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ROMAN CERAMICS PRODUCTION AND ARCHAEOMETRY IN ALGECIRAS (CADIZ, SPAIN)

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ABSTRACT

The aim of this study was the physico-chemical characterization of the ceramics documented during the excavation in one sector of the kiln at El Rinconcillo in 1991.

The materials uncovered span three phases of production in the pottery complex and thirteen stratigraphically located samples of different typologies were studied. The present paper reports their chemical, mineralogical, morphometry and porosity characterization.

Interpretation of statistical analysis of data indicates the local origin of the clay used in the manufacture of most of the fragments, and a variable range of firing temperatures.

Fabric variability as determined by morphometry and Hg-porosimetry is correlated with typologies and functionality of the pieces.

INTRODUCTION

The roman kiln known as El Rinconillo is situated on the municipal boundary of Algeciras (Cadiz, Spain).

At the moment only three sectors of the aforementioned kiln have been discovered. They contain architectural structures of varying importance and also an abundance of ceramic materials which principally consist of amphorae of which there are several varieties, and of a lesser quantity can be found of communal kitchen table vessels and small terracotta figures (Bernal, 1993 and Fernández, 1994).

Thanks to the first archaeological investigations carried out on the kiln (Sotomayor, 1967), we have been able to document information concerning two ovens that were found to be in good condition and an abundance of other ceramic material (most of which are amphorae) which has allowed us to date the excavated sector to about the middle of the first century A.C. In 1969, the said ovens were declared to be national historic monuments.

The second archaeological investigation was carried out in another sector (sector 2) of the kiln complex and it was done out of urban neccesities in 1987 and this time the excavations were controlled.

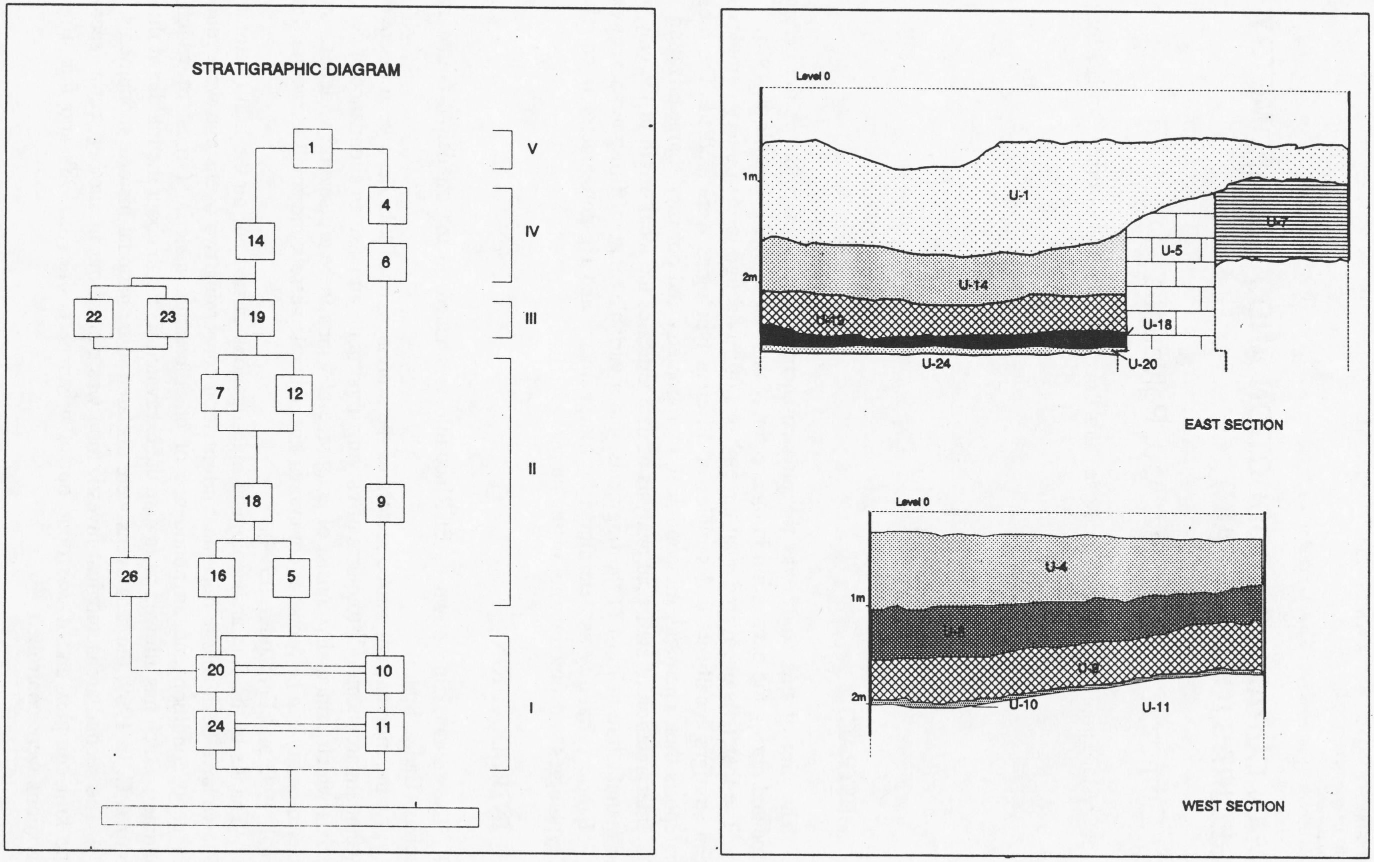
STRATIGRAPHIC DIAGRAM
1
4
14
6
22
23
19
7
12
18
9
26
16
5
20
10
24
11
V
IV
III
II
I
Level 0
1m
2m
U-1
U-7
U-5
U-14
U-18
U-24
U-20
EAST SECTION
Level 0
1m
2m
U-10
U-11
WEST SECTION

