

# Coastal erosion problems in Northern Aegean coastline, Greece. The case of the Rhodope Prefecture coasts

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## Abstract

Approximately half of the world's population are living or working in a narrow zone of a 100 km from the world coastlines. In this paper the erosion problems appearing in the central part of the Greek Thrace coastline (Rhodope Prefecture), are examined. The coastline studied is more than 100 km long and belongs to Xanthi-Komotini tectonic basin and is not well developed economically yet. From geomorphologic point of view the aforementioned coastal zone is principally a hilly area, consisting of Miocene, loose to semi-consolidated deposits (gravels, sands, silty-clays and conglomerates). This material is impregnated with  $\text{CaCO}_3$  and/or  $\text{SiO}_2$  in various degrees, forming a caliche (calcrete) deposit at the lower part of the column. The impregnation material is increasing with depth forming nodules of  $\text{CaCO}_3$  in the upper layers and turning to hard marl limestone or calcareous sandstone at greater depth. Small torrent deltas are built at the exits of valleys to the sea. The serious problems of the coastal erosion are concentrated principally to the upper, loose or semi consolidated part of the sedimentary column. The height of the coastal cliffs (bluffs) varies from one to 30 m and the rate of their retreat fluctuates from a few centimeters to 3 m/year. The causes of the coastal erosion is attributed to: (a) natural factors like sea waves and alongshore currents, subsidence of the broader area, increase of the sea water level, consistency of the material, etc. and (b) to human-induced changes e.g. regulation of water courses and construction of dams on the streams inland, which results in the depletion of sediments of the rivers' waters; construction of inlets, jetties, breakwaters and seawalls at the coastline; human induced subsidence due to groundwater over pumping, etc.

Soft shore protective measures such as beach nourishment, submerged breakwaters, artificial reefs, gravity drain systems, floating breakwaters, plantations of hydrophilic shrubs, etc. are proposed, depending upon the site and the cost.

Key words: North Aegean Sea, Thrace coast, coastal classification coastal erosion, and coastal protection.

## **1 Introduction**

Almost 80% of the world population is living in a zone of 100 km from the coastline. The intensive activities of these people impose increasing pressure on this limited space, causing the accelerated degradation of the coastal marine environments. Coastal problems include shoreline erosion, flooding, seawater intrusion, land subsidence, pollution, degradation of mangrove forests and marshes, etc. Natural phenomena like storms, tsunamis, rise of the sea level due to global warming, etc. would dramatically increase the number of people and property threatened by flooding and/or shoreline retrogression due to erosion.

In this paper we discuss briefly the geological evolution of the coastline and examine some erosion problems on a stretch of the coastal zone

## **2 Geological structure and evolution of the North Aegean coastline**

The Greek part of the north Aegean shoreline is more than 250 km long. The stretch examined in this paper extends from Fanari peninsula, up to Agios Charalambos, Rhodope prefecture. A stretch of around 100 km long (Fig. 1,2).

### **2.1 Geology**

The area under study belongs geologically to Rhodope Range geotectonic zone. This zone is consisted of high-grade metamorphic rocks like gneisses, amphibolites, mica schists, marbles, etc., and of low-grade metamorphic rocks such as phylites and metasediments. These rocks are of Mesozoic age. There are some younger formations as well, for example palaeogene and neogene sediments and some igneous intrusions, and volcanic deposits. Quaternary sediments cover, mostly, the southern area.

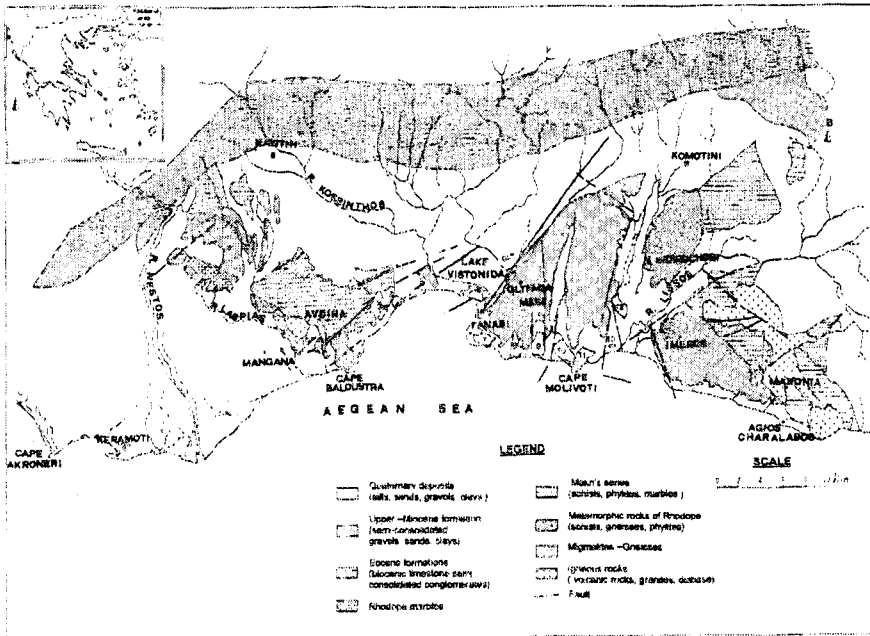
### **2.2 Geomorphology and relief of the broader area**

