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The Northern Bay of Safaga (Red Sea, Egypt): An Actuopalaeontological Approach I. Topography and Bottom Facies

Die Nördliche Bucht von Safaga (Rotes Meer, Ägypten): ein aktuopaläontologisches Beispiel I. Topographie und Bodentypen

by

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in cooperation with

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Summary

Topographically the Northern Bay of Safaga can be subdivided into 4 parts: the "East area" with water depths down to 55 m exposed towards the open sea, the shallow "North area", the "West area" with a central basin of 30 to 38 m depth, and the "Southwest channel", which is connected to the Southern Bay. Mapping of the sea bottom allowed several bottom facies to be distinguished: 1) Coral reefs, which can be subdivided into fringing reefs, patch reefs (platform reef, miniatoll, pinnacle reefs), and coral patches. 2) Rock bottom, representing subtidal rocky substrate without or with sparse sediment cover and lack of dense stony coral settlement. 3) Coral carpet, showing areal covering of hard bottom by abundant stony corals without vertical zonation. 4) Sand bottom, where in addition to pure sands several other subtypes occur (sand with coral patches, sand with seagrass, sand with macroids, muddy sand). 5) Mud bottom, rich in infauna and lebensspuren. 6) Rocky tidal flats. 7) Mangrove. The bottom facies distribution is mainly controlled by the underlying morphology and by water currents.

Zusammenfassung

Aufgrund der topographischen Gegebenheiten kann die Nördliche Bucht von Safaga in 4 Teile gegliedert werden (Fig. 3): der exponierte „Ostteil" erreicht Wassertiefen bis 55 m und wird gegen das offene Meer durch eine submarine Schwelle bzw. eine Reihe von Untiefen, die an die Wasseroberfläche heranreichen, abgegrenzt. Der „Nordteil" umfaßt ein ausgedehntes Flachwasserareal, das durch einen intertidalen Rücken gegliedert wird. Der „Westteil" wird durch ein scharf begrenztes Becken mit einer Wassertiefe zwischen 30 und 38 m charakterisiert. Dieses Becken verengt sich im SW und leitet in den „Südwestkanal" über, der im Süden mit einer Engstelle und Untiefe in die Südliche Bucht von Safaga mündet.

Die Wassertemperatur zeigt eine jahreszeitliche Abhängigkeit aber keine schichtungsbedingten Unterschiede; ebenso die Salinität, die mit Werten zwischen 40 und 46 ‰ sehr hoch ist. Die Wasserströmung innerhalb der Bucht folgt der generellen N–S Richtung am Außenrand, zeigt aber in Abhängigkeit von der Morphologie ein komplexes Muster (Fig. 5).

Die Kartierung des Meeresbodens erbrachte eine Einteilung in verschiedene Bodenfaziesbereiche (Kartenbeilage): Unter den größeren Korallenriffen können 2 Saumriffe (Ras Abu Soma, Tubya al-Hamra – Tubya al-Bayda) und mehrere Fleckenriffe beobachtet werden. Letztere sind durch ein Plattformriff (Tubya al-Kabir), ein Miniatoll (Gamul al-Kabir) und mehrere Turmriffe (Tubya Arba, Tubya al-Saghira, Gamul al-Saghira) vertreten. Die kleineren Riffbildungen wurden als Buckelriffe zusammengefaßt. Weite Flächen der Bucht werden von mehr oder weniger dichtem Korallenbewuchs überzogen, der keine deutliche Zonierung erkennen läßt. Diese Bereiche wurden als Korallenrasen ("coral carpet") bezeichnet und leiten häufig gegen das tiefere Wasser bei abnehmender Korallendichte in Felsböden über. Eine starke Differenzierung lassen die sandigen Weichböden erkennen, was zu deren Untergliederung führte. Reiner Sandboden tritt hauptsächlich in Küstenbereichen auf und weist hier einen teilweise hohen Anteil an terrigenem Material auf. Im flacheren Wasser werden die Sande häufig durch Buckelriffe oder/und Seegras besiedelt. Bei zunehmender Häufigkeit dieser Buckelriffe kann ein Übergang in Korallenrasen entstehen, dichter Bewuchs mit Seegras wurde als eigenständiger Bereich behandelt. In Wassertiefen unterhalb von 50–55 m ist am östlichen Steilabfall der Bucht ein Sand mit Makroiden aus acervuliniden Foraminiferen, Corallinaceen und Bryozoen entwickelt. In den tieferen und geschützten Bereichen der Bucht tritt zunehmend feinkörniges Sediment dazu, was zur Bildung von schlammigem Sand führt. Im geschützten Becken des Westteiles zeigen die Sedimente die geringste Korngröße und werden dem Schlammboden zugeordnet. In manchen Küstenbereichen ist auf unterlagerndem Korallenkalk ein Felswatt ausgebildet, am Nordwestende von Gazirat Safaga ist ein kleiner Mangrovebestand vorhanden.

Die Vielfalt und Verteilung der Bodenfaziesbereiche kann durch die Bodenmorphologie und die hydrodynamischen Verhältnisse erklärt werden, die unmittelbare Nachbarschaft von völlig unterschiedlichen Bodenfaziesbereichen erscheint für Untersuchungen im Fossilbereich bedeutend.

1. Introduction

With the increasing importance of palaeoecology and facies, the interest in actualistic studies has increased during the last decades. This field of study comprises a broad spectrum of quite different approaches and methods. One of the most important sites for actualistic investigations are reefs and connected carbonate environments. Therefore a great number of studies has been carried out in all larger tropical to subtropical carbonate and reef provinces. In accordance with the complex subject matter such studies have often covered a large investigation area or have dealt with very specific problems. This has brought forward very heterogeneous results, which often cannot be compared or combined.

Considering the actuopalaeontological accent of these studies an extreme polarization on coral reefs s.str. is observable. This can be explained by the extraordinary complexity of this biotope and by its importance for geosciences. The environments surrounding the coral reefs and partly associated with them have also been taken into consideration (e.g., NEWELL et al., 1959; PURDY, 1963a, b; PURSER, 1973; WANTLAND & PUSEY, 1975), but often in an unsatisfactory way, especially with respect to palaeontologically important groups. Frequently, such studies have merely offered a systematic list of organisms, while distributions, if investigated at all, have been carried out on a very large scale and been inadequately explained (e.g., ROBERTS & MURRAY, 1988).

This raises the need for an actualistic study carried out in a relatively small area immediately adjoining coral reefs and containing many different facies. Such a study should investigate selected groups of benthic organisms

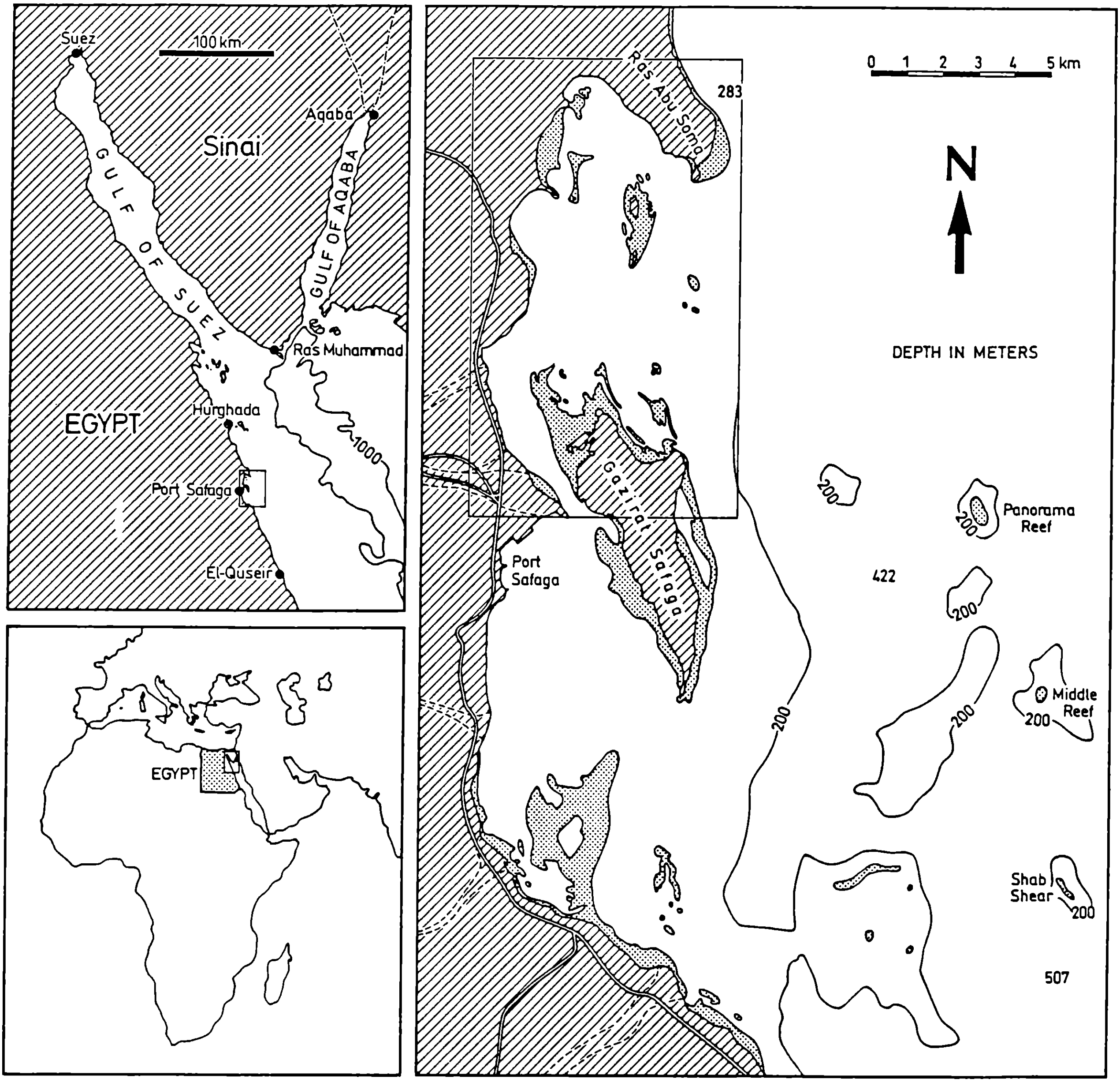

Fig. 1. Location map of the Northern Bay of Safaga.

with respect to their palaeoecological significance in addition to sedimentological parameters. This study should not focus on the associations of the coral reefs but rather on those of the surrounding environments.

The investigation area must fulfill several important requirements. One of the most essential is the presence of many facies types in a small area. The different facies should not be restricted to extreme shallow water of only a few metres (e.g., like on the Great Bahama Platform); at the same time the water depth should permit sampling and in situ observations by SCUBA-divers.

In general the Red Sea would seem to be poorly suited for such a study: the breaking up of the African–Arabian platform (AVRAHAM et al., 1979; FRIEDMAN, 1985) created a deep (>2000 m) but very narrow (29–350 km) ocean characterized by extremely steep margins and no well-developed continental shelves. Nevertheless an area was found complying with the imposed requirements. The Bay of Safaga, a shallow water bay with a maximum water depth of 55 m, is situated on the west coast of the Red Sea on Egyptian territory between 33°56' and 34° longitude and between 26°37' and 26°52' northern lattitude (Figs. 1, 2). On the western margin the bay is bordered by a narrow arid coastal plain (Pl. 1, Fig. 1). Toward the east it discharges into the open ocean by a very steep slope; at a distance of 500 m a water depth of more than 200 m is reached.

The N–S oriented Safaga Island (Gazirat Safaga) equally subdivides the bay into a northern and a southern part. Both parts are distinctly separated by a shoal and connected only by a narrow channel. Additionally, the prevailing water current from north to south prevents the harbour of Safaga, which is situated in the southern part, from influencing the Northern Bay. Therefore the northern part was selected for investigation.

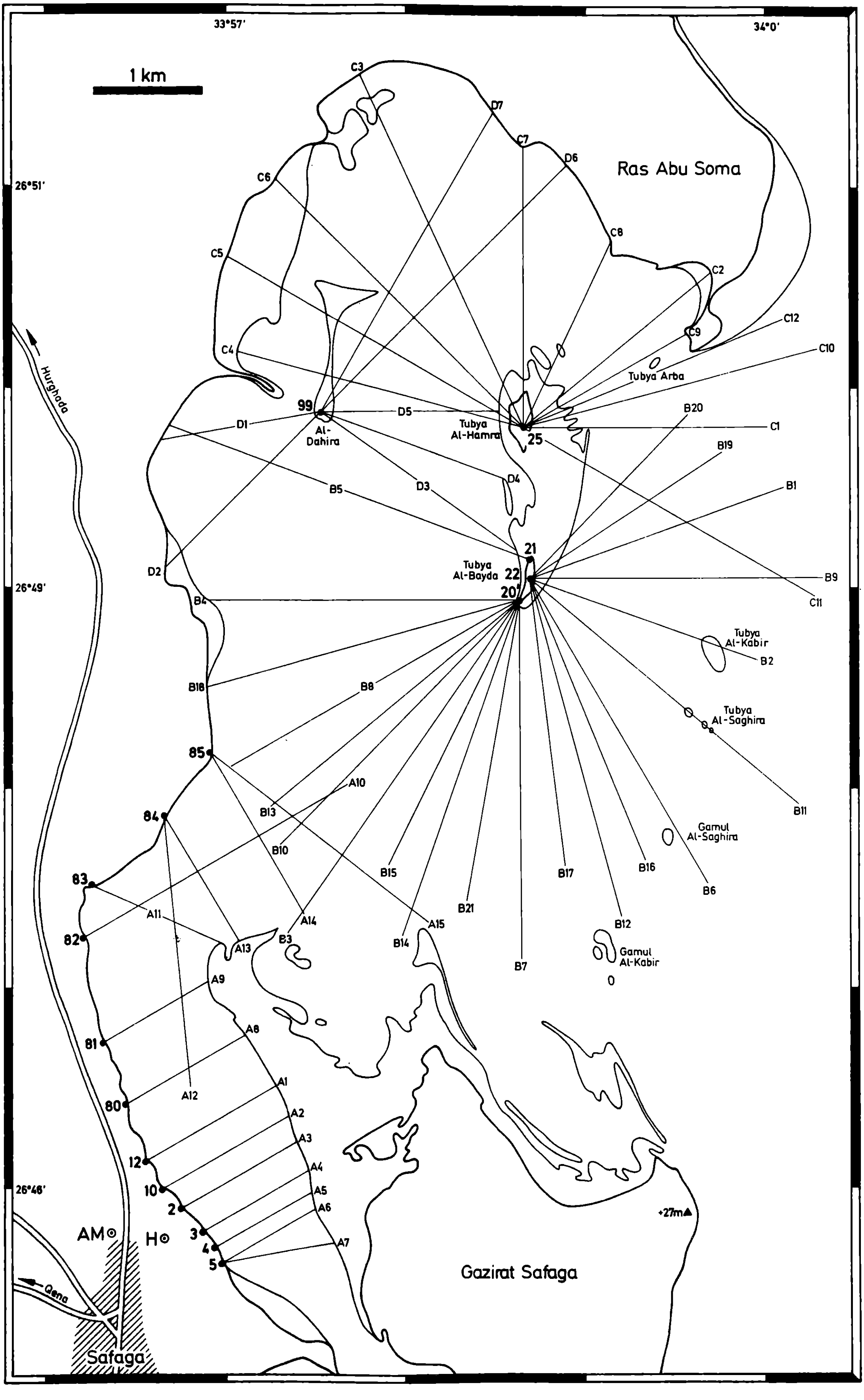

Fig. 2. Positions and designations of transects.
Land points (bold typed numbers) represent fix points for the survey. AM = Aerial mast, H = "Safaga Hotel".

After preliminary studies in autumn 1984, four- to six-week field investigations were carried out in April/ May 1986, November 1986, February 1987, and July/ August 1987. The participation of all authors in the field work permitted a wide range of observations and the collection of a large number of different samples. The samples will be studied in respect to sedimentology by A. Mansour and W. Piller, to foraminiferes by Ch. Rupp and W. Piller, to molluscs by F. Steininger and R. Golebiowski, to lebensspuren by P. Pervesler, to corals and boring bivalves by K. Kleemann, and to echinids by J. Nebelsick. The present paper will provide the base for these forthcoming studies by presenting the topography of the investigation area and by providing a description along with the distribution of the different bottom facies.

2. Field methods

The detailed documentation and characterization of the differen` bottom facies in the Northern Bay of Safaga required mapping the sea bottom on a scale of 1:25000. The British Sea map no. 3043 (Harbours and Anchorages in the Red Sea) – part "Safaga Island Anchorages" – on a scale of 1:75000 served as a basis. Additionally an aereal photograph – not rectified – was used for a more exact separation of the intertidal areas. However, information of these documents in the subtidal areas was unsatisfactory and special surveys were conducted to create a detailed map.

Two land marks were selected as fixed points: an aerial mast in the town of Safaga (point AM, Fig. 2), and a smaller transmitting aerial on top of an elevation at Gazirat Safaga (point +27 m at Fig. 2). The "Safaga Hotel" complex (point H at Fig. 2) served as an additional orientation. From these fixed points appropriate land points were surveyed (Fig. 2): they served as starting-points for a dense net of transects covering the entire area (Fig. 2). Depending on the topography, the transects have a star-like orientation away from the islands; to the north of the town of Safaga they run perpendicular to the channel axis.

The survey required 2 co-operating working groups: one at the respective land point, the other on a fishing boat. The fishing boat was equipped with a simple, exteriorly mounted echo-sounding apparatus (Silva 3000), suitable for a depth range from 0.6 – 120 m. An electronic distance-meter (Fennel 10000 marine) on the boat measured, by reflection of a transmitted laser beam, the distance to the respective land point. The reflecting unit on the land point was built of 11 circular prism mirrors (Wild GPR1) on a tripod. Under favourable conditions the maximum distance measurable with these units was appr. 3.5 km. A theodolite next to the reflecting unit was used to maintain the boats course.

Steering along the transects permitted distances and depths to be recorded; the character of the sea bottom was also observed down to 20 m depth using a bathyscope. Altogether 55 transects with a total length of 125.8 km were made; the depth and position of more than 5000 points of the sea bottom were documented.

In mapping the different bottom facies, areas not observable from the boat were investigated by SCUBA-diving; the maximum depth was more than 70 m. At the same time, samples were taken using a variety of methods.

The large amount of information was used to construct profile sections demonstrating the bottom relief as well as the character of the sea bottom (Figs. 6, 7, 8). Finally, an isoline map (Fig. 3) and a map of the bottom facies distribution of the Northern Bay of Safaga (Enclosure 1) were drawn.

