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# 5 Configuration of the Egypt-to-Canaan Coastal Margin and North Sinai Byway in the Bronze Age

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## Introduction

The northern Sinai continental margin in the southeastern Mediterranean (Fig. 5.1a) was used as a byway for exchange between Egypt's late Predynastic and Old Kingdom and Canaan in Early Bronze Age I–II. Evidence for this is provided by archaeological material recovered at sites in the Nile Delta, Israel and the coastal margin between the two (Fig. 5.1b). Important findings pertinent to this exchange were derived from investigations between 1972 and 1982 by the North Sinai Expedition of Ben-Gurion University. This program identified Neolithic and Chalcolithic encampments, and mapped nearly 250 settlement sites of Early Bronze Age between Qantara along the northern Suez Canal and Gaza to the east (Oren 1993: 1387). Also discovered as a result of this program were nearly one hundred localities of Middle Bronze Age, including numerous small campsites concentrated south of Bardawil lagoon. Mapping of numerous structures such as forts, water reservoirs and granaries indicates that, by Late Bronze Age, the 250km-long coastal strip between the eastern Nile Delta and southern Israel (the 'Way of Horus') became the principal artery for Egyptian administration of Canaan and Syria to the east (Oren 1989, 1993: 1388).

The North Sinai Expedition, more recent investigations (reviewed in Levy *et al.* 1997; Redford 1992; van den Brink 1992, 1993) and chapters in this volume record evidence of a land connection across which material interchange occurred in northern Sinai between Egypt and southern Canaan at the beginning of the Dynastic age. Recognition of this byway helps account for the presence of Egyptian pottery in southern Canaan and Canaanite material in northern Sinai and in Egyptian graves (Fig. 5.1b). Such archaeological observations tend to support the contention by Oren (1973: 204) and others that, by using northern Sinai as a springboard, Egypt forced her way into Canaan in the early proto-Dynastic period, and that southern Canaan became an Egyptian domain.

Not all exchanges were restricted to the northern Sinai land bridge, which today is a harsh desert terrain comprising a sandy coastal plain backed by discontinuous carbonate-cemented sandstone (*kurkar*) ridges, *sabkhas* (salt flats), extensive dune fields and the hypersaline Bardawil lagoon (Fig. 5.1a). Oren (1973: 204) has proposed that relations between Egypt and Canaan in the Old Kingdom period were facilitated by maritime traffic, and archaeological investigations cited in van den Brink (1992), Redford (1992) and others also favor such a maritime exchange. In this volume, Gophna proposes a possible maritime route used by traders along the coast of Canaan, and speculates on the presence of some as yet poorly defined anchorage points along the southern and central Israel coast during Early Bronze Age I. Such trade routes seaward of Sinai would have supplemented and/or replaced some overland traffic during this and subsequent periods.

This chapter focuses on physiographic aspects of the coastal margin between the eastern Nile Delta and southern Israel, and delineates general oceanographic conditions along the shore and shelf during the Early to Late Bronze Ages, i.e. in the mid- to late Holocene, from *c.* 5100 to 3200 years ago. An evaluation of physical conditions is needed to interpret the evolution of this margin at the time of proposed maritime exchange in the Bronze Age. Paleogeographic reconstructions, particularly those pertaining to the Nile Delta and Sinai margin, are presented here as an outgrowth of research conducted through the Geoarchaeology-Global Change Program sponsored by the Smithsonian Institution's National Museum of Natural History in Washington DC.

## Coastal margin evolution in the southeastern Mediterranean

### Changes from the early to mid-Holocene

Oceanographic conditions that affected Nile Delta development and the southeastern Mediterranean coastal morphology changed markedly from 8000 to 7000 years (uncorrected) before present (yrs. B.P.). These changes would have had direct ramifications on the positioning of settlements at and near the coast between Egypt and Canaan, and the selection of navigational paths off this

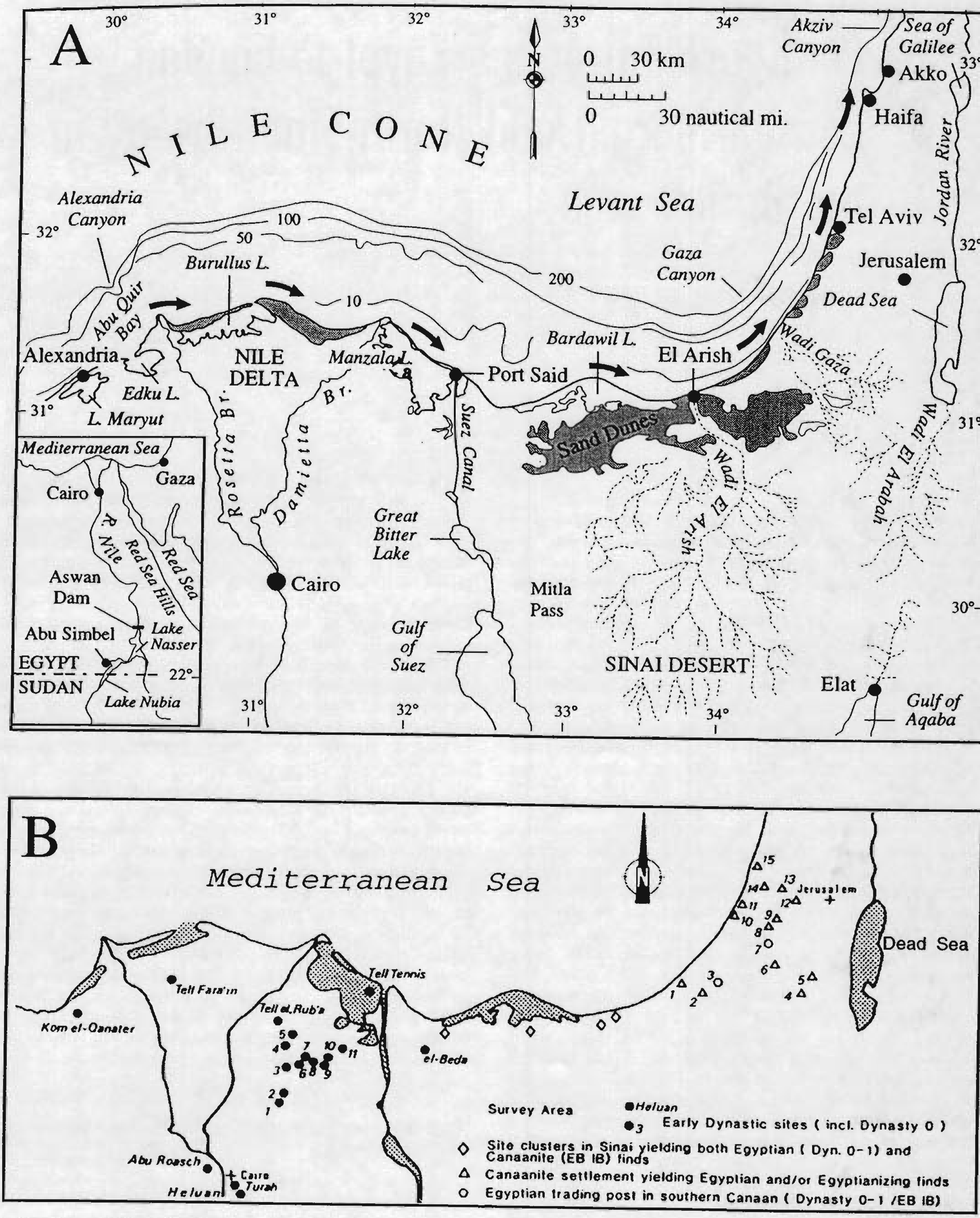


**Figure 5.1** **A** Map of the southeastern Mediterranean margin, between the Nile Delta of Egypt and northern Israel, showing localities discussed in the text and prevailing longshore current pattern. Contours are in meters; wadis and rivers in Israel are not shown. Modified from Inman and Jenkins (1984). **B** Distribution of archaeological sites yielding Egyptian and Canaanite finds in the Nile Delta, Northern Sinai and Canaan dating from about 5000 years ago (after van den Brink 1993)

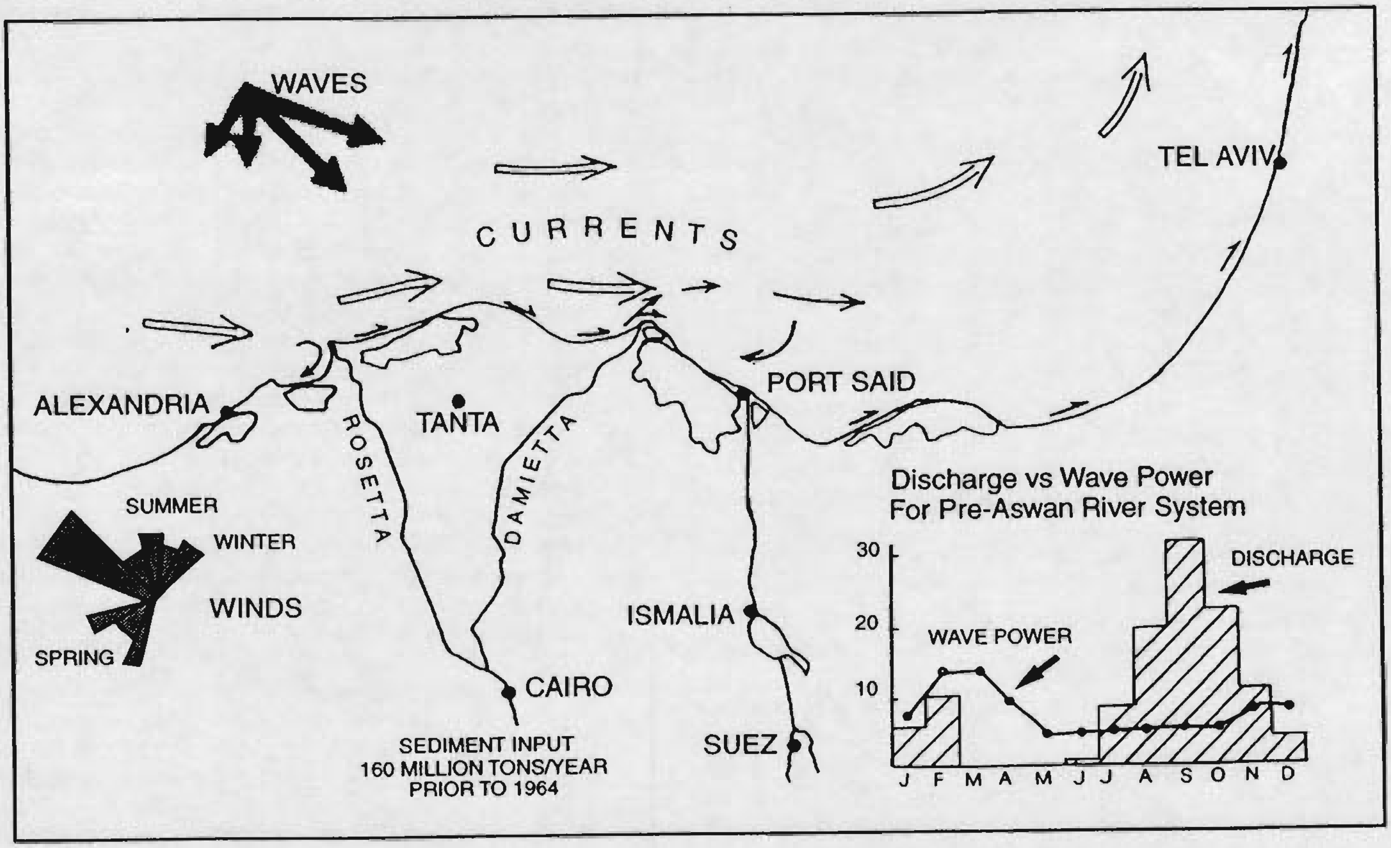


**Figure 5.2** East-directed coastal, shelf and offshore flow, driven by wind, waves and geostrophic currents on the southeast Mediterranean margin. The graph summarizes the relative influence of wave power and sediment discharge, on a monthly basis (after Sestini 1989)

margin. During this period, for example, eastern Mediterranean low tidal conditions remained, but the water column became more stratified than at present (Stanley 1978: 150) and river runoff was higher along many Mediterranean margins (Combourieu-Nebout *et al.* 1998: 312; Macklin *et al.* 1995: 15). Moreover, Neolithic finds now submerged off the Israeli coast incorporate biological and mineralogical contents distinct from ones that have prevailed subsequently in the late Holocene (Stanley and Galili 1996: 14). The sum of observations suggests that, until approximately 7500 years ago, prominent current flow along the Egypt–Sinai–Gaza–Israeli margin was directed toward the west, i.e. clockwise from east and northeast to west and southwest.

