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Preliminary archaeometric analysis on amphorae, in VI and V centuries B.C., from excavations at Gela (Sicily)

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ABSTRACT. — This work is part of a joint research project between the Department of Geological Sciences of the University of Catania and the Department of Antiquities, Archeology Section, of Messina. It aims at characterizing ceramics coming from several Greek colonies in Sicily and Calabria (Gela, Agrigento, Segesta, Selinunte, Naxos, Sibari, Locri).

Current scientific documentation regarding the archaeometric study of these ceramics is very limited. In particular, the present work focuses on amphorae found in the acropolis of Gela.

These amphorae, used for transport and table purposes, are either «massaliote» (VI-V centuries B.C.) or «pseudo-chiota» (V century B.C.) in shape, or imitations of Corinthian ware (V century B.C.).

Samples were analysed by X-ray diffractometry (XRD), optical analysis under a polarized-light microscope (OM), X-ray fluorescence (XRF) and plasma emission spectrometry (ICP-MS).

Data processing revealed that most of the amphorae were made in Gela itself, with the exception of one sample which had a chemical composition remarkably similar to that of samples found at Agrigento. The Gela samples were subdivided into three groups according to the grain size of the aggregate. It is interesting to note that the oldest ceramic products (VI century B. C.) are made of a mainly coarse mixture, whereas the more recent products (V century B. C.) are made of an increasingly finer original material.

RIASSUNTO. — Il presente lavoro fa parte di un progetto di ricerca in collaborazione tra il Dipartimento di Scienze Geologiche di Catania e il Dipartimento di Scienze dell'Antichità, Sezione di Archeologia di Messina. Lo scopo è quello di caratterizzare ceramiche provenienti dalle diverse colonie greche in Sicilia ed in Calabria (Gela, Agrigento, Segesta, Selinunte, Naxos, Sibari, Locri).

Allo stato attuale, infatti, la documentazione scientifica riguardante lo studio archeometrico di tali ceramiche è molto esigua. In particolare, in questo lavoro, è stata rivolta l'attenzione allo studio di anfore da trasporto rinvenute presso l'acropoli di Gela.

Si tratta di anfore da trasporto e da tavola di forma massaliota (VI-V sec. A.C.), pseudo-chiota (V sec. A. C.) e di imitazione di anfore corinzie (V sec. A. C.).

I campioni sono stati analizzati tramite analisi diffrattometrica (XRD), analisi ottica al microscopio in luce polarizzata (OM), fluorescenza ai raggi X (XRF) e spettrometria di emissione al plasma (ICP MS).

L'elaborazione dei dati ha consentito di determinare il luogo di fabbricazione delle anfore, che per la maggior parte dei campioni è Gela, ad eccezione di un campione che presenta una

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composizione chimica molto simile ai campioni di Agrigento. I campioni di Gela sono stati suddivisi in tre gruppi sulla base della granulometria dell'inerte utilizzato. È interessante mettere in evidenza che i prodotti ceramici più antichi (VI sec. A.C.) presentano un impasto prevalentemente di tipo grossolano, mentre via via i prodotti più recenti (V sec. A.C.) presentano un impasto più depurato a grana fine.

KEY WORDS: *Amphorae, ceramics, petrographical and geochemical characterisation, gehlenite, diopside, Gela (Sicily).*

INTRODUCTION

Mineralogical, petrographic and chemical analyses were carried out on fragments of amphorae used for transport and table purposes, from the archaeological site at Molino a Vento near the acropolis of Gela.

One of the main difficulties in studying ceramic findings, and in particular amphorae used for transport, is knowing the exact whereabouts of their provenance, frequently problematic, precisely because of their purpose in the ancient world. Most food products (oil, grain, wine) could only be transported and sold thanks to ceramic containers of a characteristic shape suitable for transport by sea. Amphorae are differentiated according to the shape and the type of clay typical to the place of manufacture. In the early colonial cities, it is known that the containers were produced in Greece and that only later local potteries were set up to produce amphorae and other useful ceramic objects, modelled to imitate those made in Greece. This explains the difficulty in distinguishing products of diverse provenance.

Comparative study by morphological and compositional type facilitates interpretation of the socio-economic phenomena and may aid in understanding past trade flow over the centuries. With regards to the examined findings in this work, on the basis of historical and archeological considerations, archaeologists (Spagnolo, 1995) believe that they came from the western production and that, in particular, the potteries can be identified as those manufactured between Gela and Agrigento.

The enormous quantities of archaeological material recovered during the course of several digs confirm that Gela was an important trading centre. The marketplace of this Greek colony, near the port, has recently been found in the Bosco Littorio area. The port is now difficult to identify, due to changes in the geomorphology of the site, caused by pronounced coastline retreat. The area was once easy access for trading ships bound for Gela, loaded with goods sometimes imported from Greece itself. Both imported and local products were destined for cities further inland, and were transported by raft along the river (Panvini, 1996).

The number of transport amphorae indicate that many agricultural products were extensively imported and exported, especially staples such as oil, wine, etc., from Greece or from its colonies in Sicily (Spagnolo, 1995).

It is known that, until the mid-VI century B.C., many manufacts from the workshops of Rhodes and eastern Greece, as well as from Corinth, were imported to Sicily. Local ceramic production began in the first half of the VII century, as shown by kiln findings: products typical of Corinth, Rhodes and Crete were imitated in local pottery factories. The Gela artisans were dependent, from a stylistic viewpoint, on Greek models until the second half of the VI century, a period when autonomous production began to take form (Panvini 1996).

Once in possession of the site, the inhabitants of Gela, the *Geloi*, began a process of commercial and political expansion along the coast and inland. Especially during the VII and VI centuries, they were committed to conquering the central and southern territories of Sicily, partly to ensure possession of productive areas providing economic sustenance for their citizens (Fiorentini, 1985). Between the end of the VI century and the early decades of the following century, their expansionistic aims turned towards the conquest of the northern and eastern regions of the island, in order to control the Strait of Messina (Spagnolo, 1995).

ARCHAEOLOGICAL MATERIALS AND ANALYTICAL PROCEDURE

The analysed samples belong to amphorae for transport and table purposes.