The isoline map was perfected by a computer program (Uniras-Unimap) capable of complex interpolations; this permitted realistic results even in areas with sparse primary information (e.g., NE of Gazirat Safaga). The program also enabled the presentation of vivid block diagrams of the entire investigation area from different viewpoints (e.g., Fig. 4).

3. Topography

The Northern Bay of Safaga measures appr. 10 km in north–south- and appr. 7 km in west–east-direction. The northern border is formed by the prominent peninsula of Ras Abu Soma: its eastern side is developed as a rocky steep shore which flattens towards the south and ends in a small sandy peninsula. East of the rocky shore, a crescent tidal flat area with a maximum width of 500 m is developed.

The investigated area is bordered in the south by Gazirat Safaga (Safaga Island). In front of its northern margin extends a richly structured, wide, shallow water area (down to 5 m) separated from the island by a rocky intertidal flat reaching its greatest extension in the northwest.

Two islands are located in the centre of the Northern Bay, named here the "Tubya Islands". They are founded together on a N–S extended topographic high-structure of 2.5 km length and 0.75 km width. Both islands are also extended in a N–S direction but are different in their morphologic appearence. The northern island Tubya al-Hamra (= Geziret Tubya of the nautic map) measures appr. 500 x 250 m and is mainly built of fossil (or subfossil) coral limestone. The centre of the island rises appr. 12 m above sea level. Its coast is characterized by a steep rocky wall with a maximum height of 4 m; a flat sandy beach is developed only towards the south. In contrast, the southern island Tubya al-Bayda (= Sandy Island of the nautic map) is extremely flat (Pl. 9, Fig. 4) and can be largely flooded during spring and storm tides. Its N–S extension reaches appr. 400 m and its width appr. 100 m. The foundation of both islands is made up of a rocky base whose more or less flat upper surface is located in the tidal range.

According to its general morphology the Northern Bay of Safaga can be subdivided into four main parts: an "East area", which is turned towards the open sea and reaches the greatest water depths, a more protected "West area" with a basinal character, a very shallow "North area" and a "Southwest channel", originating from the "West area" and representing the connection to the Southern Bay of Safaga.

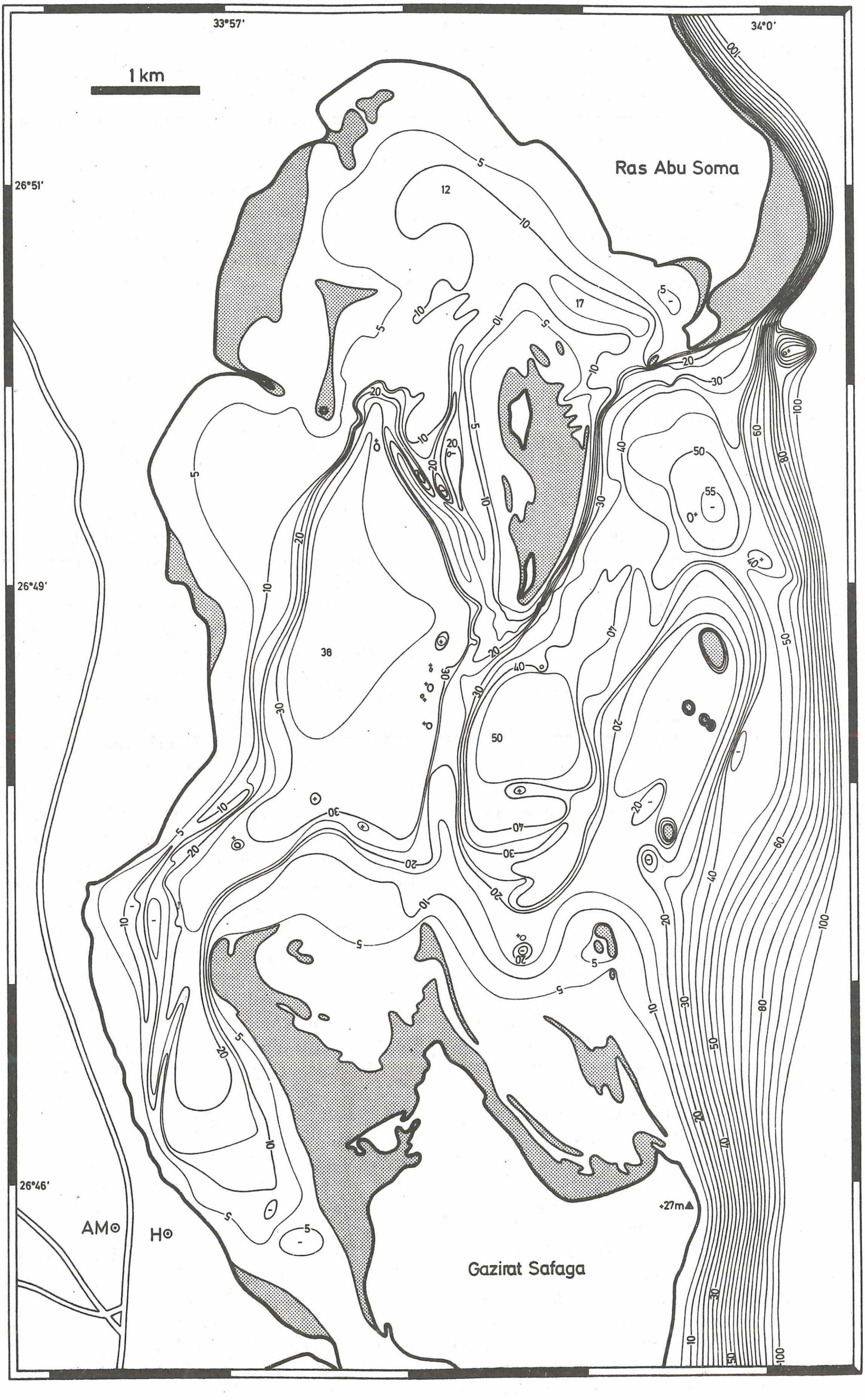

Fig. 3. Bathymetric map of the Northern Bay of Safaga.

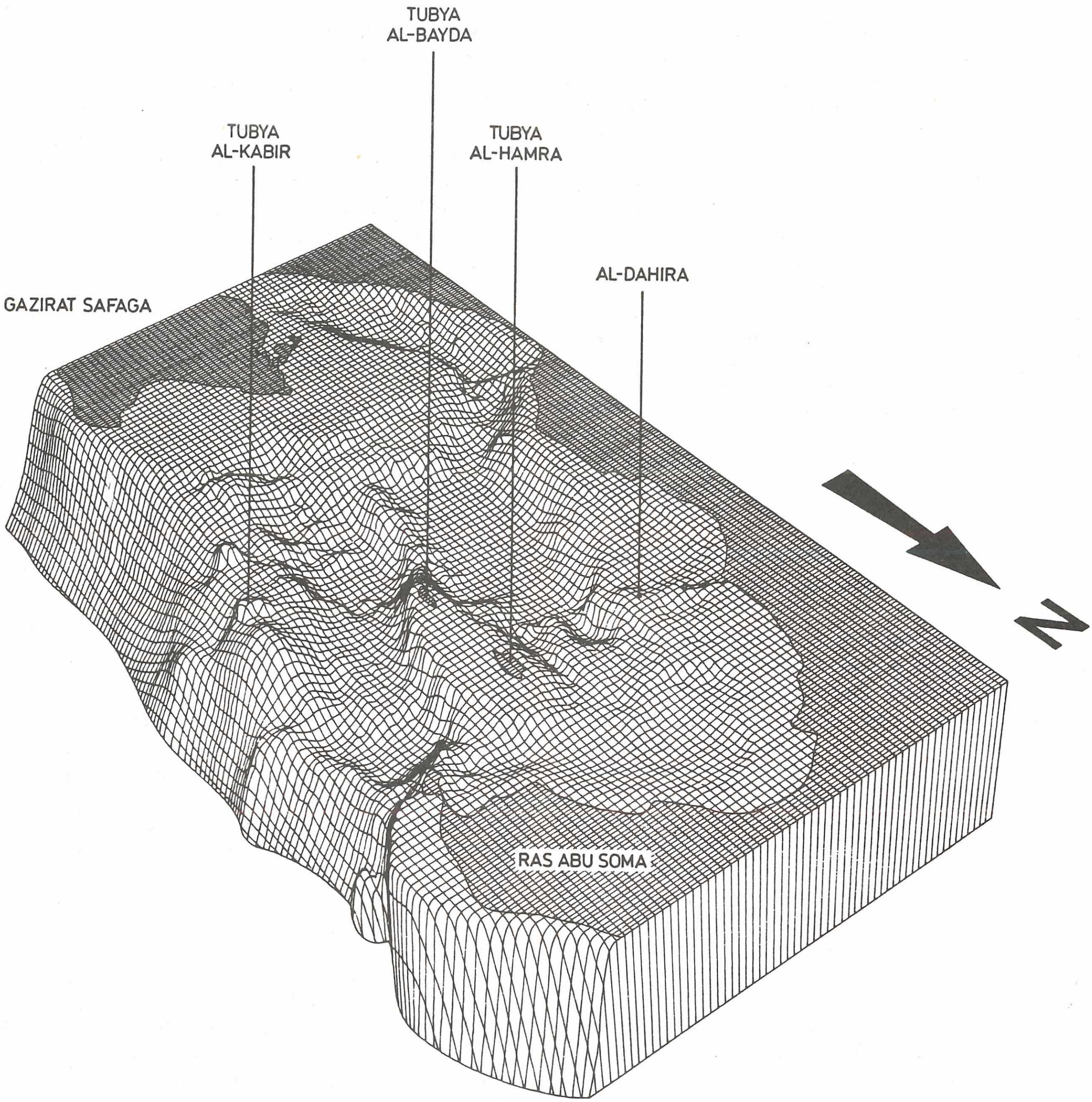

Fig. 4. Block diagram of the Northern Bay of Safaga.

3.1. The "East area"

This part of the bay, exposed to the open sea, includes the area marked by the line Ras Abu Soma – Tubya Arba (= Arba Abu Soma) – Tubya Islands (Tubya al-Hamra + Tubya al-Bayda) – northern cusp of Gazirat Safaga – northeastern cusp of Gazirat Safaga – Gamul al-Kabir – Gamul al-Saghira (= South Fairway Reef) – Tubya al-Saghira + Tubya al-Kabir (= North Fairway Reefs) – Ras Abu Soma.

Two basin-like depressions are developed in the centre of this area. The northern basin, between 40 and 55 m water depth, is delimited from the open sea by a ridge rising up to 35 m. This ridge represents the submarine continuation of Ras Abu Soma and leads to the area of Tubya al-Kabir – Tubya al-Saghira – Gamul al-Saghira as well as Gamul al-Kabir, which separates, with its shallow water depths, the southern basin against the east. This southern basin is N–S oriented, has water depths between 40 and 50 m, and is appr. 1 km wide in the south and narrows against the north.

The Tubya Islands form a distinct western margin of the "East area"; in their southeastern part they slope steeply toward the southern basin. This slope flattens toward the north and splits into two depth floors. The shallower one (<15 m) leads into the shallow "North area", the deeper one (>15 m) bends to the east and leads via Tubya Arba to Ras Abu Soma bordering the northern basin.

A ridge representing a submarine continuation of the Tubya Islands separates the "East area" from the "West area"; its maximum depth is appr. 20 m; toward the south it shows a continuous transition into Gazirat Safaga.

The entire region north of Gazirat Safaga is a shallow water area with a very rugged bottom morphology; nevertheless, it leads continuously over into the southern basin of the "East area". Gamul al-Kabir, which rises up with steep flanks from appr. 8 m water depth to low water level, is located north of the northeast cusp of Gazirat Safaga. Northward, as part of the ridge separating the bay from the open sea, follows the area with Gamul al-Saghira, Tubya al-Saghira, and Tubya al-Kabir. This N–S oriented region is developed as a submarine plain (1.5 x 0.7 km; appr. 15 m deep) functioning as a base for several shoals rising up with steep flanks towards low water level. This plain and Gamul al-Kabir are separated by a NW–SE oriented flat trench, which leads from appr. 18 m water depth down into the open sea.

The slope separating the Bay of Safaga from the open sea runs in a more or less N–S direction and exhibits a relatively constant descent to several hundreds of metres (see nautic map). The slope of the eastern margin of Ras Abu Som is especially steep: only 300 m seaward, water depth of 280 m is reached.

3.2. The "West area"

This part is separated from the "East area" by the Tubya Islands and their southward running submarine continuation. Its western border is formed by the N–S running coast, while in the north it follows the line Al-Dahira – Tubya al-Hamra. In the south it borders Gazirat Safaga on the one hand and grades continuously into the "Southwest channel" on the other.

The centre of this area is formed by a N–S oriented flat plain (4 x 1.5 km) between 30 and 38 m depth; it narrows continuously to the north. Except in the south and southwest this plain is bordered by steep flanks strengthening the basinal character. Along its margins the bottom of this plain is in some places interrupted by steep flanked risings up to 10 m height. In the northeast the steep ascent from the basin floor is followed by a flattening in appr. 20 m, which grades continuously into the basement of the Tubya Islands. This flattening exhibits a rugged bottom morphology, being furrowed by narrow trenches (appr. 100 m wide, up to 15 m deep) with steep walls and leading over into the "North area".

As in the "East area" the "West area" is characterized by a continuous transition from the basin bottom into the shallow water region north of Gazirat Safaga.

Along its western margin the basin shows various forms of transitions to the coast. In the north a rapid ascent from 30 to 10 m depth takes place and a wide shallow water area is developed towards the beach; in the south a continuous transition occurs. The shallow water area in the northwest forms a semicircular bay separated by a spit of land from the "North area".

3.3. The "North area"

This part is semicircularly enclosed by land in the north; its southern border is defined by the line Al-Dahira – Tubya al-Hamra – Tubya Arba – south cusp of Ras Abu Soma.

A pronounced subdivision of the area is produced by two elevated topographic structures. The first originates from the island Al-Dahira, a minute rocky elevation of 1–1.5 m above sea level, and represents a narrow intertidal ridge; it runs northward for appr. 1 km, turns ENE, and descends to the centre of the "North area". This ridge separates a protected area in the north from a more open one in the south. The other topographic elevation is formed by the northward extended basement ot the Tubya Islands, which projects wedge-shaped into the "North area" and leaves open a curved connection between the "East area" and the "West area". The border to the "East area" is marked by a pronounced descent in 15 m water depth. Tubya Arba, built by several pinnacles reaching up to the water surface, is located at the margin of this descent. The border to the "West area" is more continuous; only at the margin to the basin is a sharp line developed. The mean water depth is around 10 m. West of the Tubya Islands the bottom morphology is rugged, with small trenches down to 20 m; east of the islands, the bottom is smooth and only 17 m deep.

The maximum water depth in the centre of the protected northern part is 12 m; this area has a gentle transition to the coast and resemble a shallow pan. A 500 m wide and 2 km long, N–S oriented intertidal flat is developed in front of the western main coast.

3.4. The "Southwest channel"

The "Southwest channel", with a length of appr. 5 km and an average width of 1 km, represents the connection between the Northern and Southern Bay of Safaga. In the northeast the channel develops gradually from the "West area", runs appr. 1.5 km in southwestern direction, turns to SSE and discharges after appr. 3.5 km with a bottleneck and shoal between the land and Gazirat Safaga into the Southern Bay of Safaga.

In the transitional zone to the "West area" depths of more than 30 m are reached; here the channel represents the extension of the flat plain of the "West area", which continuously rises up to 20 m. In this part of the channel, like in the marginal parts of the basin, small, steep-flanked risings with a maximum height of 10 m occur. A steep ascent towards Gazirat Safaga and an initially steep, then (towards the west coast) flattening but richly structured morphology borders this flat plain. Towards the southern end of the "Southwest channel" the sea bottom rises continuously to a depth less than 5 m; the transition to the coast flattens more and more and the channel narrows to appr. 700 m.

4. Environmental parameters

4.1. Temperature, salinity, and ph

In the course of taking micro- and sediment-samples water samples for determination of temperature, salinity, and ph were taken at regular intervals.

Water temperature clearly reflects seasonal changes: in February 1987 the mean temperature was 22.8°C, in May 1986 24.7°C, in July 1987 28.4°C and in November 1986 26.9°C. These values are valid for bottom as well as for surface water, with the exception of extremely shallow areas, where much higher values were reached due to solar radiation (compare Table 1).

A similar seasonal trend could be observed for salinity. A mean value of 41.7‰ was measured in February 1987, 42.7 ‰ in May 1986, 44.5 ‰ in July 1987 and 43.4 ‰ in November 1986. In certain extreme areas higher salinity values were also measured; generally no significant differences between surface and bottom values were observable (Table 1).

The ph-value of the sea water varied between 7.5 and 8.2. Relations to other parameters could not be detected.

4.2. Water currents

Although water current direction and intensity were not measured, numerous observations during the diving descents allowed a reconstruction of a general water current pattern.

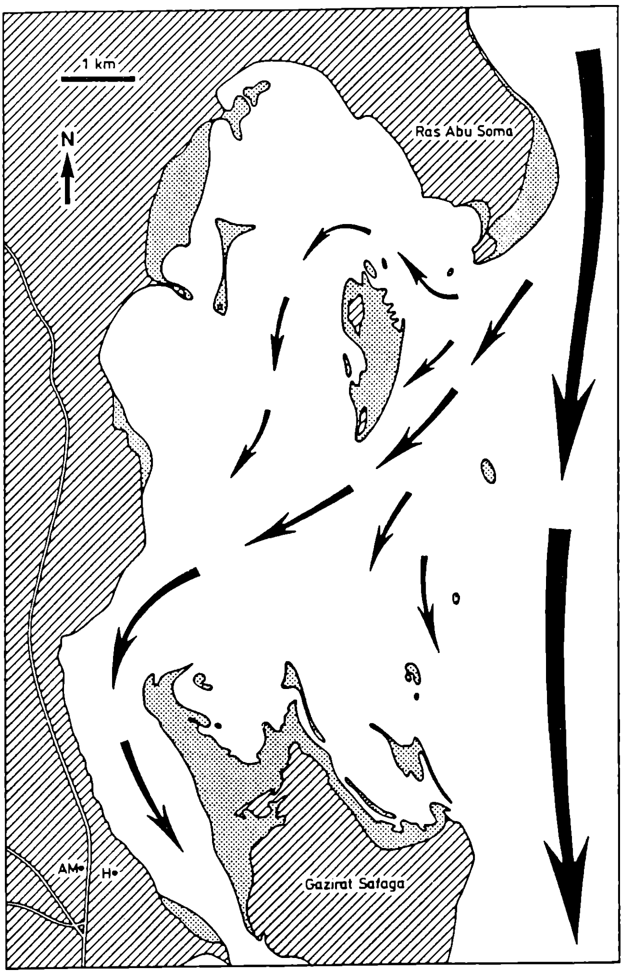

Fig. 5. Generalized pattern of water currents in the Northern Bay of Safaga.

