THE GEO- AND MORPHODYNAMICS OF AN ISLAND SYSTEM, AS THE FACTORS CONTROLLING THE FORMATION OF DEPOSITIONAL COASTAL SYSTEMS. CASE STUDY: ANDROS ISLAND (CYCLADES - GREECE)

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Abstract

In the present paper we aim to approach the mechanisms of the geo- and morphodynamics of an island system, as the factors influencing the formation of coasts. Emphasis is given to the formation of depositional coasts. As case study area Andros island is selected. The geodynamics of the area is characterized by the uplifting tectonics and the fragmentation of the area. The geodynamics controlled the morphology of the area, the formation of drainage basins and the hydrographic networks. All these geo- and morphodynamical processes resulted to the formation of the coasts. The rocky coasts dominate. The depositional coasts have limited extension. They have the form of "pocket beaches".

The dominating length of the beaches fluctuates from less than 50 m till 200 m. The width of the "pocket beaches" can be differentiated in the active beach zone (5-15 m) and the older depositions, which reach a mean width of 50 m. The beach material consists on very well rounded gravels and coarse sand.

Tourism and the recreational settlements, called "second houses" are the main activities threatening the coasts of Andros island. There is a need to manage the coasts of Andros island.

Key words: Andros island, drainage systems, depositional coasts

1. Indroduction

The aim of this work is to study the mechanisms of the geo- and morphodynamics of an island system, as the factors controlling the formation of depositional coastal systems. The study area is the Andros island (Cyclades - Greece). The rocks, their properties and their areal distribution, the erosion, the morphology as well as the hydrographic network, are factors controlling the processes of the sediment production, sediment transport and sediment deposition. In Andros island the man's impact is low, so that the original natural conditions are almost conserved.

This study helps the understanding of the concept of the provenance research that means to look rational at the processes, from the producers to the products, from the source to the sediment.

The study is more empirical and data oriented. Modern GIS techniques are used.

2. The study area

For the purpose of this study, Andros island in Aegean Sea (Cyclades – Greece) is selected (Fig. 1). Andros island is the northest island of Cyclades island complex in Greece, with an elongated form and an orientation NW-SE, a length of 39,5 km and a maximum width of 14,5 km.

Fig. 1: Localization of Andros island in Aegean Sea (Greece)

3. The factors controlling the production of sediments

3.1. The geodynamics

The Cyclades islands are underlaid by high pressure metamorphic rocks that represent the crustal roots of the Mesozoic orogenic belt. The orogen is fragmented during the continental extension. The resulted fragments have undergone vertical movements, which created the island complexes in the Aegean Sea (Lister & Raouzaios, 1996).

Looking at the geological structure of Andros island (Fig. 2) (IGME, 1978) metamorphic rocks are dominated, divided into two main tectonic units, the lower unit of an unknown age and the upper tectonic unit, which is overthrusted over the lower unit. The age of the upper unit is Upper Paleozoic.