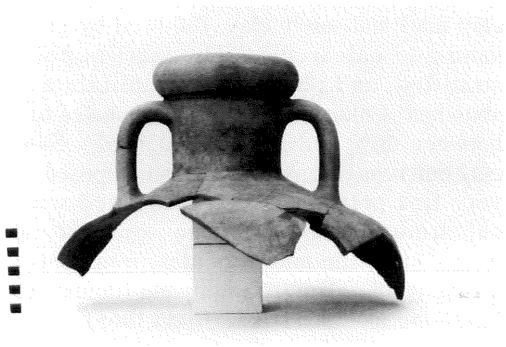
They are, after archaeological classification (Spagnolo 1995):

– «Ionic-massaliota» (nos. 23, 24, 26, 30, 37, 38, 39, 40 41 and 44: VI-V century B.C.) (photo 1a, 1b),

– «pseudo-chiota» form (27, 34, 35, 36 and 42: V century B.C.) (photo 2),

– imitations of Corinthian wares (45, 46 and 48: V century B.C.)

– table amphorae (75, 76, 77, 78: V century B. C.) (photo 3)



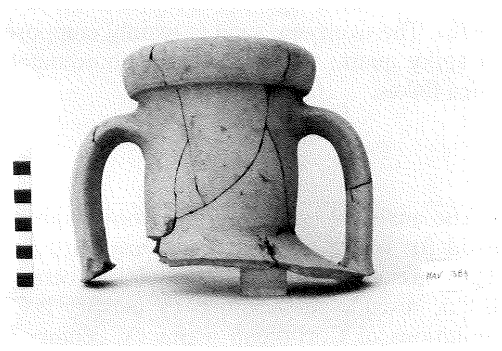


Photo1a-1b – Ionico-massaliota amphorae. Samples 23-26

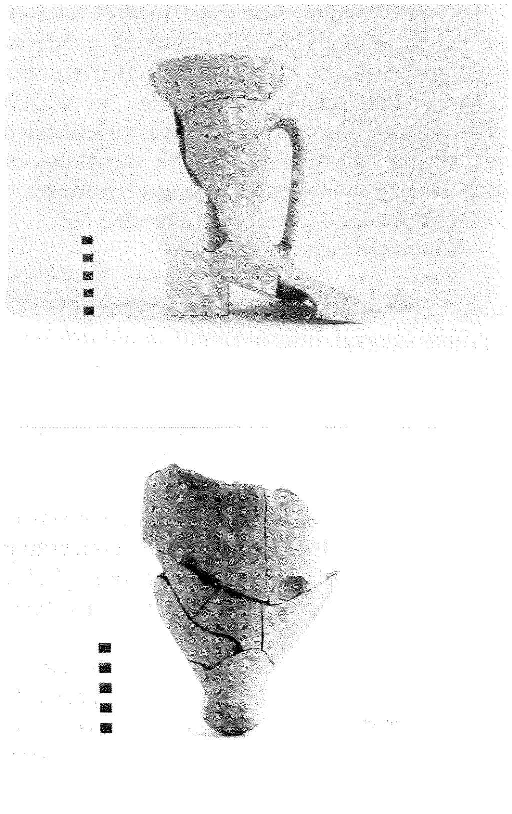


Photo 2 – Pseudo-chiota amphorae. Sample 35

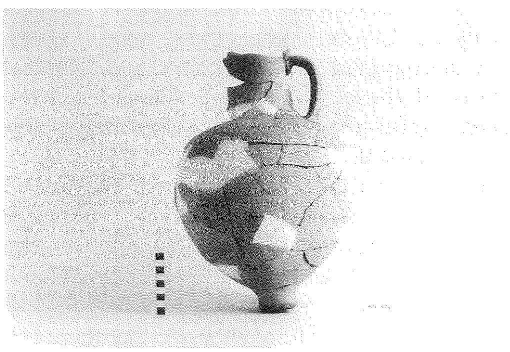


Photo 3 – Table amphorae. Sample 75

The petrographical analysis in thin section, carried out initially on all samples by polarised light microscope (OM), allowed different ceramic classes to be chosen, on which subsequent analytical techniques were carried out, taking into account that the quantities of material available were not always sufficient.

The following analyses were carried out:

– X -ray diffraction (XRD);

– X-ray spectrometry analysis (XRF) for major elements. The results were calibrated against several international standards and reproducibility was better than 0.5% after analytical values.

– Inducted coupled plasma-mass spectrometry (ICP-MS) for trace elements; analytical uncertainty is given as lower than 5%.

With the aim of constituting a comparison database for further considerations concerning the area of production of the amphores, 7 clay samples coming from the Gela area have been chosen.

In particular, samples GE3A, GE5A, GE6A and GE9A from the south of Gela (respectively at *Villa Iacona*, *Villa Vella*, *Poio a Crita*, and samples GE4A, GE7A GE8A, from the north of Gela respectively *Poggio San Rosario* and an unused railway station were chosen.

The raw clay materials have been analysed through XRD and XRF.

Finally, the analyses of brick samples from actual furnaces in Gela, although of recent manufacture, were carried out for comparison purposes. These samples represent macroscopic characteristics similar to the amphorae samples analysed (Colour, compactness, matrix, clast). The petrographic, diffractometric and chemical study of these manufactured articles, have given useful information about the clay matrix and the clast used.

In ancient times, furnaces were established near clay-sandy quarries, because transportation of raw materials for the manufacture of the ceramics was very difficult and onerous.

Therefore, we can hypothesize that there is a close relationship between the components of the ceramic body (clay matrix and clasts) and the geology of the area of origin. With this in mind, a brief petrographical and geological account of the zone is given.

Brief petrographical and geological account

The Molino a Vento area occupies the eastern flank of the hill of Gela, facing the river of the same name.

In the study area, the stratigraphic succession are distinguished (from bottom to top) as follows: brown flaky clay and variegated flaky clay; brown marl, brecciated clay, Tripoli, basic limestone, gypsum, brecciated clay, Trubi, bluish-white marl, greyish-brown sandy clay, yellow sand and calcarenite, terraced and present-day alluvial soil (Grasso *et al.* 1995, Di Grande & Muzzicato 1986).

