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A Siliciclastic Coastal Sabkha, Red Sea Coast, Saudi Arabia

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ABSTRACT. A modern, siliciclastic sabkha occupies the widespread, low lying and almost flat area to the east of Al-Kharrar lagoon on the west of Saudi Arabia. Four sedimentary facies were recognized in shallow cores: (1) surface sand layer associated with halite crust; (2) light brown clayey-sandy unit displaying interstitial evaporatic minerals; (3) grey calcareous sandy unit which represents sediments accumulated during marine transgression; and (4) basal poorly sorted gravely-clayey sands of continental origin (Pre-Holocene alluvial deposits). The thickness of the sabkha and marine-lagoonal facies (facies 1, 2, 3) in general decreases towards the south and east.

There are two evaporative assemblages in the studied sabkha. The first assemblage occurs in the southern part and includes gypsum, high Mg-calcite and dolomite. It has formed through reworking of the sediments by flood water from the lagoon and subsequent rapid evaporation. The absence of aragonite in the surface sediments and its presence in those of the subsurface indicate that not only penecontemporaneous alteration of aragonite to dolomite but also later diagenetic processes have been active. The second assemblage in the central and northern parts of the sabkha is dominated by gypsum and high Mg-calcite in the surface sediments. Aragonite occurs only in subsurface sediments. Mg concentrations did not reach a level to initiate diagenetic dolomitization.

The observed mineralogical distribution is typical for coastal-marine evaporative system.

Introduction

Accumulation of extensive sedimentary evaporites has been attributed to primary and diagenetic processes involving sea-derived brines. So far there is full agreement on the need for the proper environment in which evaporation may produce the saline brines and that the primary precipitation could be the major process of evaporite formation. There is however still uncertainty in the literature about the exact processes and environments in which these evaporites may form and the major factors influencing them. The major environments of evaporite accumulation considered until now have been the shallow marine shelves, enclosed basins and supratidal sabkhas. In recent years, studies of modern equivalents of such environments have shown the evaporites to form mainly in supratidal sabkhas, thus adding more credibility to this type of environment (Dean *et al.* 1975, West *et al.* 1979, Rouse and Sherif 1980, Yehia and West 1983, Warren and Kendall 1985). These studies were carried out on the coasts of arid to semi-arid areas where evaporation is intensive and sea water resupply is possible.

A clear restriction has been made in the literature between the continental and coastal sabkhas (Kinsman 1969). The continental sabkhas are formed by concentration of airborne salts in local basins with internal drainage and high water table.

The coastal sabkhas have been studied more intensively than the continental sabkhas. On the basis of their morphology and hydrodynamics Gavish (1980) classified them into two types :

a. Open supratidal environment with unrestricted and continuous hydrodynamic flow regime. In these sabkhas brines form a saline ground water table which extends continuously from the edge landwards. The brines get into the sediment by continuous subsurface seepage and sometimes by occasional floods. This type of sabkha typically occurs in the Persian Gulf and has been studied extensively by a number of investigators (Illing *et al.* 1965, Kinsman 1964, 1969, Wood and Wolfe 1969, Purser 1973).

b. Sea marginal brine pans (pools) with restricted and uneven marine water supply. These types of sabkha pools have been studied in the Pakelmeer Lake in Bonaire (Deffeyes *et al.* 1965, Murray 1969), in the Emphemeral Lakes of the coorong district (Skinner 1963, Alderman 1965), in the Solar Lake on the southern coast of Sinai, Red Sea, and more recently in the Ras Shukhier pool, west Gulf of Suez, Egypt (Keheila *et al.* 1989).

In spite of the dominance of both types of coastal sabkhas on the Red Sea coast of Saudi Arabia (Jado and Zotl 1984) however they remained relatively untouched and there is a conspicuous lack of knowledge on hydrochemistry, mineral reactions and sedimentation processes in these coastal environments. Therefore, the purpose of this paper is to record the occurrence of sedimentary evaporatic minerals within siliciclastic sediments that were deposited in a Red Sea coastal sabkha.

