Archaeol Anthropol Sci (2017) 9:1125–1135
DOI 10.1007/s12520-016-0345-9

ORIGINAL PAPER

An archaeometric approach to gain knowledge on technology and provenance of Apulian red-figured pottery from Taranto

Lorena Carla Giannossa[1] · **Rosa Maria Mininni**[2] · **Rocco Laviano**[3,5] · **Fabrizio Mastrorocco**[4] · **Maria Cristina Caggiani**[4] · **Annarosa Mangone**[4,5]

Received: 24 September 2015 / Accepted: 23 May 2016 / Published online: 11 June 2016

Abstract A large sampling of Apulian red-figured pottery fragments (fifth to fourth century BC) coming from Taranto (Italy) was analyzed by a multi-technique approach. The ceramic bodies' elemental composition has been obtained by inductively coupled plasma mass spectrometry (ICP-MS), the mineralogical composition of pastes by polarized-light optical and electron microscopies (OM and SEM-EDS), and X-ray powder diffraction (PXRD). The results obtained from the statistical treatment of compositional data, combined with those driven from mineralogical composition of pastes, allow to formulate hypotheses about the provenance of the objects and the manufacturing tradition of the workshops, starting to make it possible to understand the relationships among ceramic technology, artistic expression, and workshop practice in the samples analyzed.

Keywords Archaeometry · Apulian red figured pottery · Chemical analysis

✉ Annarosa Mangone
annarosa.mangone@uniba.it

1 Dipartimento di Economia, Management e Diritto dell'Impresa, Università Aldo Moro, Largo Abbazia Santa Scolastica 53, 70124 Bari, Italy

2 Dipartimento di Matematica, Università Aldo Moro, via Orabona 4, 70126 Bari, Italy

3 Dipartimento di Scienze della Terra e Geoambientali, Università Aldo Moro, via Orabona 4, 70126 Bari, Italy

4 Dipartimento di Chimica, Università Aldo Moro, via Orabona 4, 70126 Bari, Italy

5 Centro Interdipartimentale "Laboratorio di Ricerca per la Diagnostica dei Beni Culturali", via Orabona 4, 70126 Bari, Italy

Introduction

Archeological framework

The study of Apulian red-figured pottery from Taranto is included in a more extensive study focused on the investigation of production, technical, and manufacturing features of this class. Among the figured pottery produced in Magna Graecia within fifth and fourth century BC, Apulian red-figured pottery is the one numerically most significant, widespread, and marketed in regional and extra-regional area, as well as the one with the most relevant representative skills and an astonishing development of the quality profile. The almost complete absence of technological productive data and the awareness that a systematic research on samples coming from representative sites of the entire area of production could represent a resource not exclusively local, since most of the vases are located in archeological museums inside and outside Italy, have driven the whole research project. Indeed, a systematic archaeometric study, providing compositional and structural information of bulk and surfaces, could allow to recognize the manufacturing processes of ancient objects and to contribute in solving the wider question of the raw materials and objects provenance. The opportunity to distinguish the objects according to the site of provenance by the statistical analyses of fabric composition is an important result itself. Indeed, it makes possible to identify locally produced and imported finds and can be used to "reallocate" pottery whose origin is unknown (i.e., artifacts in museums and private collections or material from clandestine markets). Unfortunately, pottery of undisclosed origin represents a huge amount of the entire Apulian red-figured production.

So far, the research activity concerning this class, as well as the Attic pottery class (Beazley 1963), has been motivated both by historical and artistic interests and intended to credit painters (Trendall and Cambitoglou 1978, 1982; Trendall 1989), groups, and workshops with items from this class. Workshops' localization had been also hypothesized upon stylistic-archeological considerations. Furthermore, Apulian red-figured pottery has often suffered from the "poor cousin" syndrome. In fact, without dedicated investigations, its technology and productive processes have been assumed to be the same of the Attic.

However, we believe that an important contribution to the study of this class may come from an accurate investigation of raw materials and technological production.

Lastly, few archaeometric works concerned the Apulian red-figured ware, absolutely insufficient to provide a clear picture about technological aspects and possible similarities/differences with the Attic production (Noble 1960; Tite et al. 1982; Jones 1986; Kingery 1991; Graves et al. 1997; Ingo et al. 2000; Tang et al. 2001; Mirti et al. 2004a; Mangone et al. 2008, 2009b, 2013; Thorn and Glascock 2010; Robinson 2013, 2014a).

Nevertheless, our preliminary results from a systematic study of Apulian red-figured vases, found in excavations of important sites of Apulia (Mangone et al. 2008, 2013), have shown peculiar features related to the technological process in the fourth century BC, different from the Attic one and never reported before in the literature. This result is twofold important: it sheds light on the technological aspects, still not perfectly clear, of Apulian production; moreover, it provides an objective element of discrimination from the Attic production and allows to comprehend the phase of transition from following an Attic model to an Apulian one, which took place during fourth century BC. The study also produced a first batch of compositional data that, properly integrated with those from Taranto, can be the starting point to set up a useful database on the Apulian products. This database can be fruitfully employed to reconstruct the origin of vases.

