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IMPACT OF A FUTURE RISE IN SEA-LEVEL ON THE COASTAL LOWLANDS OF THE MEDITERRANEAN

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I. Introduction

During the meeting on Implications of Climatic Changes in the Mediterranean (Geneva 11-13 May, 1987) it was agreed that specific problems needed to be analysed on the Mediterranean scale. One of the specific problems is the physical alterations of coastlines, sanddunes, wetlands, coastal lakes etc. in relation to a future rise in sea-level. In this contribution an outline of the above-mentioned specific problem is given and an indication of the various coastal regions concerned (see map 1). More detailed and specific information can be found in the case studies concerning the delta's of the Ebro, Nile, Po, Rhone, and Lac d'Ichkuel.

An increasing body of evidence suggests that in the coming decades a global warming due to the greenhouse effect will lead to a substantial rise in sea-level. Estimates for the next 100 years range from 0.5 to 3.5 metres. This range is due to the fact that the input to the models has many uncertainties. G. de Q. Robin (1985) expressed this problem as follows: "With our lack of knowledge of certain aspects of the hydrological cycle and the dynamics of the oceans and the polar ice sheets, forecasting of global changes of sea-level involves considerable extrapolation and speculation".

Because a large part of the population lives in low lying areas near the sea, a rise between 0.5 and 3.5 metres will have an important impact on society. Most low lying coastal areas, especially deltas, are subject to slow tectonic subsidence which will increase the predicted sea-level rise.

In deltaic areas with dense populations and heavy industrial development, man-induced land subsidence due to overdrawing of groundwater is already a serious problem (the Venice-Po delta area). A further man-induced subsidence is caused by draining of land and making polders in these areas.

The tourist industry developed on the Mediterranean shorelines has caused the destruction of natural shoreline defences such as sand dunes for the provision of hotel accomodation and amenities.

More details about the occurrence of the coastal lowlands and about man's economic and social activities are given in chapter II.

During the past years, five conferences have been devoted or partly devoted to the entity and the impacts of a future sea-level rise. The first was the international conference on the assessment of the role of carbon dioxide and of other greenhouse gasses in climate variation and associated impacts in Villach, Austria, in October 1985 (UNEP, ISCSU and WMO), see Bolin etal. 1986. The second was an international conference on the Health and Environmental effects of changes in stratospheric ozon and global climate, organized by U.S. environmental Protection Agency and UNEP in June 1986 at Crystal City, USA and included a workshop on sea-level rise (Titus, 1986). In August 1986 the Delft Hydraulics Laboratory organized an international workshop in The Netherlands on the impact of sea-level rise on society (Wind ed. 1987).
The fourth conference was a workshop on climatic change, sea-level, severe tropical storms and associated impacts held at the climatic research unit of the University of East Anglia, Norwich U.K. in September 1987.
The fifth was a session on the impact of a future rise in sea-level on the European Coastal Lowlands during the European Workshop on interrelated Bioclimatic and Land-use changes in The Netherlands, Noordwijkerhout, in October 1987 (Jelgersma, 1987).

The general conclusions on the causes and the effects of a future sea-level rise of the UNEP-EPA workshop are given below:

Causes

The projected global warming would accelerate the current rate of sea-level rise by expanding ocean water, melting alpine glaciers, and eventually, causing polar ice sheets to melt or slide into the oceans.

Global average sea-level has risen 10 to 15 cm over the last century. Ocean, and glacial studies suggest that the rise is consistent with what models would project, given the 0.4°C warming of the past century. However, no cause and effect relationship has been conclusively demonstrated.

Projected global warming could cause global average sea-level to rise 10 to 20 cm by 2025 and 50 to 200 cm by 2100. Thermal expansion could cause a rise of 25 to 80 cm by 2100; Greenland and alpine glaciers could each contribute 10 to 30 cm through 2100. The contribution of Antarctic deglaciation is likely to be between 0 and 100 cm; however, the possibilities cannot be ruled about out that (a) increased snowfall could increase the size of the Antarctic ice sheet, thereby offsetting part of the sea-level rise form other sources; or (b) meltwater and enhanced calving of the ice sheet could increase the contribution of Antarctica to as much as two metres.

Desintegration of the West Antarctic Ice Sheet might raise sea-level an additional six metres over the next few centuries. Glaciologists generally believe that such a disintegration would take at least three hundred years, and probably as long as five hundred years. However, a global warming might result in sufficient thinning of the Ross and Filcher-Ronne ice shelves in the next century to make the process irreversible.

Local trends in subsidence and emergence must be added or subtracted to estimate the rise at particular locations.

Effects

A substantial rise in sea-level would permanently inundate wetlands and lowlands accelerate coastal erosion, exacerbate coastal flooding, and increase the salinity of estuaries and aquifers.

Bangladesh, Egypt and China, estuaries of N.W. Europe appear to be among the nations most vulnerable to the rise in sea-level projected for the next century. Up to 20 percent of the land in Bangladesh could be flooded with a two meter rise in sea-level. Although less than 1 percent of Egypt's land would be threatened, over 20 percent of the Nile Delta, which contains most of the nation's people, would be threatened.

A large fraction of the world's coastal wetlands may be lost, threatening some fisheries. A rise in sea-level of one to two metres by 2100 could destroy 50-80 percent of U.S. coastal wetlands. Although no study has been taken to estimate the worldwide impact, this result is probably representative.

Erosion caused by sea-level rise could threaten recreational beaches throughout the world. Case studies have concluded that a thirty-centimetre rise in sea-level would result in beaches eroding twenty to sixty metres or more. Because the first row of houses or hotels is often generally less than twenty metres from the shore at high tide, if available studies are representative, the recreational beaches throughout the world would be threatened by a thirty-centimetre rise unless major beach preservation efforts are undertaken.

<u>Sea-level rise would increase the costs of flooding, flood protection, and flood insurance in coastal areas.</u> Flood damages would increase because higher water levels would provide a higher base for storm surges; erosion would increase the vulnerability to storm waves; and decreased natural and artificial drainage would increase flooding during rainstorms.

<u>Future sea-level rise may already be an appropriate factor to consider in the designing coastal drainage and flood protection structures.</u>

<u>Increased salinity from sea-level rise would convert marshes swamps to open water and threaten drinking water supplies.</u>

<u>The adverse impacts of sea-level rise could be ameliorated through anticipatory land use planning and structural design changes.</u>

<u>Other impacts of global warming might offset or exacerbate the impacts of sea-level rise.</u> Increased doughts might amplify the salinity impacts of sea-level rise. Increased hurricanes and increased rainfall in coastal areas could amplify flooding from sea-level rise. Warmer temperatures might enable mangrove swamps - which can accrete vertically more rapidly than salt marshes - to advance further north and south, perhaps decreasing wetland loss caused by sea-level rise.

As mentioned before, the estimates of the amount of a future rise in sea-level during the next 100 years show a great variation due to our lack of knowledge of various physical aspects. The scientific results of the Villach and Norwich conferences indicate that the maximum amount of sea-level rise during the coming 100 years should have a maximum value of 1 meter.
Accordingly in this study an evaluation will be made of the likely impact of projected sea-level rise of 1 meter on the coastal lowlands surrounding the Mediterranean.
It can be expected that further modelling of the involved parameters will change this amount of expected sea-level rise.

II. Environment, land use and shoreline behaviour

a. Environment of the Coastal Lowland

Coastal Lowlands comprise the area in which sediments are laid down under the direct influence of waves, tides and currents while the indirect influence of these factors resulting from the backing up of brackish and fresh water.
These sediments include peats, clays, silts, and sands in general lying in the intertidal and subtidal zone. Inland of the above-mentioned sediment zones coastal wetlands are presently showing a zonation from salt and brackish water environments, marshes and lagoons to fresh water peats.
The salt water environment of the supratidal zone is strongly influenced by climate; particularly rainfall. In general the Mediterranean climate is characterized by long dry warm summers and rainy winters.
In the Southern and Eastern Mediterranean the climate is warmer and precipitation less in comparison to coastal zones of the Northern Mediterranean. Accordingly in the last mentioned areas salt marshes and lagoons can be met as in the first mentioned area evaporites (Sebkhas), hyper saline lagoons, desiccated mud flats and algal mats are present.
In some areas the coastal zone is bordered by low dunes. Due to climatic circumstances and the presence of calcite they can be cemented. Eolonites, are found in Israel and West of the Nile Delta.
The Mediterranean shorelines include important river deltas such as the Ebro, Rhone, Po, Seyhan, and Nile. They show great variation due to dominant processes of waves, currents and fluvial sediment input. The above-mentioned important delta areas are described in the case studies.
The complex of sub environments of the shore zone: interdial flats, marshes, channels, lagoons, fresh swamps and sebkas have shifted landwards due to the Holocene rise in sea-level. The latter is caused by the melting down of the continental ice caps of the last glaciation which caused a sea-level rise of more than 100 m.
It must be kept in mind that sea-level changes can also be caused by tectonic movements. Most deltaic areas like the Po and the Nile delta are situated in slowly subsiding basins (several cm/century). Most of the Mediterranean is however situated in a tectonically active zone, characterized by the occurrence of earthquakes and volcanic eruptions.
Areas of Greece and Italy are extremely active tectonically. An example is the earthquake that occurred in 1908 at Messina, Italy, which increased the relative sea-level by 57 cm. The mentioned active tectonics are due to the position of the Mediterranean between the African-Arabian and the Eurasion

continents. A series of deep sedimentary follows indicates the junction between these continents (fig. 1), Pirazzoli (1987) claims to have geomorphological evidence of shorelines indicating a major tectonic uplift in the Eastern Mediterranean between 300 and 550 A.D.
The geoid, the relief of the sea surface topography reflects the variations in density of the earth crust. The map presented in fig. 2 shows variations in the mean sea surface topography as high as 50 m clearly reflecting the changes in density of the underlying earth crust (Barlier etal. 1983). In such a tectonic area these densities are likely to shift, by doing so the geoid will change resulting in a change of sea-level.
Shoreline processes in the Mediterranean are characterized by weak currents, very low tides, winter storms with a direction SW, NW to NE and rivers with poor discharge mainly due to human interference. In the map of the Mediterranean the coastal lowlands and the river deltas are roughly indicated.

b. Land use in the coastal zone

From prehistoric time onwards most of the coastal lowlands are places of human settlements and are strongly influenced by human activities.
As compared to the south margins of the North Sea, the extent of coastal low-lying plains and deltas on the Mediterranean shores is fairly limited (map 1). The demographic, economic and ecological importance of these areas is nevertheless very considerable on a local, national and international scale. Besides settlements involving millions of people, vital agriculture and fishing resources, as well as industrial, commercial and communication centers, and the increased recreational use of beaches, most areas still contain patches of little modified natural ecosystems of irreplaceable value. It must also be mentioned that the discovery and exploitation of the giant oil and gas fields of North Africa (the Polignac basin in Algeria and the Syrte basin in Libya) have given rise to the construction of oil harbours, pipelines and oil refinaries all around the Mediterranean.
A brief description is given below of the coastal lowlands around the Mediterranean.

Spain

The lowlying coastal segments are mainly located in Neogene tectonic depressions. These depressions form large sandy bays, with coastal lagoons, coastal dunes and marshes. The most important lagoons are La Albufera de Valencia and El Mar Menor. Besides fishery and agriculture the above mentioned areas are of great economic value as they are extensively developed in tourist resorts. Further to the North the deltas of the river Llobregat and of the Ebro river are found.

The Ebro delta is small (285 km^2) but of high economic value as a rice producing area and for fishing (shellfish). Part of the delta is still wetland and of great value for migrating birds. At the present time the delta is subject to erosion due to the constructing of dams and reservoirs in the upstream part of the Ebro river. About 96% of the river sediment is trapped in the reservoirs (Marino, 1987).
The other sandy beaches along the Mediterranean shoreline are also subject to erosion, in many places they are protected by groynes.
In fig. 3 and 4 the type of coastlines along the Spanish Mediterranean are indicated. More information can be found in Marques etal. 1985.

