Microbial and Physical Sedimentary Structures in the Tidal Flats of Khor Al-Zubair, NW of Arabian Gulf

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Abstract This present study deals with the microbial sedimentary structures which are mainly induced by the cyanobacteria in the tidal flats of Khor Al-Zubair, northwest of the Arabian Gulf. There are three types of sedimentary structures in the area: (i) physical genetics, (ii) biological genetics, and (iii) biophysical genetics. The last one represents the microbial-induced sedimentary structure appeared in ten forms, which led to increasing of tidal flats resistance to erosion process and concentrating the coarse-grain sizes that accompanied with these structures. The identification of cyanobacteria shows five genera, four of them are filamentous, *Microcoleus* sp., *Lyngbya* spp., *Oscillatoria* spp., *and Schizothrix* sp., while the other is coccoid *Aphanothece* sp.

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Keywords Cyanobacteria · Tidal flats · Khor Al-Zubair · Arabian Gulf · Iraq

1 Introduction

The microbial mats represent a film cover of the surface sediments and appear in many forms and colors (Gerdes et al. 2000), which give a fascinating panorama. Microbially induced sedimentary structures are formed on the surface of sediments; these structures are induced by cyanobacteria which are also known as blue-green algae. This blue-green bacteria or Cyanophyta is a phylum of bacteria that obtain their energy through photosynthesis. This group of organisms is able to reduce nitrogen and carbon in aerobic conditions that may be responsible for their evolutionary and ecological success and produce cyanotoxins (Popa et al. 2007). Before they were called stromatolites; now they have many names such as Cyanophyta,

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L. A. Jawad (ed.), *The Arabian Seas: Biodiversity, Environmental Challenges and Conservation Measures*, https://doi.org/10.1007/978-3-030-51506-5_12

Myxophyceae, Cyanophycophyta, Cyanochloronta (Bold and Wynne 1978), and blue-green algae. The cyanobacteria is called now the microbially induced sedimentary structures (MISS), which formed in shallow, wide, and gentle slope marine environments and recorded from Archaean age to recent (Noffke et al. 2006). Many scientists suggested that cyanobacteria are responsible for the generation of oxygen in the atmosphere (Bold and Wynne 1978; Collerson and Kamber 1999). Cyanobacteria could be also involved in some reactions which lead to formation and precipitation; one of them is cyanobacteria calcification (Kamennaya et al. 2012). Cyanobacteria grow to high densities in tropical marine environments; they are widely distributed and live in different environments from fresh to marine waters, on the rocks, soil, and plant stems of low alkalinity, but some species prefer to live in acidic environment of pH which is between 4 and 5, or in hot springs, by photosynthesis (Bold and Wynne 1978). Cyanobacteria are adapted to live in high temperature and salinity, distributed in tidal flats from supratidal to intertidal zones (Gerdes et al. 2000). In the tidal flats of hot and dry such as the sabkha (Taher 2014), the microbial mats become flourishing and attract a notable quantity of dust fallouts.

Cyanobacteria cover the most tidal regions within the tropical and subtropical range of a warm and nutrient-rich climate, for example, the Arabian Gulf, the Red Sea coast, the Egypsian coast on the Meditterranian Sea, and some lakes in the Egypt.

The distribution of cyanobacteria is controlled by the soil texture, precipitation, nutrients, and salinity (Zhang et al. 2016); the increase in the precipitation and high content of coarse-grained sediments is improving the diversity and growth of cyanobacteria.

Taher and Abdel-Motelib (2015) studied the cyanobacteria in detail in the alkaline hypersaline El Beida Lake of Wadi El Natrun in the western desert sector of Egypt. They found many microbially induced sedimentary structures (MISS) such as knotty surfaces, mat cracks, wrinkle structures, reticulate surfaces, pinnacle mats, sieve-like surfaces, gas domes, and mat chips. They found also authigenic minerals such as thenardite, trona, and halite. Aref et al. (2014) studied the MISS in the west of Alexandria, Egypt, and Al Zeeb sabkha, Saudi Arabia, due to the local factors; they found the microbial sedimentary structure and the physically induced sedimentary surface structures (PISSS) together. The MISS is represented by mats, wrinkles, blisters, pinnacles, cones, domes, and petee structures, whereas the PISSS are represented by polygonal cracks and tepee structures.

The MISS of coastal sabkha in Ras Gemsa, Red Sea coast, was studied by Taher (2014); the area is covered by terrigenous siliciclastic sediments, and the sedimentation rate is low, little wave action, protected by disseminated vegetation, and lack of bioturbation. These conditions are favorable for the growth of cyanobacteria. There are specific sedimentary structures such as frozen multi-directed ripples, salt-encrusted crinkle mats, jelly roll structures, and petee structures.

In the present study, both sedimentary structures MISS and PISSS were studied in the Khor Al-Zubair area, south of Iraq. The aims of the study are to explain the main types of structures and the favorable environmental conditions to develop these structures which could be helpful for the studies concerned by the ancient traces of these structures.