As for Apulian red-figured pottery from Taranto, it is worth to point out that, though there are no solid evidence for Apulian red-figured manufacturing main areas yet, the belief that such production had begun in this city in 440 BC is widespread among scholars. It is widely thought that Taranto had been the only manufacturing center for Apulian red-figured pottery during the major part of the fourth century BC. It has also been conjectured that over that span there had been a transfer of tarantine potters to other Apulian settlements, which developed into branch centers of manufacturing. However, these assumptions that Taranto was predominant in the Apulian red-figure pottery production began to being disputed by (Thorn 2009; Robinson 2014b; Fontannaz 2005).

It is therefore clear that analyzing findings from Taranto cannot be overlooked to study the Apulian red-figured pottery.

Experimental

A collection of 62 fragments, found in the archeological site of Arsenale and stored in the deposit of National Archaeological Museum of Taranto (MARTA), one fragment with a fired sketch of a human head on its interior surface—almost certainly a firing tester—(Castoldi 2006) and two vitrified clay samples, from a pottery workshop (fifth to fourth century BC) producing black gloss and plain ware, located in Taranto (Dell'Aglio 2002), were analyzed.

The group of the fragments from Arsenale is part of an incredible figured pottery assemblage consisting of more than three hundred fragments, mostly related to large monumental forms, in which there are substantial claims of high artistic quality relating to Italiot production, along with Attic imports. It is important to underline that any documentation on the discovery that took place between 1912 and 1913 is missing. It is only possible to affirm that the items come from the frequentation levels of the particularly rich and vast necropolis area. Mainly, stylistic considerations were adopted to select samples to investigate (Table 1, Fig. 1).

Techniques

The objects were examined by the following: polarized-light optical (OM) and electron microscopies (SEM-EDS) (Axioscop 40 (Carl Zeiss) and EVO-50XVP (LEO)) with Oxford-Link Ge ISIS energy dispersive spectrometer), X-ray powder diffraction (XRPD) (Philips X'Pert Pro) and inductively coupled plasma mass spectrometry (ICP-MS) (PerkinElmer Elan 9000).

The petrographical observations were performed on polished thin sections. The elemental composition of the pastes was carried out as described in reference (Mangone et al. 2013).

The multivariate statistical treatment of compositional data, usually applied to split wares in groups distinctly discriminated per archeological category (Aruga et al. 1993; Bruno et al. 1994), provenance (Mirti et al. 2004b; Mangone et al. 2009a, 2011; Giannossa et al. 2014), or manufacturing process (Mangone et al. 2008, 2009c, 2013), was carried out on standardized data using the software package Minitab®.

The concentrations of 20 elements were determined (Fe, Al, Mg, K, Ti, Ca, Mn, Ni, Cr, Ce, Ba, Zn, Na, Sr, Co, Pb, V, La, Sm, Nd). A distinct clustering with 55 % explained variance diagrams in the first three principal components was obtained by the PC treatment performed on a matrix of 20 chemical parameters. However, to achieve a more affective analysis, we applied statistical criterion of selecting features, e.g., comparing the means and the variances of the different variables prior to PC treatment (when the mean is quite the same in each assumed class and/or the intra-class variance is high the relative elements are removed). The selected subset of variables was reported in Table 2.

Results and discussion

Table 2 reports the selected element concentrations of the paste of items coming from the archeological site of Arsenale.

Table 1 Samples analyzed

	Attribution (painters or workshops)	Identification number	Sample	Cluster
Archeological site of Arsenale	Darius Painter	51381	FT 01	A1
	Darius Painter	227162	FT 19	A1
	Darius Painter	227196	FT 26	A1
	Darius Painter	227199 B	FT 29 B	A1
	Darius Painter	227219	FT 57	A1
	Darius Painter	227229	FT 58	A1
	Darius Painter	227231	FT 59	A1
	Darius Painter	227130	FT 48	A1
	Darius Painter’s workshop	227205	FT 35	A1
	Darius Painter’s workshop	227206	FT 36	A1
	Darius Painter’s workshop	227161 A	FT 53 A	B2
	Darius Painter’s workshop	227161 B	FT 53 B	A1
	Darius Painter’s workshop	227163 A	FT 54 A	A1
	Darius Painter’s workshop	227163 B	FT 54 B	A1
	Darius Painter’s workshop	227183	FT 56	B1
	Darius Painter’s workshop	227247	FT 62	A1
	Darius Painter’s workshop	227255	FT 63	A1
	PisticciPainter	52231 A	FT 64 A	A1
	AmikosPainter	227201	FT 31	A1
	Amikos Painter’ workshop	227202	FT 32	A1
	Amikos’ workshop	227203	FT 33	A2
	Amikos’ workshop	227204	FT 34	A1
	SchwerinGroup	227068	FT 10	B2
	Underworld Painter	227237	FT 61	A1
	Truro Painter	227184	FT 21	B1
	Truro Painter	227185	FT 22	B1
	Truro Painter	227001	FT 03	B1
	Truro Painter	227002	FT 04	B1
	Truro Painter	227007	FT 09	B1
	Truro’s workshop	227003	FT 05	B1
	Truro’s workshop	227004	FT 06	B1
	Hoppin Painter	227186	FT 23	B1
	Tarpoley Painter	227129	FT 47	B1
	Tarpoley Painter	227159	FT 18	B1
		227092	FT 12	A1
		227094	FT 14	A1
		227095	FT 15	A1
		227006	FT 08	B1
		52231 B	FT 64 B	B2
		227179	FT 20	B1
		227207	FT 37	A1
		227200 A	FT 30 A	B1
		227200 B	FT 30 B	B1
		227200 C	FT 30 C	B1
		227005	FT 07	B1
		227091	FT 11	B1
		227093	FT 13	B1
		227096	FT 16	B2
		227097	FT 17	B1

