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Approaching Surface Treatment in Prehistoric Pottery: Exploring variability in tool traces on pottery surfaces through experimentation.

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Abstract

The surface treatment of handmade pottery is often described in ceramological studies of prehistoric collections. However, beyond inferences about its meaning, few works have addressed this issue in depth. For this study, an experimental program has been carried out, where the main variable being explored was the category of tool involved in the fabrication of prehistoric handmade pottery. Therefore, we start from the hypothesis that different tools generate differentiable traces. A catalogue of traces generated by five pottery tools (pebble, flint spatula, pottery spatula, shell spatula and linen rag) was created, with the aim of characterizing and systematizing them. The resulting macroscopic analysis allowed a first qualitative classification of the traces. Microscopic analysis by confocal microscopy then confirmed the classification with quantitative data. The potential of the proposed methodology for traceological and textural analysis of surface treatment in ceramics is highlighted. Hence, the possibility of discriminating different surface treatment techniques opens new perspectives for the study of prehistoric pottery.

Keywords: Experimentation, Traceology, Pottery surface, Toolkit, Reference collection.

1. Introduction

Analogy plays an important role throughout the development of archaeological science. It helps to reconstruct the bridge between a past human activity and the material record that exists in our present. It allows the archaeologist to recognize in an inert trace the living process that generated it. In this sense, some of the methodological developments in archaeology have been based on the construction of models that allow us to establish this association between action and matter, between gesture and trace. The consolidation of disciplines such as experimental archaeology and ethnoarchaeology is integrated in this approach (Johnson, 1999).

One of the limitations of analogy is the distance between the present and the past social reality. However, it is useful when it comes to analysing processes and concrete situations, as long as its scope is previously delimited. This implies that, by definition, it is a deductive procedure. The relevance of the analogy must be established prior to the observation, even if this is done by using the knowledge already accumulated for the discipline (De Gortari, 1974; Bate, 1998; Johnson, 1999). And it is precisely this prior design that must establish its validity and the guidelines for reading its results.

This methodological procedure is followed here. We start with analytical modelling of the ceramic production process, where we isolate surface treatment as a phase in the fabrication of the containers. We also assume that in the manufacture of handmade pottery, where there is no rapid rotation of the container during modelling or finishing, the technical conditions that lead to the process are standardised. Similarly, that the recreation under controlled conditions of this part of the production process can provide guidelines to identify certain actions involved in it in the finished product.

Surface treatment refers to the series of actions in the production of ceramic recipients in which the internal and external walls of the vessel are smoothed and prepared for a functional and/or aesthetic purpose. It can also be defined as all the technical actions aimed at modifying the inner and outer surfaces of a recipient. Surface treatment can be separate from or connected with the procedure to create the shape of the recipient, depending on whether it is carried out during or after modelling the shape, or even after firing (Timsit, 1997).

This aspect of hand-made pottery manufacture has not been studied in any depth in archaeological ceramic studies, which have tended to focus on other stages of pottery production, such as the procurement and preparation of the clay, the techniques used to make the recipients, decorations and firing processes. Consequently, precise proposals have rarely been made about the activity of surface treatment, which has become diluted as another aspect in the creation of a pot. However, some scholars have vindicated the need to explore, in terms of investment in labour and means, the set of actions required to finish ceramic recipients. It is a promising avenue of research, in which those productive actions are individualised in order to study them in greater depth (Martineau, 2001, 2006, 2010; Lepère, 2014; Forte, 2014, 2019; Skochina, 2016).

This work presents some initial results of the experimental program carried out on the basis of the previous considerations with the purpose of defining objective references to understand a segment of ceramic production, surface treatment, from the observable traces on the surface. In general terms, the aim is to empirically characterise the incidence of economic factors (the amount of work invested) and technical factors (the actions carried out and the tools used) (Gassiot, 2002).

The programme was based on the hypothesis that different forms of surface treatment, produced by the combination of different variables (tools, movements, intensity of work, characteristics of the clay, etc.) should result in substantial differences that can be observed at qualitative and quantitative levels. That is to say, they should generate diverse but diagnostic traces.

The main methodology of this study, through which the questions raised will be answered, is experimentation applied to archaeology. Since it can help to reconstruct the relationship between the material record and the activities that generated it, in recent years experimentation has consolidated as a scientific method within prehistoric archaeology. However, this methodology has been one of the foundations of archaeological methods ever since it was first applied in the 19th century (Evans, 1860, 1872; Rau, 1869; Smith, 1893; in Skakun et al. 2017: 6).

The comprehension of some phases of past productive processes through material remains often requires the creation of references that can guide the identification and characterisation of the actions that generated them. In this sense, experimentation can reconstruct the connections between the archaeological record and past technological processes. It is therefore an excellent way to obtain information about productive activities and the economy of ancient societies, as well as to develop new analytical methodologies at macro- and microscopic levels (Skakun et al, 2017: 7).

Experimentation applied to archaeology is an invitation to go beyond aseptic and merely descriptive studies of material remains and has led to a wide range of hypotheses about work processes and the use of objects in the past (Ascher, 1961; Schiffer et al. 1994). Thus, in prehistoric pottery studies, experimentation came into widespread use in the mid-20th century with some pioneer researchers (Danthine, 1953; Semenov, 1981; Garidiel, 1985; Rice, 1987; Echallier, 1988; Arnal, 1989). In the 1990s and early 21st century, Skibo (1992), Orton (1993), Timsit (1997), Chevillot (1996), Clop (1998; 2002; 2008), Martineau (2000; 2001) and Roux (2016) demonstrated the importance of this line of research as they designed projects that focused on the different stages in the production of pottery and put into practice more complex experimental programmes mainly to address particular archaeological issues. In this context, experimental programmes have been applied to different kinds of implements, such as lithic tools (Gijn, 1989; Rodríguez et al. 2006; Mazzucco et al. 2017), osseous utensils (Maigrot, 1997; Mozota et al., 2017a; Mozota et al., 2017b), marine shells used as tools (Pascual, 2008; Salanova, 2011; Cuenca-Solana et al., 2010, 2015 and 2017; Manca, 2013, 2016), ceramic spatulas (Korobkova, 2001; Gosselain, 2002; Godon and Lepère, 2006; Vieugué et al., 2010), and textiles (Andersson et al. 2012; Forte and Lemorini, 2017), to name just a few examples (Clemente et al. 2019).

Experimentation studying fabrication marks on prehistoric pottery is analogous to the functional analysis of lithic artefacts. The marks, whether they were produced during manufacture (technological traces) or by use (functional marks) possess a determinate origin that can be identified by reproducing the same actions that generated them (Vila, 1981; Clemente, 1997; Pijoan, 2001; Terradas and Clemente, 2001; Vila and Clemente, 2001; Roux, 2016; Skochina et al. 2016).

2. Objectives

This study is part of an experimental programme aimed at exploring the technical conditions of a phase in the production of hand-made pottery: the surface treatment of the recipients. Through the creation of an experimental collection, the objective has been to show how the different surface treatments can be discriminated at several levels of analysis, both macroscopically (with the naked eye) and microscopically (to study the texture/surface topography; for further information, see Leach, 2013: 2; Evans et al. 2014; Calandra et al. 2019).

In order to resolve the validity of the proposed programme, several questions need to be answered. The main one is whether different surface treatment processes, both in terms of working time and technical characteristics and the tools used, leave different traces. This general problem can, in turn, be fragmented into other more limited problems: Is it possible to identify the tools used from the type of trace generated on the surface? Does the type of clay and its state of loss of humidity condition the development and appearance of the trace? Can the intensity of the work invested, which is a determining factor in the cost of production, be inferred from the characteristics of the traces?

This paper focuses on resolving the first of these specific issues: exploring the hypothesis that different tools generate differentiable traces. Related to this purpose, it is also intended to proceed to an objective description of the different traces. Likewise, we seek to confirm their observation by means of two, *a priori*, independent procedures, one macroscopic and the other by means of laser-scanning microscopy. To avoid distortion and noise, the other variables involved in the monitored work process have been maintained unchanged.

3. Materials and methods

3.1. Design of the experimental programme

The experimental programme was based on analytical modelling of surface treatment processes. This model differentiates between two sets of variables, environmental variables and technological and economic variables, to which are added those linked to the subsequent observation of the traces.

In order to understand the effect of tools on the pottery surfaces, the environmental variables that mainly affect the characteristics of the clay have remained constant. Within the second group of variables, the following have been considered: type of clay, drying time, working time and toolkit. To focus on the resolution of the question posed, all of them have been kept constant, except for the tools used. Once this factor has been understood, new variables will be introduced in the experimental programme, such as degree of dryness or different working times.

The initial part of the experimental programme involved the preparation of ceramic squares 10 x 10cm in size and one centimetre thick. The surface of each one has been treated following a specific combination of variables according to the plan designed beforehand. Finally, once the experimentation was finished, the pieces were fired in an electric kiln at 850ºC to facilitate their analysis and conservation.

Five pottery squares produced in the programme are studied here. They demonstrate the results of experimentation using different types of utensils: a pebble, a knapped flint artefact, ceramic spatula, a *Glycymeris glycymeris* marine shell and a linen rag.

