Journal of Coastal Research	12	1	70–78	Fort Lauderdale, Florida	Winter 1996

Sediment Transport Patterns of Southern Sinai Coasts and their Role in the Holocene Development of Coral Reefs and Lagoons[1]

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ABSTRACT

NIR, Y., 1996. Sediment transport patterns of southern Sinai coasts and their role in the Holocene development of coral reefs and lagoons. *Journal of Coastal Research*, 12(1), 70–78. Fort Lauderdale (Florida). ISSN 0749-0208.

The two Sinai gulfs, Eilat ('Aqaba) and Suez developed coral reefs during the Pleistocene with specific narrow, elongated and/or barrier characteristics. Besides these reefs, the gulfs are known to have typical lagoons, the origin of which is discussed herein. The prevailing northerly winds in the Gulf of Eilat and the north-northwesterly winds in the Gulf of Suez are the most important factors in the longshore sediment transport system. This regime, which has existed at least since the last post-Glacial sea level rise, affected the morphological features and later became the substrate for reef growth on the one hand and the development of lagoons and sabkhas (playas) on the other.

ADDITIONAL INDEX WORDS: *Coral reefs, lagoons, main longshore trend, Holocene, Gulf of Eilat ('Aqaba), Gulf of Suez, Sinai, Egypt.*

INTRODUCTION

The Gulf of Suez and the Gulf of Eilat are large elongated marine embayments extending from the northern Red Sea and bordering the Sinai peninsula (Figure 1). The Gulf of Suez is oriented in a SSE–NNW direction, and the Gulf of Eilat ('Aqaba) in a SSW–NNE direction. Both gulfs are tectonically controlled. The Gulf of Eilat is 180 km long, very narrow and deep, while the Gulf of Suez is 280 km long, wider, very shallow, with water depths that never exceed 70 m in the central and 90 m in its southern section. The recent connection of the Gulf of Suez with the Mediterranean Sea through the Suez Canal commenced in the late sixties of the 19th century, causing a large scale biologic migration, known as the Lessepsian Migration (POR, 1971). According to ABDEL-GAWAD (1970), the embrionic gulf existed as a shallow embayment of the old Tethys Sea during the Carboniferous.

Barrier islands, spits, etc., are known from many coasts around the world (NUMMEDAL, 1983; RICE and LEATHERMAN, 1983; SNEH and FRIEDMAN, 1984; SCHWARTZ and ANDERSON II, 1986; SCHWARTZ *et al.*, 1987; SCHWARTZ *et al.*, 1989). Their importance as backshore defenders, lagoon and lowlands protectors has been described in detail by NUMMEDAL (1983). Many organic "patches", with very low relief "shallows", fringing, and barrier-reefs are typical of the Suez and the Eilat gulfs (LOYA, 1972; FISHELSON, 1972; GVIRTZMAN *et al.*, 1977). Those in the Suez are from north to south: Sheratib (Belayim) shallow, e-Tor bank, Morsby shallow, Poynder shallow, Felix James patches, Sh'ab 'Ali (Ras Kanisa—'Ras' means head or promontory in Arabic) and Sh'ab Mahmud ("Sh'ab" = reef in Arabic). The Reefs in Eilat are mostly of the fringing type and many are nameless, while those known to have names are small, very shallow islets, found around its southern straits: Gordon, Thomas, Woodhouse, and Jackson. Aridity on both gulfs, the Egyptian (the "Eastern Desert") and the Sinai, is the most characteristic climatic and physiographic feature that affects both coasts and their beach sediments.

Many wadis (dry creeks), some very large with very high gradients at their mountainous section, drain the nearby land to the gulfs. Rain and floods are infrequent, resulting in irregular sediment transport to the beaches. The terrain bordering the Gulf of Suez is composed of a great variety of rock types: the coastal plain, whenever it exists, consists of Tertiary formations and wide alluvial plains. The elevated areas in the Sinai and Egyp-

94238 received 12 November 1994; accepted in revision 23 January 1995.
[1] In memory of David Popper who devoted his life to the biological study of the Sinai coasts.