Table 1 (continued)

Attribution (painters or workshops)	Identification number	Sample	Cluster
	227190	FT 24	A1
	227194	FT 25	B1
	227197	FT 27	B1
	227198	FT 28	B1
	227208	FT 38	B1
	227209	FT 39	A1
	227563	FT 41	B1
	A1513 A	FT 42	B1
	A1513 B	FT 43	B1
	A1513 C	FT 44	B1
	227009	FT 46	B2
	227142	FT 51	A1
	227143	FT 52	B1
Pottery workshop (Dell'Aglio 2002)	51703	FT 02	
	196086	clay 1	
	197190	clay 2	

The statistical treatment of data highlighted two markedly distinct groups, labeled A and B (see each find belonging in Table 1), without any overlap, and an outlier—sample FT38—(Fig. 2).

The compositional diversity of the samples belonging to groups A and B, and, above all, of the sample outlier FT38, agrees with the minero-petrographical diversity among samples highlighted by MO, SEM-EDS, and XRD investigations.

Results highlight that fragments of both clusters have in common a compact ceramic body, with a porosity ranging from 5 to 10 % volume ratio, with lower average values for samples of cluster A. In some cases, the presence of secondary calcite at the edges of the pores can be observed. The non-plastic inclusions consist mainly of quartz, alkaline feldspars and micas (biotite and muscovite) and in lower amount Fe-oxides and hydroxides, plagioclases, ilmenite and rutile and rarely calcium phosphate,

Fig. 1 Some finds analyzed. (From *left* to *right*, *up*: FT10, FT22, *down*: FT29B, FT31, and FT38)

Table 2 Ceramic body composition of samples coming from the archeological site of Arsenale

Sample	Element concentration							
	(wt %)				(μg g^{-1})			
	Fe	Al	Mg	Ca	Mn	Ni	Cr	Ce
FT01	4.70	9.63	1.53	6.30	768	74	132	76
FT19	4.96	9.56	1.51	7.81	880	67	142	73
FT26	4.99	11.08	1.57	6.99	879	59	135	73
FT29b	4.89	11.14	1.66	8.21	936	64	134	82
FT57	5.21	8.91	1.53	5.57	801	59	142	78
FT58	5.28	9.07	1.54	8.14	833	55	135	80
FT59	5.03	8.54	1.47	7.30	753	56	122	77
FT35	5.29	10.36	1.64	7.60	953	66	134	75
FT36	5.32	10.27	1.66	6.04	983	83	144	77
FT54A	5.06	10.07	1.45	6.33	884	59	147	84
FT54B	5.25	10.40	1.49	6.75	926	65	161	94
FT62	5.42	9.32	1.58	8.40	884	56	125	68
FT63	5.31	9.44	1.56	8.20	685	54	123	75
FT46	3.26	9.21	1.12	4.05	437	106	153	77
FT23	4.34	8.92	2.00	7.91	652	118	201	71
FT03	4.11	7.80	1.94	9.57	594	107	177	67
FT04	4.31	9.00	1.92	7.23	809	122	201	72
FT12	4.66	9.75	1.56	6.73	859	58	110	86
FT15	4.41	9.15	1.54	7.35	801	58	106	83
FT14	4.43	9.14	1.67	7.55	955	79	132	82
FT31	4.20	8.53	1.40	7.34	1099	72	115	74
FT64B	4.41	9.24	1.74	5.90	589	110	164	69
FT32	4.60	9.51	1.47	6.00	1073	65	115	79
FT33	4.68	9.54	1.74	5.26	1117	70	134	76
FT34	3.77	8.77	1.29	7.38	1097	57	105	68
FT18	4.37	8.96	1.75	9.82	707	111	189	71
FT22	4.57	8.82	2.19	9.91	634	121	220	77
FT25	4.53	8.54	2.18	8.70	575	138	234	68
FT28	4.29	8.27	2.03	7.30	553	111	189	69
FT24	4.82	10.38	1.59	7.93	826	58	128	85
FT64A	4.45	9.10	1.20	4.39	1067	63	103	85
FT48	4.71	10.56	1.34	8.87	1074	55	136	81
FT37	5.19	10.78	1.65	6.79	860	57	135	111
FT47	4.41	8.74	1.89	7.84	546	136	191	77
FT10	4.66	9.22	1.71	7.28	770	73	148	65
FT61	4.93	8.89	1.42	8.28	867	59	115	76
FT39	4.79	9.73	1.56	7.00	914	60	120	71
FT16	4.22	8.48	1.68	9.20	716	78	130	81
FT41	4.37	9.36	2.19	9.97	603	153	216	67
FT51	3.47	8.68	1.60	7.00	451	109	134	63
FT09	4.64	8.86	2.18	8.26	682	115	215	66
FT38	5.56	8.49	2.66	4.27	704	368	573	58
FT53A	3.92	8.23	1.57	8.80	474	116	144	64
FT53B	3.88	7.96	1.67	8.43	555	125	135	63
FT56	4.55	7.32	2.05	12.20	585	141	242	60
FT21	4.45	8.40	2.08	9.77	602	133	212	73
FT05	4.23	7.92	1.82	8.76	594	117	198	74
FT06	4.20	7.84	1.98	8.75	690	115	191	68
FT30a	4.34	7.52	1.88	9.41	592	136	212	73
FT30b	4.82	8.07	2.24	9.81	697	133	207	63
FT30c	4.42	8.17	2.10	10.30	621	129	198	63
FT27	3.50	7.02	2.12	10.85	542	111	182	61
FT07	3.73	7.30	1.67	9.24	510	95	173	56
FT08	4.16	7.96	1.96	10.16	640	111	181	58
FT11	4.45	8.05	2.10	9.45	624	111	157	71
FT13	4.00	7.81	1.52	9.00	473	96	161	70
FT17	3.45	7.03	1.36	12.18	528	88	176	73
FT42	4.13	8.64	2.20	10.13	661	133	206	70
FT43	3.54	8.03	2.11	14.71	666	120	182	62
FT44	5.27	8.80	2.19	10.73	884	126	239	70
FT 52	3.53	6.83	1.78	9.70	677	85	144	58
FT 20	4.69	8.53	1.63	7.71	652	168	246	78

