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EULER NUMBER: A METHOD FOR STATISTICAL ANALYSIS OF ANCIENT POTTERY POROSITY

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Abstract

This study uses digital granulometry for computing Euler number. Euler number is useful topological feature in evaluating the pore structure of ancient pottery. The qualitative measurements of pore structure are accomplished for digital processing of SEM images. There are analysed two sets of samples. First set contains seven genuine samples belonging to Cucuteni culture. The second set of samples contains seven fake sample but presenting similar visual characteristics as the original artefacts. We used pixel dimensions of the pores in order to discriminate between the 'true' and 'false' ancient ceramic sample. This analysis method is applied on authentic and fake specimens.

Keywords: ancient pottery, SEM, pore structure, digitalized image, Euler number

1. Introduction

The Cucuteni culture is the most representative Chalcolithic civilization in the North Danube area, characterized by a remarkable material and spiritual culture whose evolution can be dated between 4600 and 3500 B.C. The spiritual elements of the old Chalcolithic civilizations in the North Danube area survived during the millenniums as substratum elements and at the moment when Christianity spread to these regions they were integrated by the new religion giving it peculiar features. This is why the understanding of the characteristics of the Romanian Christianity involves the study of the old Chalcolithic civilizations in the Carpathian-Danube-Black Sea area, especially the Cucuteni culture, from both a material and a spiritual point of view. In this context, the archaeometrical analyses are meant to give further information when the classical archaeological methods are limited.

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The material analysis of artefacts method has been found to be a powerful tool to reconstruct ancient cultures. Ceramics are intensely studied by means of archaeometric methods [1] due to their abundance and durability, and due to several macroscopic and microscopic attributes of interest to archaeologists [2]. Moreover, the materials used in this pottery (clay, sand and other natural material) present a unique chemical composition and result in a specific material structure.

This study is a multidisciplinary approach to archaeological pottery studies related to the provenance of raw materials and to ancient technologies (such as firing conditions during the manufacturing process). A method based on the digital measurement of individual pores and qualitative porosity estimation is presented. This method was successfully applied to ceramic specimens of the Cucuteni culture.

Ancient ceramics present a large range of porosities and pore sizes. Porosity is an important parameter of pottery because it influences the paste density, strength, permeability, resistance to weathering and abrasion, resistance to thermal shock affecting the functionality of the vases. Pore size distribution and pore density can be carefully controlled by the choice of clays, organic and inorganic composite and the added amount, by the precision in paste making operations (leavening, removing coarse particles, kneading) and by firing.

Firing leads to important changes in the porosity of the paste depending on the stage in which it is carried out and on temperature. Therefore, porosity increases during the early stages at lower temperatures as water is driven off and the carbonaceous matter is oxidised but is reduced during the late stages of the process when sintering and vitrification begin [3]. We also need to mention that clays differ in the porosity they attain on firing. Thus, kaolin and siliceous clays show high porosity even on firing at temperatures up to 1300°C, while other clays attain porosities of only 1-5% at about 1200°C [3]. Hence, porosity signatures are specific to the technology that was applied to the manufacturing process, thus, from the perspective of micro-structural analyses, this parameter can give information about authenticity of ancient ceramic samples.

The material may have two types of pores: open and closed pores. Porosity shows features imposed during the manufacturing process. Throughout the detailed studies on the microstructures a lot of useful information can be obtained, either on manufacture process or on authenticity.

Recently scientific tests have been introduced to help us determine whether an object is ancient or not, but in essence, all have their shortcomings [4-8].

The objective of this study was the scientific analysis of pore structure from ancient ceramic samples and to establish a method that allows us to differentiate between the true and false ancient ceramic sample.

SEM is a widely applied non-destructive technique, but rarely used for archaeometric purposes, i.e. for ceramics or glass remnants [9-13].

We used SEM images of ancient ceramics as object sources for image processing based on finding that topological properties that remain invariant under various transformations are useful in porosity characterization. The Euler number, which is defined as the difference of the number of connected components (objects), and the number of holes, is an important topological feature of a binary image [14,15]. Formally, the Euler Number is given by:

$$E = n_{comp} - \sum_{i=1}^{n_{comp}} n_i^{hole} \tag{1}$$

where n_{comp} is the number of foreground connected components and n_i^{hole} is the number of holes for i^{th} connected component.

The purpose of this study is to use the Euler number in order to discriminate between the true and false ancient ceramic sample by means of porosity signature. Being a fundamental topological feature, it has numerous applications in image processing in field of the analysis of sandstone for geological/archaeological applications [16].

2. Experimental

We studied two groups of samples: the group of genuine ancient ceramic (symbol GA) belonging to Cucuteni culture and the group of samples consisted of false ceramic (symbol GF). At the first glace, the fake samples appeared to be similar to the first group. The SEM analysis of the original and fake samples revealed discrepancies between their porosity structure, indicating that they were manufactured through different techniques and/or at different locations, despite their apparent similarity.

