observed trend of decrease in most of the pore water anion and cation contents and TDS with depth and the similar trend in TSS of soil of the soil layer above the water table confirm the dominant effect of evaporation which

leads to greater brine concentration and salt deposition at smaller depths. This suggests that sabkhaization starts at or near the ground surface and progresses downwards with time i.e. a trend of progressive sabkhaization downwards, within the crust.

## 8. Conclusions

The observed mineralogy and pore water chemistry of subsoil above the watertable and the TDS of groundwater at two locations in Obhor Sabkha indicates that:

- 1) The predominance of evaporites like halite, gypsum, aragonite and calcite at Stations 1 and 2 and their decrease with increasing depth prove the sabkha nature of the subsoil at and around these stations in Obhor and the trend of progressive sabkhaization from top downwards.
- 2) Station 1 with higher soluble salts contents (TSS) (up to 28%) in soil and interstitial water salinity (up to 384,200 mg/l) is in a well developed sabkha, and Station 2 with lower TSS and salinity is in a slightly developed sabkha.
- 3) Clay mineral smectite was identified as a trace (in bulk powder sample) at 45 cm depth at Station 1 and illite at same depth at Station 2.
- 4) Further investigation is necessary for more detailed knowledge of the clay minerals and understanding of the ongoing sabkhaization process in this sabkha.

## References

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