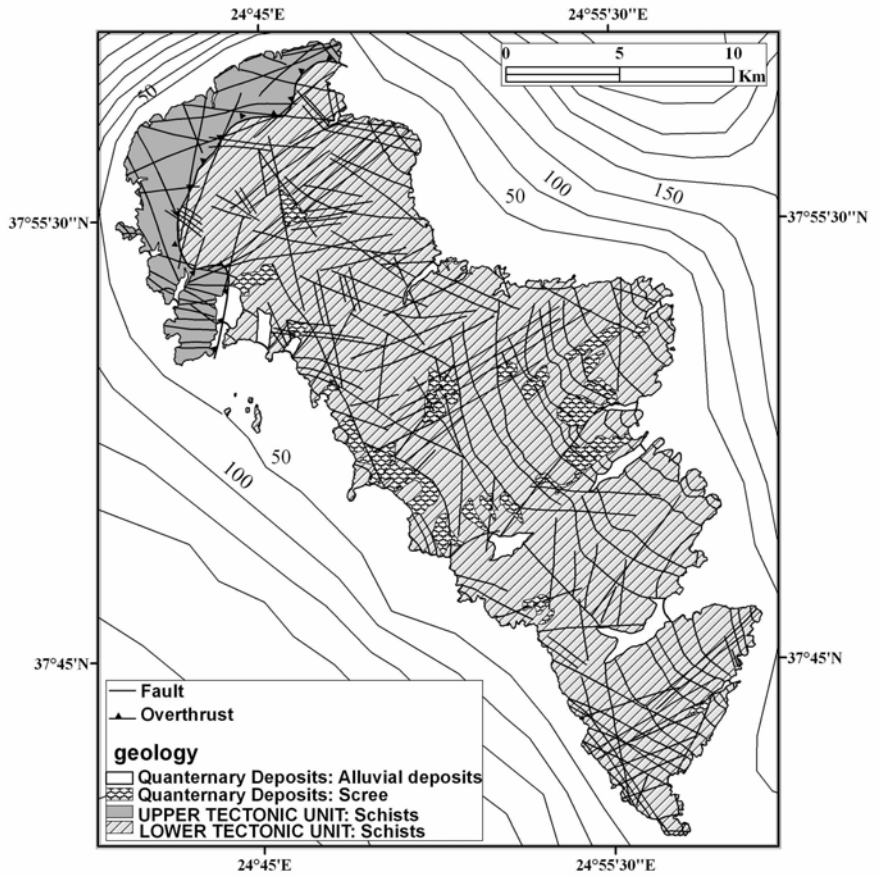

Fig. 2: The geological map of Andros island (based on the map of IGME, 1978)

Both units consist of schist, which is the dominated petrographical formation. In some areas schist is alternating with marble horizons, marble thin layers and marble lenses. The study area is underlaid by an active uplifting tectonics, The faulting phase of the island is characterized by the domination of two fault systems, the first one with the NW-SE direction and the second one with the SWW-NEE direction. Both systems, but mainly the fault system of SWW-NEE direction, influenced the morphodynamical evolution of the area. The post deformational history of the island is characterized by the Quaternary sedimentary deposits, scree, consisting of loose breccias with boulders of marbles and schist into a silty sandy matrix, and alluvial deposits, mud, sand and gravel.

3.2. The morphodynamics

The area shows a relief relative high and differentiated, with elevations more than 900 m (Fig. 3). Steep slopes dominate. The basin and channel network is studied in order to understand how the processes of sediment formation in the coast are influenced by the geomorphology. Further of it, it is aimed to determine if there are any definable and quantifiable geomorphological characteristics, which are transmitted as distinguishable signals into the river mouth sediments of the basins. Drainage divides, drainage basins and channel network are treated.