2 Appropriate Growth Conditions

Cyanobacteria grow in the limnic and marine environments, flourish in fresh, brackish, and salty water, and they grow also in the cold and hot springs (Mur et al. 1999). The growth of cyanobacteria needs appropriate conditions: climate, nutrients, physiography, and physical and chemical properties of the environment, and the main conditions typically include favorable salinity, ample supply of nutrients, calm water, stratified conditions, plenty of irradiances, and warm water temperatures (SCCWRP 2015). Cyanobacteria are nourished in the intertidal and low supratidal zones of tidal flats and coastal sabkha (Porada et al. 2007). The salinity plays a big role in the formation of the cyanobacteria, where the spreading of some species was a witness of the geographical extent into the mesohaline (5–15 ppt) reaches of coastal systems (Paerl and Paul 2012).

Cyanobacterial biomass is accumulated in the water column of the amount nutrients (N and P). In fresh water, cyanobacteria are limited by nitrogen and phosphorous and frequently laid to the excessive phosphorous (Elmgren and Larsson 2001; Paerl 2008; Schindler et al. 2008; Amaral et al. 2013). In the estuaries and marine environments, cyanobacteria are more kinked to nitrogen loading; the eutrophication due to cyanobacterial growth is frequently linked with excessive N loading (Paerl 2008; Conley et al. 2009; Ahn et al. 2011). The increasing of pollution by human activities tends to increase the nitrogen and phosphorous in the water column, also the lowering of the water column and increase in water temperature lead to a large growth in the cyanobacteria. It is suggested that increases in the dissolved N/P ratio above 20 could control the growth of cyanobacteria.

The temperature is also an important factor in the growth of cyanobacteria; their temperature growth is between 25 and 35 °C (Lurling et al. 2013). Lower growth temperature optima for some species are around 25 °C, whereas the optima of fresh water are greater than for marine cyanobacteria which range between 20 and 27.5 °C (Breitbarth et al. 2007). Generally, cyanobacteria show a low rate of growth in cold temperature and vice versa in high temperature.

Cyanobacteria growth increases in the intertidal and the lower of the supratidal zone due to the abundance of carbon dioxide, lack of suspended matter, low water movement, and the presence of fine grains of sand and silt (Porada et al. 2007).