tian vicinity consist of igneous rocks of pre-Cambrian age in the south and Paleozoic to Cenozoic sedimentary rocks in the central and northern regions. The Gulf of Eilat is surrounded mostly by pre-Cambrian igneous rocks, both on the west—Sinai and the East—Midyan, with additional sediments of Palaeozoic and Cretaceous age which mostly consist of sandstones and carbonate rocks. According to EYAL *et al.* (1985), the drainage system of the Sinai peninsula started to develop as early as the Pliocene period. According to EYAL *et al.* (1985), a large scale uplifting which reached some 4,000 m in Sinai resulted in the development of high-gradient slopes of the wadi courses. These high gradients and the torrential nature of desert-rains result in floods rich in huge amounts of unsorted sediments which are transported to the coastal areas of the two gulfs. These sediments are derived from the following sources (given in order of importance): (a) alluvial sediments transported to the sea from the mainland, primary and sedimentary rocks; (b) syngenetic sediments, including coral-reefs and other organic debris, calcium carbonate oolites at the northern beaches of the Gulf of Suez only (*e.g.*, the Ras Matarma lagoon) and beachrock; (c) shore erosion of cliffs such as raised marine terraces or other rocky promontories.

A description of the various sedimentological environments of the coastal plain of the Sinai side of the Gulf of Suez, especially its sabkhas (playas), and coral reefs, the spit shape morphology and origin and some features of lagoon formation, is given by SASS *et al.* (1972), SNEH (1978), SNEH and FRIEDMAN (1984). NIR (1973) has given a full description of the small bays found along the Gulf of Eilat and their bathymetric and sedimentary features.

Tides are semi-diurnal with gradually decreasing magnitude from two meters near the city of Suez to the nodal zero point at the city of e-Tor, some 210 km to the south. Whenever the southern part of the Gulf of Suez has low water, high water occurs in its northern part and vice versa. The tides of the Gulf of Eilat are similar in type but differ in magnitude, usually around 60–70 cm (U.S. NAVY, 1952; ARAD, 1971). Large magnitude tidal currents are developed in the almost-closed lagoons such as at Ras Matarma and Belayim at the Gulf of Suez and the Ras Abu Galum lagoon at the Gulf of Eilat. Dominant north-northwesterly winds and gales are responsible for the main trend and longshore sediment transport along the gulfs. This transport has a clear direction with a net trend from NNW to the SSE and from NNE to SSW in the gulfs of Suez and Eilat respectively. A most pronounced sediment accumulation is found on the northern side of all solid artificial shore structures (breakwaters, groins, *etc.*, which serve as barriers, as shown in Figure 2). This accumulation clearly indicates the net 'southerly' directed sediment transport. Ras Matarma la-

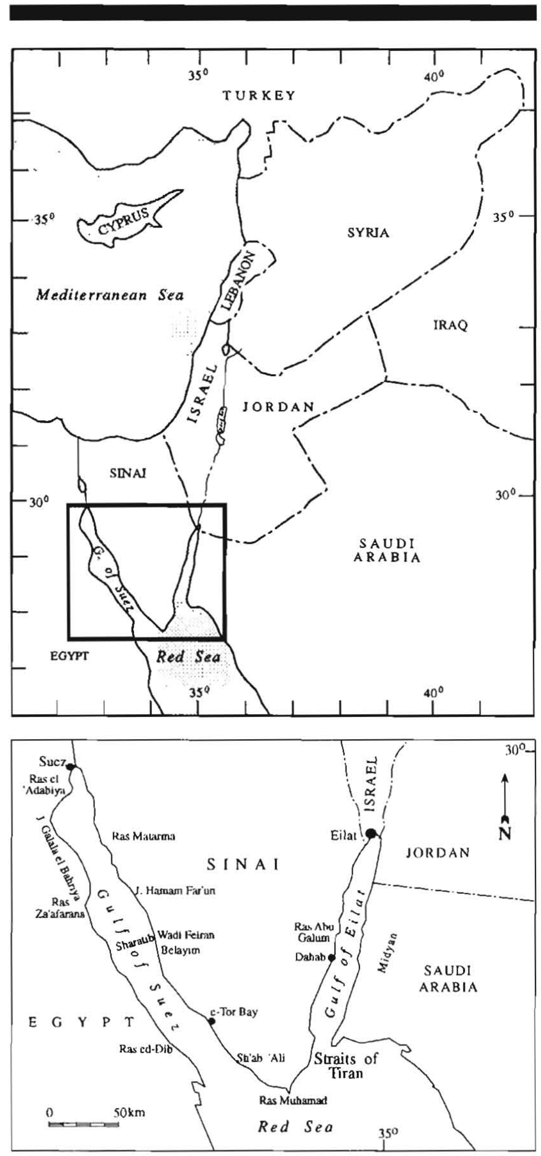


Figure 1. Location map.