3.1.1. Clay

The experimentation samples were made with commercial clay[1]: a purified, processed and packaged natural clay. It maintains the degree of hygrometry in optimal conditions for a long time once it begins to be used. With this type of clay, the traces are clearer because of the small volume of inclusions. This allows a more direct assessment of the hypothesis underpinning the programme without the distortion that the larger quantity and variability of inclusions in non-commercial clay might introduce.

3.1.2. Degree of dryness

Once the samples had been prepared, and before treating their surface, they were left to dry for a time until the consistency required for the experimental programme was reached. Therefore, it was necessary to consider the *hygroscopicity* of the materials: i.e. their capacity to absorb humidity. Ceramic clay is not an exception and two determinant factors must be considered in the drying process: the water content in the clay and atmospheric humidity. The percentage of atmospheric humidity and water contained in the walls of a recipient determine the rapidity with which the water will evaporate. Thus, at a low temperature and high humidity, the water in the clay will be lost slowly. In contrast, with high temperatures and low atmospheric humidity, the drying process will speed up. The drying speed influences some properties of the clay fabric in the different phases of the pottery fabrication process, including the final finishing phases.

All the experimental samples have been worked with the same amount of initial water and in the same environmental conditions of temperature and humidity, so they have undergone the same gradual drying process. Consequently, the temperature and humidity have remained stable by establishing an optimal temperature range between 24 and 28ºC, and atmospheric humidity between 30 and 55%. In this way, they hygroscopic loss was maintained stable and similar for all the experiments (Díaz

[1] The model is PA84BIS15 Pasta Húmeda Roja Bisbal, with a humidity percentage of 18-21%, provided by Anper Cerámica (Rubí, Spain).

Bonilla, 2019). As a result, those days when the temperature and humidity varied significantly from the fixed parameters were not considered suitable for experimentation, for example, on wet rainy days or in the middle of summer.

The determination of drying times is subject to multiple factors: quality of the clay fabric, quantity and type of inclusions, environmental conditions, place of work (indoors or in the open air), water added to the surfaces *posteriori*, etc. The drying time is possibly the environmental variable that is most difficult to define and control as, in addition to the atmospheric conditions, it also depends on the characteristics of the raw material used, in terms of both the mineralogy and its capacity of hygroscopic retention.

In the case of the commercial clay, the hydric volume contained in the clay is stable as the same amount of water is always added per kilogram of clay, resulting in between 18 and 21% humidity. Its definition has been based on previous studies on pottery technology and ethnography (Garidiel, 1985; Martineau, 2010; García-Rosselló et al. 2013; Lèpere, 2014; Roux, 2016).

For the present study, samples in a humid state after a drying time of 14 hours have been selected. This is a state in which the clay is still malleable but has acquired consistency and a pottery recipient will remain firm by itself without losing the shape it has been given. However, the walls are still fresh enough to be worked. This is the ideal state in which to create the definitive shape and carry out surface treatment.

3.1.3. Working time

The different times of the investment in labour, pottery tools, and degrees of dryness determine the result of the surface treatment and therefore also of the experimental samples. Therefore, reproducing the approximate working time employed in hand-made pottery fabrication enables a general picture to be obtained about the labour invested and relate it with the result obtained – a particular surface (Gassiot, 2002).

In the design of the experimentation programme, the amount of work was established in terms of time. To do this, it was assumed that its intensity (e.g., in terms of strength or rapidity of movements) is constant. In consequence, given a certain drying time and use of a specific tool, with more work, the traces and condition of the surface will vary.

In the case of the present study, all the samples were worked for five minutes. This is long enough to generate a considerable number of traces on the surface of the sample.

All the experimental samples have been worked by the same person to avoid variability due to different workers.

3.1.4. Toolkit

This is the modifiable variable in the experimentation described here. The variation in the tool used for the surface treatment is aimed at analysing the changes that occur on the ceramic surfaces.

Many of these tools would have been made from perishable materials and therefore their conservation in the archaeological record is difficult or impossible. Such utensils may have been made with animal or plant materials, such as wool, leather and cloth made from plant fibres (flax or hemp) or wooden spatulas. In contrast, some mineral and animal tools have been documented archaeologically, like river pebbles, flint flakes, bone spatulas, shells, and reused pieces of pottery or *estèques* (Gassin and Garidiel, 1993; Manca, 2016; Vieugué et al., 2010; Maigrot, 2010; Mazzucco et al., 2015; Cuenca-Solana et al., 2017; Margarit, 2017; Cuenca-Solana and Clemente, 2018, Mazzucco, 2018; Clemente et al., 2019, to cite just a few examples).

In the present study, the experimental samples produced with five tool types have been selected. They differ in their nature and morphology: pebble, flint spatula, pottery spatula, marine shell spatula and linen cloth.

The pebble is small, shiny, and polished. It is always used on the same side. This tool allows a back and forth motion. The flint spatula was obtained by flaking a larger flint core. The resulting spatula is an elongated tool. The contact face used to scrape ceramic is always ventral one. This tool allows a back and forth motion. The pottery spatula is made from a broken fragment of a hand-made vessel. It contains medium-size granitic inclusions. The marine shell spatula belongs to the species *Glycymeris glycymeris.* Small in size, this was used without any previous preparation or shaping. The pottery surface is worked with the external face of the shell, following a back movement. Finally, the linen cloth has a thick weave. It is used wrinkled, hand held, with a back and forth motion (for more detailed information on the tools used, see Clemente et al., 2019).

3.1.5. Firing

The experimental pieces were fired for two reasons: 1) to assimilate the sample as much as possible to the pottery production process, so that the result of the experimental samples can be compared with the archaeological objects; and 2) to preserve them from the damage they would suffer if stored unfired and to fix the traces. Firing lasted three hours with a gradual increase in temperature to 850ºC. Scientific publications show certain consensus in that this is the usual temperature that an artisanal kiln in the ground could reach, although there may always be exceptions (Echallier et al. 1992; Vázquez-Varela, 2003; García-Roselló et al., 2006, to cite just a few examples).

3.2. Production of samples

The experimental samples were made in the High Mountain Archaeology Group (GAAM) and ARCHEOM laboratories in the Prehistory Department at the Autonomous University of Barcelona. This was ideal because, as it is in a semi-basement (on MRA building), the room maintains stable temperature and humidity conditions, with only small oscillations, all year round. This meant that experimental samples could be prepared at all times, except on the hottest days of summer and when humidity was higher because of rain.

There were made with two pieces of wood placed on a large piece of linen cloth. The clay was kneaded and prepared as a plaque which was spread out and smoothed with a wooden roller.

Metal moulds, 10 x 10 cm in size were used to cut square pieces of clay without hardly any deformations. These pieces were numbered on their reverse side and were left to dry for the time required for each experiment. The temperature and humidity were recorded in the database twice: when the pieces were made and just before they were worked (Fig.1).

After being worked, the pieces were left to dry for at least seven days so that all the water contained in them would have been lost. This decreases the risk of fracture of the samples. After firing, the pieces were labelled with their inventory number and stored in plastic bags with a zip closure to guarantee their appropriate conservation.

The five experimental samples worked with tools are analysed from a control sample. The control sample was made following the previous scheme. After being smoothed with the roller and cut with the square mould, the fingers are lightly passed over it to remove the impressions of the wood. This creates a completely smooth surface with no visible marks or traces. The control sample has been photographed and analysed at the same level as the experimental samples, so that they can be compared with each other.

FIG. 1

3.3.Analytical protocol: qualitative and quantitative

The experimental samples (Table 1) were analysed in two ways, a qualitative or macroscopic observation and a quantitative or microscopic analysis.

Sample	**Tool**	**Degree of dryness**	**Working time**	**Type of kiln**	**Firing temperature**
M 1.0	-	14h	5’	Electric	850 º
M 1.45	Pebble				
M 1.46	Flint				
M 1.50	Pottery spatula				
M 1.52	Shell spatula				
M 1.53	Linen rag				

3.3.1. Qualitative analysis

An Access database was created in Microsoft Office to contain the qualitative data. The variables follow the pattern proposed by Clemente (1997) and García-Rosselló and Calvo (2013). These variables concentrate on the characterisation of the traces. The main trace is described with all its variations (Fig.2). The categories chosen to describe the traces focus on their morphological and topographic characterisation.

The experimental samples were photographed with a Leica IC 3D MZ16FA binocular microscope at 6.30 and 10.1X, in the laboratories of the Archaeology of Social Dynamics (ASD) research group of the Spanish Council for Scientific Research (CSIC). One series of photographs was taken with double oblique lighting (gooseneck system). Another was taken with a vertical light from a led corona, with variable intensity of the beam of light. The combination of light and shadow enable the observation of the traces.

This graphic material, together with the piece *in situ* and direct observation through the binocular, was used for the macroscopic analysis.