The studied sabkha is located immediately to the east of Al-Kharrar lagoon on the coastal plain northwest of Rabigh on the west coast of Saudi Arabia (Fig. 1). This coastal lagoon is connected to the Red Sea by a narrow channel on the northwestern side.

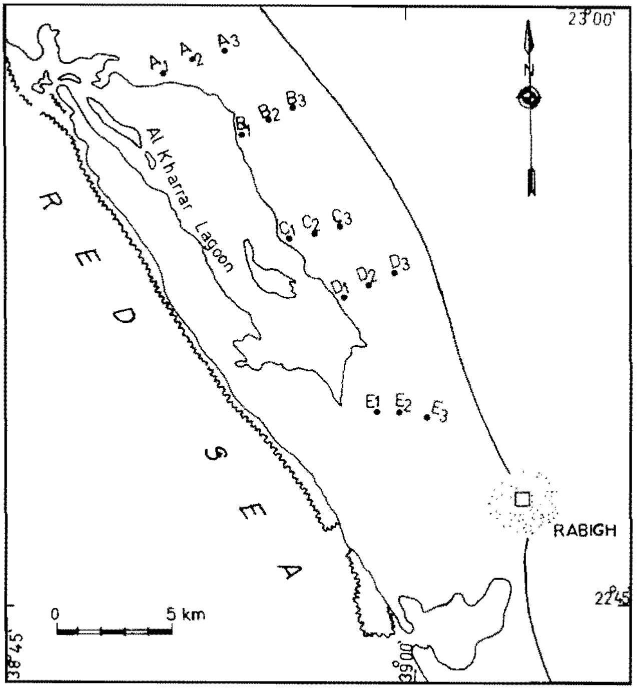

FIG. 1. Location of sediment cores and water samples in sabkha Al-Kharrar.

The lagoon water enters the sabkhas by continuous subsurface seepage and sometimes by occasional floods. In some places, particularly in the northeastern part, an elevated sandy berm separates the sabkha from the lagoon. In this part, the low lying areas of the sabkha nearer to the lagoon are occasionally filled with water and subsequently evolve in the brine pools. The bottoms of these brine pools are covered with algal mats. Areas away from the lagoon are covered by a layer of permanently moist sediments. In the southern and southeastern sections where the sandy berm is absent, the lagoon water floods the sabkha which after evaporation, will be covered with a thin sheet of white salt crust. This salt crust will be dissolved in the next flooding but reappears after a few days creating a cycle process.

As the subsurface water mainly originates from the adjacent lagoon, the ground water level in the sabkha remains almost at the lagoon water level. Pits dug in different parts of the sabkha showed that the underground sea water extends more than 1 km landwards.

Climate and Hydrography

A hot arid climate is dominant in the west coast of Saudi Arabia. The air temperature during the sampling period varied from 31 to 35°C and the sabkha surface temperatures are higher with values of more than 50°C. Relative humidity varies from a maximum of 68% during summer to a minimum of 50% during winter. Daytime humidities are significantly higher than those at night. Precipitation is scarce (average 6 cm y^{-1}) and evaporation is intense (205 cm y^{-1}), the evaporation rates are higher in the intertidal flats, which are inundated only during high tide (Behairy *et al.* 1980). Even though the tidal range of the Red Sea near Jeddah is low (30 cm), flood waters during high tide cover large areas of sabkha Al-Kharrar. Prevailing northern and northeastern winds influence the movement of the lagoon water to the adjacent sabkha, particularly during storms. Because of the low tidal range the lagoon water inundates the sabkha as a sheet and not through a network of tidal channels that are common on coasts with high tidal.