Fig. 1

Finally, in 1991 the existence of archaeological remains were discovered in an area which came to be known as sector three of the kiln and subsequently work was carried out in this area as a matter of urgency. If the documented architectural remains marked out an oven with small dimensions, a small pavement, and a protective/defensive wall, the interest in the discovery was confirmed by the succession of stratified units that the cited remains covered. After the abandonment of these settlements in the middle of the first century B.C. the area was used as a drain for the adjoining ovens. Through the study of the deposit the development of the kiln over five chronological periods and three phases of production (Fig. 1) has been established:

1.- The stratigraphic units 11 and 24 represent an indefinite period of time previous to the production activities in the area.

2.- The first phase of kiln production was dated in the second third of the first century B.C. when the installations of sector three are operative (stratigraphic units 26, 16, 5, 18, 9, 12, and 7).

3.- The layer that includes stratigraphic units 19, 22, and 23 shows the abandonment of activity in sector three.

4.- Between the end of the I century B.C. and the first quarter of the I century A.C. is dated the first dumping of ceramics produced in other sectors of the pottery area and correspond to the second phase of the kiln production (stratigraphic units 14, 6 and 4).

5.- During the second quarter of the I century A.C. there is a third phase of production of the kiln (stratigraphic unit 1) with another level of dumped ceramics.

METHODS AND RESULTS.

From an archaeological point of view, 13 representative specimens have been studied which belong to the different types of ceramics that have been documented. Reference to their typological description, and stratigraphic context, along with the mineralogical, chemical, morphometry, and porosity clustering of samples can be found in Table 4, which will be further analysed later.

Chemical Analysis

Chemical analysis of major elements (Potts, 1992) was carried out by atomic absorption spectrometry (Table 1). Multivariate statistical data analysis show that the three first principal components represents 85% of the variance.

The equal sign high correlation of Al, Fe, Mg, Na, K and Mn with the first PC accounts for the highest chemical dispersion, probably associated with differences in the composition of original clays and feldspars (Fig. 2).