zircons and pyroxenes. In some samples, all belonging to cluster B, small clasts (20–50 μm) of carbonatic rocks (limestone) are also present. The clay matrix is sufficiently rich in Ca, especially in the samples of cluster B. In addition, very small crystals (<5 μm) with micaceous composition (biotite and muscovite) can also be found, mostly in the samples of cluster A. Differences between clusters can be identified also in the paste texture (quantity and dimension of coarse inclusions) of the samples. In particular, the samples in cluster A, excluding FT64A, which present a scarce amount of fine sand, are characterized by a unimodal grain size distribution (from fine silt to medium silt—not exceeding 32 μm), whereas the cluster B samples feature a coarser texture, with inclusions of sizes ranging from medium silt (>32 μm) to fine sand (not exceeding 125 μm). The dimension of inclusions in cluster A samples suggest the use of a refined clay for the process of manufacturing. Also the sintering degree is, on average, higher for cluster A samples, and micas and pores were parallel orientated to the walls of the pottery wares.

The outlying position of FT38 sample, highlighted in Fig. 2, is confirmed by its minero-petrographical features, different from the objects of both clusters. In fact, its ceramic body, particularly rich in micas (mostly muscovite), highlights some Ca-phosphate crystals, very small crystals of rare earth phosphates (monazite-like) and pyroxenes besides quartz, micas, K-feldspar, plagioclases, rutile, ilmenite, Fe-oxides, and hydroxides. The grain sizes are similar to cluster A samples. According to archeological studies, it is presumed an

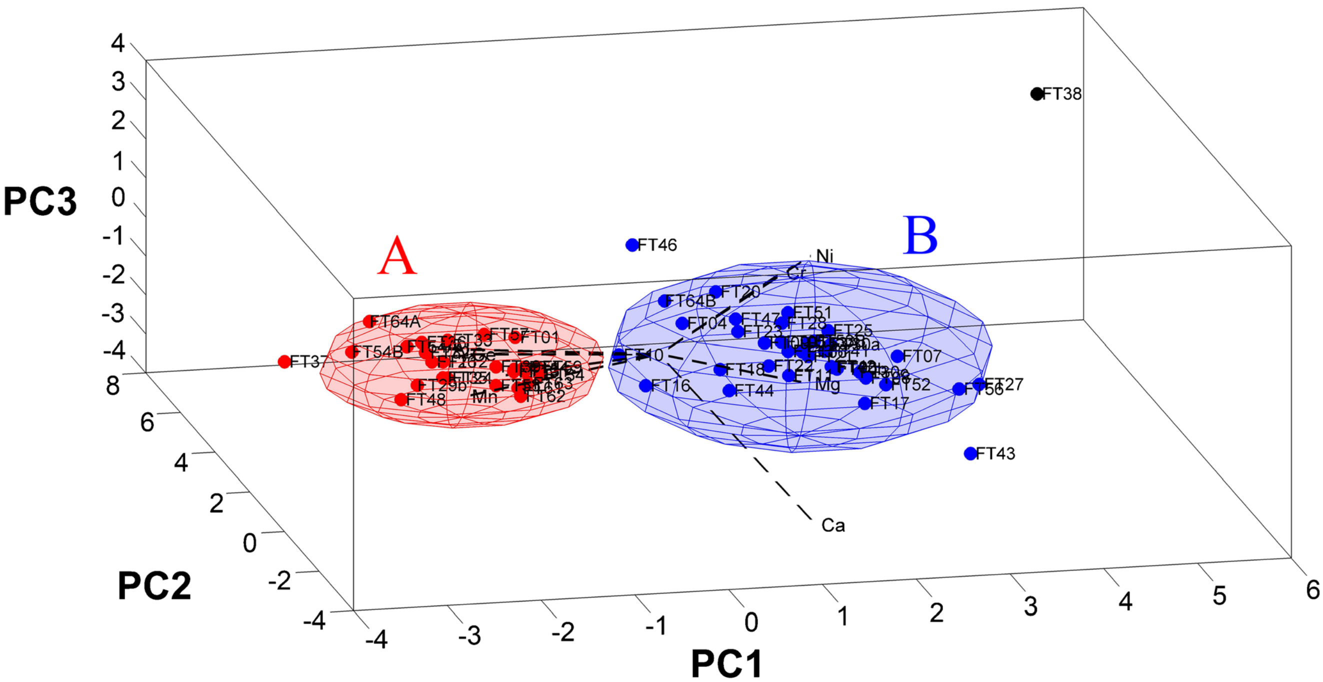


Fig. 2 Scores and loading plot onto the first $k = 3$ PCs, related to the finds from the Arsenale archeological site. Ninety-five percent confidence ellipsoids are also showed. The accounted variance is 84 % of the total variance