The change to a dominant easterly flow pattern (Fig. 5.2) at about 7000 years ago is linked to altered widescale climatic conditions that affected monsoonal precipitation patterns (Jolly *et al.* 1998: 641), and a different water exchange system with the Black Sea (Stanley and Blanpied 1980: 540). Palynological and sedimentological investigations and climate modeling also indicate that the period from *c.*7000 to 5000 yrs. B.P. was characterized by increased aridity (Adamson *et al.* 1980: 54), diminished stratification of Mediterranean water masses, and a consequent shift from anoxic to oxidation conditions on the deep seafloor of the Mediterranean (Anastasakis and Stanley 1986: 194). This evolution induced the change from a westerly directed flow pattern in the early Holocene to the counter-clockwise, easterly directed flow that has prevailed in this region from the Bronze Age to the present (POEM Group 1992: 302).

Moreover, during the early Holocene this region was affected by a marked change of worldwide-eustatic (Pirazzoli 1993: 146) and more localized relative sea-level stands (Zerbini *et al.* 1996: 43). As climatic and oceanographic conditions changed, the shoreline at *c.*7500 yrs. B.P. was positioned between 10 and 15m below present sea-level (Fairbanks 1989; Stanley and Warne 1993b; Summerhayes *et al.* 1978). It is proposed here that the coast at that time lay south of the present eastern Nile Delta–Gulf of Tineh coast, north of the Sinai coast, and seaward (to the north and northwest) of Gaza and southern Israel.

Probably the most significant response to these changes, especially the decrease in the rate of world sea level rise from about 10 to 1–2mm/yr (Pirazzoli 1993: 144), was initiation of the Nile Delta on Egypt's northeast coast about 7500 years ago (Stanley and Warne, 1993a: 629). The Holocene delta, with an area of approximately 20,000km², is the largest such coastal depocenter in the eastern Mediterranean. It formed at the mouth of the Nile, one of the world's longest rivers (6690km), which flows northward across 35° of latitude and drains the central-eastern African basin with an area of approximately 2,880,000km². Delta development is the result of several key parameters: (1) large volumes of River Nile flow and fluvial sediment input to the coast; (2) sufficient accommodation space to trap a considerable amount of sediment near several Nile distributary mouths on the lower alluvial plain and adjacent coast and shelf; and (3) sediment removal by wave- and storm-induced erosional processes at the coast and near the mouths of the Nile (*cf.* Sestini 1989; Stanley and Warne 1998; UNDP/UNESCO 1977, 1978).

## Conditions prevailing since Early Bronze Age

The pollen record indicates that by mid-Holocene, about 5000 years ago, the south-east Mediterranean region was subject to substantially increased aridity. The coast remained low tidal (spring tides average only 30–40cm), and water mass and current patterns on the continental shelf off Sinai became similar to those at present (Fig. 5.2). It is likely that offshore surface geostrophic eddy velocities ranged to >0.25cm/sec, as now (POEM Group 1992; Sharaf El Din 1973). More directly pertinent for sailing and emplacement of coastal settlements has been the prevailing pattern of wave energy, oriented primarily toward the east and southeast across the eastern Mediterranean (Fig. 5.3a, b). This trend produces an oblique wave approach along Nile Delta and Sinai coasts and inner shelves as shown in Figure 5.3c.

As a response to wave approach, active east-directed longshore currents are generated with velocities measuring from 20 to 50cm/sec, and occasionally to >100cm/sec (Sharaf El Din 1973; UNDP/UNESCO 1977). Moreover, storm waves with heights up to 3m approach the coast from the northern quadrant, actively eroding and displacing sediment as coarse as sand from the Nile Delta coast eastward as far as northern Israel (Carmel *et al.* 1984; Emery and Neev 1960; Fanos 1986; Nir 1984; Pomerancblum 1966; Por and Ben Tuvia 1981; Sharaf El Din and Mahar 1997; Stanley 1989; Stanley *et al.* 1998). Seasonal variability of wave approach, however, produces locally converging and diverging current patterns that modify erosive activity and sediment displacement patterns along the coast, especially on the southern Israeli margin (Goldsmith and Golik 1980: 166).

During and after the mid-Holocene, sea level rose more slowly (1–2mm/yr.; Fairbanks 1989: 639; Stanley and Warne 1993b: 437). With sea level still approximately 4–5m lower than the present stand, the shoreline remained positioned south of the present coast in the eastern Nile Delta, north of most of the Sinai coast, and northwest of Gaza and Israel. Changes of sea level, coupled with vertical motion of land relative to sea level (Neev *et al.* 1987: 79–92), continued to alter the configuration of the Sinai margin, and thus affect selection of nearshore settlements and navigation tracks.

Controlling physical parameters during the late Holocene included large-scale seasonally variable atmospheric patterns; regional circulation of Mediterranean water masses driven by wind, wave and geostrophic currents; and dominant sediment discharge and dispersal patterns (see Figures 5.2 and 5.3). Important climatic fluctuations were induced by altered weather patterns in central and North Africa, and in the shorter term by events such as the cataclysmic Upper Minoan (Upper Theran) eruption at Santorini, north of Crete. Volcanic ash from this latter event, dated from 3600 to 3500 yrs. B.P., was discovered in sediment sections of several cores recovered in the Nile Delta (Stanley and Sheng 1986: 734).

Evaluation of navigational conditions at that time requires an estimate of wind direction and its intensity, shelf and coastal currents (particularly those affected by storm and winter wave events), Nile flood water and sediment discharge to the sea (especially in late summer to early fall), and offshore dispersal of sediment derived from the various distributary mouths of the Nile and El-Arish Rivers. With regards to sailing from west to east, indirect calculations such as those based on longshore movement of water hyacinth that involve the combined effects of wind and currents during storm periods predict a current velocity of around 100cm/sec (3.6km/hr). Such velocity would suggest a travel time of about four to five days between the Nile Delta and Israel's Carmel coast—a distance of approximately 400km (Galili and Weinstein-Evron 1989: 108).

The above factors that have influenced the configuration of the northeast Egyptian–Sinai–Gaza–Israel coast and shelf are incorporated in a comprehensive Nile littoral cell model (Fig. 5.4) derived for this region by Inman and Jenkins (1984: 37). Evidence that supports easterly water flow and sediment transport patterns depicted in this littoral cell includes the regional distributions of quartz-rich sand and smectite-dominated clay assemblages derived from the River Nile and eroded Nile Delta coast. Their presence is recorded in late Holocene to modern coast and shelf deposits as far from the Nile as northern Israel (Emery and Neev 1960: 10; Nir 1984: 115; Pomerancblum 1966: 173; Stanley 1989: 825; Stanley *et al.* 1998: 214).

## Nile influence on the coastal margin

The configuration of the north Sinai byway between Egypt and Canaan was in large part influenced by fluctuations of River Nile flow through time (Said 1993: 95–169), consequent formation of the Holocene fluvio-marine Nile Delta, and dominant east-directed dispersal of Nile sediment. Climatic change affecting Africa during and following the Bronze Age resulted in annual flood flow volumes that diminished to only one-third, or less, of those prevailing in the early Holocene (Said 1993: 132). This reduction would have modified the seaward progradation of the eastern Nile Delta coast that had ranged to approximately 10m/yr (Coutellier and Stanley 1987: 272), avulsion of fluvial branches in the delta proper, and promontories at distributary mouths (Frihy 1992; Frihy *et al.* 1988).

Major disruption of Nile flow, and consequently of the Nile littoral cell, occurred after the placement of a series of barrages on the Nile between Upper and Lower Egypt (Waterbury 1979: 34), construction of the dense waterway irrigation network in the delta (Stanley 1996: 192), and the closure in 1964 of the High Dam at Aswan (Said 1993: 233). The Nile cell model depicted in Figure 5.4 summarizes conditions along the coast and on the shelf that were in effect when Nile water and sediment were still actively discharged directly to the sea. Prior to the closure of the High Dam at Aswan sediment discharge to the coast was seasonal: more than 80 percent of the Nile's