The inverse correlation of Al,Fe vs Ca,Ti characterize the second PC (Fig 2). Minor amounts of heavy minerals (or the pyroxenes identified in M2) could explain this source of variation.

Principal Component Analysis (Fig.2) of chemical composition of the sherds allows the identification of four different groups of samples.

A first cluster with samples M1, M3, M4, M5, M6, M7, M12 and M13 accounts for the homogeneous clay material employed in the production of the pieces.

Table 1

Samp.	Al_2O_3%	Fe_2O_3%	CaO%	MgO%	Na_2O%	K_2O%	TiO_2%	MnO %	H_2O^+
M1	16.09	4.56	3.11	1.92	0.91	1.98	0.82	0.070	0.57
M2	10.79	3.50	6.34	1.50	0.37	1.64	0.56	0.075	2.06
M3	16.69	4.49	2.47	2.28	0.66	2.01	0.62	0.091	2.51
M4	14.77	4.22	1.60	1.90	0.39	1.49	0.67	0.064	0.15
M5	13.00	4.45	3.16	1.56	0.51	1.59	0.53	0.019	0.51
M6	14.53	4.21	2.52	2.20	0.64	2.17	0.70	0.103	0.56
M7	15.63	4.52	2.60	2.46	0.37	2.13	0.75	0.101	0.67
M8	18.50	5.25	5.14	5.62	0.76	3.06	0.82	0.165	4.80
M9	18.37	5.56	2.45	1.29	0.52	1.76	0.39	0.010	2.30
M10	18.94	5.46	3.34	4.43	0.90	3.45	0.35	0.163	n.d.
M11	15.39	5.40	2.08	1.65	0.27	1.44	0.33	0.015	0.57
M12	13.87	4.69	2.30	1.92	0.52	1.62	1.02	0.075	6.98
M13	14.27	4.15	2.98	2.57	0.91	1.98	0.84	0.070	2.37

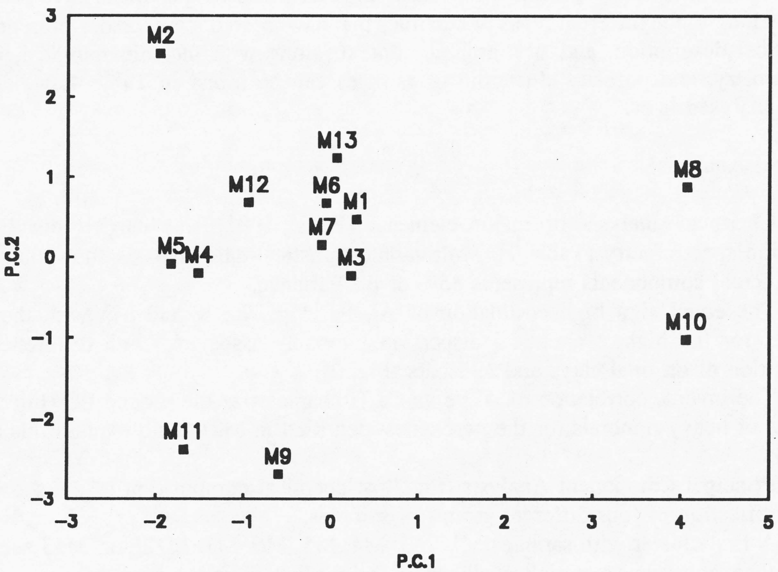

Fig. 2: Principal Components of chemical composition.

Sherds M8 and M10 of close chemical composition both belonging to amphora that imitates campaniens typology and located in the same stratigraphic unit U9 defines a second cluster.

Sherds M9 and M11 of the stratigraphic unit U18 are pieces of a glass of fine walls and a amphora cover (Dressel 1A) respectively, and defines a third cluster.

Sample M2 with Dressel 7-11 typology represents a peculiar fragment whose possible foreign origin can be presumed.

X-ray diffraction

X-ray diffraction of the bulk samples analysis has been carried out on powder specimens with a Phillips PW1130/90 equipment, with automatic divergence slits, Cu X-ray tube and a Ni filter.