FIG.2

3.3.2. Quantitative analysis

In order to test whether the visual differences observed between the various surface treatments can be quantitatively measured, laser-scanning confocal microscopy (LSCM) has been tested. Laser-scanning confocal microscopy has proved to be an accurate and easy to use technique for surface microtexture measurement (Evans and Donahue, 2008; Stevens et al., 2010; Ibáñez et al., 2014, 2019; Stemp et al., 2018). For this analysis, we have used a Sensofar Plu Neox, a programmable array scanning confocal microscope, in the laboratories of the Archaeology of Social Dynamics (ASD) research group of the Spanish Council for Scientific Research (CSIC). A total of 240 areas, each one 650×500 μm in size, have been sampled: 40 areas for each tool-class (flint tool, pebble, shell, *estèque*, and linen cloth), as well as an untreated, natural clay surface. Areas were randomly measured on the clay plate to cover the textural variability entirely. A EPI 20×N (0.45 NA) objective, with spatial sampling of 0.83 μm, optical resolution of 0.31 μm, vertical resolution of 20 nm and a z-step interval of 1 μm, has been used. The monochromatic blue LED (460 nm) has been used as light source. After measurement, all areas were processed with Mountains7 software (SensoMap Standard), from Digital Surf. A levelling operator using the least squares (LS) plane method was used to correct the lack of horizontality. Afterwards, spatial filtering has been applied to isolate the roughness components of the surfaces using a Gaussian filter with a 0.08 mm cut-off (Le Goïc et al., 2016; Caux et al., 2018).

In a first phase, 30 parameters (Annex 1) were extracted from Mountains7 for each one of the 240 areas. Successively, all variables failing the tolerance test were removed

(Annex 2_a) and/or those that showed a non-significant discriminant capacity through Wilk's lambda test (Annex 2_b) (Ibáñez et al., 2016). Afterward, on the basis of the structure matrix (Annex 2_c), nine parameters, which offer the greatest size of correlation within the first function (that explains 86% of the total variance), were selected (Annex 3). Selected parameters (included in the ISO 25178 standard) (Annex 3) are:

1. Height parameters, a class of surface finish parameter characterizing the distribution of heights (*Sq*, root square mean height –represents the standard deviation of heights; *Sa*, arithmetical mean height –expresses the difference in height of each point compared to the arithmetical mean of the surface).
2. Functional parameters, which are related to the distribution of heights and its cumulated curve, called the Abbott-Firestone curve (*Smc*, inverse areal material ratio –is the height [c] that gives the areal material ratio p=10%; *Sxp*, peak extreme height – difference of heights at the areal material ratio values p=50% and q=97.5%; *Spk*, reduced peak height –represents the mean height of peaks above the core surface)
3. Feature parameters, calculated on particular points, lines or areas of the surface, detected by watershed segmentation (*Spc*, mean peak curvature –represents the arithmetic mean of the principal curvature of the peaks on the surface; *S10z*, ten-point height – is defined as the average height of the five highest local maximums plus the average height of the five lowest local minimums.
4. Volume parameters, which are defined with respect to the Abbott curve (*Vvv*, valley void volume), which represents the void volume of dales at the areal material ratio p=80%.
5. Hybrid parameters, which use both height and lateral information (*Sdr*, developed interfacial area ratio –this parameter is used as a measure of the surface complexity, expressed as the percentage of the definition area's additional surface area contributed by the texture as compared to the planar definition area).

Once the parameters have been selected, the "used_tool" variable on which the discriminant analysis is run is removed from half of the sample. Afterwards, a canonical discriminant function is carried out. In this way, a blind classification of half of the data is obtained.

4. Results

4.1. Qualitative analysis

A qualitative description of the traces observed in connection with the different utensils can be made at a macroscopic level (Fig. 3a and 3b). They are described thus:

- Control sample. This is an experimental sample that was smoothed with fingers to create a flat, matt surface with no striations. It is a neutral sample, a state of surface without any evidence of being worked with a tool. It has only received the smoothing action by means of the wooden roller (see the section on the production of samples) and a slight smoothing with the fingertips to eliminate any mark of wood.
- Pebble. Sample M 1.45 was treated with a granite river pebble. At macroscopic level traces can be seen on the surface of the sample in the form of a wide groove. The edges of the groove are prominent, which is to say that they are clearly marked because material has been dragged and accumulated on the edges because of the pressure of the tool. The ends or limits of the traces are similarly marked: the dragged clay means that they finish abruptly.

  The cross-section of the traces has been considered an irregular surface as the grooves do not possess a totally defined cross-section. The traces are distributed in parallel groups. The surface is matt and irregular because of the prominence of the traces.
- Flint spatula. Sample M 1.46 was worked with a chipped flint fragment. Clearly marked traces are observed macroscopically. The traces are fluted, with prominent edges as a result of the clay being dragged by a smooth hard tool with sharp edges. The ends of the traces are clear, as the combination of implement and movement causes them to finish abruptly. They possess a U-shaped cross-section with striated bottom. The traces cross over each other owing to the swivelling motion of the hand.

  In this case of the experimental sample worked with flint, some traces can be regarded as secondary. They are grooves with flat sides, without prominences or dragged clay. The ends of the traces are marked. These grooves are so slight that their cross-section is superficial and flat, without irregularities. The grooves cross over one another because of the varying movements of the hand during the work.

The surface is slightly shiny owing to the repeated action with the hard-mineral tool.

- Pottery spatula. Sample M 1.50 was worked with a pottery fragment that had been shaped to work in the production of a new recipient. The edges were smoothed and given the typical rounded shape of the pottery spatulas documented archaeologically (Viegué, 2010; Clemente et al. 2019).

  The traces were fluted with prominent sides and marked ends owing to the hard nature of the tool, which also contains inclusions in the clay fabric. Their cross-section is U-shaped with striated bottom because of the irregularities in the surface of the tool.

  The traces cross over each other, a result of the kinematics in the use of the implement. The surface is rough, as the fluting formed by the pottery spatula is very marked and visible.

- Shell spatula. Experimental sample M 1.52. The traces are classified as fluted with prominent sides, as some clay was dragged and left accumulated on the sides. The ends of the traces are marked, as they finish abruptly.

  The cross-section has been classified a U-shaped with flat bottom as the morphology of the tool is smooth without any noticeable irregularities. The traces are criss-crossing as the tool is small and the movements of the hand produce new traces that cross over the previous ones.

  The surface is slightly shiny, caused by the friction and smooth hard nature of the tool.

- Linen rag. Sample M 1.53 was worked with a piece of linen cloth, used as a rag to rub the pottery surface.

  The rag produces striations whose sides may be irregular, depending on the pressure exerted with the hands. The ends of the traces are blurred, as the soft utensil does not apply enough force to finish the striation abruptly. It is not possible to attribute a definite cross-section shape as the striations are superficial; therefore, the cross-section has been classified as irregular.

Owing to the morphology of textile weave, the traces are distributed over the surface in parallel groups that do not overlap or cross over each other.
The surface is smooth and matt.

FIG 3a.

FIG 3b.

4.2.Quantitative discrimination

Discriminant function analysis shows consistent discrimination between the different surface treatment techniques. Results provide a correct percentage of 84.6% (203 of 240 areas). Significant mean differences (Wilks' Lambda) (Annex 4) were observed for all the selected parameters. Most of the variability is expressed in the first dimension (88.9%) (Annex 4), in which the pottery spatula (*estèque)* group is clearly separate from the other treatment techniques (Fig. 4). Pottery spatula-treated surfaces are correctly classified at 100%. It can therefore be stated that surfaces treated with the pottery tool are significantly different from the others, showing higher surface roughness values. Fisher's linear discriminant function indicates that the parameters that best characterize the pottery spatula group are *Vvv*, *Sa*, and *Sxp*, for which mean values differ considerably from those of the other tool-classes. Regarding the other surface-treatment classes, most overlapping occurs between shell and flint spatula and between untreated surfaces and pebble (Annex 4) as also visible from the plot (Fig. 4) (Table 2).

FIG. 4

		PREDICTED GROUP MEMBERSHIP						
		PEBBLE	***ESTÈQUE***	**FLAX**	**SHELL**	**FLINT**	**UNTREATED**	**Total**
Count	**PEBBLE**	37	-	1	-	-	2	40
%		92.5%	-	2.5%	-	-	5	100
Count	**POTTERY**	-	40	-	-	-	-	40
%		-	100%	-	-	-	-	100
Count	**FLAX**	-	-	32	5	3	-	40
%		-	-	80%	12.5%	7.5%	-	100
Count	**SHELL**	-	-	-	29	7	4	40
%		-	-	-	72.5%	17.5%	10%	100
Count	**FLINT**	1	-	1	-	38	-	40
%		2.5%	-	2.5%	-	95%	-	100
Count	**UNTREATED**	1-	-	-	3	-	27	40
%		25%	-	-	7.5%	-	67.5%	100

In order to better understand the differences between the remaining treatment techniques, it is helpful to remove the pottery spatula from the sample. The analysis is therefore run once again. The Eigenvalue values now show that Function 1 explains 42.9% of the variance, Function 2, 28.1% and Function 3, 26.4% (Annex 5).

FIG.5

The classification table (Table 3) shows a correct classification percentage of 84.5%. The lowest degree of classification occurs for plates treated with shell (57.5), which are mostly mixed with those worked with a flint tool and untreated surfaces. The rest of surface treatment techniques are correctly identified between 92.5% and 82.5%.