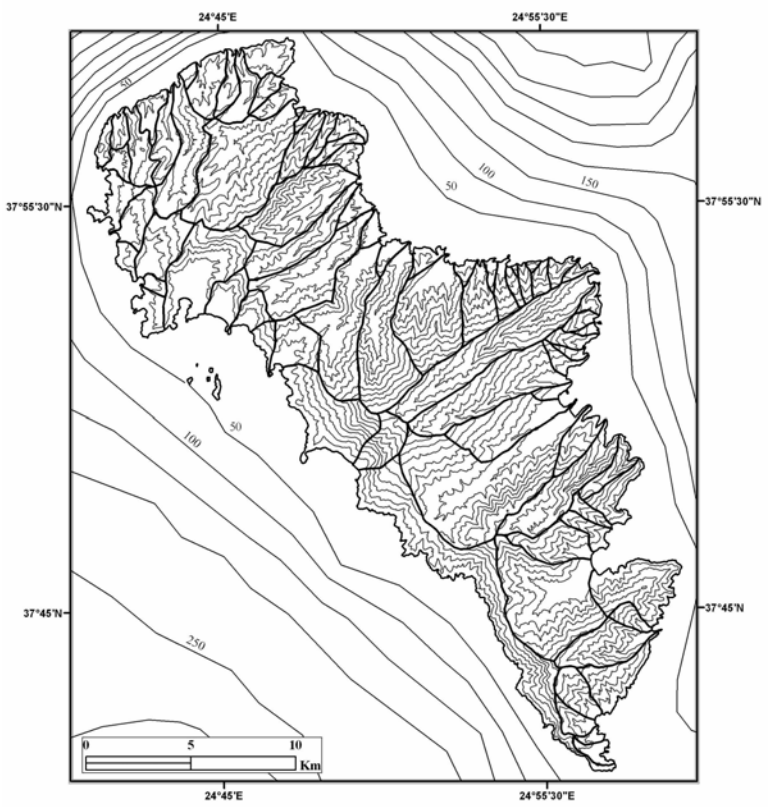

Fig. 3: Geomorphological map of Andros island, hundred meters isolines and the drainage basin divides (For the production of this map three basic maps, 1:50.000, are used, edited by the Hellenic Military Geographical Service, HMGS, 1990, 1990a, 1991).

a. The drainage divides: The drainage divide or watershed is the line of separation between two adjacent drainage basins. We define the central drainage divide of the island as the zero order. Each divide branching of this zero order is a first order divide. The first order divide branches and forms the second order divides, from the bifurcation point and so on. We distinguish also a concrete number of segments with a concrete length. We counted 139 segments (elements) of drainage divides (s. Fig. 4). The drainage divide segments are classified in orders (from 1 to 9) and their frequency distribution show that the most frequent are the first order segment with the 25% frequency and the second order segment with the 24,5% frequency, the third and fourth order segments with the corresponding 18,5 % and 13,0 % frequency. We calculate the mean and the total length of the divide segments of each order. The mean lengths of the divide segments are: in the 1st order 2,5 km, in the 2nd order 2,4 km, in the 3rd order 1,9 km, in the rest orders (4-9) ~1,5 km. The total length of the divide segments of each order are: for the 1st order 88 km, the 2nd order 82 km, 3rd order 50 km, 4th order 26 km, 5th order 15 km, 6th to 9th order 3-7 km. The orientation of the drainage divides follows the directions of the SWW-NEE fault system

b. The drainage basins: A drainage basin (drainage area or catchments area) is the area enclosed by the drainage divides and the coastlines. A number of 84 basins is outlined (Fig. 4). However the term basin is delimited to the 47 relative larger rivers, with a treatment of their fluvial sediments. The smaller drainage basins without such a treatment are designated as interfluves. The interfluves are mainly the real inter basin areas along the coast, between the river mouths of the larger basins. Most of these interfluves have no clear or no barely distinguishable networks or outflows to the sea. The basins show mainly a SWW-NEE direction, as a result of the second fault system, which show the same direction. The basins are also classified in orders (from 1 to 9) (s. Fig. 4). Number of basins, area and orders are statistically analyzed in order to go deeper to the understanding of the complexity of the natural processes and to formulate some general conclusions. From the 84 basins and interfluves, 30 are classified in the 1st order, 19 in the 2nd order, 13 in the 3rd order, 9 in the 4th and the rest 13 in the 5-9 orders. The mean area of the basins and interfluves for each order are: ~8 km^2 for the first order, ~4 km^2 for the 2nd order, 2 km^2 for the 3rd order and ~1km^2 for the rest of the orders (4-9 orders). The total area (sum) of the basins in each order are: ~250 km^2 in the 1st order, ~80 km^2 in the 2nd order, ~25 km^2 in the 3rd order, 15 km^2 in the 4th order and ~5 km^2 for the rest of the

orders (5-9 orders). The 47 larger river basins can be grouped in some basin shapes: rectangular subparallel, rhomboidal, pear-shaped, bottle shaped, angular basins (Fig. 5) (Ibbeken & Schleyer, 1991). Elongated basins are by far the most common in the study area. The interfluves show triangular and rhomboidal shapes.

