RECENT SEDIMENTS FROM A COASTAL POND, EASTERN MARGIN OF THE DEAD SEA, JORDAN

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ABSTRACT: A marginal pond on the eastern coast of the southern part of the Dead Sea in Jordan receives fresh and thermal waters from adjacent areas. The pool has a narrow "intertidal" zone in which halite-encrusted stromatolites flourish. The muddy sediments of the pond consist of a mixture of detrital clay minerals and calcite with authigenic halite and dolomite. The association of halite with dolomite supports the assertion that dolomite is an evaporitic mineral. The absence of gypsum in these sediments is attributed to bacterial reduction of sulfates.

INTRODUCTION

Marginal ponds, lakes and lagoons must have formed along the shores of the Dead Sea throughout much of its history. Judging from the nature of the sediments found in the Dead Sea area, there have been several fresh and brackish water lakes in the region. Bentor (1961) and Begin (1975) reported the presence of a Lower Pleistocene fresh water body - Samra Lake. The most significant was the Lisan Lake, which represents the major Pleistocene precursor of the Dead Sea. This lake exceeded 225 km in length and 17 km in width. The lake reached depths of about 200 m at the stage of maximum development. The main sediments of Lisan Lake are thinly laminated aragonite and gypsum with diatomite (Begin et al. 1974; Kaufman et al. 1992).

The deposits of these fresh-water bodies are sand and mud of fluvial and lacustrine origin with fresh water fossils (Bentor 1961; Abed 1985). Some of the ponds are of particular interest because they represent an environment of mixing of the salt water of the Dead Sea with fresh water coming from the nearby land. They are therefore peculiar environments in terms of both organisms and sediments.

According to Salameh (1997), the eastern shore of the Dead Sea is the result of stream erosion that deposited large volumes of fluvial sediments in shallower parts of the subsidizing lakes predating the Dead Sea. Livant and Kronfeld (1990) described the carbonate sediments of small Pleistocene lakes preserved in the margin of the Arava Valley. Almogi-Labin et al. (1992) reported the presence of the foraminifera *Ammonia beccarii* in a small hypersaline inland pool on the Israeli side of the Dead Sea Rift.

The main control on the sediment characteristics of these environments is the introduction of fresh water. Rosenthal et al., (1989) attempted to reconstruct the geologic history of some Quaternary fresh water lakes in the Dead Sea Rift using the isotopic composition of gastropod shells recovered from them. They suggested that the lakes were fed by a drainage system cutting through Late Eocene and Jurassic carbonates or through basalt. In some cases, where the influx of fresh water was high, a considerable change in the water level of the Dead Sea itself was reported. Oren et al., (1995) described a bloom of the green algae *Dunaliella parva* on the surface water of the Dead Sea during the winter of 1991-1992 due to floodwaters. This influx diluted the surface water to about 70% of its original salinity. Yakir and Yechieli (1995) reported a plant invasion of the newly exposed lowstand margins of the Dead Sea making use of frequent floods of rainwater. Nissenbaum et al., (1990) suggested that the pore-water of Dead Sea sediments contributes more than 80% of the ammonia and 30% of the phosphate content of Dead Sea water. This continuous enrichment may be responsible for the frequent outbreaks of algal blooms.

AIM

This study documents the general setting of a small marginal pond on the eastern shores of the Dead Sea and investigates the nature of its Recent sediments and their biological components. The study explores the unique sedimentary environment of the pond, in which hydrothermal water mixes with saline water from the Dead Sea leading, eventually to the formation of dolomite.

STUDY AREA

The area studied is a salt marsh located at the southern end of the Dead Sea on the Jordanian side of the political boundary, just south of the Arab Potash Company Township, (Fig. 1). Within the salt marsh is a pond about 6 meters long and 3 meters wide. It has a small "intertidal" zone containing algal mats ringed by Recent alluvial (sand and gravel) deposits. Its margins are covered with halophytic shrubs. During the rainy season, some fresh-water vegetation also thrives briefly. The salt marsh was probably covered by the Dead Sea until its shrinkage during the last few years.

The area to the east is heavily faulted with rocky outcrops of the Cambrian Burj Dolomite-shale, and Umm Ishrin Sandstone, Cretaceous limestone and cherty limestone and Tertiary conglomerates and sand. There are several valleys draining into the Dead Sea from this region. The largest of these is Wadi Issal (lower right, Fig. 1). Landward, the pond is accessible from the Safi-Mazraa Road that runs parallel to the

Carbonates and Evaporites, v. 17, no. 1, 2002, p. 79-86.