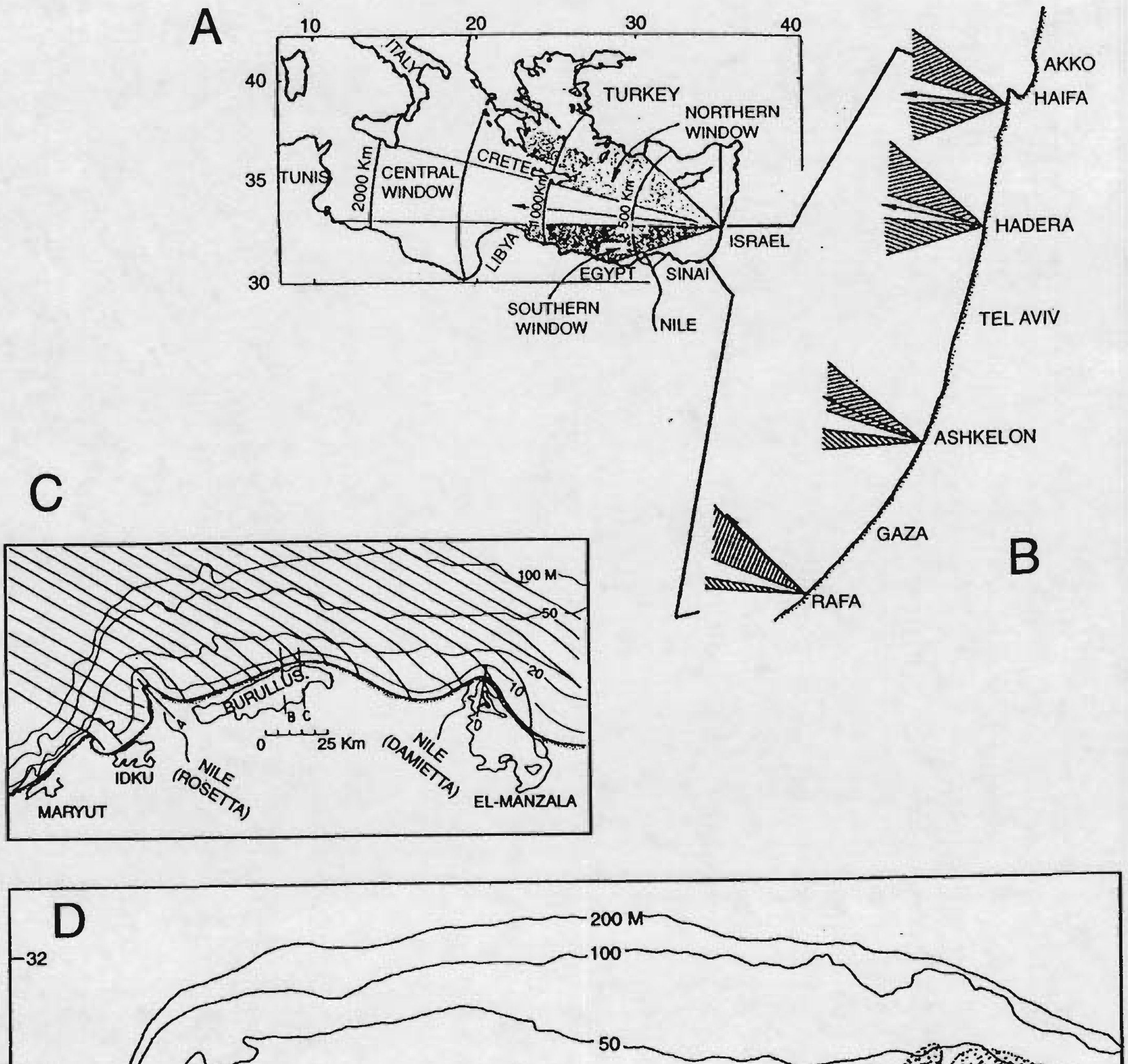


**Figure 5.3** **A** Three windows for approach of deep water waves in the eastern Mediterranean. **B** Wave approach on the Gaza and Israeli coasts; the central window is shown in white and northern and southern windows by hachure (after Carmel *et al.* 1984). **C** Wave refraction along the Nile Delta coast depicted for a meter-high, 3-second wave moving from N60°W (after Inman and Jenkins 1984). **D** Sandy sediment transport paths off the Nile Delta coast toward the Gulf of Tineh (after Inman *et al.* 1993)

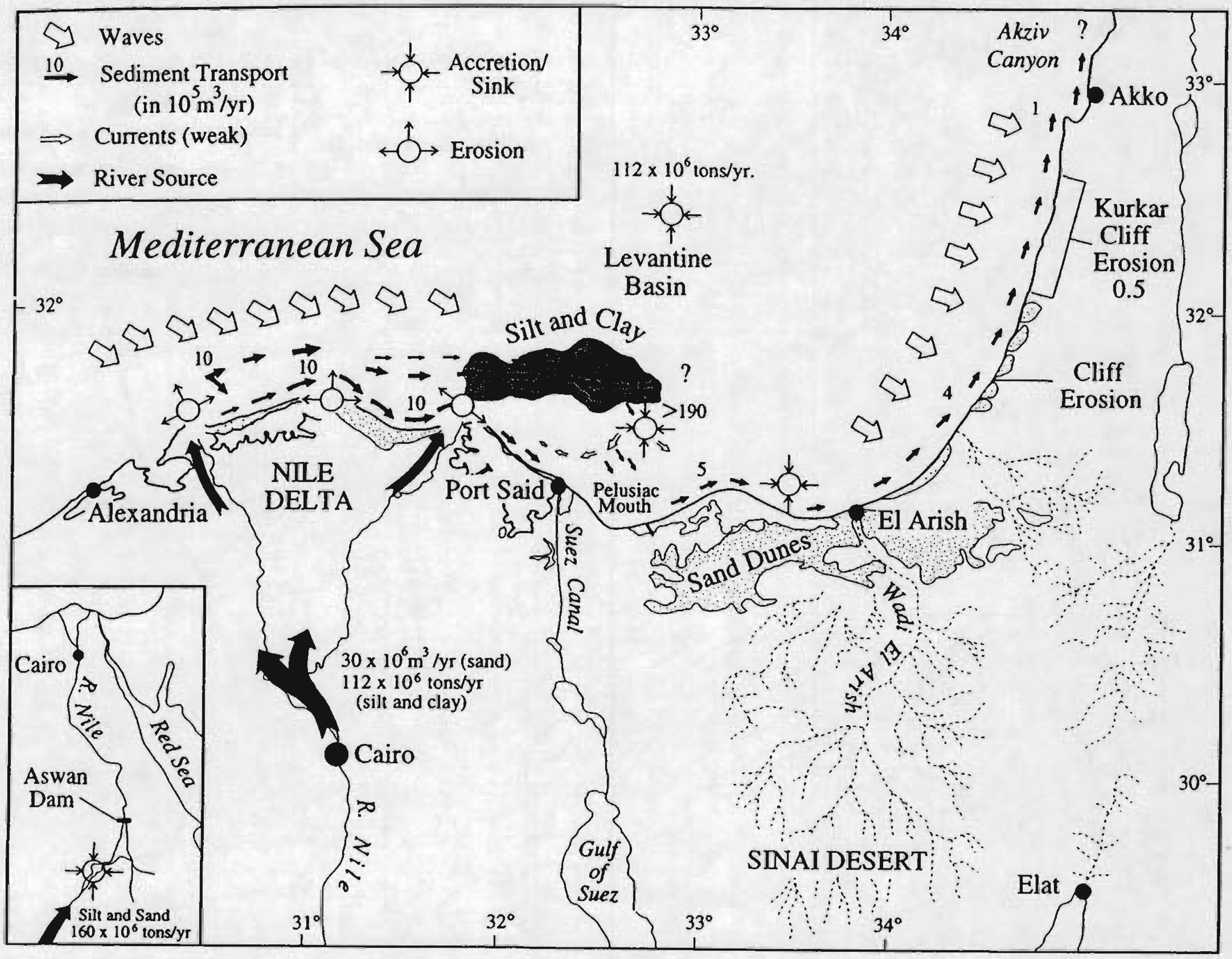


**Figure 5.4** Nile littoral cell highlighting major physical processes active between the Nile Delta and northern Israel, prior to the closure of the High Dam at Aswan (modified from Inman and Jenkins 1984)

total was released from August to October, and only 20 percent was distributed during the other nine months (summaries in Sestini 1989 and Said 1993). For comparative purposes, it is recalled that average annual discharge had decreased to little more than 100 billion m³ by the nineteenth century, and then was further reduced to an average of 84 billion m³ during the first half of the twentieth century.

During the mid- to late Holocene, wave-related coastal processes have maintained a 2.5–7km-wide zone of active sediment transport extending along the coast from the Nile Delta to the Levant. The average grain size of suspended load in the River Nile during past annual late summer to early fall flood periods (Fig. 5.2) was 25 percent sand, 42.5 percent silt and 32.5 percent clay. Sand and coarse silt in the nearshore zone are stirred and displaced toward the east and northeast (Frihy *et al.* 1991; Inman *et al.* 1992; Manohar 1976, 1981; Stanley *et al.* 1982), in some instances to depths reaching 40–50m, as depicted in Figure 5.3d (Coleman *et al.* 1980: 323). The distribution of diverse, and in some cases coarse-grade, sediment types on the shelf provides an additional record of strong east-directed currents: depositional facies are aligned along eddy current patterns (Murray *et al.* 1981: 53), and are also parallel to the coast and contour lines (Bernasconi and Stanley 1997: 1210; Stanley and Bernasconi 1998: 83; Summerhayes *et al.* 1978: 49–54). Additional data on physical conditions that affect the coastal and inner to mid-shelf sectors in the study area are available in several reference sources (Inman and Jenkins 1984; Sestini 1989; Stanley and Warne 1998).

The different factors cited above would have affected the overall configuration of the continental margin during the Bronze Age, and their influence is evaluated in reviews of three coastal margins discussed in the following sections: northeast Nile Delta–Gulf of Tineh, north-central Sinai and Bardawil lagoon, and El-Arish to southern Israel. Interpretations that pertain to these sectors incorporate information from published investigations cited herein, topographic maps (1501 series at a scale of 1:50,000 and 1:250,000, published by the US Defense Mapping Agency Hydrographic/Topographic Center, Washington, DC),

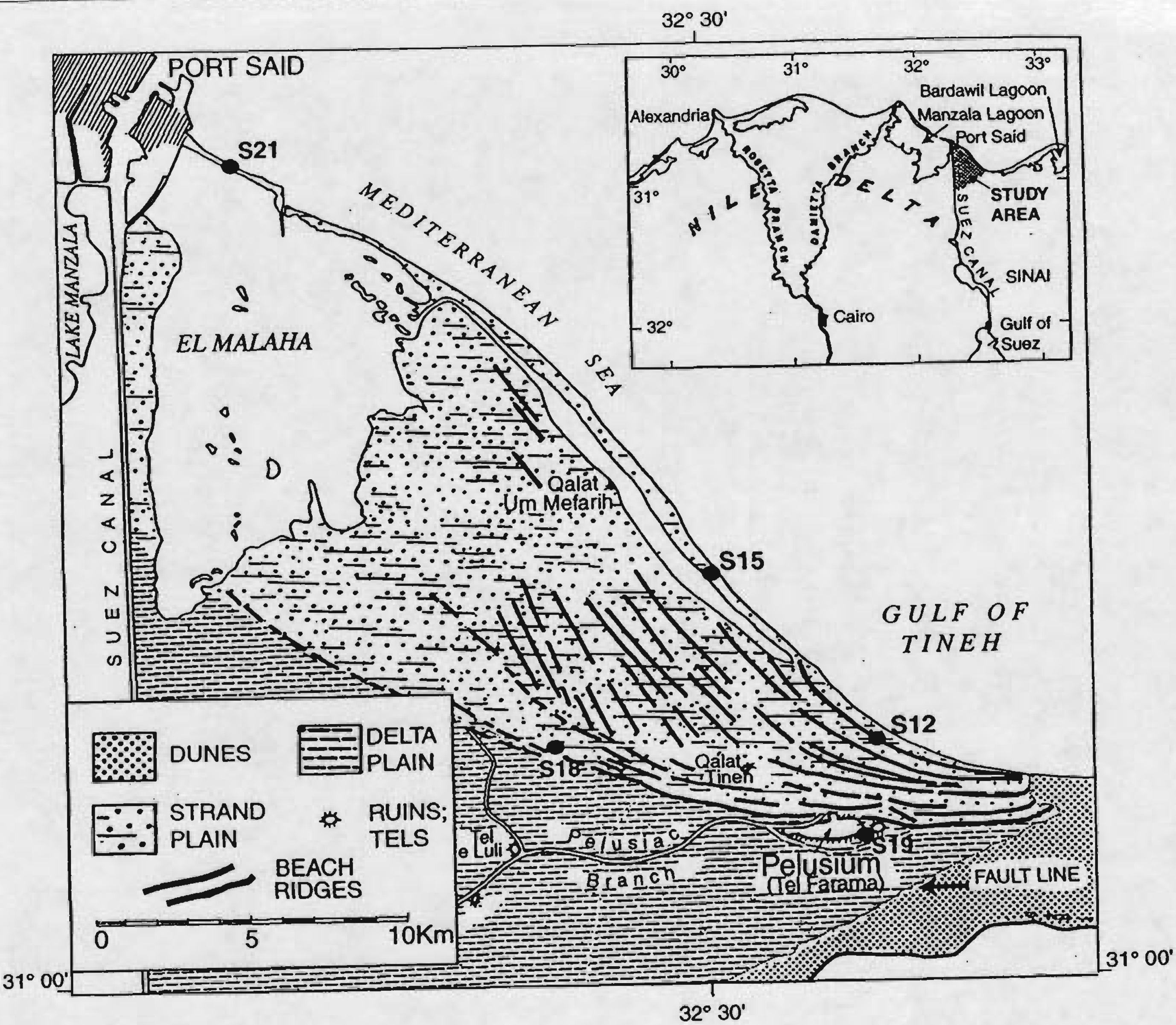


**Figure 5.5** Western Gulf of Tineh sector showing features discussed in the text, including positions of five Smithsonian cores, Pelusiac fault trace south of ancient Pelusium (Tel Farama), and former Pelusiac branch channel (after Sneh and Weissbrod 1973, with modifications from Goodfriend and Stanley 1998)

satellite imagery, aerial photographs and analyses of surficial and core sediment.