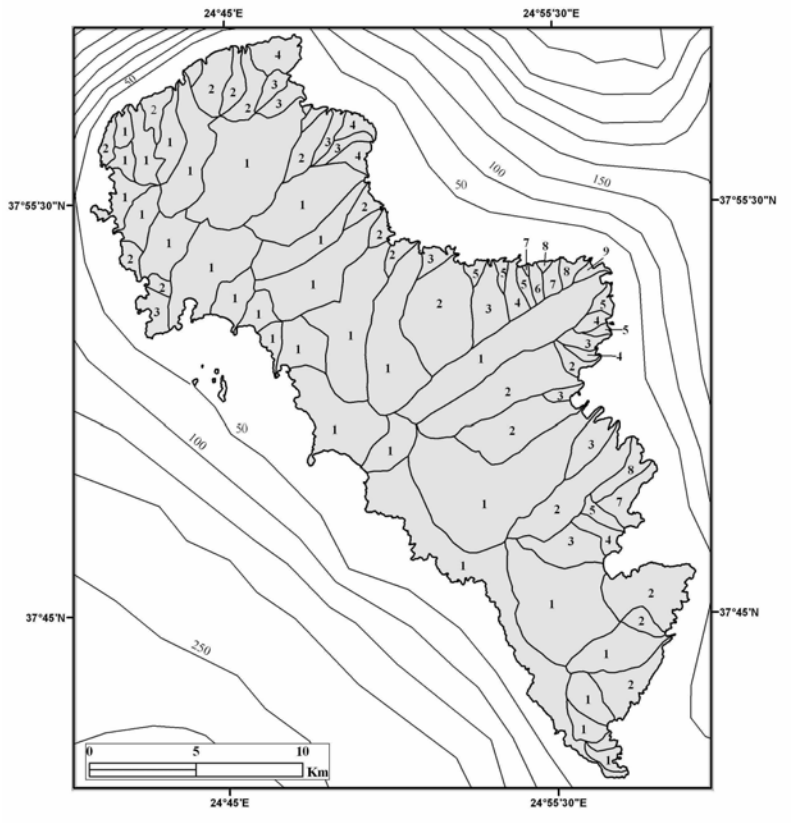

Fig. 4: Map showing the drainage basins, the interfluves and their order of Andros island. The numbers show the order of the basins and interfluves.

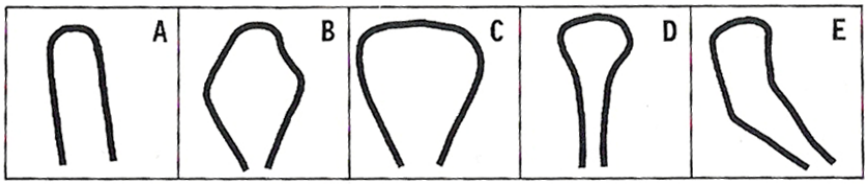

Fig. 5: Basic basin shapes used for grouping the basins and interfluves of Andros island: A rectangular subparallel, B rhomboidal, C pear-shaped, D bottle shaped, E angular basins (after Ibbeken & Schleyer, 1991, p. 23).

c. The channel network: We analyzed the channel network using the principles established by Strahler (1964). In Fig. 6 the hydrographic network for each drainage basin is shown. The stream orders are studied designating the smallest fingertip channels of a network as order 1. Where two first order channels join a channel segment of order 2 is formed, where two of order 2 channels join a segment of order 3 is formed and so on. A significant result of this approach is the orientation of the channels. The dominated directions of the channels are the NE-SE and the SW-NE, following the fault orientations (s. geological map in Fig. 2). The main streams of the channel network have the orientation SW-NE.

d. Some important remarks to the submarine morphology: The submarine morphology around the Andros island shows sharp rocky cliffs along the coastlines and a sea bottom with relative intense slopes. The mean declination of the sea bottom around the island shows values from 2-5 %. These remarks are important in order to define the capacity of the sea bottom along the coasts as receiver of the transported

sediments through the river systems. This coastal and submarine morphology do not allow the accumulation of sediments along the coasts and the formation of beaches.