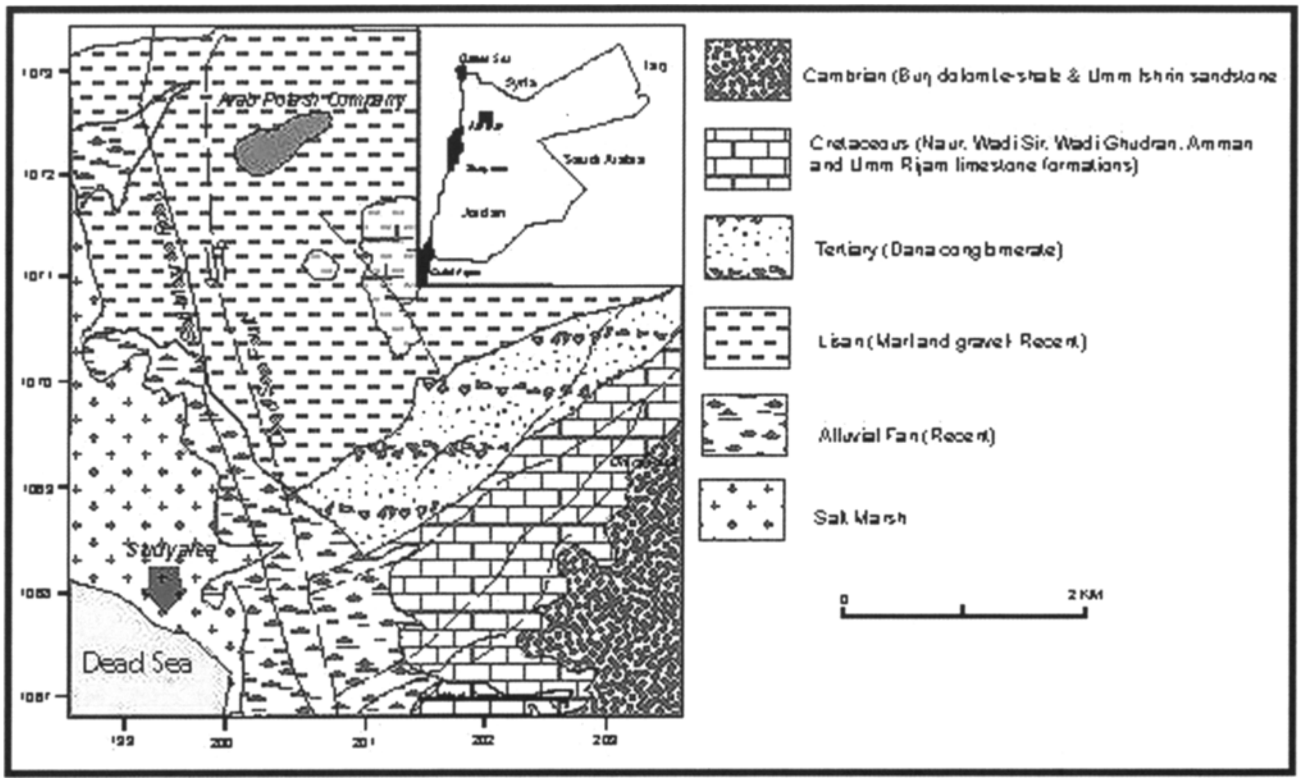

Figure 1. Location map of the studied area showing also the main geologic formations exposed in the immediate neighborhood. (Modified from the archives of the Arab Potash Company).