Daytime water temperatures in the lagoon during the sampling period in April and May 1988 were around 29°C. However, the temperatures of isolated evaporative pools water and the sabkha subsurface waters have considerably higher temperatures, ranging from 32 to 35°C and from 35 to 44°C, respectively. The salinities of the lagoon waters vary around 40%, although more saline waters (about 43%) sometimes occur in the southern parts of the lagoon whereas the salinity of sabkha waters ranges between 51 and 54%. Furthermore, the waters of isolated pools have salinities (about 133%) several times higher than those of the lagoon and sabkha subsurface waters. The pH in the intertidal lagoon water ranges between 8 and 8.1 and in the evaporitic pools about 8.78. The pH of the subsurface water decreases landwards from about 7.5 in the lagoon margin to 6.4 in station D_3 (Fig. 1).

Material and Methods

During April and May 1988, several field trips were made to the sabkha Al-Kharrar to collect sediment and water samples. Sediment cores were obtained at 12 stations by driving plastic tubes down to a depth of about 2 meters with a hammer. To prevent the sediment from falling out during recovery of the tube, the top was sealed with a tight rubber stopper. Long sediment cores down to depths of 7 to 11 meters were obtained by auger drilling (Fig. 1).

Water samples were collected from the shallow bore-holes immediately after the sediment cores were retrieved. They were also collected from the isolated brine pools and from the lagoon. pH and temperature measurements were performed during the sampling. Immediately after brine water collection in the field, the solution was filtered with a membrane filter (0.45 μm) using a polycarbonate filter holder, and a portion of the filtered brine water was diluted 10 times to avoid crystallization of salts. The water was transferred to tightly sealed bottles. In the laboratory, the sealed bottles were refrigerated until analysis could be performed. All analyses were completed within 6 months of taking samples.

Chlorinity was measured on diluted samples using the classical gravimetrical methed like $BaSo_4$ Alksliniy was measured by potentiometric titration. Ca and Mg were determined by atomic absorption spectrophotometry.

Representative sediment samples from cores were subjected to microscopical analyses and x-ray diffraction. In addition, sand and mud content and total carbonate concentrations were estimated.

Sedimentary facies

The spatial arrangement of the facies is observed in the vertical profile of the cores taken from the sabkha. Four distinct lithological units can be recognized (Fig. 2).

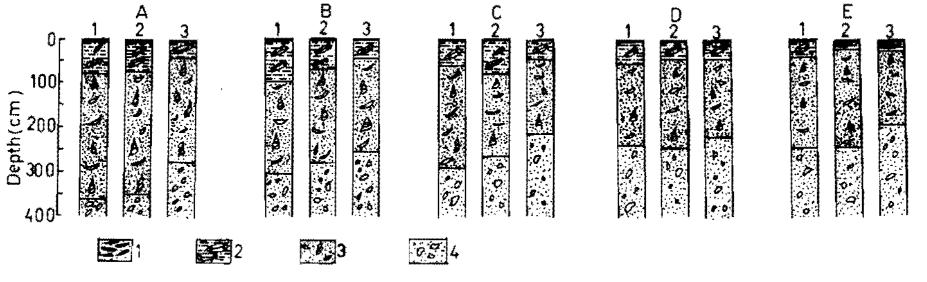

FIG. 2. Thickness and sedimentary facies of the cores in sabkha Al-Kharrar (1 = Unit I, 2 = Unit II, 3 = Unit III, 4 = Unit IV).

An uppermost unit of the surface quartz sand is usually up to 20 cm thick and commonly cemented by halite. Locally, the sand is mixed intimately and incorporated into algal mats.

The second unit (20 cm - 1 m thick) is composed mainly of light brown medium to fine sands and clays. This unit is characterized by the presence of evaporitic minerals.

The third unit (1.5-3.7 m) consists predominantly of grey coloured medium to fine sands with abundant amounts of shells and shell fragments. This unit contains less clay material than the former.

The basal unit shows a distinctive appearance of alluvial deposits of Pre-Holocene (Jado and Zotl 1984) and is composed mainly of reddish brown clastic sands with some gravels and clay of continental origin.

In general, it is clear from Fig. 2 that the thickness of both the second and third units decreases remarkably towards the south and the west.