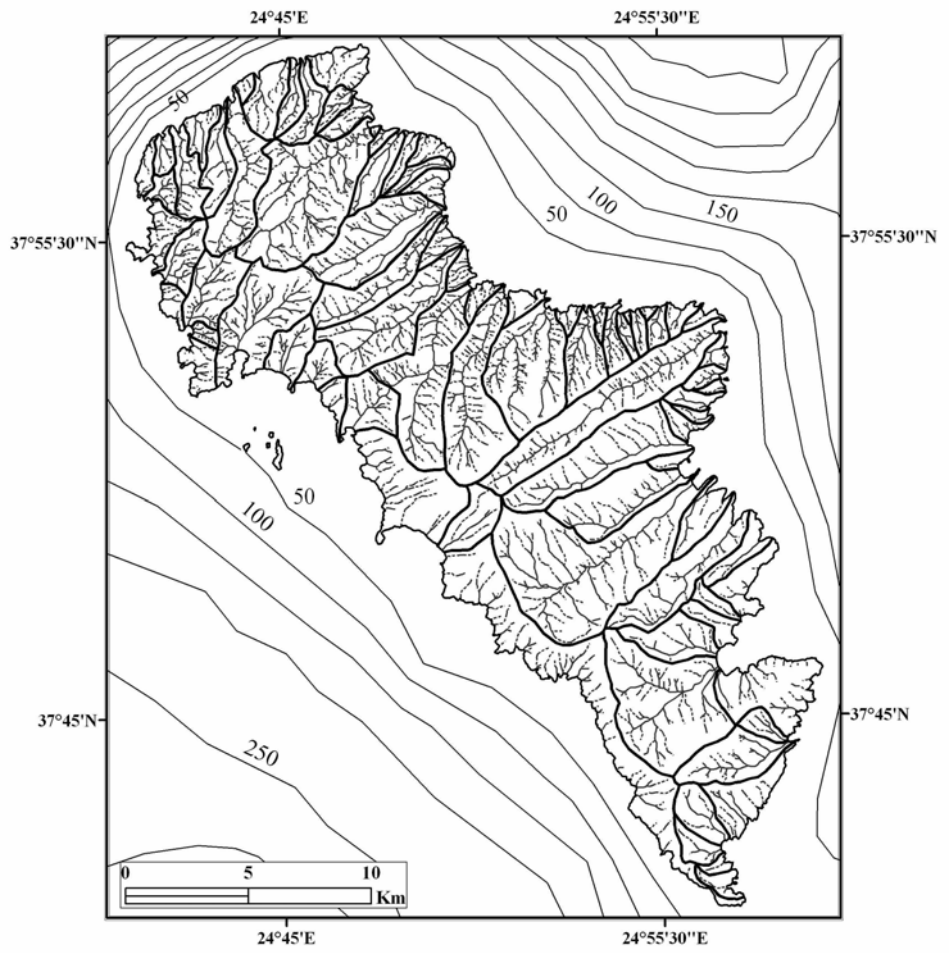

Fig. 6: The channel network and the drainage basins of the Andros island.

4. Depositional vs rocky coasts

All the geo- and morphodynamical processes mentioned, resulted to the formation of the coasts. The uplift tectonics and the intense fragmentation caused intense relief in the whole island and steep coastal morphology. The rocky coasts dominate in Andros island. The rivers of the hydrographic network of the island, with the transported sediments, outflow to the sea in small embayments. They form depositional coasts limited between rocky headlands. The steep coastal morphology acts as the limiting factor for the progression of the depositional coasts.

