**pp. 89-98** https://doi.org/10.7427/DDI.23.11

# 11. The Danube evolution within the Romanian sector Cotul Pisicii - Ceatal Izmail based on the archaeological discoveries and remote sensing

**PANAIT Valentin[1*], STĂNICĂ Aurel Daniel[1], MIERLĂ Marian [2]**

*1-"Gavrilă Simion" Eco-Museal Research Institute - Tulcea, str. Progresului, no. 23, RO-820003, Tulcea, Romania*
*2- Danube Delta National Institute for Research and Development - Tulcea, str. Babadag, no. 165, RO-820112, Tulcea, Romania, e-mail: marian.mierla@ddni.ro*
**Address of author responsible for correspondence: -"Gavrilă Simion" Eco-Museal Research Institute - Tulcea, str. Progresului, no. 23, RO-820003, Tulcea, Romania e-mail: panvali@gmail.com*

**Abstract:** The purpose of this study was to develop a working method for analysing the natural environment according to archaeological data. In order to achieve these results, the data obtained from classical archaeological and historical studies were correlated with those obtained by field studies and remote sensing techniques. In this paper, the studies focused on the evolution of the Lower Danube, in the sector Cotul Pisicii - Ceatalul Izmail.
Data processing was based on free and open source applications. Through this, data from archaeological studies and satellite imagery was processed, thus obtaining a trace of the form and distribution of archaeological sites on vector strata. These were used to determine the current shape of the Danube fairway.
Preliminary data available at the moment revealed an intensive alluvial process of the Danube bank in the Cotul Pisicii - Crapina Lake area, upstream of the Noviodunum fortress (Isaccea) area, and in the sector Revărsarea - Ceatalul Izmail. The intense erosion process was found in the Noviodunum fortress (Isaccea) area. The correlation of these processes with data on the spatial distribution of the archaeological sites as well as on the historical periods that belong to them can provide a valuable indicator of the evolution of the lower sector of the Danube.

**Keywords:** Lower Danube, promontories, cluster, sub-cluster, historical periods.

## INTRODUCTION

This study focused on identifying and developing a method of analysing the evolution of the natural environment based on archaeological data. In order to be able to use the data obtained from historical and archaeological studies, we must extract the quantitative information which these contain. In order to achieve these, the studies have focused on the historical periods measured in years identified within the archaeological sites discovered in the Cotul Pisicii - Ceatalul Izmail sector. Data processing was done used free and open source applications.

Many studies in the past have been carried out both on the natural environment and on the archaeological sites. Under these conditions, the present study is part of the current trend to determine the complex evolution of the natural environment through interdisciplinary research. Of course, from this point of view, the purpose of this study is to complete the data obtained by studying the stratigraphic sedimentary sequences.

Unfortunately, archaeological information is generally qualitative and, ironically, the more valuable information we have, the more difficult it is to identify the key information. From this point of view, it is more efficient to study the traces of human activities based on sedimentary stratigraphic sequences.

In order to use the archaeological information almost at the same level as the sedimentological ones, the data obtained through classical archaeological and historical studies were correlated with those obtained by field studies and remote sensing techniques.

In this paper, the studies focused on the evolution of the Lower Danube in the sector Cotul Pisicii - Ceatalul Izmail. Based on the spatial distribution of archaeological sites over historical periods, the evolution of this sector has been tracked over time. Data processing was based on cluster analysis, as well as free and open source applications. The analysis of the cluster was performed based on data obtained through historical and archaeological studies.

Based on the connectivity-based clustering (hierarchical grouping), observations made within the archaeological sites were grouped into classes (groups or clusters) of similar elements (historical periods). The evolution of the sector Cotul Pisicii - Ceatalul Izmail was tracked using the data obtained in the cluster analysis in relation to their spatial distribution.

## MATERIALS AND METHODS

The fact that the observations on the natural environment are generally punctual implies a degree of inconsistency in the data obtained.
To solve this problem, we can use the following solutions:
1. **Fill the gap between values** by statistical and mathematical methods (white box);
2. **Leaving blank the gap between values** and treating it as a black box;
3. **The mixed method** involves placing the variable containing the values in a known category but leaving blank the gap between them and treating it as a black box (gray box).