## Port Said–Gulf of Tineh sector

The western Gulf of Tineh margin, approximately 40km in length, extends from Port Said in the northeastern Nile Delta to westernmost Bardawil lagoon (Figs. 5.1a, 5.5). Physiographic reconstructions discussed here are derived from historic documents (Fontaine 1951–1952; Goodfriend and Stanley 1998; Shafei 1946; Toussoun 1922), land surface mapping (Sneh and Weissbrod 1973; Sneh *et al.* 1975; Stanley *et al.* 1982), and stratigraphic analyses of sediment drill cores (Coutellier and Stanley 1987; Sneh *et al.* 1986; Stanley *et al.* 1996). The dominant characteristics of this margin during the mid- to late Holocene are: (1) important fault-related subsidence (to 5 mm/yr) of eastern Manzala lagoon and the northeastern corner of the delta (Stanley 1988, 1990; Stanley and Goodfriend 1997: 335); (2) rapid accretion of large volumes of sediment from Nile floods and delta coastal erosion transported eastward to this region; and (3) seaward deltaic progradation at an average rate that locally exceeded 10m/year (Coutellier and Stanley 1987: 272).

Lowering of land surface in this sector has occurred at the highest rate measured in the Nile Delta region (Stanley and Warne 1993a: 630; Warne and Stanley 1993: 715). Subsidence of this magnitude is associated with a major structural system involving fault motion and isostatic loading that was active in this sector during the late Quaternary. The basinal depression that underlies modern Manzala lagoon, and accelerated lowering rates affecting the margin east of the Suez Canal (Fig. 5.6), are attributed

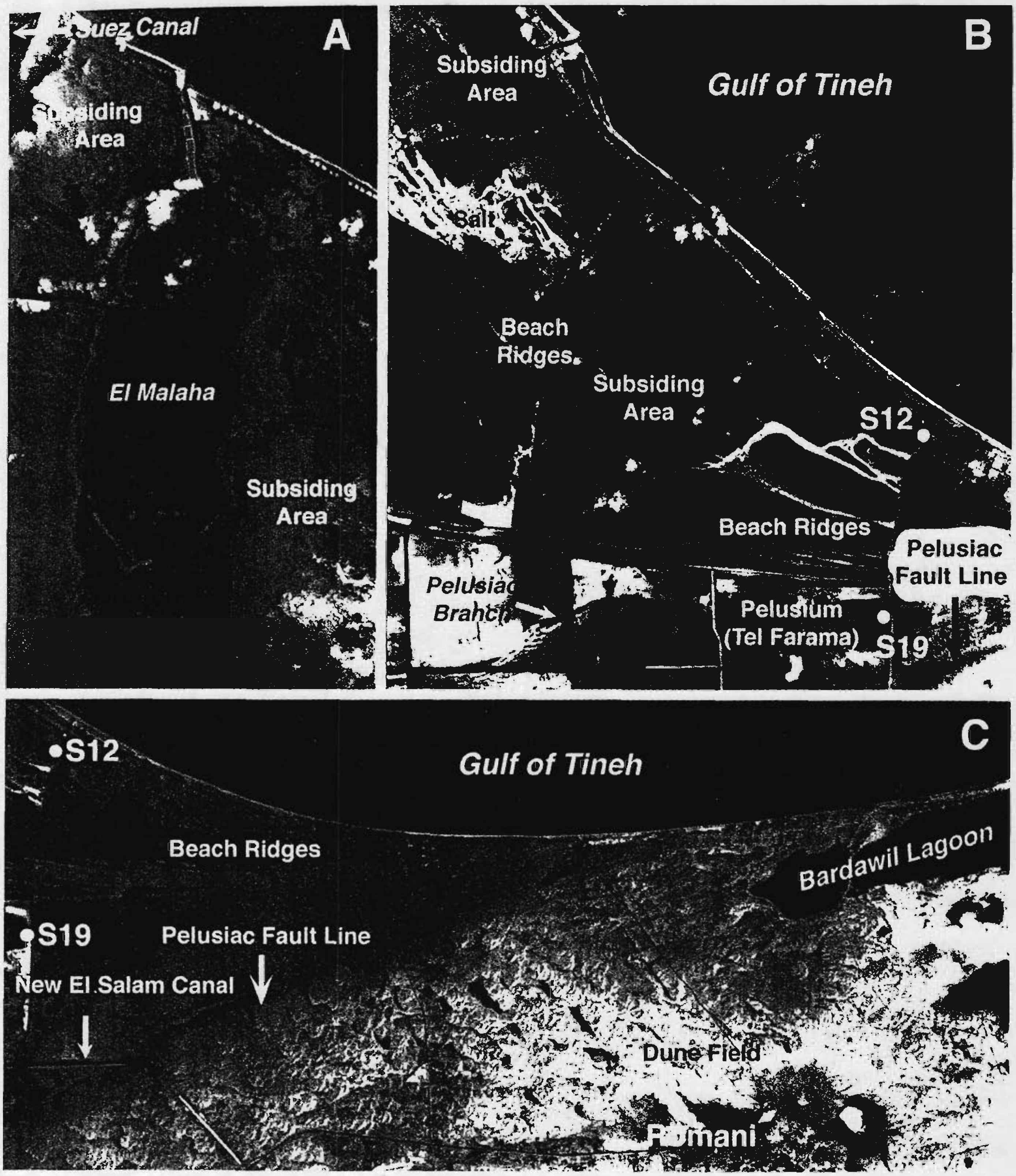


**Figure 5.6** Views of the western Gulf of Tineh sector in northwest Sinai, selected from Spot satellite images, August 1995. Core S12 and S19 locations are shown in Figure 5.5. **A** Subsiding area east of Suez Canal that includes expanding El Malaha saline lake. **B** Subsiding area east of A characterized by expanding salt flats, coalescing beach ridges (north of ancient Pelusium), relict Pelusiac branch and Pelusiac fault trace. **C** Margin east of B, located south of the Gulf of Tineh and west of Bardawil lagoon; sector south of the Pelusiac fault is encroached by dune fields

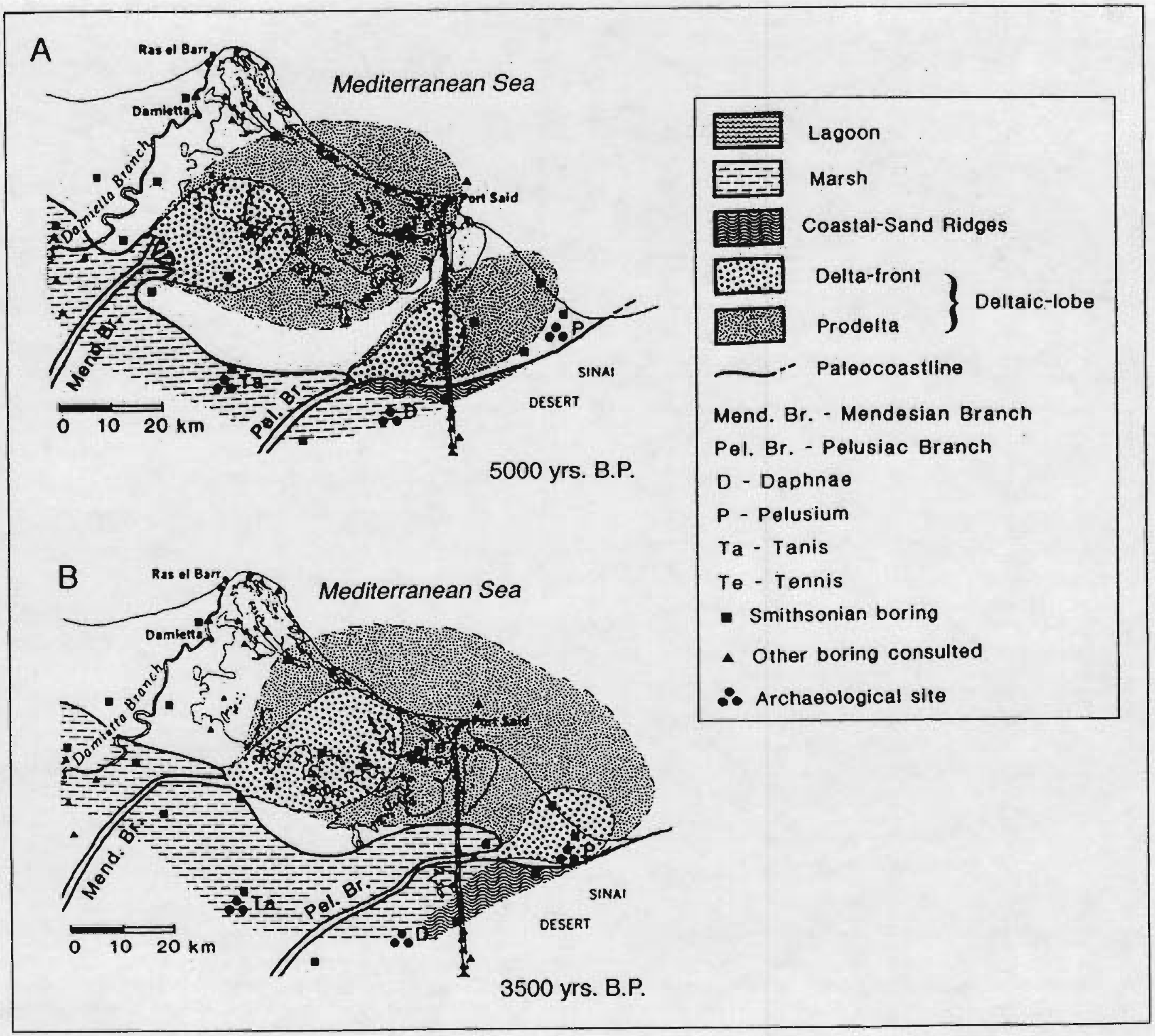


**Figure 5.7** Palaeogeographic interpretations of the western Gulf of Tineh sector at around 5000 and 3500 years ago. Note that, at that time, a large part of the subsiding region east of the Damietta branch was covered by the sea (modified from Coutellier and Stanley 1987)

to periodic reactivation of a major fault system that extends across the area. The trend of this structural feature, the Pelusiac fault, is oriented from the northeast (seaward of north-central Sinai) landward to the southwest (Neev *et al.* 1976: 41). The fault trace is clearly denoted west of Bardawil lagoon and along the eastern margin of the Nile Delta (Figs. 5.5, 5.6b and c). Rapid subsidence of land has produced a large depression serving as accommodation space during the Holocene, i.e. a lowered basin surface on which a particularly thick sequence (to about 50m) of Nile-derived sediment accumulated during the past seven millennia (Stanley and Goodfriend 1997: 335). The consequent Holocene sediment accumulation rate of around 5 to 7cm/yr is much higher than recorded elsewhere in the Nile Delta and on adjacent margins.