Attic origin due to the presence of an inscription written in Greek characters and of the frieze typology.

The newly formed pyroxenes and gehlenite, revealed by XRD analyses (Table 3), indicate that all vases were fired at about 950 °C (Heimann and Maggetti 1981). The lower sintering degree and the presence of calcite clusts—even bigger in size (50–100 μm)—in cluster B samples indicate that for these ceramic bodies such high temperatures were kept for a shorter time than the ceramic bodies of cluster A samples. As far as the FT38 sample is concerned, the low amount of pyroxenes and the scarce sintering, revealed by SEM analysis, show two different possibilities due to a firing procedure not perfectly carried out: an irregular temperature in the firing process or an insufficient firing time.

Table 3 Mineralogical composition, by PXRD analysis, of representative samples of clusters A and B

Sample	Cluster	Mic	Qtz	Fld	Cal	Px	Gh	Hem
FT01	A	/	XXXXX	XXX	/	XX	tr	Tr
FT31	A	/	XXXXX	XX	XX	XXX	X	X
FT08	B	/	XXXX	XX	X	XX	XX	Tr
FT17	B	/	XXXX	XX	XX	XXX	XX	X
FT27	B	/	XXXX	XX	XXX	XX	X	Tr
FT21	B	/	XXXXX	XXX	Tr	XX	/	Tr
FT30C	B	/	XXXXX	XXX	X	XX	XX	Tr
FT38	Outlier	XX	XXXXX	XX	/	X	/	Tr

Mic micas, *Qtz* quartz, *Fld* K-feldspar and plagioclase, *Cal* calcite, *Px* pyroxene (diopside), *Gh* gehlenite, *Hem* hematite, *Tr* Trace. Number of X is in relationship with mineralogical phase abundance (Kretz 1983)

For all samples, the black gloss shows the same structural and compositional features. These characteristics are the same highlighted for all Apulian pottery samples we have analyzed up to now. For cluster A samples, and partly for cluster B ones, the black gloss is coated on the ceramic body (Fig. 3). Differently, for some objects of cluster B, an engobe layer, which distinguish itself from the ceramic body by a more compact and finer paste—richer in matrix and poorer in silt—is observed on the body. Its thickness ranges from 80 to 200 μm (less compact and with a fine silt) to 1 mm (more compact and clayey) (Fig. 3).

The mineralogical assemblage is the same in the engobe and ceramic body, the only difference consists in the quantitative ratio among minerals: more quartz and feldspars in the body, more micas (biotites and muscovites) and clayey minerals in the engobe.

Moreover, the engobe clay fraction of samples characterized by a very Ca-rich body shows a higher Ca content. Combining all the results obtained, we can suggest the employment of the same raw material for both the engobe and ceramic body, refined in case of the engobe.

The difficulty of defining the actual origin of the objects in absence of reliable indicators of production (kiln dumps, wasters etc.), besides the remarkable chemical and mineralogical diversity of the sample FT38, jointly with the hypothesis

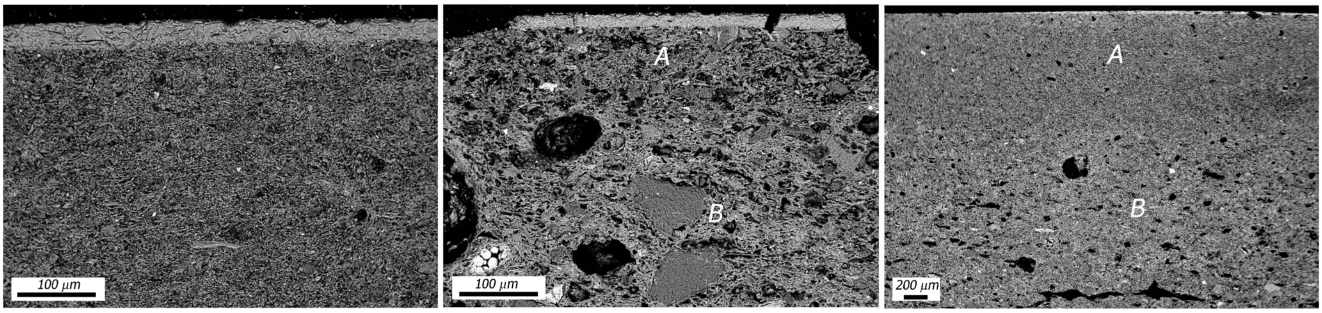


Fig. 3 SEM-BSE images of fragments FT01 (*left*), FT5 (*center*), and FT30B (*right*) show black gloss layer (*brighter*, *upper*) on the ceramic body (FT01), black gloss layer on red engobe (**a**) and ceramic body (**b**) in FT5 and FT30B ones

of an attic provenance, motivated us to look for compositional bulk data related to red-figured findings of certain Attic provenance in the literature.