We can associate the last two solutions with the following data analysis techniques:
1. Supervised classification, data analysis technique involving the processing of data sets by associating them with a particular class (label) whose identity is known (association of data with a certain known class is typical of grey boxes and black box);
2. Unsupervised classification (clustering) is an efficient way of dividing data into classes with a minimum amount of initial information about the identity of these classes (typical for the black box).

For historical and archaeological data analysis we used the method of hierarchical clustering the values of historical periods.

- "Cluster analysis is a convenient method for identifying homogenous groups of objects called clusters. Objects (or cases, observations) in a specific cluster share many characteristics, but are very dissimilar to objects not belonging to that cluster. " (Sarstedt, Mooi, 2014)
  „The goal of data clustering, also known as cluster analysis, is to discover the natural grouping(s) of a set of patterns, points, or objects. Webster (Merriam-Webster Online Dictionary, 2008) defines cluster analysis as ''a statistical classification technique for discovering whether the individuals of a population fall into different groups by making quantitative comparisons of multiple characteristics." (Anil, 2010)
- Many different types of clustering algorithms have been developed (Santo, 2010, Newman, 2012). Among these, hierarchical clustering methods play an important role in linking well-known scale-free and small-world network models as well as predicting the missing links (Duncan and Strogatz, 1998; Barabási and Réka, 1999; Ravasz and Barabási, Scales-Pardo et al., 2007, Clauset et al., 2008) (Yu et al., 2015)
- In order to group the values of the historical periods into a hierarchy of classifiers, the intracluster correlation (*ICCor*) was used. „The intracluster correlation coefficient, or ρ (the Greek rho), is a measure of the relatedness of clustered data. It accounts for the relatedness of clustered data by comparing the variance within clusters with the variance between clusters. Mathematically, it is the between-cluster variability divided by the sum of the within-cluster and between-cluster variabilities". (Killip et al., 2004)

The way in which historical periods measured in years (Val) are grouped in clusters was determined on the basis of their statistical deviation.

$$Dev = Val_i - \mathrm{m}(Val)$$

where,

$Dev$ - statistical deviation;
$\mathrm{m}(Val)$ - the arithmetic mean value of historical periods (in years)
$Val_i \in Val$, $i = 1, 2, 3, \dots, n$.

Based on intracluster correlation (*ICCor*) the values of the historical periods were grouped into a hierarchy of classifiers by the following formula:

$$ICCor = \frac{\underset{i=1->n}{\mathrm{SUM}}(Val_i - \mathrm{m}(Val))^2 - (Val_i - \mathrm{m}(Val))^2}{\underset{i=1->n}{\mathrm{SUM}}(Val_i - \mathrm{m}(Val))^2}$$

This method is fully correct because it uses only *squared euclidean distances* to compute centroids in euclidean space.

The classifiers obtained by intracluster correlation (*ICCor*) were bring into the hierarchical structure through the linkage criterion. This criteria include the probability that candidate clusters spawn from the same distribution function (V-linkage).

Where,

*Dis = 1 - abs(ICCor)*

are the **complementary cumulative distribution function (tail distribution)** and

$$Dis = \frac{1}{\sqrt{2\pi}} \mathrm{e}^{\frac{-\mathrm{ICCor}^2}{2}}$$

the **standard normal distribution**.

For the analysis of the evolution of the lower sector of the Danube, the public cartographic materials and scientific information were generally used. These are either available in the Danube Delta Eco-Tourism Museum Center, on the Internet within the National Archaeological Register (http://ran.cimec.ro/) or on Google Earth Map (Google Hybrid, available under QGIS).