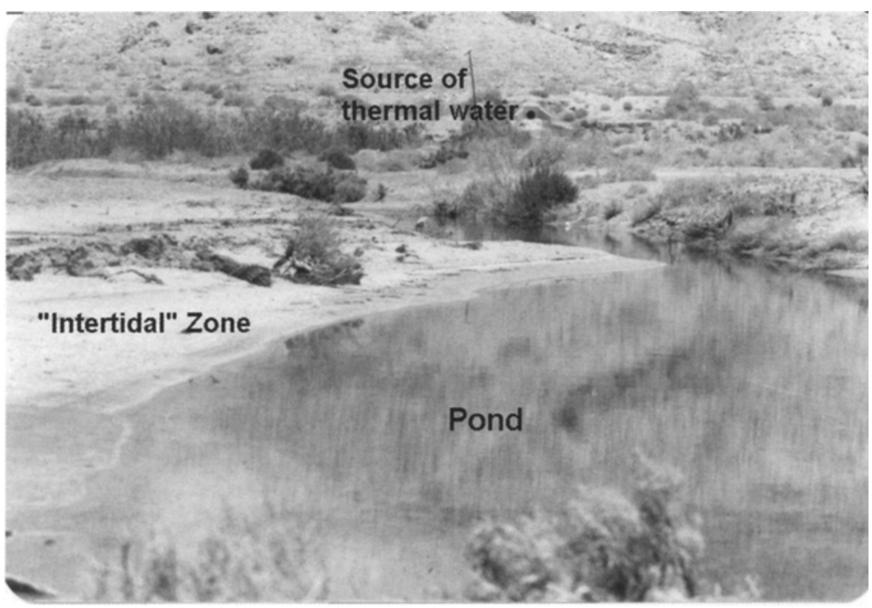

Figure 2. General view of the studied pond and the thermal water charging point. Notice the small "intertidal" zone to the left.

Dead Sea coast. Valleys intersecting the road were bridged so that hydrothermal fluids and rainwater from the Karak Mountains can discharge into the Dead Sea (Fig. 2). The discharging water varies both in quantity and in quality. During rainy seasons, the water is mostly fresh, carrying large amount of clastic and carbonate materials. During summer, the water is derived mainly from the scattered springs in the region and has a strong sulfuric smell.

The western end of the pond is connected to the Dead Sea by a small channel. The channel is around 3 m in length and covered with relatively coarse, clean sandy sediments (Fig. 3).

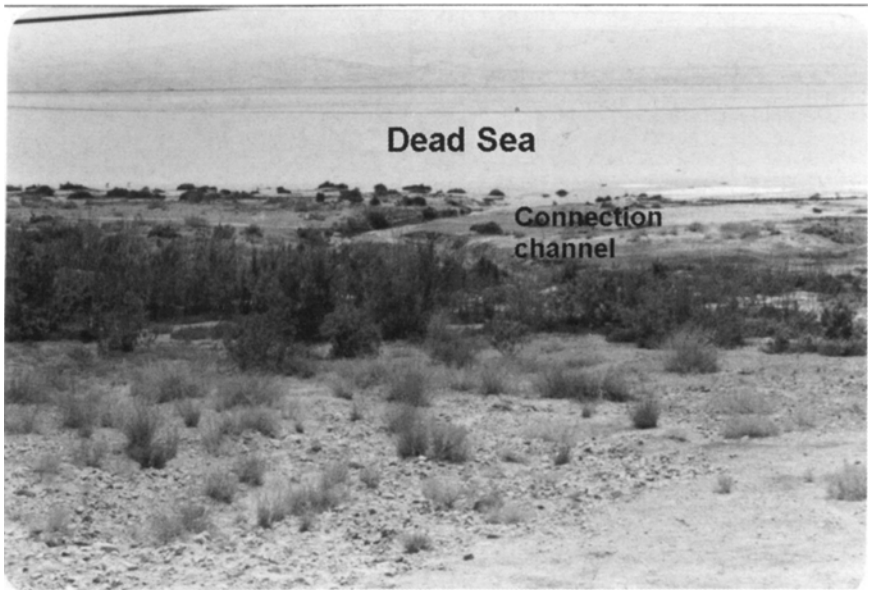

Figure 3. The channel connecting the pond with the Dead Sea.

Figure 4. Detailed view of the pond. Notice the main channel, the light lime mud covering the internal parts and the algal encrustation on the margins.

The pond averages about 30 cm in depth with a slightly deeper central channel (Fig. 4). The central part of the pond is light in color due to the presence of a thin cover of lime mud. The margins and the deeper parts of the pond are, however, covered with black mud with a strong sulfurous smell. Some of the pond fringes are encrusted with mats of green and yellow algae.

METHODS OF STUDY

Sediment samples were collected from the margins and bottom part of the pond. Sediment samples were analyzed to determine their grain-size. Selected samples were also x-rayed to determine their mineralogical compositions. Others were examined by Scanning Electron Microscope to determine their nano- scale features. Two water samples were collected from the flowing channel and were analyzed for their major chemical components.

WATER CHEMISTRY

Dead Sea water is distinct from that of many similar hypersaline water bodies. These differences are inherent in the general setting of the sea itself and the geology of the neighboring areas. The Dead Sea has more than 30 times the Ca concentration and 40 times the Mg concentration of

Table 1. Concentration (in gm/l) of the major ions in the Dead Sea water and in other saline water bodies from different parts of the world (after Watzman, 1997).