France

The coastal lowlands of France are situated between the mountainous coast of the Pyrenees and the elevated coast of the Provence. The coastal plain of Roussillon and Languedoc is a barrier coast with lagoons and low plains. Economic activities include agriculture like cattle breeding, rice, vegetables and vinegards. Also important are saltpans extraction and industry. During the last 20 years more than 40% of the shoreline has been developed into beach resorts. Part of the shoreline is receding, part advances (Corre, 1987).
The Rhone Delta is situated on the eastern side of the Gulf de Lyon. The area covers about 17000 ha and is characterised by the shifting course of the delta distributaries. The morphology and shape of the delta is the result of the combined effects of waves and fluvial sediment input (van Andel etal. 1960).
In recent time however the Rhone river catchment area has been harnessed with many large dams that have reduced the sediment discharge to the sea from 40 million tons per year at the end of the 19th century to 12 million tons in 1956 and to 4 million tons in 1970 (Guilcher, 1985). Accordingly erosion prevails nowadays along the delta shoreline. Part of the delta is of great importance as natural reserve for (migrating) birds. Also important agriculture is present in reclaimed and irrigated parts of the delta.
On the East side of the lowlying coastal strip lies the city of Marseille, population 1.100.000.
This city has an economically important strategic industry and an important harbour.

Italy

The Italian coastline which extends for 7500 km shows an alternation of rocky and low lying sandy shorelines (see fig. 5 and 6).
The coastal lowland of the Tyrrhanian sea are related to the delta's of the rivers Arno, Ombrone, Tevere and Volturno are present the most important harbours, strategic industries and large cities are situated near Genua, Livorno, Rome and Napoli. In the south valuable lowlands are near Caghari, Catania and Tarente.
On the Adriatic Sea the most important lowlying coastal areas can be found in the Po river basin. This subsiding basin has accumulated a high amount of sediment brought down by rivers from the Alps and the Appennine mountains. The Po plain itself is the most important agricultural and industrial area of Italy. It is bordered by the sea and by the coastal lowlands of Veneto and Romagna. These consist of low sandy beaches enclosing marshes and lagoons. Well known are the ancient cities of Venice and Ravenna, the lagoons and the Po delta (wetlands of international importance) and the string of beach resorts that yearly attract millions of tourists. About 2 million people live in the coastal plains involved in agricultural, commercial and industrial activities. The strategic industries formed in this area, oil refineries, ship building and chemistry, are of great importance for the whole country.
Most of the coastal lowlands in Italy are at present subject to erosion which is mainly thought to be caused by man's activities like reducing the sediment load of rivers to the shore by the construction of dams and reservoirs (see paragraph C). For more information reference is made to Sestini 1987 and Zunica 1985.

Yugoslavia

During the post glacial rise of sea-level the sea invaded a coastal area whose topography of parallel limestone ridges, separated by wide valleys created a coast with many bays and a number of long islands streching parallel to the shore. The littoral plains along the coast were reduced to small patches overlooked by strips of bluffs beyond which peaks rest at 1900 m. The ranges of limestone plateaus rise in impressive grandeur and form impressive cliffs above the Adriatic Sea.
It may be concluded that along the Adriatic coast the few coastal lowland occur. The region of Trieste and Rycka have important harbours and vital industries are located here. See also Sestini 1987 and Shuisky 1985.

Albania

In the SE Adriatic the 385 km long coast of Albania includes 190 km of low sandy beaches, marshes, lagoons and deltas related to the rivers Drin, Buna, Matia, Skumbini, Semeni and Vogussa (Sestini 1940, Charlier etal. 1985). The lowlands, population around 700.000, constitute a large proportion of prime agricultural land in a country that is mostly mountainous and rugged. Vlone and Durres are the country's ports and main industrial centers (oil harbour and oil refinery). Due to the suppletion of sediment by the rivers many parts of the Albanian low lying coast have advanced or have been stable during the past hundred years. More details concerning this subject are dealt with in the next paragraph.

Greece

Greece has an extremely long shoreline in comparison with its area. The entire coastline and county has been, and still is, strongly effected by tectonic and volcanic activity. This has led to an extremely rugged topography reflected along the entire coastline. In relation to this tectonic activity a large number of horsts and grabens extend in a northwest-southeast direction. The coastal lowland of Greece are found in the graben. Compared to the whole shoreline lowlands are very limited, but nevertheless of high economic value for the whole of Greece as here are the only places for harbours and related strategic industry. The most significant deltaic lowland of primary, agricultural and industrial importance is at the mouth of the Achelaos river, the Axios river, near the important industrial area of Thessaloniki (Thermaikos Gulf) and at the Nestos Erros deltaic plain.
Fig. 7 gives an indication of the topographic lowlying areas in Greece and fig. 8 and 9 examples of coastal lowland related to the occurrence of grabens (Tziavos etal. 1985).

Turkey

The Aegean and Mediterranean coastline of Turkey has a length of more than 5000 km structurally controlled by tectonic movements (graben and horst). It is a shore of rocky cliff coasts alternating with deltaic lowland with sandy shorelines (graben).
These small but economically important deltaic plains are at the Aegean coast: the Gediz delta at Izmir, the Havran at Edremut and the Kucuk and Buyuk Menderes delta's.

On the Mediterranean: the Aksu deltaic plain near Antalaya and the large Cukurova plain near Adana. The latter built by two large rivers, the Seyhan to the West and the Ceyhan to the East. Southeasterly waves have formed broad beach accretion plains bordering the shoreline. Much of the plain was formerly swampy or marsh but is now a large well drained agricultural area of great economic importance. In and around this plain live about 2 million people, and the cities of Iskandirun and Mersin are important industrial centers. Shoreline erosion is not a problem in these lowlying deltaic coasts as river sediment input is sufficient to keep the coasts in equilibrium with sea-level rise and tectonic subsidence. Fig. 10 and 11 give the geological and geomorphic features of the coasts of Turkey, fig. 12 indicates the major structural lineaments (Erol 1985).

Syria and Libanon

The length of the coastline of Syria and Lebanon is about 400 km. The straight coastline is related to tectonic structure: the coast runs parallel to the Jubal Alaouite anticline (North-South) in Syria and to the Lebanese mountains (North-Northeast-South-Southeast) the western slope falls more or less steeply to the coast. In spite of the proximity of mountains the shoreline is in generally low though often rocky.

The occurrence of lowlying deltaic plains is limited, the most important being the bay of Akkar. In fig. 13 a map of the coasts of Syria and Lebanon is given (Sanlaville 1985).

Tripoli is an important oil exporting harbour, it is connected by oilpipe lines with the oilfields of Syria.

Israel

The straight coastline of Israel is also structurally controlled. The coast has low relief with only two mountains reaching the shore: mount Carmel in Haifa and Rosh Hanigra Ridge. Elsewhere the foothills are separated from the sea by a coastal plain which is fairly wide in the south (up to 40 km) but narrows towards the north reaching only a few hundred meters in the Carmel plain. North of Haifa (Carmel plain) the coastal plain widens again. Most of the coastline is characterised by cliffs composed of carbonate cemented sands and loams.

About 13 ephemeral rivers (wadis) drain to the coastline from the mountains. These rivers have only a limited sediment load carried during the wet season. Due to this fact deltaic plains are absent in Israel. Beach erosion is a problem in Israel, it is thought to be caused by human activities along the beaches (constructing and sand mining) and by the reduction of the amount of sand transported by littoral currents from the Nile delta (Nir 1985).

Egypt

In Egypt the deltaic plain of the Nile river is the most important coastal lowland of the Egyptian shoreline. Before 1964 the delta could be classified as wave and river dominated. Since then it is entirely dominated by marine processes. The shoreline of the delta consists of a serie of lagoons separated by beaches, spits and barriers from the sea. The water of the lagoons can reach very high salinities and even be transformed to extensive salt pans (sabkhas) due to the strong evaporation. Of the several distributaries of the Nile that once excisted, only the Rosetta Branch and the Damietta Branch are left.
The present deltaic plain overlies a sedimentary basin containing a 2-3000 m of sediment due to input of river and marine sediments and to tectonic subsidence (El-Ashry etal. 1985 and Sestini 1987). The Nile delta region is of enormous economic importance to Egypt. The region not only contains 20% of the country's population but also is its main commercial outlet with the strategic industrial and recreational centers of Alexandria and Port Said. Agriculture and fishing account respectively for 15% and 60% of national production. One third of the migrating and wintering birds is estimated to use the deltaic lagoons.
The shoreline of the Nile delta has undergone severe changes during the last 100 years. Erosion has occurred at several important locations along the coast: El Gamil, Ras el Bar, Baltim and El Bury, Roseta, Abu Qir and Alexandria (see fig. 14). At the same time accretion is occurring near the entrance of the Suez Canal, in front of Port Said breakwater causing navigational problems and requiring dredging at great expense. This severe erosion along the shoreline is mainly due to reservoir developments on the Nile which has gradually decreased the sediment load supplied to the near shore zone by the two branches of the Nile (Delta Barrages, 1882, Aswan Dam completed in 1902). The closure of the Aswan High Dam in 1964 has brought the Nile in Egypt under full control and has reduced the flow and sediment load of the river to insignificant quantities.

Libya

The shoreline of Libya is about 1900 km long. Coastal lowland can be found along the Gulf of Sirti: a barrier lagoon coast locally with dunes and backed by extensive sebkhas (salt pans). Agriculture is locally possible along this shoreline.
In this area the oil trans shipment facilities from the inland Sirti oil and gasfield are of high economic value for the country.
In fig. 15 a map of the coast of Libya is presented (Schwarz 1985).

Tunesia

The coastline of Tunesia is about 1700 km long, the coastal landforms are indicated at the map at fig. 16.
One of the important coastal lowlands is the delta of the river Medjerda at the Gulf of Tunis.
Near Bizerta Lake Ickkeul is an important ecological wetland and a bird reserve. Other coastal lowland is present along the Gulf Hammanet and the Gulf of Gabes.
The lowlands of Tunesia are of great economic importance in view of agriculture, urbanisation, harbours and important industry and the important tourist development.
The tourist industry is mainly based on sea and sun, and has been a major priority of the authorities since 1960. It has become the second source of foreign exchange for the country.
The building to accommdate the tourist boom has caused unwise human intervention in the shoreline which is thought to be responsible for the recent serious shoreline recession. In fig. 17 a map presenting erosion and aggradation of the shoreline is given (Paskoff 1985).

Algeria

The Algerian coastline, length about 1100 km is almost completely bordered by chains of mountains plunging abruptly into deep water with intervening small stretches of low sandy coasts. The latter are related to Wadi's entering the coastline. It is evident that no important lowlands are present along the Algerian shoreline. Due to this fact ni important tourist industry has yet developed (Mahrou etal. 1985).

The oil trans-shipment facilities in the harbour of Arzen, Algiers, Beyaia and Skikda built to transport the mineral resources of the Polignac oil and gas basin are of high economic value for the country.

Morocco

The Mediterranean coastline of Morocco is strongly influenced by the Rif Mountains: rocky cliffs correspond to the folds and beaches to the synclines. The occurrence of coastal lowlands is very limited, SE of Melilla a lagoon (sabkha) separated from the sea by dunes is present and the river Moulowya has a small delta (Weisrock 1985). Fishing is carried out in the lagoon and the lowlying coastal plain with a nice sandy beach near Al Hoceima is an important tourist area.