		PREDICTED GROUP MEMBERSHIP					
		PEBBLE	**LINEN RAG**	**SHELL**	**FLINT**	**UNTREATED**	**Total**
Count	**PEBBLE**	37	1	-	-	2	40
%		92.5%	2.5%	-	-	5	100
Count	**LINEN RAG**	-	37	-	3	-	40
%		-	92.5%	-	7.55	-	100
Count	**SHELL**	-	3	23	7	7	40
%		-	7.5%	57.5%	17.5%	17.5%	100
Count	**FLINT**	-	1	-	39	-	40
%		-	2.5%	-	97.5%	-	100
Count	**UNTREATED**	5	-	2	-	33	40
%		12.5%	-	5	-	82.5%	100

Linen rag and Untreated surfaces show higher coefficients in the first function; Pebble and Flint in the second (Fig. 5). Function coefficients (Annex 5) show that *Sa* and *Vvv* show greater values for the first dimensions, while *Spc* and *Spk* show important loads on the second one. Surfaces treated with Pebble are the most similar to untreated surfaces, and both show higher values for all roughness parameters; surfaces treated with Flint spatula appear to have more rounded and shorter peaks (low values for *Spc* and *Spk*) (see Annex 5).

To confirm the confidence of the classification rule, we classified half of the sample (120 areas) blind with regards to the other half. Samples were randomly chosen from the database, 20 areas for each surface treatment. For these 20 areas no indication of group membership (i.e. pebble, pottery spatula, linen rag, shell, flint, and untreated) is provided before running the quadratic discriminant. The results of this blind classification are quite satisfactory, as 73.4% cases are correctly classified (Table 4).

		BLIND_TEST					
		PEBBLE	***ESTÈQUE***	**LINEN RAG**	**SHELL**	**FLINT**	**UNTREATED**
Count	**PEBBLE**	16	0	2	0	0	2
%		80%	-	10%	-	-	10%
Count	**POTTERY**	0	20	0	0	0	0
%		-	100%	-	-	-	-
Count	**LINEN RAG**	0	0	17	2	1	0
%		-	-	85%	10%	5%	-
Count	**SHELL**	-	-	1	10	8	1
%		-	-	5%	50%	40%	5%
Count	**FLINT**	1	-	-	4	15	-
%		5%	-	-	20%	75%	-
Count	**UNTREATED**	4	1	1	4	-	10
%		20%	5%	5%	20%	-	50%

The lowest percentage of correct classification is provided again by surfaces treated with a Shell, which are mostly mixed with those worked with a Flint; this result is coherent with the data previously obtained (Fig. 5). In general terms, it can be stated that surface treatment can be correctly classified using microtexture analysis.

5. Discussion

The objective of the present study is to begin to systematise the technical actions in which the surfaces of hand-made pottery are shaped and prepared. This can be achieved with systematic experimental programmes that examine different aspects of production. It has been based on the hypothesis that different utensils used to treat pottery surfaces will leave different traces. Therefore, the working instrument involved can be objectified and identified. Indeed, the results show how the traces can be classified into different types owing to the various aspects that are taken into account in the analysis of the experimental samples. This qualitative macroscopic classification is supported and consolidated with quantitative data gathered microscopically. In this regard, the results of the statistical tests provide a classification percentage of 84.6%. The result of the blind test also provided a strong classification, with 73.4% of areas correctly classified.

The ceramic spatula stands out from all the other tools used in the samples because it generates a particular appearance. The traces are quite visible even to the naked eye because of their prominence.

From the qualitative point of view, the surfaces worked with a pottery spatula possess fluted traces with a U-shaped cross-section and striated bottom. The edges of the traces are clearly prominent and the ends are clear.

The morphology of the pottery spatula helps to generate such evident traces. The inclusions and the shape of the fired and fragmented ceramic fabric mean that the active edge that operates on the experimental surface is hard and irregular.

This circumstance is clear in the quantitative tests in which the data referring to the ceramic spatula are separate and clearly differentiated from the other data. It possesses the highest value of Function 1, which suggests that some variability exists (Fig. 6).

FIG. 6

The traces left by the pebble are moderately visible to the naked eye. The grooves are wide with an irregular cross-section that does not clearly display a U-shape. The edges are irregular as some are prominent whereas others are flat because the groove is not deep enough, and the ends of the traces are marked. Due to the variable movement of the hand, the traces are grouped together; they never lose contact with each other and are distributed parallel to each other.

The pebble tool produces such wide grooves that, together with the malleable state of the clay, the traces possess an irregular cross-section. This is expressed quantitatively by the irregularity in the trace depth. The wide grooves mean that there are no large distances in the topography of the surface, i.e. there are no great differences between the highest and lowest points on the surface. As a result, the data are not compact but clearly grouped and differentiated from the other treatment groups because they are grooves. This also means that the data referring to the pebble tools are close to and even mixed with the data from the negative sample, which is completely smooth with no traces or irregularities. The centroid of the pebble data displays medium values, near 0 in each function (Fig. 7).

FIG.7

The flint tool generates a very marked microtopography when observed macroscopically. At a qualitative level, the samples display fluted traces with a U-shaped cross-section and striated bottom. The sides of the fluting are prominent and the ends of the traces are marked. The swivelling motion of the hand makes the traces cross over each other.

The tool possesses a complex morphology as it is a large chipped flint blade with numerous faces and sharp edges. Its texture is slightly granulated. This means that the edges of the tool penetrate abruptly in the clay fabric and generate fine but deep traces.

This is also seen at a quantitative level. In the second chart, the data corresponding to surface treatment with the flint tool are grouped and compact, but mixed with other tools that also generate fluted, but substantially different, grooves. These tools are discussed fully below. Surfaces worked with flint display very high values in Function 1 and 2. This is explained by the great topographic variation in the values of the data that was collected. The fluting is very deep and Fisher's Test classifies these values accordingly. Its centroid displays the highest value in Function 2 and is situated very close to the centroids of the samples treated with a marine shell (Fig. 8).

FIG.8

The marine shell spatula, consisting of a *Glycymeris glycymeris* shell, generates a highly visible microtopography macroscopically. At the qualitative level, the traces are fluted with a U-shaped cross-section and flat bottom. The edges of the traces are prominent, and the ends of the traces are marked. The movements of the hand result in criss-crossing marks. Since the tool is small, it has to be passed several times to be able to cover the whole surface.

Quantitatively, the data for the surface treatment with a shell spatula possess values near to 0 in Function 1, whereas they are a little higher, 1.5, in Function 2. As noted above, these datasets approach the data obtained for the flint spatula, as the traces are very similar. However, they differ sufficiently for the centroids of each type of treatment not to touch one another and the datasets are distributed mostly in opposite directions: the data for the surfaces treated with the flint spatula tend to the value 2 in Function 2, while those for the marine shell tend to the value -2. The values of both types of surface treatment are between 0 and 1.5.

The main difference between the two tools is seen in the type of bottom of the traces; as the traces created with the flint tool are striated while those generated with the marine shell are flat. This difference is enough to express quantitative differences (Fig. 9).

FIG.9

The linen rag is moderately evident in the microtopography of the sample. At macroscopic level, treatment with the linen rag generates characteristic traces: the fine striations. The sides of the traces have been classified as irregular and their ends are blurred. The cross-section has been classified as an irregular surface. The striations are so fine, superficial and delicate that it is difficult to classify the cross-section type in the photographs taken with the binocular microscope. The hand movement varies little because the rag is large and covers much of the sample surface. This means that the traces are grouped but remain separate and are parallel to one another.

At the quantitative level, the surfaces treated with the linen rag form a disperse group, but close together. It is somewhat distant from the other groups of data: between 0 and -5 in Function 1 and between 1 and -2 in Function 2. Some of the values of the surface worked with the rag are mixed with the values obtained for the flint and marine shell tools owing to the morphology of the traces. Fluting and striations share more characteristics in terms of size and shape than a striation and a groove.

At the same time, as the striations are slight, they create a surface with few extreme oscillations in the topography. This means that some values are mixed with those obtained for the control experimental sample (Fig. 10).

FIG.10

6. Conclusion

According to the results that have been presented, it can be concluded that it is possible to discriminate different types of tools employed for the surface treatment of experimental samples. The initial hypothesis is therefore confirmed: different implements generate different traces.

The tools chosen for this experimental programme generate traces that have been classified into grooves, fluting and striations. Each one creates a unique topography, which can be identified at the macro and microscopic level and can therefore supply valuable information about how a recipient was made, the means of production and the investment in labour.

The future of this type of study lies in the design of systematic experimental programmes that combine different variables, such as clay fabric types, degrees of dryness, working times, type of kiln, firing temperature, and so on. When the results have been obtained, new methodologies of analysis and data collection should be implemented. This must include the establishment of a series of categories allowing the systematisation of the observations and the automation of pottery analysis. Confocal microscopy and systems of textural analysis are effective for this purpose. The application of quantitative systems will not only improve and confirm the visual interpretation of the traces but also create reference datasets for other future analyses. These will grow and expand as new experimentation is carried out, enabling increasingly precise comparison with the archaeological record.

The possibility of discriminating the different surface treatment techniques opens new perspectives for the study of prehistoric pottery. Although the present study needs to be extended by testing a larger number of variables (working time, degree of dryness, clay types, etc.), the creation of an experimental reference collection will allow pottery traditions in prehistory to be approached from an original point of view. This will improve our understanding of pottery production processes, the organisation of the labour and the social characteristic of the pottery makers.

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TABLES AND FIGURES – DESCRIPTION

Table 1. List of experiments undertaken.

