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Colorimetric Study of Ayla-Aksum amphorae from the Red Sea Coast of Eritrea

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Abstract – **Colorimetric evaluation was applied on archaeological pottery from the ancient port city of Adulis in the Red Sea coast of Eritrea. Pottery samples belong to Ayla-Aksum typology, which had never been analysed by means of this technique. The experimental work focused on colorimetric measurements on different parts of the ceramic bodies to comprehend how the data can be related to fabric classification. Differences in the colorimetric parameters could provide helpful information on both technological processes of manufacture and fabric classification. Subtle variations in the colour coordinates have been detected and are interpreted in this study to ascribe differences. It has been proven that the information provided by colour measurements can be partially correlated to observations from stereo-microscopy and optical microscopy for a more in-depth description of the fabrics in the study of archaeological pottery.**

Key Words: Colorimetry, Pottery, Fabric

I. INTRODUCTION

Colour measurements on archaeological pottery have been applied particularly for the evaluation of the original firing conditions [1, 3]. On the other hand, the colour of ceramic bodies is not only affected by temperature, but also by firing duration and atmosphere, as well as by the mineralogical composition of the raw material used. Experimental analysis to evaluate the colour change with temperature by re-firing can enable to record colour alterations of a specific clay body and to evaluate the behaviour of different sherds. [1-2]. In general, the archaeometric study of ancient pottery mainly aims at locating the production centres, the specific technology involved in pottery production and understanding distribution patterns. Provenance is often tackled by determining chemical or mineralogical compositions and comparing them with the composition of reference groups. Mirti and Davit (2003) demonstrated that colour measurements may help in assessing provenances and/or technologies of production. The general agreement is that sherds made from different clays or from the same clay processed in different ways would show different colour curves, while ceramic materials obtained from a single clay processed following a similar procedure should display a similar curve [3]. In this study, pottery assemblages from the archaeological site of Adulis, the primary port of the Aksumite Empire in late antiquity in the Red Sea coast of Eritrea were investigated by means of colorimetry. In particular, analyses were focused on Ayla-Aksum amphorae, which were among the most widespread vessels for trading products in the Red Sea region between the 4th and 7th century CE. Studies on Ayla-Aksum amphorae in this geographical area are rare [5] and colorimetric studies have never been applied. The aim of this survey was to establish a preliminary fabric classification relevant for provenance determination. The results and limits of colorimetric evaluation are reported in the following.

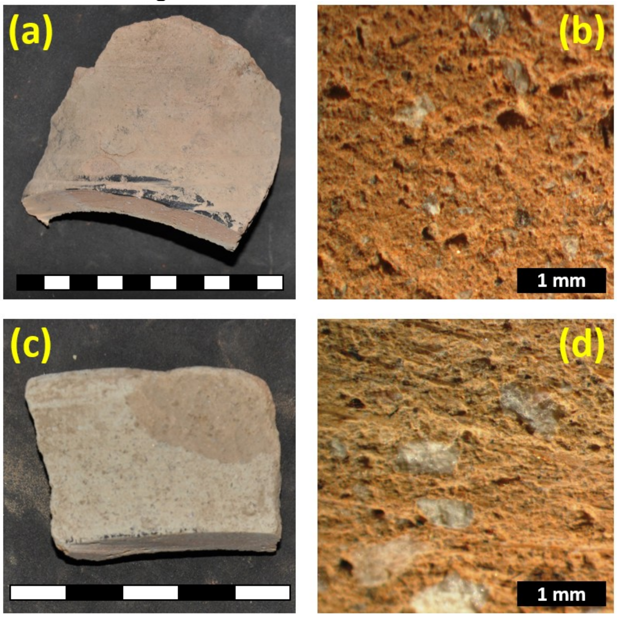

Fig.1. Sample 1.3(2): general view (a) and stereo-microscopic image (b); sample 2.0 general view (c) and stereo-microscopic image (d)

II. MATERIALS AND METHODS

A set of seven potsherds was selected for colorimetric measurements among a collection of 22 small finds under archaeometric investigations: part of them, were in fact, discarded being too small, or showing color vibration due to post-depositional alteration or contamination. All the samples were collected in 2019 in frame of on-going Italian-Eritrean excavations at Adulis. All these samples, apart from sample 1.9, belong to the Ayla-Aksum amphorae and their production span over a period from the 4th to 7th century CE based on dated stratigraphic contexts. Sample 1.9 has been classified typologically as Late Roman Amphorae 1 and it is studied here in comparison to the Ayla-Aksum fabrics. In Fig.1 are shown two samples (black/white scale in cm) and the stereo-microscopic image of their fresh cut.