C. Shoreline behaviour

In the brief review of the Mediterranean coast something has been said about the present erosion or aggradation of the various shorelines.
It may be concluded that the majority of the shorelines at the present time is subject to erosion.
Looking at the deltas in the Mediterranean the following may be noted: the Po and Ebro delta are very young deltas. They have arisen due to deforestoration of the river valley and the catchment area after the Roman period. Accordingly a high amount of eroded sediment could reach the shoreline. During the last decades the Ebro, the Nile, the Rhone, and Po rivers basins have been subject to dams and reservoir construction and accordingly the sediment supply to nourish beaches and deltas was greatly reduced. This reduction of sediment load resulted in shoreline erosion in these regions. The industrial dredging of sand from the river bed also contributed to reduce the sediment load to the shoreline. In the Nile delta case there are also consequences for the Israel shoreline. The anticlockwise current in the S.E. Mediterranean nourishes the beaches of Israel with sediment derived from the Nile delta river system. The strong reduction of the sediment is thought to be one of the causes of shoreline erosion in Israel. It is striking to realize that from the Albanian and Turkish river deltas and adjacent coastal plains no erosion is mentioned, in those river basins the construction of dams and reservoirs has just started.
Outside the delta areas the following data can be mentioned.
In Israel human activity along the beaches have had mostly destructive results either to quarring high amounts of sand or constructing groynes, harbours and

detachted breakwaters which accumulate sands, thus removing them from the drifting system. These activities have caused beach erosion (Yacov Nir 1985). In Tunesia, Paskoff (1985) indicated that recent shoreline recession has been dramatically increased by unwise actions related to the tourist boom, that has affected the shoreline during the last two decades. There has been sand mining on the beach for building purposes. In many places the fore dune has been completely destroyed by hotels built very near the seaside. The removal of dead leaves of Posidonia, which accumulate on the shore and inhibit sunbathing, has increased wave action, which is also enhanced by degradation of the infralittoral meadows damaged by sewage.
The same facts mentioned by Nir and Paskoff are valid for most of the Mediterranean beaches. The conclusions is that most beaches are subject to erosion not only of a recent rise in sea-level but mainly to man's economic and social activities. Especially interference at places where shorelines are eroding, stone jetties and concrete or wooden groynes are built to lessen sand drift. This method is disputable as it seems to be that as a reaction to this artificial works, erosion of the rest of the unprotected shoreline is increasing. Beach nourishment (sand supply from the sea) seems to be a more successful method. A general description of the critical balance of the Mediterranean shorelines can be found in World's Shoreline 1985 edited by M.L. Schwartz and E.C. Bird.

Due to human activities not many natural coastal wetlands like marshes and lagoon remain in the Mediterranean. The most important areas left can be found in the deltas of Rhone, the Ebro, the Po and the Nile. In Tunesia lake Ichkeul is a reserve. For the European part of the Mediterranean the salt marsh inventarisation is given in a map edited by the Council of Europe. It should be recommended to extent this inventarisation for the rest of the Mediterranean shorelines.

Man's intervention on the coastal zone can be summarized as follows:
- Drained and reclaimed wetlands for agriculture, commercial, industrial and housing use. This results in lowering of the original elevation due to compaction.
- Making reservoirs in rivers and dredging sand from rivers. This results in a strongly reduced sediment supply to the shoreline: coastal erosion.
- Construction of Breakwaters and harbours involving also excavation of marshes and wetlands. This results in interruption of longshore transport: coastal erosion.
- Removal of sand from the beach. This results in coastal erosion.

- Groundwater extraction and mining of gas and oil. This activity has caused locally land subsidence.
- Embankments of Creeks and Channels. This activity reduces sediment supply to the wetlands.

III. Impact of a future sea-level rise

To predict the impact of a sea-level rise of 1 m in the coming 100 years on the coastal lowlands of the Mediterranean we need to analyze the following starting points.

1. The relative movements of sea-level deduced from tide gauge observations.
2. Data about erosion and/or aggredation of the various shorelines.
3. The frequency of storm surges.

The working method is as follows: on a given shoreline in the Mediterranean tide gauges have indicated a relative rise of sea-level of 10 cm/century. Shoreline observations and measurements have calculated an erosion of the shoreline of 50 m/century.
If it is accepted that the amount of historical retreat can be directly correlated with the observed rate of sea-level rise than a future increase in the rise of sea-level will cause a related increase in shoreline erosion. By doing so a certain prediction is possible and the discussion can start either to defend the shoreline or make the choice for a planned retreat.
About the tide gauges the following can be said:

Tide gauge measurements during the last 100 years along parts of the coasts of Europe indicate a rise in sea-level between 15 and 20 cm during this period. This rate of rise is greater than in the geological past: from Roman time to the present time only 1 metre which indicates 5 cm/century.
The recent relative rise in sea-level is thought to be partly caused by the greenhouse effect. In the Mediterranean the number of tide gauges with recordings dating back to the last 100 years is very limited. Tide gauges are also unevenly distributed along the Mediterranean shorelines: more in the Western than in the Eastern part.
Pirazzoli (1987) analysed the available stations, and concluded that no increase in sea-level has occurred in recent years. His conclusion is that various tectonic movements strongly influence the eustatic sea-level rise. The problem with the tide gauge observations is that especially those observed for less than 30 years the derived signal could either be representative or noise. Accordingly a conclusion cannot yet be made.

More data are known from the Nile Delta basin and the Padan-Adriatic basin. These basins show a continued tectonic subsidence super imposed on the sedimentary compaction of clays and peats. Tide gauge measurements in the eastern part of the Nile delta near Port Said indicate a sinking rate of 1.2 mm/year. In the Po delta and in the Venice area a subsidence of 4.8. mm/year is observed (Emery etal. 1987). During the last 30 years this subsidence has dramatically increased (to 10 cm/year) due to excessive groundwater extraction and the mining of oil and gas.

Regarding shoreline behaviour the following can be concluded and recommended: During the Inqua Congress in Ottawa (1987) the Inqua Shoreline Commission advised its members to start working during the intercongress period o.a. on the impact on shorelines of a future sea-level rise.

In October 1987 at a workshop in The Netherlands the same item was stressed. During this European workshop on Interrelated Bioclimatic and Land Use changes 12 papers were presented on the impact of a future rise in sea-level on the European coastal lowlands. Among these papers four dealt with coastal lowlands of the European part of the Mediterranean and one with the Nile Delta. In the following pages conclusions, recommendations and research proposals from this session are given which also apply for the Coastal Lowlands of the Mediterranean.

Conclusions

1. The unequivocal signal from the session was that all the European coastal lowlands and their shorelines were already experiencing damage from erosion, inundation during storm surges, storm waves, subsidence and salt water intrusion as the consequences of sea-level rise, increased incidence of storminess and man's activities. Man's economic and social activities are exacerbating the situation and comprise:
   - Sand extraction from beaches and offshore for reclamation and the construction industry
   - The destruction of natural shoreline defences, such as sand dunes, to provide of hotel accomodation and amenities for the tourist industry
   - The interruption and diversion of longshore sediment transport by groynes, jetties and harbours
   - The reduction of the sediment load of rivers by water management in drainage basins and the construction of dams and reservoirs, cutting of sediment supply to nourish beaches and deltas
   - The canalisation of rivers for navigational purposes

- The reclamation of coastal lowlands for agriculture, industrialisation and residential development
- The utilisation of groundwater for drinking water and irrigation which has led to subsidence, and the intrusion of salt water

The disastrous effect of man's activities in and off the shoreline is also known from the North African and Near East shorelines which were discussed in chapter II.

2. The maximum rise of sea-level rise during the recent geological past did not exceed 2.2 m/100 years, and during the past 4000 years when the rate of rise was considerably less, sedimentation has kept up with and locally exceeded sea-level rise. In natural areas, where man's activities are not pre-eminent, such as the Dutch, German and Danish Wadden Sea, sedimentation has kept up with the present rise of sea-level of 10-15 cm/100 years. Investigations of the sediments of the coastal lowlands indicate that, given a natural sediment budget, these areas responded and adjusted to a range of rates of sea-level change and climatic change in the past.
3. Current data bases are uneven spatially and temporally, and are inadequate for the purposes of prediction. Environmental, social and economic data are required from existing sources and new investigations in compatible and accessible forms. A notable deficiency in the environmental data base is analysed information on the sediment budget of the shorelines of coastal lowlands and adjacent shorelines, waves, tides, the strength and direction of tidal currents and the range of variation of these parameters in time. Geographic information systems should be employed to integrate data collection, analysis, management and display.
4. The risks from sea-level rise and the impacts on coastal lowlands can be evaluated by the application of cost-benefit analysis. Land use conflicts are a feature of coastal lowlands and decisions will need to be made on which activities and functions need protection and which can be lost without cost to the human community. A concept of sacrificial areas needs to be accepted.

<u>Research proposals</u>

1. Monitoring the movement of sea-level employing the tide gauge data maintained and updated by the Permanent Service for Mean Sea-level, I.O.S., Bidston, U.K. to determine the increased rate of sea-level rise, and local variations.

2. Monitoring the impact of sea-level rise, neotectonic movements (earth quakes) and man's economic and social activities on shorelines and coastal lowlands using satellite imagery analysis.
3. Investigations on the coastal dynamics of shorelines to determine changes in the sediment budget as a result of sea-level rise.
4. Investigations on the recent geological history of coastal lowlands and the determination for each lowland of rates of sea-level change and the responses in terms of sediment type and distribution, of land forms and of paleogeography. These investigations will serve as an analogue for future sea-level changes. Data from Unesco/IGCP projects 61 and 200 on sea-level change can be utilised, and enhanced by new data, contributed by the INQUA Shorelines Subcommissions and the IGU Coastal Commission.
5. The development and application of objective criteria to be applied to land use planning in the coastal lowlands and the production of maps showing high, intermediate and low risk zones in relation to the EPA sea-level scenarios to AD 2100.
6. The updating of the Council of Europe's map of salt marshes of Europe, and an extended inventory to include coastal wetlands and natural areas. The impact of sea-level rise, using different sea-level scenarios should be undertaken for selected areas of international significance for the world conservation strategy as identified by the U.N. and I.U.C.N. and within the framework of the E.C., UNEP and the INQUA Man and Biosphere programme.

Recommendations

1. **Action now**

- Control coastal development, to minimise risks to human life from sea-level rise.
- Control land reclamation, to reduce the growing area of coastal lowlands susceptible to inundation.

- Control ground water exploitation to reduce subsidence and salt water intrusion.
- Zone land in lowlands into high, medium and low risk categories. Strategic industries, such as electricity generation, should be located in future away form high risk zoned land.
- Suspend all dumping/storage of toxic and radioactive wastes in high risk zones in coastal lowlands susceptible to long term inundation sea-level rise.

2. **Action over next 5 years**

- Sponsor research programme to generate new data from coastal lowlands
- New and existing environmental data and social and economic data will be integrated in Geographical Information Systems (GIS), developed on PCs to permit interchange of information.
- Models of sea-level change will be tested rigorously against empirical data collected from the coastal lowlands at different spatial scales from the local scale (individual estuary) to the regional scale (southern North Sea Basin, Mediterranean Basin).
- An evaluation of the cost effectiveness of shoreline protection of coastal lowlands will be undertaken and an inventory of European and North African coasts made to determine which segments of coasts need protection and which segments can be sacrificed.

An inventarisation of the occurrence and frequency of storms along the various coastal segments of the Mediterranean is also an important tool to understand historical shoreline behaviour. Also the damages to the shoreline due to the different storms should be analysed.

In general it can be stated that a future rise in sea-level will affect the Mediterranean low lying shorelines by:
- increase the risk of inundating reclaimed lowlands
- accelerate the already occurring coastal erosion
- increase the risk of flood <u>disasters:</u> cities and industries located on coastal floodplains
- create problems with respect to drainage systems
- increase salt water intrusion into groundwater, rivers, bays and farmland
- damage port facilities and coastal protection structures
- destroy quality farmland
- disrupt fisheries and bird habitats, and disrupt ecological balance in coastal systems
- result in the loss of recreational beaches
- shift sedimentation in rivers more up stream, hamper shipping.