Mineralogy

Microscopic examination and x-ray diffraction scans of the sediments showed that the bulk mineralogy of the sabkha Al-Kharrar sediments is composed mainly of quartz, feldspar, high Mg-calcite, calcite, gypsum, halite, dolomite and aragonite (Fig. 4). The major evaporite and carbonate components in the upper first meter of these sediments are unevenly distributed with depth as seen in Fig. 3, where evaporitic minerals show a distinct distribution pattern. Gypsum is present only in the top sediments (0-30 cm). High Mg-calcite is the common carbonate mineral in all the sabkha sediments, but its proportions may locally be very low. Contrary to high Mg-calcite, aragonite is very rare and is found mainly in the subsurface sediments of the central and northern parts of the sabkha. Dolomite occurs both in surface and subsurface sediments but is confined mostly to the southern part of sabkha. Detrital quartz and feldspars occur in almost all the surface and subsurface sediments of the sabkha.

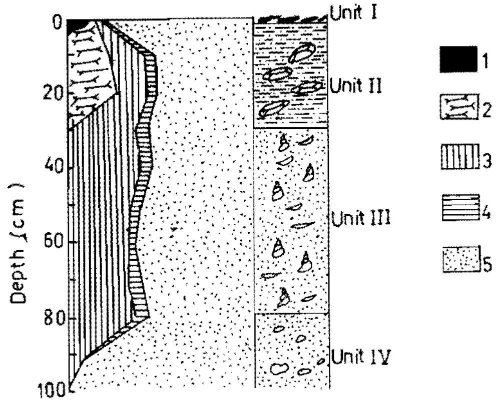

FIG. 3. A profile of a typical supratidal sabkha along Al-Kharrar lagoon showing the distribution of the major minerals in its different layers (1 = halite; 2 = gypsum; 3 = high Mg-calcite; 4 = calcite + aragonite; 5 = silicates).

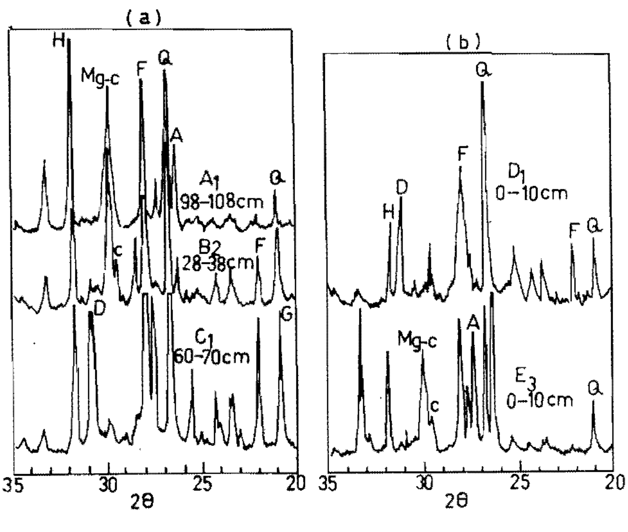

FIG. 4. Typical x-ray diffraction patterns of sabkha Al-Kharrar sediments (G – gypsum, Q – quartz, A – aragonite, F – feldspar, C – calcite, Mg-C – high calcite Mg, D – dolomite, H – halite).

The sediments in the areas that are directly influenced by the lagoon water during flooding are characterized by a dolomite assemblage whereas those in the areas influenced by lagoon water through seepage are characterized by an aragonite assemblage.

The minerological assemblage of the suspended sediments in the evaporitic brine pools in the sabkha is dominated by halite, dolomite, high Mg-calcite and some gypsum (Fig. 5).

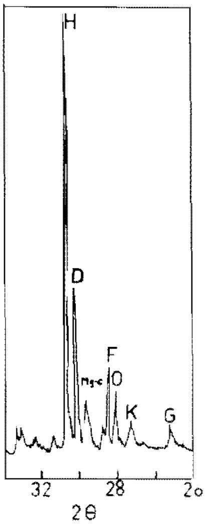

FIG. 5. X-ray diffraction pattern of a brine pool suspended sediment from sabkha Al-Kharrar (G – gypsum, Q – quartz, F – feldspar, Mg-C – high Mg calcite, D – dolomite, H – halite).

