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Depositional Environments, Facies Pattern and Marine Plants Distribution in Ras Muhammad Area, Sinai, Egypt

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ABSTRACT

Ras Muhammad Marine National Park is located on faulted and uplifted Neogene blocks that are partially covered by Quaternary limestones of predominantly coralgal facies. The physiography of the reefal limestone cropping out in the area and also the present-day depositional environments are tectonically controlled. Surface morphology observations show that earthquake pools that cut through the uplifted Pleistocene reefs indicate continuing recent movements, as indicated by numerous records of seismic activity in the study area. The morphostructural-generated depositional facies patterns on the peninsula are a wide tidal belt with tidal shoals and coastal spits, barrier and fringing reefs, three elongated embayments, Hiddan Bay, mangrove and tidal channels, Ras Muhammad pool and sabkha, and earthquake pools (two earth fissures). The distribution of marine plants is described for each area. The abundance of algae in Ras Muhammad appeared to be inversely related to the abundance of living corals.
Key words: Depositional environments, morphostructural setting, marine plants, Ras Muhammad, Sinai.

INTRODUCTION

Ras Muhammad Marine Natural Park (27° 34.15' N, 34° 15.59' E) (Fig. 1), situated at the southernmost tip of Sinai Peninsula, has fascinated the world's diving community for decades because of its rich variety of reefs. It is bordered to the west by a relatively shallow elongate depression from the Gulf of Suez (average bathymetry of 70 m), and to the east by the deep waters of the Gulf of Aqaba that attain a depth of 1850 m caused by transformation movements along the Aqaba-Levante structure (Garfunkel *et al.*, 1981). The great depth and sheer walls of the southern part of the Gulf of Aqaba have given the coasts of Sinai admirably clear waters for most of the year. The whole area and the present-day depositional substratum consist of a sequence of marine Miocene and Quaternary coralline limestone.

The morphostructural setting of Ras Muhammad area is controlled by two factors: (1) its position at the triple junction between the Arabian plate, the African plate and the Sinai subplate, and (2) the NE motion of the Arabian plate. Therefore, the whole area is faulted and shows active recent seismicity. The area was studied by Gvirtzman *et al.* (1977), Friedman (1980), Bentor and Eyal (1987), Kebeasy (1990) and Nasr *et al.* (1996).

The underwater population along the southern coast of Sinai is particularly exceptional and many pelagic and benthic species gather there from the open sea to search for food and shelter (Khemeleva, 1970).

The marine macrophytes support about two-third of the autotrophic biomass in the world ocean (Smith, 1981), and their production is similar to that of phytoplankton in the continental shelves of the world oceans (Charpy-Roubaund and Sournia, 1990). The high biomass of marine macrophytes implies that they must be responsible for an important fraction of the light absorption by phototrophs in the ocean. Yet, virtually all marine macrophytes are benthic and therefore, inhabit a shaded environment depending on the geological structures of the substratum. In general, the northern part of the Red Sea was the subject of extensive works on the distribution of species by Nasr (1947) and Hegazi (1992 and 2002).

The aim of this work is therefore to determine the depositional facies patterns related to the morpho-structural setting of the Ras Muhammad area and the distribution of marine plants from selected environments.

MATERIALS AND METHODS

Ras Muhammad area was studied during a number of reconnaissance field trips that covered the entire parts of the area. Sampling of some sediment was carried out along a traverse normal to the shoreline from the land seaward, down to about a 10-15 m water depth. Some samples were petrographically studied with binocular microscope using staining standard techniques for identification of carbonates and evaporates (Friedman, 1959). Aerial photographs at a scale of 1:40,000 were used to prepare a photo-mosaic for the study area. The data collected from the field observations and aerial photographs were used to identify the different depositional environments and to construct the main structural features (mainly faults) in the area.

The analyzed samples were selected from the major marine habitats (sandy bottom, mud flats, grass beds, mangroves, coral reefs, and rock outcrops) that found in and around Ras Muhammad Marine Natural Park.