Location	Na	Cl	Mg	Ca	Other ions	Total dissolved salts
Wadi Natrun, Egypt (at Gaar)	137.0	173.7	0	0	63.5	374.2
Dead Sea (1977 average)	40.1	224.9	44.0	17.2	13.4	339.6
Great Salt Lake, Utah (north arm)	105.4	181.0	11.1	0.3	34.7	332.5
Marine saltern, Puerto Rico	65.4	144.0	20.1	0.2	24.2	253.5
Red Sea (at Eilat)	12.2	22.0	1.5	0.5	3.8	40.0
Seawater (average)	10.8	19.4	1.3	0.4	3.1	35.0

Table 2. Chemical analysis of the Dead Sea water and the hydrothermal water (in gm/l) flowing into the coastal pond. Dead Sea water data are averaged values from Bentor (1961).

Variable	Dead Sea water (average) (gm/l)	Thermal water (gm/l)
pH	6.4	-
Ca	15.8	1.83
Mg	42	3.2
Na	34.9	4.65
K	7.6	0.96
CO_3	0.24	1.25
SO_4	0.54	1.34
Cl	208	7.89
Br	5.9	trace
I	-	trace

ordinary seawater, due to the high evaporation rates (Table 1). Abed (1985) summarized the main distinctive chemical features of the Dead Sea waters. These can be listed as follows:

1. Cl concentration is very high.
2. SO_4^{-2} concentration is lowest amongst data collected from any similar water body.
3. CO_3^{-2} is practically absent.
4. Ca^{+2} concentration is about 15.75% and is probably the highest for any similar water body.
5. Since Ca^{+2} and Cl^- are found in high concentrations, Calcium is normally found, as $CaCl_2$ and this is a rare case in nature.
6. Na: K concentration ratio is around 4.6 and this is lower by 3-20 times compared to water from any stream discharging into the Dead Sea, and lower by 6 times compared the average seawater.
7. Br^{+2} concentration is higher for any other similar water body.

He also noticed that the concentration of Na, K, Mg and Br increases southwards due to the higher evaporation rates in the southern parts of the Dead Sea. SO_4^{-2} concentration is also deceasing toward the south but due to the precipitation of gypsum. He found also that Br, Mg and K might be retained in the water most of the time.

Fresh and hydrothermal waters flow from the nearby mountains, under the main road and into the studied pond. Although there are no major hydrothermal springs in the immediate neighborhood, several small springs exist in the region. To the north, the well-known Zarqa Ma'in thermal springs form a major tourist attraction. The water is believed to flow from the Kurnub Sandstone (Lower Cretaceous) on the evidence of its associated travertine deposits. These waters are believed to result from geothermal activities, which are in turn, controlled by tectonic setting of the Dead Sea region. Temperatures up to 65°C are reported from the main springs, which contain exceptional concentrations of iodine and bromine. A water sample was collected from the mouth of the channel flowing into the study area and analyzed. Results are shown in Table 2. The water sample contains relatively high SO^{-4} as compared to water from the Dead Sea.

The introduced waters are characterized by low concentrations of the main chemical elements found in the Dead Sea but are relatively high in dissolved sulfate and carbonate. The mixing of Ca rich Dead Sea waters with SO_4^{-2} thermal waters is expected to promote the chemical precipitation of Gypsum and calcite (or aragonite), rather than the usual halite or sylvite.

LITHOLOGICAL CHARACTERIZATION

There are two major types of sediment in the study area: sands and muds. The detrital component of the sediment includes clay minerals, carbonates, and quartz, while the authigenic components are mainly halite and dolomite.

Coarse, dark sand has been deposited along the connecting channel between the coastal pond and the Dead Sea. These sands are well sorted and contain a high proportion of igneous-derived particles (including pebbles), probably sourced from the igneous bodies within the Cambrian Sarmoj Limestone Formation. The clastic sediments are probably transported from the source along the interior channel of the pond during flash floods accompanying heavy winter rains. Dark sands are also found on the nearby shores of the Dead Sea to the south of the coastal pond. These sands are believed to be of eolian origin.

Mud-sized sediments are found on the margins and in the bed of the pond itself. Mechanical analysis of the studied sediments indicates that they are composed mainly of pyritic, mud-sized grains ranging from 2 to 50 micrometers, and averaging 3 to 4 microns. The pyritic mud may be microbially fixed by green and cyanobacterial algae, whereas sand is carried further to the Dead Sea (Fig. 4). Mud samples were analysed by x-ray methods to identify the main components, namely clay minerals, carbonates and halite (Fig. 5).

Clay Minerals

X-ray analysis and SEM examination of the clay fraction of the studied sediments and their examination under the SEM, indicate that the major clay minerals are montmorillonite, montmorillonite-illite, kaolinite and kaolinite-chlorite. Some of these are probably allogenic (Figs. 6,7).

