

# Morphometric measures to assess the maturity of the submerged drainage basins. The case of the Taranto Canyon upper reach

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**Abstract** – The upper reach of the Taranto Canyon is the main signature of the continental slope in the western Taranto Gulf. It starts at the shelf break 30 m deep and reaches 450 m of depth, covering a total area of about 50 km<sup>2</sup>; the minimum distance from the coast is 2,5 km. Multibeam data were acquired to reconstruct a detailed Digital Elevation Models (DEM), and then a morphometric analysis was carried out allowing to identify several drainage basins and to define the active morphodynamic processes acting in the upper reach. The measures of the morphometric parameters have allowed to obtain the hypsometric curves, reconstructed to establish the maturity [1] of drainage basin. The latter was divided in two branches, the northern one characterised by curves typical of “Youth” basins and the southern one with those typical of the “Maturity” basins. These results highlighted a different evolution of the two branches and active erosional processes are dominant in the northern branch while depositional processes affect the southern one. Because of the erosional processes produce the back shifting of the upper reach margin, an approaching of the northern branch margin to the coast can be hypothesized making the Metapontine coastline a vulnerable area.

## I. INTRODUCTION

The upper reach of the Taranto Canyon is the main element of the continental slope in the western offshore of Taranto Gulf (Fig. 1). It starts at the shelf break at a depth of about 30 m and reaches a depth of 450 m, covering a total area of about 50 km<sup>2</sup>; the minimum distance from the coast, offshore of Metaponto, is 2,5 km. Multibeam data were acquired with the aim to reconstruct a detailed Digital Elevation Models (DEM), and then a morphometric analysis was carried out allowing to identify several drainage basins composing the upper reach and to define its morphodynamic processes.

## II. MATERIALS & METHODS

To study the morphology of the seafloor in the area, multibeam echo-sounder data (MBES) were used, collected by the University of Sannio and the University "Sapienza" of Rome, in 2005 as part of the CARG Project.

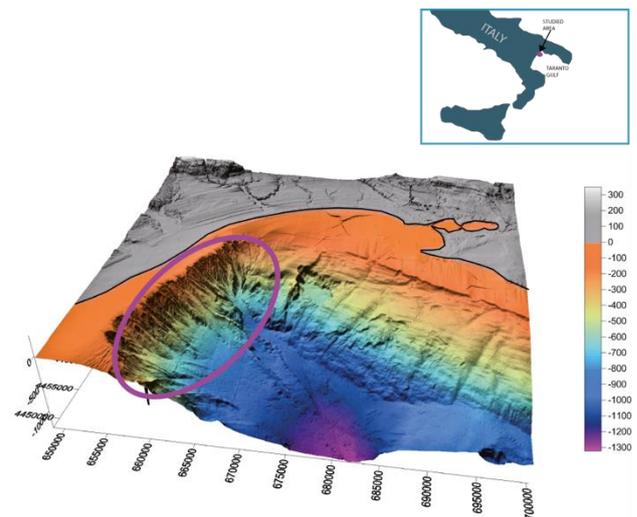


Figure 1: Upper reach of the Taranto Canyon

Furthermore, Multibeam bathymetric data, were collected during the Oceanographic cruise “MAGIC Conisma 11/2010”, held within the MaGIC Project, with the MBES Reason Sebat 8160. Approximately 1600 km<sup>2</sup> and 670 nautical miles were collected and all data were referenced to Mean Sea Level (MSL).

The data were processed using the software Caris Hips & Sips, obtaining a grid with very high resolution.

For quantitative analysis the upper reach of the Taranto canyon is divided into 6 + 7 elementary drainage basins (6 in the northern branch and 7 in the southern branch), whose a quantitative geomorphologic analysis was performed (density drainage, average gradient, bifurcation index). Hypsometric curves have been realized for each river and statistical moments for each curve have been analyzed

(skewness, kurtosis and hypsometric integral). The limits of the basins were defined from DEM; the submit (upper limit) and the outlet (lower limit) have been identified for each branch of the reach of the canyon; total areas of each basin and the areas associated with each depth interval were also determined (hypsometric curves) [1, 4].

Classification, prioritization and implementation of hypsometric curves of drainage basins, are made using the software Global Mapper 14 and Open Source GIS.