Another important factor that can influence the coastal areas is how the climate will change due to the predicted rise in temperature. If the weather pattern and climate change, will the run off from rivers increase in winter and decrease in summer? Dryer summers will have serious concequences for the Mediterranean.

The increased run off can give problems for the embankments. A decreased run off can cause important salt water intrusion in the up stream area.
Another aspect of a change in climate can be an increase in storminess along certain parts of the coasts. It is well known that the most important damages on coastlines occurs during storm surges at the time of high tide. If this increase in storminess should occur along the coasts of the Mediterranean the results in the coastal lowlands, with a high concentration of population and industry, would be disastrous.
Also this should seriously damage coastal areas where the important tourist industry is concentrated.
Unless remedial actions are taken now, as are recommended in the European Workshop report, the social and economic impacts will be profound and widespread.

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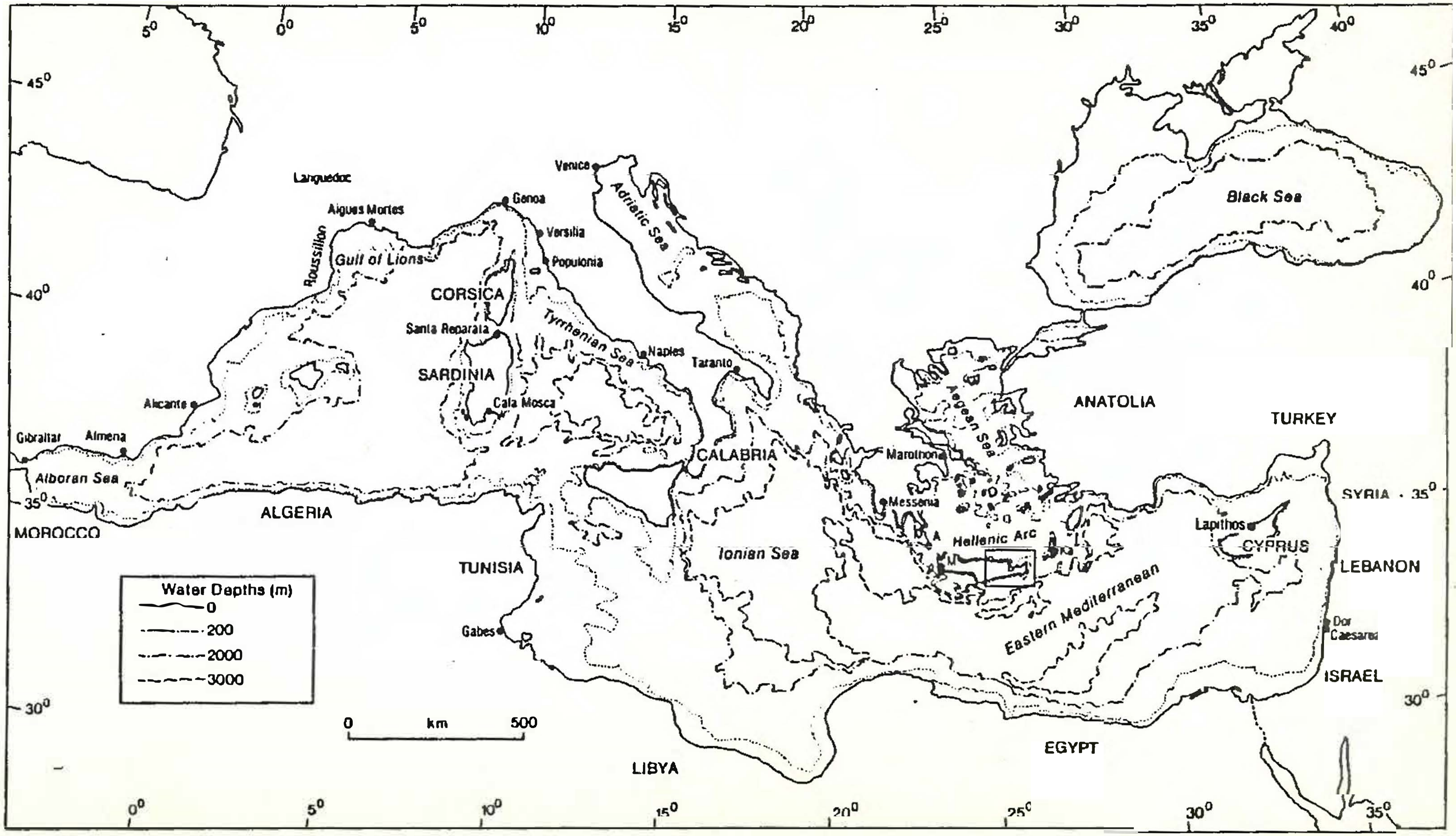


Figure 1 A map of the Mediterranean area.

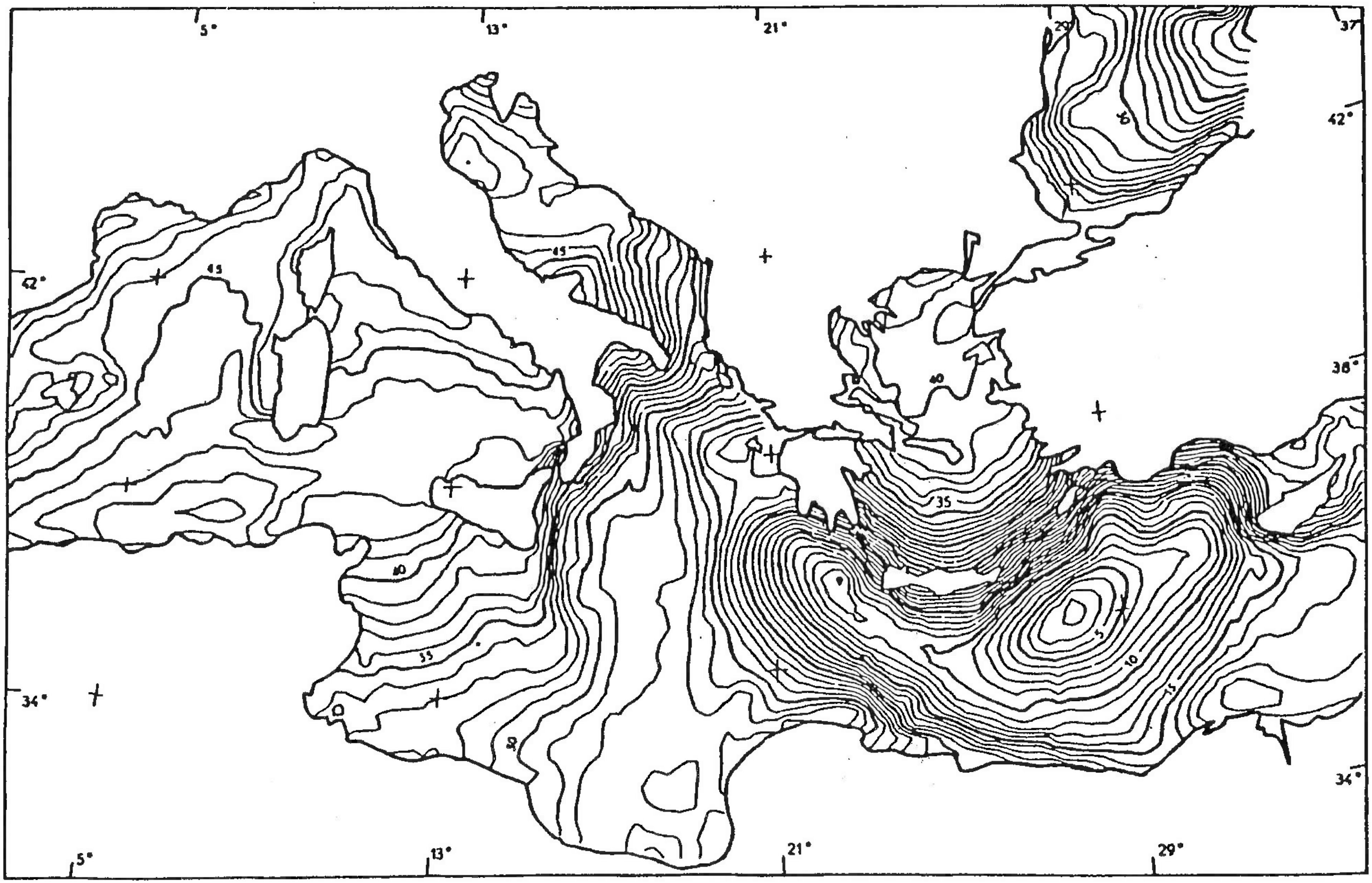


Figure 2 Mediterranean sea surface topography based on SEASAT altimeter data, according to Barlier *et al* (1983). Contour interval: 1 m

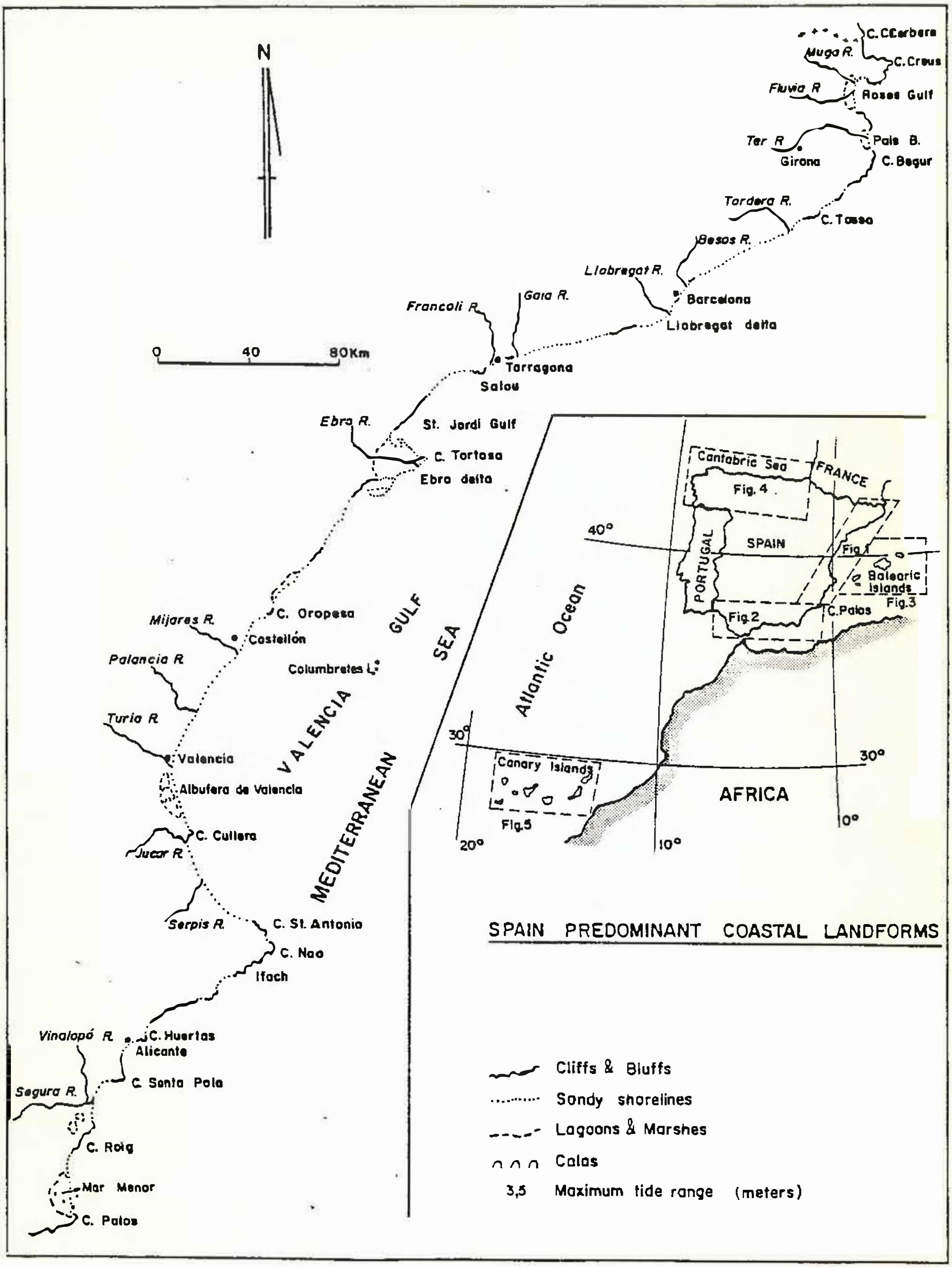


Figure 3 . Location map for the five coastal sectors of Spain, together with a geomorphic map of the southeast mainland coast.