Calcite and Aragonite

Calcite is usually the major component of these sediments. Some of this carbonate may be detrital, but the majority has formed by water evaporation in the semi-restricted pond. The fibrous texture of some of the grains suggests the presence of authigenic aragonite (Fig. 8). Some of the sediments contain a considerable number of coccoliths (Fig. 9,10). The coccoliths are most probably detrital derived from the Upper Cretaceous Wadi Ghudran Chalk, which forms outcrops surrounding the studied area. However, local accumulation of the coccoliths is also possible in view of reports of coccoliths from similar environments to this coastal pond. Coccoliths have been described from pond and other shallow water environments with salinity lower than normal seawater and low input of continent-derived organics (Busson et al. 1993; Noel et al. 1993). Freytet and Verrecchia (1998) mentioned that coccolithophorids are organisms that associate with microbial mats and biofilms. Coccoliths also may be a local source of sulfur. According to Robinson (1995) they represent the most important producers of dimethysulfide in the environment. Matrai and Keller (1993) also noticed that production of dimethysulfide is related to the stage of the coccolith bloom. Organic sulfur-rich coccolith limestones in

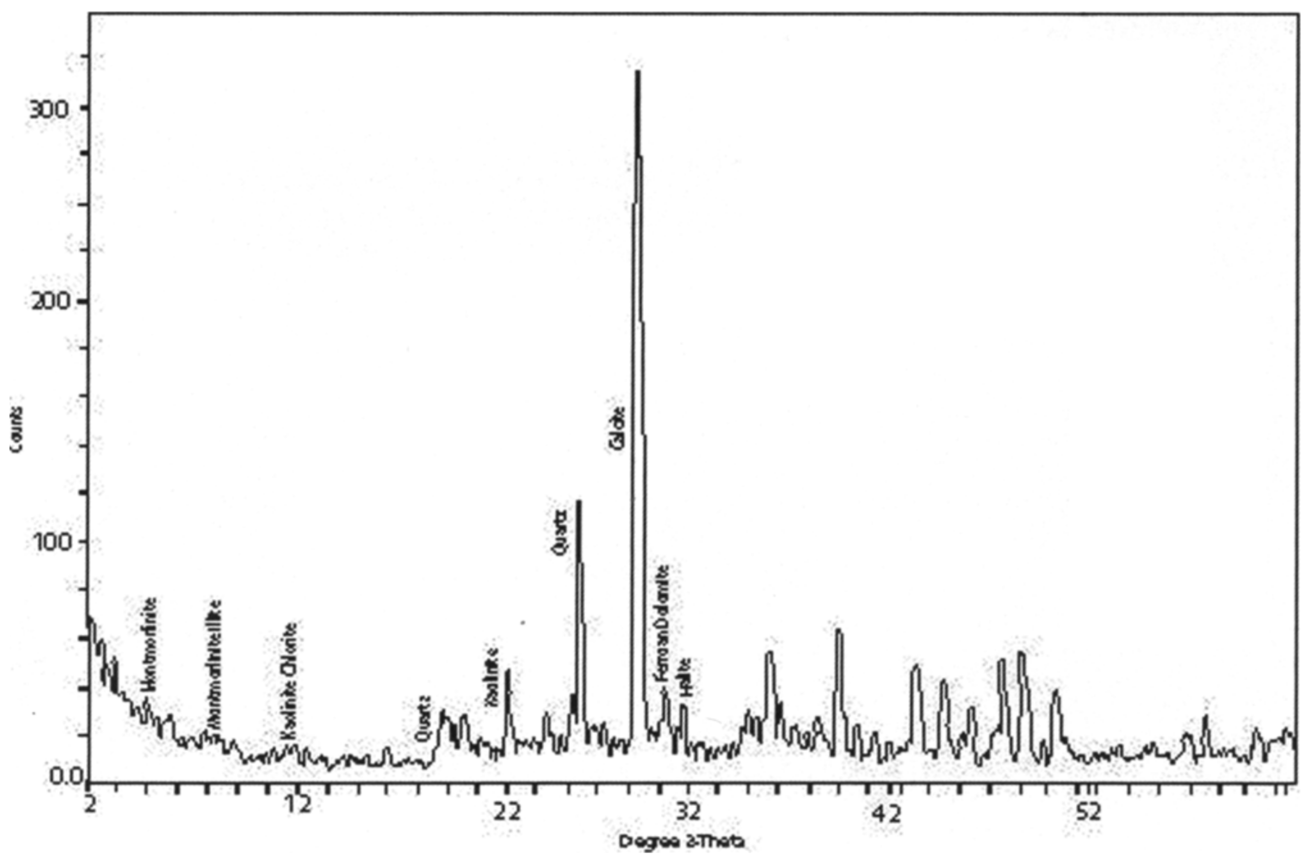

Figure 5. X-ray diagram showing the main components of the clay faction of the Recent sediments in the studied pond.