**RESULTS AND DISCUSSION**

The cluster separation was performed based on a series of successive cuts performed at different levels of the dendrogram, as follows:

*Cut1 = to_real(substr(to_string("disdiccor" ), 1,6))*
*Cut2 = to_real(substr(to_string("disdiccor" ), 1,7))*
*Cut3 = to_real(substr(to_string("disdiccor" ), 1,8))*
*Cut4 = to_real(substr(to_string("disdiccor" ), 1,9))*
*Cut5 = to_real(substr(to_string("disdiccor" ), 1,10))*

The formula used for cluster separation is based on the observation that any attempt to reduce the number of decimals in a real number leads to the rounding of the last digits. Thus, to obtain a reduction in the number of decimals without rounding out the last digits, the values defining the clusters (disdiccor) have been converted to text (to_string ()). The next step was to select the number of characters to be stored (substr ()). Finally, the resulting values were converted from text format into numeric format with support for the decimal (to_real ()).

The number of clusters per cutting varied as follows:

1. Cut1 = 2 clusters (0.4022 and 0.3989);
2. Cut2 = 4 clusters (0.40222, 0.39896, 0.39895 and 0.39894);
3. Cut3 = 6 clusters (0.402227, 0.398960, 0.398956, 0.398944, 0.398943 and 0.398942);
4. Cut4 = 8 clusters (0.4022278, 0.3989602, 0.3989561, 0.3989443, 0.3989430, 0.3989426, 0.3989424 and 0.3989422);

5. Cut5 = 8 clusters (0.40222789, 0.39896025, 0.39895619, 0.39894433, 0.39894304, 0.39894262, 0.39894240 and 0.39894228).

But the values in years of each period are grouped in the total number of 9 clusters. This is due to the presence in cluster 0.39894228 of two subclusters 0.398942282 and 0.398942283. This is the explanation of the presence in Cut5 of only 8 clusters.
The Intracluster Correlation, performed in these works, was based on the removal of the *squared euclidean distances* of a value to the arithmetic mean from the sum of the all *squared euclidean distances* of the values to the arithmetic mean, and the result that remains, after we report everything to the sum of squared deviations, is the probability of associating the values in the clusters. For this reason, the resulting numerical values represent the likelihood that a particular event (cluster) occurs over one or more historical periods.
The distribution of the different stages of the evolution of the Lower Danube sector (sub-clusters) according to the historical periods in years is performed within the different sub-phases (sub-clusters) and time interval or phases (clusters), as can be seen in Table 1.

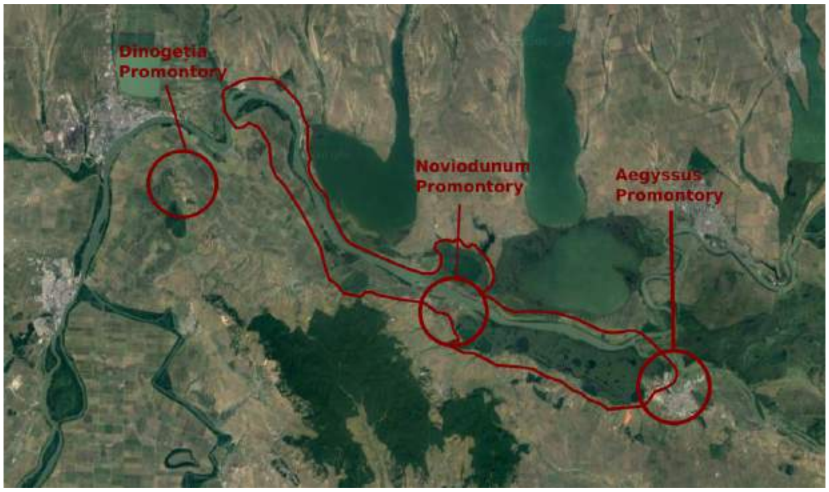
**Table 1.** Stages and phases of the Lower Danube sector evolution