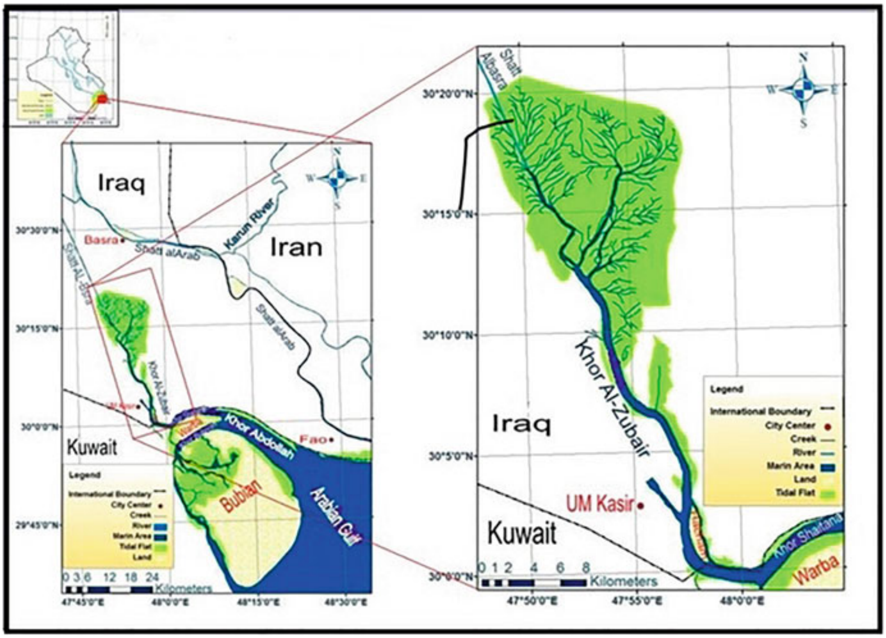

Fig. 1 Location map

3 Geologic Settings

3.1 Location of the Study Area

The study area is the outer limits of the tidal flats, represents a marine sabkha, a part of tidal flats of Iraqi coast, starting from Khor Al-Zubair, and continues surrounding the Faw Peninsula to the mouth of the Shatt Al-Arab River, south of Iraq. Khor Al-Zubair is a marine tongue extended from the northwest part of Arabian Gulf, its length is about 40 km, and the width is between 1 km in low tide to 2 km in high tide, whereas the depth is between 15 and 20 m. In 1983, the north end of Khor Al-Zubair was connected with a canal of Shatt Al-Basrah, which is also the last canal connected with the canal of Al-Massab Al-Aam. The later one is an artificial canal to flush the soils from Baghdad to the south of Iraq. From that time Khor Al-Zubair has been considered as a new estuary and represents the interaction between the brackish water of Al-Massab Al-Aam and marine water of the gulf. The study area includes the creeks of the Khor (Fig. 1). The area is covered by quaternary sediments of Dibdibba and Hammar formations, followed by fluvial sediments of Tigris, Euphrates, and Karun Rivers; Dibdibba Formation is an alluvial composed of gravel and sand sediments of Upper Miocene-Pleistocene (Aqrawi et al. 2010). The Hammar Formation is considered as a transgressive phase of marine clay sediments in the recent period (Buday 1980). The tectonic setting of the studied area is situated in Mesopotamian zone of the unstable shelf (Buday and Jassim 1987), due to the influence of Alpine orogeny movement, tectonic of salt domes, and uplift of basement rocks (Al-Mutury and Al-Maiahi 2010; Darweesh et al. 2017). Khor Al-Zubair could be formed during Wurm glaciations by a subsidence due to fault with the trend from current Al-Hammar Lake to the southern end of Khor Al-Sabiya (Al-Mussawy 1993). The northwestern part of the Arabian Gulf manifests many variations during its history such as erosion, sedimentation, recent tectonism, and climate changes. These factors provided a great influence on its sediments and structure (Al-Azawi 1996).

3.2 Physical Conditions of the Area

The tides in the Khor Al-Zubair area are semidiurnal influenced by mixed of diurnal and semidiurnal tides (Al-Ramadhan 1986), for that the tidal flats of Khor Al-Zubair are covered twice daily by water. The northern end of Khor Al-Zubair formed from many tidal channels (creeks); this tidal flat is divided into subtidal, intertidal, and supratidal zones. The subtidal zone starts from the lower limit of intertidal during the ebb tide to a depth of 2–3 m. below the lowest water level (Kadhim 1999). Its width is 5–10 m, characterized by high side slope of the bank (approximately 35 degrees). This zone represents unstable zone due to the continuous erosion and deposition, let it be a special character in the area (Al-Mulla 1999). The intertidal zone in the creek area to the east of the Shatt Al-Basrah canal is widely covered by fine sediments to the silty and sandy clay in the outer limits. The supratidal zone represents a horizontal flat with few undulations covered by water (Kadhim 1999), and its elevation is no more than 2 m above sea level (Al-Mulla 1999). The sediments of the tidal flats vary in texture, dominant by silt and little amount of sand (Darmoian and Landqvist 1988); it is believed these detrital sediments are transported from the surrounding area (Aqrawi and Darmoian 1986; Aqrawi and Evans 1994). Albadran and Albadran (1994) concluded that the recent sediments of Khor Al-Zubair and Khor Abdullah are products of different transport agents. The eastern side of Khor Al-Zubair composed of fine and soft sediments, and these sediments are washed sediments of the tidal flats, whereas the sediments of Khor Al-Zubair channel are a mixture of mud and marley silts with mollusks, foraminifera, and ostracods (Albadran et al. 1991). The water temperature and salinity vary with the seasons, time, and place. They are low in winter and during the increase of discharge of Shatt Al-Basrah. The outer limits of tidal flats are more saline than the rest of the tidal area, where the evaporation and air temperature are high. The mean, maximum, and minimum air temperature are 49.63, 51.7, and 30.40 °C in the summer season and in winter was between 19.32 and 23.40 °C for the mean of high temperature to 8.37 to 11.19 °C for the mean of low temperature (OIAA 2010).