Granulometry deals with the determining the size of objects in a digital image. The advantage of this method consists in avoiding segmentation process for objects encompassed into image. Our goal was to calculate the size distribution of pores in an image. For accurate results, the SEM images were transformed in binary images. The pore patterns visible in porosity images are complex structures because of the geometrical projection associated with the radiographic technique.

The SEM images are digitized and in some cases improved using a grey tone treatment in the view of reducing the quantity of information. Then, they are thresholded to obtain a binary images in order to separate what corresponds to the phase to be measured (namely, we talking about the porous phase) from the rest of the image (dense material). The excessive noise or large zones of excessive brightness are eliminated by means of filters, allowing feature smoothing and small size particle elimination [17].

The image treatment is relevant for one type of image (similar level of brightness, contrast and noise). In this case, all images are acquired with the same magnification (500x).

SEM used in our measurements is Quanta 200 FEI type and characterizes both conductive and non-conductive samples. The method was presented in a previous study [11].

The algorithm for computing the Euler number of a binary image is based on counting certain (2 x 2) pixel patterns called bit-quads [18] over the entire image [19]. Gray [18] used the fact that the Euler number of a space region is locally countable [20]. The Euler number is related to convexities and concavities in the image and it is computed as the difference between the number of connected components and the number of holes. The main advantage to use Euler number in assessing the porosity of ceramics arises from the fact that it is independent from the specific geometric shape of the pores. It also allows us to obtain the global properties in spite that it used in its formalism local measure and local neighbourhood. The binary images are used. The formalism assigned '1' value to an object pixel and '0' value to the background. Any object pixel can be in the 8 (or 4) neighbourhood and a hole can be in the 4- (or 8-) neighbourhood (Figure 1). As general rule, it always must be chosen different neighbourhood metrics for objects and backgrounds. The commercial image processing toolbox MATLAB was used for Euler number computation.

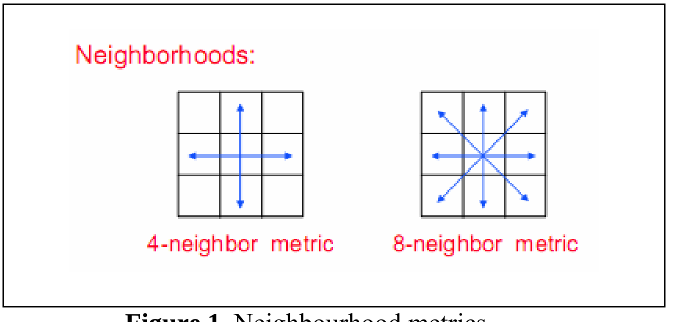

Figure 1. Neighbourhood metrics.

3. Archaeological materials and description

The analysed pottery fragments are part of a lot gathered during a surface research carried out in the Cucuteni settlement at Cucuteni-Cetățuie. The Cucuteni culture has a long evolution and it is one of the last brilliant cultural expressions of the Copper Age. For exemplification, four ancient ceramic samples used in this study are presented in Figure 2. This study is done on a lot of 14 samples.

3.1. Sample no. 15 (GA015)

It is a fragment from a vessel with a bi-truncated cone shape, with a very well marked shoulder, made of very fine paste, without temper, very homogenous, extremely compact and reduced porosity. The colour on the surface is grey, non-uniform (with a grey – brick-red tint here and there). The colour in section is brick-red which makes us believe that the vessel undergone a secondary, semi-reductive firing. The complete firing of the vessel wall proves a good quality initial firing. There are no traces of painted decoration, but the probable shape and the quality of the paste suggest it belongs to the Cucuteni B phase.

 GA015	 GA019
 GF061	 GF062

Figure 2. Photos of true (GA) and false (GF) ancient ceramic samples.

3.2. Sample no. 19 (GA019)

It is a pottery fragment belonging to a glass with a tall neck, with flaring and slightly averted rims. Based on its shape and decoration it can be assigned to Cucuteni B_1, subphase B_{1a} or B_{1b} [21]. The paste is of good quality, without impurities, homogenous and reduced porosity. No temper was used in the paste. The oxidant firing is complete and uniform, but traces of a slight secondary firing are reflected by the grey colour present on most of its surface. The decoration is painted in black on the brick-red background of the vessel and is made of a horizontal strip traced immediately under the rim, accompanied by thin, parallel lines of the same colour. The thin lines also appear on the shoulder of the vessel.