The assessment of marine plant abundance and distribution was obtained by the quadrate method using snorkeling and SCUBA diving. The marine plants were investigated within a few hours of collection, so most of them were kept cold in an ice box, whereas some species were preserved for later detailed study. Crustose

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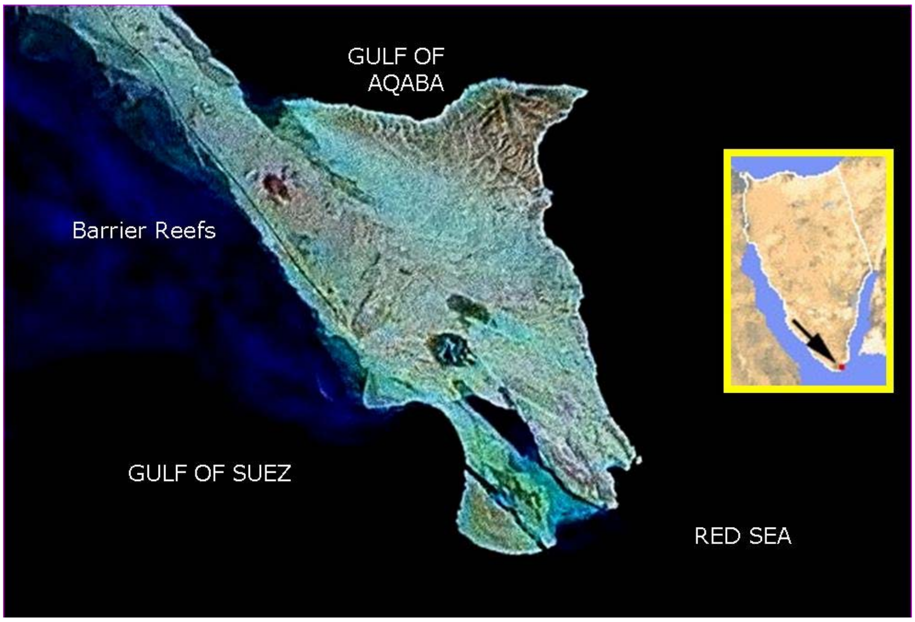

Figure (1): Location map of Ras Muhammad area.

algae were dried in their natural substrate and kept in boxes of suitable size, while articulate coralline algae were soaked in 30-50% glycerine solution before drying.

GEOLOGIC SETTING

Regional geology

The Red Sea forms a part of the rift system that includes the Gulf of Aden and the East African rift in the south, and the Gulf of Suez and the Gulf of Aqaba in the north. These rifts initiated in the Late Oligocene-Miocene time and fragmented the once continuous Afro-Arabian shield. The Gulf of Suez was developed as an early part of the rift in the northern Red Sea in the mid-Miocene prior to the development of the transform motion through the Gulf of Aqaba (Garfunkel and Bartov, 1977). The axial depression of the Red Sea deepens slightly south of Ras Muhammad reaching depths greater than 1200 m; it is terminated in the north by a NNE-trending high that extends from Shadwan Island toward the southwestern margin of Sinai. To the south of Ras Muhammad, there is an elongate escarpment trending N 23^{o} having a relief of 100 m (Martinez and Cochran, 1988). It forms the trace of the boundary fault of a major half graben. Its asymmetric pattern is similar to that of a series of deeps in the Gulf of Aqaba (Ben-Avraham, 1985). These deeps form asymmetric rhomb-shaped half grabens which continue southward in an en echelon geometry along the axis of the Gulf of Aqaba and into the Red Sea. The escarpment is in alignment with this series of deeps, and the half graben south of Ras Muhammad is a continuation of this structural pattern. Both are the expression of the Aqaba-Dead Sea transform fault, which intersects the Red Sea and Gulf of Suez rifts at the deep area south of Ras Muhammad (Garfunkel *et al.*, 1981; Ben-Avraham, 1985; Martinez and Cochran, 1988).

Local structural patterns

Data on the structural setting of southern Sinai are available in Garfunkel and Bartov (1977), Ben Avraham (1985), Lyberis (1988), and Purser and Hotzel (1988). The first structural interpretation of the Ras Muhammad area was given by Bentor and Eyal (1987), who related its presence to the Suez Rift tectonics (NW-SE direction). Its location along the southward extension of El-Qaa plain and the common northwest-trending structural units in the area support the assumption made by Bentor and Eyal (1987). The tectonic pattern of Ras Muhammad is distinguished by two faulted and inclined Neogene blocks that are partly covered by Quaternary reef limestones, which constitute an independent unit from the general framework of the tectonic history of southern Sinai.