As expected, the physiography of the western Gulf of Tineh coastal margin has changed considerably during the Holocene as a result of these events involving coeval structural displacement and rapid deposition. The principal branches of the River Nile that at that time flowed and released large volumes of sediment to this region were the Mendesian and Pelusiac, east of the present Damietta distributary (Fig. 5.7). The present shoreline position east of the Suez Canal, in effect, is of recent origin: the wide stretch of coalescing beach (largely shell) ridges (Figs 5.5, 5.6b) formed near Pelusium (Tel Farama) and prograded seaward since the ninth century CE (Goodfriend and Stan-

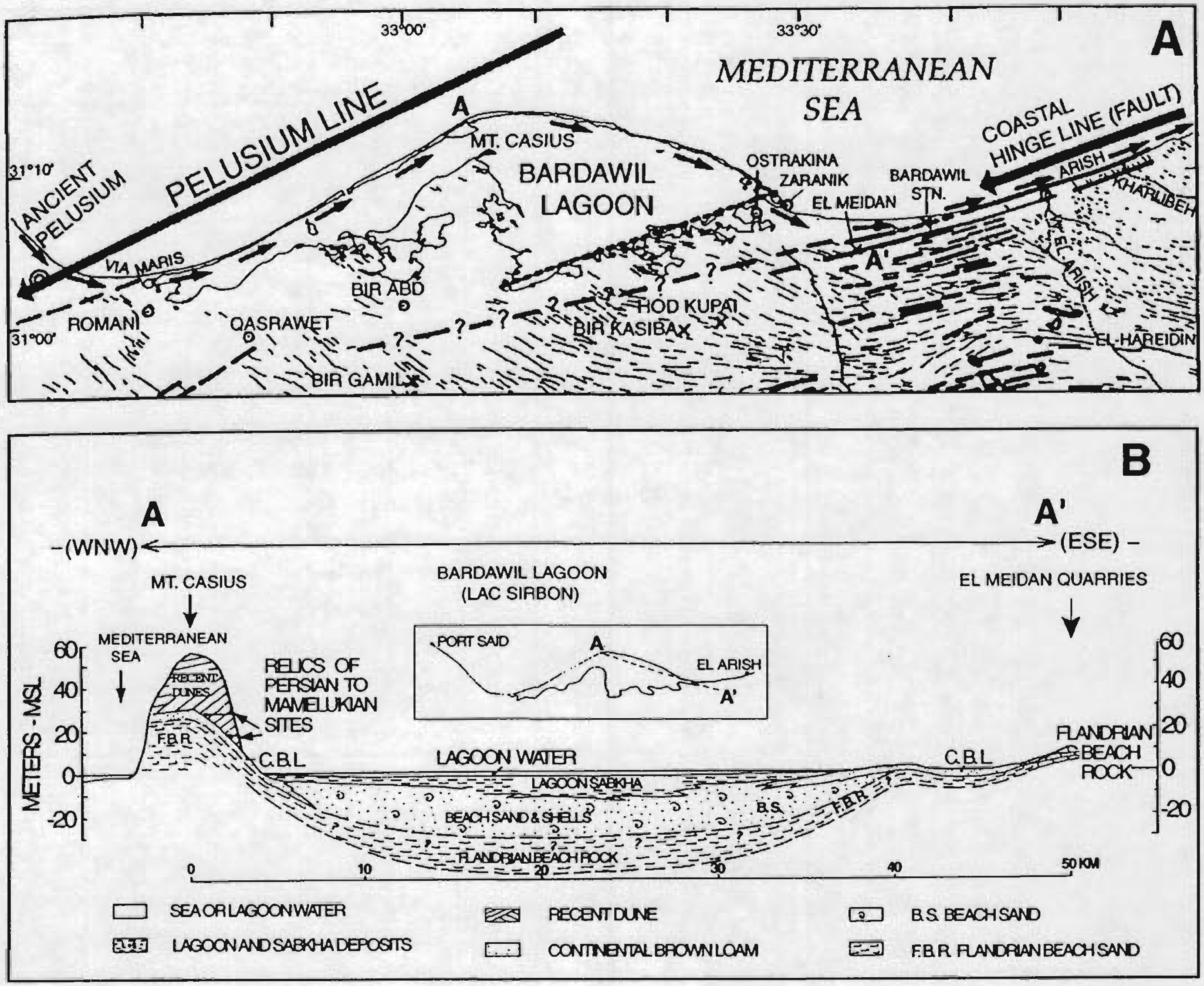


**Figure 5.8** **A** North-central Sinai margin dominated by the Bardawil lagoon (modified from Neev *et al.* 1987). The straight western coastal barrier separating the lagoon from the open sea is parallel to the Pelusiac fault system (Pelusium line). Heavy dashed lines are tectonic lineaments; narrow lines denote linear sand dunes. **B** Cross-section A–A' between Mt. Casius and El Meidan quarries (see in **A** above) is about 50km long. Mt. Casius is the highest part of Bardawil's western coastal barrier

ley 1998). The accretionary coastal ridges between the Suez Canal and western Bardawil lagoon are backed by subsiding deltaic terrains (Fig. 5.6b), the formation of an expanding shallow saline lake (Fig. 5.6a) and extensive salt flats (Fig. 5.6b).

Stratigraphic and lithofacies analyses of drill borings place the Bronze Age shoreline near the town of El-Qantara on the Suez Canal, or nearly 30km south of Port Said and the coast. The presently emerged north-east Nile Delta near Port Said was marine in the Bronze Age, with the sea in this area reaching a depth of >20m (Bernasconi *et al.* 1991: 33). Drill cores indicate that the subsiding area north of the Pelusiac fault received sediment from the two Nile branches in the form of marine delta-front and pro-delta sequences (Fig. 5.7). As a result of syndepositional lowering, the subsurface sequence of this part of the Nile Delta provides the best stratigraphic record of thick, well-developed marine delta lobes that formed seaward of delta distributary mouths (Coutellier and Stanley 1987: 270–1; Pugliese and Stanley 1991: 292; Stanley *et al.* 1996: 61–4).

## Bardawil lagoon sector

The north-central Sinai is highly arid, and in some years receives less than 100mm of rainfall. Bardawil lagoon, known as Sirbonian lake in historic documents, is the dominant geographic feature on the north Sinai coast (Fig. 5.8a). The wetland surface is large, covering 67,000 hectares (Verheugt 1996: 513), arcuate and parallels the coast. Its western shore lies north of the town of Romani, and the eastern margin at Zaranik is approximately 85km to the east; the maximum width, from the coast landward, is 22km.

The predominant factors that controlled the configuration of north-central Sinai and the position of coastline during the Bronze Age are the Pelusiac fault system (Fig. 5.8a), eastward dispersal of sediment by longshore currents, and a lower sea-level position. Bardawil's origin differs markedly from that of the brackish lagoon-wetland systems in the northern Nile Delta. Delta lagoons are (1) brackish, as a result of the closure of shallow coastal areas influenced by fluvial systems, and (2) separated from the sea by sandy coastal barriers formed by longshore processes (Kerambrun 1986; Loizeau and Stanley 1993, 1994). Bardawil, unlike these wetlands, is not backed by major fluvial sources that provide freshwater to the coast. Moreover, the shallow (<1–3m, for the most part <1.5m depth) hypersaline water body (Levy 1974, 1977a, 1977b; Por and Ben Tuvia 1981) is separated from the open sea primarily by its western coastal barrier, a structurally raised linear strandline bar. Mediterranean water enters the lagoon at several artificially maintained inlets: openings west (bughaz 1) and east (bughaz 2) of Mt. Casius (Fig. 5.9c, d), and at Zaranik inlet along Bardawil's eastern margin (Fig. 5.9d). Some marine water and sediment are also driven as overwash across the barriers and into the lagoon by winter storms. High evaporation rates result in seasonally variable, but high, salinities to 60–80 percent or more (Kerambrun 1986: 30; Krumgalz *et al.* 1980: 406), well in excess of Mediterranean water (<40 percent) seaward of the inlets.

From 5000 to 3000 years ago, the evolution of the north-central Sinai margin differed markedly from the margin west of Bardawil lagoon: the shoreline west of Pelusium (Tel Farama) was positioned well to the south of the present coast, while the shore east of Pelusium lay seaward of the present coast. Coastal configuration is primarily a response to the Pelusiac fault system that has had a major control on the northern-central Sinai margin during the Holocene (Neev and Friedman 1978: 428), and is largely responsible for the barrier that now separates the wetland from the open sea (Gvirtzman *et al.* 1987; Neev *et al.* 1976; Neev *et al.* 1987). The western barrier is narrow (<1km), elevated (2->4m), and remarkably straight. Its trend is southwest to northeast, and rises toward the northeast, reaching its highest elevation at Mt. Casius (Kathib El-Qals) off the central lagoon (Figs. 5.8a, b, 5.9a–c).

At Mt. Casius, the basal depositional sequence of the western ridge rises to nearly 30m. It comprises late Quaternary strandplain deposits (Fig. 5.10a), with interstratified shallow marine strata (locally shell rich laminae, Fig. 5.10b), calcareous concretions, and poorly cemented paleosol (also described as brown continental or hamra-like) sediments (Fig. 5.10a). Radiocarbon dates of marine shells forming semi-consolidated strata in this feature (Fig. 5.10b), raised to an elevation of at least 8m, record an age as old as late Pleistocene (25,550 +/- 110 yrs. B.P.) and as young as Holocene (6420 +/- 30 yrs. B.P.). This indicates that the coastal barrier in the vicinity of Mt. Casius has been rising at a long-term average rate of 2–3mm/year (investigation in progress). The basal sequence, in turn, is covered by dunes of recent age (Figs 5.8b, 5.10c) that reach an elevation of about 60m (Neev *et al.* 1987: 86). Pottery sherds and other debris exposed between the basal unit and recent dune cover range in age from Persian to Mamelukian. Some authors indicate that the Mt. Casius region was affected by oscillatory tectonic motion during the past 4000 years. The presence of elevated terraces and early Holocene beach rock exposed on the southern margin of the lagoon (Fig. 5.8b) provides additional evidence of synchronous late Holocene deposition and tectonics (Neev *et al.* 1987: 88–90).

The eastern coastal barrier that confines the lagoon east of Mt. Casius differs from the tectonically controlled western barrier. It is more arcuate, of lower elevation (average 1–3m), and somewhat wider (Fig. 5.9c, d). This barrier is subject to storm overwash, and its origin more closely resembles that of coastal barriers of northern Nile Delta lagoons. Sediment, derived from the west at the Nile Delta and Gulf of Tineh margin (Frihy and Komar 1996; Frihy and Lofty 1997; Stanley *et al.* 1997), is transported by longshore currents to the northeast, along the raised, structurally controlled western ridge (Otterman *et al.* 1974: B24–B25). Offshore, sand accumulates on the shelf north of the western barrier (Fig. 5.11), and on land, wind-blown sand accumulates in the Mt. Casius sector, accounting for the recent formation of thick dunes in this region (Figs. 5.9c, 5.10c).

Nearshore coastal currents displaced a considerable amount of sand beyond the western barrier, thus forming Bardawil's eastern coastal barrier. Finer-grained sediment is deposited offshore, north of the eastern barrier (Fig. 5.11; El-Sammak 1995: 907). Migration of the Zaranik spit (Fig. 5.9d) indicates that Nile sand is transported even farther to the east, beyond the lagoon; shallow coring suggests that this outlet has migrated about 3km toward the north since late Roman times (Neev *et al.* 1987: 88). Moreover, strong east-directed currents within Bardawil periodically pile up water at the lagoon's eastern end, and this phenomenon (a 'seiche') produces an overflow that drives water and sediment from the wetland to the sea, near the Zaranik opening.