3.3. Fake samples GF061 and GF062

Since the raw material, the paste preparation, the shaping and the firing are similar, we are going to consider these samples together, showing the differentiation aspects. The fragments belong to two vessels experimentally made in 2007. The experiment was carried out at Cucuteni, Iasi County, and its main purpose was to get vessels made of a paste qualitatively similar to the Cucuteni pottery using local raw materials.

One of the two fragments belongs to a vessel in the shape of a bi-truncated cone (sample GF062) and the other one to a truncated cone vessel. The vessels were shaped from the same paste made of fine clay, without many impurities, well cleaned and tempered to get high plasticity and homogeneity. Previously, the clay mixed with water was left to leaven for two weeks for mechanical weathering and homogenization [22]. The paste was prepared without temper. The firing was made in oxidant atmosphere, in a kiln with two chambers. The pots were completely fired, but due to the way the kiln was charged, the firing was not uniform, variations appeared from a vessel to another or even on different areas of the same vessel, visible as variations in the firing colour. Thus, in the case of GF062 sample, the firing colour is orange, while for GF061 sample the colour is brick-red.

4. Analysis

The seven fragments of true ancient ceramic samples (GA) and seven fake ceramic samples (GF) were analyzed. For exemplification, Figure 3 presents the SEM binary images of two true ceramic samples and two fake ceramic samples and the correlation between pores size and pixels number allocated for each pore.

From the intensity values (or pixel values of opened objects, which are the pores in our case) it can be observed that porosity of the true samples is smaller with up to an order of magnitude compared with porosity of fake samples (see the graphics from Figure 3).

Experimental results on 14 ceramic samples reveal that Euler number has a strong discriminatory power for screening the samples. The values of Euler number of the ceramic samples widely vary between -7628 to 3649. For the fake samples all Euler numbers are negative and the value range is more homogeneous. On the other hand, the Euler number of the true samples has positive and negative values. All studied samples (genuine and fake) have different Euler numbers.

Table 1. Values of Euler number for the true samples.

Samples	GA11	GA 14	GA 15	GA 17	GA 18	GA 19	GA 21
Euler number E	-2750	3649	-3222	-5112	1988	-7628	-2003

Table 2. Values of Euler number for the fake samples.

Samples	GF58	GF 61	GF 62	GF64	GF66	GF 67	GF 68
Euler number E	-4960	-3404	-1746	-4648	-5634	-4510	-2958