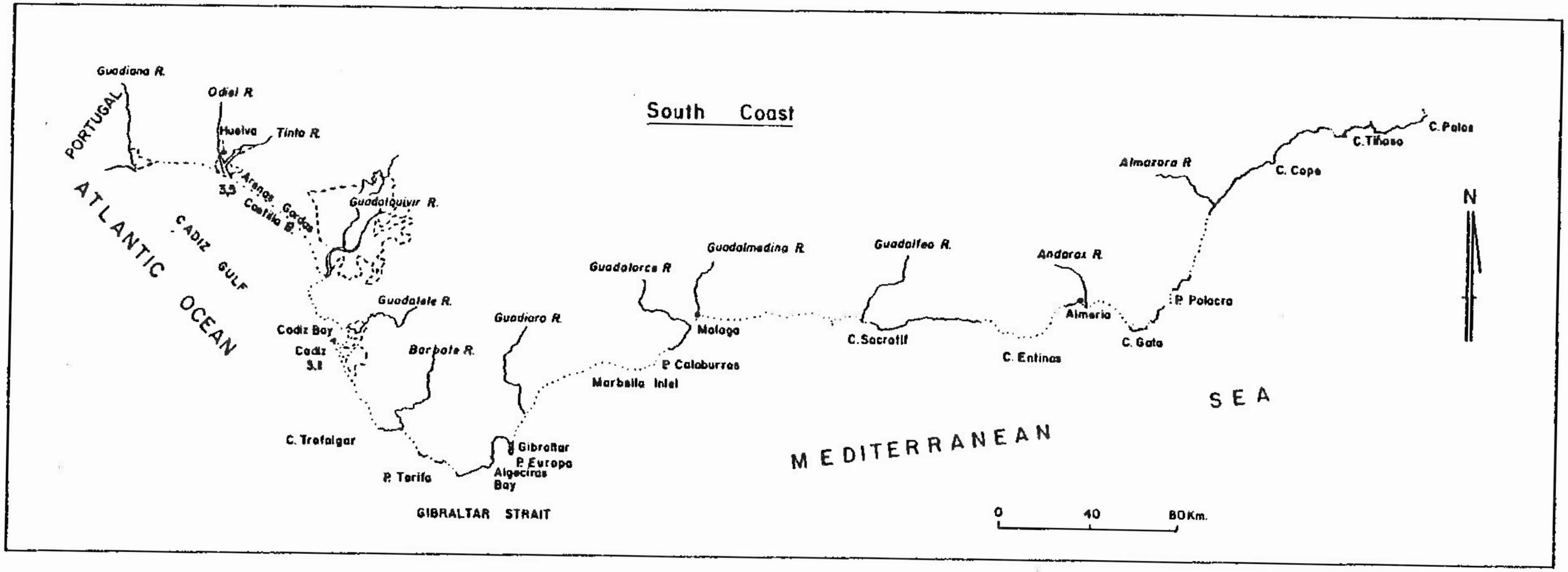
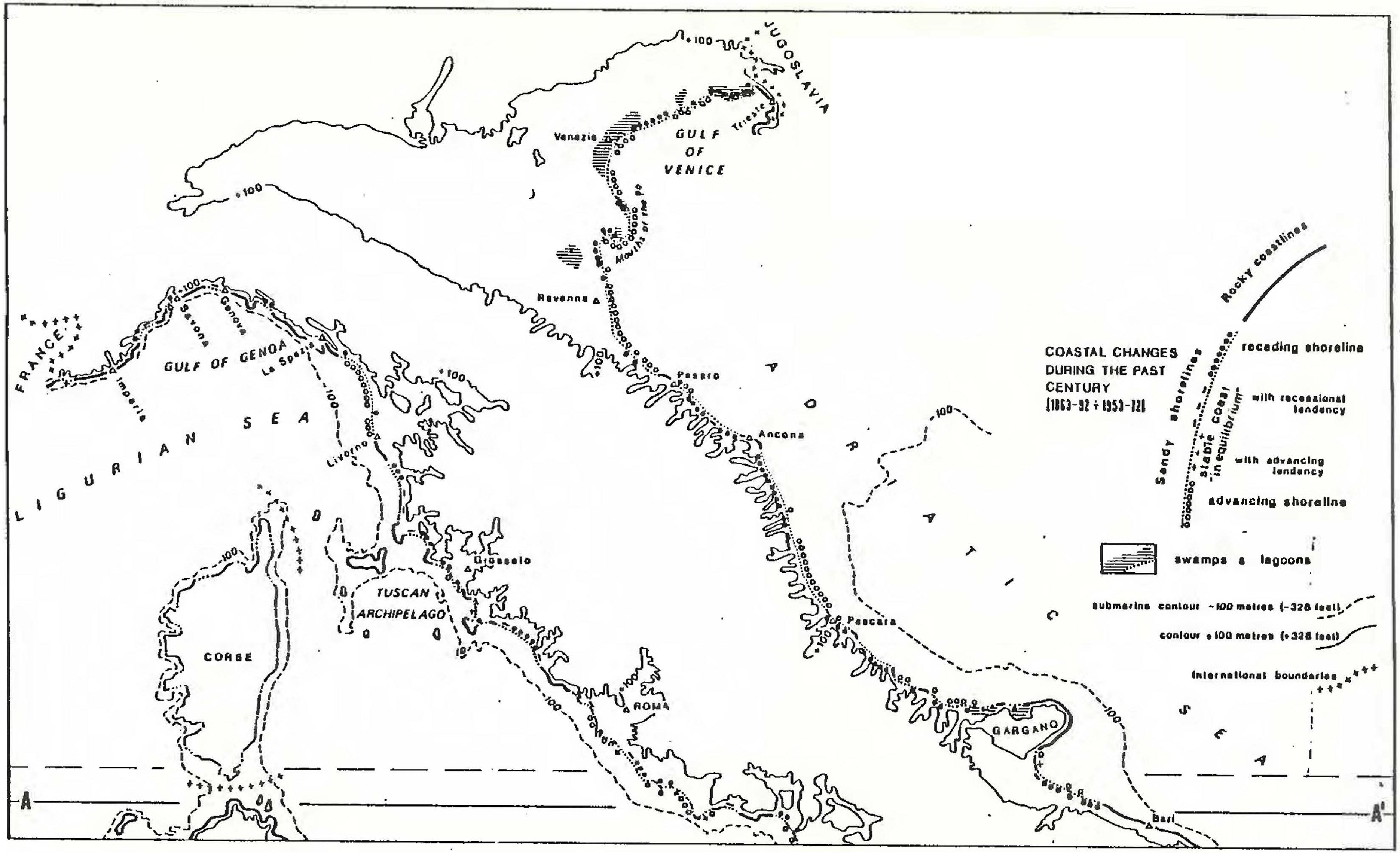


Figure 4 . Geomorphology of the southern coast of Spain.


COASTAL CHANGES
DURING THE PAST
CENTURY
(1863-92 ÷ 1953-72)
Rocky coastlines
receding shoreline
Sandy shorelines
stable coast in equilibrium
with recessional tendency
with advancing tendency
advancing shoreline
swamps & lagoons
submarine contour -100 metres (-328 feet)
contour +100 metres (+328 feet)
international boundaries
JUGOSLAVIA
FRANCE
GULF OF VENICE
GULF OF GENOA
LIGURIAN SEA
ADRIATIC SEA
TUSCAN ARCHIPELAGO
CORSE
GARGANO
Venezia
Trieste
Mouths of the Po
Ravenna
Pesaro
Ancona
Pescara
Bari
Genova
Savona
Imperia
La Spezia
Livorno
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ROMA
A
A'

Figure 5

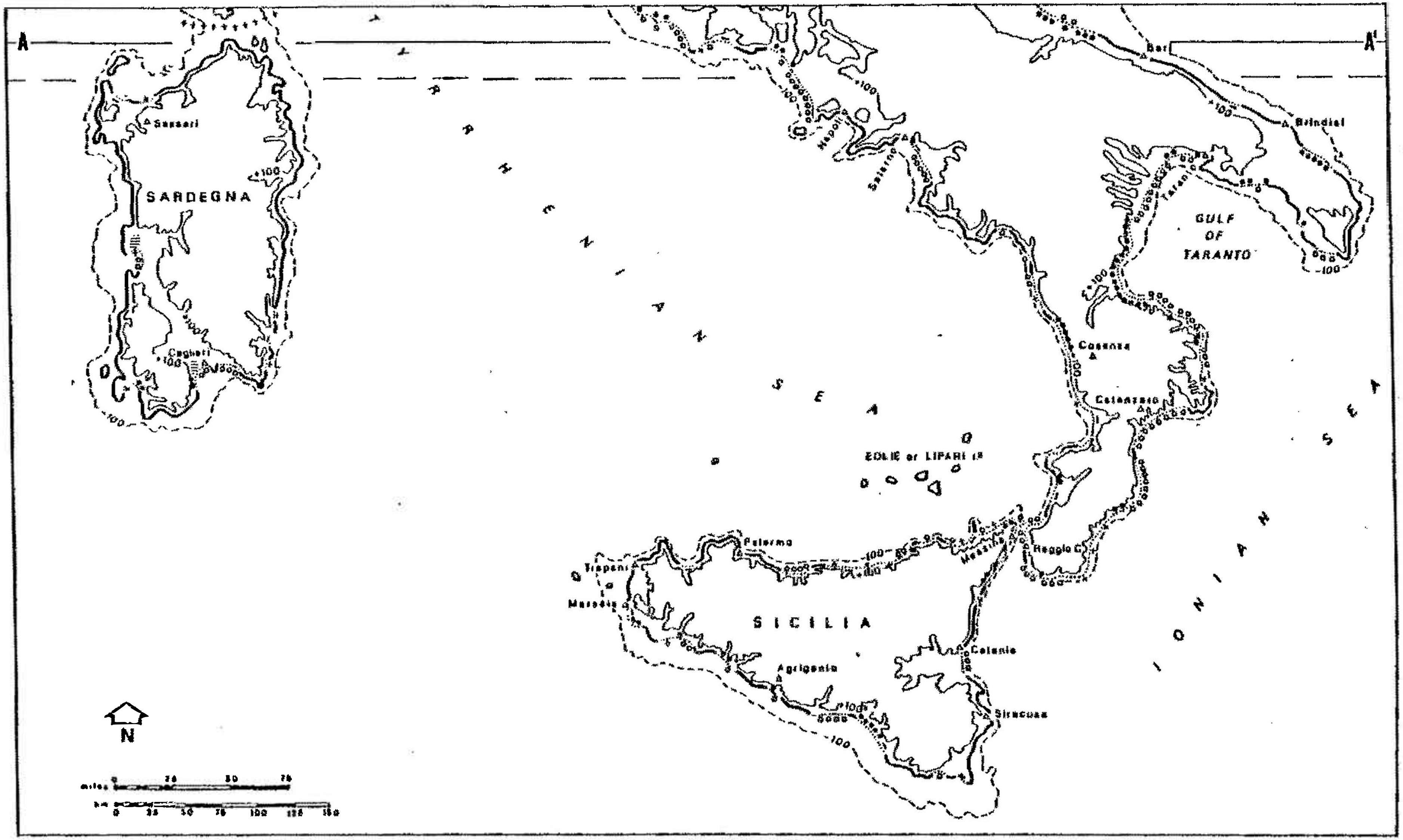


Figure 6 Italy: predominant coastal landforms.