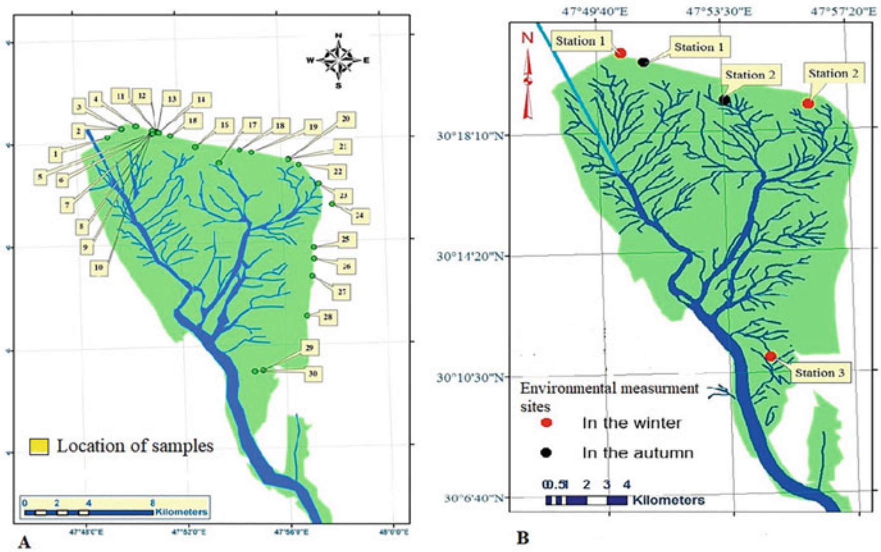

Fig. 2 Locations of sampling and environmental measurements

4 Materials and Methods

The study area is located on the eastern side of Khor Al-Zubair (Fig. 1). The fieldwork started from October 2009 to February 2010. Thirty surface sediment samples were collected in 12/10/2009 and 10/2/2010 from different places (Fig. 2a). The samples are distributed around the outer limits of tidal flats due to the access difficulties of the wet and soft area. The samples were gathered manually, and the sediments were isolated from the cyanobacteria. The sediments are kept in plastic bags, and the algae are kept with fresh water in plastic bags and stored in the refrigerator. Seasonal field measurements were carried out using portable pH meter (Lovibons / pH 200) and EC meter (Lovibond/ con 200), in addition to the water and air temperatures using a thermometer in three stations (Fig. 2b). XRD analysis for powder of six samples was carried out using instrument type X'Pert. The cyanobacteria were classified according to their external shape and dimensions as the length and width by using a compound microscope (HM-Lux 3) and refer to the literature of classification such as Desikachary (1959), Prescott (1975), and Bold and Wynne (1978).

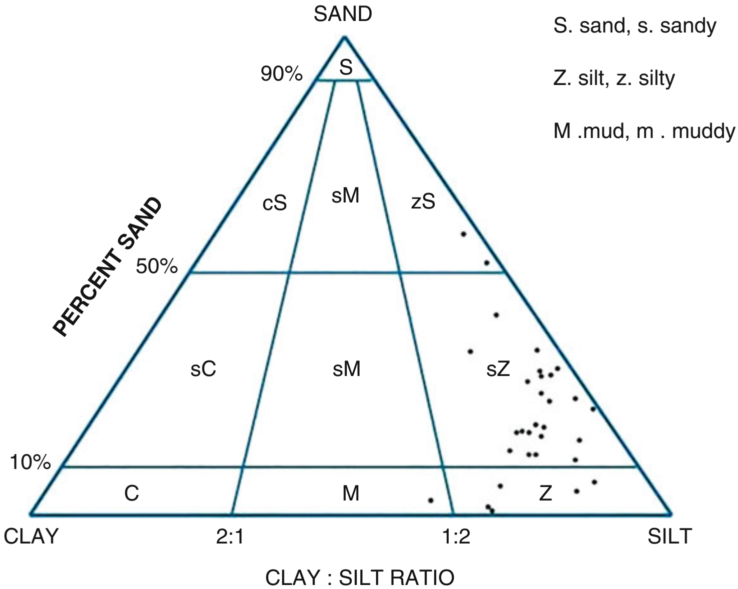

Fig. 3 Texture of surface sediments

Table 1 Mineral composition of sediments

Sample no.	Depth/ cm	Calcite %	Quartz %	Feldspar %	Gypsum %	Halite %	Dolomite %	Clay minerals%
1	Surface	22.24	33.18	7.26	22.16	11.35		3.81
3	Surface	23.08	35.65	10.19	26.55	4.53		
3	25 cm	38.96	21.47	9.85	5.87	3.47		20.38
7	Surface	28.86	24.45	12.27	16.49	5.50		12.38
20	Surface	43.52	10.71	10.65	6.62		13.08	15.42
22	Surface	64.61	14.40	11.09			4.76	5.71
Average		36.83	23.30	10.35	12.90	4.04	2.97	9.61

Table 2 Chemical and physical properties of water in study area

Measurements	12/10/2009			10/2/2010		
	First station	Second station	Third station	First station	Second station	Third station
Temperature/°C	26.00	26.00	Ebb tide	16.70	15.00	17.00
Salinity/‰	42.36	62.20	Ebb tide	31.00	36.80	44.80
pH			Ebb tide	8.05	8.12	8.04

Table 3 Analysis of extracted water from sediment samples

12/10/2009			10/2/2010		
Sample no.	EC/mmhs	Salinity ‰	Sample no.	EC/mmhs	Salinity ‰
11	52.30	33.40	1	45.80	29.31
12	271.60	173.82	3 surface	38.00	24.32
13	72.60	46.46	3 depth 25 cm	45.20	28.92
14	46.60	28.60	5	80.40	51.45
15	56.60	36.22	6	92.20	59.00
16	73.80	47.23	7	105.00	67.20
17	62.20	39.80	8	97.00	62.08
19	108.20	69.24	9	52.00	33.28
25	181.60	116.22	18	94.00	60.16
29	167.00	106.88	20	40.40	25.72
			21	41.00	26.24
			22 bed	16.80	10.75
			22 bank	24.80	15.87
			23	18.78	12.02
			24	45.20	29.00
			26	80.20	51.32
			27	87.80	56.20
			30	32.40	20.73