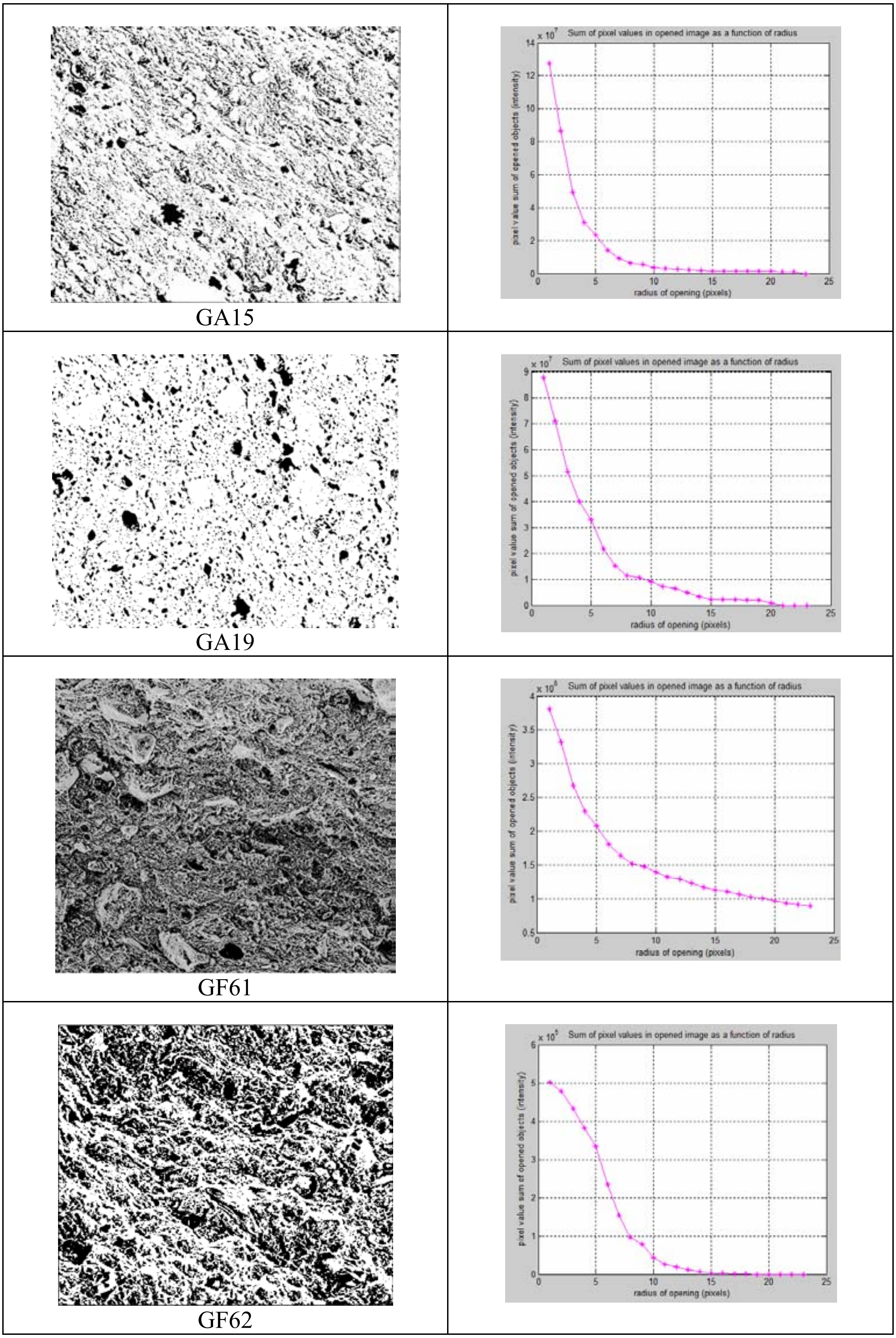

Figure 3. Binary SEM images of pores and distribution of the porosity image derived from digitalized SEM images.

5. Discussion

In spite of wide area of archaeological studies, there is a lack of information regarding porosity- material/technique and period/area relationship. One can always seek more for effective empirical curve fitting to differentiate among the various artefacts. There are various models that fit porosity data, at least approximately, but these data are often variable in quality [23]. The fundamental reason why these studies have been limited in their effectiveness of characterization the ancient ceramic is that these models are based on a single, fixed character of porosity (e.g. all bubbles, or all pores between particles of fixed shapes and stacking). In reality, both mixtures and changes of porosity need to be considered. Furthermore, these special categories of artefacts belonging to national patrimony limit the sampling possibility.

Porosity signatures can give information about the authenticity of ancient ceramic samples. Image analysis provides data on the distribution (pixels) related to the size of the pores. SEM analysis may reveal air bubbles in the walls, a finding that indicates poor handling of the clay. The digitized SEM images of the first group of genuine samples (symbol GA) differ significantly from that of samples of the second group (false samples symbol GF) indicating different formation conditions.

The true ancient ceramic samples present some smaller pores that indicate good handling of the clay. Bigger interconnected pores are observed due to the release of gases formed during burning of organic material. The false ancient ceramic samples present bigger pores that indicate a poor handling and firing of the clay.

Despite their apparent similarity, analysis of the true and fake samples revealed discrepancies between their porosity structure, indicating that they were manufactured through different techniques and/or at different locations or, as is this study case, manufactured at other time moment.

When considering the correlation between the pores size and pixels, the group GF presents larger pore sizes in comparison with those of the authentic sample group (see Figure 3). This method can allow a successful identification of the ancient pottery with regard to their authenticity by their porosity and pore sizes. This means that the groups of samples we have studied have statistically different porosity, which are determined by their manufacture materials and/or batch composition.

Being a topological parameter, Euler number analysis is based on the fact that regions of the holes are distinctively darker from the rest of the solid structure regions and show up as dark areas after proper thresholding in the intensity level.

The negative values of Euler number indicate that the number of holes (namely porosity) is greater than the number of object (or solid structure). This is a way to use the Euler number to discriminate between the true and false ancient ceramic sample by means of porosity signature. However, we estimate that it will be necessary to process a large number of ancient ceramic samples to be able to match the correct values of porosity and Euler number, possibly by using neural networks.

6. Conclusions

SEM facilitates the study of ancient ceramics by providing more accurate, less time-consuming profiles of all types of pottery as well as new insights into pottery-making techniques. SEM profiles make it possible to test the theoretic explanation for pottery-making techniques. This can be carried out with each individual piece of ceramic.

The main error arising in the image analysis concerns the image acquisition and the brightness adjustment of the microscope and of the camera. In addition, there are errors resulting from the SEM operator's skills in measurement technology. The image processing method presented in this study allows us to surpass these errors.

Euler number can be used to discriminate between the true and false ancient ceramic sample by means of porosity signature. The negative values of Euler number indicate highly porosity of the ceramic samples.

We demonstrated the potential of both SEM technique and image processing for the characterization of ancient ceramics. This non-destructive analysis offers a way to get information on the process and even sometimes on the date of ancient artefacts.

In order to use effectively the SEM images by means of the Euler number algorithm it is necessary to handle a large number of samples by generating a dedicated database. This will be a further stage of our work as the primary data has already been procured in this study.

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