Ras Muhammad area is the closest to the triple junction between the southern rhomb-shaped half graben of the Dead Sea Rift, the southern terminal of the active fault of the Suez Rift and the northern termination of the Red Sea axial trough. Therefore, the whole area is faulted and tectonically active. A network of faults affect certain onshore coral reef terraces in two dominant directions (NW-SE and NE-SW trends) indicate this very clearly. Spectacular examples are cropping out especially in the eastern and southern parts of the study area, where the vertical exposed cliffs of older Pleistocene reefs (up to 30 m high) demonstrate a strong tectonic control of reef morphology. This indicates that tectonic activity was rejuvenated in this area during the Quaternary. Furthermore, these faults

Figure (2): Fossiliferous coral skeleton of Pleistocene reef terraces along southern coast of the area.

controlled the development of the horst-graben patterns. Some grabens are in the form of embayments or elongate channels running in northwest-southeast direction, the most obvious of which is the tidal channel and Mangrove channel.

The area cut by fissures (earthquake pools) on the raised Pleistocene reefs indicate that tectonic movements are still continuous, as proved by recent earthquake activities in and around the investigated area. Locally, these cracks were revealed after the 1969 earthquake (Ben-Menaham and Abodi, 1971) with a main direction nearly parallel to the Red Sea - Gulf of Suez direction.

Results and Discussion

Two lithological units were defined in Ras Muhammad area: The lower unit (Miocene age, syn-rift) is made up of two outcrops of inclined beds; the western one, in and around the Black Hills, is composed of sandstone, dolostone, and gypseous shales with bedded dolomite and fossiliferous limestone at the top. The eastern outcrop consists of dark weathered sandy limestone. The upper most unit is the Quaternary sediments (post-rift) consisting of shallow-water limestones predominated by coralgal facies cropping, in most of the area, as two uplifted coral reef terraces (Fig. 2 and Plate 1A), and continental alluvial deposits.

Late Quaternary climatic fluctuations and eustatic sea level changes, together with tectonic uplift rates of about 0.1 mm/year (Gvirtzman, 1994), are responsible for the formation of these two sequences. There are also submerged Pleistocene coral terraces representing relatively low stand sea-level. Holocene corals, on the other hand, associate the horizontal reef-flat (one meter above the present-day reef flat) and fringe the south-western coastline of the area representing late Holocene higher sea level (Gvirtzman, 1994). Different depositional patterns are recognized in the study area (Fig. 3). The following paragraphs give a brief account of each.

Tidal flats

The western coast is a broad, gently sloping tidal zone. It faces the Gulf of Suez and extends along the way to Ras Muhammad in a northwest-southeast direction. The developed barrier reefs protect the tidal flat which is sporadically flooded by seawater during exceptional tides and storms. The intertidal zone is 400 to 800 meters wide and it is characterized by muddy carbonate sediments of typical sheltered environments. Its landward part is marked by a thin crust of halite that periodically destroyed by tides (Fig. 4). Well-lithified beach rock with carbonate sediments consisting of skeletal fragments and pellets are frequently observed along the beach. In the supratidal zone, there is an accumulation of dispersed crystals of anhydrite and gypsum within the coarse clastic sediments and a surfacial crust of halite. These two zones commonly resemble modern coastal sabkha formed under evaporation and with desiccation cracks. The northern part of the intertidal zone is marked by a group of tidal shoals or bars in a southeast direction. The height of the shoals is approximately 50 cm. Quartz grains and non-skeletal ooids and peloids dominate these tidal sands. Small fragments of corals that derived from the adjacent offshore barrier reefs represent the skeletal grains in this the tidal flat along the southwestern shore of the pool. This zone was dominated by endolithic blue-green and had extremely few littorinids. Delicate forms such as *Antithamnion pygmaeum* and *Ceramium tenuissimum* grow in shallow water sheltered under projecting rocks flat. The tidal currents distributed the sediment, so that several small marine spits are developed in a southwest-south direction, north of Qad El-Baira Bay. These spits are composed of sand deposits and reflect the accretion process.