5 Results

The grain-size analysis shows that the sediments of the studied area are sandy silt, silty sand, and mud (Fig. 3). Mineral composition by XRD of bulk samples seems the dominant of quartz followed by calcite (Table 1). Environmental measurements (Table 2) including temperature, salinity, and pH of water were taken during the fieldwork in three stations (Fig. 2b) which covered the study area. Salinity and electrical conductivity were also measured in a laboratory from the extracted water of sediments (Table 3).The classification of Bold and Wynne (1978) was applied to classify the cyanobacteria. Five genera were identified (Table 4), which appeared in ten forms of MISS (Plates 1, 2, and 3) in the study area such as wrinkles structures, ridges, domes, polygonal mat, tepee, mat crakes, chips mat, finger structure, irregular mounds, and pinnacles.

Table 4 Identified genera of cyanobacteria in study area

Sample no.	*Aphanothece microscopic*	*Oscillatoria* spp.	*Lyngbya* spp.	*Schizothrix* sp.	*Microcoleus* sp.
1	–	+3	+	–	+3
5	–	+	+	–	+
6	–	+	+2	+	+
7	–	+	+3	–	+
7	–	+3	+3	–	+
8	–	+3	+	–	+3
9	–	+	–	–	+
10	–	+	+2	–	+3
11	–	+	–	–	+
13	–	+	+	–	+
15	–	+	+	–	+2
17	–	+	+	–	–
18	–	+	+3	–	+3
19	–	+	–	–	–
20	–	–	+3	–	+3
21	–	+	+3	+	+
25	–	+	–	–	–
26	+3	+	–	–	+
29	–	+	+2	–	+

- Absent, + rare, +2 few, and + 3 abundant

6 Discussion

The grain-size distribution indicated the abundance of sandy silt texture from the other types. It is considered that the presence of sand in samples could be related to the road bank erosion as the samples are on the periphery of the tidal flats near the main road of the area. It is difficult to get access to the middle of the tidal flats, due to the nature of sediment, soft and fine sediments. Cyanobacteria have the ability to attract the coarse sediments of windblown. Also, other considerations about the coarse-grained sediments are related to the nearest of the study area to the Dibdibba Formation (Basi et al. 1989). The other source of sand material is the aeolian deposits, and dust fallout arrived at the northern part of the study area (Al-Ali 2007).

The mineralogical composition of sediments shows the high ratio of quartz (Table 1) due to the contribution of the bed erosion (Darmoian and Landqvist 1988) and aeolian sand (Al-Ali 2000; Al-Ali 2007). The aeolian sand is more abundant in calcite than dolomite (ROPME 1987), for that, the ratio of dolomite is less than calcite (Table 1). The relative abundance of gypsum mineral could relate to the diagenetic gypsum which is accompanied with the algal mat like the coast of Santa Pola in France (Busson and Schreiber 1997) and Union of Arab Emirates (Kendall et al. 1998). The high temperature and evaporation of the groundwater

Plate 1 (**a**) Tidal dendritic creeks at the northern end of Khor Al-Zubair, (**b**) Salt crest, pencil in the upper left to scale, (**c**) Salt ridges, pencil in the mid of photo to scale, (**d**) Burrows of crabs, (**e**) Rounded opening of burrows, red scraper to scale, and (**f**) Small ridges

raised to the surface (Al-Bassam 1986) add also gypsum to the sediment budget. The study of Issa et al. (2009) does not mention the gypsum, which could attribute to the sampling place of this study near the high limits of tidal flats. Clay minerals appeared in the bulk sediments and the major part of clay minerals derived by fluvial, tidal currents, and dust fallouts (Al-Dhabagh and Albadran 1995).

The temperature is considered as the main influencing factor on the physical, chemical, and biological nature of any area. Water temperature is a controlling factor on the density and distribution of marine biota (Power et al. 2000). The temperature of air and water in the area was 34 and 26 °C, respectively. It was 20 °C for air in February. Water temperature varies from 15 to 26 °C in the creeks (Table 2).