In the uppermost water layers east of the Bay of Safaga a clear N–S current prevails following the steep slope of the outer margin. Inside the shallow water area of the bay a differentiated pattern depending on topography is observable (Fig. 5).

On the outer edge, south of the spit of Ras Abu Soma, a branch splits off the main current in a southwest direction. This branch passes the southeast margin of the Tubya Islands, discharges into the "Southwest channel", and later into the Southern Bay of Safaga. Several subordinate branches originate from this main branch. One runs around the northern cusp of the Tubya Islands, takes on a N–S direction and discharges together with the main current branch into the "Southwest channel". Additional smaller branchings occur in the area west of Tubya al-Kabir and Tubya al-Saghira: they branch south to southeast and turn, in the area of Gamul al-Saghira and Gamul al-Kabir, to the main current direction at the outer margin.

This current pattern can be superimposed by tidal currents leading – depending on the actual tidal situation – in some parts to opposite current directions.

Detailed observations of the tidal range are lacking, and only general observations can be provided: the tidal range during spring tide is less than 1 m, with the average tidal range being distinctly smaller. Generally the tides are of semidiurnial type. These observations coincide with measurements made in the northernmost parts of the Red Sea near the entrances into the Gulfs (ROBERTS & MURRAY, 1988).

4.3. Winds and waves

Over the whole year, winds from north to northeast predominate; only in rare cases does the wind blow from a southern direction. In general, wind velocity was distinctly higher during the day. This can be explained by the higher temperature differences between the more strongly heated land mass and the sea water during the day.

These winds create a mainly NE–SW oriented wave motion, leading to distinctly higher waves in the exposed "East area" than in the protected parts of the bay. The main water currents (Fig. 5) correspond with the prevailing wind directions.

Because of nearly permanent air- and water-turbulences a complete mixing of the water column occurs and no stratification can develop inside the bay. This is reflected in the temperature and salinity values, with no significant differences between surface and bottom waters (Table 1).

5. Bottom facies

The differentiation and description of various bottom facies in the Northern Bay of Safaga was the primary intention of this paper. These bottom facies, documented in a bottom facies map (enclosure 1), are based exclusively on field observations. Detailed laboratory investigations (sedimentology, distribution of faunal and floral elements, their interaction and palaeontological importance) have not been incorporated in order to make a repetition of these observations possible directly in the field.

The various bottom facies were not differentiated by means of one single parameter (e.g., grain size distribution); rather, various characteristics — depending on the actual situation — were drawn into consideration. This led in certain cases to mixed bottom facies, because a sharp separation was not always possible.

5.1. Coral reefs

Due to the general development during the younger geologic history, the recent coral reefs of the Red Sea and therefore also of the investigated area reflect the underlying morphology (BRAITHWAITE, 1982, 1987; HEAD, 1987). The thickness of the Holocene reefs was not studied, but they apparently represent only a thin covering of the underlying rocks. Dependent on the relative position to the land or the bottom morphology, generally 3 reef types can be distinguished.

5.1.1. Fringing reefs

This reef type (sensu GEISTER, 1983) occurs in the mapped area at the eastern margin of the Ras Abu Soma peninsula and east of the Tubya Islands (Pl. 1, Fig. 2; Enclosure 1); that of Ras Abu Soma is the larger one. In both cases the reef flat is characterized by common occurrences of the coral genera *Pocillopora verrucosa* (ELLIS & SOLLANDER) and *Styllophora pistillata* (ESPER); the areas between the coral heads consist of a wavy, rocky bottom with a smooth surface covered by various calcareous (mainly coralline) and soft algae (Pl. 1, Fig. 3). This hardground is frequently populated by *Tectus dentatus* (FORSKAL). In a more back reef position, *Brachidontes variabilis* (KRAUSS) and *Modiolus auriculatus* (KRAUSS) are byssally attached in clusters to rock fissures. At the reef slope, several species of the genera *Acropora* (Pl. 1, Fig. 4) and *Porites* (Pl. 2, Fig. 1) are dominant, in the more shallow parts together with *Millepora* (Pl. 2, Fig. 2). Distinct spur and groove systems are absent because of the relative low water energy.

5.1.1.1. Ras Abu Soma

This fringing reef follows the eastern flank of the peninsula semicircularly and continues outside the mapped area to the NNW. The reef flat, only a few meters wide, is followed leeward by a shallow (down to appr. 2 m) and irregular boat channel, which grades into an up to 500 m wide intertidal zone. Seaward, the reef flat is sharply bordered by the reef slope, which descends in the north continuously and very steeply (up to 70°). Dense growth of framebuilding corals extends down to appr. 25 m; below this depth fan corals prevail (Pl. 2, Fig. 3). Below 50 m these fan corals decrease and the environment becomes dominated by rock bottom, which forms parallel ridges running perpendicular to the slope; the flat grooves in between are filled with detrital material.

Towards the south the general shape changes. This is due to the development of a terrace in 20—25 m depth dominated by coarse debris; it widens to the south and grades into coral carpet. Together with this change a general flattening of the reef slope, connected with a more intense structuring, is observable. This flattening favours the growth of table-like *Acropora*-colonies, especially in the deeper parts of the reef slope.

5.1.1.2. Tubya al-Hamra — Tubya al-Bayda

At the eastern margin of the basement of the Tubya Islands a 1.5 km long fringing reef is developed. In the north it begins at the level of the southern cusp of Tubya al-Hamra and ends in the south at the level of the southern cusp of Tubya al-Bayda (Enclosure 1). The very narrow reef flat is bordered leeward by a poorly developed, very shallow (<1 m) boat channel (Pl. 1, Fig. 2). On the exposed side, the differentiation from north to south is remarkable. Whereas the reef slope is very steep in the south, ending at 20—22 m, the morphology in the north is flatter and a sharp lower boundary is missing. Here the reef slope continuously grades downward into coral carpet. These differences in morphology are reflected in different coral associations: in the north *Porites* dominates, in the south *Acropora*.

To the north, the upper depth floor of the reef bifurcates — in dependence on the bottom morphology — into two branches; the lower floor gradates into coral carpet. To the south, the reef slope becomes increasingly interrupted by sand grooves, leading to a complete disintegration of the reef and development of sand bottom in the shallow parts and transition into coral carpet in deeper water. The increasing sand sedimentation, suppressing reef growth, is explainable by the general pattern of water currents (Fig. 5).

5.1.2. Patch reefs

In this pater, the term patch reef is used to summarize reef-structures representing isolated topographic elevations of various form and size. One platform reef, one miniatoll and several pinnacle reefs (all definitions sensu GEISTER, 1983, p. 185) could be differentiated, which are also documented on the map.

Some reef-like structures, especially southwest of Tubya al-Bayda, allow no clear classification. These are up to 15 m high, coral-covered topographic elevations with steep flanks, which ascend from muddy bottom in appr. 30 m depth. The corals form a more or less continuous covering of the preexisting morphology and show no clear zonation in their associations. These structures are externally similar to patch reefs, but their internal organization corresponds with coral carpet; therefore they are mapped with the latter.

5.1.2.1. Platform reef

The only coral reef of this category is Tubya al-Kabir, which is located on the outer rim of the Northern bay. It is ovate in outline, measures appr. 300 x 150 m, and has a NNW—SSE oriented long axis. Together with patch reefs of other types it ascends to the water surface from that submarine plain (in appr. 15 m), which in fact represents the boundary of the bay against the open sea (compare Fig. 3). The current-exposed NNE-side of the reef descends steeply down to this plain, whereas the leeward side shows a more flat morphology. The coral associations also differ distinctly between the windward and the protected side. Dense and diverse coral growth is restricted to the outer rim; the back side is characterized by a morphology structured by sand grooves. The dominant coral genera are *Acropora* and *Porites,* the first dominating at the more current-exposed northwestern side, the second prevailing in the south. The reef flat shows no continuous coral growth, but is structured by sand grooves oriented parallel to the water current and widening leeward.

5.1.2.2. Miniatoll

The reef of Gamul al-Kabir is ovate in outline (350 x 200 m), lengthened NNW–SSE, and descends steeply on all sides. Dense coral growth is restricted to the annular rim on top of the reef; a lagoon-like depression is developed in its centre. This area has a sandy bottom partly covered with seagrass and small coral patches. In the NW the reef rim is interrupted by a channel reaching the level of the lagoon bottom.

5.1.2.3. Pinnacle reefs

This reef type is developed at Tubya Arba (Pl. 2, Fig. 4), Tubya al-Saghira, and Gamul al-Saghira. All localities contain several pinnacles in groups. All show very steep to nearly perpendicular flanks, rising from 8–15 m depth to near the water level. The reef surface is always flat and can be covered nearly completely by corals or only at its margin, with rocky bottom in the centre.

5.1.3. Coral patches

This term summarizes reef-structures representing topographic elevations, which are similar to the patch reefs but distinctly smaller. Whereas the distinction from the patch reefs is always clear in the investigated area, transitions exist between coral patches and coral carpet. Because coral patches can function as initial structures for both patch reefs and coral carpet they should be classified as an independent category and, contrary to GEISTER (1983), not be summarized under the term patch reef. Equivalent structures in the Red Sea are named "coral heads" by REISS & HOTTINGER (1984) and "coral knolls" by BRAITHWAITE (1982).

Coral patches are widespread in the investigated area and can extend horizontally from deci- to decametres and vertically up to 3 m. Most commonly they occur on sandy bottom in shallow water, although isolated ones can be observed down to 40 m. The density of the patches is highly variable, spanning from isolated (Pl. 3, Fig. 1) to very dense occurrences (Pl. 3, Fig. 2), which can fuse to coral carpet. The bottom between the coral patches consists of coarse biogenic debris and sand (Pl. 3, Fig. 3), which can be covered by seagrass in variable densities.

The standing crop of living stony corals is much higher in coral patches on coarser sediment (e.g., plain around Tubya al-Kabir – Tubya al-Saghira; area north of Tubya al-Hamra) than in areas with higher fine sediment content (e.g., southern "Southwest channel"), where soft corals and sponges dominate. Contrary to the fringing and patch reefs, generelly no coral genus dominates in the coral patches. The more common frame builders are *Millepora, Acropora, Favia, Montipora, Goniastrea, Echinopora,* and *Seriatopora; Porites* is rare. The bivalves *Lopha cristagalli* (L.) (Pl. 3, Fig. 4) and *Pinctada margaritifera* (L.) are characteristic inhabitants of the patches, whereby *Lopha* often settles on *Chama ruppeli* REEVE, especially in areas with higher suspension content. Both species *(L. cristagalli* and *P. margaritifera)* were not observed in the patch reefs or fringing reefs of the study area, and only in smaller frequencies in coral carpet.

Due to the small dimensions of the coral patches, individual documentation was not possible; on the map (Enclosure 1) their occurrence is expressed by using additional symbols.

5.2. Coral carpet

Wide areas of hard bottom in the bay are covered by a more or less dense stratum of coral framework following the preexisting morphology. After REISS & HOTTINGER (1984) this bottom facies should be named "coral carpet". BRAITHWAITE (1982) uses the term "coral rock frame" for comparable structures.

Typically, coral carpet occurs on wide, plane or wavey hard bottoms (Pl. 4, Fig. 1); because of its strong dependence on the underlying morphology it is also developed in the study area on very steep to nearly perpendicular walls. The thickness of the coral framework fluctuates strongly, depending on water depth and bottom morphology. The greatest thickness (appr. 3 m) occurs in shallow (<20 m) and flat regions, whereas in steep and/or deep areas thickness distinctly decreases. On flat morphology, where abraded material is not removed, debris and sand accumulate between the corals. This leads to the formation of troughs by suppression of further coral growth (Pl. 4, Fig. 2). Increasing frequencies of such troughs towards the margins of the coral carpets may lead to their disintegration into coral patches (Pl. 4, Fig. 3). If sediment thickness inside the troughs is high enough, settlement by infaunal organisms occurs. With increasing content of fine sediment, clusters of openings of burrowing crustaceans *(Axiopsis* sp.) become very characteristic (Pl. 4, Fig. 4).

In the more shallow areas the content of living stony corals can exceed 50 %; with increasing depth this content decreases. Similar variations in diversity are also observable, but here, besides bottom morphology and water depth, water movement and, more important, sedimentation rate are the limiting factors. These influences lead to higher diversities in deeper water with steep morphology than in shallower water with flat bottom.

In the study area, coral carpet has its widest distribution in the "**East area**"; especially north of Gazirat Safaga and on the plain around Tubya al-Kabir – Gamul al-Kabir it shows its typical appearance. Coral carpet covers the ridge between the "East area" and the "West area" and grades into the fringing reef of the Tubya Islands, from which it develops again on the lower topographic level at the northern end. It follows the slope between the "East area" and the "North area", widening around Tubya Arba and grading into the fringing reef of Ras Abu Soma. In the transitions to the fringing reefs the coral carpet shows coral associations similar to those of the reefs, especially at the northern end of the Tubya Islands, where *Porites* is dominant. In contrast, the coral carpet on the ridge between the "East area" and the "West area" and in the centre of the "East area" is only poorly developed and with its high content of soft corals *(Xenia, Sarcophyton)* it, in fact, represents a transition to rock bottom (Pl. 5, Fig. 1). Whereas on the ridge between Ras Abu Soma and Tubya al-Kabir coral carpet starts to develop gradually from rock bottom at appr. 40 m (Enclosure 1), this transition occurs on the ridge between the "East area" and the "West area" at a depth of appr. 25 m. The boundaries to the soft bottom areas of the basins of the "East area" are sharply developed (Fig. 8). The transitions to the sands with coral patches are gradual (Fig. 8), whereby west of Tubya al-Kabir the coral carpet disintegrates into a polygonal pattern.

The northern margin of Gazirat Safaga as a direct continuation from the "East area" to the "West area", is also typically covered by coral carpet. In the more shallow area it passes into sand with coral patches and seagrass. The associations of the coral carpet show a high coral diversity; also remarkable is the frequent occurrence of *Tridacna crocea* LAMARCK and *Spondylus*. Coral carpet generally frames the muddy basin of the **"West area"** (Enclosure 1), whereby the boundary between the basin bottom and the coral carpet is marked by an abrupt rising of the bottom morphology. With a steep wall up to 15 m, this rise is very sharply developed at the eastern margin of the basin. Here, the coral carpet is not only restricted to the steep wall, but continues upward into flatter areas (Fig. 7). The coral diversity of the steep wall is higher than in the flatter area. At the western margin of the basin the rise is less striking, and in the flatter areas a transition occurs from coral carpet into "sand with coral patches" (Fig. 7) or "seagrass" or into "rock bottom".

In the **"Southwest channel"** coral carpet is less abundant and mainly restricted to elevated structures. In the **"North area"** two areas can be distinguished: one at the transition to the "West area" the other at the border to the "East area". The first represents a relatively large continuous area at the border to the basement of the Tubya Islands. It is limited by a system of sand-filled trenches cut into the coral carpet area down to 10 m (Fig. 7, transect D4). The second coral carpet area is spread out around Tubya Arba and continues at the northern margin of the basement of the Tubya Islands.

5.3. Rock bottoms

This bottom facies comprises those areas in which the sea floor consists of rocks without substantial sediment covering. These rocks represent the exposed underground of mainly coral limestone, which normally is covered by various recent sediments or coral framework. These rocks were not analysed, and therefore no data on their stratigraphic position can be presented. Comparable bottom types in intertidal areas are not included herein; they are classified as special bottom facies.

In the investigated area "rock bottom" occurs in very shallow waters as well as in greater depths. Its widest distribution is in the exposed **"East area"** (Enclosure 1), where it forms the deep ridges and – at the fringing reef of Ras Abu Soma – the downward continuation of the reef slope. On the ridge against the outer margin of the bay, in the centre of the "East area", as well as on the ridge between the "East area" and "West area" it is covered with decreasing depth by coral carpet. The rock bottom is settled by soft corals (Pl. 5, Fig. 2), sponges, bryozoans, several algae (especially coralline algae and in remarkable densities *Padina pavonia,* Pl. 5, Figs. 3, 4) and by *Heterostegina;* in shallow depressions, thin sand-covered areas occur, which, with increasing areal covering lead over into the sand bottom facies without a sharp boundary. Transitions occur also into coral carpet (Pl. 6, Fig. 1).

Smaller rock bottom areas are also developed in the "West area" and "North area" (Enclosure 1), but are of subordinate importance. In the **"West area"**, one such area between 10 and 20 m represents a transition between coral carpet into "sand" and "seagrass" as well as into "sand with coral patches". In the **"North area"**, rock bottom represents the subtidal continuation of the intertidal ridge north of Al-Dahira. It extends down to 5 m, where it grades into "sand with seagrass and coral patches". Both areas show a relatively high covering by sand resp. coral heads and/or seagrass. In fact, its classification as rock bottom represents a compromise.

5.4. Sand bottoms

This category includes areas dominated by sandy bottoms. Depending on their composition and covering a further differentiation can be made. **Pure sand** bottoms are not very widespread in the investigated area (Enclosure 1), being mainly restricted to shallow water areas near the coast; they show a relatively high percentage of larger foraminifera (soritids) and often a certain amount of terrigenous material. These "pure sands" contain a distinct mollusc fauna of numerous species of *Terebra, Rhinoclavis,* and strombids *(Lambis truncata sebae* (KIENER), *Strombus tricornis* HUMPHREY, *S. gibberulus albus* MÖRCH) as well as lucinids (e.g., *Codakia tigerina* (L.)), *Tellina staurella* (LAMARCK), and *Fragum auricula* (FORSKAL). "Pure sands" occur additionally at the base of steeper slopes with coral carpet or at the reef bases; here, as narrow strips (a few metres to decametres), they separate the coral carpet or the reef base from seagrass areas. These sand strips are characterized by clusters of *Axiopsis* sp. burrow openings as in some areas of coral carpet (Pl. 4, Fig. 4) and are conspicuously rich in shallow infaunal molluscs *(Turritella sanguinea* REEVE, *Fusinus* sp., *Glycymeris pectunculus* (L.), *G. heroicus* (MELVILL & STANDEN), *Trachycardium* sp., *Nemocardium* sp., and numerous venerids (*Lioconcha ornata* (DILLWYN), *Circe corrugata* (DILLWYN), *Tapes sulcarius* (LAMARCK), *Periglypta reticulata* (L.)).