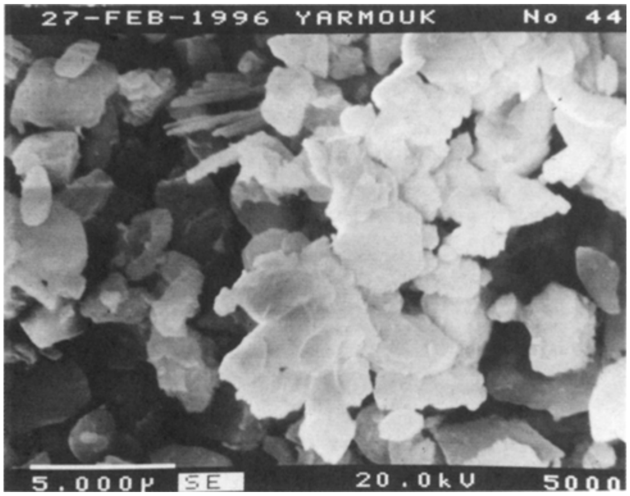

Figure 6. SEM micrograph of stacked kaolinite (left side) with some coccoliths (central part of the left side) with broken coccolith at the lower left corner of the photo.

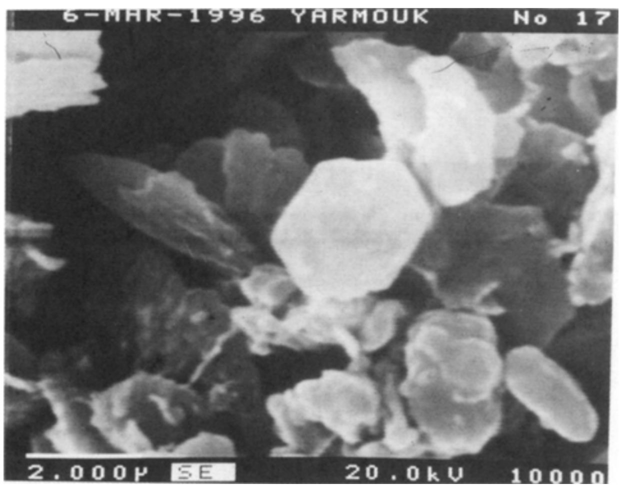

Figure 7. SEM micrograph of a pseudohexagonal plate of kaolinite.

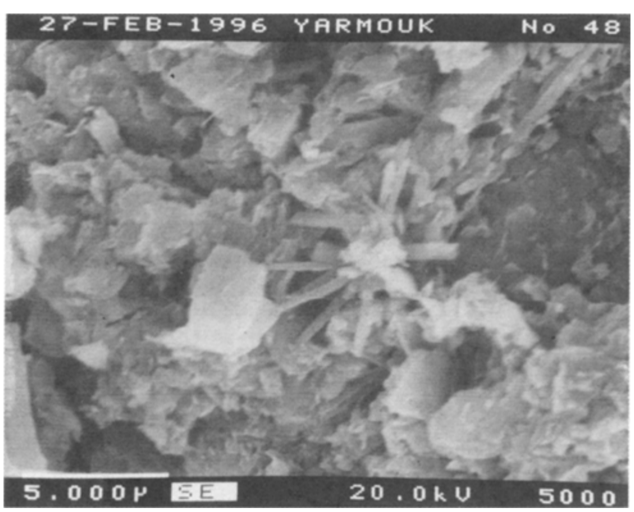

Figure 8. SEM micrograph of detrital clay minerals with possible k-feldspar in the center of the image.