Additional factors controlling the topography and the material quality of the depositional coasts are the prevailing winds and waves in the extended area. In Table 1 data for the mean wind speed and wind directionality, prevailing in the coasts of Andros island, in different seasons (Autumn, Winder, Spring, Summer) are presented (Soukissian et al, 2007). The elongated form of the island and its NW-SE orientation leads us to the decision to present the data separately for the N, NE coasts and S, SW coasts respectively. The dominated winds are the winds blowing from the northern directions with a frequency of occurrence of 90-100%. These winds act on the N, NE coasts of Andros island and have a mean wind speed of 5-8 m/s. Winds with speed greater than 6 m/s are considered. The S, SW coasts of Andros island are “protected” from the northern winds, they are influenced only from the winds blowing from the southern direction, with a frequency of occurrence of 5-10 %.

The mentioned wind regime over the sea of the adjacent area of the Andros island regulate the wave situation in the area. In Table 2 data for the mean significant wave height and the wave directionality prevailing in the seas around Andros island in different seasons (Autumn, Winder, Spring, Summer) are presented (Soukissian et al, 2007). The dominated waves are the waves propagating from the northern

direction with a frequency of occurrence of 80-100%. These winds act on the N, NE coasts of Andros island and have a mean significant wave height of 0,6 – 1,2 m. Waves with significant height greater than 1 m are considered. The S, SW coasts of Andros island are "protected" from the northern waves, they are influenced only from waves propagating from the southern direction, which have a frequency of occurrence of 10-20 %.

Table 1: Mean wind speed and wind directionality prevailing in N, NE coasts and S, SW coasts of Andros island (extracted data from Soukissian et al, 2007)

	N, NE coasts of Andros island	**S, SW coasts of Andros island**	**Wind directionality**
	Mean wind speed	**Mean wind speed**	**Direction from wind blows / Frequency of occurrence of wind blowing (%)**
Autumn	**5-7 m/s**	**4-5 m/s**	**N / 90% - S / 10%**
Winter	**6-8 m/s**	**5-6 m/s**	**N / 90% - S / 10%**
Spring	**5-7 m/s**	**3-5 m/s**	**N / 95% - S / 5%**
Summer	**5-7 m/s**	**3-4 m/s**	**NNW / 100%**
Annual	**5-7 m/s**	**4-5 m/s**	**N / 90% - S / 10%**

Table 1: Mean significant wave height and wave directionality prevailing in N, NE coasts and S, SW coasts of Andros island (extracted data from Soukissian et al, 2007)

	N, NE coasts of Andros island	**S, SW coasts of Andros island**	**Wave directionality**
	Mean significant wave height	**Mean significant wave height**	**Direction from waves propagate / Frequency of occurrence of waves propagating (%)**
Autumn	**0,8-0,9 m**	**0,5-0,6 m**	**N / 90% - S / 10%**
Winter	**1,1-1,2 m**	**0,7-0,8 m**	**N / 80% - S / 20%**
Spring	**0,7-0,9 m**	**0,4-0,5 m**	**N / 90% - S / 10%**
Summer	**0,6-0,8 m**	**0,3-0,4 m**	**N / 100%**
Annual	**0,8-0,9 m**	**0,4-0,6 m**	**N / 80% - S / 20%**

Field observations and measurements from the coasts of Andros island, carried out in Spring 2006 allow us to classify the coasts. The steep rocky coasts, with a schist geological substratum, dominate. In between rocky headlands depositional coasts as "pocket beaches" are formed. An overview of the coastal morphology of Andros island is made also by Alexouli-Leivaditi & Leivaditis (2004).

The total length of the coastline of Andros island reaches 185,7 km. The rocky coasts have a length of 170,5 km, representing ~92% and the depositional coasts have a length of 15,2 km, representing ~8% of the total length. We observed 82 depositional coasts, "pocket beaches" in 73 locations (some locations have at the same place two beaches separated from a small headland). The locations of the depositional coasts of Andros island are shown in the Fig. 7.