Considerably larger areas of sandy bottoms are settled by seagrass in variable densities (Pl. 7, Figs. 3, 4), leading in some cases to dense seagrass meadows. The latter – although basically representing sandy bottoms – constitute a special biotope and are classified as an independent bottom facies. Sands with a less dense seagrass cover are marked on the bottom facies map by special symbols (**Sand with seagrass**).

Most frequently sand bottoms are settled by corals, from isolated, small heads up to coral patches in variable dimensions and densities: **Sand with coral patches** (Pl. 3, Figs. 1, 2). Increasing coral patch frequency lead to a transition from "sand with coral patches" into coral carpet (Pl. 4, Fig. 3). The content of coarse biogenic debris in "Sand with coral patches" is always higher than in "sand with seagrass" (Pl. 3, Fig. 3). In immediate neighbourhood of coral patches the burrows in which alpheids and gobiids live together (KARPLUS, 1987) are particularly striking. More abundant occurrences of coral patches on sand are marked on the map (Enclosure 1) by special symbols.

In a narrow zone on the outer margin of the Bay of Safaga below appr. 55 m, **Sand with macroids** (sensu HOTTINGER, 1983; Pl. 6, Figs. 2–4) is developed; this represents a very characteristic bottom subfacies and is also marked on the map by special symbols.

Sandy bottoms in the larger basins of the bay generally possess a high content of fine-grained material; this character allows a distinction of these sediments as **Muddy sand**. Enormous quantities of *Operculina* and star-like lebensspuren at the sediment surface (Pl. 7, Fig. 2) characterize this subfacies.

A sharp distinction of "muddy sand" against either "pure sand" or "mud" is as difficult as the distinction between the other subfacies of the sand bottom, because transitions are always present. This condition led to the creation of mixed areas and combined symbols on the map (Enclosure 1).

In the "**East area**", sand bottom is mainly represented by three subtypes. The largest area is occupied by "muddy sand", which mainly covers the two basins. Whereas the "muddy sand" in the northern basin and in the connecting zones to the southern basin exhibits a seagrass covering of variable density (Pl. 7, Figs. 3, 4) the southern basin is uncovered. Here the sediment surface is densely settled by *Operculina*, besides that the bivalve genus *Malleus* and the gastropods *Xenophora, Stellaria,* and *Tonna* are also diagnostic. In the areas with seagrass, exclusively represented by *Halophila*, both the operculinas and the seagrass-inhibiting soritids are abundant. "Pure sand" bottoms occur in the northern basin as a narrow zone between the seagrass-settled "muddy sand" and coral carpet, as well as – more widespread – to the west of the rock bottom ridge between Ras Abu Soma and Tubya al-Kabir. This ridge separates the sandy basin from the outer "sand with macroids" (Fig. 8). This bottom subfacies is developed on the slope against the open sea at a depth below 55 m, where the angle of the slope decreases and a thin sand cover occurs on the rock bottom. The transition to the rock bottom is normally developed gradually (Pl. 6, Figs. 3, 4); beyond that, uncovered rock bottom areas also appear inside the "sand with macroids". This subfacies was followed down to 70 m. Its lower boundary could not be reached. The macroids possess a flattened spheroidal to ellipsoidal shape with a maximum diameter of appr. 20 cm and are mainly built by acervulinid foraminifers, bryozoans, and coralline algae. The plain around Tubya al-Kabir and Gamul al-Saghira as well as the area around Gamul al-Kabir is generally covered by "sand with coral patches", which on the one side grades into the patch reefs and on the other into coral carpet (Enclosure 1).

Contrary to the "East area" the "**North area**" is dominated by "sand with coral patches" or "sand with coral patches and seagrass". "Pure sands" occur as narrow strips around the northern cusp of Tubya al-Hamra and, rich in terrigenous material, parallel to the coast of the northern margin of the bay. In the northernmost part coral patches are less frequent, but increase toward the south together with increasing seagrass content. The boundaries both to the seagrass areas as well as to the coral carpet in the south are gradual. "Sand with coral patches" representes the connection between the coral carpet areas to the east and west of the Tubya Islands; it also influences the "pure sand", adjoining to the south, by supplying fine-grained sediment.

In the "**West area**" the sands, although occurring in relatively small areas, show a distinct differentiation. The western margin of the muddy basin is bordered against the coral carpet by a narrow strip of "muddy sand" (Fig. 7). This strip widens toward the south and continues into the "Southwest channel". In the shallow water areas of the "West area", "sands with coral patches" and "sands with coral patches and seagrass" dominate; they show gradual transitions into the neighbouring seagrass, coral carpet, and "pure sand" areas. In the "pure sand" west of the Tubya Islands, thin-branched rhodoliths are common. At the south cusp of Tubya al-Bayda, an area with highly mobile sand is developed. It grades toward SW into "sand with coral patches", the latter extending in a tongue-shaped manner into coral carpet.

The "muddy sand" reaching from the "West area" into the "**Southwest channel**" covers a large area, mainly in the centre of the channel (Fig. 6). Whereas at the outlet of the "West area" this subfacies is developed at depths between 20 and 30 m, it ascends at the southern margin of its occurrence to 15 m and grades into "sand with coral patches", which is interrupted by larger seagrass areas. Near the southern boundary of the "muddy sand", between 15 and 20 m the bottom is very hilly. These hills are formed by enteropneusts and consist of densely spaced conical mounds and adjacent craters, both with diameters up to 1 m (Pl. 7, Fig. 1). In contrast to the deeper "muddy sands" of the "East area", the mollusc fauna is characterized by *Divaricella ornata* (REEVE) and *Murex tribulus* (L.). The coral carpet areas at the margins of the "Southwest channel" grade into "sand with coral patches" or "sand with coral patches and seagrass". Along the W- and NW-coast and along the intertidal area of Gazirat Safaga, small strips of "pure sand" with a high content of terrigenous material and soritid foraminifers are developed.

5.5. Seagrass bottoms

In the studied area three species of seagrass were observed *(Halophila stipulacea, Halodule uninervis,* and *Cymodocea rotundata),* but their spatial distribution was not mapped. The most abundant species, also having the greatest bathymetric range, is *H. stipulacea* (Pl. 8, Figs. 1, 2, 4, 5). It was observed from the shallowest subtidal down to 50 m. Contrary to the observations of JONES et al. (1987) its leaves are larger in shallow than in deeper water. *H. uninervis* occurs only in small quantities and is present mainly from the lower intertidal down to a depth of a few metres. Pure stands are almost exclusively restricted to the shallowest part of its range; more often it occurs together with *Halophila* (Pl. 8, Fig. 1). *Cymodocea* (Pl. 8, Fig. 3) was observed mainly between 2 and 10 m depth, although it extends to low water level. Its areal distribution is low and it mainly grows monospecifically; only in its shallowest occurrences is it mixed with *Halophila* and *Halodule.*

Althou;h seagrass is always found growing on sandy substrate, dense stocks represent a special environment separated by specific organism associations from the sand bottoms. In the map only larger areas of continuous seagrass cover are summarized under "Seagrass bottom"; loose stands are classified with subfacies of the sand bottoms. Typical faunal elements of seagrass meadows are soritids among the larger foraminifers (Pl. 8, Fig. 4). Among the molluscs the opisthobranchian gastropod *Smaragdia rangiana* (RECLUZ) dominates; *Atys cylindricus* (HELBLING) and *Otopleura mitralis* (ADAMS), as well as the prosobranchs *Phasianella variegata* LAMARCK, *Ancilla acuminata* (SOWERBY), and a small terebrid species *(Duplicaria* sp.) are also common. Especially in the shallowest seagrass meadows a nearly monospecific mass occurrence of *Strombus fasciatus* BORN (Pl. 8, Fig. 1) is observable. The most abundant lebensspuren are mounds and adjacent craters with diameters up to appr. 1 m; these can be attributed to callianassid crustaceans of the genus *Callichirus* (Pl. 8, Fig. 5; compare VAUGELAS, 1984). Often the seagrass areas are interspersed with *Millepora* and solitary coral heads (e.g., *Styllophora pistillata),* which in some places can form small coral patches.

In the **"Southwest channel"**, seagrass bottom facies are mainly developed as narrow strips paralleling both coasts. These are up to 300 m wide, occurring in depths down to 10 m; isolated patches of seagrass occur near the southern end of the channel. In the transitional zone to the "West area" the coral carpet areas are framed by strips of seagrass.

The vast shallow water ($<$10 m) area at the western margin of the **"West area"** is covered by a relatively continuous seagrass stand covering an area of appr. 2 km^2 This area grades on the one hand continuously into the "North area" and on the other hand passes toward the south into "sand with seagrass". A small occurrence of "deeper" seagrass was observed at the western margin of the basin at the base of coral carpet (Enclosure 1). Smaller seagrass patches, not documented on the map, are located west of the Tubya Islands.

Seagrass reaches its widest distribution in the **"North area"**, whereby continuous areas of seagrass bottom facies occur together with larger isolated seagrass patches. In addition to the continuation of the seagrass bottom facies of the "West area", both the centre of the "North area" and a bay at the southwest margin of Ras Abu Soma also belong to this bottom facies. The sandy area north of the intertidal ridge of Al-Dahira exhibits a high frequency of seagrass, but is dominated by coral patches.

Seagrass is widespread on muddy sand in the northern basin of the **"East area"** and its connecting zones to the southern basin. Due to its generally low density it is marked by a special symbol on the map (Enclosure 1) rather than being classified with the seagrass bottom facies.

5.6. Mud bottoms

The relatively even basin bottom of the **"West area"** is covered by a fine-grained, intensively bioturbated sediment. This continuous and relatively sharp-bordered area between 30 and 38 m is mapped as "Mud bottom" (Enclosure 1). The silty sediment is nearly uncompacted in its uppermost part; the sediment surface is mainly covered by a brownish microbial mat and exhibits crawling traces and burrow openings in enormous numbers (Pl. 9, Figs. 1–3). The crawling traces are mainly produced by small cerithid (e.g., *Rhinoclavis* sp.), trochid *(Gibbula* sp.), and turritellid gastropods, while the burrow openings are due to the activities of various organism groups. Most striking are those of burrowing crustaceans, which give the sediment surface its uneven micromorphology by producing hills and craters (both in dm-size and in high densities) (Pl. 9, Figs. 1, 2). These structures are interspersed by numerous additional openings attributable to burrowing bivalves (e.g., psammobiids, solecurtids, tellinids) and enteropneusts. Microslumpings (Pl. 9, Fig. 2) originating from the ejected sediment of the crustacean burrows are common at the flanks of the hills. A sharp contrast in color exists between the algae-covered sediment and this ejected material. The frequent cerithid shells often are settled by the solitary coral *Heteropsammia* sp.

The mud area is continuously bordered by coral carpet to the east, whereby the even basin bottom terminates abruptly at the steeply ascending coral carpet (Fig. 7). A small strip with a maximum width of 5 m is developed in this contact area; here, debris from the coral carpet is embedded in the mud. Near the eastern margin of the mud basin, several up to 15 m high coral-settled elevations occur (see chap. 5.1.2. Patch reefs). Similar to the coral carpet transition they show steep ascending flanks and narrow debris-influenced strips at their base.

The western border of the mud bottom is less accentuated and the mud grades into "muddy sand" (Fig. 7). The density of mounds and craters decreases toward the margin of the mud bottom, leading to a more flattened micromorphology. Replacing this type of lebensspuren are crustacean burrows visible at the sediment surface as openings arranged in clusters.

5.7. Sea-marginal bottoms

The great variety of features of sea-marginal environments was not studied in detail here. Such investigations were recently done in the Gulf of Aqaba and the Gulf of Suez by FRIEDMAN & KRUMBEIN (1985) and by ROBERTS & MURRAY (1988).

Most widespread and conspicuous along the coast of the Northern Safaga Bay are tidal flats (Enclosure 1, see below). Often, however, the intertidal zone is merely a narrow belt covered with cobbles, gravel, and sand which are partly cemented into beach rock in the uppermost intertidal zone. The beach rocks exhibit a typical appearance with a seaward dipping ($10^{\circ}-20^{\circ}$). They are composed mainly of carbonate material, dominated by skeletal remains, at the island coasts (e.g., W and E coast of Tubya al-Bayda, Pl. 1, Fig. 1), and show a partly high content of terrigenous material at the west coast of the bay. The uncemented, mobile sands are characterized by the monotypic occurrence of the surf clam *Atactodea glabrata* (GMELIN). In the lower intertidal and shallow subtidal zone, hemispherical brownish-green oncolites with a small sediment content are frequent. In the shallowest submarine environment, a zone with *Padina pavonia* THIVY in dense standing crops is frequently developed (e.g., west coast in front of land point no. 12, Fig. 2); both features (oncolites and *Padina*-zone) are similar to these described by FRIEDMAN (1985, p. 60; 1988, p. 83). At the southern tip of Tubya al-Bayda and at the southwestern tip of Ras Abu Soma, rippled tidal bars are developed. They migrate permanently due to tidal currents.

Only during the field study in April/May 1986 was an algal pond observed; it was located immediately adjacent to land point no. 12 (Fig. 2). Landward from this point, which is situated just on the highest position of the beachridge, a shallow depression, running more or less parallel to the coast, is developed. During spring tide the beach ridge was flooded and the depression was filled with a few decimetres of seawater; this area was a few decametres wide and a few hundred metres long. Between high tides the water level dropped markedly or the water disappeared completely by seepage and/or evaporation; a thick, brownish-green, in the centre of the pool darkgreen to nearly black, microbial mat remained (Pl. 10, Fig. 1). Although this mat was very tough (Pl. 10, Fig. 2), it tore along desiccation cracks and was rolled up like a carpet by the wind. The salinity in this restricted pool and of the water remaining in the microbial mat increased tremendously up to $200^{\circ}/oo$.

Tidal Flats

Tidal flats of variable width are developed along some parts of the coast and along the margins of the islands (Enclosure 1; Pl. 9, Fig. 4). Because of the small tidal range these flats reach maximum widths of only 500 m. In all cases these plains represent rocky tidal flats built by coral limestone with a rugged surface. The contact to the subtidal can either occur abruptly with a step up to a few metres in height (e.g., NNW coast, NNW cusp of Gazirat Safaga) or be transitional (e.g., W coast of Gazirat Safaga). The coral limestone surface and its depressions can be covered with a thin sand layer sometimes exhibiting sparse seagrass growth *(Halodule uninervis)*. The typically wave-rippled sand can be settled by thinbranched rhodoliths of coralline algae (e.g., NNW Gazirat Safaga, Tubya Islands). Ophiurids along with the gastropods *Nerita albicilla* L., *Cerithium caeruleum* (SOWERBY), *Clypeomorus concisus* (HOMBRON & JACQUINOT), *Planaxis sulcatus* (BORN), *Volema pyrum* (GMELIN) and Thaididae (e.g., *Thais, Drupa,* and *Morula)* are abundant. Mass occurrences of the mytilid bivalve *Brachidontes variabilis* (KRAUSS) are also characteristic.

5.8. Mangrove

A small mangrove area is located near the northwest cusp of Gazirat Safaga. It extends along the coast for appr. 1 km and has a maximum width of appr. 400 m. As is the case in other mangroves in the northern Red Sea (FISHELSON, 1971; REISS & HOTTINGER, 1984; FRIEDMAN & KRUMBEIN, 1985) it consists exclusively of *Avicennia marina* (Pl. 10, Figs. 3, 4). Its growth form is bushy, its density generally sparse, and its occurrence restricted to a small coastal strip. The standing crop is more dense only in the central area around a small bay where a little channel cuts through in E–W direction (Pl. 10, Fig. 4). The thin sediment cover varies, depending on exposure, from relatively coarse sand at the current-exposed northern side to a silty sand inside the channel. The channel bottom is covered by a brownish microbial mat. Burrow openings, mainly originating from crustaceans, are abundant. On the sediment surface and on the vertical roots of *Avicennia* large numbers of small gastropods (especially *Pirenella cailliaudi* POTIEZ & MICHAUD, but also *Littorina scabra* (L.) and *Nerita)* occur in clusters. They strongly influence the composition of the sediment by production of large quantities of fecal pellets. The mangrove roots serve as a substrate for *Lopha folium* (L.). *Uca albimanus* is a typical crab species.

6. Discussion

The map and the description of the bottom facies in the Northern Bay of Safaga provide a basis for discussing the parameters which control the development and distribution of the various bottom facies. The large variability and the rapid horizontal change in this small area makes this a question of great importance, particularly in respect to its fossil relevancy.

Climate, temperature, and salinity represent primary parameters, yet are only of subordinate importance for the bottom facies distribution in the studied area.

One of the most essential factors in the origin and distribution of the bottom facies is the bottom morphology. Tectonic lines as well as various sea level stands during younger earth history produced a complex topographic pattern similar to that of other marginal areas of the Red Sea (e.g., BRAITHWAITE, 1982; ROBERTS & MURRAY, 1988). This, along with the hydrodynamic situation, can explain the distributional pattern of the bottom facies.