A qualititive estimation of the relative abundance of minerals identified in the diffraction diagram of each sample (Table 2) distinguish a very abundant (++++), abundant (+++), rare (++), some (+), and (-) non-existant presence. The results are ordered according to the nature of fragments (amphorae and other materials) and their stratigraphy (Table 2).

The analysis of the difraction diagrams indicates that the quartz and the feldespars are the most prominent minerals; in four fragments it can be observed the presence of phyllosilicates which remained untouched throughout the firing process.

All the samples with abundant, or very abundant presence of phyllosilicates (M3, M8, M12, and M13) have a quite homogeneous mineralogical composition and incorporate pyroxens in small proportions, except for specimen M12.

The aforementioned specimens have been probably fired at temperatures, lower than 650ºC or 700ºC.

Samples M1, M2, M6, M7, and M10, with variable quantities of hematites and spinel, come from objects that were probably fired at temperatures higher than 650ºC but lower than 900ºC. Only sample M2 can be distinguished from the others due to the presence of abundant pyroxens and feldespars.

To conclude, the samples recovered fom stratigraphic unit U-18 can be distinguished from the rest by the scarcity of feldespars in the temper so as the presence of high temperature minerals; in samples M4, M5, and M11 has been formed cristobalite and in sample M9 mullite; this indicates that the baking temperature likely was higher than 950ºC.

Image processing of polished ceramic surfaces.

Application of image processing techniques to quantify morphometric parameters, textures, anisotropies etc. of pores, minerals, temper, etc. can be of great interest to discriminate provenance, production techniques etc. of archaeological ceramics as well as a valuable complement to their conventional physico-chemical analysis. A growing interest and resources to develope automated applications of this general techniques concerns a wide range of cientific fields (see Russ,1992 and Gonzalez,1987).

Table 2

Ceramics Mineralogy									
Amphorae									
Sig.	Samp	Qz.	Fel.	Pyr.	Spi.	Hem.	Crs.	Mu.	Phy.
U9/10	M4	++++	+	-	+++	++	+++	-	-
U18/39	M11	++++	+	-	-	+++	+	-	-
U18/41	M5	++++	+	-	+	+++	+++	-	-
U19/12	M13	++++	+++	+	-	-	-	-	+++
U14/8	M3	++++	++	+	-	-	-	-	+++
U14/43	M1	++++	++	-	++	++	-	-	-
U18/18	M6	++++	++	-	+	+++	-	-	-
U1/22	M2	++++	+++	+++	-	-	-	-	-
U1/27	M7	++++	++	-	+++	+	-	-	++
Other ceramics									
Sig.	Samp	Qz.	Fel.	Pyr.	Spi.	Hem.	Crs.	Mu.	Phy.
U9/46	M8	++++	+++	+	-	-	-	-	+++
U9/49	M10	++++	+++	-	++	++	-	-	-
U18/75	M9	++++	+	-	-	-	-	+++	-
U22/17	M12	++++	++	-	-	-	-	-	++++
++++ Very abundant; +++ Abundant; ++ Rare; + Some; - Non existant.									

With a equipment (made up of CPU PC compatible with a colour frame grabber connected to a video camera adaptable to the microscope) images were produced by light reflected off the polished surfaces for a total of 9 specimens.Conveniently illuminated, from each polished section 3 images were produced of sizes 512x512, for their final analysis, through the calibration of the digitized pictures.

The scale chosen in the process of images capture has been such as to allow us to quantify the morphometric parameters of temper and porosity (open and close), each image representing a surface area of 0.25 cm^2.

Previously to the morphometric analysis of the images has been carried out their illumination and radiometric correction. In these corrections the transformation of the spaces RGB and IHS have been used, making the illumination correction stand out clearly in the brigtness image.

For finding out the porosity contours and temper limits has been applied a semi-automatic discrimination procedure. After appropiate binarization of pores and temper, several parameters such as surface, perimeter, maximum and minimum length and Feret parameters were measured.