The configuration of the north-central Sinai margin during the Bronze Age was considerably different than at present. The shoreline 5000 to 4000 years ago was positioned north and east of the western coastal ridge, since sea level at that time was about 3–5m lower. It is proposed here that areas occupied by the present lagoon, *sabkhas* and periodically flooded lowland in the region south of the western and eastern barriers were subaerially exposed.

## El-Arish to southern Israel sector

The coastal margin between the eastern Bardawil lagoon margin and Ashqelon on the southern Israeli coast is about 125km long. Average annual rainfall is around 100mm in the Bardawil region, and increases northward to about 350 mm in southern Israel and 600 mm in northern Israel (Macklin *et al.* 1995: 6). The physiographic configuration of this sector is primarily the result of strong wave energy driven upon it (40 percent of total waves exceed heights of 1m), and powerful longshore currents that have eroded the coast formed of unconsolidated and/or poorly cemented Quaternary formations. Largely as a consequence of erosive processes concentrated in the southeast Mediterranean, the coastline has been shaped to a gentle arcuate and remarkably smooth form, with only minor topographic crenulations (Fig. 5.12).

In this sector, trends of both coast and offshore margin

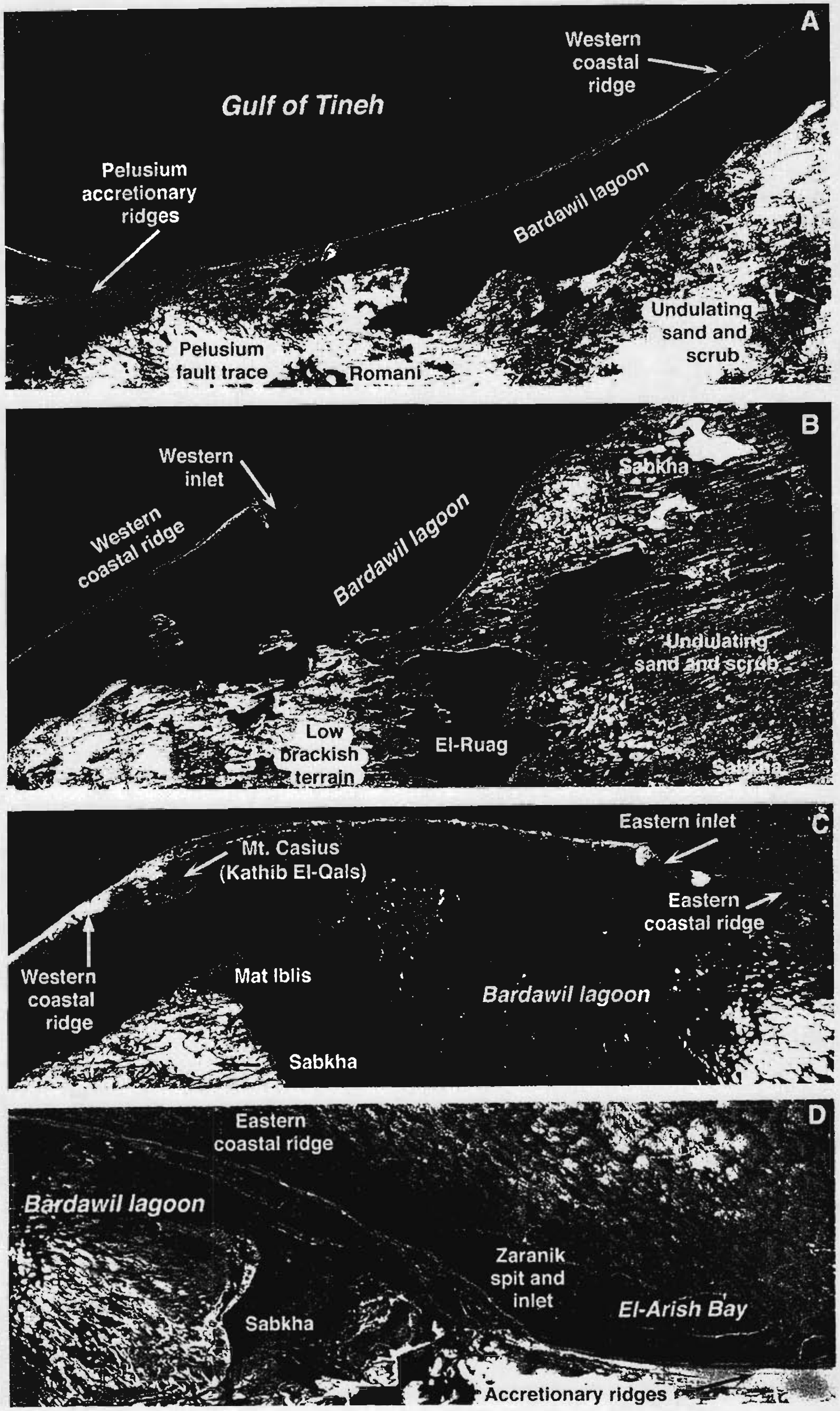


**Figure 5.9** Views of the north-central Sinai sector, selected from Spot satellite images, August 1995. **A** and **B** Western Bardawil lagoon separated from the open sea by the western coastal ridge. **C** Central Bardawil lagoon, including Mt. Casius, eastern inlet and eastern coastal ridge. **D** Eastern Bardawil lagoon separated from El-Arish bay by the eastern coastal ridge. Note Zaranik spit and inlet, and accretionary ridges to the east

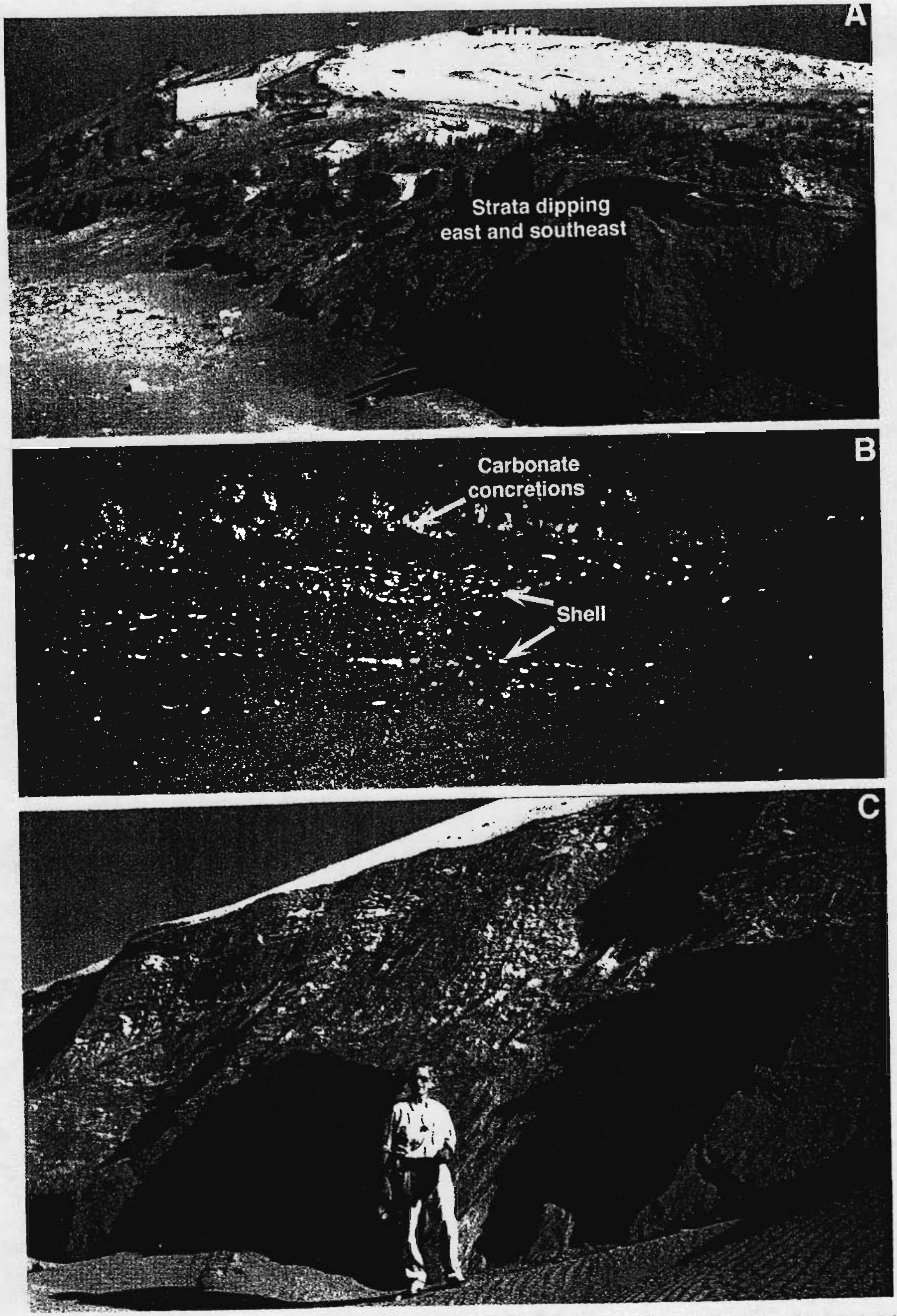


**Figure 5.10** Photographs taken in the Mt. Casius area (November 1997). **A** View toward the northeast showing basal units, including paleosol, dipping toward the east and southeast; shoreline and open sea are to the left and Bardawil lagoon to the right. **B** Thin layers of carbonate concretions and shell (some partially dissolved), in the basal strandplain unit (late Pleistocene to early Holocene) exposed at cliff facing the open sea. **C** Cliff, facing the open sea, showing exposed basal stratigraphic unit that includes partially stratified layers (see B); basal unit is covered by dunes of more recent Holocene origin

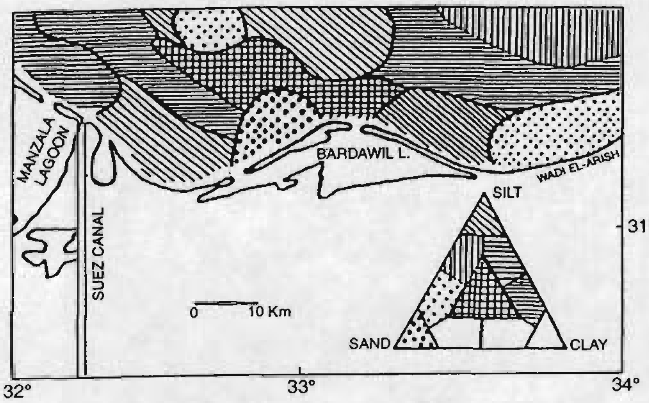


**Figure 5.11** Grain size distribution of surficial sediment off the north Sinai margin (modified from El-Sammak 1995)

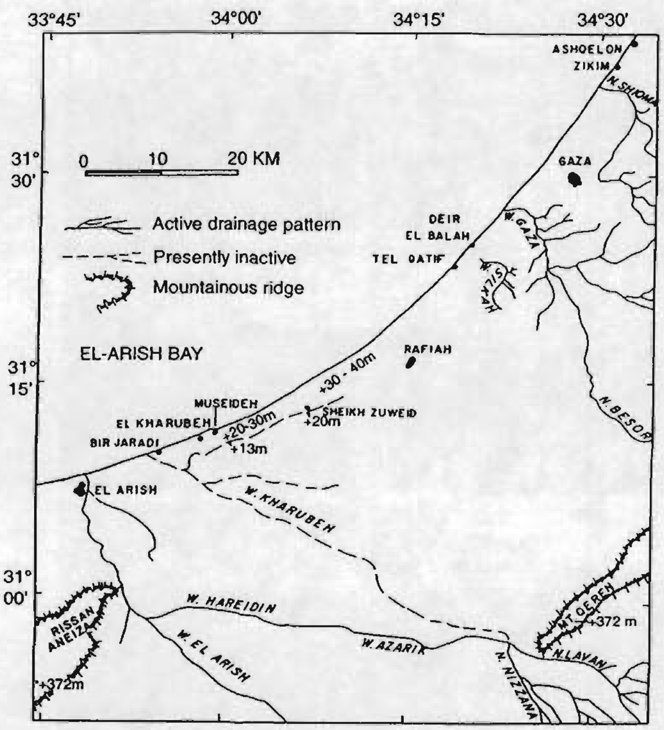


**Figure 5.12** El-Arish–Gaza–southern Israel sector characterized by a gently arcuate and remarkably smooth coastline, largely a response to erosion by coastal processes. Note the presence of fluvial systems, including some wadis, such as W. Silkah, separated from the coast (after Neev *et al.* 1987)