Thus, an appropriate statistical analysis could allow to identify similarities and/or differences and postulate some hypotheses of import. The data matrix—Table 2—was then extended to compositional data of Attic (Jones 1986, http://helios.unive.it/-termo/DataBank/Attica/AiginaandMegaride/Athens.htm) and Apulian (Mangone et al. 2008, 2013) red-figured pottery coming from different sites.

Figure 4 highlights that two distinct clusters, one relating to the Attic findings and the other to the Apulian ones are the results of the PCA treatment. The space position of the sample FT38 inside the Attic cluster confirms the archeological assumption abovementioned.

As far as a stylistic analysis concerns, cluster A group samples encompass a wide chronological range (all samples credited to the Pisticci, Amykos, Darius, and Underworld painters gather in this cluster). On the contrary, cluster B groups vases that are stylistically datable to the first half of the fourth century BC. Indeed, this last cluster gathers each sample that has been credited to the Schwerin Group (Intermediate Group), and to Tarporley, Truro, and Hoppin Painters.

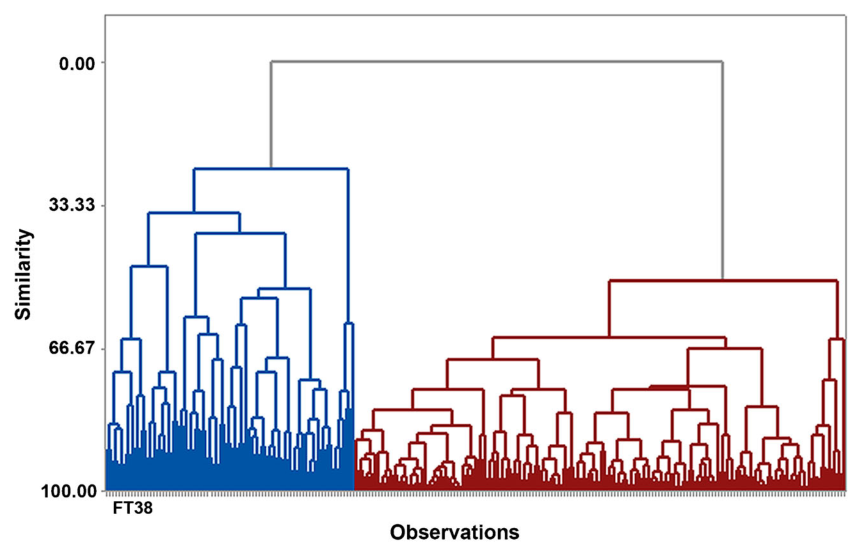
Both clusters were individually analyzed and the results are shown in Fig. 5.

Figure 5 highlights the further division of cluster A in two subgroups, namely A1 and A2: the group A2 including the findings attributed to the Darius Painter and his workshop and to the Underworld painter, the group A1 including the findings attributed to the Pisticci Painter, and to the Amikos Painter and his workshop.

Even cluster B shows a separation in two subgroups, namely B1 and B2. From a technological point of view, it is relevant to note that in the cluster B1 are grouped all samples with an engobe layer.

About cluster B1, the statistical analysis seems to suggest a further division into two subgroups. It could be attributable to a different amount in secondary calcite (Table 3) formed during the burial—it is a circumstance rather usual, which can lead to observe differences in secondary calcite even in objects recovered in the same tomb. Besides, in the two subgroups, there are no differences in production technologies or raw materials.

Fig. 4 Hierarchical clustering dendrogram by complete linkage method with Manhattan distance metric of autoscaled variables related to the Attic (in *blue*) (Jones 1986, http://helios.unive.it/-termo/DataBank/Attica/AiginaandMegaride/Athens.htm) and Apulian (in *red*) (Mangone et al. 2008; Mangone et al. 2013) red-figured pottery, including that from Taranto