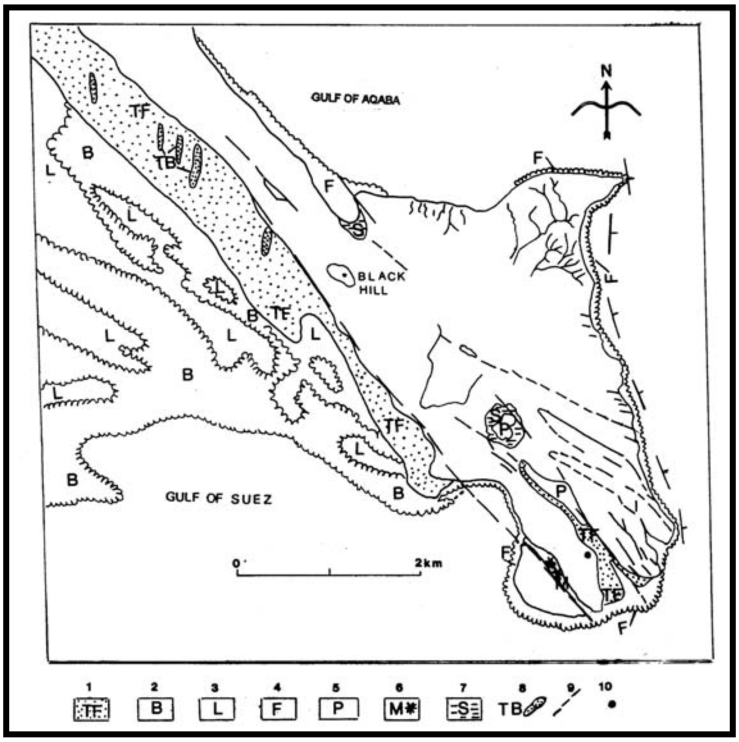

Figure (3): The distribution of the depositional facies patterns and major lineaments in Ras Muhammad: (1) Tidal flat (2)Barrier reefs (3) Lagoon (4) Fringing reefs (5) Pool (6) Mangroves (7) Sabkha (8) Tidal bar (9) main faults (10) Open Cracks and Earthquake pool.

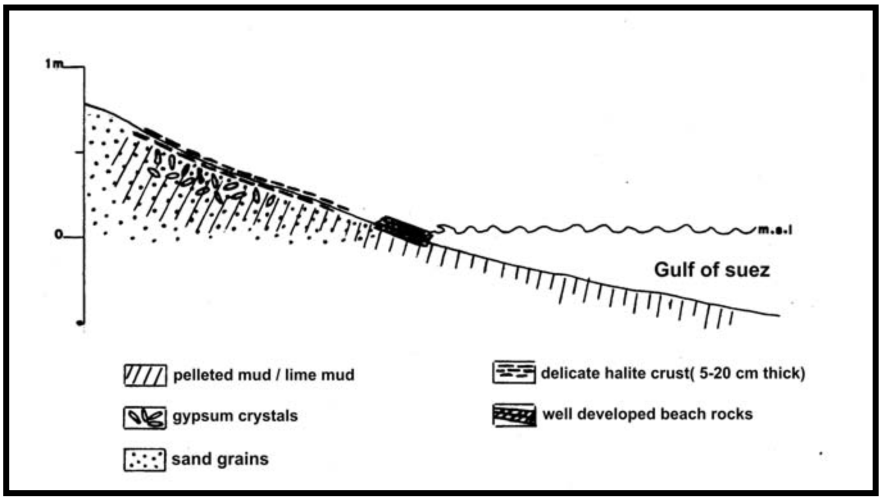

Figure (4): Cross section showing sediment types.of the Gulf of Suez tidal flat-sabkha along Ras Muhammad area.