From the geological viewpoint the hill of Gela, from bottom to top, contains greyish-blue clay marl and sandy clay, followed by gravel, sand and calcarenite. The marl is poorly stratified, and planktonic foraminifera are abundant. Calcimetry reveals carbonates to be between 46% and 26% (Roda 1965). Sandy clay outcrops extensively and is composed of a very fine pelitic deposit, associated with a calcareous deposit; also present are microfauna, limonitic nodules, fragments of quartz smaller than 0.25 mm, and fragments of limestone and mica flakes (Roda 1965).

According to faunistic observations, this clay is of Pleistocene age (Di Geronimo & Costa 1978). The overlying sand is mainly composed of spiky quartz fragments and, subordinately, mica flakes.

Discussion

The analysed samples come from amphorae used for transport and tableware purposes. They are «Ionic-massaliota» (VI-V century B.C.), «pseudo-chiota» form (V century B.C.), imitations of Corinthian wares (V century B. C.), and table amphorae (V century B.C.) (Spagnolo 1995).

Optical data

The Gela samples were subdivided into three groups according to the grain size of the aggregate. It is interesting to show that the oldest ceramic products (VI century B. C.) are made of a mainly coarse mixture, whereas the more recent products (V century) are gradually made of an increasingly finer original material.

1. The samples with coarse-grained aggregate (Tab. 1) contain the ionic-massaliota samples (23, 24, 37, 38, 40, 44,39 see photo 4a), as imitations Corinthian (48), and table amphorae (75 and 76).

The colour ranges from pale reddish-yellow in colour (Munsell's index 5 YR 7/6) to red (2.5YR 5/6 o 5/8), only samples 37 and 38 have a more pinkish colour (7.5YR 6/4). This colour appears as a very pale brown (10Y 8/2) for some samples, and more yellowish for others (2.5 Y 8/3). The surface has a faded appearance, as do most of the samples manufactured at Gela.

The clasts are almost exclusively quartz (Qz), with crystals ranging in shape from rounded to subangular, seldom as feldspars (Kf). In the matrix there are iron oxides, rare flakes of muscovite (Ms), moulds of microfossils and rare microforaminifera. Sometimes the microfossil moulds are filled with recrystallized microcristalline calcite (Cc).

2. The medium-grained aggregate group (photo 5a) contains the ionico-massaliota (26, 30, 41), and pseudo-chiota (27, 34, 35, 36) samples.

The colour ranges from pale reddish-yellow (Munsell's index 5 YR 7/6) to red (2.5YR 5/6 o 5/8), and the external surfaces uniformly faded are, for some samples, very pale brown (10 Y 8/2) and for others yellowish (2.5 Y 8/3).

Group medium grained aggregate samples differ from a coarse grained group because of a more homogeneous mixture a more abundant microfossil mould filled with recrystallized microcrystalline calcite, very rare microfossils, many of these still sound and in their variable contents of muscovite in the ground paste from scanty to abundant, particularly in sample 41 in which the mica is oriented.

3. The fine-grained group includes 1) the samples of Corinthian imitation (45, 46) (photo 4b), 2) table amphorae (77) with fine- grained aggregate and 78 very fine grained.

The intense red colour is 2.5 YR 5/6 or 5/8. Their external surface is always faded, but was probably only covered with a thin slip of the same yellowish-white colour (10YR 8/2) as in that of previous groups. The external surface of sample 78 is not always faded.

The clasts are mainly composed of quartz, feldspars, and small quantities of Fe-oxides. In the ground paste there are abundant moulds of microfossils.

The various mixtures are not always homogeneous, and sometimes contain a few vacuoles varying in shape from rounded to oblong, probably resulting from tiny air bubbles trapped in the clay during modelling of the manufact, or small grains of lime and/or organic matter in the clay and later oxidized or decomposed during firing.

In order to discover the provenance of these fragments, samples of modern bricks were also studied, produced in present day brick works in Gela, with macroscopic features – colour, compactness and inclusions – remarkably similar to those of the ancient samples.

In particular, modern bricks Ge3M, GE4M and GE5M have a grain and mineral content similar to the ancient samples of this medium grained group (photo 5b). GE1, GE2 e GE6 on the other hand have optic characteristics similar to the coarse grained samples.

Diffractometric analysis

1) Diffractometric analysis also revealed that the group coarse aggregate samples have variable quantities of quartz, plagioclase (Pl), calcite, hematite (Hm), K-feldspar, muscovite, gehlenite (Geh) and diopside (Di).

Gehlenite and diopside are criptocrystalline mineralogical phases produced by the reaction between illite, quartz and calcite under high temperature.

According to experiments by the reactions

TABLE 1

Optical data of study samples.

	samples	Ground-paste	Sandy skeleton					
			Grain size	Qz	Pl	Kf	Cc microcry stalline	Oxide
23	Ionico-massaliota VI-V B.C.	Moulds microfossil microforaminifera	Coarse	Abundant: Angular-subangular	X	X	X	X
24	Ionico-massaliota VI-V B.C.	Micaceus in trace, abundant moulds, microforaminifera	Very coarse	Abundant: Angular-Subangular,		X		X
37	Ionico-massaliota VI-V B.C.	Moulds microfossil Micaceus in trace	Coarse	Abundant angular		tr	X	X
38	Ionico-massaliota VI-V B.C.	Moulds microfossil Micaceus in trace	Coarse-average	Abundant sub-angular,		tr	tr	X
39	Ionico-massaliota VI-V B.C.	Moulds microfossil Micaceus in trace	Coarse	angular			tr	
40	Ionico-massaliota VI-V B.C.	Micaceus in trace abundant moulds, microforaminifera	Coarse	Abundant sub-angular		tr	X	X
44	Ionico-massaliota VI-V B.C.	Micaceus in trace abundant moulds, microforaminifera	Very coarse	Angular, subangular	X		X	X
48	Imitation Corinthian V B.C.	Abundant moulds, microforaminifera	Coarse	Abundant angular, polycrystalline			X	X
75	Table amphorae V B.C.	Micaceus in trace, abundant microforaminifera	Coarse	Abundant sub-angular		tr		X
76	Table amphorae V B.C.	abundant microforaminifera	Coarse	Abundant sub-angular	X	Tr		X
GE1M	Modern brick	Micaceus in trace	Coarse	Abundant angular		tr		X
GE2M	Modern brick	Micaceus in trace Moulds microfossil	Coarse	Abundant sub-angular, angular	X	tr		X
GE6M	Modern brick	Moulds microfossil	Coarse	Very abundant				X
26	Ionico-massaliota VI-V B.C.	Moulds microfossil Micaceus in trace	Average	Abundant sub-angular				X
30	Ionico-massaliota VI-V B.C.	Paste micaceus, microforaminifera Moulds microfossil	Average	Very abundant Sub-angular			X	X