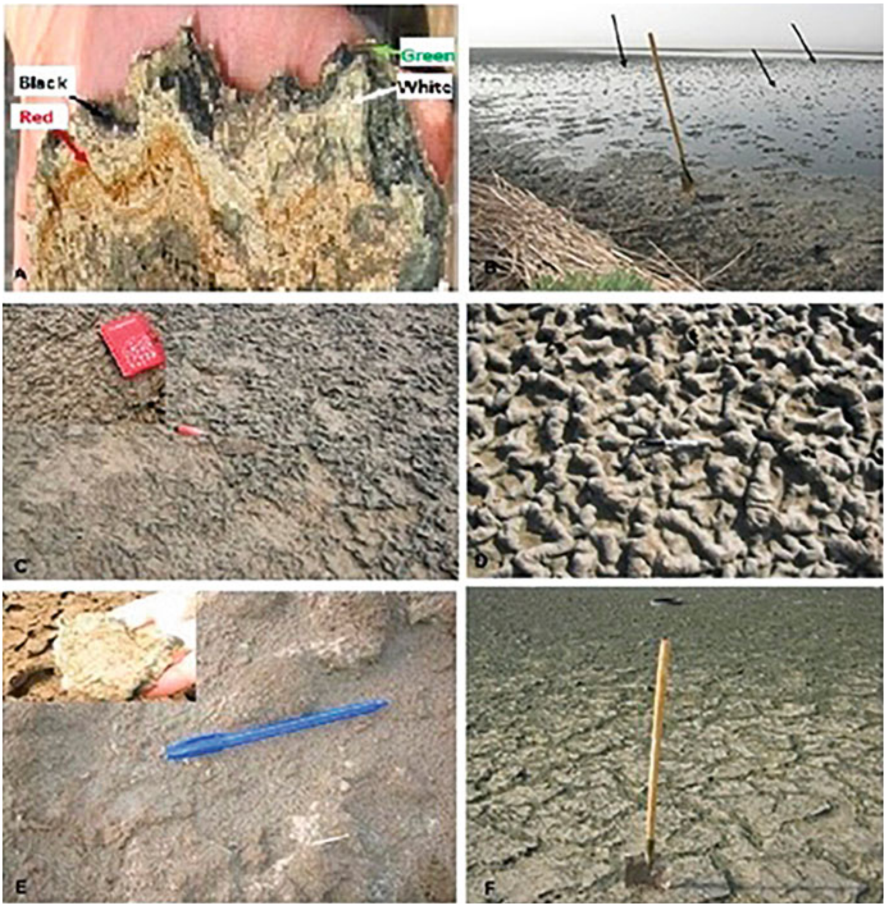

Plate 2 (**a**) Color cyanobacteria layers reserved on hand to scale and shows the layers in bellow, (**b**) Submerged MISS, arrows to show it and the shovel to scale, (**c**) Wrinkle structure, red scraper in the mid of photo to scale, (**d**) Ridge structure, the pencil in the mid of the photo to scale, (**e**) Dome structure, pencil to scale, and upper left, inversed piece in hand, and (**f**) Polygonal mat in green color, shovel to scale

Maximum water temperature was 33.5 °C in August and minimum on January 10 °C near the north station of the current study.

The water salinity of the studied area is high and considered as euhaline and hypersaline, according to the classification of Nelson-Smith (1977), whereas it was mesohaline (it was 6.7 to 10.5‰) for Al-Mulla (1999) and Kadhim and Al-Mulla (2002), for the same area. This variation in salinity could be related to the high temperature, shallow water in tidal flats, a salinity of the influx of water from Khor Abdullah, and the discharge of brackish washing water from Shatt Al-Basrah canal. The last factor could be more effective than the others, where during the studies of Al-Mulla (1999) and Kadhim and Al-Mulla (2002), the discharge of Al-Massab

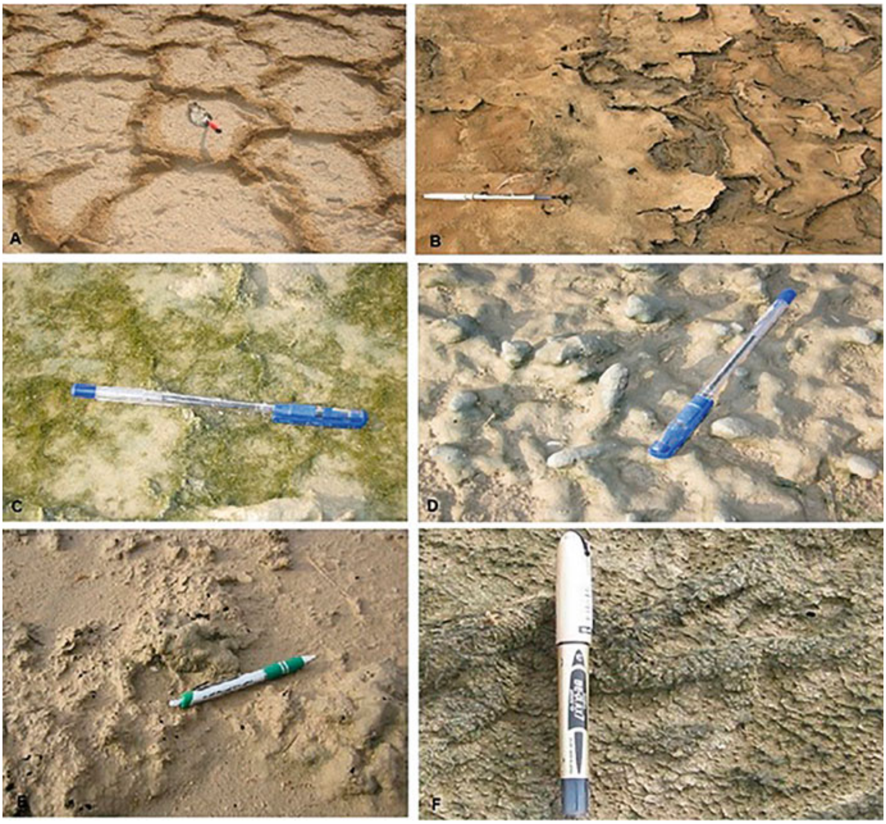

Plate 3 (**a**) Tepee structure, scraper to scale, (**b**) Crack in the mat, (**c**) Chips mat, (**d**) Finger structure, covered the root or stems of dead plants, (**e**) Irregular mounds, and (**f**) Pinnacle shape