#### A. General Physiography of the Reach of the Taranto Canyon

The analysis of the submarine channel networks was employed [1]'s method of classifying channels by order, that analyzes the properties of linear hydrographic networks and the properties ranges of drainage basins, using the application of statistical techniques. The main concept which underpins this analytical method is that of the "hierarchy of river networks", defining for each channel a hierarchical order. Each channel with no tributaries constitutes an element of the first order; by the confluence of two channels of first order originates a channel of second order, and so on. If a channel of order  $u$  meets an order channel  $u + 1$  does not happen the increase in hierarchical order. The order of the basin will be the same as the main channel present in the basin itself. To define internal organization of the networks within the submarine basins, the measurements of drainage densities (Dd) and bifurcation ratios (Rb) were utilized for each network [1].

The bifurcation ratio (Rb) is a measure used to describe the structure of river networks [2] and the complexity of branching [1, 3]. It was therefore defined:

$$Rb = N_u / N_{u+1} \quad (1)$$

where  $N_u$  is the number of streams of order  $u$  and  $N_{u+1}$  is the number of channels of the next order.

The drainage density (Dd, [2]), that relates a linear property of a basin with a property range, is defined by:

$$Dd = \Sigma L / A \quad (2)$$

where  $L$  is the ratio of the total length of all channels of a given basin and  $A$  the area of the basin itself.

#### B. Hypsometric curves & Parameters

Hypsometric analysis denotes a dimensionless relationship between the horizontal cross-sectional area captured by a basin and its elevation [1]. Hypsometric curve (HC) represents the relative proportion of a basin and is obtained by plotting the relative area along the abscissa and relative elevation along the ordinate, where elevations are normalized by the relief of the area captured

by the network, so they range from 0 to 1 [4]. This analysis of elevation distribution is commonly used for topographic comparisons because it gives three dimensional information for a two-dimensional approach [4, 5].

The integral (Int) of the hypsometric curve the area under the curve was calculated:

$$Int = (h - h_{min}) / (h_{max} - h_{min}) \quad (3)$$

where  $h$  is the average height of the basin.

[6, 7, 8] suggest that since the hypsometric curve is not Gaussian, there are statistical moments (skewness and kurtosis) that can be used to quantify the shape of the hypsometric curve and thus assist in their initial shape based classification.

Such statistical measures are skewness and kurtosis that describe the deviation of the distribution relative to the normal distribution. Skewness characterizes the degree of the asymmetry of a distribution around the mean: a positive value of skewness signifies a distribution with an asymmetric tail extending out towards more positive values (i.e. skewed to the right) and a negative value signifies a distribution whose tail extends out towards more negative values (i.e. skewed to the left). Kurtosis measures the relative "peakedness" or flatness of a distribution, relative to a normal distribution: a larger kurtosis indicates a "sharper" peak than a normal distribution and a smaller kurtosis indicates a "flatter" peak than normal distribution [e.g., 9]. Both skewness and kurtosis of the hypsometric curves were analyzed to quantify the form of the curve [10, 4].

The classification of the hypsometric curves, characteristics of drainage basins, was performed by reference to the classification proposed by [1], which confers on each curve, a different level of the evolution of the basin that is characterized. Three types of curves are then identified: the first, concave, representative of basins called "old age", in which there is a very low erosive activity; the second, called "maturity" that indicate basins where the erosive activity is still in progress, but the profile of the slope is basically balanced; The latest, called "Youth", which represents basins where erosion is intense and modelling processes occur mainly for linear erosion.

### III. RESULTS

Taking the statistical parameters of the 13 submarine basins (Tab. 1) and following the classification of [4], it was thus possible to define 4 drainage basins submerged characterized by a curve of type II (defined at the shape of a "J") and a group of basins characterized by curves of type III (defined convex) (Fig. 2). It was performed a correlation between the values of skewness and kurtosis, which confirms the existence of two types of hypsometric curves; the first shows that with positive values of

asymmetry, the coefficient of kurtosis decreases with increasing asymmetry, on the contrary however, with negative values of asymmetry, it is observed an increase of the coefficient of kurtosis as increases asymmetry (Tab. 2); the basins characterized by hypsometric curves of type III are found, mainly, in the northern branch; those of type II instead, inside the southern branch.