TABLE 1: *Continued*

	samples	Ground-paste	Sandy skeleton					
			Grain size	Qz	Pl	Kf	Cc microcry stalline	Oxide
41	Ionico-massaliota VI-V B.C.	paste Micaceus abundant, mica isoriented microforaminifera Moulds microfossil	Average	Very abundant Sub-angular		tr	X	X
27	Pseudo-chiota V B.C.	Micaceus in trace Moulds microfossil	Average-fine	Scarce sub-angular,		tr		X
35	Pseudo-chiota V B.C.	Paste micaceus, isoriented Moulds microfossil	Average	Abundant Sub-angular			tr	X
34	Pseudo-chiota V B.C.	Micaceus paste, abundant microforaminifera and moulds	Average	Abundant subangular			tr	X
36	Pseudo-chiota V B.C.	Paste micaceus, microforaminifera Moulds abundant microfossil	Average	Very abundant Angular,	tr		tr	X
42	Pseudo-chiota V B.C.	scarce micaceus, very abundant microforaminifera	Average	Abundant angular, sub-angular			X	X
GE3M	Modern brick	Paste micaceus, Moulds microfossil	Average	Very abundant Angular		tr		
GE4M	Modern brick Paste micaceus	Average	Abundant	Angular, sub-angular				X
GE5M	Modern brick Paste micaceus,	Moulds microfossil	Average	Abundant			tr	X
45	Imitation Corinthian V B.C.	Paste micaceus, Moulds microfossil	Fine-average	Very abundant Angular, polycrystalline			X	X
46	Imitation Corinthian V B.C.	Paste micaceus very abundant Moulds microfossil, microforaminifera	Fine-average	Very abundant Angular,		tr	X	X
77	Table amphorae V B.C.	microforaminifera, Moulds microfossil	Fine	Scarce			tr	
78	Table amphorae V B.C.	Moulds microfossil	Very fine	Scarce				X

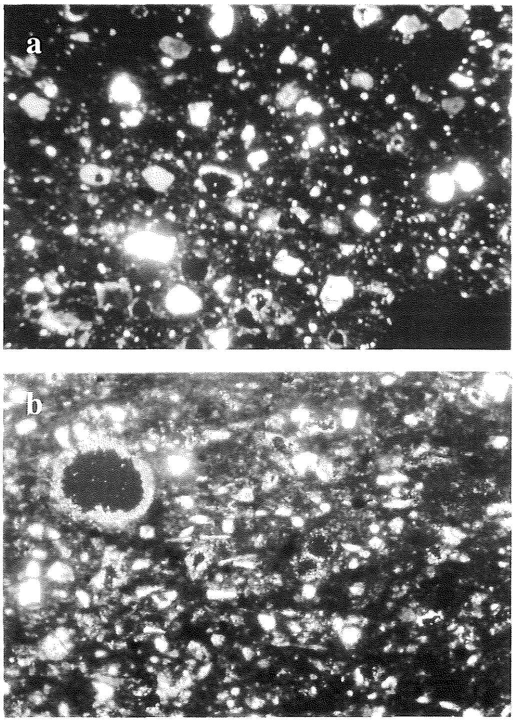


Photo 4a – Optical microscopy analyses (39). Ingr. 2.5.Crossed nicols (magnification x 50)
Photo 4b – Optical microscopy analyses (46). Ingr. 10. Crossed nicols (magnification x 200)

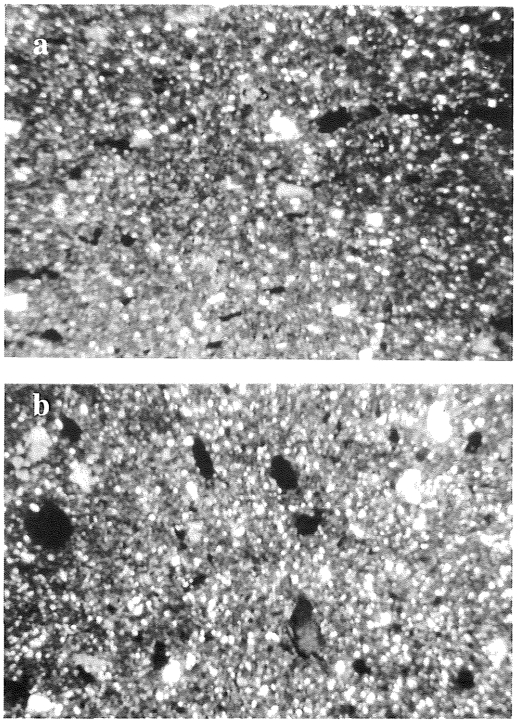


Photo 5a – Optical microscopy analyses (30). Crossed nicols (magnification x 50)
Photo 5b – Optical microscopy analyses (GE5). Crossed nicols (magnification x 50)

of Capel *et al.* (1985) and Duminuco *et al.* (1996), the presence of microfossils prove that these samples were fired at temperatures of about 850° ÷ 900°C.

2) The medium grained samples always have quite high quartz contents, whereas calcite tends to be less abundant than the coarse-grained group, except for sample 30. Gehlenite is absent or only present in traces; diopside is always found (except in sample 30), and is more abundant in sample 35.