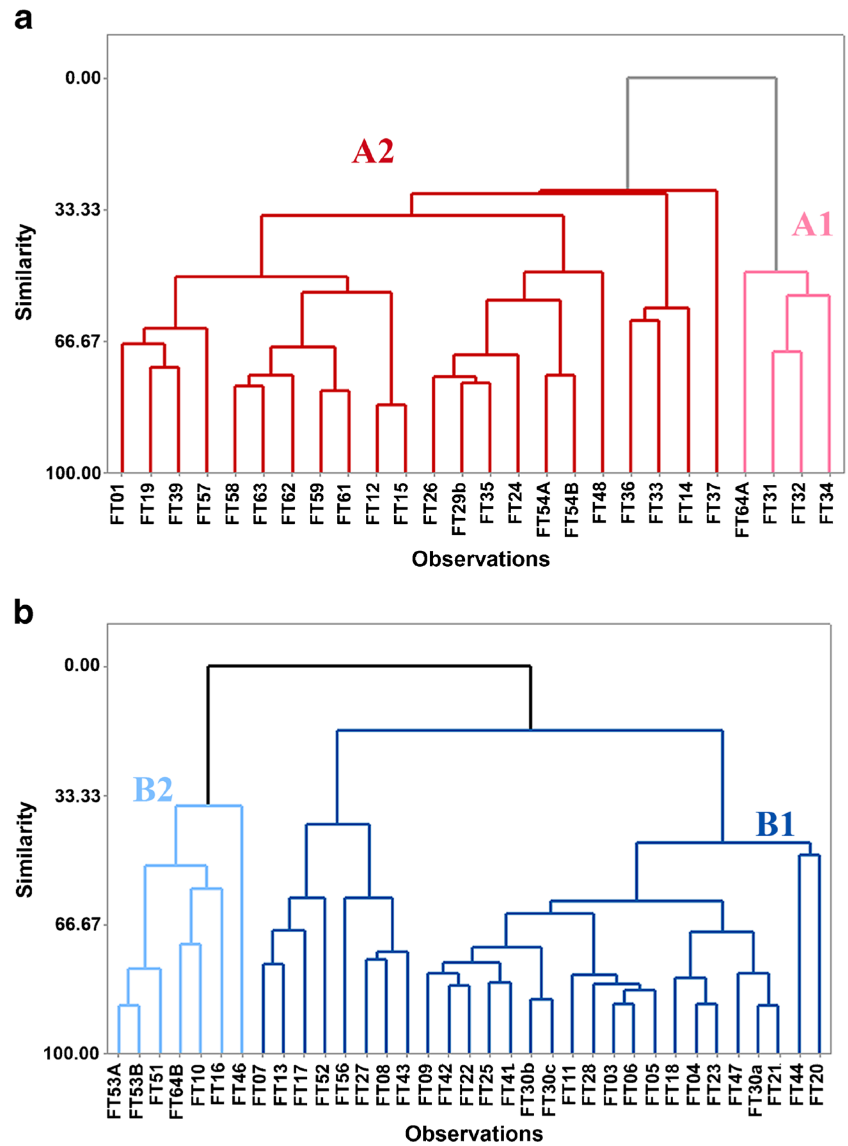


Fig. 5 Hierarchical clustering dendrograms related to the finds of cluster A (*left*, complete linkage; Euclidean distance) and cluster B (*right*, complete linkage, Manhattan distance)

The group B1 includes all the samples attributed, on a stylistic base, to the Tarporley, Truro, and Hoppin painters; the group B2, the sample credited to the Schwerin Group.

In the light of the limited number of objects under investigation in each group, which are for the most part fragments of small size (and the consequent difficulty of obtaining detailed archeological information needed to justify any separation), we concluded not carrying on further investigations.

With regard to the provenance of samples of cluster A and B, the opportunity of analyzing a probable firing tester FT02 (Castoldi 2006) and two vitrified clay samples—196086 and 197190—coming from a pottery workshop located in Taranto (Dell'Aglio 2002), allows us to obtain interesting information. The results of their chemical analyses are reported in Table 4.

The data matrix of findings from the Arsenale, excluding the outlier FT38, was therefore extended to compositional data of FT02 and clay samples. The compositional similarity between objects is highlighted by the dendrogram in Fig. 6.

The fact that the samples of certain tarantine production (FT02, 196086, and 197190) were located in cluster B1 allows us to hypothesize that all samples in this cluster had been

Table 4 Ceramic body composition of samples coming from a pottery workshop at 52, Leonida street (Taranto) (Dell'Aglio 2002)

Sample	Element concentration							
	(wt %)				(μg g^{-1})			
	Fe	Al	Mg	Ca	Mn	Ni	Cr	Ce
FT02	4.51	7.95	2.00	9.23	604	150	198	66
196086	3.21	8.93	1.45	11.00	499	85	152	53
197190	3.07	8.87	1.67	10.70	537	83	144	49

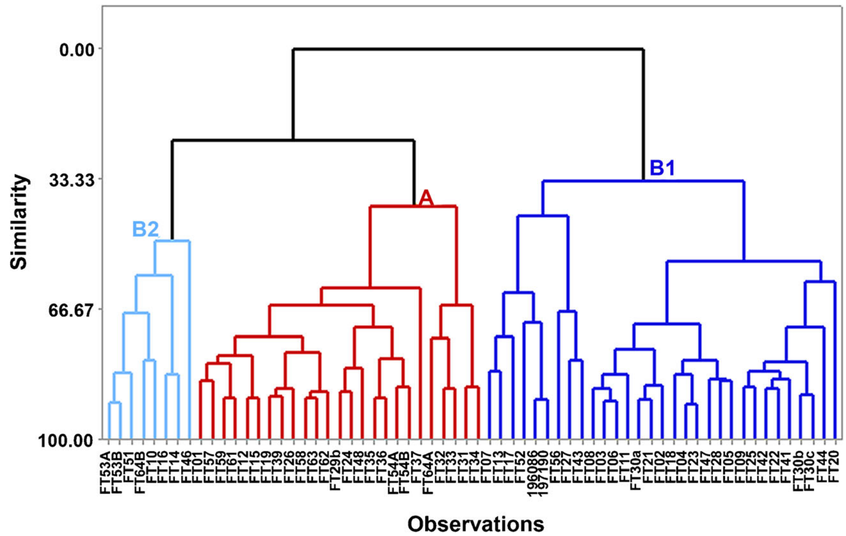


Fig. 6 Hierarchical clustering dendrograms—complete linkage, Manhattan distance—related to the finds from the Arsenale site, the probable firing tester FT02 (Castoldi 2006) and two vitrified clay samples—196086 and 197190—from pottery workshop in Taranto (Dell'Aglio 2002)