change from east–west to northeast–southwest, with the continental shelf becoming narrower and its slope steeper toward the northeast. This is recorded by offshore contours that merge progressively toward the northeast, off Gaza and Israel (Fig. 5.1a). The shoreline around 5000 years ago, when sea level was lower, lay offshore within 1km from the present Gaza and Israeli coasts (*cf.* Galili *et al.* 1988: 38). Presently the coast is backed by low elevation sandy strandplains and dunes, and some high scarps and discontinuous *kurkar* ridges interbedded with *hamra* loam layers. Offshore, four coast-parallel *kurkar* ridges have been mapped. There is considerable literature pertaining to this sector that describes the stratigraphy and physiography (Gvirtzman *et al.* 1983–1984; Neev *et al.* 1987; Nir 1976, 1984, 1988) and coastal sediment transport processes (Goldsmith and Golik 1980; Otterman *et al.* 1974; Shoshany *et al.* 1996 and many others).

The margin east of Bardawil lagoon, unlike the western and north-central Sinai sectors, presently receives some fresh water (Fig. 5.12), albeit intermittently, from Wadi El-Arish (30km east of Bardawil lagoon; Fig. 5.13b), Wadi Kharubeh (8km east of El-Arish; Fig. 5.13b), Wadi Gaza (7km southwest of Gaza City; Jarad *et al.* 1994: 17–22) and Wadi Shiqma (6km southwest of Ashqelon). The Israeli coast north of Ashqelon is characterized by a higher density of fluvial channels, including several small rivers and at least 20 wadis (Emery and Neev 1960; Raban 1987; Stanley *et al.* 1997). Vegetation associated with wetter conditions is recorded during the later Epipaleolithic, but expansion of sand dune fields (Fig. 5.14b) covering much of the northern Sinai, Gaza and western Negev occurred during the generally more arid half of the past 5000 years (Goldberg 1986: 242). As aridity increased from early to mid-Holocene, there was a decreased discharge of water and sediment to the coast from these relatively short channels.

In the past, the largest fluvial system in this sector, Wadi El-Arish, regularly drained much of the northern and central Sinai (Fig. 5.1a) and flowed to the coast, discharging an important flux of water and sediment. At present, however, it is frequently dry for most of the year, and only floods sporadically. Examination of El-Arish sediment shows that it differs mineralogically from that of the Nile (El-Shazly *et al.* 1986; Shukri and Philip 1961; Stanley 1989; Stanley *et al.* 1998), and thus can serve as a gauge to measure provenience and offshore regional dispersal. However, there has been insufficient study to determine its former discharge frequency and water volume in the Early Bronze Age.

The importance of coastal currents in eroding and reworking sediment eastward off northeast Sinai is recorded by a Wadi El-Arish flood that transported several hundred million cubic meters of water and sediment to the shore in February 1975. This single flood event resulted in the formation of a new delta that extended offshore more than 400m (Nir 1982: 1840). These fluviodeltaic deposits, however, were rapidly eroded by strong east-directed longshore currents, and in short order the shoreline was again straightened. Evidence of prevailing east and northeast directed transport is also shown by preferential accumulation of sand west of groins (Fig. 5.13b) and other coastal structures between El-Arish and Israel (Nir 1982, 1988). In addition to smoothing and straightening the coast (Fig. 5.13c), the strong nearshore transport regime truncates minor deltas that form during floods on the Gaza and Israeli margins (Fig. 5.14a; Stanley *et al.* 1997: 510). Coastal processes have long played a role in shaping the coast, including the formation of the almost 20km-long belt of accretionary ridges east of Bardawil lagoon (Fig. 5.13a), and seasonal displacement and sediment infill of wadi mouths at the coast.

Mapping of the Israeli margin has revealed the presence of a rectangular grid of tectonic structures that cause offset both parallel and perpendicular to the coast. Vertical displacement of coastal terrains bearing archeological finds (Flemming and Webb 1986) and tide-gauge data (Emery *et al.* 1988) record uplift in this southern Levant region

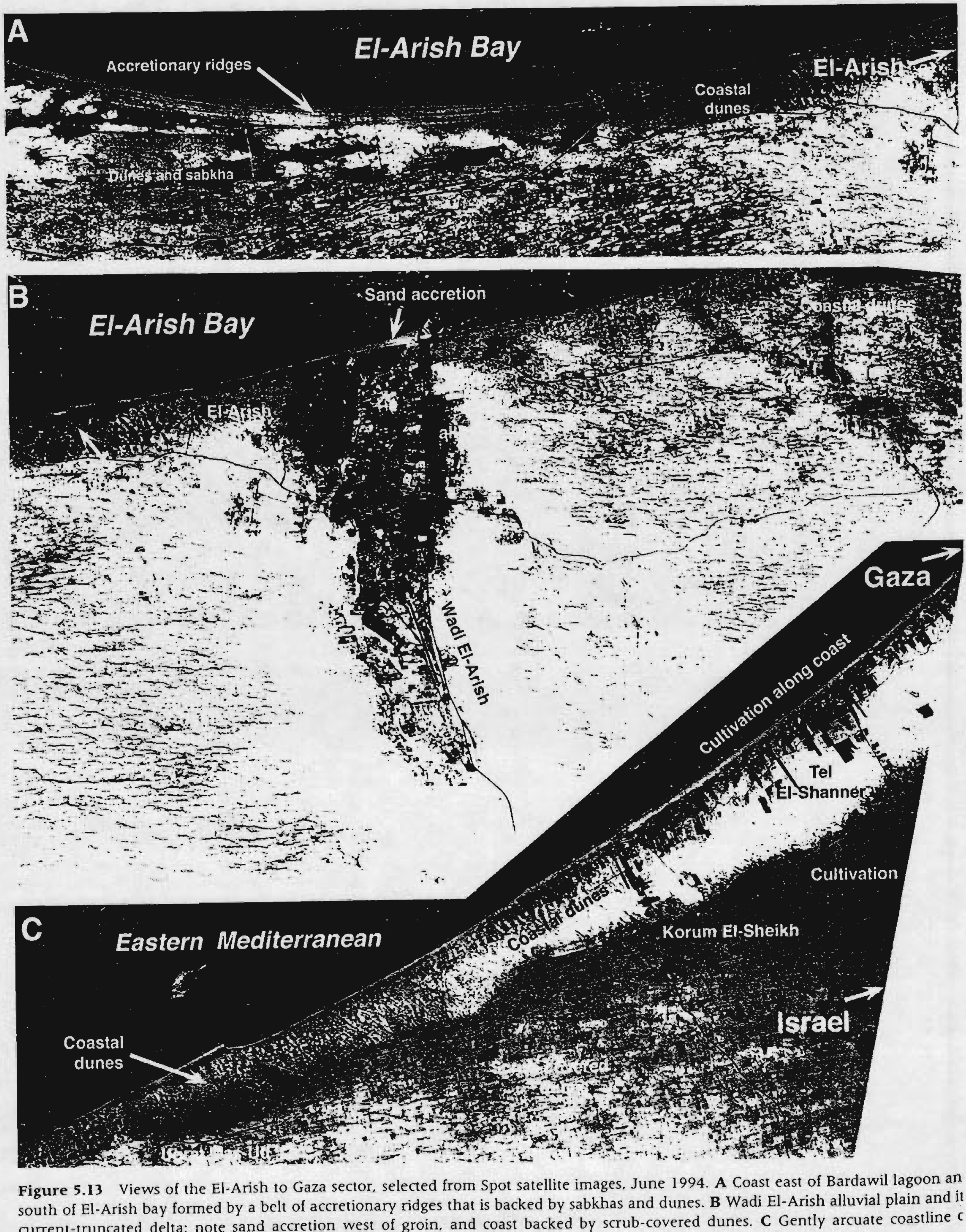


**Figure 5.13** Views of the El-Arish to Gaza sector, selected from Spot satellite images, June 1994. **A** Coast east of Bardawil lagoon an south of El-Arish bay formed by a belt of accretionary ridges that is backed by sabkhas and dunes. **B** Wadi El-Arish alluvial plain and it current-truncated delta; note sand accretion west of groin, and coast backed by scrub-covered dunes. **C** Gently arcuate coastline c easternmost Sinai, smoothed by northeast-driven longshore currents, and backed by coastal dunes and cultivated terrains