Colour measurement was performed on pottery samples by means of a spectrophotometer Minolta CM-508i portable, equipped with a pulsed xenon arc lamp and an integrating sphere to illuminate diffusely the specimen surface; this was viewed at an angle of 8° to the normal (d/8 geometry). The light reflected by the sample surface (specular component included) was detected by a silicon photodiode array, which enabled to obtain the reflectance spectrum in the range 400–700 nm with wavelength pitches of 20 nm. Colour coordinates were expressed in the CIE L*a*b* system, using the illuminant D65 (average solar light) and a 10˚ (viewing angle). In this system the L*coordinate is related to colour lightness, while a* and b* are each determined by both hue and saturation [4,6].

The analysed surface during measurement was of about 8 mm in diameter implying that the detected coordinates relate to an average area of about 50 mm^2. Measurements were done both on the outer and inner surfaces of the pottery fragments selected for experimental work; besides

Table1. Colorimetric measurements.

Sample	Side	L	a*	b*
1.2	outside	62.20	3.14	18.12
		61.11	4.11	19.23
	in	45.80	3.36	11.95
		47.64	2.93	11.11
1.3(1)	out	55.27	7.77	21.53
		55.30	7.82	21.71
	in	56.87	6.03	18.54
		53.37	6.15	17.69
1.3(2)	out	54.62	6.10	17.61
		54.11	5.89	16.94
		53.10	5.70	17.61
	in	52.77	7.90	18.43
		52.85	7.95	19.14
		54.44	8.26	19.51
	cross	62.05	10.65	19.22
		60.25	10.65	18.94
		59.39	10.53	18.78
	powder	65.21	8.41	17.25
1.4(2)	out	63.34	5.67	17.02
		61.71	5.39	17.98
		62.21	5.16	18.82
	in	66.23	4.32	19.75
		66.45	4.74	20.23
	cross	71.91	1.52	15.70
		67.71	1.59	17.04
	powder	75.10	1.86	15.09
1.9	out	44.77	5.97	17.34
		43.13	8.32	17.84
		47.34	8.39	18.62
	in	51.60	7.82	20.66
		49.25	7.93	16.37
		49.69	8.13	17.91
2.0	out	66.61	5.15	19.63
		69.84	3.98	19.98
	in	68.91	3.83	19.42
		70.78	3.36	19.16
		68.65	3.52	19.06
3.6	out	66.54	4.69	19.98
		61.90	4.18	18.99
		63.35	4.95	22.04
	in	61.92	5.96	20.94
		60.44	5.48	20.37

Table 2. Association to fabric groups (FG) and maximum values of ΔE_{ab} for each sample. The average for FG_A and FG_B are also shown

Sample	FG	Outside	Inside	In-Out
1.2	A	1.47	0.94	8.21
1.3(1)	A	0.19	0.86	3.34
1.3(2)	B	0.70	1.14	4.35
1.4(2)	A	1.87	0.64	1.87
1.9	C	2.74	4.29	4.29
2.0	B	1.22	0.54	1.85
3.6	B	3.15	0.75	3.15
average	A	1.2	0.8	4.5
average	B	1.7	0.8	3.1

for two samples (1.3(2) and 1.4(2)) the thickness was enough to allow measurements also on the cross-cut section. The cleanest areas on the surfaces were selected in order to obtain the best estimation of the true colour of the ceramic body. In all cases, depending on the dimension of the fragment and on suitable areas, two or three measurements were carried out to estimate the spread of the data on the same sample.
Furthermore, colorimetric measurements were done on powders of samples 1.3(2) and 1.4(2). From each of the samples, a fragment was cut, polished to avoid contaminations and crushed using a mortar and pestle to have 100 mg of powders. In this way the powders are a mix of the inner, outer and core components. Powders were put on transparent cells and the spectrophotometer calibrated to provide mean value of three measurements for every sample. Similar parameters mentioned above were maintained for the colorimetric measurements on powdered samples.
It is worth noting that many factors could contribute to the occurrence of inconsistencies in the data both within the same sample and between different samples, when untreated archaeological materials are analysed. In particular, parameters such as an imperfect flatness of the surfaces, presence of contaminants (not easily visible to the naked eye), alterations due to post-depositional processes, and porosity can contribute to this variability (see Fig. 1b and Fig. 1d). This implies that although colorimetric observations could be useful for provenance studies, they have to be treated with cautiously under these conditions.