Basin	Ord	Rb	Asim.	Kurt.	Int.	Av. Slope	Dd	Type
1	3	5,7	-0,06	1,74	0,542	12	0,04	III
2	4	3,17	-0,148	1,66	0,522	11,3	0,04	III
3	3	4,4	-0,3	1,9	0,48	13	0,04	III
4	3	5,21	-0,15	1,86	0,504	11,88	0,05	III
5	3	6,5	0,094	1,62	0,547	8,56	0,06	II
6	4	3,93	-0,19	1,79	0,499	10,72	0,06	III
N. Branch	4	3,37	-0,09	1,71	0,527	11	0,04	III
7	3	6	0,06	1,7	0,603	9,2	0,04	II
8	4	4,44	-0,14	1,8	0,555	10	0,05	II
9	4	3,65	0,02	1,78	0,611	10	0,06	II
10	5	3,29	0,03	1,7	0,592	10,74	0,06	II
11	4	3,67	-0,16	1,6	0,596	10,3	0,05	III
12	4	3,01	-0,2	1,56	0,636	9,3	0,07	III
13	3	3,75	-0,1	1,64	0,708	12	0,04	III
S. Branch	5	3,63	0,051	1,68	0,554	7	0,02	II

Tab. 1: Statistical parameters of the 13 submarine drainage basins of the Upper reach of the Taranto Canyon. It's possible to observe the difference between Type II basin (J shaped) and Type III (defined convex).

The obtained curves were compared with the theoretical curves defined by Strahler. The comparison shows that the most of the basins identified are "Youth", and therefore are characterized by intense erosive activity; there are also 4 "Maturity" basins showing that the erosive activity of the canyon reach is different along it (Fig. 3). In the morphometric analysis of the submerged drainage basin networks, the drainage density of each of them was evaluated to assess the extent of erosion in the headwall area. By comparing the drainage density values with those of the median slope of the basins, it is observed that Dd increases with the increase of the average slope gradient for all basins that have positive asymmetry values. Basins characterized by positive asymmetry do not have a predominant trend, but this is due, probably because they are not present in significant numbers.

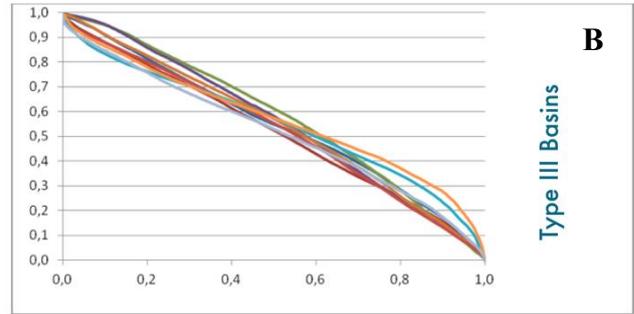
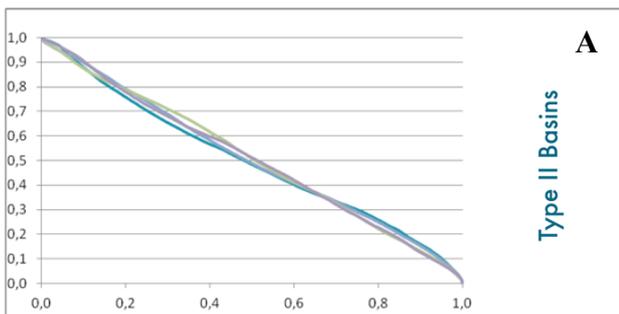
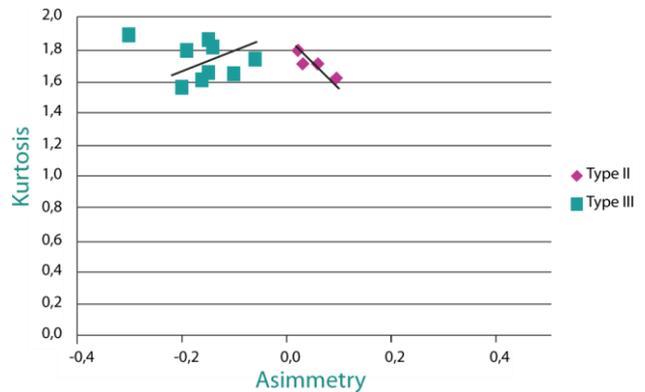


Figure 2: Hypsometric curves of the elementary drainage basins submerged, characterized by a curve of type II (defined at the shape of a "J" - A) and a group of basins characterized by curves of type III (defined convex - B).