| Location | Cluster | Interval (Phase) | Sub-Cluster | Sub-Phase | Sub-Cluster | Period | Stage |
|---|---|---|---|---|---|---|---|
| Danube Lower Sector | 0.4022 | Paleolithic Period | 0.40222 | Gulf Phase | 0.402227 | Paleolithic Period | Initial Litoral Belt development begins on the area of Caraorman and Letea islands |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39895 | Sf. Gheorghe I Delta | 0.398956 | Neolithic Period | Initial Litoral Belt, Sf. Gheorghe Fluvial Delta and Sulina Fluvial Delta (partial) |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39895 | Sf. Gheorghe I Delta | 0.398956 | Neolithic Period | Sf. Gheorghe I Fluvio-Maritime Delta |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39895 | Sf. Gheorghe I Delta | 0.398956 | Neolithic Period | Danube River follows the main land shape |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39895 | Sf. Gheorghe I Delta | 0.398956 | Neolithic Period | In the area Somova-Parcheş was a Danube gulf |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39895 | Sf. Gheorghe I Delta | 0.398956 | Neolithic Period | Siret and Prut rivers flow into two gulfs |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398944 | Early Bronze Periond | Sulina Fluvial Delta |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398944 | Early Bronze Periond | Danube River follow the main land shape |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398944 | Early Bronze Periond | Siret and Prut rivers flow into two gulfs and the rivers deltas are started |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398944 | Early Bronze Periond | In the area Somova-Parcheş was a Danube gulf |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398942 | Middle Bronze Period - Dacian Period | Sulina Delta (fluvial side and northern half of marine side) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398942 | Middle Bronze Period - Dacian Period | Chilia Delta (fluvial side - behind the Chilia Promontory) |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398942 | Middle Bronze Period - Dacian Period | Danube River follows the main land shape |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398942 | Middle Bronze Period - Dacian Period | In the area Somova-Parcheş was a Danube gulf |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398942 | Middle Bronze Period - Dacian Period | Siret and Prut rivers flow into two gulfs and the river deltas are in their early stages |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | Sulina Delta (fluvial and marine side) |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | Chilia Delta (fluvial side except the Thiagola Lack area) |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | The formation of the maritime sandbanks begins |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | Danube River follows the main land shape |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | In the area Somova-Parcheş was a Danube gulf |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39894 | Sulina Delta and Chilia Fluvial Delta | 0.398943 | Roman Period | Siret and Prut rivers flow into two gulfs and the river deltas are in their early stages |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39896 | Sulina Delta regression and Lagunar Complex development | 0.39896 | Byzantine Period | Sulina Delta erosion |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39896 | Sulina Delta regression and Lagunar Complex development | 0.39896 | Byzantine Period | The development of the Lagunar Complex |
| Danube Lower Sector | 0.3989 | Neolithic - Present (Main Evolution) | 0.39896 | Sulina Delta regression and Lagunar Complex development | 0.39896 | Byzantine Period | The Danube River begins the development of the sector Măcin-Grindu and the area Somova-Parches |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39896 | Sulina Delta regression and Lagunar Complex development | 0.39896 | Byzantine Period | In the area Somova-Parcheş the Danube divides into two branches |
| Danube Lower Sector | 0.3989 | Neolithic – Present (Main Evolution) | 0.39896 | Sulina Delta regression and Lagunar Complex development | 0.39896 | Byzantine Period | Siret and Prut river deltas |

Based on the method of hierarchical clustering proposed in this paper, a model of the evolution of the Lower Danube sector and especially of the region between the Izmail Ceatal and Cotul Pisicii (see Figure 1).

In order to understand the evolution of the Izmail Ceatal - Cotul Pisicii sector, the study had to be




extended to a much larger area. Within this area, three obstacles that have influenced the Danube way have been identified. These points were named according to the archaeological sites existing in their area, such as: Dinogetia Promontory, Noviodunum Promontory and Aegyssus Promontory.

**Figure 1.** The sector between the Izmail Ceatal and Cotul Pisicii.

Like the whole Lower Danube sector, the evolution of the area Ceatal Izmail - Cotul Pisicii can also be divided into two phases (see Figure 2): Gulf Phase (0.4022) and Main Phase (0.3989).