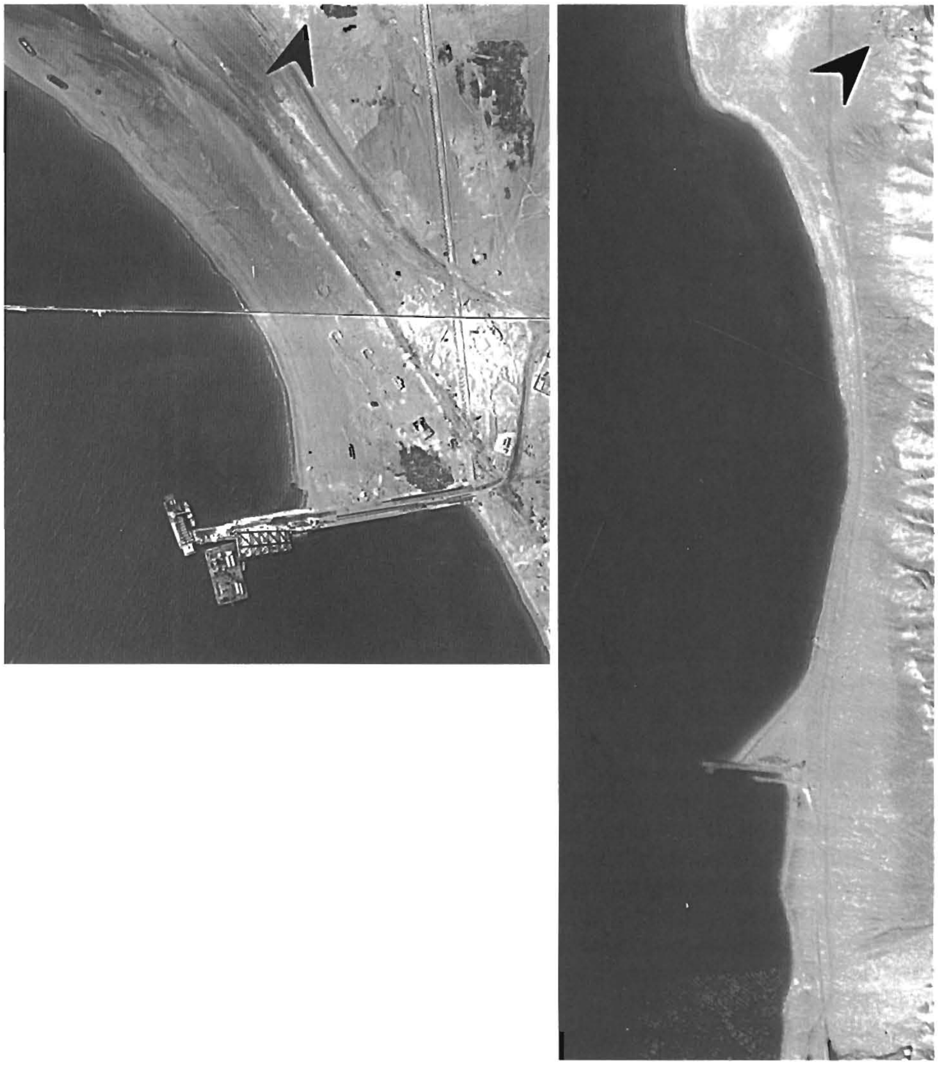


Figure 2. Asymmetrical sediment accumulation next to artificial structures: at Abu Zenima (20 km north of Sharatib); (a) 24.9.75, and Abu Darba (near Belayim); (b) 3.12.56, showing the clear south-easterly net sediment transport, which is very typical of the Gulf of Suez.

goon, described by SASS *et al.* (1972), is another example representing a combined influence of both tidal currents and the regular NNW to SSE currents of the longshore sediment transport.