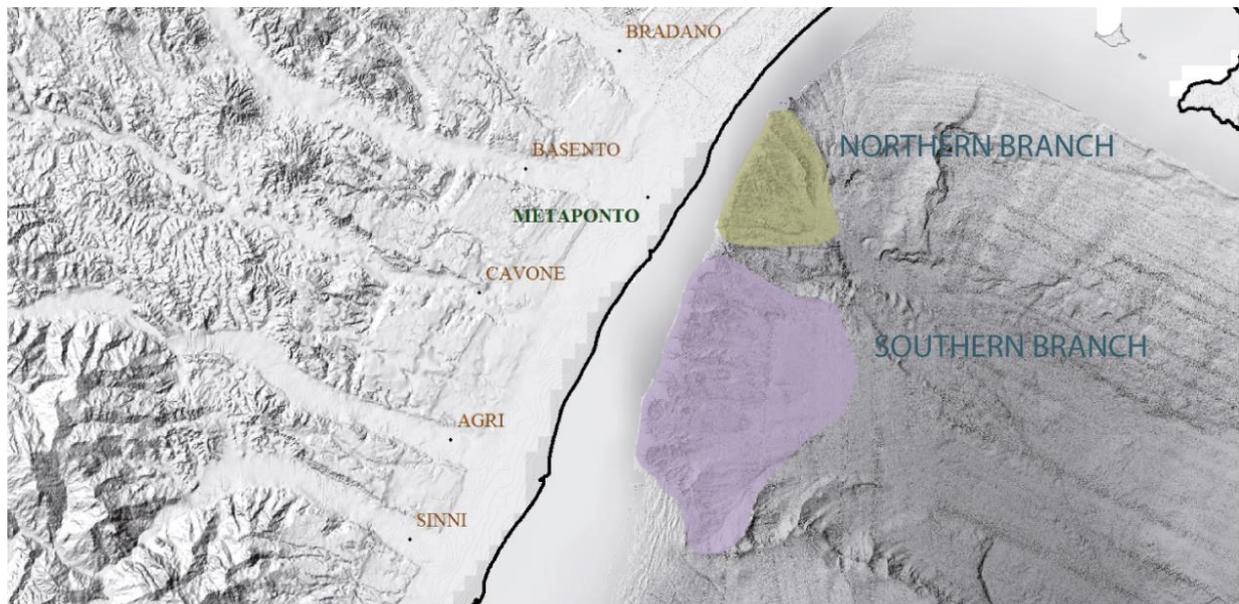


Tab. 2: The values of skewness and kurtosis were matched. With positive values of asymmetry: the kurtosis is directly proportional to asymmetry. With negative values of asymmetry: the kurtosis is inversely proportional to asymmetry.

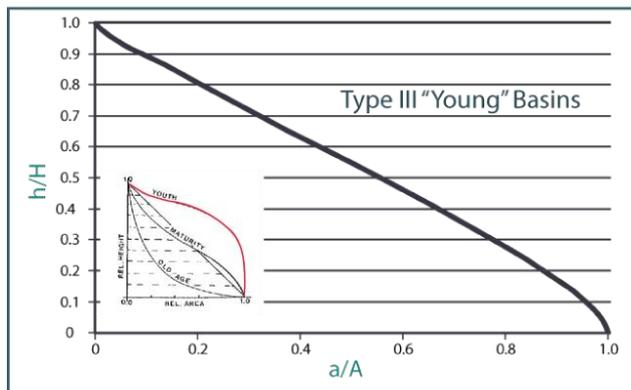
It has been observed that type II basins have a bifurcation index between 3.2 and 6.5, a slope average between  $8.5^\circ$  and  $12^\circ$  and a drainage density of between 0.039 and 0.062; Type III, instead, have an Rb of between 3 and 5.7, a slope average between 9.3 and 13, a drainage density ranging from 0.04 to 0.067. Observing the profile of the hypsometric curves within the upper reach of the Taranto canyon, it can finally be stated that the type III basins are identified with: 1) negative values of asymmetry, high kurtosis values (Tab.2), 2) negative correlation between the drainage density and slope angle of the slope, 3) the mean higher slope values; Type II basins are characterized by: 1) a relatively lower gradient, 2) positive asymmetry values and kurtosis values higher type III and a positive correlation between drainage density and gradient values average. It is evident from the observation of both types of curves that the drainage basins along the continental slope have convex shapes and this form is attributed to the type of sedimentary process active in the basins. In fact, this

form is mainly characteristic of basins subject to retrogressive erosion or any basin where sediment fallout events are significant. Comparing the curve obtained in the morphometric analysis of Taranto drainage basins with Strahler's theoretical hypsometric curves, the similarity of type II curves is apparent with the curve identified by the author to describe "mature" basins. The Type III curve is comparable to the theoretical curve characteristic of the "Youth" basins [1, 4]. This comparison indicates that the drainage basins of the southern branch, are characterized by curves of type II, have been activated earlier than the northern part of the upper reach (northern branch).