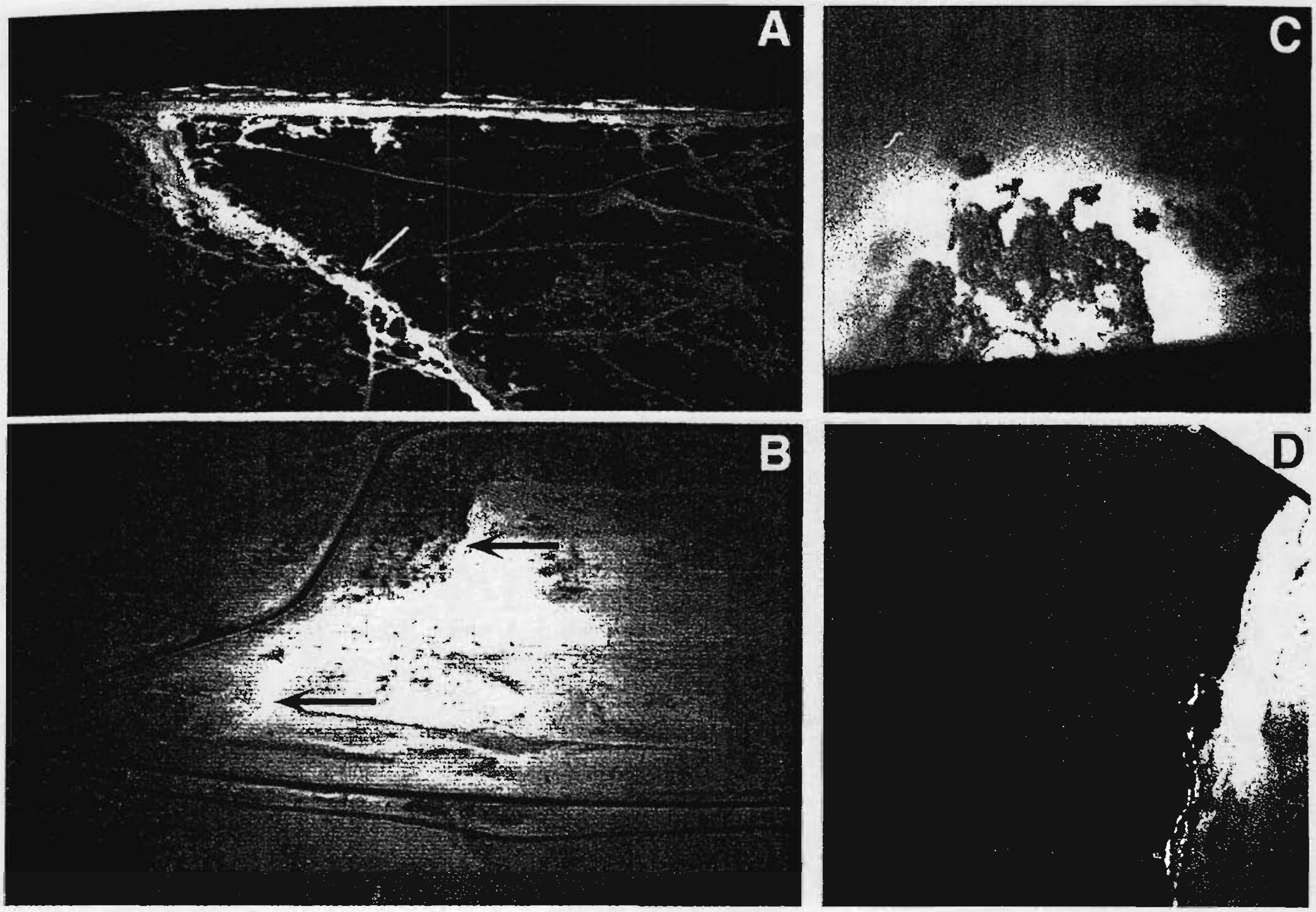


**Figure 5.14** Aerial photographs of the southernmost Israel and Gaza margin (low-altitude flight, 2 June 1995). **A** Channel of Wadi Zikim (arrow), with its mouth truncated at coast (northeast to right). **B** Coastal dunes actively migrating to northeast (direction of arrows), across older scrub-covered terrain near Rafah. **C** Partially submerged *kurkar* ridge off Gaza coast (northeast to right). **D** *Kurkar* and sandy strandplain coast near Gaza (northeast to upper right)

during the mid- to late Holocene to the present. This activity has resulted in the sharp termination of some small river mouths near the coast in this sector (Fig. 5.14a), and even separation of lower fluvial channels from the shore proper (see the configuration of Wadi Silkah near Deir El Balah, Figure 5.12). Neotectonic displacement may also explain the presence of elevated terraces of Pleistocene *hamra*-like sediments, raised and offset *kurkar* ridges near the coast (Fig. 5.14d), and submerged ridges (Fig. 5.14c) distributed offshore (Emery and Bentor 1960; Neev *et al.* 1987; Nir 1984). However, at this time, there is considerable controversy and little agreement among geographers, coastal geologists and archaeologists working in this sector as to the timing, amount and rate of vertical displacement affecting this region (see the discussion in Mazor and Neev 1974).

## Palaeogeographic interpretation and conclusions

An expanded exploratory effort by coastal geologists and archaeologists is warranted in several north Sinai sectors that, to date, have yielded few—if any—Egyptian and Canaanite finds. For example, there has been recovery of only a minor amount of early Dynastic and Canaanite material between the Pelusiac fault trace and the present coast in the region east of the Suez Canal to Bardawil lagoon (Fig. 5.1b). A palaeogeographic reconstruction of the Early Bronze Age shoreline is presented here so as to help provide new information pertaining to the exchange byway between the eastern Nile Delta and southern Israel (Fig. 5.15). The proposed configuration takes into account lower sea-level stand, east-driven current flow and sediment dispersal, erosion of the coast and inner shelf, and vertical displacement of land by neotectonic activity. The interplay of these factors has induced some pronounced lateral shifts of the coastline during the past 5000 years, especially between the eastern Nile Delta and the area to the east of Bardawil lagoon (areas A and B in Figure 5.15).

The paleoshoreline reconstruction shows that the coast from Manzala lagoon to western Bardawil was positioned well inland, as far south as 30 km from the present coast at Port Said. It would not be unexpected to discover sites, structures and anchorages in the area east of the Suez Canal, in the sector inland from the coast and positioned south, southwest and west of Pelusium (area A in Fig. 5.15). During the past 5000 years, this northwest Sinai

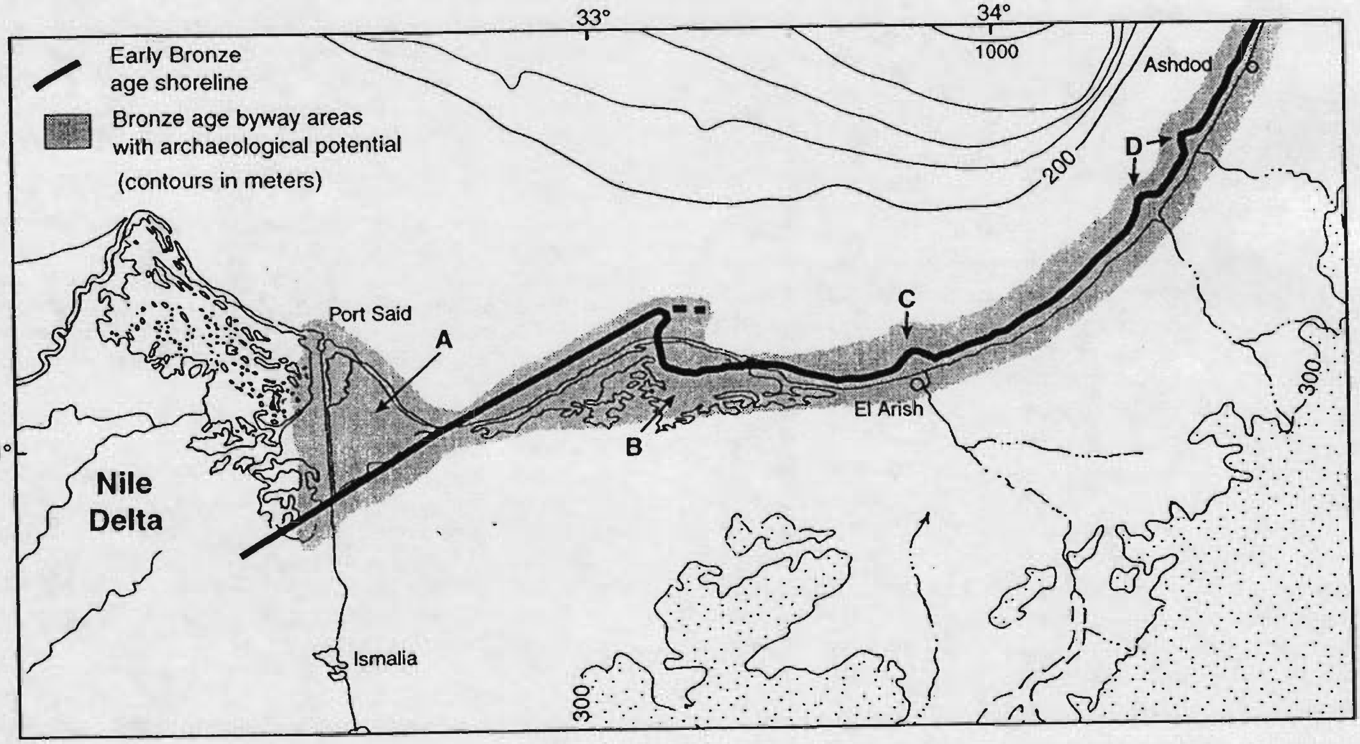


**Figure 5.15** Interpreted coastline position during Early Bronze Age is denoted by heavy line. Zones A–D along the coastal margin (shaded) indicate areas discussed in the text that warrant intensified joint geological-archaeological exploration for improved definition of the north Sinai byway

region was buried by coastal and alluvial-deltaic plain (mostly Pelusiac) deposits (Fig. 5.7) and, more recently, has been covered by a shallow saline lake (Fig. 5.6a), salt flats (Fig. 5.6b) and extensive dune fields (Fig. 5.6c). Subsurface exploratory efforts are needed especially in the region between Romani, El Beda, and Qantara (Fig. 5.5), where anchorage sites may have been selected with regards to former Nile distributary branches that flowed to the northeast delta. This area should be investigated by means of tight-grid subsurface surveys, using high-resolution geophysical profiling technology, in conjunction with core drilling and subsurface excavation.

Farther to the east, most of the north-central Sinai coast was positioned offshore formerly, i.e. north and east of Bardawil's western coastal barrier associated with the Pelusiac fault system. The presently submerged Bardawil lagoon and area north of sites that have already been recorded (Fig. 5.1b) are viewed here as particularly attractive zone areas for intensified archaeological exploration. The present western lagoon barrier once formed a raised nearshore coastal feature behind which ships transiting this region could find protection (area B in Fig. 5.15). It should be noted that during the Early Bronze Age, the low area now positioned behind the tectonic ridge was not a hypersaline lagoon, but an emergent and dry terrain. Potential anchorages are envisioned in the area to the southeast and east of Mt. Casius, i.e. in the lee of the ridge in areas that are now submerged. As sea level continued to rise, this protected zone shifted southward. Exploration of this once subaerially exposed area can best be accomplished by a tight-grid high-resolution seismic survey, coupled with core drilling of potentially attractive bottom targets. This methodology could help locate buried anthropogenic structures as well as define the configuration of channels and inlets behind the tectonic ridge that may have served as anchorages. Sand dunes that back the present coast between the Suez Canal and east of Bardawil lagoon (areas A, B and C in Fig. 5.15) are generally younger than late Pleistocene, and have been subject to several phases of stabilization during the Holocene. It is possible that potentially important archaeological evidence in this region was buried by eolian deposits and interspersed salt flats.

The shoreline from east of Bardawil lagoon to southern Israel experienced less of a landward shift during the past 5000 years than in sectors to the west. Much of the coastline here was positioned seaward, within 500m to the north and northwest of its present location. There are several terrains that should be explored east of Bardawil lagoon (area C in Fig. 5.15), and these include: (1) the offshore extension of the El-Arish channel on the inner shelf, presently covered by fluvio-marine sediment; (2) the lower Wadi El-Arish valley filled by alluvial plain sediment (Fig. 5.13b); and (3) the zone west of the El-Arish channel buried by accretionary coastal ridges and *sabkha* terrains behind them (Fig. 5.13a).

In the El-Arish region and to the east, it would also be useful to run systematic, closely spaced, high-resolution surveys seaward of wadi and river mouths (areas C and D in Fig. 5.15), to within 1km of the coast. From El-Arish to Gaza and Ashqelon, the mouths of some formerly active streams that may have served as inlets for shipping are now buried offshore by coastal deposits, and onshore by alluvial deposits and migrating dunes. It is recognized that mouths of some small rivers are not now positioned where they were 5000 years ago, but are likely to have shifted laterally to some extent and are buried by inner shelf sediment. Moreover, fluvial systems channels are truncated at the coast or disconnected from the shore, in part as a response to local tectonic displacement. Such nearshore surveys would require a seismic profiling system able to penetrate and define in subbottom the upper 5–10m of sandy sediment fill that buried former channels. Potential targets selected on geophysical profiles could then be cored. The strandline east of El-Arish is backed by scrub-covered dunes as far as southern Israel, and these are viewed as secondary exploratory targets.

In the northern Nile Delta it has been shown that drilling on land and offshore, dating of sediment core sections and identification of key stratigraphic marker beds for regional correlation, such as the Upper Minoan ash discussed earlier, provide a reliable means to interpret the configuration of former Holocene shorelines (Stanley and Warne 1993a, 1998; Warne and Stanley 1993). Joint geological-archaeological exploration along the shoreline/inner shelf margin, as delineated here, may lead to discoveries that further define onshore and marine Bronze Age traces of the north Sinai byway.

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