As a result of cliffs and mountain promontories that reach the sea such as at Jebel Galala el Bahriya in the Egyptian Eastern Desert and Jebel Hamam Far'un on the Sinai western coast which act as barriers to sediment transport, the Gulf of Suez coasts are divided into a relatively large number of independent littoral cells. The major cells for the Suez eastern coasts (Figure 1), are from north to south (each major cell might include one or more smaller cells): (1) Suez city to Jebel Hamam Far'un (110 km); (2) J. Hamam Far'un to Jebel Abu Darba (85 km); and (3) J. Abu Darba to Ras Muhamad (135 km). Those of the western shores of the gulf, along the Egyptian mainland

Figure 3. Ras es Sabil (20 km south of e-Tor) promontory with its typical crescentic sediment tongues and spits, forming a micro lagoon. (3.12.56).

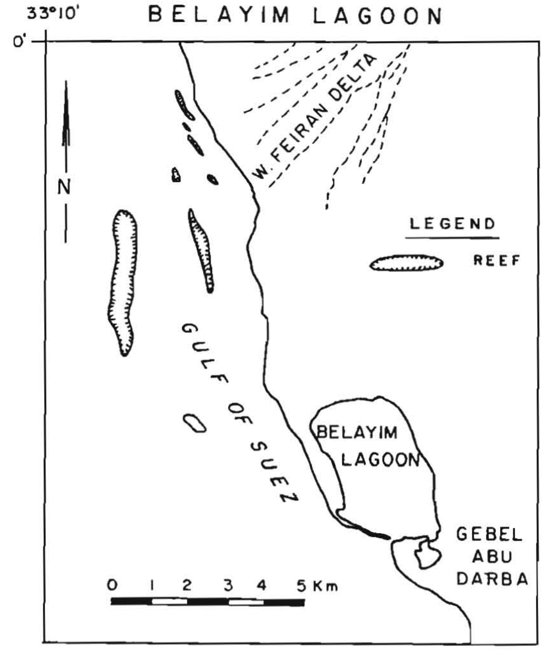
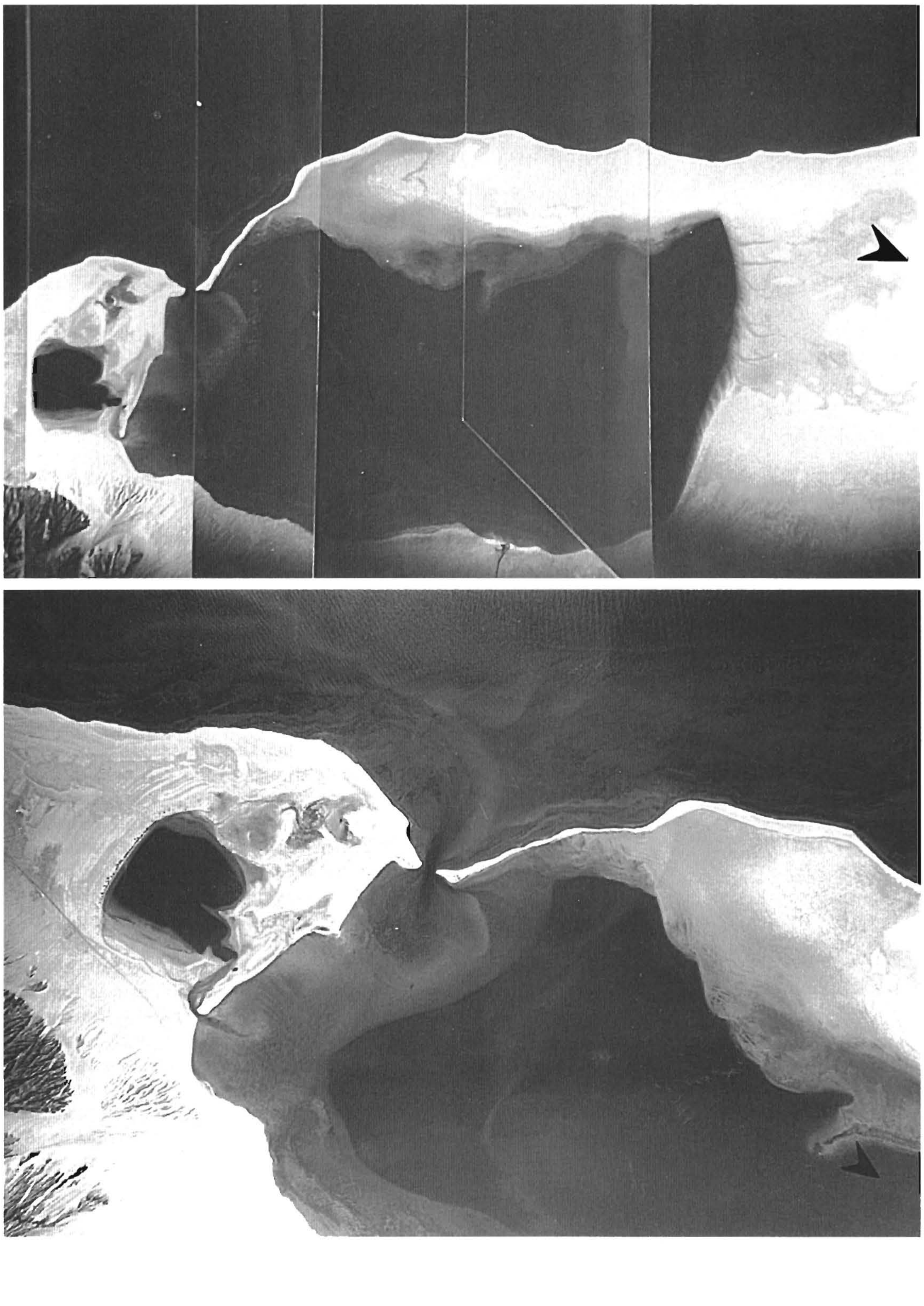