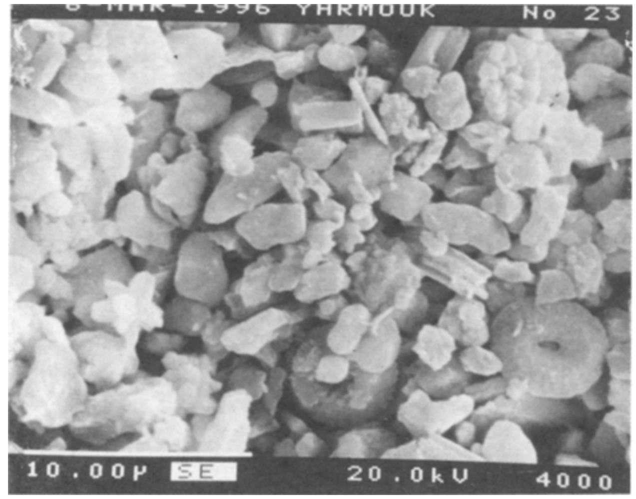

Figure 9. SEM micrograph showing a mixture of coccoliths with blade-like crystals probably of aragonite and clay minerals.

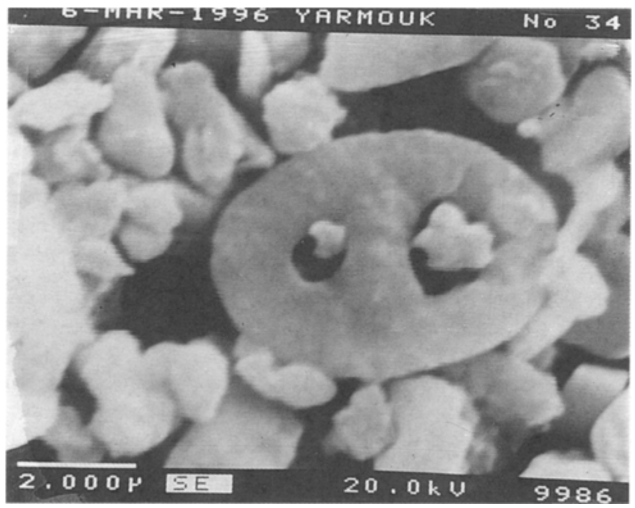

Figure 10. A close-up SEM micrograph of a coccolith from the family Helicosphaeraceae.

the Upper Jurassic of France was consistent with these sediments being deposited in a euxinic environment. These cyanobacteria are important contributors of organic matter (Vankaampeters and Damste 1997).

Dolomite

The occurrence of dolomite in the coastal pond, in close association with halite, is interesting in providing supportive evidence that dolomite is an evaporitic mineral (Fig. 11). Shatkay and Magaritz (1987) described dolomite from (6-12 cm) shallow depths in recently exposed gypsum-rich sediments on the western shores of the Dead Sea. They suggested that the dolomite formed by mixing of deep residual solutions with subsurface fresh water, in an environment where sulfate ratio was lowered by bacterial reduction. Friedman (1995) reviewed the different environments favourable for the formation of dolomite in the Levant.

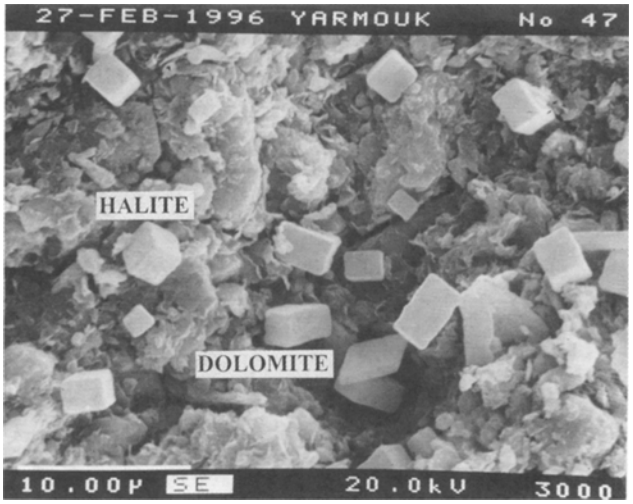

Figure 11. SEM micrograph showing authigenic cubic crystals of halite with a single dolomite rhomb growing in a vent within the sediment.

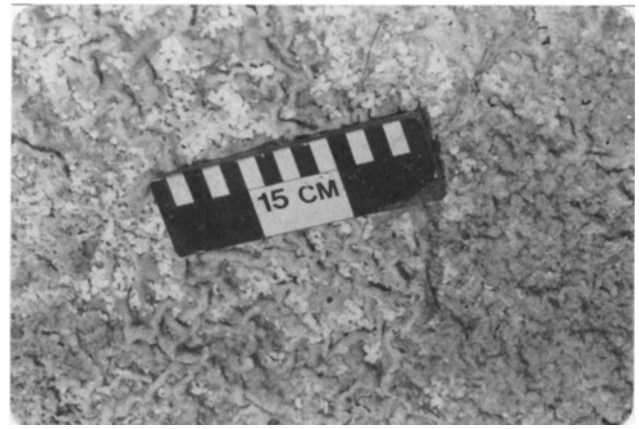

Figure 12. Stromatolites covered with salt crystals in the "intertidal" zone of the pond. The wrinkles are filled with air. The salt is believed to be formed by evaporation of the thin film of water that covers the area during higher water input.