Along the south-eastern side of the Ras Muhammad area, an elongate tidal channel runs NW-SE on the mainland (the trend of the Suez Rift). The channel separates the eastern part of the higher older reef cliffs from those of the western part of the low elevated younger reefs (Fig. 5). The main trunk of it is covered by tidal flat deposits of sand and mud except at its north-eastern end where a relatively deep elongated pool (800 x 250 m) is filled with marine carbonate sediments (Plate 1B). The pool is occasionally separated from the Red Sea at the extremely low tide, whereas, at high tide, the sea water flows from the Red Sea through the tidal flat into the pool and/or by means of underground fissures in the permeable reef rocks. Lewy (1973), and Sneh and Friedman (1973) recorded the occurrence of planar stromatolites and large modern oncolites (2-3 cm in diameter) paving the upper part of and in crevices to avoid the intense and long day light. The chlorophyta are common between tide marks and on reef flat.

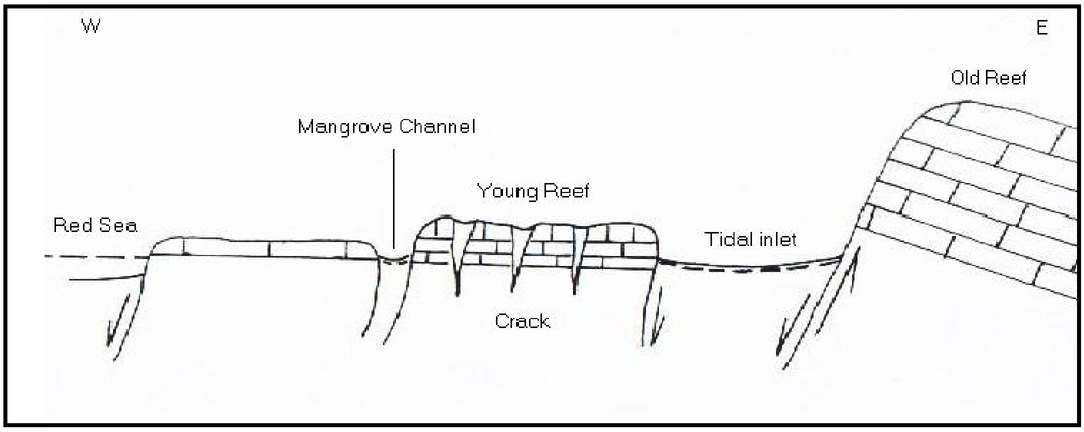

Figure (5): Simplistic sketch showing generalized morphology, SW Ras Muhammad.

Mangrove Settings

Ras Muhammad mangroves represent the present-day *Avicennia marina*. They are found in a hard, fissured substratum, cutting through fossil Pleistocene reef (Plate 1C). It appears that, the channel was recently formed by an open tectonic crack in a NW-SE direction. Therefore, it is closely related to the Suez Rift tectonic trends. The channel is veneered by small patch of mangroves, micrite sediments and fine skeletal sand derived from the breakdown of the Pleistocene walls and recent biogenic and biochemical components. The Pleistocene walls are eroded by boring cyanobacteria and by grazing chitons and *Littorina*. The fresh water and soil accompanied with flash floods and groundwater allow the trees to grow in this saline environment. The southeastern end of the channel passes into a horizontal reef flat with extensive growth of sea grass and coralline algae in the form of free branches and rhodoliths.

Generally, at the bottom of the *Avicennia marina*, there is a dense growth of *Caulerpa racemosa* and *Cladophora albida*. Between the pneumtophores, there is a diversified micro-flora of blue-green algae. The species *Caulerpa* is the most common among the habitats as compared to any other single genus in the mangrove's channel. The calcareous algae consolidate and cement coral rubble at the reef surface forming a hard-rock that act as a wave-resistant protective coat in the seaward direction. The algae and microbial organisms that secrete calcium carbonate are present as binders in Ras Muhammad reefs, as indicated by layered, crust-like growths around other reef fossils in this area (Hegazi, 1992).