Estimated firing temperatures are thought to be around 900°C or higher.

The likely firing temperatures are slightly higher than those of the coarse grained group because the microfossil moulds are more abundant and moreover, sound microfossil are very rare in this case.

3) For the Corinthian imitations (45, 46) and table (77,78) samples the firing temperature is estimated at about 900°C since diopside, together with rare gehlenite and calcite and moulds of microfossils, is present.

The XRD analyses of modern bricks reveal various contents of Qz, Pl, Kf, Hm, Geh, Ms, which are either absence or present in very small quantities of calcite, but abundant in diopside, therefore the firing temperature for these bricks is more than 900°C.

The diffractometric analyses (XRD) of the clays from Gela indicate the presence of varying quantity of illite, kaolinite, montmorillonite, clorite, quarzo (tab. 2). The calcite is particularly abundant in all samples, except for sample Ge7A.

On the bases of the petrographical and diffrattometric observations, it is possible to hypothesize a production centre in Gela,

TABLE 2

Diffractometric analyses of study samples.

sample	M.I. Inner	M.I. surfaces outer	Qz	Cc	Pl	Hm	Kf	Di	Geh	Ms
23	5YR 7/6	10 Y 8/2	XXX	tr	X	X	tr	X	tr	
24	5YR 7/6	10 Y 8/2	XX	X	X			tr		tr
37	7.5YR 6/4	10 Y 8/2	XX	XX	X	tr	-	tr	X	tr
38	7.5YR 6/4	10 Y 8/2	XXXX	X	XX	X	-	XX	X	
39	2.5YR5/6	10 YR 8/2	XXX	XX	XX	X	-	X	X	
40	2.5YR5/6	10 YR 8/2	XX	XX	tr	tr	tr	-	-	X
48	2.5YR5/6	10 YR 8/2	XXX	X	X	tr	-	tr	tr	
75	5YR 7/6	2.5 Y 8/3	XXX	XX	XX	tr	-	X	x	tr
76	2.5YR6/8	2.5 Y 8/3	XXX	XX	XX	tr	-	X	X	
GE1M	5YR 7/6	2.5 Y 8/3	XXX	-	XX	X	tr	XX	X	tr
GE2M	5YR 7/6	2.5 Y 8/3	XXX	X	XX	X	tr	XX	tr	tr
GE6M	2.5YR8/4	-	XXXX		XX	X	tr	XX	X	
26	5YR 7/6	10 Y 8/2	XX	X	X	tr	tr	X	tr	
27	5YR 7/6	10 Y 8/2	XX	X	X	tr	tr	X	tr	tr
30	2.5YR5/6	10 YR 8/2	XXXX	XXX	XX	-	tr	-	-	tr
34	7.5YR6 /4	10 Y 8/2	XX	X	X	tr	-	x	tr	tr
36	2.5YR5/6	10 YR 8/2	XXX	X	X	X	-	X	tr	X
41	2.5YR5/6	10 YR 8/2	XX	X	tr	tr	tr	X		XX
42	2.5YR5/6	10 YR 8/2	XXX	X	XX	X	-	X	X	tr
GE3M	5YR 7/6	2.5 Y 8/3	XX	tr	X	X	tr	XX	tr	X
GE4M	5YR 7/6	2.5 Y 8/3	XXX	-	X	X	tr	XX	tr	tr
GE5M	5YR6/6	-	XXX	X	X		-	X	-	tr
45	2.5YR5/6	10 YR 8/2	XX	X	X	-	-	X	tr	tr
46	2.5YR5/6	10 YR 8/2	XX	tr	X	-	tr	tr	tr	X
77	2.5YR5/6	2.5 Y 8/3	XXX	X	X	tr	-	X	tr	
78	2.5YR6/6	-	XX	-	X	tr	tr	tr	tr	

sample	Clays GELA	Qz	Cc	Pl	I	Ka	Cl	Mont	
GE3A	clay	-	XXX	XXX	X	tr	X		X
GE4A	clay	-	XXX	XX	X	X	XX	X	X
GE5A	clay	-	XXX	XXX	X	X	XX		XX
GE6A	clay	-	XXXX	XXX	XX	tr	X		
GE7A	clay	-	XX	X	tr	tr	tr		X
GE8A	clay	-	XXXX	XXX	X	X	X		
GE9A	clay	-	XXX	XXX	XX	X	X		tr

Legend: Qz = quartz; Cc = calcite; Pl = plagioclase; Hm=hematite; Kf = orthoclase; Di = diopside; Geh = gehlenite; Ms = muscovite; I = illite; Ka = kaolinite; Cl = clorite; Mont = montmorillonite.
semiquantitative determinations: xxxx = very abundant; xxx = abundant; xx = less abundant; x = scarce abundant; tr = traces.
M.I. = Munsell Index