The coastal zone (a zone of 100 km in width starting from the shoreline) could be divided into three types of relief: the mountainous with high relief or high lands, to the north; the hilly relief of the palaeogene and neogene sediments to S-E; and the low-lands or plain area and river deltas to the south and west of the region.(Fig. 1).

### 3 Climate and winds

#### 3.1 Climate

The climate of the coastal zone at the N. Aegean Sea and S. Thrace is of Mediterranean type with warm and dry summers and mild, rainy winters. It is classified as *cfa* or *cfb* in the Koppen classification and as  $C_1dB'_2b'_4$  in the



Thornthwaite one (Flokas 1997, pp. 373-380).

Fig.1. Simplified geological map of the broader area of Thrace coast, N. Greece.

#### 3.2 Winds

The winds in northern Aegean Sea are quite strong reaching speeds up to 8-9 Beaufort (35-45 Knots or 60-70 km/h) or even higher, and creating waves up to 7 m high, in the open sea. The prevailing winds are of North to Northeast direction, during the winter and summer times and south to Southeast direction during autumn and springtime. The North and South winds are usually stronger than the winds from other directions. The winds in the eastern part of the area are generally stronger than the winds in western part. During summer (July, August and September) in northern Aegean Sea local winds called Etesians or trade winds, are blown. These winds are of N to NE direction and are sometimes up to 9 Beaufort (strong gale, 55-65 km/h), but most of the time they blow at 4-5 Beaufort. As the general trend of the Thrace shoreline is E-W, the north winds move the surface sea

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water to the south (to the open sea) and sea bottom water replenishes the surface one (upwelling), carrying with it bottom sediments full of fish food and other nutrients. These sediments are deposited near or at the Thrace coastline.

### 3.3 Tides

The height of the tide in the Mediterranean Sea is generally small. In the area under consideration it amounts between 0.40 and 0.50 m. During very strong winds it may reach more than 1.00 m at some embayments.

### 3.4 Waves

As it is known the wave height is directly dependent on the wind speed and the fetch. Offshore, in the western part of the area under study the height of the waves rarely overcomes 2-3 m, whereas in the eastern part the waves may reach up to 4-5 m or even more. The Thracian coast is open to the sea from south. The closer islands are Thasos, in the west, 7 miles offshore and Samothrace, in the east 24 miles offshore (Greek waters pilot, Vol. IV 1987)

### 3.5 Sea currents

There is an anticlockwise surface sea current in the north Aegean Sea. This circulation, in the open Aegean Sea, creates an east to west longshore current along Thrace coastline. This current flows with a speed of 0.5-2 knots (1-3 km/h) along the coast and is intensified by south and southeast winds, or retarded or even reversed by southwest and west winds (Greek waters pilot, Vol. IV, 1987). The longshore current is modified locally by the geomorphology of the coast and the sea bottom. As the coasts in the area are consisting mainly of soft to medium hard materials, like soft clayey soils, conglomerates, sands, etc., an easily erodible materials, there is a significant erosion and shoreline retreat at some places along the coast. The water depth and the sea bottom inclination near the shoreline are small as well. Thus the wave height and the speed of the alongshore current near or at the shoreline are reduced, but they still are very active creating a wide surf and swash zone.

## 4 Classification of the coasts

The coasts under study could be classified according to Shepard classification system (Shepard 1963, in King 1982) as *secondary coasts, formed principally by wave erosion in heterogeneous formations*. According to Valentin classification (Valentin 1952, in King 1982) they, in most parts, are *Eroding, Retreating, Retrograding, Clifed coasts*. There are, of course, a few stretches along the coast that are *Advancing, Prograding, shaped by fluvial deposition, small deltas coasts at rivers' and torrents' mouths*. These stretches are quite limited along the coastline under examination, e.g. the river Lissos estuary (Xeidakis and Delimani 2000 and 2001).