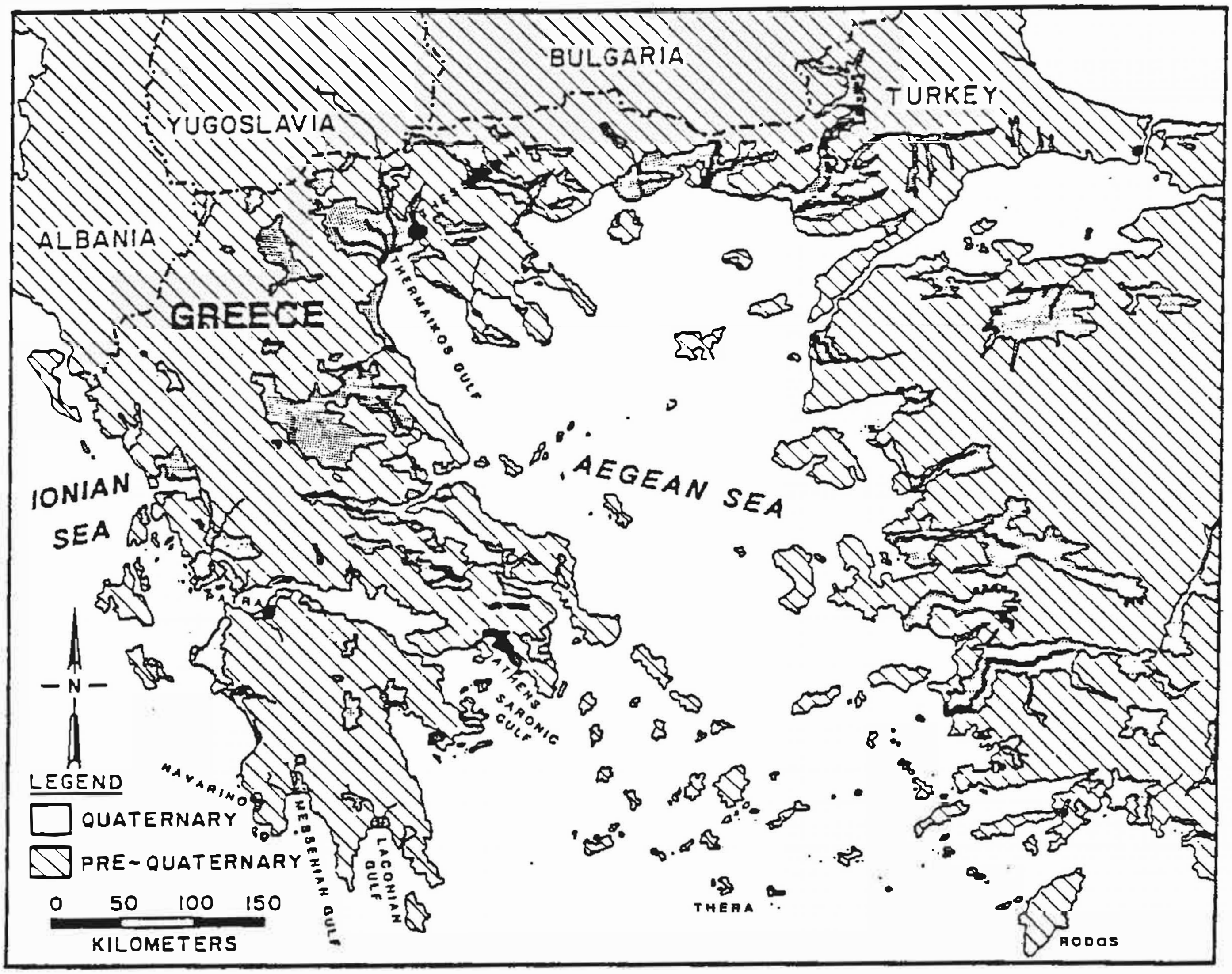


Figure 7 The peninsula of Greece and its islands in the Aegean Sea. Shaded areas are areas of Quaternary deposition and active areas of Holocene delta progradation and aggradation.

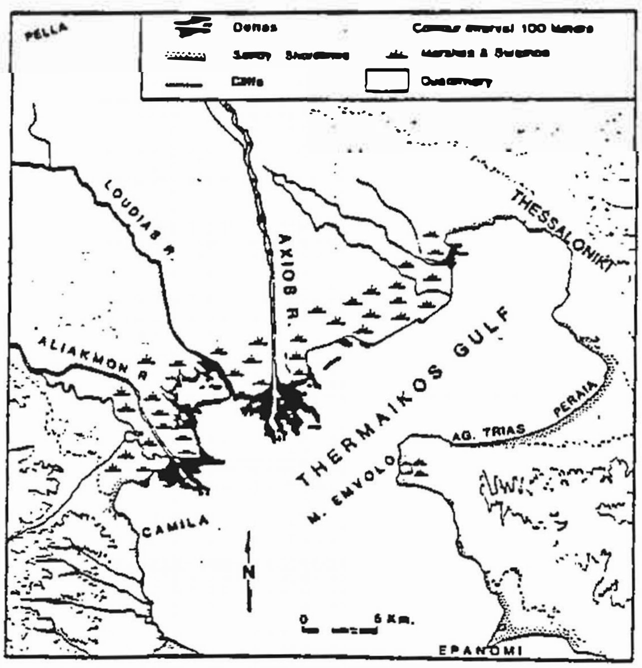


Figure 8 The delta of the Axios River and other rivers that are presently filling in the head of the Thermaic Gulf (a graben).

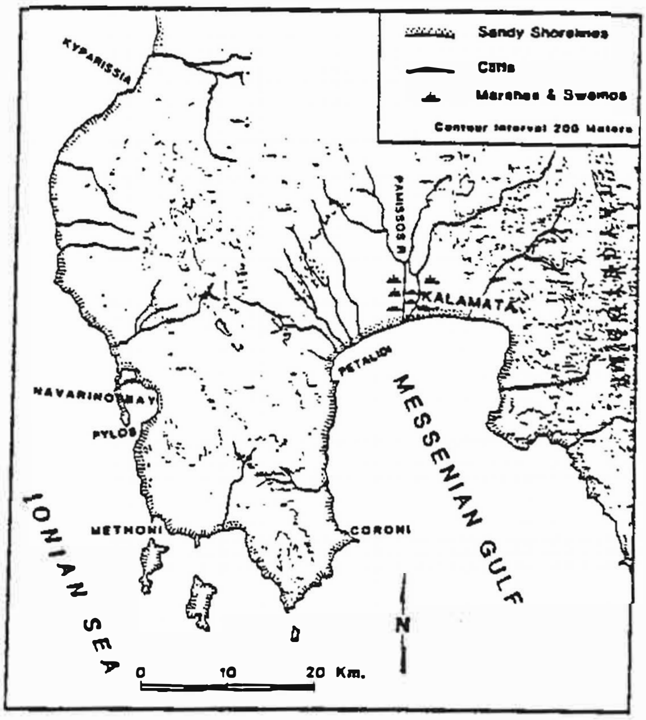


Figure 9 The Messenian peninsula and Gulf of Messenia (graben), showing the flood plain-delta of the Pamisos River and the embayment at Navarino.