Pools

There are two types of pools in the area:

(A) Ras Muhammad Pool

It is a saline, seepage pool occurring on the substrate of Pleistocene fossil reefs in the innermost part of Ras Muhammad area. It occupies the depression parallel in orientation to the structural features of the area. It has no surface connection with the Red Sea. The water level fluctuates with seasonal sea level changes, providing evidence that the pool maintain subsurface connections with the saline water of the Red Sea through pores and fissures in the porous reef substrate. It is observed that the water depth ($\approx$ 2 m in depth) and its water salinity change seasonally. It is flooded in the winter, while it appears as wetland in summer during the lowest sea level. Friedman (1980) recorded the occurrence of algal mats at the floor of the pool. The sub-bottom sediments consist of intercalated algal mats and laminites of gypsum. A rim of well-developed sabkha with typical evaporites (halite, anhydrite, and gypsum) and carbonates surround the pool. The substrates of the pool are covered by *Lyngbya majuscula*.

(B) Small Earthquakes Pools

These pools are in form of earth fissures running through the raised Pleistocene reefs to a depth of more than 10 m from the surface (Plate 1D). They are directly related to recent earthquakes in the area. Sea water seepage from the Red Sea through subsurface conduits of the permeable emergent reefs provides water with a relatively normal marine salinity. The level of water in the pool-cracks fluctuates with tide. Twenty species of fauna and flora were observed on the steep and shaded walls of the cracks. They are favourable to life in condition of high manganese and iron oxides of the substratum. These oxides were either leached from the underlying Neogene sediments or produced by hydrothermal activity in the Red Sea. The community has the highest combined coverages of fleshy and filamentous species of algae. The distribution of *Rhizoclonium grande, Codim dwarkense,* and *Botryocladia leptopoda* was similar to that of *Lobophora variegata*. Salinity, temperature, and tidal fluctuations appeared to be the main environmental factor governing the abundance and distribution of the fauna and flora in the pools.

Barrier Reefs and Lagoons

Due to the shallow environment along the coastal area of the Gulf of Suez, there are widespread barrier reef complexes as well as small reef patches, extending to a distance of 8 km from the western coastline of the area. They almost follow the main axis of the Suez rift (north-west-south-east direction). Total plant cover in

Plate (1): Depositional facies patterns. (A) Pleistocene coral reefs terraces, (B) elongated tidal channel, (C) *Avicennia marina* in mangrove channel, and (D) earthquake pool.

in this community was the lowest and it gradually decreased with depth. At the same time, sponges became more abundant and the number of algae declined until *Caulerpa racemosa* was the only alga left.

Fringing Reefs

Along most of the southern and eastern coasts of the study area, living corals form an almost continuous fringing reef belt, along the outer edges of the abraded flats. Locally, modern reefs situated in front of the grabens upon which they developed constitute a wide band, in contrast to those formed along the horsts, which is largely attributed to the diverse topography of the substratum.

Seawards biozonation of fringing reefs from shoreline is given below.

In the splash and spray rocky fossil zone, there is a number of epilithic blue green algae such as *Lyngbya aestuarii*, *Aphanocapsa littoralis*, and *Oscillatoria margaritifera*, and green algae such as *Cladophora prolifera* and *Enteromorpha ramulosa*. This community followed by fleshy and filamentous algal vegetation *Acanthophora najadeformis*, *Digenea simplex*, *Hypnea musciformis*, *Laurencia obtusa,* and *Padina pavonica*, with patches of small *Centroceras clavulatum*, *Ceramium tenuissimum*, *Enteromorpha intestinalis* and *Dictyosphaeria cavernosa* (Plate 2). The unobtrusiveness of filament and fleshy benthic algae is a characteristic feature of the shallow coral reefs.

Crustose coralline algae such as *Lithophyllum koschyanus* and *Porolithon onkodes* are abundant and form ridges growing upwards, to the level of low tide, and seawards extending the reef front. *Lithophyllum* mainly covers coral rubble lying in the brightly illuminated depressions. A considerable part of the bottom is covered with algal turf *Gelidiella acerosa* and *Ceramium tenuissimum*. This is one of the most diverse turfs of the reef in south Sinai. *Gelidiella acerosa* grows on projecting surface of dead corals and on indentations of the surface of living massive corals, probably scars of earlier injuries.

A large meadow of seagrasses *Thalassia hemprichii* and *Thalassodendron ciliatum*, with well-developed small patches of *Halophila stipulacea* and *Halodule uninervis*, may reflect turbulent water conditions generated by wave and tidal currents.