## 5 Materials and methods

For estimating the erosion rates of the coastline under this study topographic maps and air photographs of different periods were compared. At places with intense phenomena, field measurements were carried out from topographic points and other permanent points (poles) located inland or from small nails inserted, for this purpose, into the slope's surface.

In relatively soft cliff material, steel rebars (nails), 1.50 m long, were embedded into the ground (cliff) surface at 25-30 cm apart, in the vertical direction. Measurements were performed every three or six months or even each month or after a severe storm, depending on the site and the rate of the coastline changes.

## 6 Results and discussion

The results of this study show that the most part of the coastline is under erosion and retreat with a few exemptions around the river's and the torrent's mouths. However, the rate of the coastline retrogression varies from place to place from 0.0 m/yr up to 3.0 m/yr, depending upon the strength of the coastline material, the local conditions of the sea waves and alongshore currents and the direction of the shoreline in relation to the prevailing winds in the particular area.

The retreat of the shoreline is attributed to:

- the effect of the sea system (waves, currents, winds, etc. )
- the effect of the terrestrial agents (dam construction, irrigation systems, regulation of the river courses, etc. )
- the human interference at the coastline (construction of ports, breakwaters, groins, fishing ponds, etc.)
- the relative increase of the sea level, which is considered to be around 12-15 cm during the last one hundred years (Titus, et al, 1995, Maroukian, et al 1999)
- the low consistency of the soil/rock material at the coastline cliffs (loose to moderately cemented sands, gravels, silts and caliche).
- the almost vertical jointing of the hard soils in some cliffs
- the low permeability of the surface deposits due to relatively high content of clay or cementing material, which keeps high water table during the rainy season
- the entrenchment of the course of river Lissos, the bigger perennial river in the region. This resulted in depriving its delta plain of ponding waters and sedimentation material inland and the alongshore sea current of land sediments.

The more severe erosion and retreat rate of the coastline, in the area under examination, appears at the Esochi, Maronia stretch of the shoreline (eastern part). The cliff there is almost vertical and from 5,0 m to 15,0 m high. It consists, from top to bottom, of a layer of humus 0.5-1.5 m, a layer of loose to semi-consolidated sand and gravels of 4,0- 5,0 m, another layer of silty-sand to gravel-sand followed

by a layer of poorly to well cemented sand with clay (caliche). The cemented material is  $\text{CaCO}_3$ , and its content is increasing with depth, turning the formation to marl or marl limestone and calcareous sandstone (soft rock) and further deep to hard limestone and/or sandstone. The whole soil-rock column is intersected by two almost vertical joint sets, which intersect at around 70-80 degrees, each other, and 30-40 degrees with the cliff face.

The reason of the intense rate of erosion (2-3 m/year) in this hill is believed to be the relatively soft material of the cliff and the diffraction of the sea waves and alongshore current to northwest at the south breakwater end of Agios Charalambos small port; the port is around 5 km further east of the slope. It should be reminded that the prevailing sea current in this area is from the east to west (Photos 1,2,3,4,5,6)

## 7 Protective measures

Soft shore protective measures such as beach nourishment, submerged breakwaters, artificial reefs, gravity drain systems, floating breakwaters, plantation of hydrophilic shrubs, etc. would be the best way of protecting the coastline from erosion, adapted to the site and the money available. Unfortunately very little or nothing has been done so far for protecting the retreating coasts in the area, as the local authorities think that it is not cost effective, at the moment.