The length of the beaches is measured and the histogram of the Fig. 8 shows the distribution of the beaches according to their length, 15 of the 82 beaches have a length sorter than 50 m, 25 beaches have a length of 50-100 m, 15 beaches 100-150 m, 7 beaches 150-200 m, 19 beaches have a length of 200-750 m and only one reaches the length of 1200 m.

The width of the "pocket beaches" can be differentiated in the active beach zone and the older depositions. The active zone extends from 5-15 m. In general the width of the beaches shows values of ~5 m to 50 m. Some of the beaches show the formation of dunes. In some beaches formation of beach rocks is observed. The rivers of the drainage basin have the outlets in the pocket beaches. The wave dominated regime in these beaches shifts the outlet of the rivers at the side, to the beach/headland boundary.

The beach material consists on very well rounded gravels and coarse sand.

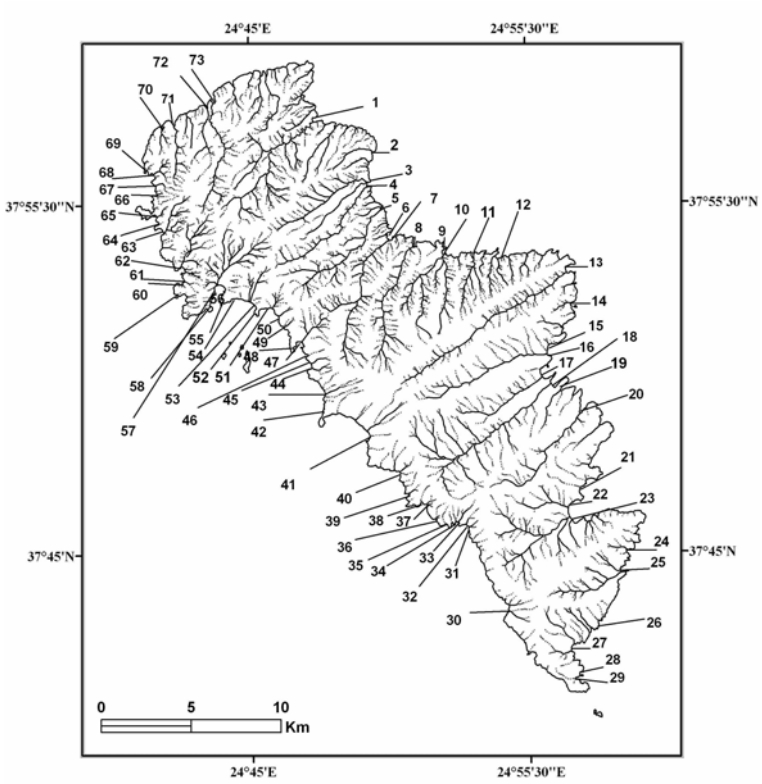

Fig 7: Location of the depositional "pocket beaches" along the coastline of Andros island.