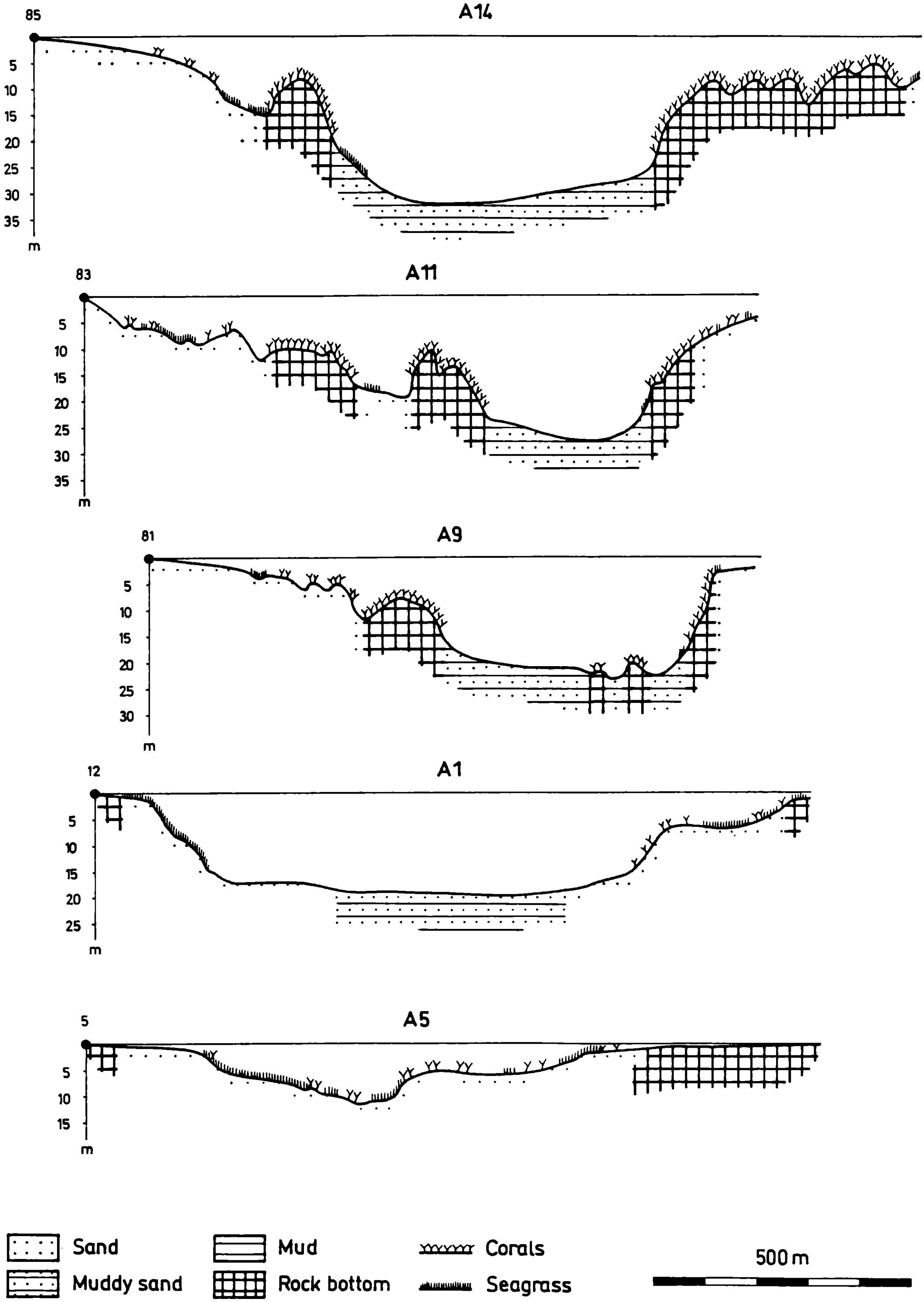

Fig. 6. Selected profiles of the "Southwest channel" showing bottom relief and bottom facies.

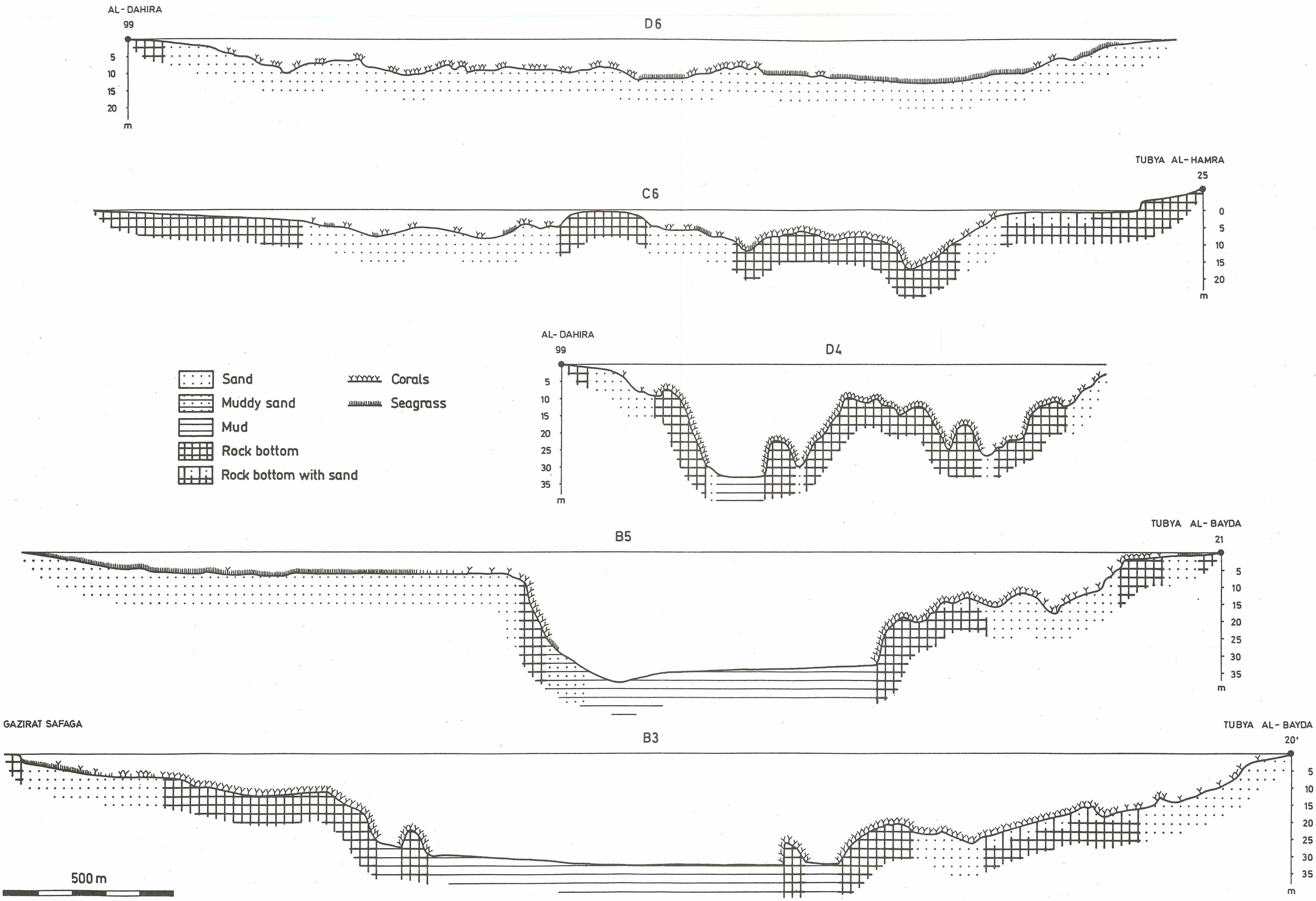

Fig. 7. Selected profiles of the "North area" and "West area" showing bottom relief and bottom facies.

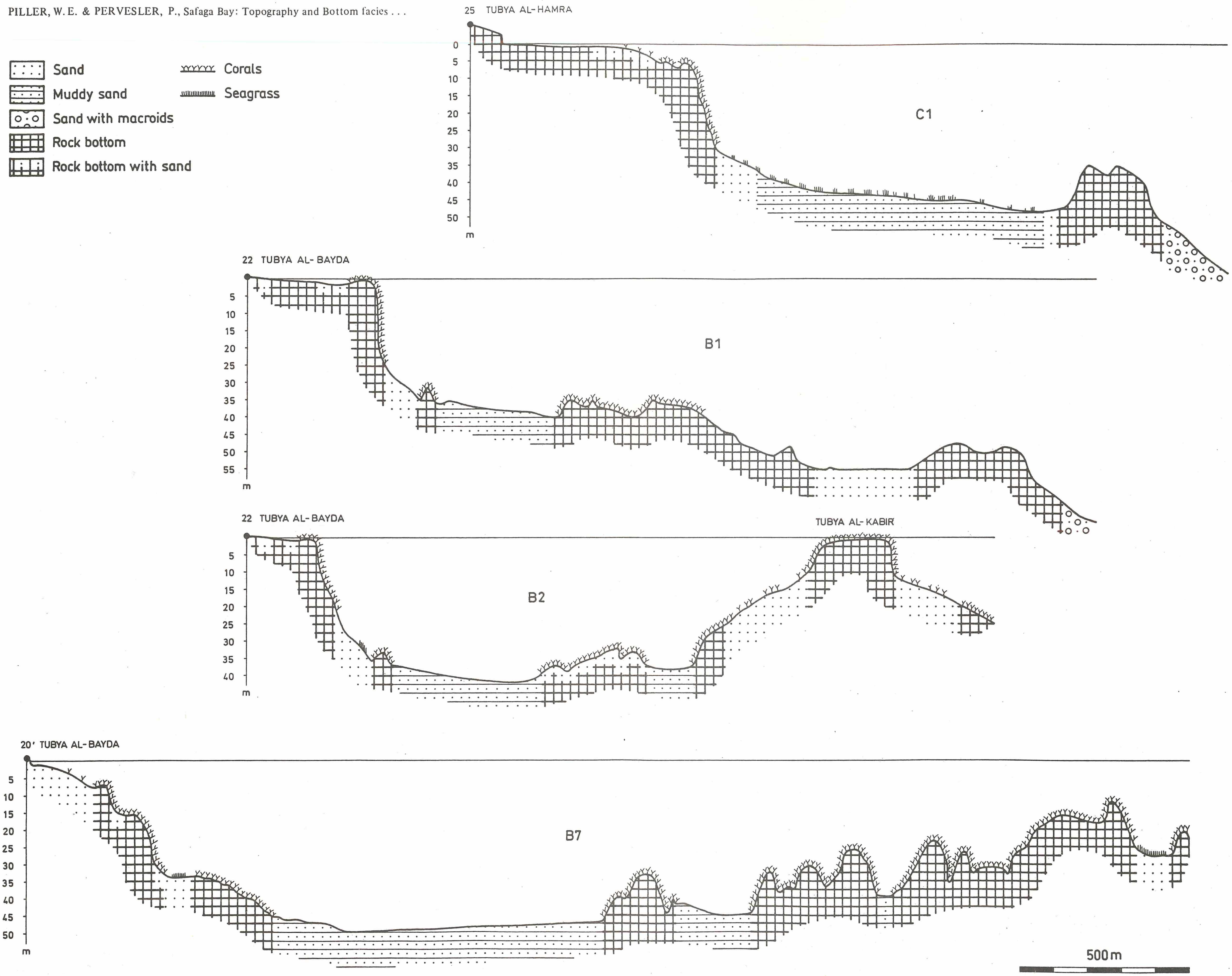

Fig. 8. Selected profiles of the "East area" showing bottom relief and bottom facies.

Wave- and current-exposed hardgrounds with steep morphology are characterized as coral reefs by the development of vertically zoned reef-associations. More flat morphology, mainly in connection with minor current exposure, is dominated by coral carpet. With decreasing light intensity, the latter grades into rock bottom. Whereas this transition occurs at the exposed margin of the bay in a depth of appr. 40 m, it already takes place in appr. 25 m on the ridge between the Tubya Islands and Gazirat Safaga. This difference could be related to a higher sediment load of the water, which originates from the Tubya Islands and is transported by the relatively high water currents in this area. The occurrence of sand with macroids shows a clear dependence on water current. This bottom facies is restricted to the outer rim of the bay in the east (below 50 m), where the strong N–S currents allow only very small sedimentation rates.

The coarser sands exhibit a high content of molluscs and corals debris. The molluscs represent a mixture of infaunal elements and hardground settlers. The highly variable coral debris content is directly related to the distance from coral-settled areas, which vary from isolated coral heads to coral patches of variable dimensions. The high sedimentation rate together with an instable sediment seem to prevent the occurrence and/or limit the expansion of coral carpet. This is evident in areas influenced by patch reefs (Tubya al-Kabir, Tubya al-Saghira, Gamul al-Saghira, Gamul al-Kabir) and in the surrounding of the Tubya Islands except the fringing reef. Along coastal areas the coarse sands contain a higher amount of terrigenous material. Generally all coarse sands are restricted to depths shallower than 20 m.

At greater depths, the sands contain a higher percentage of fine sediment ("muddy sand"). Such areas are restricted to morphological depressions, like the basins of the "East area" or the western margin of the basin of the "West area". In contrast to the coarse sand areas, where molluscs and coral debris dominate, the muddy sands are characterized by large numbers of *Operculina*. They contribute enormously to the sediment production. Among the molluscs, the gastropod *Xenophora* and the hammer oyster *Malleus* are very typical for the deeper muddy sand subfacies.

With sufficient light and sediment thickness, the sands can be settled by seagrasses in variable densities. This settlement is documented in the sediment by the high percentage of soritid foraminifers and by gastropods (e.g., *Smaragdia rangiana),* both living on the seagrass leaves. Due to the high standing crop of the soritids the sediment can be composed to a very high percentage by their tests. In the "muddy sand", seagrass is documented in the sediment by a mixture of tests of soritids and *Operculina.*

Carbonate mud is deposited in the protected basin of the "West area". In this fine sediment, scaphopods are very abundant; among the bivalves, thin-shelled, burrowing forms dominate (Tellinidae, Solecurtidae, Psammobiidae, Atyidae). Due to the small grain size, the abundant burrows of the diverse infaunal organisms are sharply outlined against the surrounding sediment. The microbial mat covering the sediment surface has a stabilizing effect on the sediment particles, prohibits their winnowing by currents, and may also have a trapping function. Because the narrowing in the transition from the "West area" into the "Southwest channel" produces higher current velocities, the mud grades – in connection with decreasing water depth – into muddy sand. Such a transition into muddy sand also occurs on the western margin of the basin due to the flat morphology, whereas the steep slope in the east produces directly adjoining mud and coral carpet areas. Debris in the mud is only found in the immediate contact area.

7. Acknowledgements

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Table 1. Temperature, salinity and ph at some localities in the Northern Bay of Safaga.
s = surface water, b = bottom water — depth in m, temperature in °C, salinity in °/oo.

date	transect	depth	temp.	salinity	ph
4.86	A 1	6–7	b 23.4	b 46	b 8.1
				s 40	
5.86	A 1	0	23.1	44	
5.86	B 1	45	b 24.1	b 42	
5.86	B 3	6	b 25.8	b 44	
5.86	B 1	0.5	29.6	44	
5.86	A 5	11.5	b 25.4	b 42	
10.86	B 5	28	b 27.3	b 44	b 8.0
10.86	B 5	37	b 26.8	b 42	b 8.0
10.86	B 5	36	b 27.0	b 44	b 8.0
11.86	B 5	33	b 26.9	b 46	b 8.1
11.86	B 5	6	b 27.2	b 43	b 8.2
11.86	A 1	0	25.9	44	8.2
11.86	B 1	40	b 25.2	b 43	b 8.2
			s 26.4	s 42	s 8.2
11.86	B 7	50	b 28.2	b 42	b 8.2
2.87	C 4	22	b 23.1	b 42	b 8.1
				s 41	
2.87	C 4	0.3	22.3	45	9.5
2.87	C 5	8	b 23.7	b 42	b 6.8
2.87	B 10	35	b 22.6	b 40	b 8.1
2.87	B 14	47	b 22.2	b 40	b 7.9
2.87	B 3	0	22.3	43	8.1
2.87	C 7	14	b 21.6	b 44	b 7.9
			s 22.6	s 43	s 8.1
2.87	A 8	23	b 23.3	b 42	b 8.1
2.87	A 8	19	b 22.9		
7.87	B 17	51	b 28.1	b 42	
7.87	C 1	34	b 28.3	b 43	b 7.8
			s 28.9	s 46	s 7.8
7.87	A 5	6	b 27.7	b 45.5	b 7.7
7.87	C 2	7	b 29.3	b 46	b 7.5
7.87	B 17	46	b 28.4	b 46	b 7.8
7.87	B 5	0.5	32.6	40	8.0

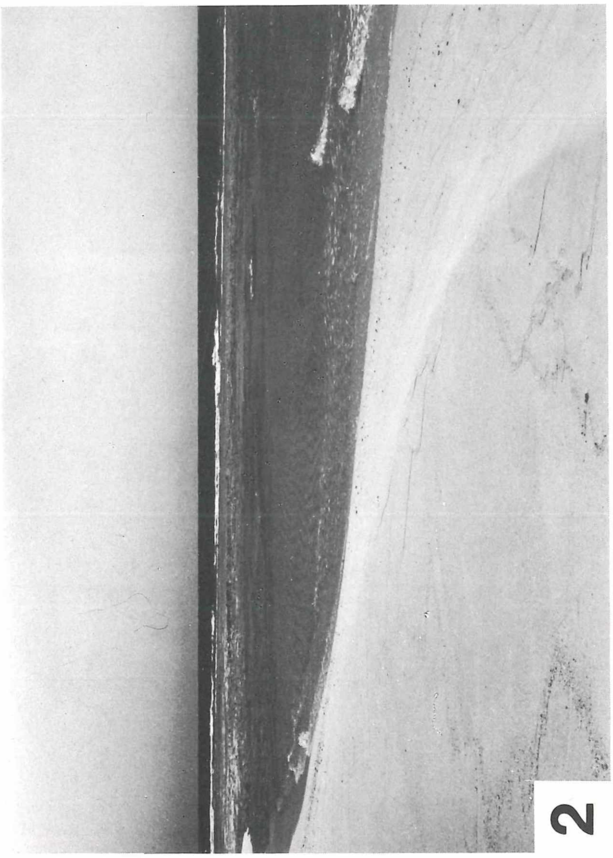
Plate 1

Fig. 1. View southwest from Tubya al-Bayda across the "West area" and the "Southwest channel". Foreground shows the west beach of Tubya al-Bayda with beach rock and rocky tidal flat during low tide. In the background the narrow coastal plain is visible between the main coast and the mountain chain.

Fig. 2. View northeast from Tubya al-Bayda during low tide showing the sandy beach, the narrow boat channel and the position of the reef crest (marked by the waves).

Fig. 3. Reef flat at the **fringing reef** of Tubya al-Bayda showing the rocky bottom encrusted mainly by coralline algae and patchily settled by *Pocillopora verrucosa* and faviid corals.

Fig. 4. Reef slope at Ras Abu Soma dominated by *Acropora.* Depth: 6 m.