Table 3

Temper parameters.							
Sample	S/10³ (μ²)	Area (μ²)	Per. (μ)	Fer.X (μ)	Fer.Y (μ)	Dmax (μ)	Dmin (μ)
M1	4418	3522	239.4	72.3	63.7	78.8	46.0
M2	1260	4063	252.3	71.8	72.8	85.8	49.2
M3	6271	2869	220.1	71.0	52.2	71.7	38.9
M4	2171	3020	211.0	62.1	58.8	68.5	41.7
M5	8697	3803	256.4	76.3	64.1	83.1	46.4
M6	3996	3752	248.8	76.5	62.3	82.2	45.5
M7	2985	3395	223.2	68.4	60.4	73.1	44.1
M10	12864	2667	205.0	60.3	53.0	64.8	36.6
M13	4454	3616	244.8	75.2	62.2	79.5	46.1

Porosity parameters.							
Sample	S/10³ (μ²)	Area (μ²)	Per. (μ)	Fer.X (μ)	Fer.Y (μ)	Dmax (μ)	Dmin (μ)
M1	4051	4112	257.8	82.6	65.5	87.9	48.6
M2	687	11726	447.7	108.5	142.3	159.3	88.8
M3	724	4475	263.4	85.5	63.7	89.0	49.9
M4	5954	5254	304.3	80.7	87.9	99.1	58.5
M5	952	4119	252.2	81.9	65.7	87.0	48.7
M6	4645	5947	335.8	113.5	68.9	115.6	53.4
M7	4387	3980	261.5	82.0	62.5	86.1	46.0
M10	1230	3697	245.9	78.5	60.9	82.4	45.6
M13	1870	5373	301.7	96.9	73.8	103.3	55.1

After processing each sample the statistical study of results was carried out and the sample median retained for further processing (Table 3). Other calculated parameters for each sample includes accumulated surface, roundness and shape factor for pores and temper.

Analysis of the correlation matrix structure was carried out by Principal Components method with the two first PC accumulating nearly 85% of variance (Fig .3). Cluster analysis of PC1 and PC2 with euclidean distance as measure of the association between observations and a single linkage strategy for grouping samples indicates that samples M2 and M10 are clearly differenciated from the wide and disperse cluster that groups the rest of the fragments.

Sample M2 is isolated from the other samples due to its higher morphometric parameters, and the lower values as concerns whole surface of porosity and temper (Table 3).

This specimen with abundant pyroxenes as a distinctive mineral, also shows a clear morphometric differentiation, which leads us to believe that despite its typology (anfora Dressel 7-11) we are dealing with a sample which belongs to an object that is of distinct origin to the other pieces.

The lowest morphometric parameters (Table 3) along with high quantity of temper characterise sample M10 as another peculiar fragment. In spite of its close mineralogy with other samples the fact that it is a sherd of a table ceramic of much higher quality can explain their morphometric differenciation.

Inside the cluster with the other studied fragments can be observed that typologies Dressel 7-11 (M1, M6 and M7), Dressel 21-22 (M3) and Dressel 1C (M13) are less disperse in PC2 that samples M4 and M5 that belongs to Dressel 1A typology.