At about 0.75 - 0.90 m depth of the Ras Muhammad reef flat *Halimeda opuntia* and *Halimeda tuna* occasionally became abundant enough to share dominance with *Caulerpa racemosa* and *Caulerpa serrulata*, the total plant cover in this community was lower than in the *Laurencia obtusa* community and it is gradually decreased with depth. *Lobophora variegata* grew on the shell of a living *Tridacna squamosa* and *Strombus tricornis*. It is worthy to mention that the

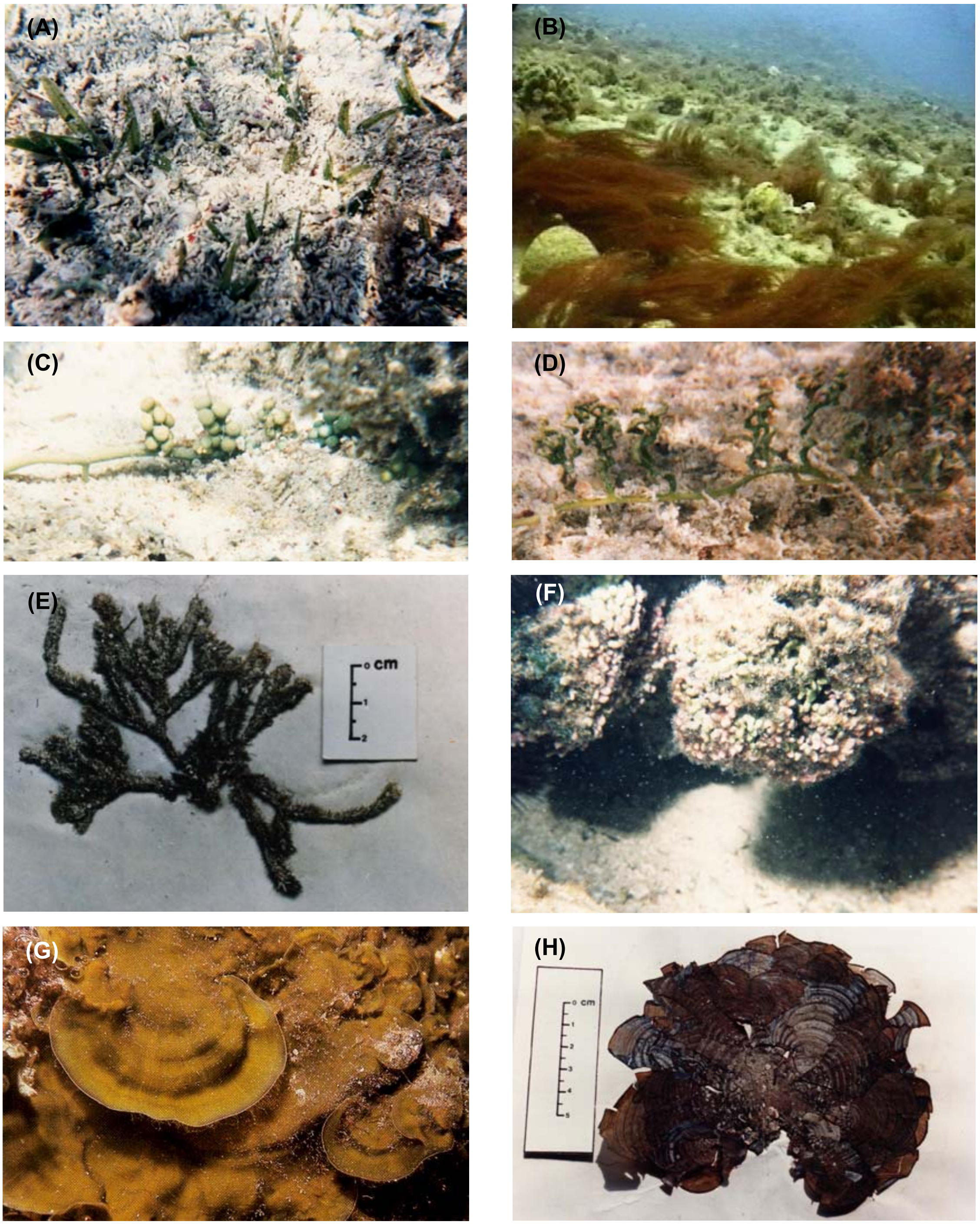

Plate (2): Marine Plants**. Seagrasses and Cyanophyta:** (A) *Halophila stipulacea* and (B) *Lyngbya majuscula;* **Chlorophyta:** (C)*Caulerpa racemosa* and (D) *Caulerpa serrulata***; Rhodophyta:** (E) *Digenea simplex* and (F) *Lithophyllum koschyanus*; and **Phaeophyta:** (G) *Lobophora variegat*a and (H) *Padina pavonica*.

fishbehaviour can modify the distribution of algae in Ras Muhammad, the establishment of territories by certain damsel fish leads to an increase in algal biomass within the area they defend. These observations agree with those of Vine (1974), who noticed a similar effect for both surgeon fish and damsel fish territories, particularly the increase of algal standing crop that led to a reduction in the settlement of coral planulae and other benthic invertebrates. The abundance of algae in Ras Muhammad appeared to be inversely related to the abundance of living corals. Because of the efficient feeding methods employed by corals, algal spores can not settle and grow on living corals. Also, most corals are efficient in acquiring and holding living space, which prevent encroachment by established algae (Hegazi, 1992).

Summary

Ras Muhammad area is made of uplifted and faulted Neogene blocks that are partially covered by the Quaternary limestones of predominantly coralgal facies. The general sedimentary framework of the area is characterized by a series of depositional facies which simply trend parallel to the general structural features. These facies are a wide tidal belt with tidal shoals and coastal spits, barrier and fringing reefs, three elongated embayments, Hiddan Bay, mangrove and tidal channels, Ras Muhammad pool with well-developed sabkha, and earthquake pools.