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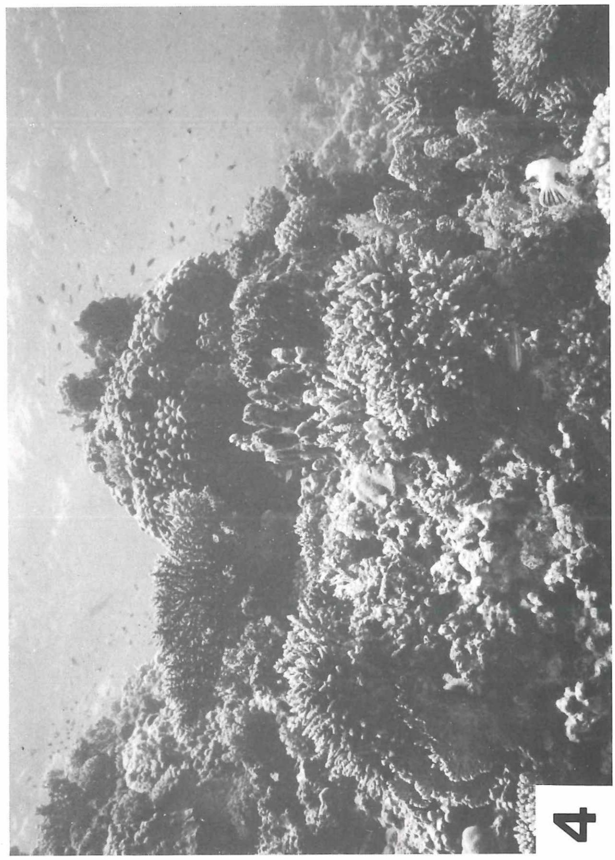

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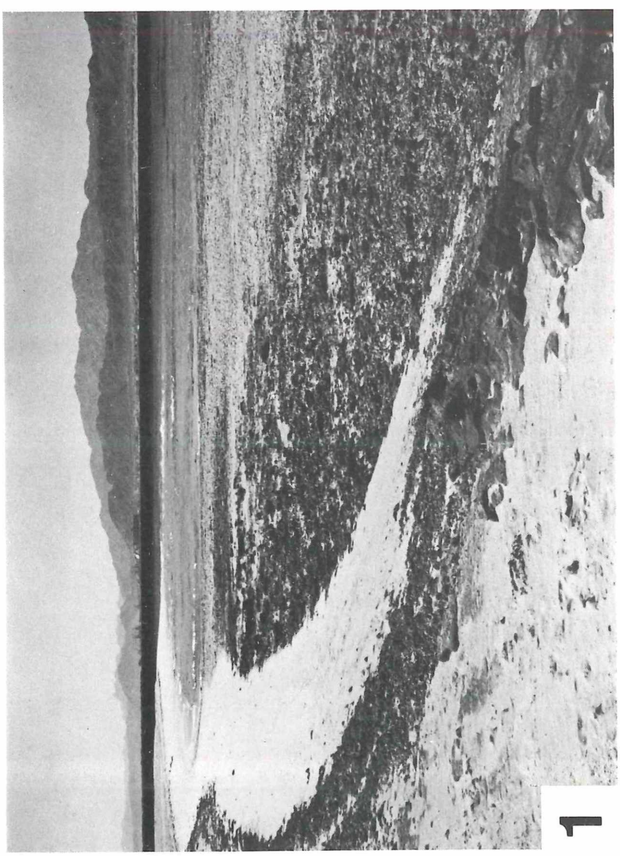

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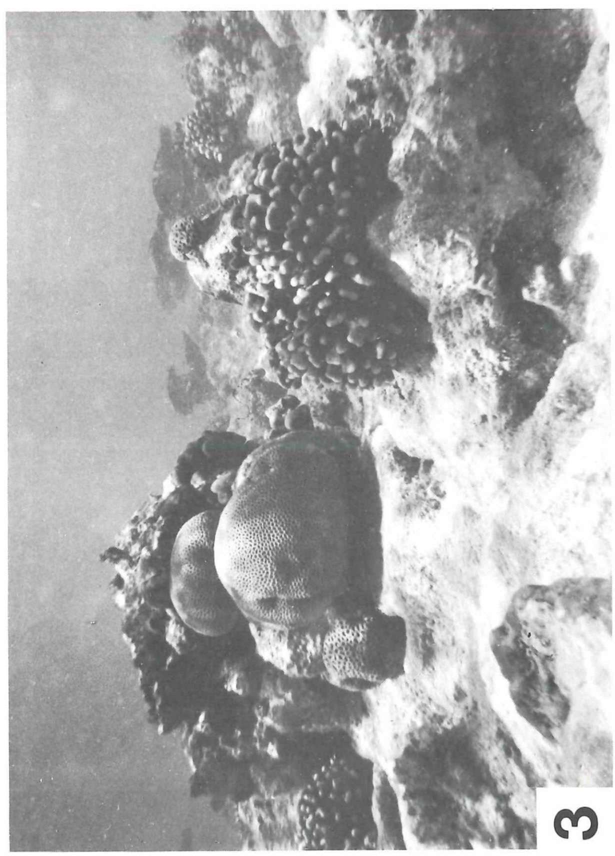

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Plate 2

Fig. 1. Reef slope at Ras Abu Soma dominated by *Porites*. Depth: 7 m.

Fig. 2. Reef slope at Tubya al-Bayda dominated by *Millepora*. Soft corals (xeniids and *Sarcophyton)* are also abundant. Depth: 5 m.

Fig. 3. Gorgonian sea fan on the steep wall of the reef at Ras Abu Soma. Depth: 30 m.

Fig. 4. One of the **pinnacle reefs** of Tubya Arba, rising from appr. 10 m depth to the water surface.


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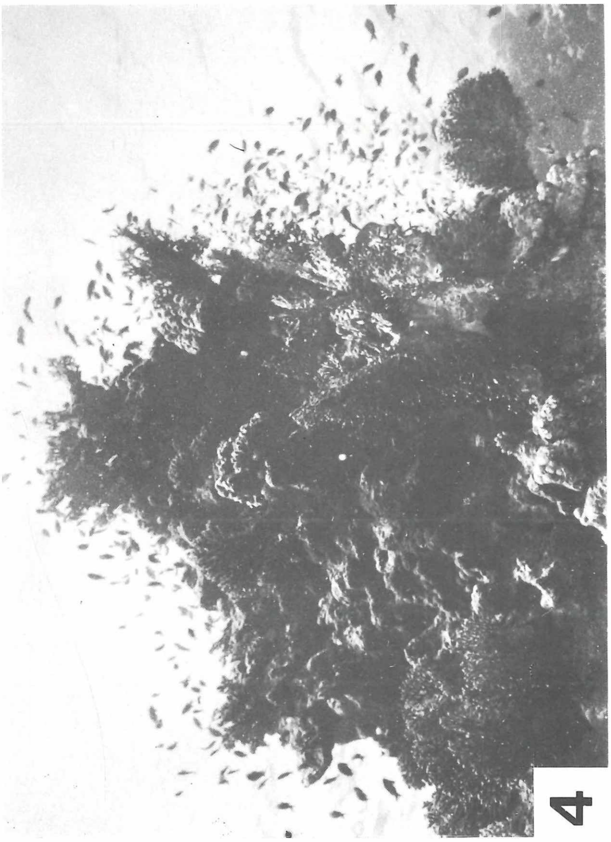
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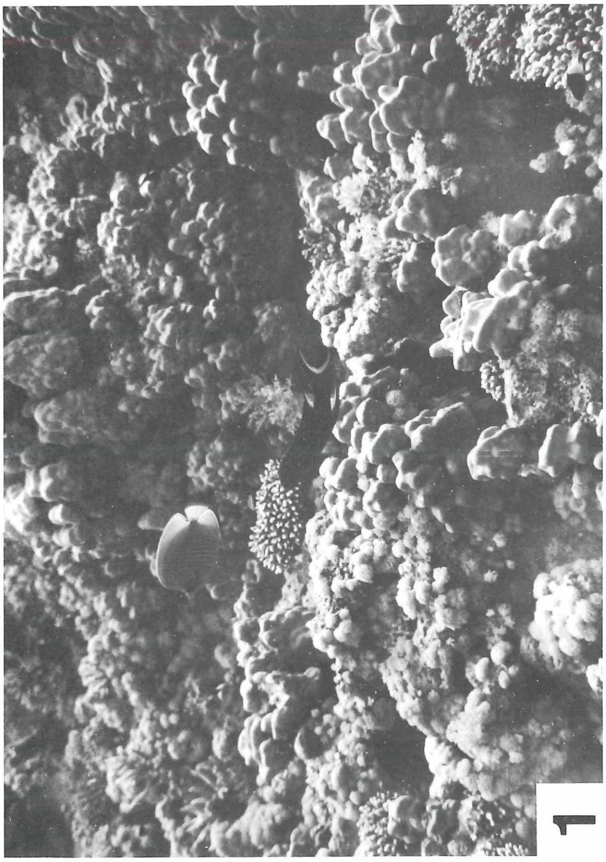
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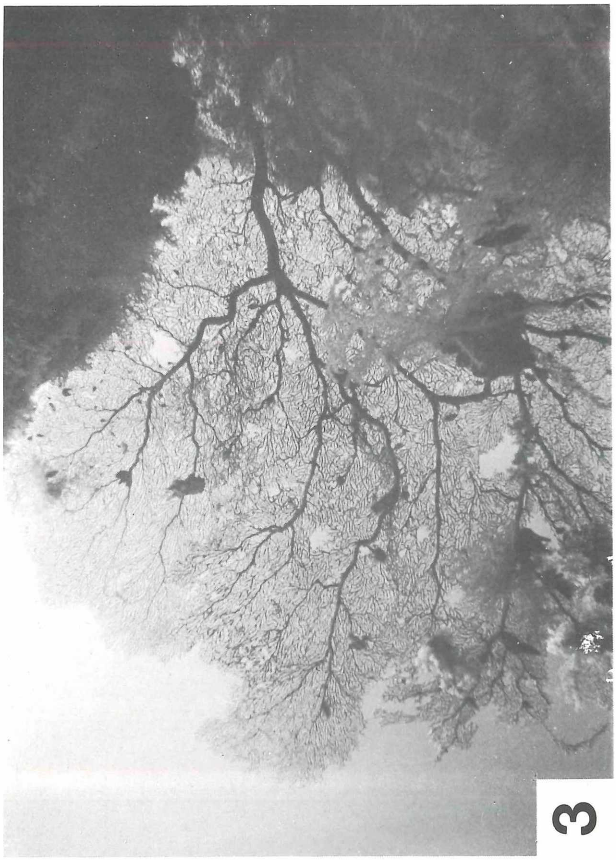
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Plate 3

Fig. 1. Small isolated **coral patches** dominated by *Acropora* and xeniid soft corals. East of Tubya al-Kabir, transect: B2, depth: 16 m.

Fig. 2. Densely spaced **coral patches** dominated by *Acropora* near the reef base of Tubya al-Bayda. ''East area", transect: B1, depth: 25 m.

Fig. 3. Sea bottom between **coral patches** consisting of coarse biogenic debris. ''North area", transect: C8, depth: 6 m.

Fig. 4. **Coral patch** with *Lopha cristagalli* settling on the coral *Platygyra daedalea.* ''Southwest channel", transect: A1, depth: 8 m.

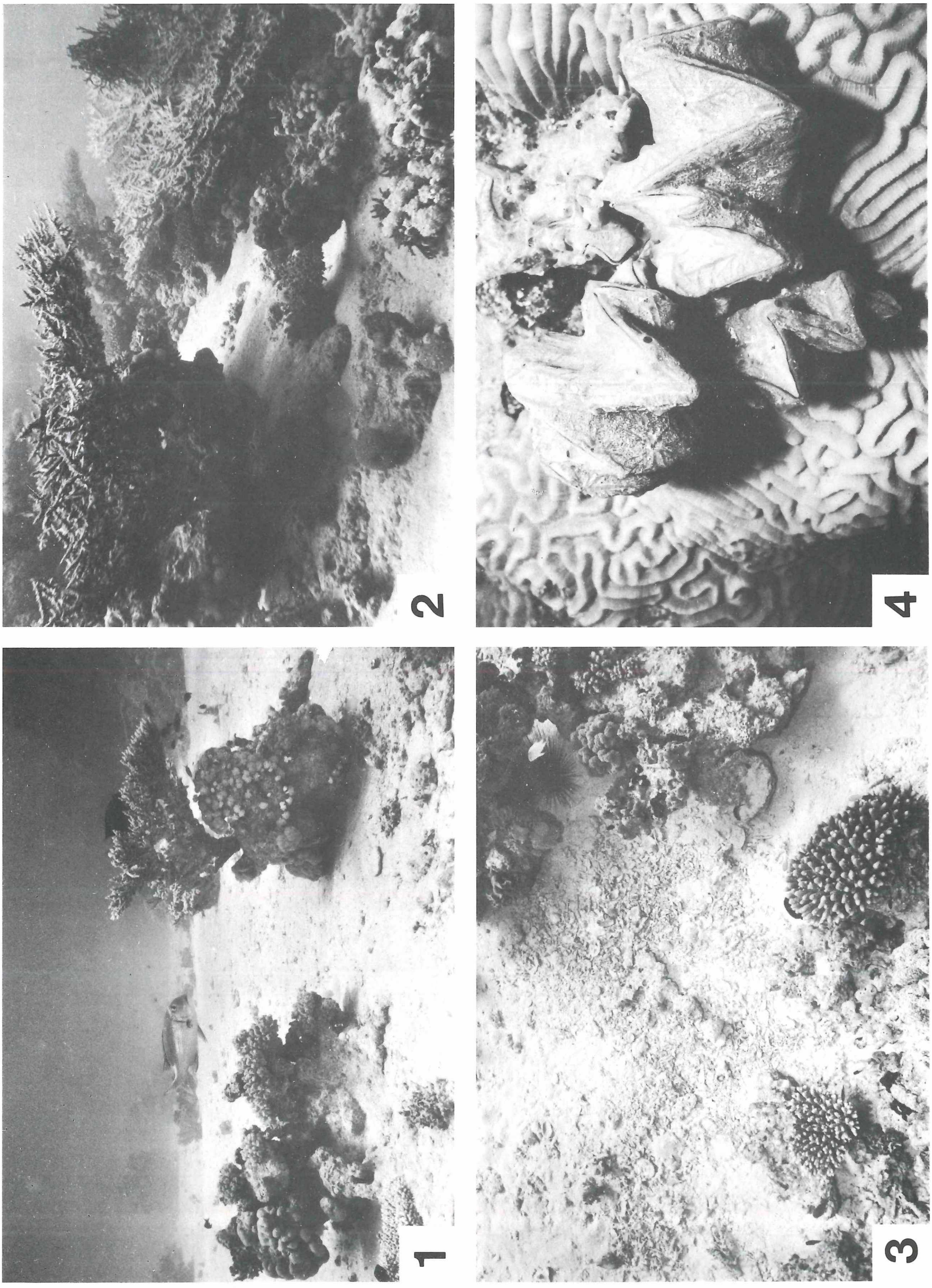


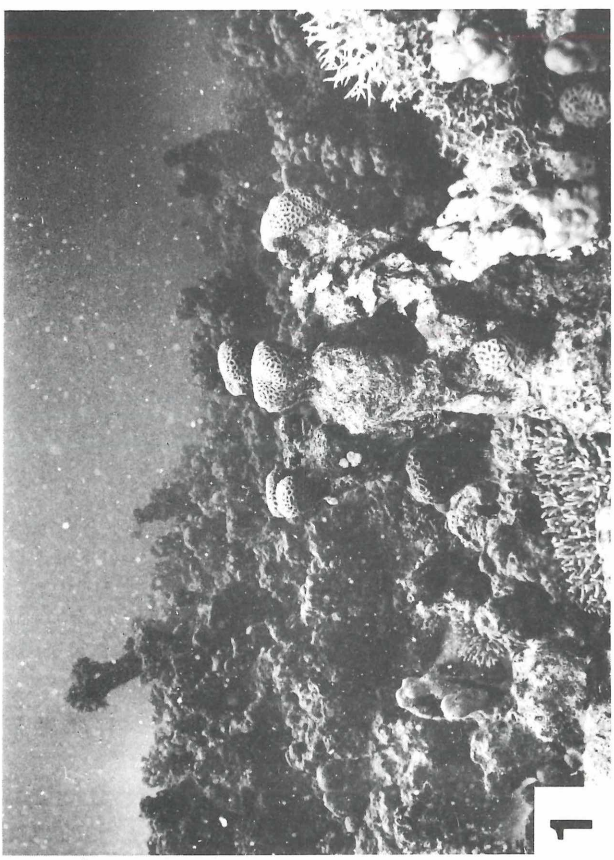
Plate 4

Fig. 1. Dense and diverse **coral carpet** with *Goniastrea pectinata, Seriatopora hystrix, Acropora* sp., and several other scleractinian corals. "Southwest channel", transect: A11, depth: 15 m.

Fig. 2. **Coral carpet** with diverse scleractinian association and *Diadema setosum;* interrupted by sand-filled depressions. "Southwest channel", transect: A11, depth: 15 m.

Fig. 3. Disintegrating **coral carpet** leading over into **sand with coral patches.** "East area", south of Tubya Arba, depth: 20 m.

Fig. 4. Depression inside **coral carpet** filled with fine-grained sediment. Clusters of holes represent openings of crustacean burrows (genus *Axiopsis).* "West area", transect: D4, depth: 28 m.