TABLE 3

Major element composition (wt%) of studied samples

sample	group	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
24	coarse	58.5	0.7	12.3	5.1	0.1	2.5	12.1	0.6	2.0	0.5	5.8
44	coarse	54.5	0.7	12.4	5.7	0.1	3.3	13.1	0.6	1.8	0.2	7.6
75	coarse	57.1	0.6	12.0	5.5	0.1	2.5	13.7	0.6	1.9	0.2	5.8
76	coarse	54.3	0.6	12.3	5.8	0.1	2.8	14.0	0.7	2.2	0.3	6.9
GE 1M	coarse	58.4	0.4	9.8	4.9	0.1	2.1	20.6	0.2	1.6	0.2	1.6
GE 2M	coarse	57.5	0.6	12.0	5.4	0.1	3.0	13.8	1.0	2.0	0.2	4.4
GE 6M	coarse	61.4	0.6	11.8	4.9	0.1	3.9	14.4	0.6	2.0	0.2	0.0
27	average	57.4	0.7	12.4	5.5	0.1	3.3	13.1	0.9	1.8	0.2	4.7
GE 3M	average	56.6	0.7	13.2	5.9	0.1	3.6	14.9	1.0	2.1	0.2	1.8
GE 4M	average	57.5	0.7	13.0	5.7	0.1	3.6	14.9	1.1	2.2	0.2	1.1
GE 5M	average	55.0	0.6	11.9	5.3	0.1	3.3	14.2	1.0	2.1	0.2	6.4
77	fine	56.7	0.7	13.0	5.7	0.1	2.5	12.7	0.7	2.3	0.2	5.4
78	very fine	58.3	0.8	17.5	7.0	0.1	2.9	6.7	1.1	3.3	0.2	2.2
GE 3A	clay	50.5	0.4	9.3	4.0	0.1	2.2	15.1	0.3	1.4	0.1	16.7
GE 4A	clay	45.5	0.6	11.4	4.9	0.1	2.9	12.1	0.4	1.8	0.1	20.3
GE 5A	clay	48.7	0.5	10.2	4.5	0.1	3.2	14.1	1.5	1.5	0.1	15.7
GE 6A	clay	47.2	0.5	11.0	3.7	0.1	4.2	11.5	0.6	1.6	0.1	19.7
GE 7A	clay	42.0	0.5	10.7	4.2	0.1	2.9	11.3	2.9	1.7	0.1	23.6
GE 8A	clay	54.3	0.3	5.8	2.4	0.1	1.4	18.4	0.4	1.2	0.2	15.6
GE 9A	clay	48.9	0.5	10.6	4.9	0.1	2.6	14.0	0.3	1.6	0.1	16.4

TABLE 4

Trace element composition (ppm) of studied samples

sample	group	Rb	Zr	Nb	Sc	V	Cr	Ni	Co	Cu	Zn	Ba	Pb
23	coarse	120	382	24	13	135	99	45	10	64	254	113	1.3
24	coarse	124	207	15	10	81	72	34	9	48	59	58	1.3
37	coarse	75	285	14	12	111	84	42	10	62	73	94	0.6
38	coarse	141	630	16	13	121	95	43	9	64	88	73	2.2
39	coarse	107	498	23	13	125	89	44	11	58	83	89	0.7
40	coarse	118	609	27	12	116	77	38	9	45	77	68	0.6
44	coarse	82	537	9	7	63	50	24	6	33	38	56	0.3
48	coarse	96	293	16	11	97	73	36	9	56	68	62	1.8
GE2M	brick						80	36	12	22	56	480	
26	average	121	428	18	15	144	102	46	11	48	68	596	
27	average	85	282	35	14	150	107	49	12	75	47	144	
30	average	103	624	19	13	128	98	41	10	32	26	70	
34	average	107	349	27	10	77	70	35	9	37	36	166	
35	average	81	220	29	11	94	73	37	10	58	41	63	
36	average	131	748	33	10	76	70	33	8	48	55	65	
42	average	129	965	10	8	69	55	26	6	34	37	62	0.9
41	average	283	2504	19	13	110	90	44	11	49	37	133	1.0
GE4M	brick						87	40	12	30	68	336	
GE5M	brick						38	18	7	21	12	280	
45	fine	135	310	34	16	128	112	52	13	47	51	59	
46	fine	148	759	23	13	117	91	48	13	72	979	86	2.0

because taking into account the raw clay, the macrofossils present, and the clast used they are evident compatibility with the clay sandy material present in the zone of Gela.

Fluorescence Spectrometer (XRF) and Plasma Emissions (ICP-MS).

Table 3 shows the results of the chemical analyses (XRF) expressed in % of the oxides, ceramic samples, modern bricks and clays from Gela. Table 4 shows the ICP-MS results of the ceramic samples and of the modern bricks.

By examining the composional table, the ceramic samples show similar concentration values, with quite contained variations of the different elements considered. Only sample 78 (a very fine grain) showed notable high values for Al_2O_3, Fe_2O_3 and K_2O, while the CaO was much lower (6.7%).

In particular these three groups of Gela amphorae are classified as calcareous ceramics (CaO > 7-8%) (Olcese & Picon, 1995). According to the classification of these authors, were made in the first type of fabric, of their three classification types.

In the binary diagram SiO_2 vs CaO (fig. 1) and in the triangular diagram proposed from Maniatis and Tite (1978, 1981; fig. 2), samples of three ceramic groups together with clays from Gela and modern bricks of Gela production