Apart from the minerals described above, clay minerals are recorded in the fine fractions of the sabkha sediments. The main species of these minerals in decreasing abundance are illite, kaolinite and chlorite. Palygorskite was recorded in minor amounts in some sediments (Fig. 6).

Geochemistry

The distribution pattern of chlorinity, density and Mg/Ca, Ca/Cl, SO_4^{-2}/Cl molar ratios in the sabkha surface water, evaporite pools water and Al-Khàrrar lagoon water are presented in Fig. 7.

Chlorinity

From the lagoon margin across the sabkha, the brine chlorinity generally rises to a maximum and decreases again towards the inland margin (Fig. 7). Similar results have been observed in other sabkhas (*e.g.* Butler 1969, Gavish 1980).

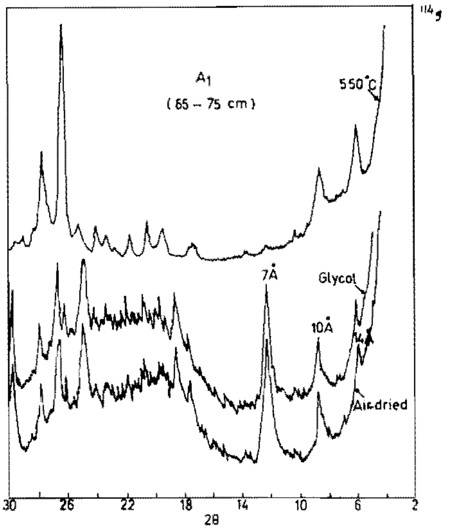

FIG. 6a. Typical x-ray diffraction pattern of clay fraction of sabkha Al-Kharrar sediments (depth: 65-75 cm).

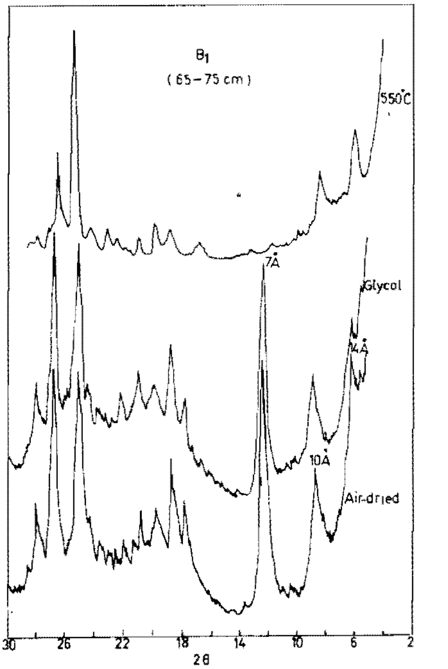

FIG. 6b. Typical x-ray diffraction pattern of clay fraction of sabkha Al-Kharrar sediments (depth: 65-75 cm).

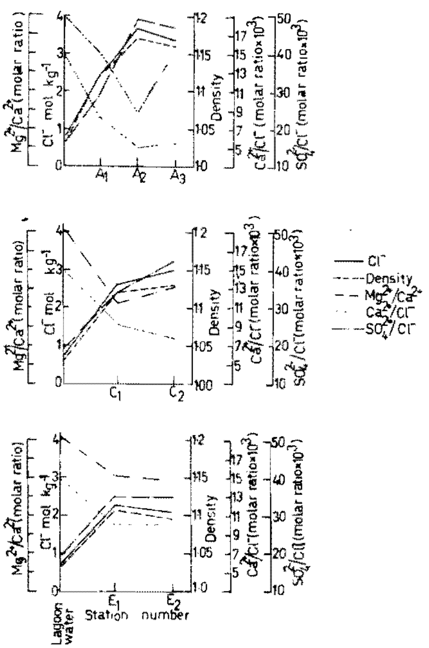

FIG. 7. Variations in chlorinity, density, Mg/Ca, Ca/Cl and SO_4^{-2}/Cl^- molar ratios in the subsurface waters at different stations in sabkha Al-Kharrar.