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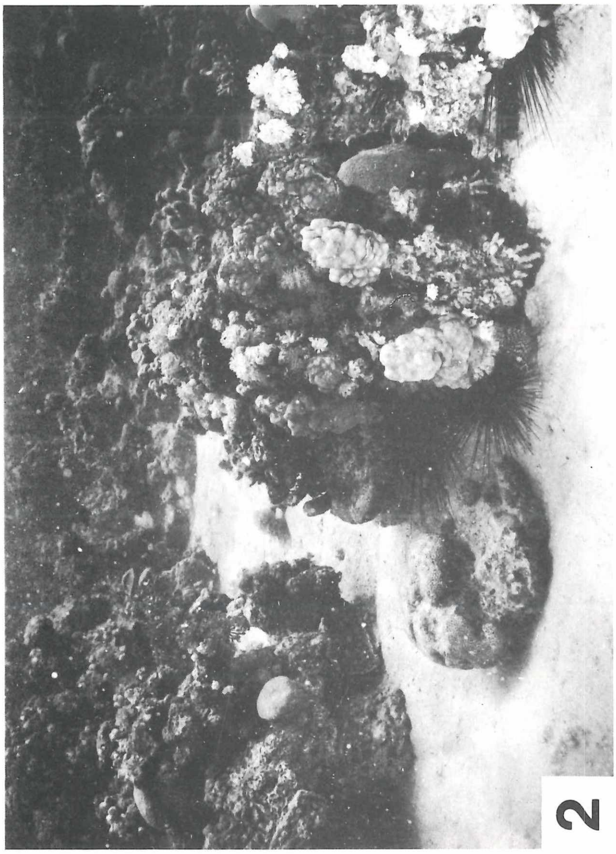

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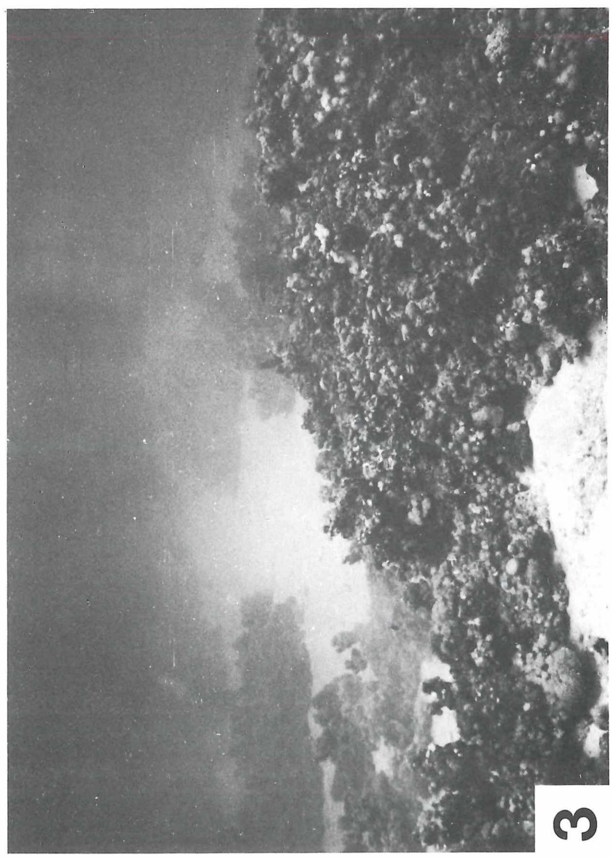

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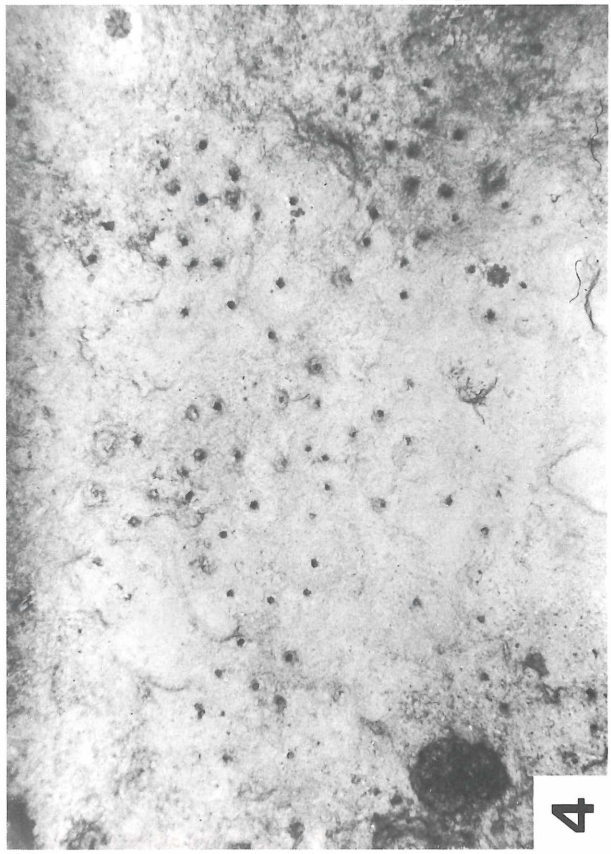

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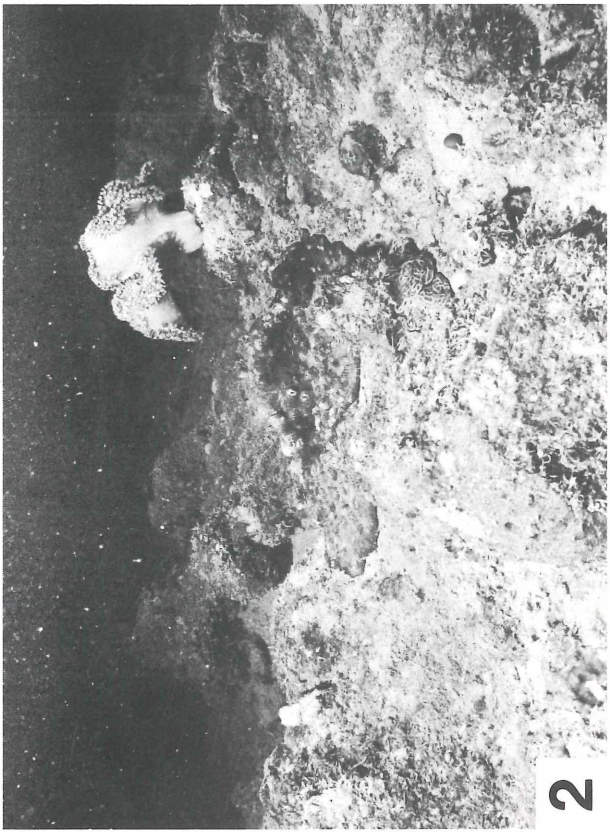
Plate 5

Fig. 1. Sparsely developed **coral carpet** with low growing stone corals as well as *Dendronephthya* and other soft corals. "East area", transect: B7, depth: 32 m.

Fig. 2. **Rock bottom** with soft corals (e.g., *Sarcophyton)* as well as incrusting and solitary (e.g., *Cynarina lacrymalis)* scleractinian corals. "East area", transect: B6, depth: 41 m.

Fig. 3. Margin of **rock bottom** at the boundary to **sand with macroids** densely settled by *Padina pavonia,* soft corals, and very rare *Halimeda.* "East area", transect: C1, depth: 55 m.

Fig. 4. Typical **rock bottom** with algal covering, rare soft corals, and *Padina.* "East area", transect: C1, depth: 48 m.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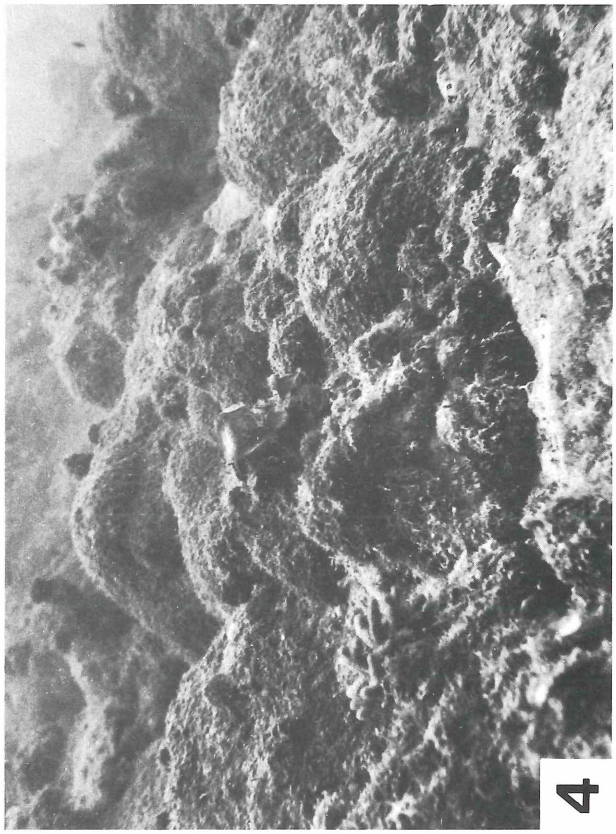
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Plate 6

Fig. 1. Transition between **rock bottom** respectively **coral carpet** into **sand bottom**. ''East area'' transect: B9, depth: 45 m.

Fig. 2. **Sand with macroids,** demonstrating dense macroid cover (diameters mainly 10–20 cm). Isolated patches of rock bottom occur in between. ''East area'', transect: B11, depth: 51 m.

Fig. 3. **Sand with macroids:** abundant macroids, but demonstrating the thin sand cover on the rock bottom. Exposed rock bottom is settled by *Padina* and soft corals. ''East area'', transect: C1, depth: 60 m.

Fig. 4. Similar to Fig. 3, but with higher macroid density and smaller areas of exposed rock bottom. ''East area'', transect: C1, depth: 60 m.

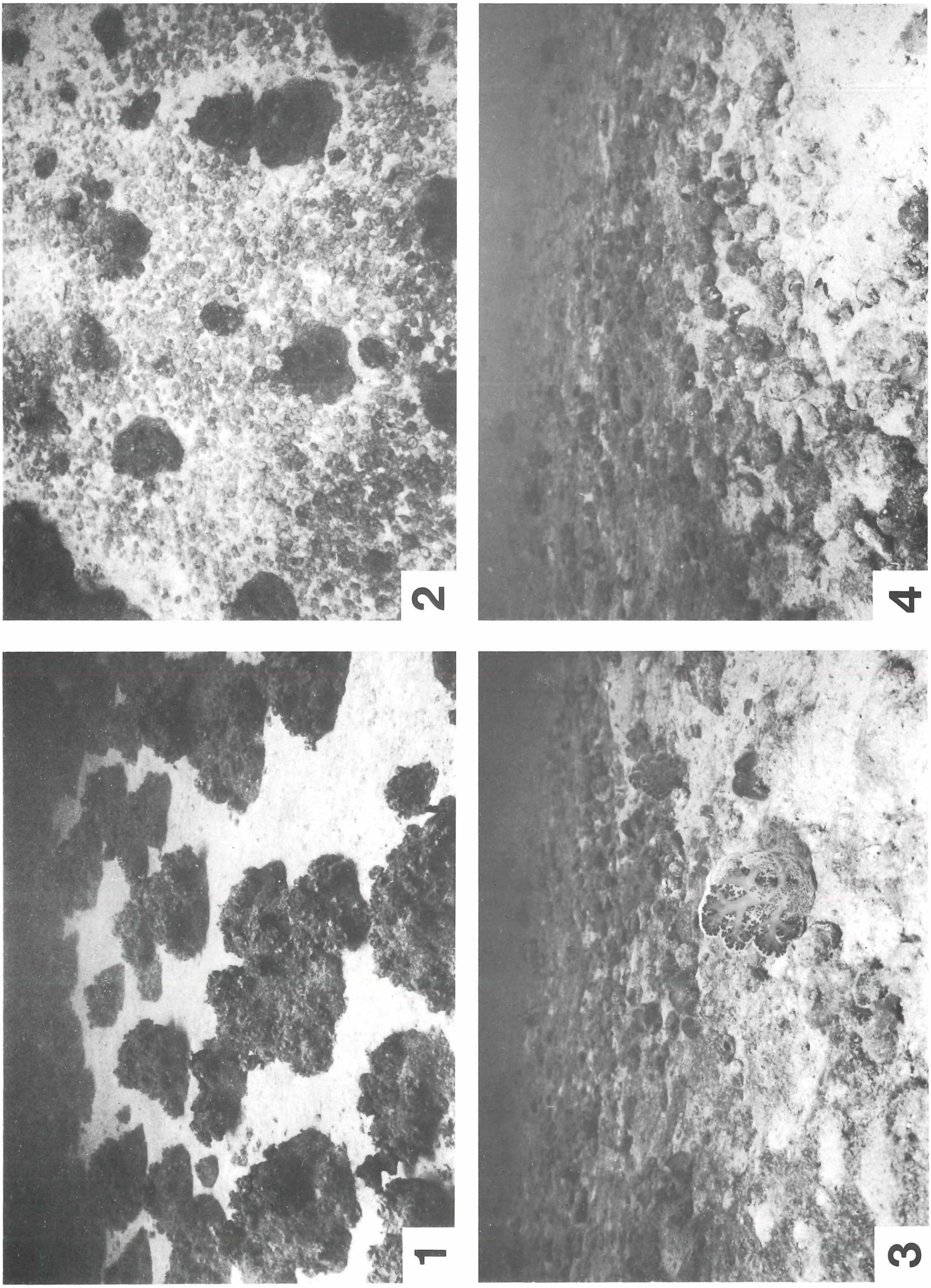
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Plate 7

Fig. 1. **Muddy sand bottom** with mounds and craters due to the activity of enteropneusts. A *Cassiopeia* is positioned on top of one mound (right foreground). ''Southwest channel'', transect: A11, depth: 20 m.

Fig. 2. **Muddy sand bottom** with typical star-like trails and bûrrow openings. ''West area'', transect: B15, depth: 32 m.

Fig. 3. **Muddy sand bottom** with small patches of the seagrass *Halophila stipulacea.* ''Southwest channel'', transect: A1, depth: 19 m.

Fig. 4. Transition between **muddy sand** and **seagrass bottom** *(Halophila stipulacea).* ''North area'', transect: C7, depth: 14 m.

Plate 7

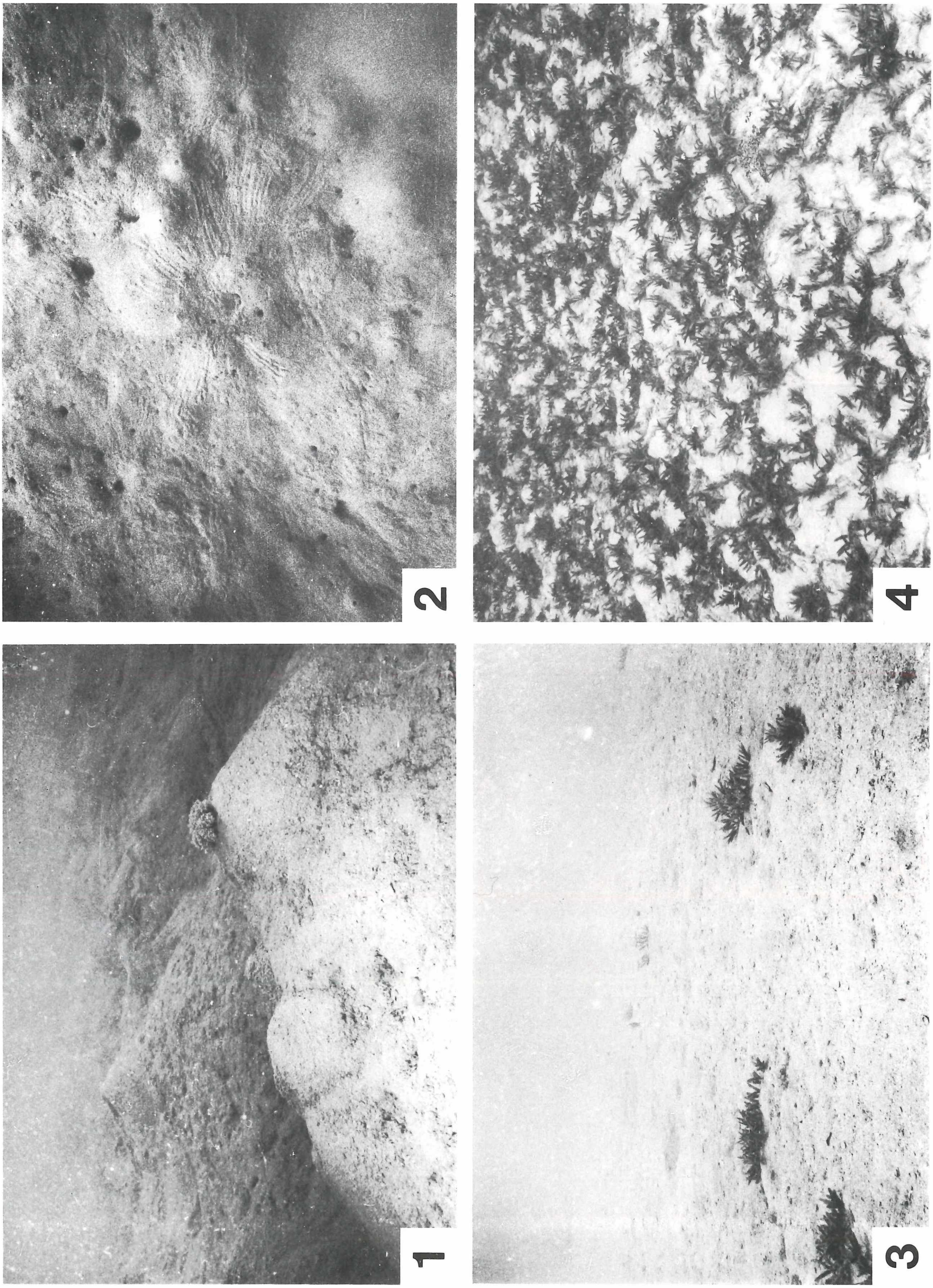

Plate 8

Fig. 1. **Seagrass bottom** with co-occurrence of *Halophila stipulacea* and *Halodule uninervis* as well as many *Strombus fasciatus* shells. "Southwest channel", transect: A1, depth: 1.5 m.

Fig. 2. Dense meadow of *Halophila stipulacea.* "Southwest channel", transect: A1, depth: 10 m.

Fig. 3. Dense meadow of *Cymodocea rotundata.* The diver is digging out a resin cast of a burrow with the aid of an air lift. "Southwest channel", transect: A1, depth: 6 m.

Fig. 4. Living soritid foraminifers attached to seagrass leaves. "West area", transect: D2, depth: 1.5 m.

Fig. 5. Loosely settled **seagrass bottom** with mounds produced by the callianassid crab *Callichirus.* "Southwest channel", transect: A1, depth: 5 m.

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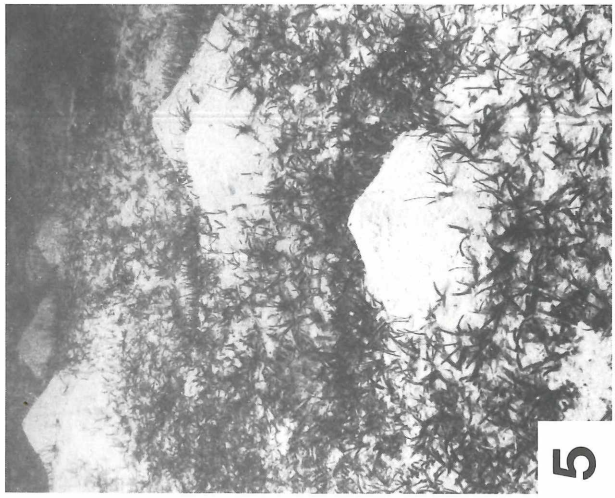

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Plate 9

Fig. 1. **Mud bottom** with trails and burrow openings. Mounds are constructed by crustaceans. The bottom is covered by a microbial mat. ''West area", transect: B4, depth: 37 m.

Fig. 2. Similar to Fig. 1, showing microslumping on the flank of the mound. ''West area", transect: B4, depth: 37 m.

Fig. 3. Vertical view of **mud bottom** showing the density of various burrow openings on the sediment surface. ''West area", transect: B15, depth: 33 m.

Fig. 4. View south between Tubya al-Hamra and Tubya al-Bayda (background) across the **rocky tidal flat**; note rugged surface during low tide.