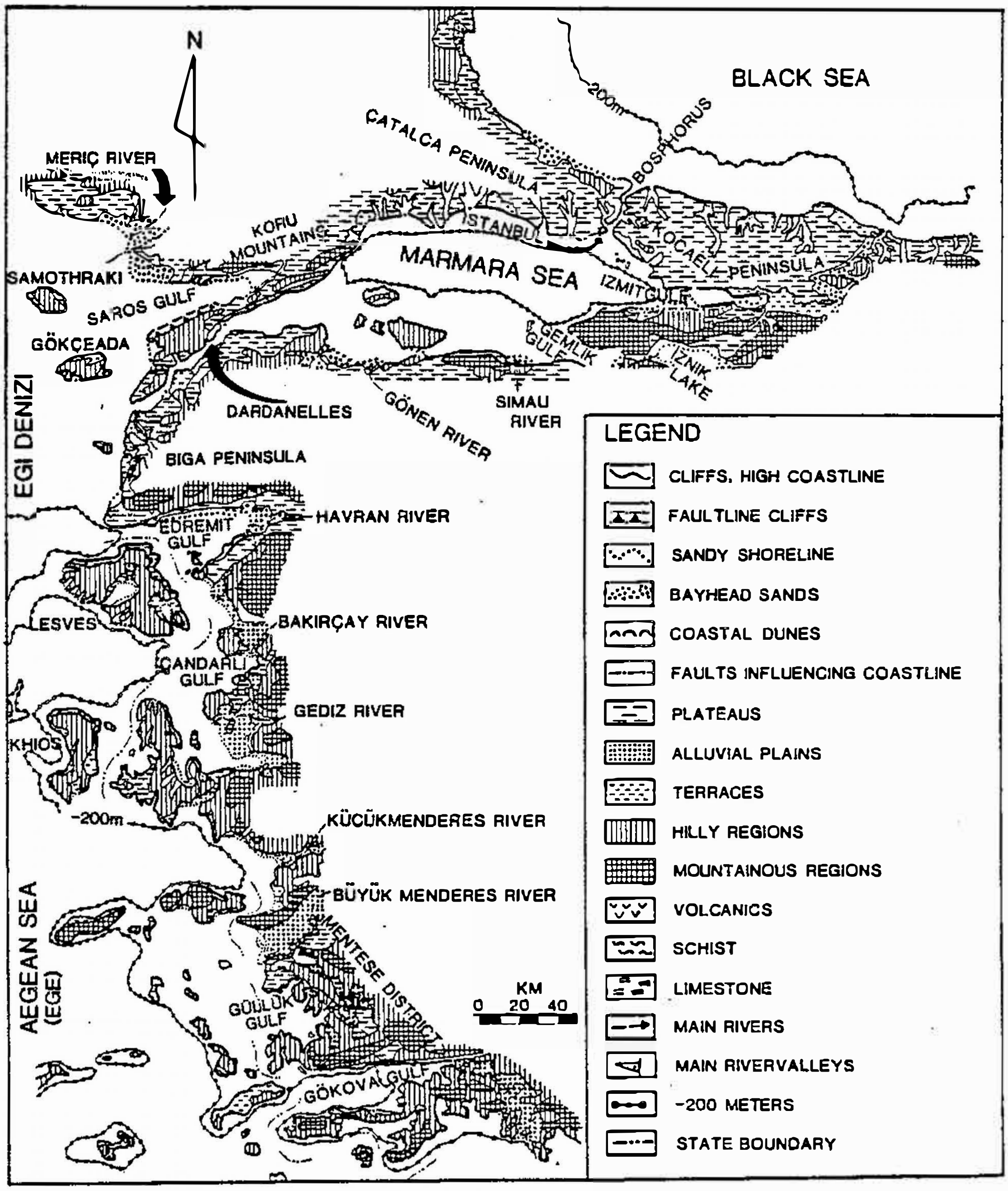


Figure 10 Geomorphic and geological features of the coasts of European Turkey

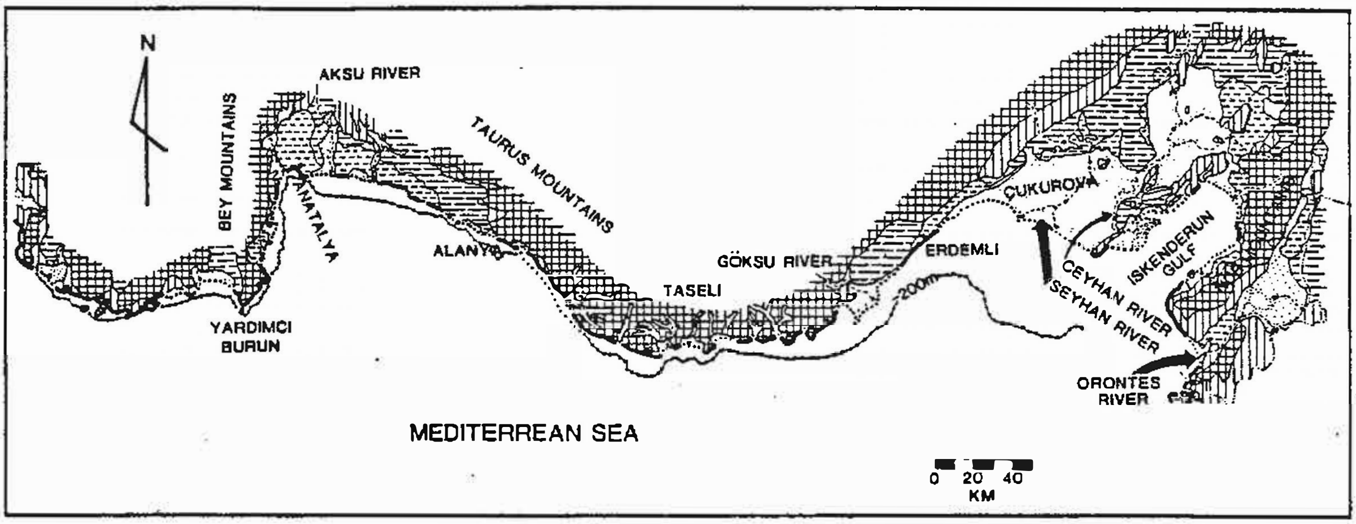


Figure 11 . A geologic and geomorphologic map of the Mediterranean (Ak deniz) coast of the Anatolian massif from Antalya in the west to the Gulf of Iskenderun in the province of Hatay in the northeastern Mediterranean. The narrow continental shelf is shown as related to the deeper Mediterranean offshore waters. See legend on Figure 68-2.

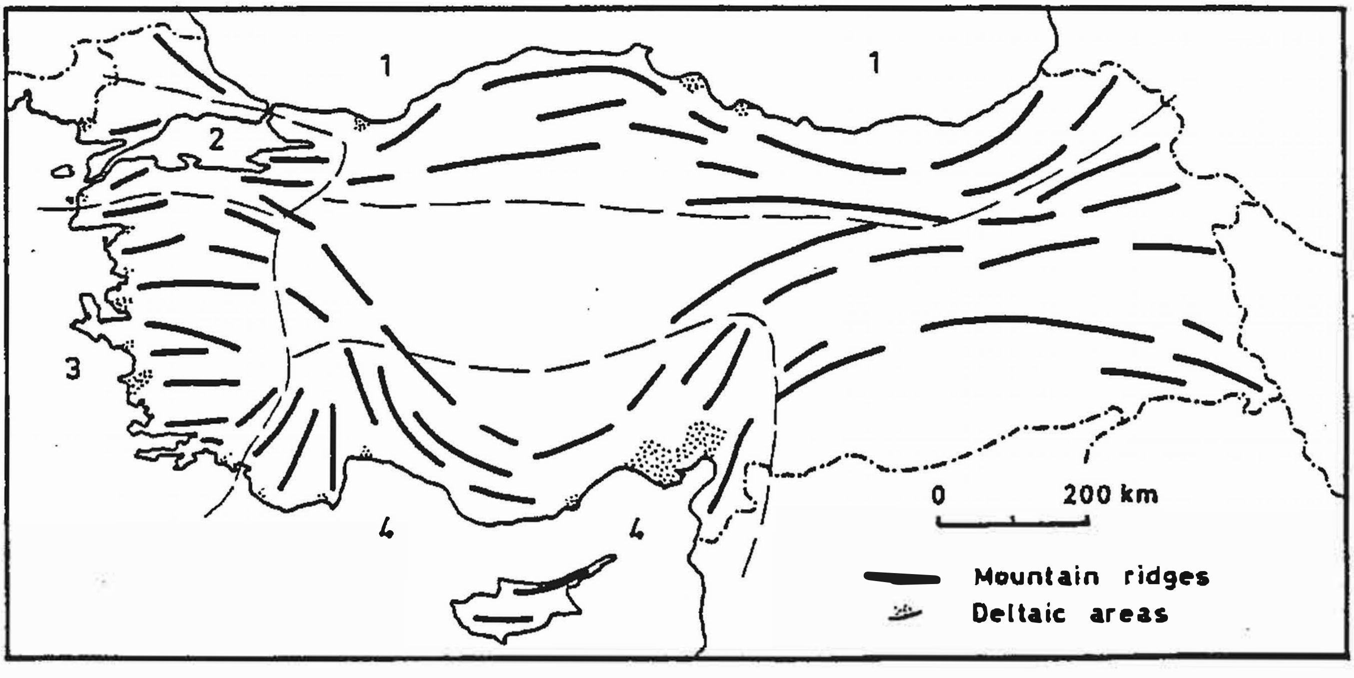


Figure 12 . Major structural lineaments as they affect the Anatolian coast.

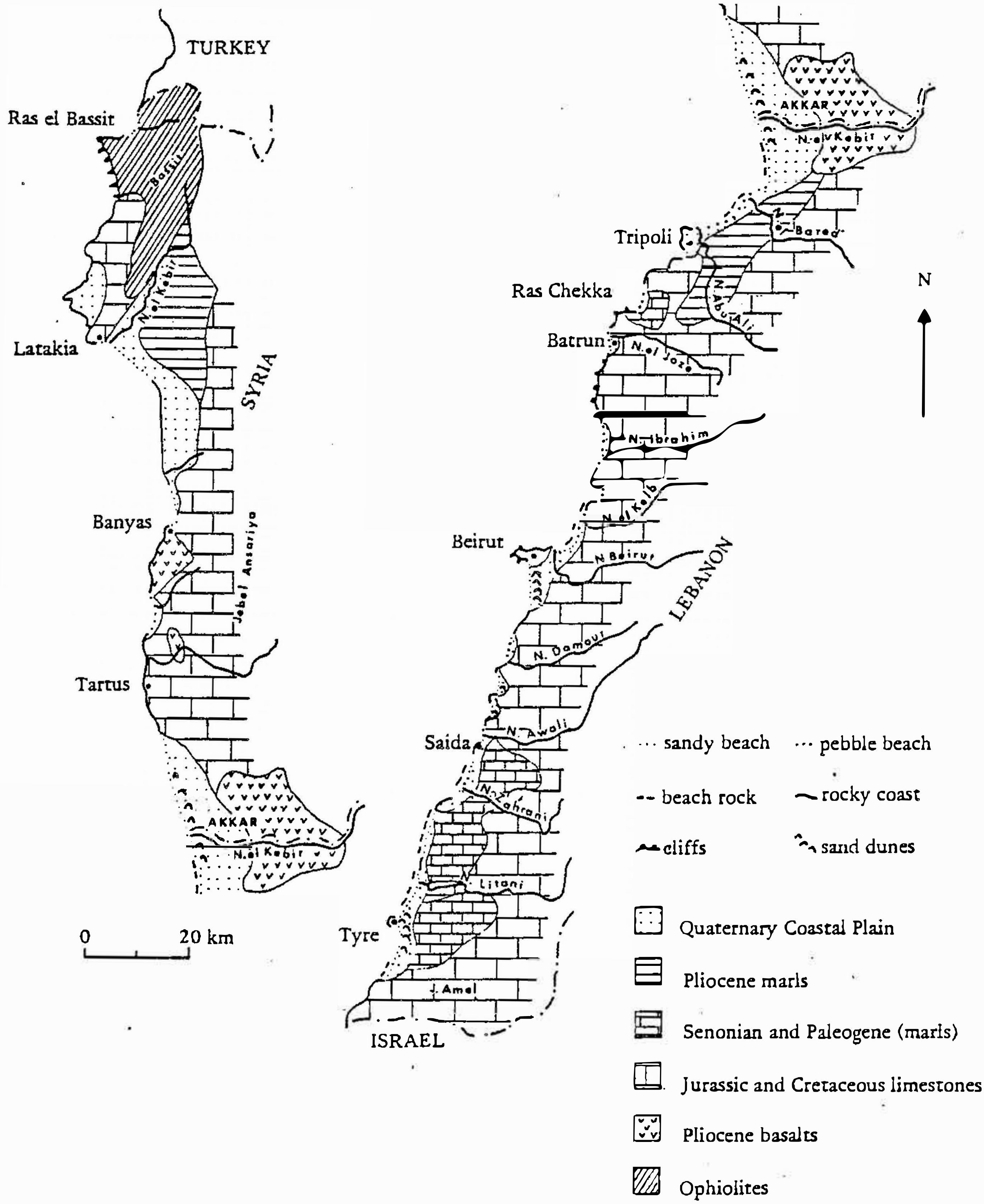


Figure 13 . Map of the coasts of Syria and Lebanon.

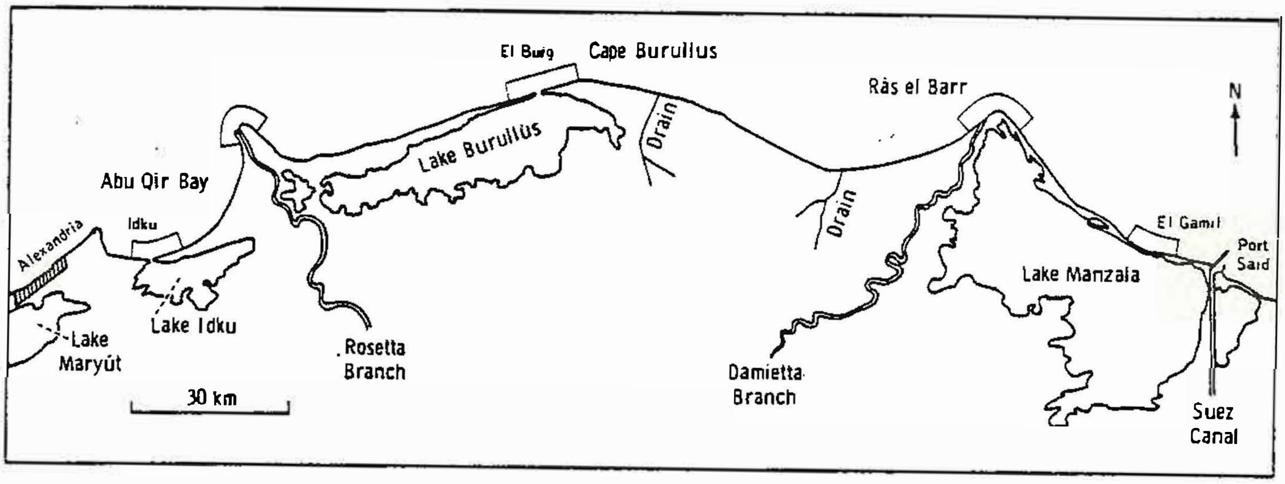


Figure 1.4. Index map showing coastal locations described along the Nile Delta coastline (after El-Ashry 1979).