Amongst these, he included the hypersaline pools of the Sinai Peninsula and the northern part of the Gulf of Aqaba.

The dolomite reported in this study is very rare and consists of well-developed rhombs 3-4 micrometers in diameter. According to XRD results, this dolomite is highly ferroan approaching ankerite in composition. The dolomite is closely associated with halite but the halite cubes appear to be a superficial layer, whereas the dolomite rhombs are found only in small vugs or voids, which may indicate local leaching.

The assumption that dolomite may precipitate from waters of the Dead Sea mixed with the thermal or the fresh water drained from the surrounding areas, presents the problem of explaining why this water has not dissolved the halite. This leaves us with the conclusion that dolomite was precipitated directly due to severe evaporation during summer. Furthermore, the Mg ions may be supplied locally by the green algae, or induced by the activity of cyanobacteria or sulfate reduction by formation of H_2S.

Halite

Halite partially covers the stromatolites in the "intertidal" zone of the pond. This halite is believed to have precipitated by the evaporation of the shallow water that occasionally covers this area during the high flood season. The salt-encrusted stromatolites are of enterolithic type (Fig. 12). These crumpled features are probably due to the generation of biogenic gases from algal activity within the sediments. In summer, this intertidal zone is exposed to drying and the desiccated stromatolites are added to the surficial sediments. Chafetz et al., (1987) described black Mn-rich stromatolites that are similar to those reported from the Dead Sea. Nishri (1984) reviewed the geochemical mechanism of Mn in the Dead Sea. Braithwaite and Zedef (1996) described hydromagnesite stromatolites from an alkaline lake in Turkey. The microbial stromatolites along the shorelines of the lakes are reported to contain a microflora of diatoms and cyanobacteria with extensive biofilms.

Well-developed halite cubes were also found in the muddy sediments of the pond, in association with dolomite (Fig. 11). These have probably formed by evaporation of salt water trapped in the muddy sediments. Halite cubes are a common component of muddy sediments on the shores of the Dead Sea.

DISCUSSION

The absence of gypsum and the direct association of dolomite with halite in the sediments of the coastal pond is puzzling. The hydrothermal waters discharging into the pond have relatively high concentrations of sulfate, which should promote the precipitation of gypsum. Furthermore, gypsum has been described from similar settings. Yechieli and Ronen (1997) suggested that the mixing of fresh groundwater and Dead Sea water would eventually lead to the sequential precipitation of gypsum with other evaporitic minerals. A possible explanation for the absence of gypsum is bacterial reduction of sulfate to sulfide, which unites eventually with iron to form pyrite. Such case was reported before from the Dead Sea by Nishri, (1984) and Herut et al., (1997) who noticed that bacterial SO_4^{-2} reduction (by anaerobic bacteria that remove oxygen from the sulfates and generate free sulfur in the reduced zone) would lead to the formation of Fe sulfides and dissolution of gypsum. In the oxidized zone, sulfur may have combined with iron to form pyrite (Goldhaber 1978).

The association of dolomite with halite argues that dolomite has formed from direct precipitation as an evaporitic mineral in these sediments. Any influx of fresh or brackish water should lead to the partial or total dissolution of halite.

CONCLUSIONS

Marginal ponds and lakes have been common features along the shores of the Dead Sea since its formation. Whereas the Dead Sea sediments are typically monotonously evaporitic, marginal ponds have more interesting features due to thermal and fresh water mixing with waters of the Dead Sea. A marginal pond on the eastern coast of the southern part of the Dead Sea (in Jordan) showed the development of a narrow "intertidal" zone in which halite-encrusted stromatolites are forming. In the pond itself, a muddy mixture of detrital and authigenic minerals contains an association of halite and dolomite. The absence of gypsum in these sediments is attributed to bacterial reduction of sulfates.

ACKNOWLEDGMENTS

We are indebted to the Arab Potash Company (APC), Jordan for the generous financial and logistic support. Naeem Wafa, resident geologist of APC introduced the senior author to the fascinating geology of the Dead Sea. Adnan Aqrawi helped with the interpretation of the XRD results. The manuscript benefited from the comments of an anonymous reviewer and that of G. Brooks (Fletcher Challenge Energy, New Zealand) and Thomas Fowler (UAE University).

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