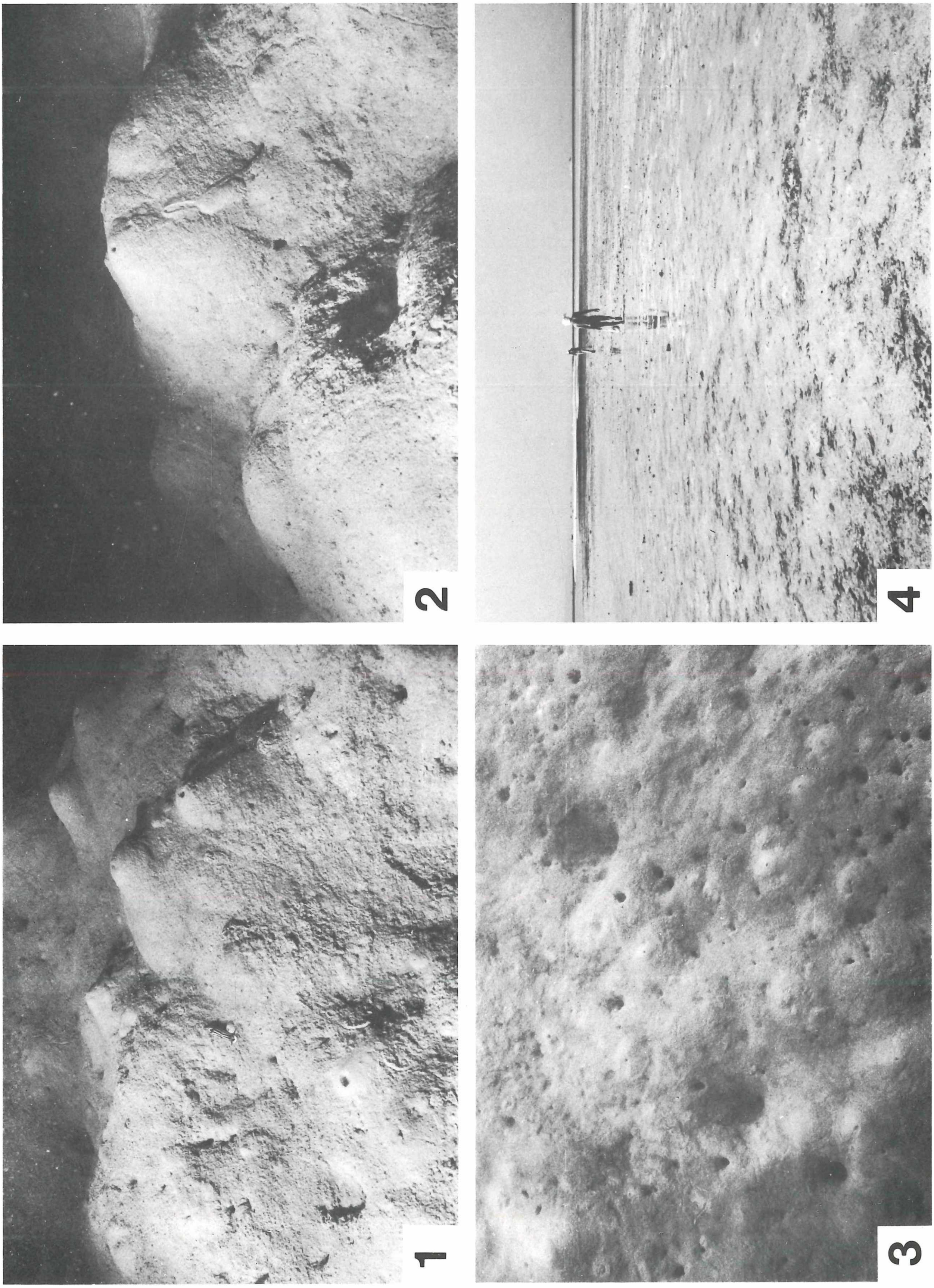
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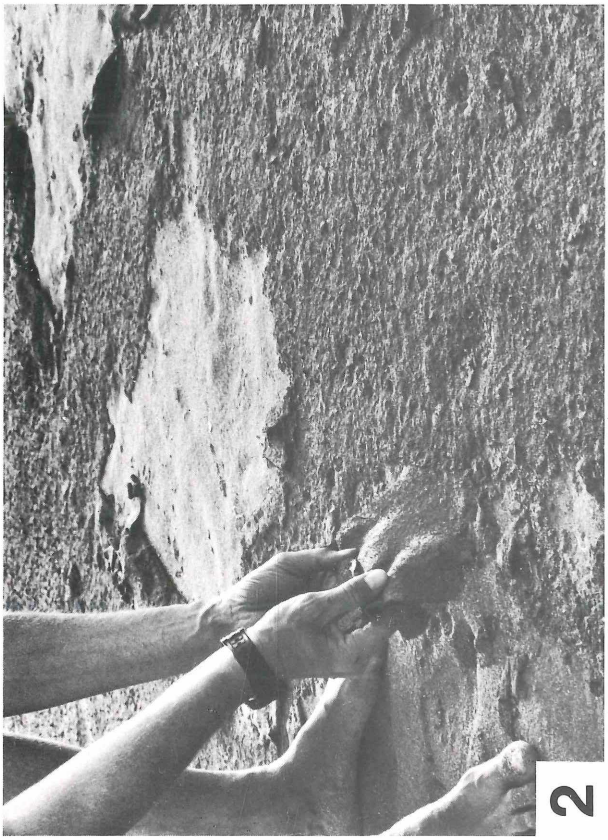
Plate 10

Fig. 1. **Algal pond** during low tide showing zonation of microbial mats (expressed in differing brightness), depending on periods of water cover. Mat is cracked and rolled up by the wind in foreground. "Southwest channel" around land point 12.

Fig. 2. Detail of Fig. 1, showing the tough microbial mat.

Fig. 3. **Mangrove** built by *Avicennia marina* showing bushy growth form. "Southwest channel", west coast of Gazirat Safaga.

Fig. 4. **Mangrove** channel framed by dense standing crop of *Avicennia marina.* "Southwest channel", west coast of Gazirat Safaga.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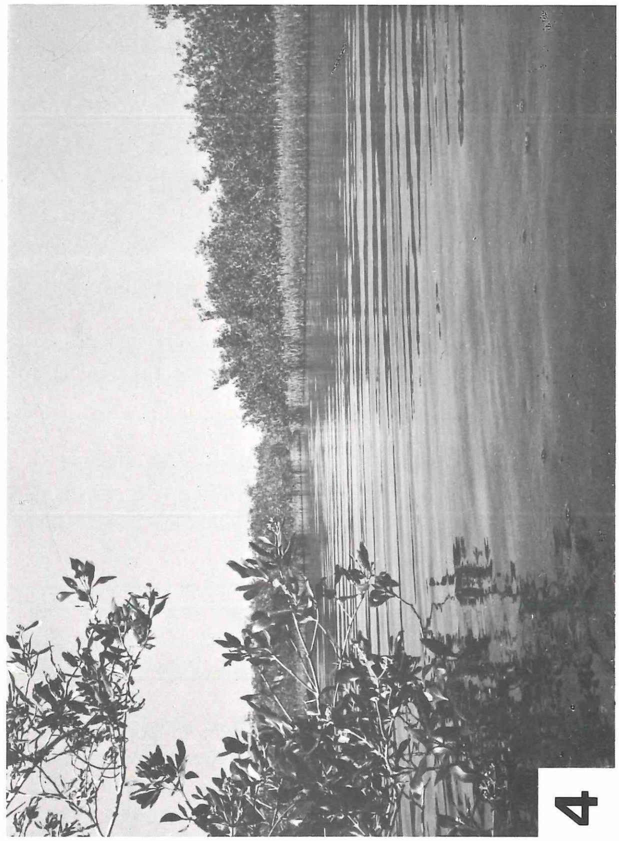
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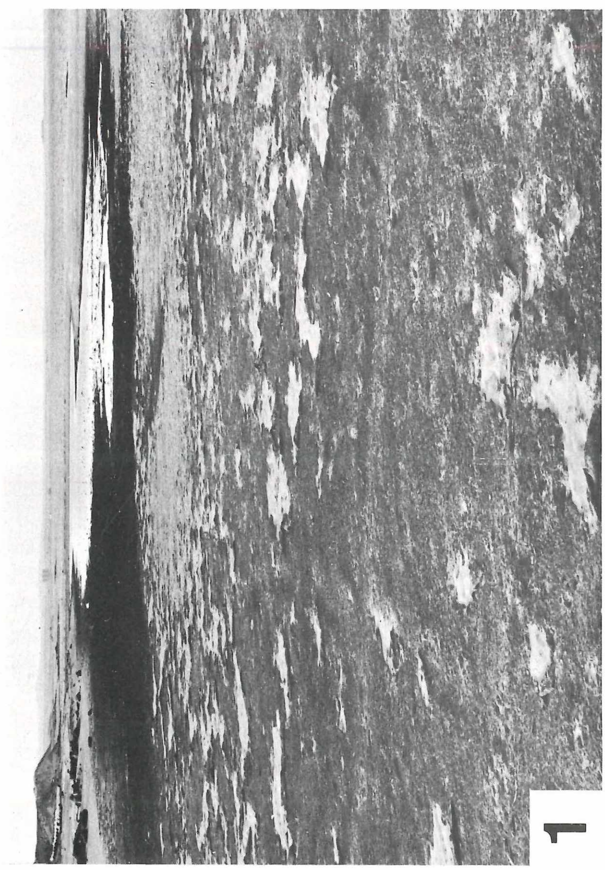
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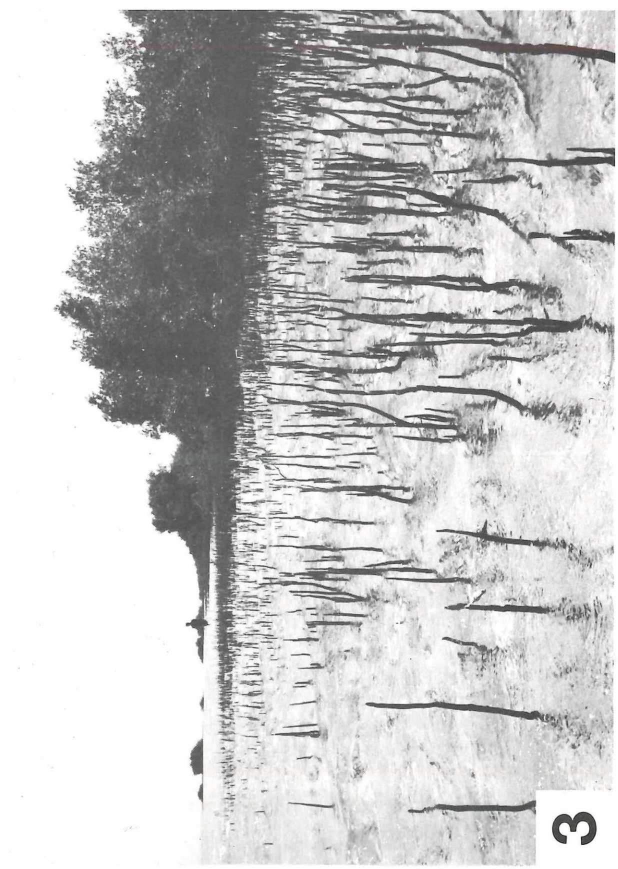
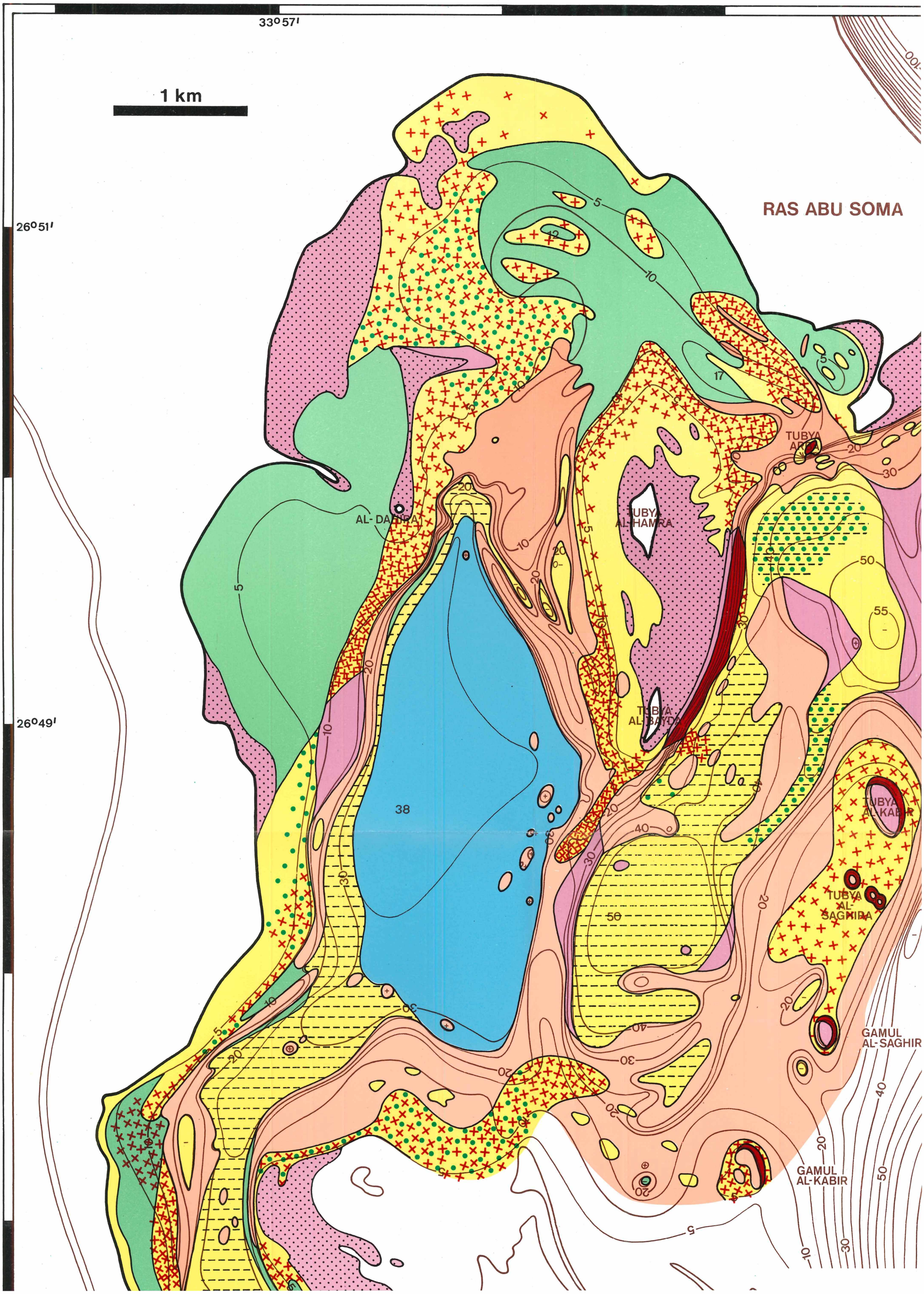
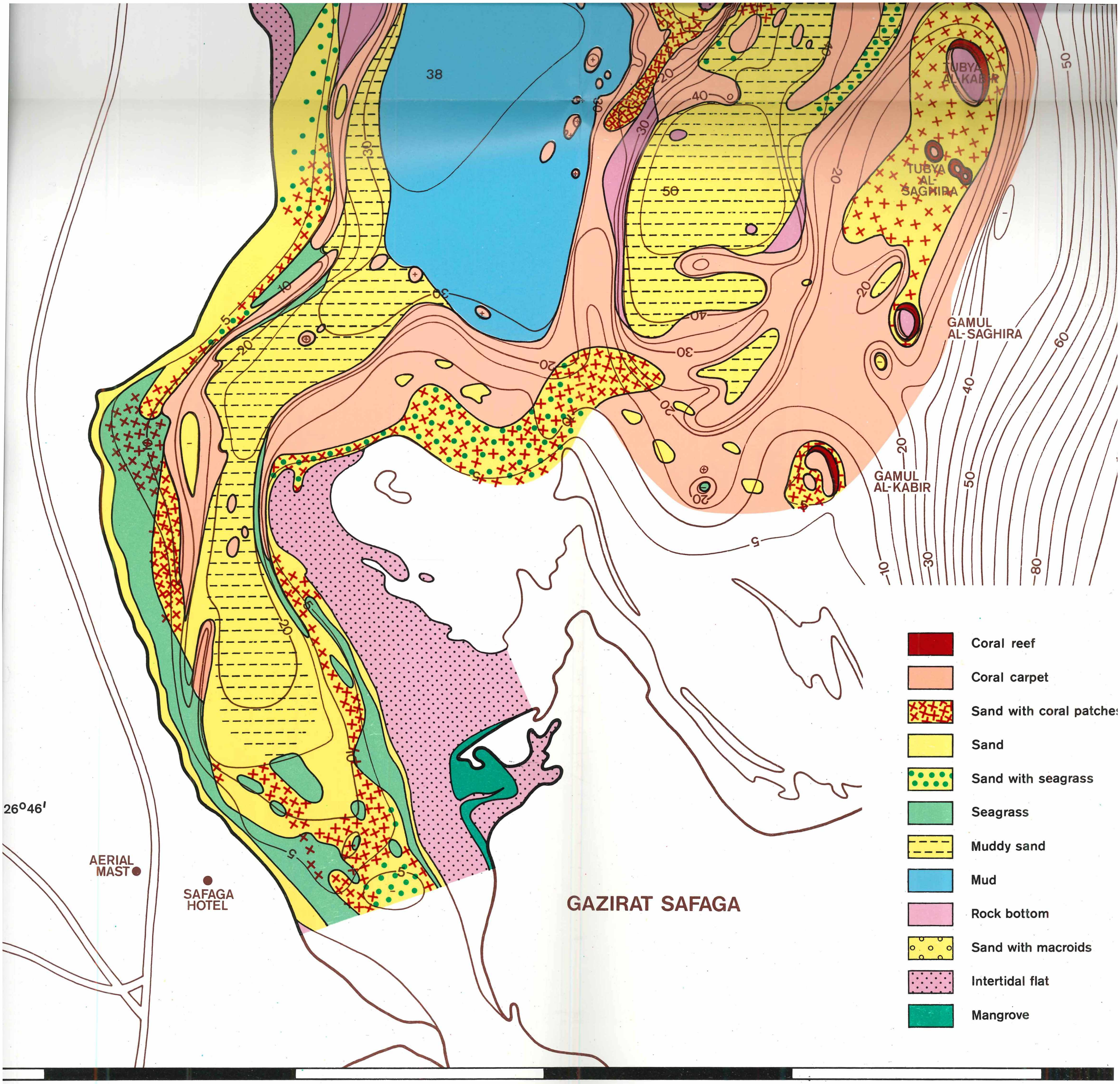

3

BOTTOM FACIES MAP OF NORTHERN SAFAGA




TUBYA AL-KABIR
TUBYA AL-SAGHIRA
GAMUL AL-SAGHIRA
GAMUL AL-KABIR
26°46′
AERIAL MAST
SAFAGA HOTEL
GAZIRAT SAFAGA
Coral reef
Coral carpet
Sand with coral patches
Sand
Sand with seagrass
Seagrass
Muddy sand
Mud
Rock bottom
Sand with macroids
Intertidal flat
Mangrove