Sulphate and calcium ratios

SO_4^{-2}Cl and Ca/Cl ratios in the subsurface waters generally decrease towards the inland margin. Such a decrease is due to the precipitation of calcium carbonate and gypsum in the sabkha sediments.

Magnesium/Calcium ratios

Mg/Ca ratios in the subsurface waters are relatively higher than those of sea water and lagoon water. The high Mg/Ca ratios are attained by the precipitation of calcium ions as carbonate and sulfate. Brines with high Mg/Ca ratio could form dolomite. Bush (1973) stated that when the Mg/Ca ratio reaches approximately 10:1, dolomitization of fine-grained aragonite occurs to produce fine-grained dolomites.

Discussion

The sedimentary sequences in the sabkha of Al-Kharrar indicate that water level variations in the lagoon associated with sea level fluctuations in the Red Sea and variations in the supply of clastic material from the adjacent mountains produced a variety of sedimentary facies. During the Holocene transgression, alluvial deposits (the basal unit) were flooded by Sharm Al-Kharrar waters and a shallow lagoonal environment was developed (Behairy 1983). In this environment, the third facies with carbonate sediments was deposited. The carbonate were mixed with clastic sediments derived from the coastal plain in various proportions. Deposition of these grey muddy sands continued until the lagoon became very shallow and further accumulation of sediments was prevented by the action of waves and currents. Sediments was transported by waves and currents to be deposited at the margins of the lagoon to form intertidal flat, this resulted in the lateral filling of the lagoon and progradation of coastline and wide intertidal and supratidal flats developed, creating conditions favourable for the apperance of evaporitic environments. Thus, early carbonate sediments of sabkha Al-Kharrar represent the transgressive phase and the later evaporite sediments the regressive phase of a cycle. Varying thickness of the facies(2-3 meter) in the sabkha suggests an irregular surface of the Pre-Holocene substrated. Furthermore, the wide variations in grain-size characteristic of the bottom alluvial deposits indicate significant changes in the Pre-Holocene drainage conditions in the area.

The grey colour of the third unit suggests that organic matter was also deposited during this period. The non-carbonate sedimentation appears to have varied from time to time and from place to place resulting in significant variations in the total carbonate concentrations of the sediments (Fig. 8 and 9). The low carbonate values in the top sediments show that the carbonate depositional environments changed to an evaporitic environment. Lack of foraminifera in these sediments supports such conditions of sediment deposition under high saline waters (Abou-Ouf, personal communication).

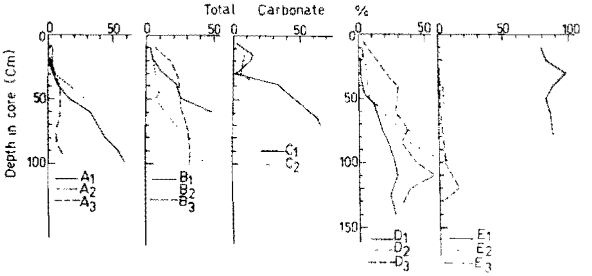

FIG. 8. Down core variations of total carbonate in different layers of the sediments from sabkha Al-Kharrar.

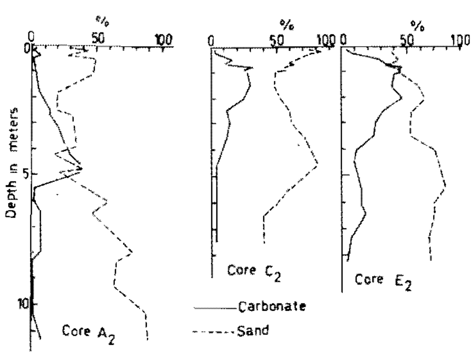

FIG. 9. Vertical distribution of coarse fraction (> 63 microns and total carbonate of sediments in cores from sabkha Al-Kharrar.