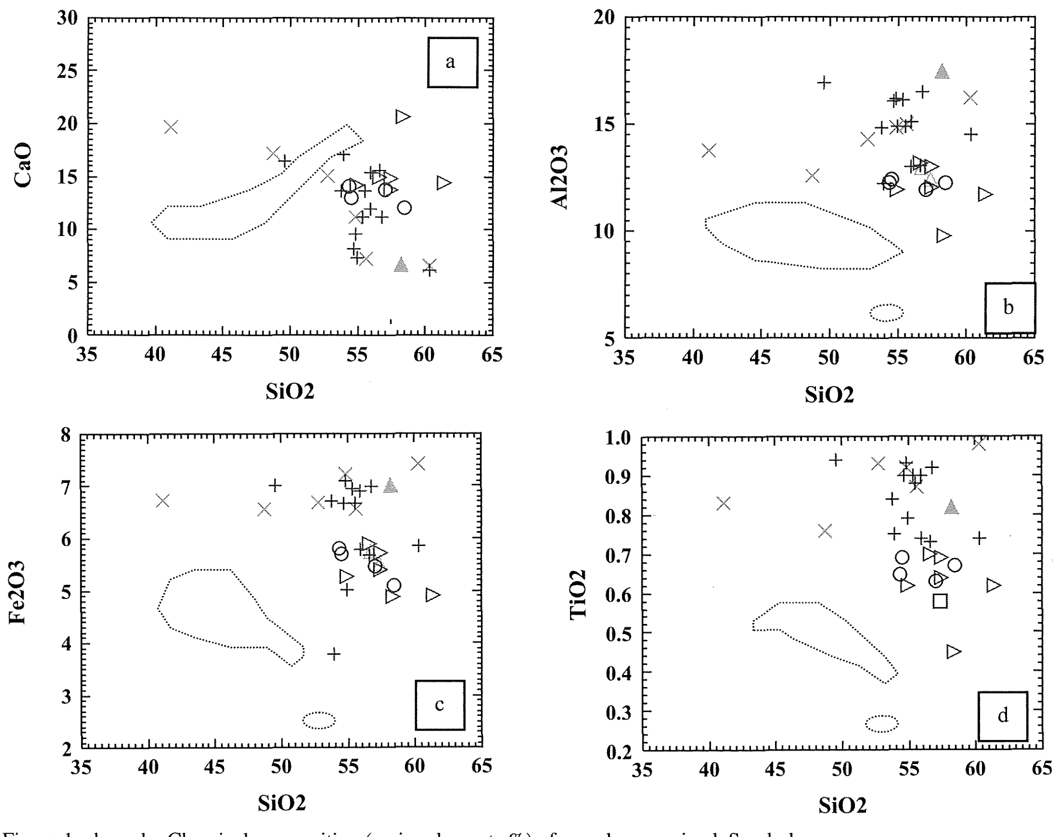
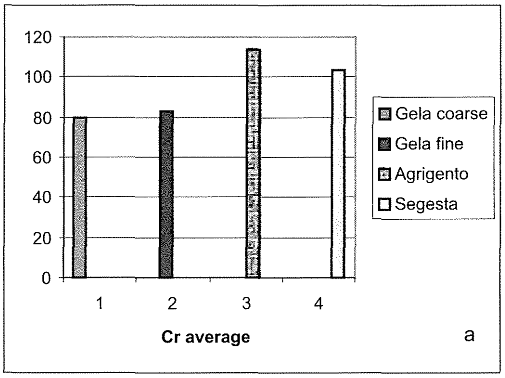
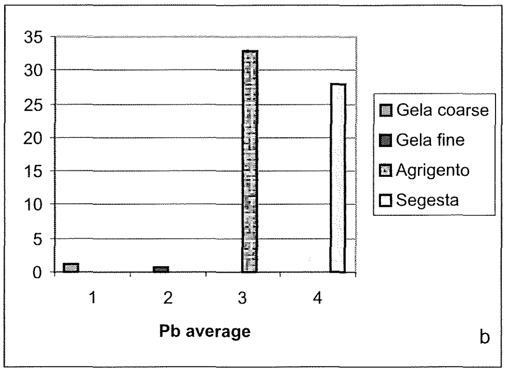


Figure 1a, b, c, d – Chemical composition (major elements %) of samples examined. Symbols: ○ = Amphorae with mainly coarse aggregate; □ = Amphorae medium grain aggregate; △ = Amphorae with finer grain aggregate; ▲ = Anfore with very fine grain aggregate; ⊵ = Modern bricks; + = samples of Agrigento (Alaimo *et al.* 1995); X = samples of Segesta (Alaimo *et al.* 1995); .... Clays Gela.





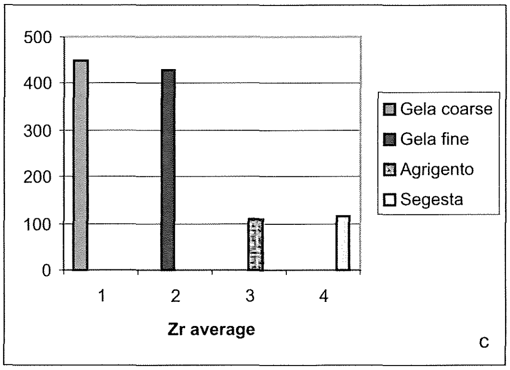


Figure 2a, 2b, 2c – Chemical composition (trace elements, ppm: Cr, Pb and Zr) of samples examined. Symbols as Figure 1.

constituted a compositional homogeneous group, found in the field of calcareous clays, as they have a CaO content including 12.1 and 11.14%, with the exception of sample 78 having an CaO less content (6.7%).

This data supports the hypothesis, formulated on archaeological and mineralogical-petrographical indications, of the existence of a centre of common production for all the samples considered with the exception of sample 78.

To formulate a better hypothesis of origin the data from Gela samples were then compared with literature data on samples from Agrigento and Segesta (Bonacasa Carra 1995) which have similar optical characteristics, i.e., mainly quartz-sand aggregate, and microfossils.

XRF and ICP-MS results (fig. 1, 2, 3) show that both the Gela amphorae and the modern bricks have perfectly comparable percentages of oxides, and only differ from the Agrigento and Segesta samples (Alaimo *et al.* 1995) because of their lower content of Al_2O_3, Fe_2O_3, TiO_2 (fig. 1b, c, d), Pb (fig. 2b), and higher Zr (fig. 2c). Only sample 78 (grained very fine) has a composition similar to that of samples from Segesta and Agrigento.

For the elements Cr, Pb and Zr the average values were plotted between their selves because of the lack of SiO2 values (fig. 2a, b, c). In particular, the Pb shows an average value of 1 ppm for the ceramics from Gela, and 27.78 ppm and 32.83 ppm for samples from Segesta and Agrigento. The Zr shows an average value of 430-450 ppm for samples from Gela (fine and big grain) and of 109 and 114 ppm for samples from Agrigento and Segesta respectively.

Cr and Ni (< 200 ppm), important elements in distinguishing Greek or Western provenance, show that the Gela samples are of Western origin (Jones 1987, Barone *et al.*