III. RESULTS AND DISCUSSION

Table 1 reports colorimetric coordinates for all measured sample while in Table 2 the values for $\Delta E_{ab,MAX}$ of each sample are indicated, computed according to the following equation:

$$\Delta E_{ab,MAX} = \sqrt{(a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \quad (1)$$

where the differences between the a_1* and a_2*, b_1* and b_2* represents the colorimetric coordinates showing the maximum differences among the set of measurements at the outer and inner surfaces, for each sample. Lightness (L*) is reputed to be a less suitable parameter than hue and saturation (a* and b*) and, due to this, it was not considered in this formulation [3].
The reported values of $\Delta E_{ab,MAX}$ are quite low for each dataset, indicating that the surface colours of both the inside and outside of the pottery samples appear to be quite homogenous. It seems that data from inner surface are less spread, being $\Delta E_{ab,MAX}$ always below about 1.14, with the sole exception of sample 1.9 which has different petrological characteristics and was included in this study despite its imperfect geometry to compare Ayla-Aksum typology with a sample from Late Roman Amphorae 1. The average values of $\Delta E_{ab,MAX}$ are 1.2-1.7 for outside depending of the fabric and 0.8 for inside surfaces, respectively.
The measurements on cross-section are particularly homogeneous in sample 1.3(2) with $\Delta E_{ab,MAX}$ = 0.46 (not shown in Table 2). This is probably due to favourable experimental condition related to uncontaminated and flat surface of the fresh cut. In samples 1.3(2) and 1.4(2) it is quite evident that differences can arise in colour coordinates depending on which side of the surface is being measured. To highlight this behavior, in Fig. 2, the bivariate plot of a* and b* parameters for all measurements on these two samples is shown.

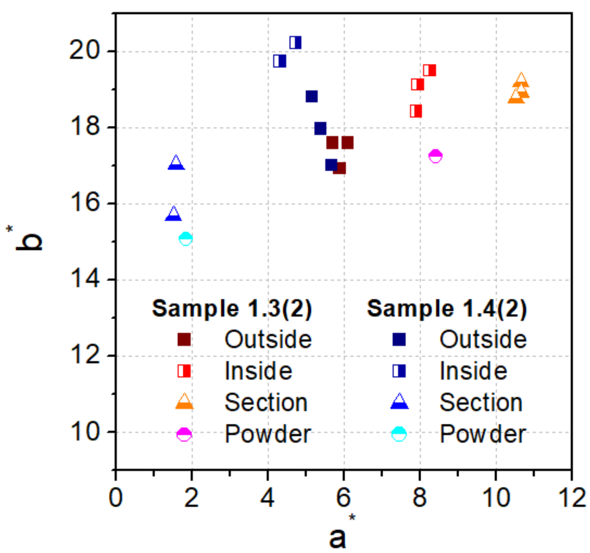

Fig.2. Plots illustrating colorimetric evaluation of sample 1.3(2) and sample 1.4(2)

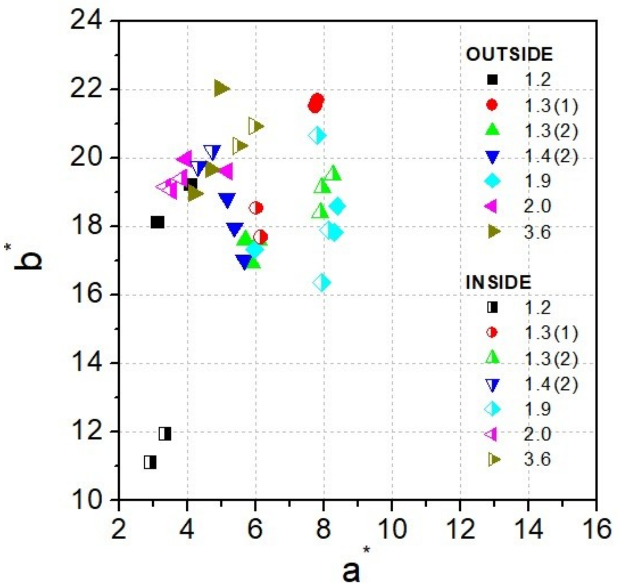

Fig.3. Plots illustrating colorimetric evaluation of all the measurements on outside and inside surfaces

For the three sets of data, $\Delta E_{ab,MAX}$ is approximately lower than 1.9, but the distance between the inner, the outer and the cross-section surfaces is up to about 5.6.

Regarding the measurements on the powders (Fig. 2), in sample 1.4 (2) the colorimetric coordinates are very close to the values obtained for cross section. However in sample 1.3(2) the powder has a color that seems a mixture of the coordinates from the inner, outer and bulk part of the sample.