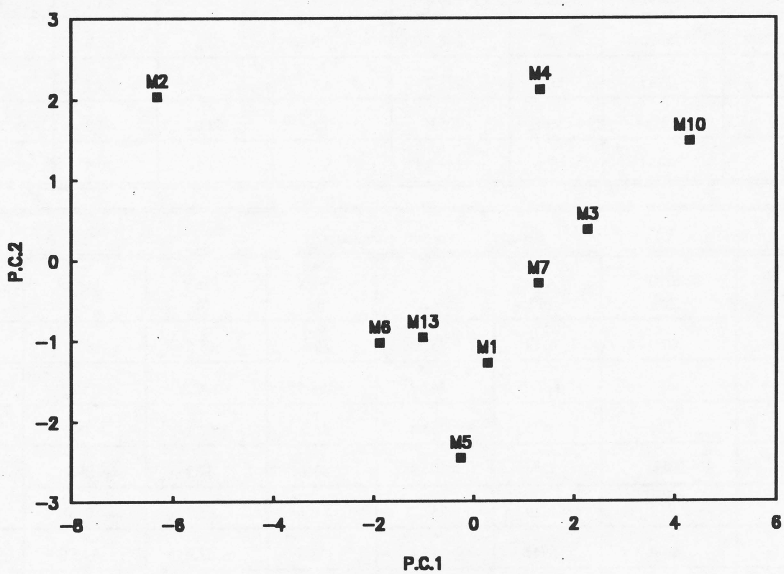

Fig. 3: Principal Components of morphometry.

Hg porosimetry.

The results of image processing has been contrasted to the open microporosity distributions determined by the mercury technique. The statistical analysis of the said open pores distributions show certain clusters of samples evidenced by the whole cummulated pore volumen vs pores radius (Fig.4).