The association of algae with coral reefs is very important as the nature of their mutual relationship significantly affect the habitats in which they occur. Algae can have deteriorative effects on reefs. Their ability to colonize all available surfaces makes them highly competitive occupiers of space on reefs. Calcified encrusting algae are significant as agents of reef cementation. On hard substrate, there is considerable competition for space between hard corals, soft corals, and algae. Hard corals will slough off algal spores and fragments, but corals killed by extreme low tide, or high temperature, are soon colonized by a rapid growth of algae. Removal of coral tissue by *Acanthaster planci*, also leads to algal development on the dead coral skeleton. Soft corals occupy substrate but do not contribute to the reef framework. The nature of their relationship with filamentous algal population is unclear. Unlike hard corals, the soft corals leave no trace when they die, disintegrating rapidly. Although corals grow much more slowly than the shorter-lived filamentous algae with which they compete for space, corals live longer, and once established grow large enough to avoid this competition unless environmental conditions become unfavourable to coral growth.

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أنماط السحنات والبيئات الترسيبية وتوزيع النباتات البحرية في منطقة رأس محمد، سيناء، مصر

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الملخص العربـــى

تعرضت كتلة محمية رأس محمد الطبيعية المتشكلة أثناء الدور الثالث من حقبة الحياة الحديثة للرفع والتصدع وتغطت جزئيا بالصخور الجيرية الرباعية، والتى يسود فيها سحنة الطحالب المرجانية، وتتحكم توزيعات الصخور الجيرية المرجانية المكشوفة فى المنطقة وكذلك البيئات الترسيبية الحالية بتكتونية المنطقة.

وأظهرت الدراسة أن نماذج السحنات الترسيبية ذات العلاقة بالوضع الظاهرى التركيبى فى الجزيرة هى: حزام واسع من المد والجذر ذات تجمعات مادية وألسنة ساحلية، الشعاب الحاجزية والحافية، ثلاث قنوات طولية (خليج حيدان - قناة المانجروف - قناة المد والجذر)، بركة رأس محمد، البرك الزلزالية والتى تظهر كشقوق أرضية، وتم وصف تجمعات النباتات البحرية لكل منطقة، وقد أتضح أن وفرة الطحالب لها علاقة عكسية بوفرة المرجانيات الحية.