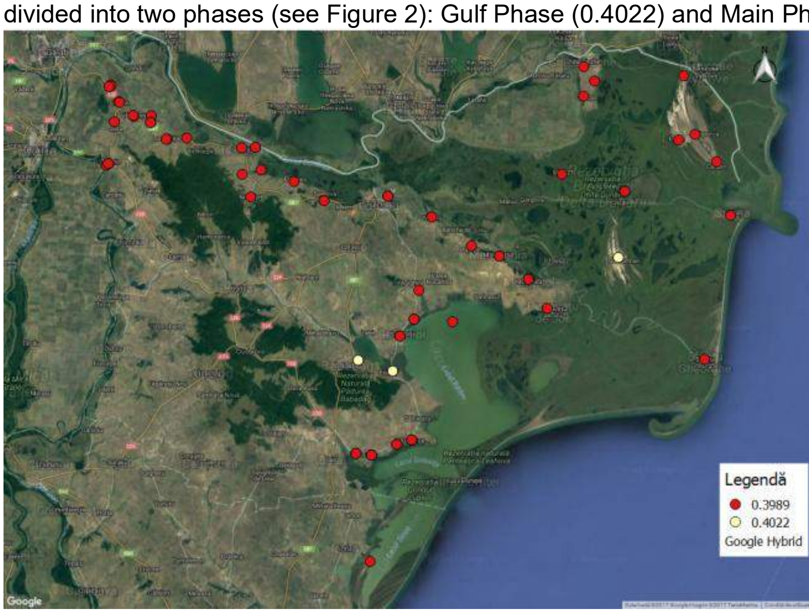



**Figure 2.** The two evolution phases of the Lower Danube sector

These two phases are divided into four sub-phases: the sub-phase of the **Tulcea Gulf** (Palaeolithic Period), the sub-phase of the **Sf. Gheorghe I Delta** and the **Sulina Delta** (fluvial side) (Neolithic Period), the sub-phase of the **Sulina Delta** and the **Chilia Delta** (fluvial side) (Bronze Period - Roman Period) the sub-phase of the erosion of the Sulina Delta and the development of the **Lagunar Complex** (Byzantine Period).

The Gulf Phase is characterized by a single sub-phase (see Figure 3): the sub-phase of the Tulcea Gulf (Palaeolithic Period - sub-cluster 0.40222).

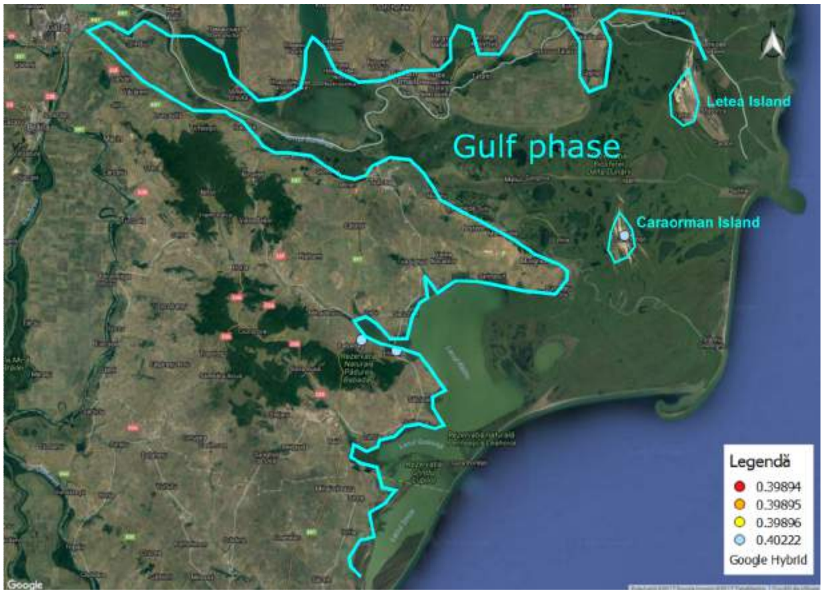



**Figure 3.** The sub-phase of the Tulcea Gulf (Paleolithic Period - sub-cluster 0.40222)

Using phases in the evolution of the Danube Delta to characterize the lower sector is not accidental. As suggested by the data on the fortifications in the Noviodunum Promontory area (see Figure 4), the Danube course was further north (about 45 m) and the water level 3 m below the current one. The presence of roman settlements in the south-eastern part of the fortifications from Noviodunum to the area Somova-Parcheş (after Gabriel Jugănaru, http://ran.cimec.ro) this considering their spatial distribution and location, suggest a harbor existence in the East of Noviodunum Promontory. That suggests the existence of a gulf between Noviodunum Promontory and Aegyssus Promontory (see Figure 5). This means that the Danube did not have enough power to develop the Delta and Izmail Ceatal - Cotul Pisicii sector at the same time. The sedimentation process between Dinogetia Promontory and Aegyssus Promontory was much lower than in the Delta area for a long period of time.