Al-Aam through Shatt Al-Basrah canal was higher than in present time. The discharge was 325 m^3/s during the flood tide and 1050 m^3/s in ebb tide (Albadran et al. 1996). The high value of salinity in the present study was 62.2‰, in summer in shallow creeks where the water depth was few centimeters, and in the sediments was from 25.72 to 116.22‰ (Table 3). The seasonal variation in this salinity could be related to the effect of rainfall in the region and the evaporation process. According to these variable physical parameters, the density of cyanobacteria in the present study varies among the stations according to the value of salinity, no records for cyanobacteria in places of low salinity and near the Khor. This means that the favored salinity for the cyanobacteria in the region is around 60‰ and 120‰ in the water and sediments, respectively. Busson and Schreiber (1997) stated that the ideal limit of salinity for algal mat formed by cyanobacteria is between 80 and 150‰. Al-Delamii (2000) gave some genera which live in hypersaline sediments such as *Lyngbya*, *Microcoleus*, and *Oscillatoria*. In addition to the salinity, the nutrients could play a role in the distribution of the cyanobacteria, where in the northern part of the creeks they are abundant in winter than in autumn; three genera were recorded in autumn and five in winter. The primary productivity in the area is high (Shamshom and Yacoub 1986; Al-Abayachi and Gani 1986). It should also consider the temperature of the water; cyanobacteria prefer to live in water temperature between 18 and 25 °C (Al-Mussawy 2007).

In the present study, three structures were classified based on the origin and motive of formation: physical, biological, and biophysical structures.

6.1 Physical Structures

The physical structures are creeks, where the area is characterized by the multibifurcation of these tidal channels (Plate 1a). These creeks give to the area a dendritic geomorphologic form (Fig. 1). These geomorphologic forms are the biggest and formed by aqueous and wind erosion in addition to the tectonic setting (Karim 1991; Al-Mulla 1999); the eroded materials by these forms are washed down to the southern end of the biggest creek.

Salt structures have a chance in the study area, formed after their deposition on the surface of sediments due to the development of gypsum and halite minerals. Salt structures occur in sabkha region rich in salts and high rate of evaporation. Salt structures exist in the other side of the road where this road prevents the tidal water from arrival to this area, and the main source of water is from the capillary phenomenon, rainfall in winter, and little bit the humidity during the humid wind of southeast direction in the region.

Two types of salt sedimentary structures are recorded in the area: salt crust and salt ridges. Salt crusts are irregular, and the thickness is 2–5 cm (Plate 1b), whereas the salt ridges are irregular, pointed end, and polygonal in shape (Plate 1c). The height of these ridges was 2–5 cm and friable in nature.

6.2 Biological Structures

Biological sedimentary structures or disturbed sedimentary structures are due to the activity of the biota such as burrows of crab and mudskipper. Burrows of crabs vary in their shape and size (Plate 1d); the depth of the burrows is 10–30 cm, and diameter was not more than 10 mm in the intertidal zone, whereas the diameter reaches 30 mm in the supratidal zone (Kadhim and Darmoian 1999). This could relate to the age and size of the crabs (Kadhim 2008). Some crabs make ridges around the opening of burrows (Plate 1e), to reinforce the opening and keep the opening from windblown sand and to prevent themselves from enemies (Kadhim and Al-Mulla 2002). Mudskipper burrows have different shapes and sizes of holes, and they build up the clay around the hole in the polygonal shape of small ridges (Plate 1f) to keep water around the hole during the ebb tide period.

6.3 Biophysical Structures

The biophysical sedimentary structures are mainly cyanobacteria. Cyanobacteria form structures which are called microbially induced sedimentary structures (MISS). These structures are products of interaction between cyanobacteria and the environment, covering the tidal flats during the annual seasons. The MISS in the studied area appears in two forms: algal mat and algal mound in different colors and forms for both. The first type formed through three stages, and the second one formed by fourth stage; these two types of mechanisms were explained in detail by Noffke et al. (2001). The internal structure of these cyanobacteria is composed of fibers with different colors as in wrinkles structures (Plate 2c) and appears in wrinkle forms parallel to subparallel each other formed due to the action of tidal currents and weak marine waves. The fibers of cyanobacteria are present in two colors, deep and pale green in locations 7 and 8 (Fig. 1). Microscopic identification indicates that the genus *Oscillatoria* sp. was responsible for the deep green color.