Figure 4. Map of the Belayim Lagoon and Wadi Feiran terrestrial delta.

coasts, (from north to south) are: (1) Suez city to Ras el 'Adabiya (Jebel 'Ataqa) (20 km), (2) J. 'Adabiya to Ras Za'afarana (135 km), and (3) Ras Za'afarana to Ras ed-Dib (155 km).

As a result of the torrential river floods and the shallowness of the Gulf of Suez, the wadis have also developed terrestrial deltas and huge subaqueous deltas. When these deltas are built, elongated southerly directed sand spits are formed. These spits are formed either as terrestrial or as underwater "tongues", originating and connected with the southern and southwestern sections of the deltas. In a few cases they bend, migrate and separate into secondary spits; forming crecentic shapes, they reunite with the main beach found to the south, forming a half-closed bay as in the case of Ras es—Sabil (Figure 3) or a fully closed lagoon with just a narrow strait-inlet as that of Belayim (Figures 4 and 5). The relief of these spits is between a few cm to a few tens of cm above high tide level. Large storms might therefore overwash the narrow spits, and in a few cases cause their migration. These storms may also transfer sediments and carry them into the semi- or totally-closed lagoon.

Following the drop of sea-level to about −120 m during the last glacial period (Wurm- Wisconsin) (Bloom, 1971; Morner, 1983), the Gulf of



Suez dried out totally (with probably a sabkhatic bottom) and survived under atmospheric conditions for quite a long time. This conclusion results from the present known bathymetry of the gulf, the depths of which do not exceed 90 m (neglecting some additional sedimentation since and due to post last glacial sea level rise). While this postglacial transgression reached a level higher than the sill at the Straits of Gubal at the southern straits of the Gulf, the sea water started to penetrate from the northern parts of the Red Sea (*ca.* 11,000 years BP) to cover its bottom. The transgressive rising waters, while reaching those structures and forms, resulted in the drowning of morphological features such as bars, spits, *etc.*, found along and parallel to the newly formed shoreline, under the gulf's water.