Table 2. Classification table of predicted group membership, with pottery spatula.

Table 3. Classification table of predicted group membership, without pottery spatula.

Table 4. Blind test classification table.

Fig 1. Production of experimental samples in the laboratory. 1) Formation of the clay plate, 2) Gripping and smoothing the clay plate with a wooden roller, 3) Experimental samples cut with square mould (10x10cm), and 4) Working on the experimental samples with a pebble.

Fig 2. Scheme of macroscopic analysis categories for surface traces.

Fig 3a. Result of the traces resulting from the work on the surface with the tools. Photographs taken with binocular microscope at 6.30x. a) Detail of the trace generated by the pebble: wide groove. Oblique light. a') The same trace with vertical light. b) Detail of the trace generated by the flint: fluted U-shaped cross-section. Oblique light. b') The same trace with vertical light. c) Detail of the trace generated by the ceramic spatula: fluted with U-shaped striated bottom. Oblique light. c') The same trace with vertical light.

Fig 3b. Result of the traces resulting from the work on the surface with the tools. Photographs taken with binoculars at 6.30x. a) Detail of the trace generated by the shell spatula: fluted U-shaped flat bottom. Oblique light. a') The same trace with vertical light. b) Detail of the trace generated by the linen rag: striated lines, superficial and irregular. Oblique light. b') The same trace with vertical light. c) Negative sample. Without labour. Only smoothed. Oblique light. c') The same with vertical light.

Fig 4. Scatter plot of the Canonical Discriminant Functions.

Fig 5. Scatter plot of the Canonical Discriminant Functions, excluding the pottery spatula from the test.

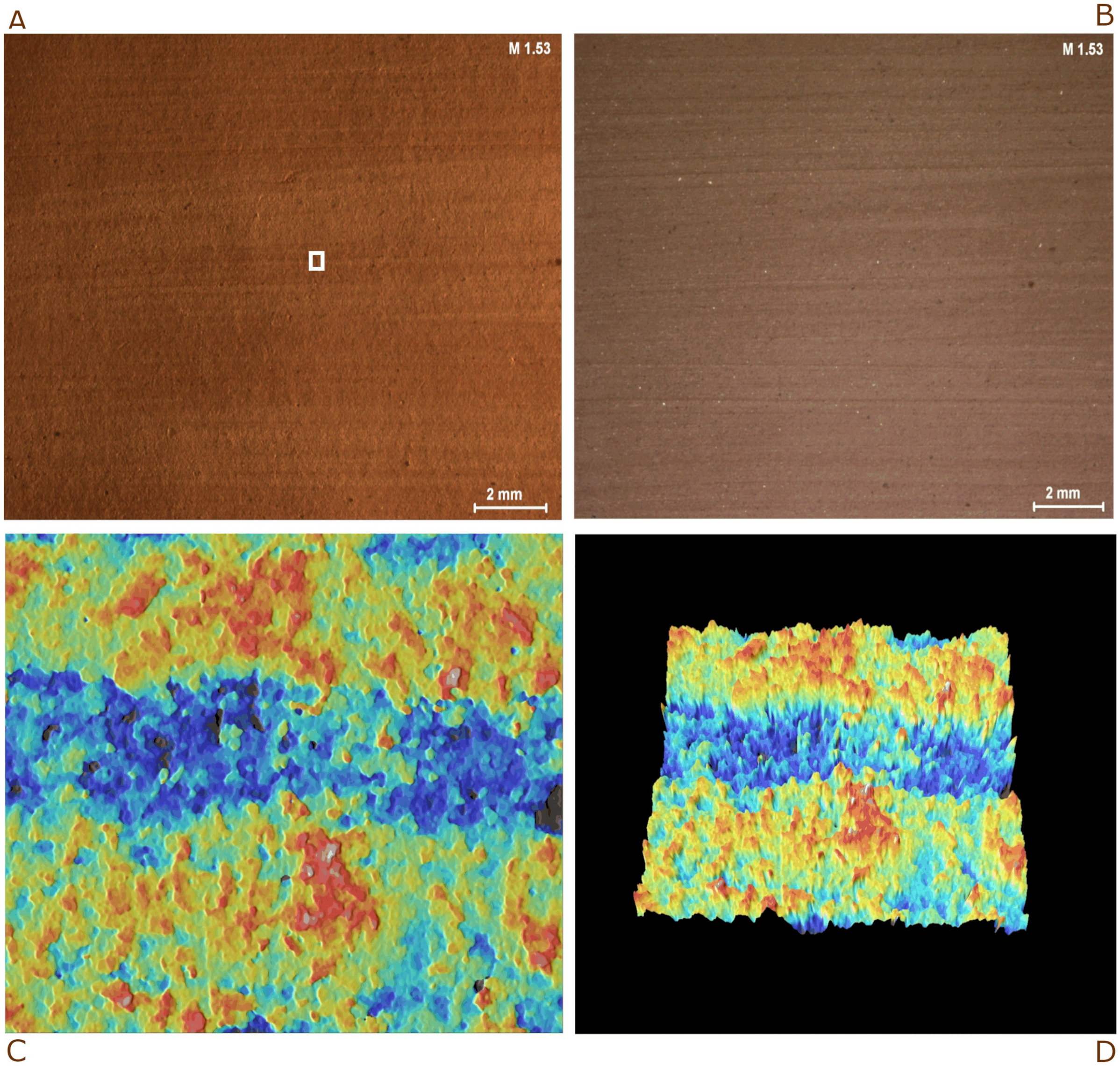
Fig 6. Result of the traces created by working the surface with pottery spatula. A) Photographs taken with binocular at 10.1x. Oblique light. B) Photographs taken with binocular at 10.1x. Vertical light. C) Photograph of texture surface taken with confocal microscope dimensions -magnification of the shot taken from the white frame in Photo A-. 2 dimensions. D) Photograph of texture surface taken with confocal microscope. 3 dimensions.

Fig 7. Result of the traces created by working the surface with the pebble. A) Photographs taken with binocular at 10.1x. Oblique light. B) Photographs taken with binocular at 10.1x. Vertical light. C) Photograph of texture surface taken with confocal microscope-magnification of the shot taken from the white frame in Photo A-. 2 dimensions. D) Photograph of texture surface taken with confocal microscope. 3 dimensions.

Fig 8. Result of the traces created by working the surface with a flint spatula. A) Photographs taken with binocular at 10.1x. Oblique light. B) Photographs taken with binocular at 10.1x. Vertical light. C) Photograph of texture surface taken with confocal microscope dimensions -magnification of the shot taken from the white frame in Photo A-. 2 dimensions. D) Photograph of texture surface taken with confocal microscope. 3 dimensions.

Fig 9. Result of the traces created by working the surface with a shell spatula. A) Photographs taken with binocular at 10.1x. Oblique light. B) Photographs taken with binocular at 10.1x. Vertical light. C) Photograph of texture surface taken with confocal microscope dimensions -magnification of the shot taken from the white frame in Photo A-. 2 dimensions. D) Photograph of texture surface taken with confocal microscope. 3 dimensions.

Fig 10. Result of the traces created by working the surface with a linen rag. A) Photographs taken with binocular at 10.1x. Oblique light. B) Photographs taken with binocular at 10.1x. Vertical light. C) Photograph of texture surface taken with confocal microscope dimensions -magnification of the shot taken from the white frame in Photo A-. 2 dimensions. D) Photograph of texture surface taken with confocal microscope. 3 dimensions.