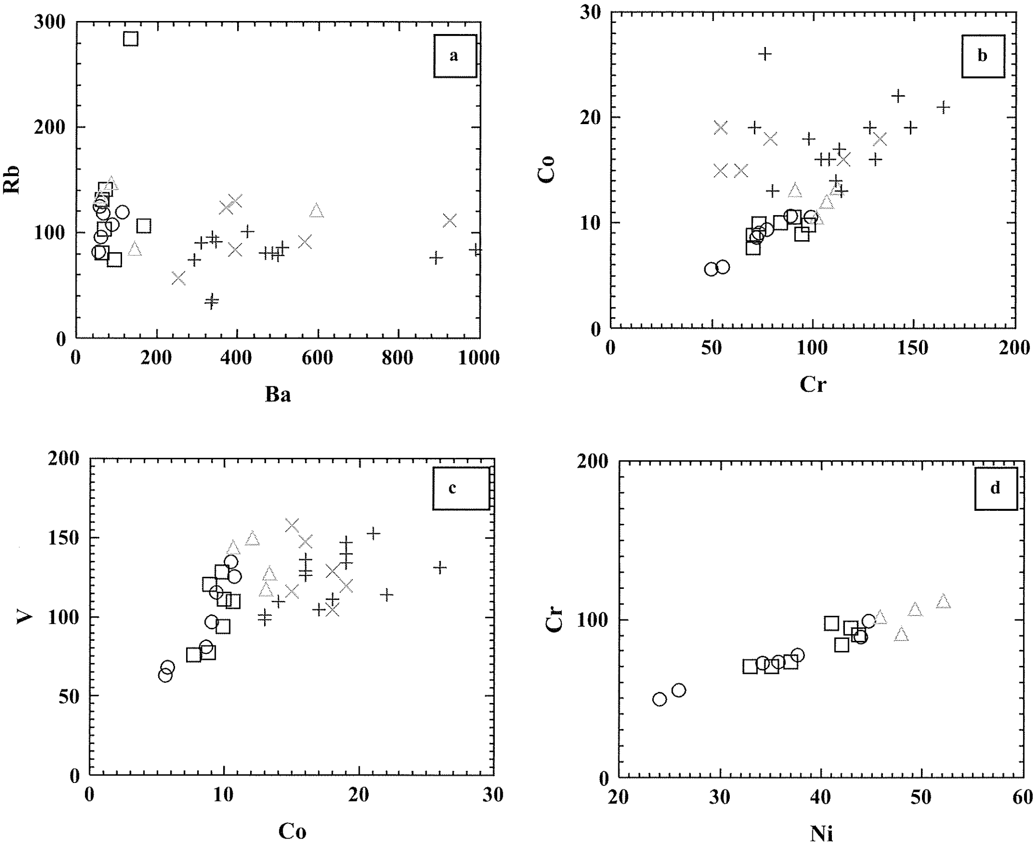


Figure 3a, 3b, 3c, 3d – Chemical composition (trace elements, ppm: Ba-Rb; Cr-Co; Co-V; Ni-Cr) of samples examined. Symbols as Figure 1.

2002): in particular, Ni ranges between 24 and 52 ppm in the Gela samples, whereas the Cr represent a medium content of 80, and the Segesta and Agrigento samples have a medium content of 103 and 113 ppm (fig. 2a).

Lastly, the Ni vs Cr pattern (fig. 3a) shows that the Gela samples, with respect to that of the coarse grained, have a higher content of Ni e Cr, probably because of their provenance from a different quarry.

With respect to the above comparative samples, the Gela samples also have less Co and Ba (fig. 4). Almost all the samples have Rb between 50 and 150 ppm - considerably higher in sample 41 (283 ppm) due to abundant muscovite.

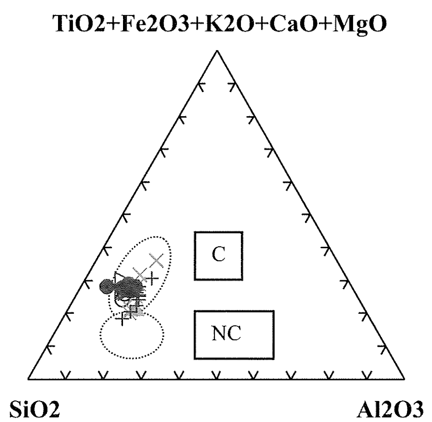


Figure 4 – Pattern after Maniatis e Tite (1978). Legend: C= calcareous clay; NC= not calcareus clay.

CONCLUSIONS

The fragments of transport and table amphorae examined in this work were collected from the archaeological site of Molino a Vento, near the acropolis of Gela (Sicily).

The samples have been subdivided into three groups according to clasts size, resulting from optical microscopic analyses.

The analyses by optical microscopy (OM) and X ray diffraction (XRD) revealed that the most ancient samples (VI century B.C.) have coarse-grained quartz sand and estimated firing temperatures less than 900°C (there are traces of calcite and new minerals such as Geh and Di produced by firing and a few sound microfossils), whereas the later samples have finer grain and were fired at temperature exceeding 900°C (there are only Di and moulds of microfossil present).

These manufacts, fired at about 900°C, are particularly tough and resistant, and have a superficial faded surface effect, since the colour of calcareous ceramic ware fades as firing temperature increases during the prevailing reducing phase and oxidizing cooling phase.

Superficial fading, for example, resulting from a very pale slip layer on the surface of the ceramic body, is also due to the presence of calcite and kaolinite in the raw clay, and probably also to the use of seawater during modelling and polishing. Salt, being hygroscopic, coordinates OH so that, as the temperature rises during firing it is withheld longer, slowing down drying and avoiding thermal shock to the ceramic body.

By comparing the samples and also the bricks and clays from Gela, it was possible to obtain important indications which has help in resolving the question of provenance and manufacture of the samples.

The calcareous clay, the microforaminiferae in the matrix, the traces of muscovite and the prevalent quartz clast are compatible with the geological zone of Gela.

The great optical and chemical similarities between the ancient amphorae, modern bricks and raw clay, shows that the samples were produced in kilns at Gela at temperatures slightly less than those of modern firing techniques. The modern bricks also have the same faded effect as that of the ancient amphorae, and were fired between 850°C and 1000°C in reducing conditions.

To develop a better hypothesis on the provenance of the samples the analytical results of the Gela samples were then compared with literature data of samples from Agrigento and Segesta (Bonacasa Carra 1995), which have similar optical e typological characteristics.

Chemical XRF and ICP-MS results have allowed the different products to be distinguished.

The Gela amphorae and the modern bricks have both perfectly comparable percentages of oxides and trace elements and differ from the Agrigento and Segesta samples (Alaimo *et al.* 1995) particularly by means Al_2O_3, Fe_2O_3, TiO_2, Pb, Zr, Co, Ba, Ni, e Cr. Finally we can assume that all samples examined are of Gela production, except the sample 78 which has a chemical composition similar to that of samples from Agrigento.

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