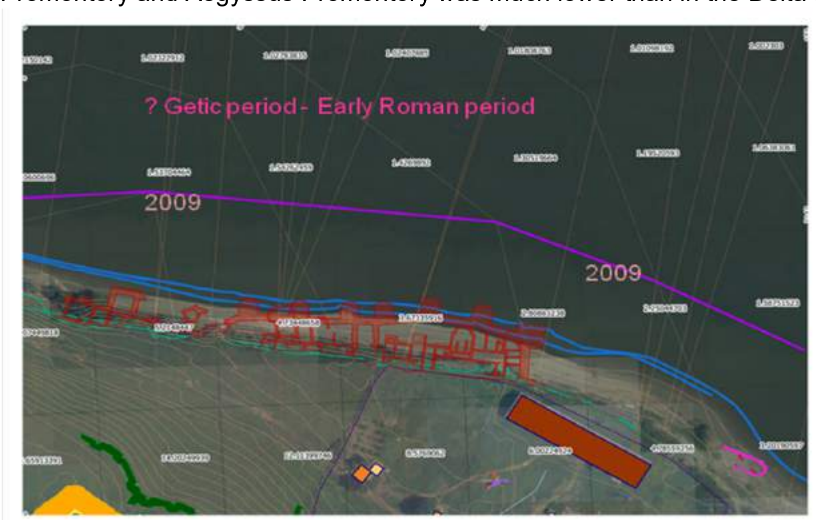



**Figure 4.** The fortifications in the Noviodunum Promontory area and probable limit to the first terrace of the Danube River (2009)


**Figure 5.** The potential presence of a Roman port in the East of Noviodunum Promontory

The Main Phase of the Lower Danube (cluster - 0.3989) is characterized by 3 sub-phases: Sub-Cluster 0.39895 (the sub-phase of the Sf. Gheorghe I Delta and the Sulina Delta (fluvial side) (Neolithic Period)), Sub-cluster 0.39894 (the sub-phase of the Sulina Delta and the Chilia Delta (fluvial side) (Bronze Period - Roman Period)), Sub-cluster 0.39896 (the Sulina Delta erosion and the development of the Lagunar Complex (Byzantine Period)).

The sub-cluster 0.39895 (Neolithic Period) is the second important sub-cluster in the main phase of the Lower Danube sector. Towards the end of the Mesolithic period and the beginning of the Neolithic, the Danube strikes the Noviodunum Promontory and is pushed to the north, where it hits another promontory and is pushed to the south-east. An intense sedimentation process in the northern part of the Palaeo-Danube course also occurs in the promontories Dinogetia and Noviodunum. This leads to an intensive process of deposition of the alluvium in the north and the formation of a bay in the south (the area Somova-Parcheş), between Noviodunum and Aegyssus promontories. During the Neolithic period, the Danube River follows the main shape of the land, and the Siret and Prut rivers have begun to create their own deltas (see Figure 6).

The sub-cluster 0.39894 is the most important cluster of Main Phase and contains three sub-clusters. The sub-cluster 0.398944 (Early Bronze Period) characterizes a dynamic stage in which the Danube River follow the main land shape as in the previous stage, but the settlements disappear along the Danube. If the restoration of the settlement in the following stages leads us to the conclusion that the form of the course has not changed, instead their disappearance in the Early Bronze Age signifies an increase of the level of the Danube (see Figure 7). Within Sub-cluster 0.398942 (Middle Bronze Period - Dacian Period), the Danube River follows the main land shape and apparently during this period there are not major events. The Siret and Prut deltas continue their development (see Figure 8). If in Sub-cluster 0.398943 (Roman Period) the Danube River follows the main land shape at the beginning of the period, when the Sulina Delta finishes its development, the Danube moves its course southwards. The water level is growing. Also, at this stage begins the clogging of the bay in the area Somova-Parcheş in its eastern part. Furthermore, the development of the sector behind the Dinogetia Promontory begins (see Figure 9).