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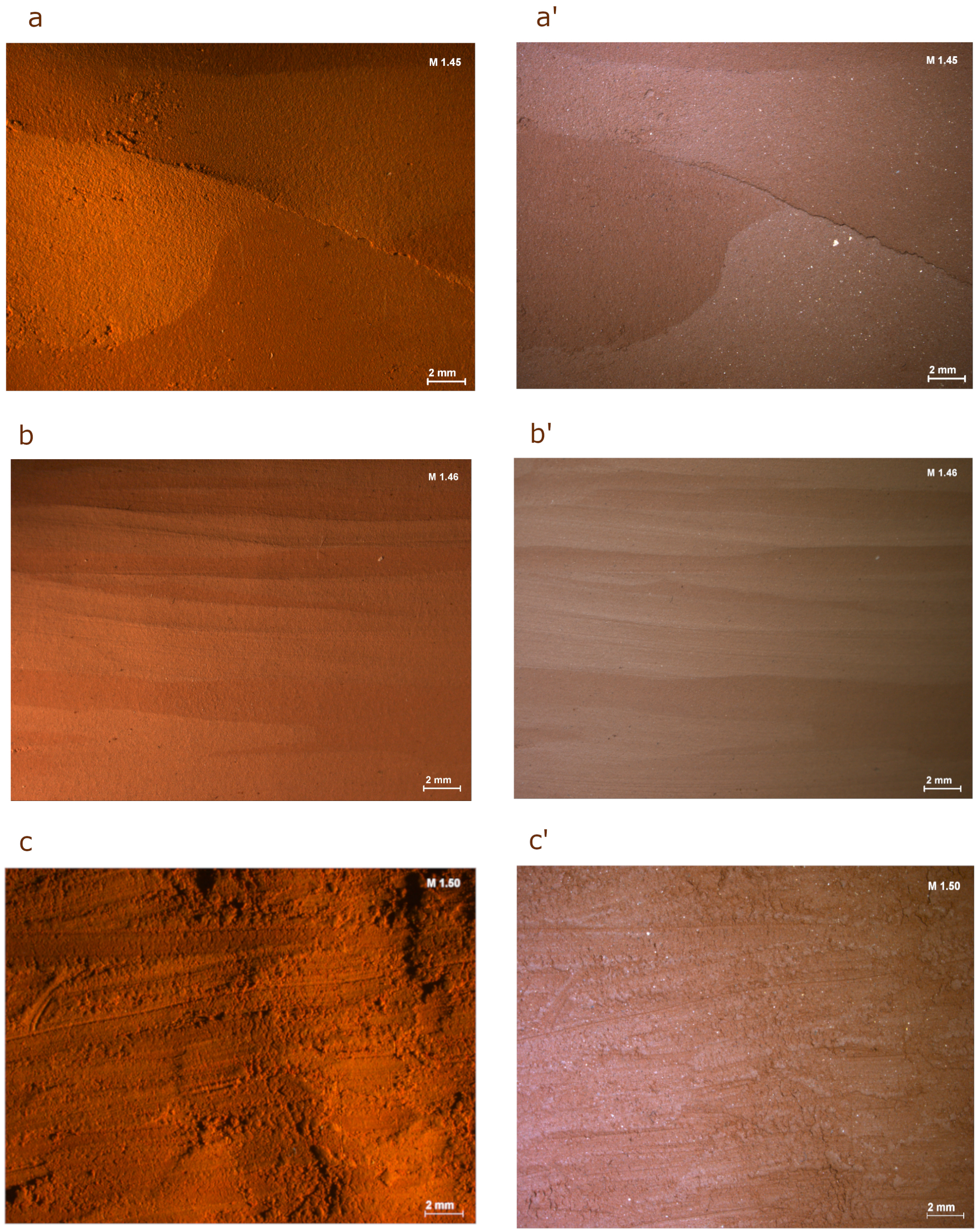
C
D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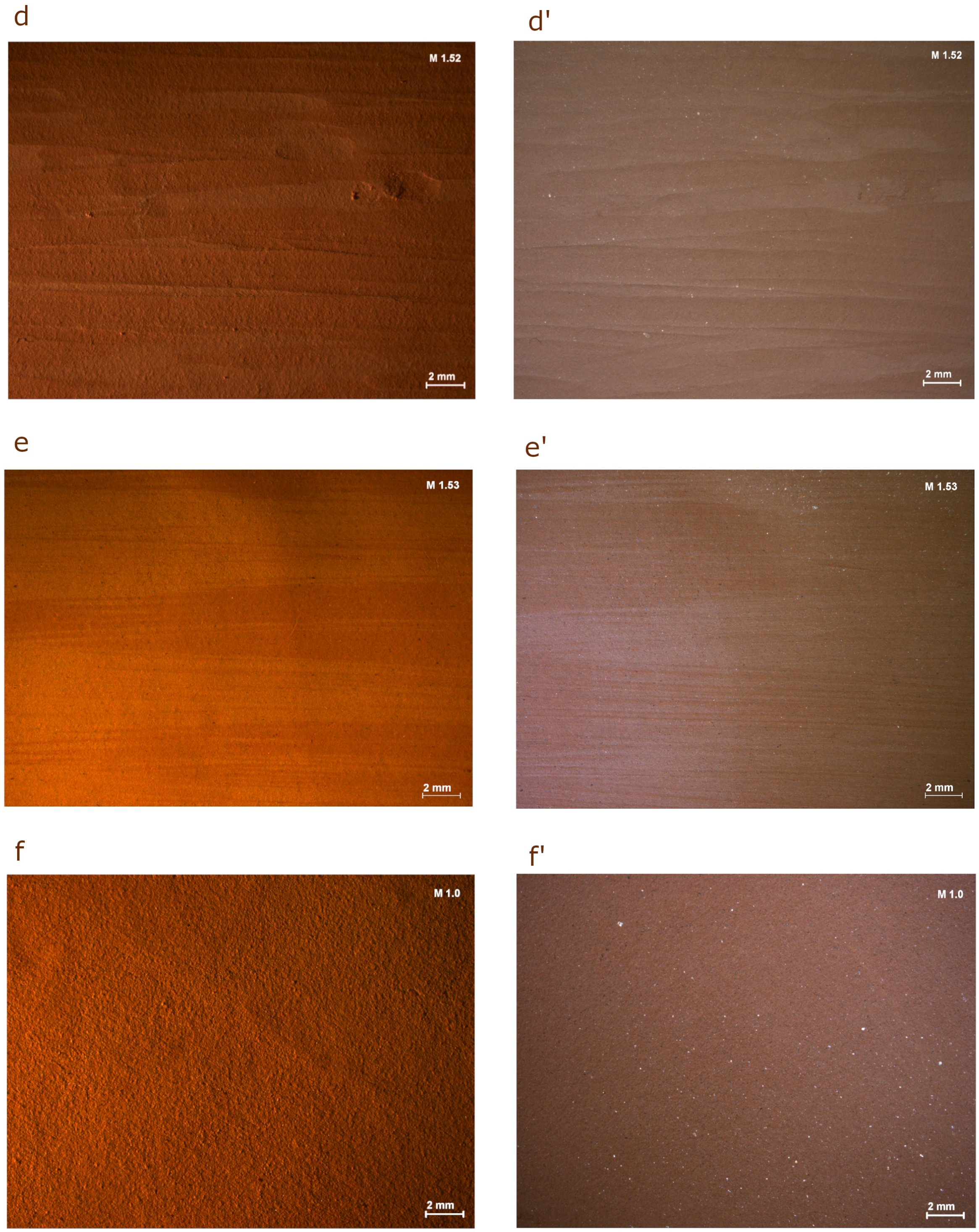
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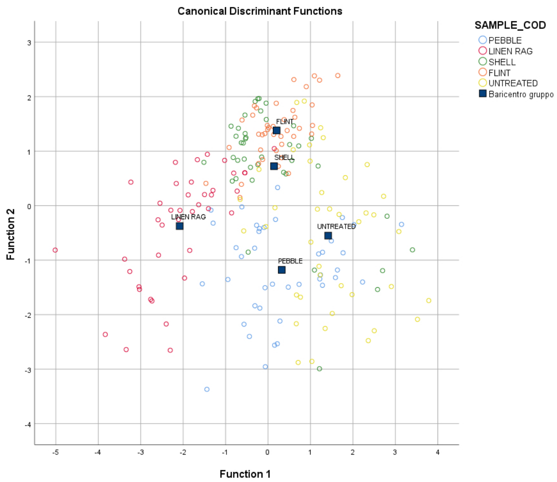
Canonical Discriminant Functions
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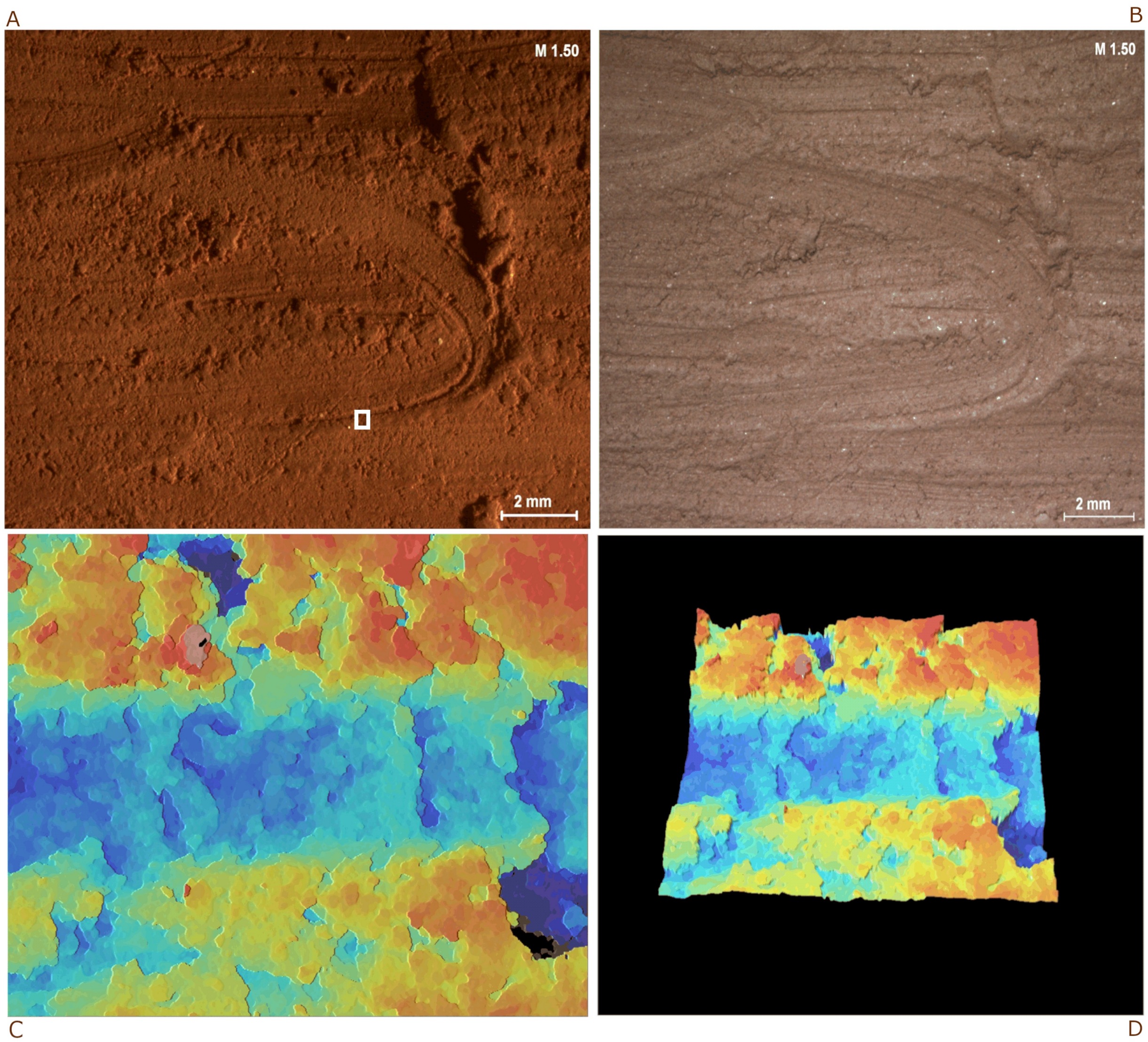
LINEN RAG
SHELL
FLINT
UNTREATED
Baricentro gruppo
FLINT
SHELL
LINEN RAG
UNTREATED
PEBBLE
Function 1
Function 2
3
2
1
0
-1
-2
-3
-4
-5
-4
-3
-2
-1
0
1
2
3
4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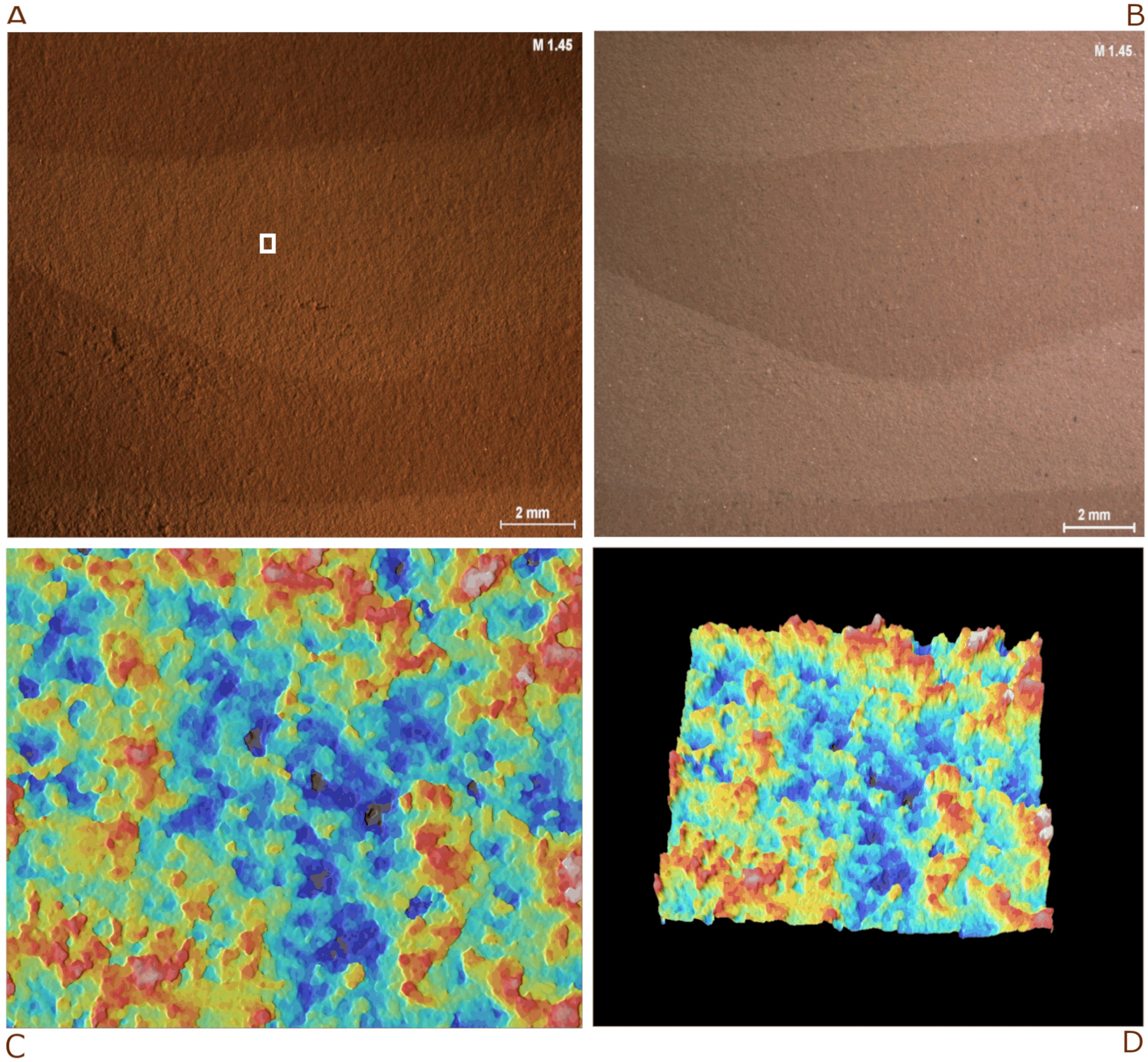