The two evaporite mineral assemblages recorded in the sabkha Al-Kharrar appear to be related to the degree of restriction in the availability of lagoon water. In the southern and south-eastern parts, the lagoon waters flooding the sabkha are rapidly evaporated to a degree that permits high Mg-calcite and dolomite to have been precipitated in addition to gypsum. These conditions are comparable to the isolated brine pools where a closed evaporite system result in concentrated brines rich in Mg and leads to precipitation of Mg-calcite, gypsum and dolomite. Absence of aragonite in these two places suggests that either the high Mg concentrations prevented aragonite formation or to the penecontemporaneous transformation of aragonite to dolomite. Guantilaka *et al.* (1984) reported penecontemporaneous replacement of aragonite by dolomite in a subtidal environment of a hypersaline lagoon in Kuwait. However, the occurrence of aragonite in some of subsurface sediments indicates not only penecontemporaneous replacement but also later diagenetic processes. Levy (1977) noticed that dolomite occurring in some of the sabkhas was formed diagenetically through the interaction between formerly precipitated calcium carbonates and concentrated marine brines rich in magnesium.

In the central and northern parts of the sabkha both aragonite and dolomite are absent in the surface sediments where gypsum and high Mg-calcite dominate. However, aragonite occurs in the subsurface sediments. Dolomite is noticed only in one subsurface sample away from the lagoon. Such a distribution pattern of the minerals indicates evaporation from sea water. Gavish (1980) noted that increase in the concentration of brines as they move upwards causes firstly the precipitation of carbonates, then above of them sulphate and finally halite (Fig. 3). The lagoon water enters the sabkha through subsurface seepage and becomes concentrated by evaporation through the sediment cover. The mechanism of evaporative pumping (Hsu and Siegenthaler 1969; Hsu and Schneider 1973) is responsible for the upward migration of the concentrated lagoon water. Furthermore, the increasing salinities of the subsurface waters landward maintain the flow of water from the lagoon to the sabkha. Lack of direct supply of lagoon water and evaporation at the surface such as in the southern part of the sabkha might have prevented the development of concentrated brines rich in Mg for the formation of dolomite. Persistence of aragonite in the subsurface sediments also indicates that Mg concentrations did not reach a level to initiate diagenetic dolomitization of aragonite. This hypothesis is supported by hydrochemical data (Fig. 7) which show lower Mg/Ca molar ratio of the subsurface waters in these parts of sabkha compared to the southern region and to the evaporitic pools.

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سبخة شاطئية سليسية على شاطيء البحر الأحمر بالمملكة العربية السعودية

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المستخلص . هنـاك سبخـة شاطئية سليسية حديثة في منطقة منخفضة نسبيًا ومسطحة تقريبًا تقع شرق لاجون الخرار على الساحل السعودي للبحر الأحمر . ولقد أوضحت دراسة هذه السبخة أنها تحتوى على أربع سحن رسوبية هي كالآتي :

١ - طبقة من الرمل بها قشرة ملحية .
٢ - طبقة رملية لونها بني فاتح توضح معادن المتبخرات .
٣ - طبقة رملية جيرية ذات لون رمادي تمثل فترة الغمر البحري .
٤ - طبقة قاعدية تتكون من الرمال المختلطة بالطين والحصى ذات أصل قاري .

ولقد أوضحت الدراسة أيضًا أن هناك صحبتين من معادن المتبخرات ، الأولى توجد في الجـزء الجنـوبي من منـطقـة الـدراسة وتشمل المعادن الآتية : الجبس والكالسيت الغني بالمـاغنسيوم والدولوميت .

ولقد تكونت هذه المعادن نتيجة لتعرض الرواسب الشاطئية للمياه المتقاذفة من اللاجون والتبخير المتعاقب لهذه المياه . أما الصحبة الثانية فتوجد في الجزء الأوسط والشمالي من منطقة الـدراسة وتتميز بأنها يشيع بها الجبس والكالسيت الغني بالمـاغنسيوم وذلك في الرواسب السطحية . أما الأراجونيت فيوجد فقط في الرواسب تحت السطحية .

إن توزيع المعادن في هذه السبخة يوضح نظاما نموذجيا للتبخير الشاطيء - البحري .