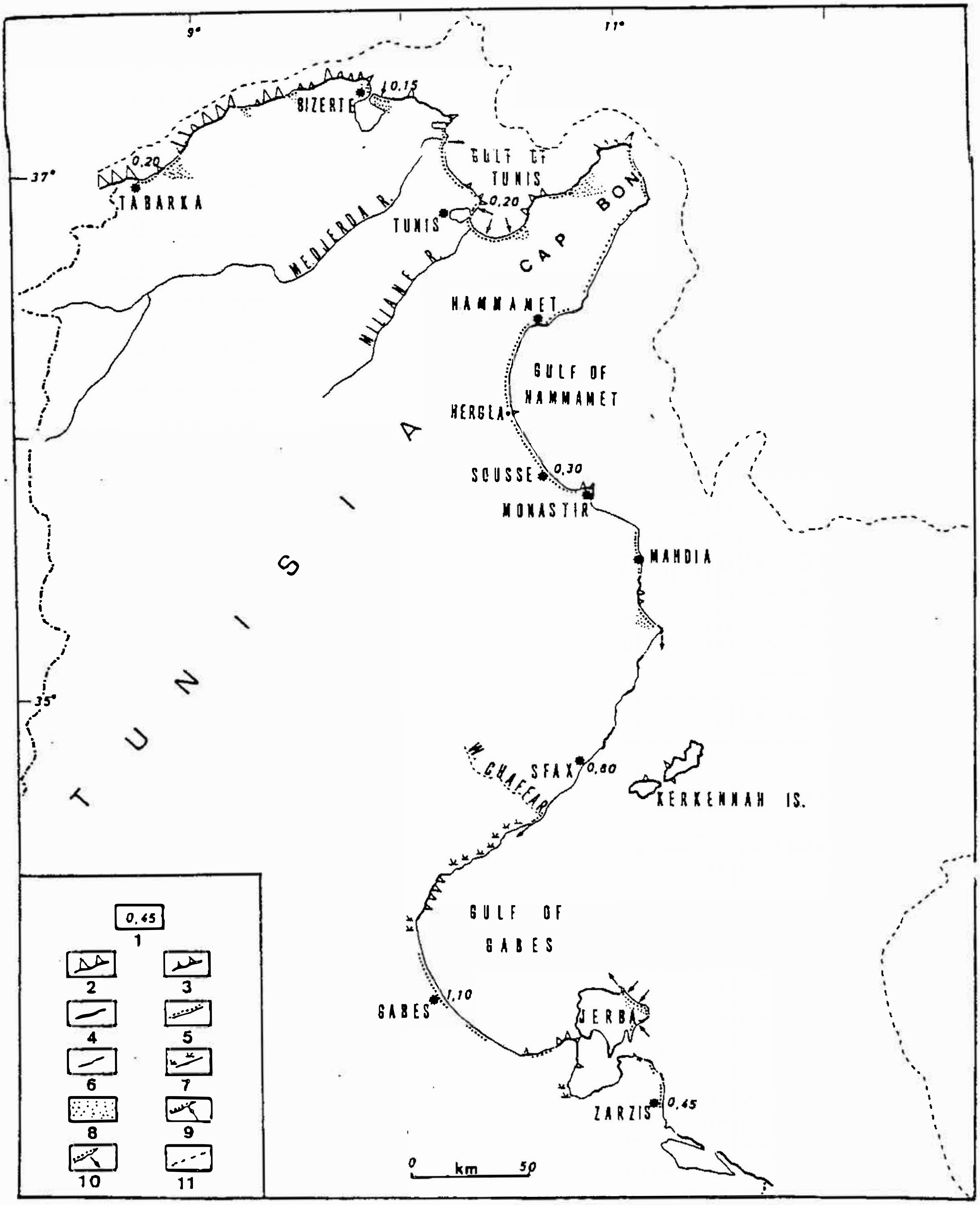
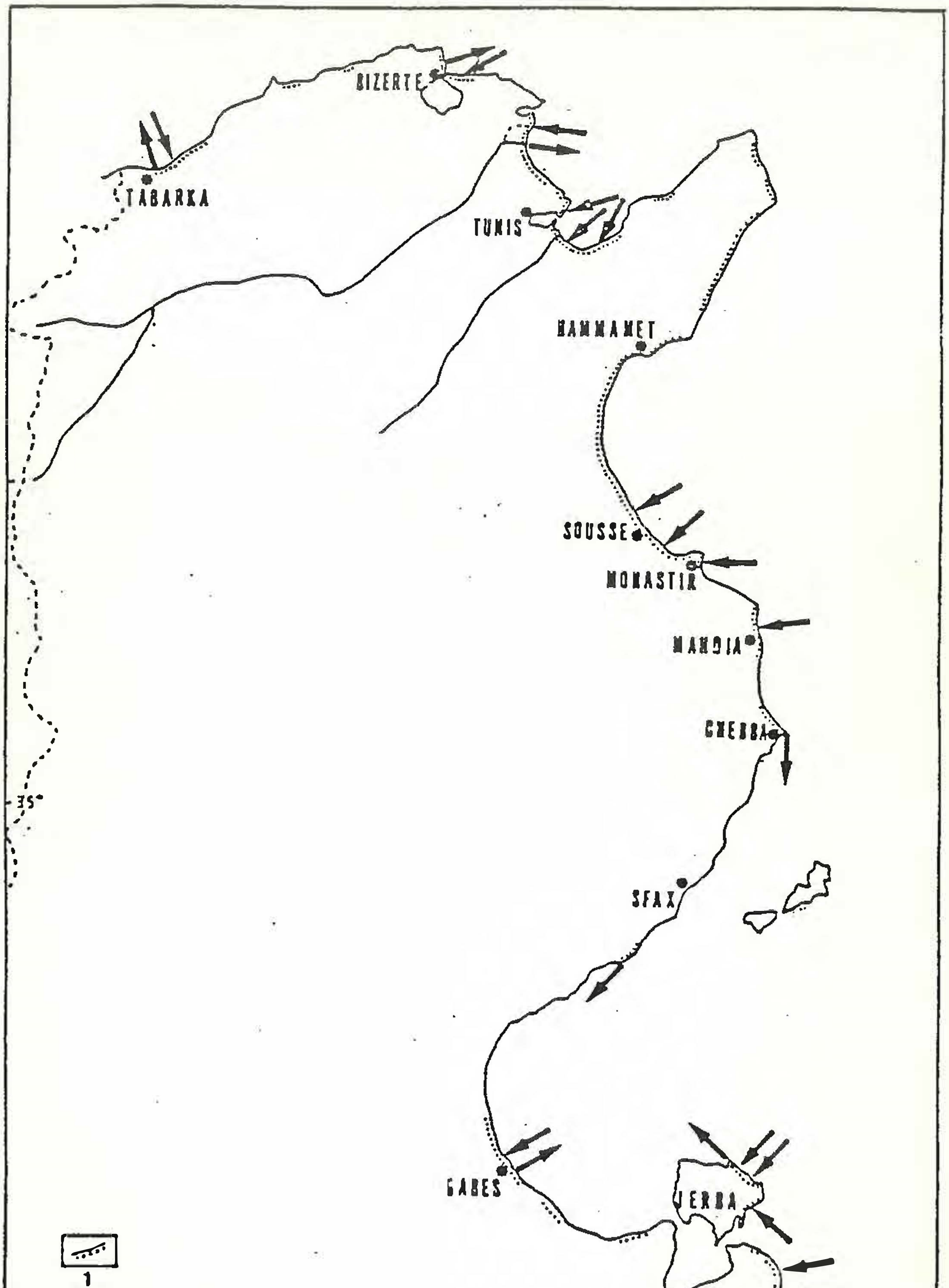


Figure 15 Predominant coastal landforms in Tunisia. 1. mean tide range; 2. cliff (more than 15 m high); 3. cliff (less than 15 m high); 4. low rocky shoreline; 5. sandy shoreline; 6. silty shoreline; 7. salt marshes; 8. coastal dunes; 9. retreating beach; 10. prograding beach; 11. −200 m isobath.



1. Plage stable
2. Plage en cours d'érosion
3. Plage en cours d'engraissement

Fig 16— Les plages en Tunisie

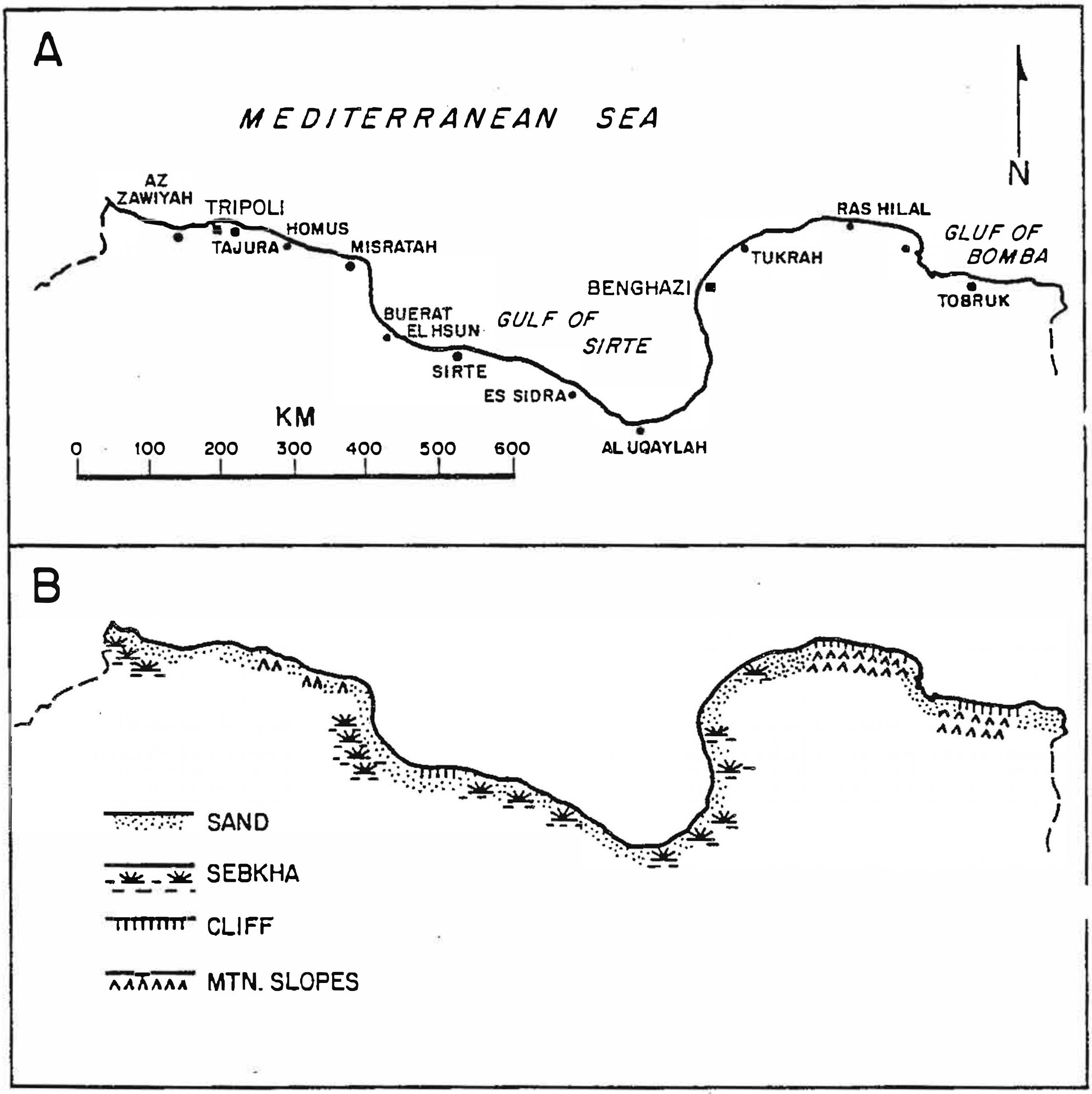


Figure 17 Maps of the coast of Libya: *A.* geographic; *B.* geomorphic.