C
D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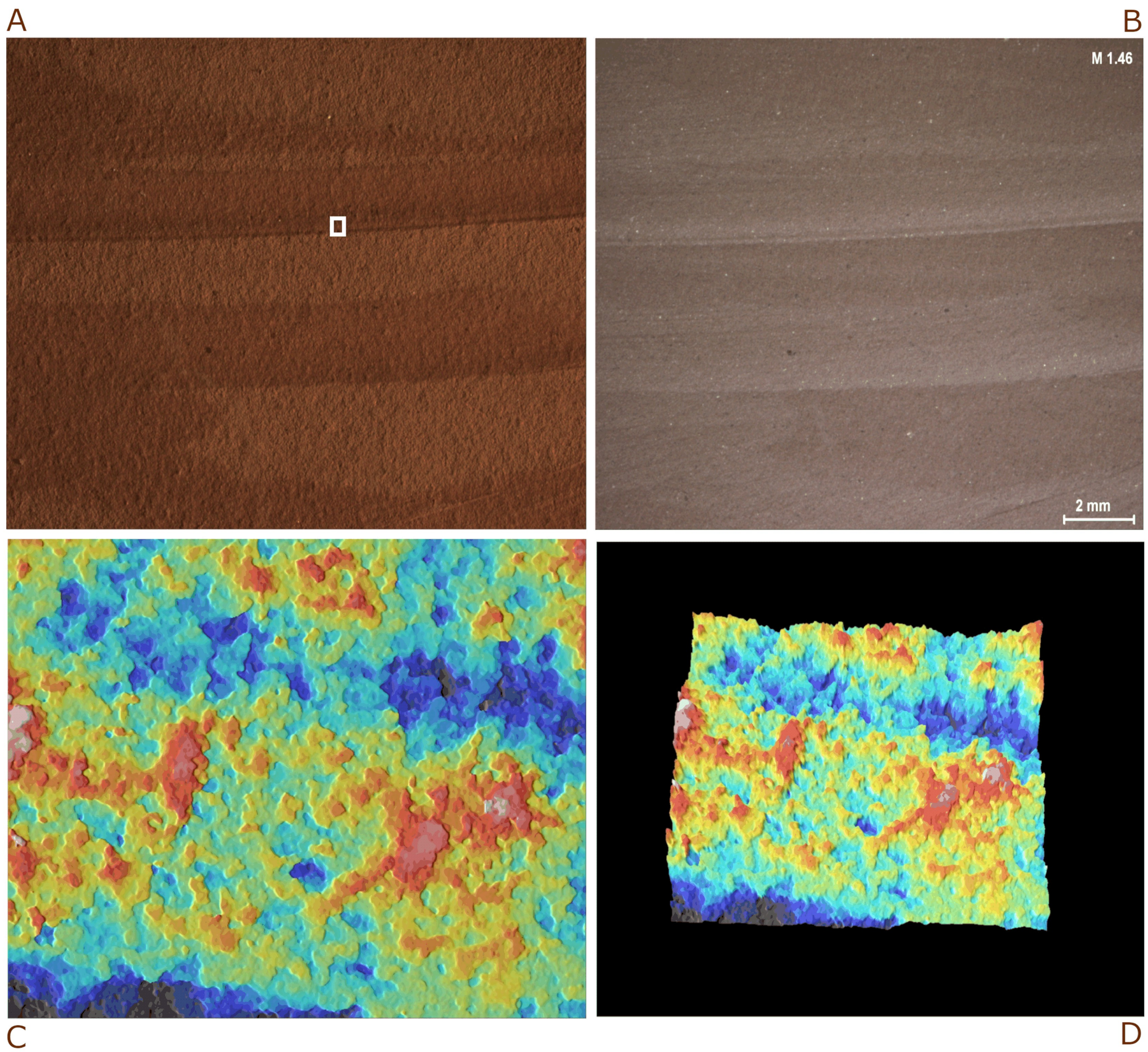
2 mm
C
D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B
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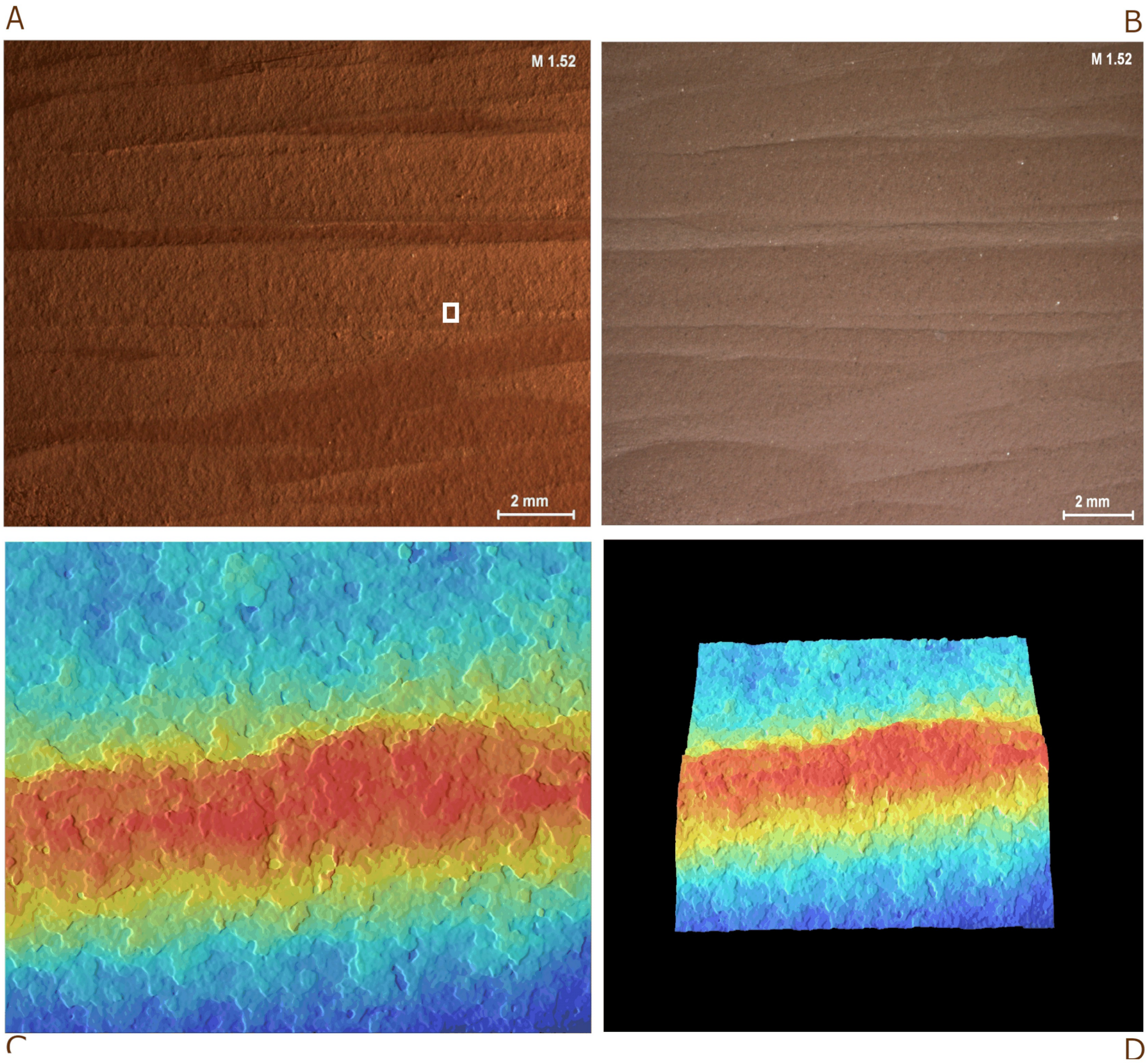
C
D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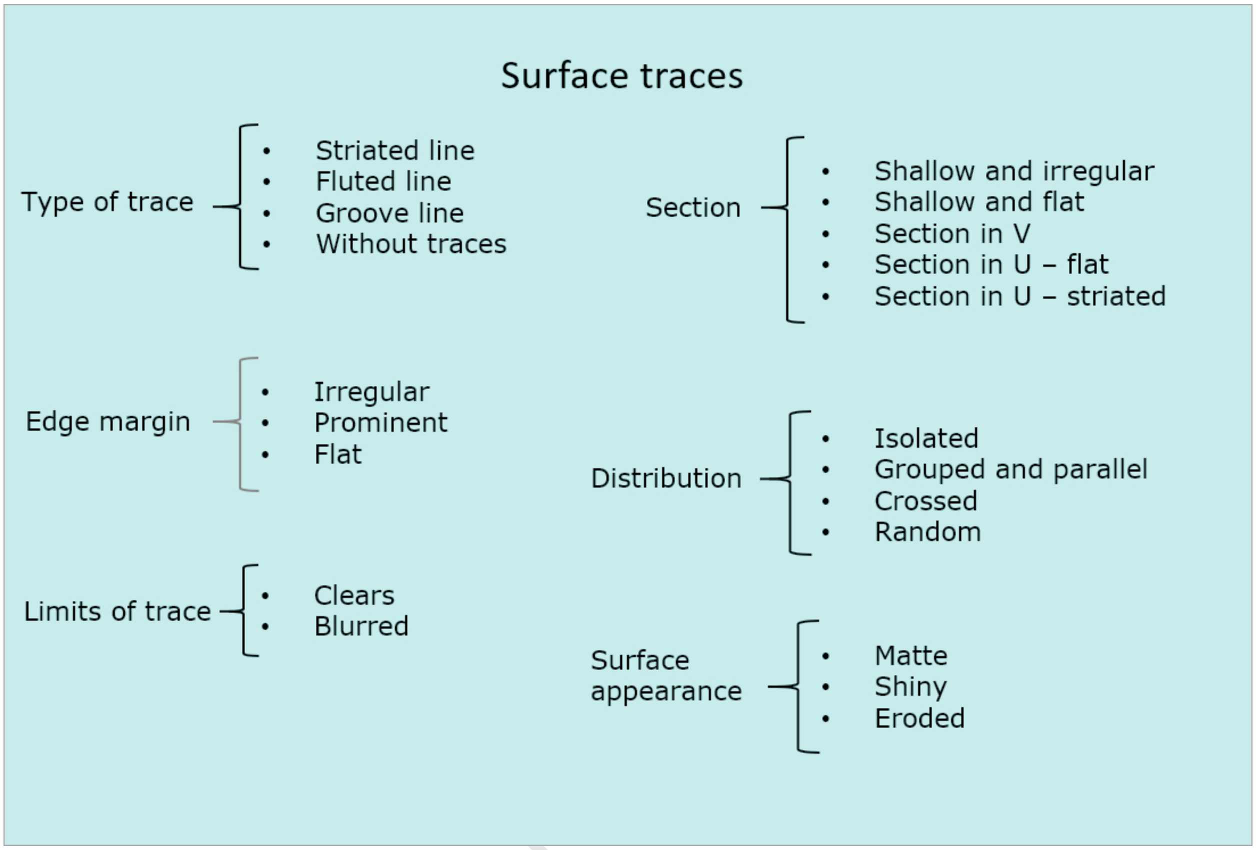
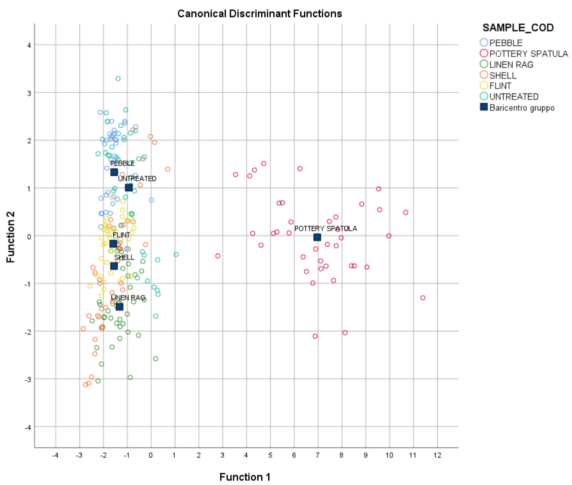
C
D


a
b
c
d


Surface traces
Type of trace
Striated line
Fluted line
Groove line
Without traces
Section
Shallow and irregular
Shallow and flat
Section in V
Section in U – flat
Section in U – striated
Edge margin
Irregular
Prominent
Flat
Distribution
Isolated
Grouped and parallel
Crossed
Random
Limits of trace
Clears
Blurred
Surface appearance
Matte
Shiny
Eroded


Canonical Discriminant Functions
SAMPLE_COD
PEBBLE
POTTERY SPATULA
LINEN RAG
SHELL
FLINT
UNTREATED
Baricentro gruppo
Function 1
Function 2

Conflicts of Interest Statement

Dear Editor,

The authors of **Approaching Surface Treatment in Prehistoric Pottery: Exploring variability in tool wear on pottery surfaces through experimentation**" whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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