Colorimetric observations were done in order to check potential grouping with respect to fabric description obtained by means of stereo-microscopy and petrographic

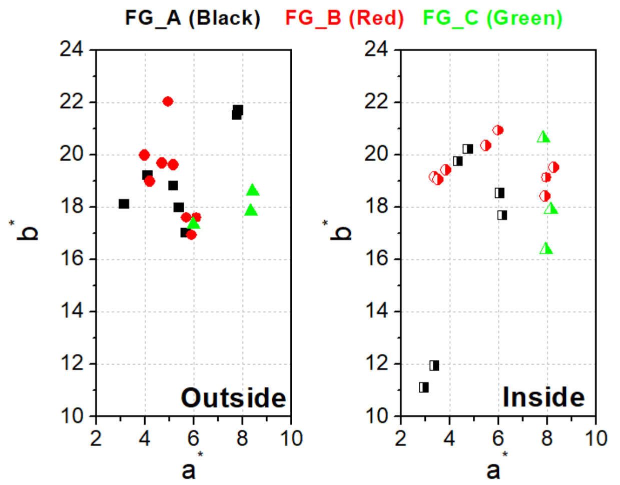

Fig.4. Colorimetric evaluation of all the measurements on outside and inside surfaces. Colour refer to the fabric classification as reported in Table 2

observations (see Table 2). In this respect, the correlation of the colorimetric information to observations from stereo-microscopy and petrography can be drawn for the Ayla-Aksum amphorae samples. A comparison between the colour values from the inside and outside surfaces of the pottery fragments for each sample is also considered in order to note differences (Fig. 3). Subtle differences in color measurements are interpreted as discriminating parameters to establish fabrics. In Fig. 4 and Fig. 5 bivariate plots are shown, in which data are gathered together on the basis of fabric groups and differentiated between inside and outside surface measurements. Although samples of the same fabric show some degree of grouping, there is not strong evidence in the a* vs. b* bivariate plots to hypothesize a differentiation between them (see Fig. 4 and Fig. 5 on the left). However, when the L* values are also considered, good results are obtained for the inside surface measurements especially differentiating sample 1.9, (belonging to a different fabric group) with respect to the rest (Fig. 5 on the right). Indeed, the sample is characterized by shell tempers. It is worth noting that the microscopic analysis and the colorimetric results obtained in this work are coherent with the attribution to another production, Late Roman Amphorae 1. This observation pinpoints that colorimetric measurements can be useful to complement petrographic studies for in-depth fabric description. The correspondence of the colorimetric groupings with petrographic observations is a further indication that the information from colorimetry can be useful to tackle provenance and/or technological studies of archaeological pottery. Different parts of the ceramic body offer a variety of sampling decisions for colorimetric evaluation in non-invasive procedures. Subtle differences in the colorimetric values attained on these different surfaces of the ceramic body can however, pose sampling issues

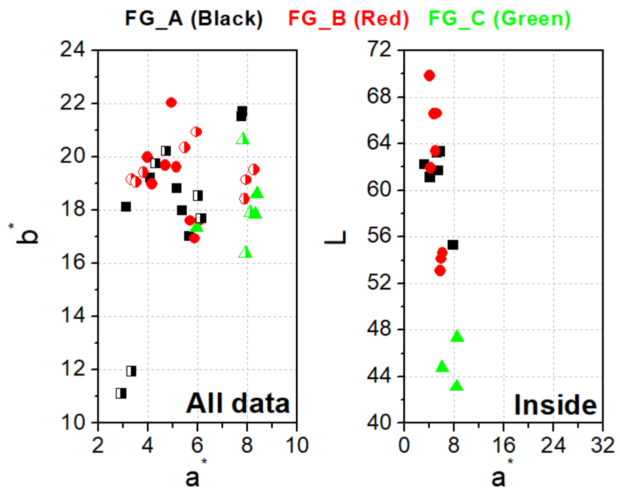

Fig.5 Colorimetric evaluation of all the measurements and using L-a* coordinates for inside surfaces.*

which need to be resolved by, for instance, treatment of archaeological pottery. It should be noted that the reliability of such results might be enhanced by increasing the statistics of analyzed samples, a subject considered for the study of different pottery assemblages recovered from excavations at Adulis.

IV. CONCLUSIONS

Colorimetric evaluations performed on ancient Ayla-Aksum amphorae showed differences in colour observations, particularly in the inside and outside bodies of some pottery fragments. Discrepancies could, however, result on the measurement being performed on rough or curved surfaces – which is particularly true in the case of pottery fragments. Sampling issues can be compensated by attaining suitable flat surfaces for measurements, re-firing pottery sherds up to a chosen temperature or by conducting colorimetric evaluation on powdered samples. Moreover, it was shown that colorimetric measurements could be useful, at least in some cases, to ascribe preliminary fabric determination when coupled to complementary techniques – such as optical microscopy. Such information could be used in order to understand – at least partly – the technological processes as well as to trace the provenance of a given artifact, together with complementary techniques.

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