They occur almost in each basin identified and are certainly produced by currents flowing in channel and gullies and by landslides, mainly slumps released from the sides of the basins. These processes, which have been recognized through numerous seismic profiles and are typical of canyons lateral margins [11, 12], could be responsible of the retrogressive shifting of the northern upper reach margin corresponding to the shelf break. It follows that, over the time, the reach will approach the coastline, and the erosive action can produce effects on the human activities and infrastructures, representing a significant geohazards in the North Ionian Sea.



Hypsometric Curve of Northern Branch



Hypsometric Curve of Southern Branch

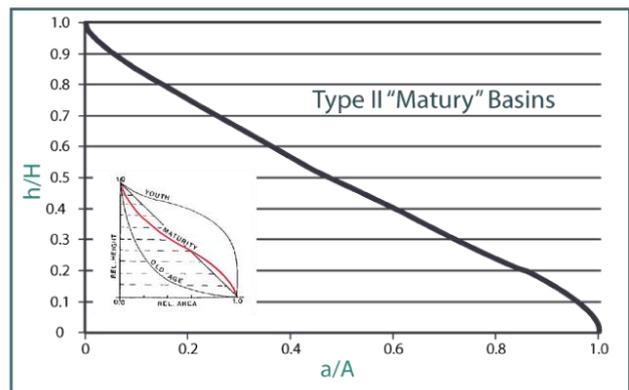


Figure 3: Hypsometric curves of the drainage basins submerged (Northern and Southern branches) and comparison with theoretical curves of Strahler.

#### IV. CONCLUSIVE REMARKS

The measured parameters and their interpretation pointed out the existence of erosive processes affecting prevalently the northern branch of the Taranto canyon upper reach.

#### V. REFERENCES

- [1] A. N. Strahler, "Hypsometric (area-altitude) analysis of erosional topography", Geol. Soc. Am. Bull.,

- vol.63, pp.1117 – 1142, doi:10.1130/0016-7606 [1117: HAAOET] 2.0.CO; 2, 1952.
- [2] R.E. Horton, “Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology”. *Bulletin of the Geological Society of America* vol.56, pp275-370, 1945.
- [3] A.N. Strahler, “Quantitative Geomorphology of Drainage Basin and Channel Network”, *Handbook of Applied Hydrology*, pp. 39-76, 1964.
- [4] D. Vachtman, N.C. Mitchell, R. Gawthorpe, “Morphologic signatures in submarine canyons and gullies, central USA Atlantic continental margins”, *Mar. Pet. Geol.*, vol.41, pp. 250–263, 2013.
- [5] G. Willgoose and G. Hancock “Revisiting the revisiting the hypsometric curve as an indicator of form and process in transport - limited catchment”, *Earth Surface Processes and Landforms Earth Surf. Process. Landforms*, vol. 23, pp. 611–623, 1998.
- [6] W. F. Tanner, “Examples of departure from the gaussian in geomorphic analysis”, *Amer. Jour. Science*, vol. 257, pp. 458-460, 1959.
- [7] I.S. Evans, “General geomorphometry, derivatives of altitude, and descriptive statistics”. In: Chorley, R.J. (Ed.), *Spatial Analysis in Geomorphology*. Methuen & Co., London, pp. 17– 90, Chap. 2, 1972.
- [8] D. R. Montgomery, “Slope Distributions, Threshold Hillslopes, and Steady-state Topography”. *Am. J. Sci.* April/May, vol.301, pp. 432-454, 2001.
- [9] J. F. Kenney and E. S. Keeping, “The  $\chi$ -Statistics.” §7.9 in *Mathematics of Statistics*, Pt. 1, 3rd ed. Princeton, NJ: Van Nostrand, pp. 99-100, 1962.
- [10] W. Luo, “Quantifying groundwater sapping processes with a hypsometric analysis technique”. *J. Geophys. Res.*, vol.105, pp.1685–1694, 2000.
- [11] M.R. Senatore et al., "Frammenti sulla scarpata continentale pugliese del Golfo di Taranto (Alto Ionio, Italia)." *Geologica Romana* vol. 21, pp. 497-510, 1982.
- [12] A. Meo et al., “The Upper reach of the Taranto Canyon (Northern Ionian Sea). New insight on the foredeep evolution of the Southern Apennine Chain”, *Rendiconti Online SGI*, vol. 41, p. 64, DOI: 10.3301/ROL.2016.167, 2016