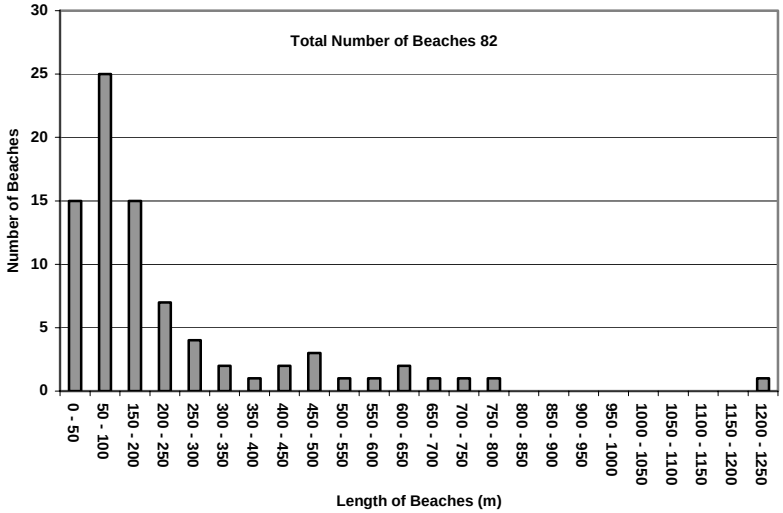

Fig 8: Distribution of the 82 depositional "pocket beaches", identified along the coastline of Andros island, according their length

5. Discussion

Trying to find a relation or distinguishable signals between geo- and morphodynamical processes on the one side and coastal morphology on the other side, we can say that the coasts are formed as a result of the uplifting tectonics, the tectonic fragmentation of the area, the resulted formation of the drainage basins and the channel network activity.

The intense tectonic fragmentation and the steep relief along the coasts of the area are the factors controlling the formation of rocky coasts, which dominate and the formation of embayments, where the depositional coasts are formed. The petrologic composition of the geological formation (mainly schist) forms

an appropriate source for materials needed for the formation of depositional coasts. The fault system of SWW-NEE direction influences the morphodynamical evolution of the area in conjunction with the hydrographic network of the island.

The total length of the coastline of Andros island reaches 185,7 km. The rocky coasts represent ~92% and the depositional coasts ~8% of the total length. In 73 locations 82 depositional coasts, "pocket beaches" are observed and mapped. The dominating length of the beaches fluctuates from less than 50 m till 200 m. The width of the "pocket beaches" can be differentiated in the active beach zone (5-15 m) and the older depositions, which reach a mean width of 50 m. The beach material consists on very well rounded gravels and coarse sand.

The coasts of Andros island since some years are staying under anthropogenic pressure. Tourism and the recreational settlements, called "second houses", are the main activities threatening the coasts of Andros island. The coasts, rocky coasts and the beaches are goods for the society. There is a need to manage the coasts of Andros island.

Satisfactory management of the coastlines requires an understanding of the nature and dynamics of coastlines systems, the various physical, chemical, biological and social interactions that take place on and around them, and the aims and perceptions of people, who come to use them. Beaches have been the focus of interest, attention and activity over the past. Nowadays the interests of the society are stronger.

References

-Alexouli-Leivaditi, A. & Leivaditis, G. (2004): Coastal morphology of Andros island. *–Proceedings of Panhellenic Congress of the Hellenic Geographical Society, pp. 377-384, Mytilene. (in greek)*

-HMGS (1990): Topographic map of Gavrion – Scale 1:50.000. *–Hellenic Military Geographical Service.*

-HMGS (1990a): Topographic map of Piso Meria – Scale 1:50.000. *–Hellenic Military Geographical Service.*

-HMGS (1991): Topographic map of Andros – Scale 1:50.000. *–Hellenic Military Geographical Service.*

-Ibbeken, H. & Schleyer, R. 1991: Source and sediment – A case study provenance and mass balance at an active plate margin (Calabria, Southern Italy). *–Springer Verlag, Berlin etc, p.286.*

-Lister, G. S, & Raouzaios, A. (1996): The tectonic significance of a porphyroblastic blueschist facies overprint during Alpine orogenesis: Sifnos, Aegean Sea, Greece. *–Jour. of Structural Geology, vol. 18, no 12, 1417-1435*

-Soukissian, T., Hatzinaki, M., Korres, G., Papadopoulos, A., Kallos, G., Anadranistakis, E. (2007): Wind and Wave Atlas of the Hellenic Seas. *–Hellenic Center for Marine Research Publ., 300 pp*

-Strahler, A. N. (1964): Quantitative geomorphology of drainage basins and channel networks. *In Vent e Chow P.H.D. (ed) Handbook of applied hydrology. McGraw-Hill, N. York, pp 4-76.*