The sub-cluster 0.39896 (Byzantine Period) is the last as importance. The Danube River begins the development of the sector Măcin-Grindu and the area Somova-Parcheș. The Siret and Prut deltas are fully formed (see Figure 10).

**Figure 6.** Sub-Cluster 0.39895 the situation of the Neolithic Period

**Figure 7.** Sub-cluster 0.398944 the situation of the Early Bronze Period

**Figure 8.** Sub-cluster 0.398945 the situation of the Middle Bronze Period - Dacian Period


**Figure 9.** Sub-cluster 0.398946 the situation of the Roman Period


**Figure 10.** Sub-cluster 0.39896 the situation of the Byzantine Period

## CONCLUSIONS

The preliminary data present at this moment revealed an intense alluvial process of the Danube bank in the area of Cotul Pisicii - Crapina Lake (beginning in the Neolithic period, but having the greatest development during the Byzantine period), upstream of the Noviodunum Fortress area (between Dinogetia and Noviodunum promontories) and in the sector Revărsarea - Ceatalul Izmail (beginning from the Roman period - between the Novoidunum and Aegisus promontories). The intense erosion process (beginning in the Roman era) was found in the Noviodunum Fortress (Isaccea) area. During the medieval period, the Danube takes control of the Prut and Siret deltas which are included in the main stream.

## REFERENCES

Barabási Albert-László, Réka Albert (1999) Emergence of Scaling in Random Networks, Science, Vol. 286, Issue 5439, pp. 509-512, DOI: 10.1126/science.286.5439.509;

Clauset, C. Moore and Newman M. E. J. (2008) "Hierarchical Structure and the Prediction of Missing Links in Networks," Nature, Vol. 453, No. 7191, pp. 98-101. doi:10.1038/nature06830;

Duncan J. Watts & Strogatz Steven H. (1998) Collective dynamics of 'small-world' networks, Nature, Vol. 393, Macmillan Publishers Ltd.;

Jain Anil K., (2010). Data clustering: 50 years beyond K-means, In Pattern Recognition Letters, Volume 31, Issue 8, Pages 651-666, ISSN 0167-8655, https://doi.org/10.1016/j.patrec.2009.09.011;

Killip, S., Mahfoud, Z., & Pearce, K. (2004). What Is an Intracluster Correlation Coefficient? Crucial Concepts for Primary Care Researchers. Annals of Family Medicine, 2(3), 204–208. http://doi.org/10.1370/afm.141;

*** Merriam-Webster Online Dictionary, (2008). Cluster analysis.http://www.merriam-webster-online.com;

Newman, M.E.J. (2012) Communities, Modules and Large-Scale Structure in Networks. Nature Physics, 8, 25-31; http://dx.doi.org/10.1038/nphys2162;

Ravasz Erzsebet and Barabasi Albert-Laszlo (2003) Hierarchical organization in complex networks, Physical Review E., Volume 67, Issue 2, Publisher American Physical Society;

Sales-Pardo Marta, Roger Guimerà, André A. Moreira, and Luís A. Nunes Amaral (2007), Extracting the hierarchical organization of complex systems, Proceedings of the National Academy of Sciences of the United States of America, 104(39), 15224–15229. http://doi.org/10.1073/pnas.0703740104;

Santo Fortunato, (2010), Community detection in graphs, Physics Reports, Volume 486, Issues 3–5, Pages 75-174, ISSN 0370-1573, https://doi.org/10.1016/j.physrep.2009.11.002;

Sarstedt M., Mooi E. (2014) Cluster Analysis. In: A Concise Guide to Market Research. Springer Texts in Business and Economics. Springer, Berlin, Heidelberg;

Yu Meichen, Hillebrand Arjan, Tewarie Prejaas, Meier Jil, van Dijk Bob, Van Mieghem Piet, and Stam Cornelis Jan (2015) Hierarchical clustering in minimum spanning trees, Chaos: An Interdisciplinary Journal of Nonlinear Science 25:2.

Received: 17 October 2017
Revised: 22 January 2018