LAGOON FORMATION

The main trend of longshore sediment transport along the Gulf of Suez coasts is from north-northwest to south-southeast. The most pronounced morphological feature on the beaches is the bar-spit which developed attached and rooted to wadi deltas. These spits are mostly parallel to the shoreline; their maximal advancement, according to SNEH and FRIEDMAN (1984), is as high as 14 m/yr. In a few cases mainly in connection with river deltas and at some distance offshore, these spits engulf a bay and form a half-closed or a closed lagoon. These spits were definitely formed in both gulfs during the later part of the last-glacial transgression, possibly earlier. Sea level started to rise, breaching spits and detaching them from the shores; therefore, they are found at various depths. The sediments of these forms, if compacted, cemented and at correct depths, provided a perfect substrate for intensive reef-growth. The reefs inherited and maintained the original morphological features of the detached spits. It seems that the region was under a similar meteorological regime, with northwesterly winds during the time when the spits were formed in pre- and post- last-glacial times. Spits of the same character were also formed along the shores of the Gulf of Eilat. Here, as a result of the very steep slopes and bathymetry of the Gulf's nearshore regions, the number of spits is smaller and are limited to the flats and main river deltas only.

Many lagoons are found along the shores of the two gulfs under discussion. These are relatively young and affected by present sedimentological factors, and therefore show permanent morphological changes. The largest (*ca.* 8 sq. km) is the Belayim lagoon, located in the central part of the eastern shore of the Gulf of Suez a few km south of the gigantic terrestrial and submarine delta of Wadi Feiran (Figure 1). It is almost rectangular in shape, approximately 2×4 km with a maximum depth of 11 m, and a flat horizontal bottom (resulting from either uniform 'soft' sedimentation, or from a former sabkhatic nature with flat evaporitic layers). Steep slopes are found on the east and west fringes of the lagoon (Figure 6). The lagoon is separated from the Gulf of Suez by an almost 3 km, elongated low-relief bar. This bar is 400–500 m wide in the north and just 40–50 m wide along its southernmost 1,400 m (Figure 5). To the SE of the main lagoon, a very small and shallow lagoon 1/4 km^2 is found, the Belayim southern lagoon. It is connected with the main Belayim lagoon by very shallow straits and has very wide bars on its northern and western sides (Figure 6). Field relationships show that this small lagoon probably started to develop earlier than its larger northern twin, at *ca.* 6,500 yBP when the sea reached its present level. In later stages (or contemporaneously) when the Feiran Delta found to the north protruded offshore, the supply of sediments to the small lagoon gradually declined and the main bar of the Belayim lagoon was formed. The western bar of the main lagoon is of sedimentological origin, resulting from the rapid southward progradation of a spit that originated from the main terrestrial delta of Wadi Feiran. This spit protected the new lagoon subsequently formed at a later stage and engulfed, creating a semi-closed lagoon. Although this spit was developed in a short time, it could not entirely close the newly formed bay through sedimentation and cut the lagoon's connection with the main gulf's water. This was prevented by the strong

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Figure 5. Aerial photos of the Belayim Lagoon: (a) 5.12.56, the main lagoons, the large northern, and the small southern. In the original aerial photo ancient shoelines are clearly seen north of the lagoon; and (b) 12.5.70 the southern section of the main lagoon, and the southern smaller lagoon. Note the ancient advancing southern shorelines of the small lagoon.

Figure 6. 12.5.70 aerial photo of typical fringing reefs of the Gulf of Eilat.

tidal currents at the straits, currents which are much stronger than the damming potential of the sediment load brought along the spit. The lagoon presently has an approximately 70 m-wide strait (Figure 5) with a very shallow inlet canal (1 m only), deepening abruptly to some 6 m at the straits. The width and depth of the straits will change only if the sediment load differs completely from its present rate, otherwise it will remain alike. Traces of very clear ancient shorelines can be seen at both lagoons: to the north of the big lagoon, and to the south of the small one. Due to the fact that they are all elevated beach terraces, it is clear that they represent prograding beaches rather than a shrinking lagoon. A half closed lagoon is found near the city of e-Tor where sediments of the protruding underwater delta of Wadi e-Tor developed a spit that advanced southwards (Figure 2). To the north, at Ras Matarma, there is another very shallow lagoon which is mostly subaerial during low-tide conditions.