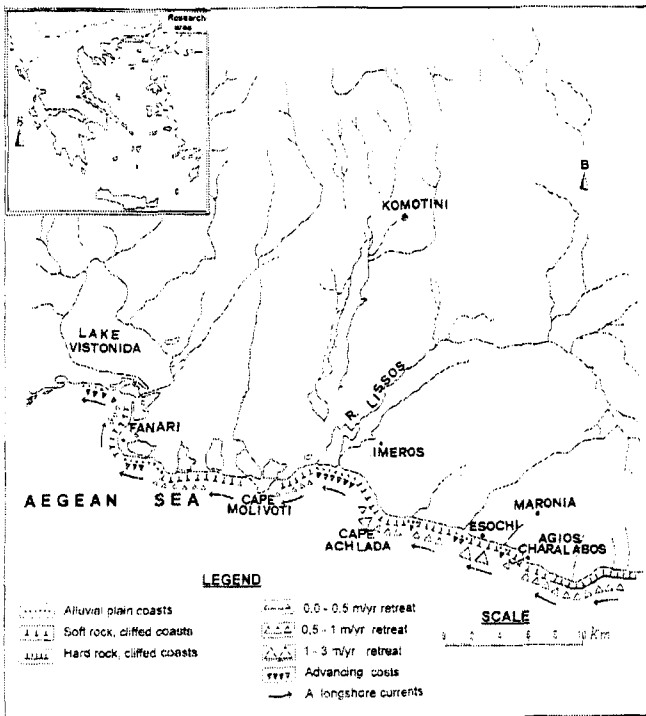


Fig.2. Erosion rate at Rhodope Prefecture coasts, Thrace, northern Greece.

## 8 Conclusions

From the aforementioned study the following conclusions could be withdrawn:

The coastal zone is vital for the survival and the prosperity of the Greek people

The coastal zone in the area has a hilly relief with hills from 0.0 m to 50 m high

The shoreline is principally cut in soft rock to hard soil material forming cliffs of 0.0 m to 30 m high. The cliffs are consisted of layers of gravels, sands, silts and clays, alone or mixed up, semi-consolidated and cemented by  $\text{CaCO}_3$ . The lower layers of the column turn to calcareous sandstone and/or to limestone.

The prevailing winds in the area are moderate to strong (speeds up to 60-70 km/h, 8-9 Bf) and of north to northwestern direction during winter and summer time and south to southeastern during autumn and spring time.

The sea waves height offshore varies from 3 m to 5 m and the prevailing alongshore current is from east to west direction flowing with a speed not more than 1-3 m/h.

The coasts in the examined part are classified according to Shepard as secondary, wave cut coasts, and according to Valentin as eroding, retreating and cliffed coasts with a few stretches of advancing coasts.

The part of the shoreline under examination is principally eroding and retreating with a rate that varies from a few centimeters a year up to 3 m/yr.

The erosion of the shoreline is attributed to the effects of the sea system (waves and currents), the intervention of man to the hydrographic system inland and the construction of engineering works at the coastline (ports, groins, breakwaters, etc.), to sea level increase, to relatively soft material of the coastline, and so on.

The suggested protective measures are soft shore protective ones like beach nourishment, submerged breakwaters and groins, plantation of the cliffs with hydrophilic shrubs, etc.

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Photo. 1. Sand-silt-clay soil impregnated with  $\text{CaCO}_3$  (Caliche) at Glyko Nero, Imeros, Rhodope Prefecture



Photo. 2. Slope failure (soil falls) in silty-clay soil (old slide material) at kyria location, Proskynites coast, Rhodope.

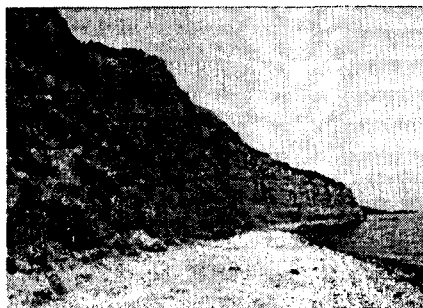


Photo. 3. Cliff failure due to wave undercutting in gravel-sand-clay, semi-consolidated soil (hard soil/soft rock) at Korakies site, Proskynites coast, Rhodope Prefecture. Retreat in soft soil 1-2 m/yr, in hard soil 0.10-0.30 m/yr. Height of slope 29 m

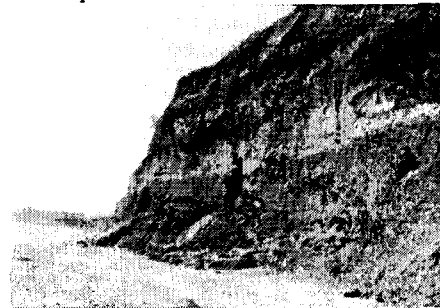


Photo. 4. Slope failure (falls) due to wave undercutting in loose to hard sand-silt soil with clay at Esochi site, Proskynites coast, Rhodope Prefecture. Height of slope 13 m. Rate of retreat 2-3 m/year



Photo. 5. Nails embedded in caliche (calcrete) on a cliff face to measure erosion.



Photo. 6. Cliff undercutting at Glyko Nero, Imeros, Rhodope. The variation in erosion is due to the differences in soil consistency. Height of the cliff 12-15 m.