Sometimes the mat of cyanobacteria is rushed by tidal currents as in the ridge structures (Plate 2d), multi-faces, and antiform in shape. These are formed from the rush of mats by tidal currents, mostly hollow and filled later by sediments to form zones in the antiform. The color of this structure varies with seasons, deep color in winter and pale in autumn. This structure is found in locations 5, 6, 20, and 25 (Fig. 1). The sediments stick on the surface of fiber by a polymer material secreted from the fiber, extracellular polymeric substances (EPS). This is noted in dome structures, formed by the rush action of gases in the mats after filling of mats by sediments and salt crystals (Plate 2e). Porada et al. (2007) found that the coccoid cyanobacteria are responsible for the formation of this structure. The microscopic study in the current study reveals that the spherical genus *Aphanothece* sp. forms this structure and heavy secretion of EPS. This structure presents in locations 19 and 26 (Fig. 1). This EPS material was a gelatin composed of protein, carbohydrates, and starch which led to catching the sediments (Guadrado and Pizani 2007). The adhesive sediments with fiber make zones in the structure from 1 to 4 micrometer in thickness (Stephens et al. 2008). In the study area, the colors of these zones are green, black, white, and red (Plate 2a). For Stephens et al. (2008), the variation in color depends on the variation in chemical composition; green color comes from the interaction of fibers of algae, black could be related to reduction, while white color belongs to the deposition of salts, and the red one is from the oxidation by dissolved oxygen in the water. It could also possible to form authigenic minerals in the structures of cyanobacteria as siderite and pyrite (Noffke 2000). The growth of EPS, nature of sediments, and erosion and sedimentation processes act on the development of MISS to submerge to the water surface (Plate 2b). In other places where the environment suffer from alternative wetness and dryness, many MISS are developed such as polygonal mat, which represents an extended mat with elevated edges in hexagonal forms (Plate 2f), found in location 13 (Fig. 1). Tepee structure is a polygonal mat exposed to desiccation (Plate 3a) formed in location 12 in the sabkha near the tidal area (Fig. 1), and mat cracks are formed in thin mat from the alternative subsequent wetness and dryness during flood and ebb periods and recorded in location 18 (Fig. 1). The cracks take place in the weak periphery area (Plate 3b). Chips mat is a thin mat (Plate 3c) found in location 11 (Fig. 1), which could be the first step to form the mat. The finger structure was associated with plant roots and stems, the remains of dead plants could play a role in the formation and development of this MISS where the later growth on these remains in this tidal flats which formed due to the uplift of algal mat in a finger form in the area (Plate 3d), and it was recorded in locations 10 and 13 (Fig. 1).

The area is a witness of notable windblown and raised sediments from the traffic on the road; these raised sediments could be attracted by cyanobacteria due to their adhesive surface, and forming the *elevated* irregular mounds (Plate 3e) found in locations 1 and 9 (Fig. 1), the evidence is the nearest of this structure to the road, where the sediments arrived from movement in the area.

Pinnacles is a pointed form like a pencil (Plate 3f), found in location 15 (Fig. 1). This structure is a small bridge originated from algal mats due to a difference in the behavior of cyanobacteria fibers network with sediments. Two genera are responsible for this structure: *Oscillatoria* and *Microcoleus*.

From field observations and laboratory analysis, there is no accordance between the presences of cyanobacteria and burrows of crabs. This could be related to the high cohesive mats formed by cyanobacteria, where the crabs could not able to burrow it, in addition to the cyanobacteria which prefer the high salinity area to live. The tidal currents are weak in the area for that the erosional MISS are absent and the algal mat cohesion is strong and capable to resist the erosion (Noffke and Krumbein 1999; Gerdes et al. 2007), where the EPS material increases the shear strength of structure and subsequent increase in consistency against erosion (Guadrado and Pizani 2007).

7 Conclusion

Three types of sedimentary structures are present in the study area: physical, biological, and biophysical structures. Sediment textures and physical and chemical properties of the study area are convenient to cyanobacteria to life and grow. Cyanobacteria are the most frequent sedimentary structures in the area, formed in many types as wrinkles structures, ridge structures, dome structures, polygonal mat, tepee structure, mat cracks, chips mat, finger structures, and irregular mounds. They attract the windblown and eroded sediments by the EPS. These cyanobacteria differ in shape and structure in accordance with the genus, the cohesion of fibers, and density of EPS, physical and chemical parameters of the environment. Algal mats increase the resistance of tidal flats against the erosion. The presence of cyanobacteria is not in accordance with the presence of crabs.

Acknowledgments The authors would like to thanks College of Science, the University of Basrah for funding this work, thanks also to Dr. Nedaa Al-Mussawy from biology department/the

University of Basrah, Iraq, for her help in the identifications of cyanobacteria, and to Dr. Adel Albadran from Environmental Agency-Essex, UK for reading the manuscript and his comments.

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