Similar features were developed along the western shores of the Gulf of Eilat: el Kra' near Dahab (Figures 1 and 7), and Ras Abu Galum small and shallow lagoon (0.5 km^2) (Figure 1). They have the same sedimentological characteristics and origin as the Gulf of Suez lagoons. Here too, the lagoon was formed by the engulfing-bar advancement from the north.

SHAPE OF CORAL REEFS IN THE GULFS OF SUEZ AND EILAT AND THEIR RELATIVE AGES OF RECOLONIZATION

Coral reefs are intensively developed along the Red Sea coasts and its two northern gulfs (these are the most northern latitudes of coral-reef dis-

Figure 7. 12.5.70 aerial photo of small barrier reef islets which are mostly parallel with the main shoreline (1970).

tribution). Ecologic conditions in the Gulf of Suez differ entirely from those found in the Gulf of Eilat ('Aqaba) and in many other parts of the Red Sea (GVIRTZMAN *et al.*, 1977; SNEH, 1978; MERGNER, 1984). The reefs in the Gulf of Suez are mostly of the barrier, patchy and knoll types; whereas the Gulf of Eilat reefs are mostly of the fringing type. It seems that conditions for reef growth became optimal during the rising level of the sea in post last-glacial times. Many of the Pleistocene Period reefs of the gulfs, found at present water depths down to about 100 m (NIR, 1973), died during the glacial periods' regressions and were rejuvenated and recolonized. Old spits located, in most cases, parallel to the main shores (and compact enough) became suitable substrate for reef growth. Reefs of that period have typically elongated shape, represented by the barrier reefs of Ras Kanisa (Sh'ab 'Ali) (Figure 8), and those NW of Belayim (Sharatib shoal).

During the above mentioned sea level rise of post last-glacial time, many reefs followed, developed, and "climbed" with the rising sea level in order to survive, a phenomenon which lasted until sea level stabilized at its present level some 6,500 years ago. It may be concluded that, in many cases, the development and growth of new reefs in the gulfs of Suez and Eilat has been reactivated during post last-glacial times, when the two gulfs were transgressed by the advancing sea waters. Reefs were preferably developed on ancient morphological compact features and on the newly detached and drowned alluvial and sandy consolidated spits. Their present shape was to a large

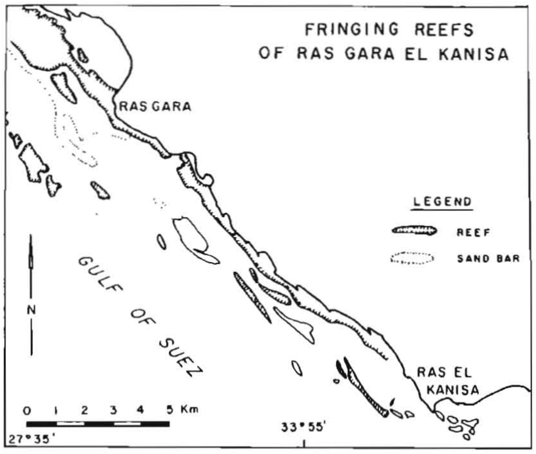

Figure 8. Combination of fringing and barrier reefs of the Ras Kanisa region, showing the Ras Gara (near Sh'ab 'Ali) underwater bar, and the parallel nature of the various barrier reefs. Suggestion for use—coloured slides: Ras Abu Galum; Belayim Bar; El Kra'a (3); Ras Matarma.

extent determined by this earlier morphology which mostly parallels the shoreline (Figure 8). There is no doubt that reefs that are found at present in shallow waters have a relatively younger history of recolonization than those found in deeper waters. It is also suggested that many of the gulfs' reefs represent several periods of growth with no activity during Pleistocene low water periods resulting from glaciation and high activity during inter-glacial periods.

ACKNOWLEDGEMENTS

The author wishes to thank Prof. M.L. Schwartz of Western Washington University for his critical reading of the manuscript, to Mr. Arie Pe'er of the Geological Survey of Israel for the maps, to Mr. E. Shamai for the valuable support, and to the Pantomap Photogrametric Co. for the aerial photos.

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