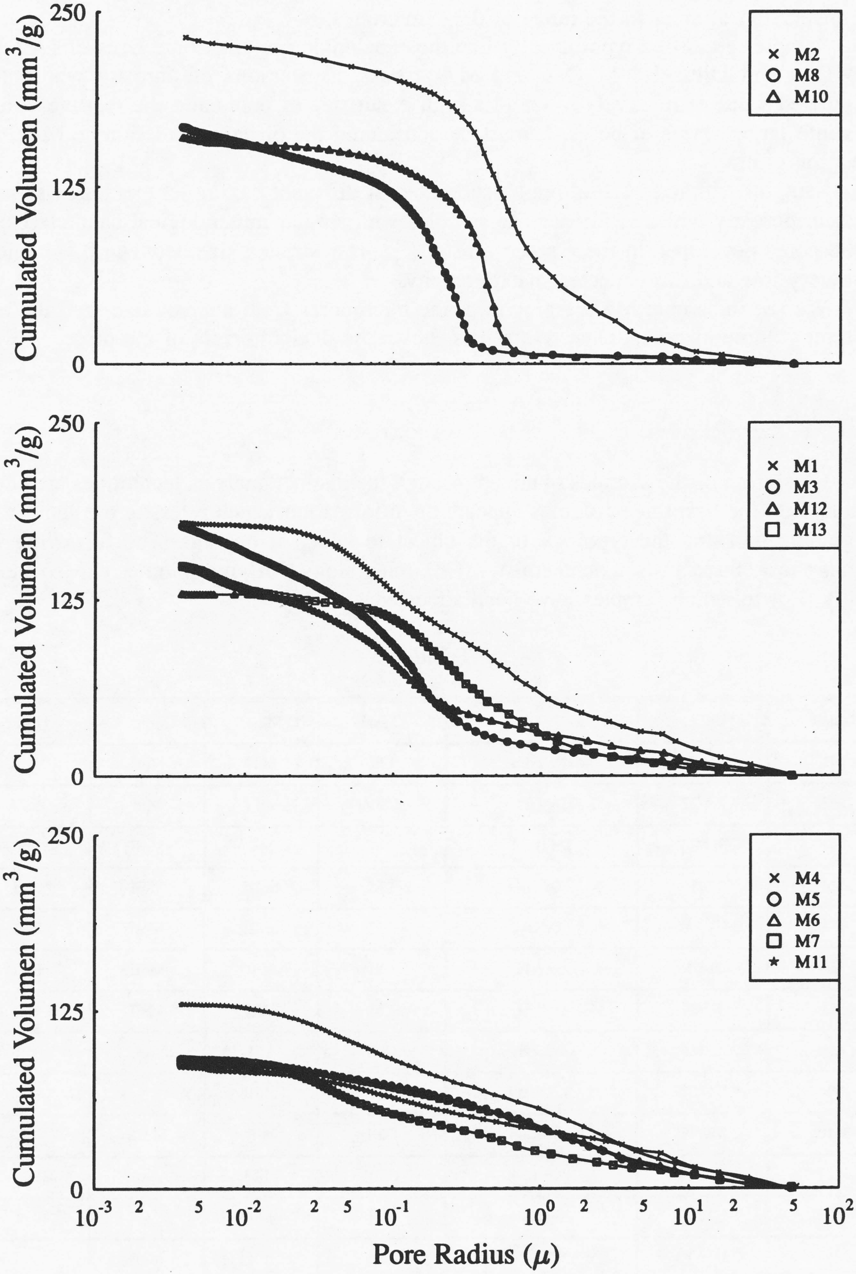

Fig. 4: Hg porosimetry

In samples M1, M3, M12, and M13 there are two connected pore systems, whith a small dispersion of sizes in the range of 0.2-2 micron.

Samples classified typologically like those belonging to amphorae Dressel 1A (M4, M5 M11) and Dressel 7-11 (M6 and M7) show distributions of porosity whose total accumulated value is relatively low and a high mean size of pores and the relative volume grows into largest sizes of pores. It must be considered the difference of sample M11 with respect the group.

Samples M8 and M10 although submitted at different baking temperatures shows a growth in porosity which is different to samples with similar mineralogical characteristics , and the pores developed in these pieces are of a more restricted size between 0.1-1 micron with a very low and disconnected macroporosity.

We see in sample M2 the growth of the micropores from a small size and the most important volume of pores. Once again it is shown the distinct origin of the piece.

CONCLUSIONS

Clustering of the samples obtained through the distinct analysis techniques are shown in Table 4. In the first three columns appears the information which refers to the sample, the stratigraphic unit and the typology of the object to which it belongs. The following four columns show clusters based on chemistry (Ch), mineralogy (Mi), morphometry (Mo) and Hg porosity (Po) to which samples have been allocated.

Table 4

Sample	Un/Inv	Typol.	Chem.	Mine.	Morp.	Hg P.
M1	U14/18	Dr.7-11	ChI	MiII	MoII	PoI
M2	U1/22	Dr.7-11	ChIV	MiIV	MoI	PoIV
M3	U14/8	Dr.21-22	ChI	MiI	MoII	PoI
M4	U9/10	Dr.1A	ChI	MiIII	MoII	PoII
M5	U18/41	Dr.1A	ChI	MiIII	MoII	PoII
M6	U14/18	Dr.7-11	ChI	MiII	MoII	PoII
M7	U1/27	Dr.7-11	ChI	MiII	MoII	PoII
M8	U9/46	Pseudocamp.	ChII	MiI	-	PoIII
M9	U18/75	G.F.Walls	ChIII	MiIII	-	-
M10	U9/49	Pseudocamp.	ChII	MiII	MoIII	PoIII
M11	U18/39	Dr.1A	ChIII	MiIII	-	PoII
M12	U22/17	Amp.Cover	ChI	MiI	-	PoI
M13	U19/12	Dr.1C	ChI	MiI	MoII	PoI

Within the amphora production all the typologies are characterized by their chemical homogenity (Group ChI) and justify the local origin of the clay employed; their mineralogical variablitiy can be explained by the different firing conditions. Wine transport amphorae Dressel 1-A are characterized by a high temperature firing of the ceramics while lower temperatures for Dressel 7-11 typology employed for the fish sauces transport.

According to the close characteristics of amphorae Dressel 21-22 and Dressel 1C it is suggested that probably both types were locally employed for the transport of salted fish and not wine as is proposed for Dressel 1C typology. This interpretation is founded in the most recent studies of the economic developement of the area in the roman periode (Fernandez, 1994).

Of all the studied amphorae sherd M2 is of a different provenance and its origin has not been established.

The other studied sherds show that different processes in the selection of clay and firing are justified in the production of luxury ceramics that imitate campaniens (samples M8 and M10). The finest sherd M9 show the highest firing temperature and the best size selection of clay.

We can conclude from all this that different manufacturing procedures were employed and instead of a clear evolution in time the differences observed are mainly based on the distinct fuctionality for which the ceramics was produced.

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