manufactured in Taranto. The similarity of mineralogical composition of FT02, 196086, and 197190 to the samples in cluster B1 supports this hypothesis. In particular, as the clay samples are concerned, the XRD spectra highlight that quartz and calcite are the prevalent phases followed by alkali feldspar and plagioclase. Diffraction peaks of illite/muscovite and biotites were also detected. The calcite is largely represented by fossils (Fig. 7) and fragments of limestone, whose dimensions are also extremely low (<10 μm). Moreover, calcium is highly present in areas with grain sizes both coarse and fine, as the ED analysis reveals, made upon sample parts with different grain sizes (coarse to very fine). A similar result fits in with the obtained data for every cluster B samples' matrix.

Conclusion

The results of this study lead us to the conclusion that the findings analyzed differ principally in raw materials (clusters A and B), as stressed out by the marked compositional diversity of objects.

As far as cluster A is concerned, all items had been made according to classical attic technology. Hence, the grouping of samples that, upon stylistic analysis, belongs to a wide chronological range, just as observed by other authors (Thorn and Glascock 2010), indicates the employ of the same, or very similar, raw material and manufacturing process for the whole span of the production. Every information achieved from this study shows that samples in cluster A underwent a more accurate manufacturing process than those of cluster B, starting from the choice of raw materials to its refining, production, and firing, made at a higher temperature and lasted long enough. A further statistical analysis on the samples of cluster A highlighted the existence of small diversities among the objects. Similar differences lead to a split of the samples in two different subsets. This distinction could be linked to two aspects. A chronological difference (the activity of Amykos, Pisticci, Darius and Underworld painters are dated between 430 and 410 BC, 440–430 BC, 340–320, and 330–310, respectively) or provenance, since Pisticci painter is considered the father of the "Lucanian" workshops and the Amikos painter, defined by Trendall as "a pupil of the Pisticci Painter"

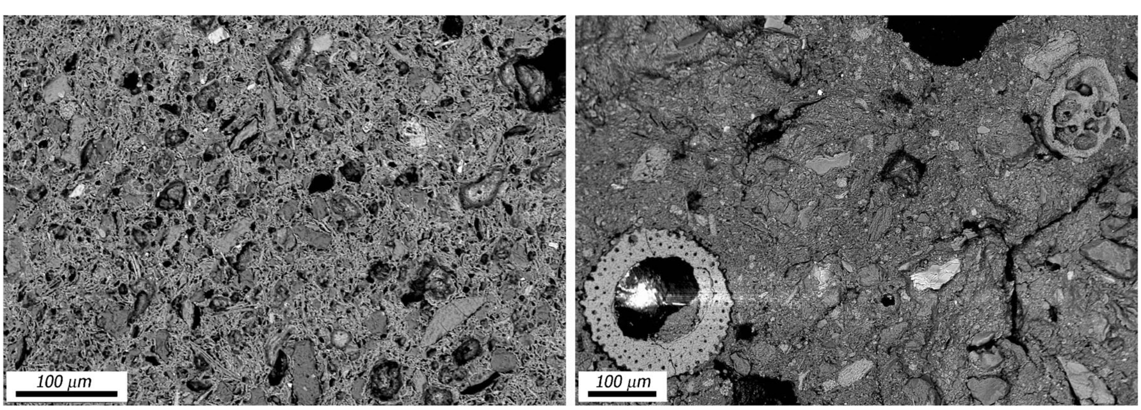


Fig. 7 SEM-BSE images of fragment FT02 (*left*) and clay sample 196086 (*right*)

(Trendall 1967), is considered "the most important of the early Lucanian artists" (Trendall 1989).

Cluster B is also divided in two subgroups B1 and B2. Cluster B1 groups samples made with two different technologies: with or without engobe layer. Furthermore, the chemical and minero-petrographical similarity to cluster B1 samples of a fragment of certain tarantine manufacturing and two clay samples, recovered in a pottery workshop in Taranto (Dell'Aglio 2002), led us to suppose that all cluster B1 objects were made in Taranto. This hypothesis is confirmed by the presence in this cluster of all the fragments attributed to the Truro Painter—thought to be one of the most famous painters from Taranto—and the Hoppin Painter—that scholars (Trendall 1989; Trendall and Cambitoglou 1978, 1982) believe had worked in closed association with the Truro Painter.

The presence of an engobe also on the vases manufactured in Taranto strengthen our suggestion that its use in late Apulian pottery production was not an isolated case, but a common technological expedient in the manufacturing of Apulian red-figured pottery, and then a peculiar technological feature of Apulian potters. The reasons that caused this change in production technology are not clear yet. A first hypothesis may be related to an economic motivation, namely cheaper productions, probably commissioned by clients with a lower rank, since it enabled to reduce the amount of raw materials used compared to classical manufacturing. A second hypothesis may be related to the need of a more congruous raw material, to create larger vases. Since the fragments analyzed did not show a considerable thickness and a very accurate manufacturing process, data driven from Taranto seem to support the first hypothesis.

Acknowledgments The authors thank Dr. Luigi La Rocca (Superintendent for Archaeological Heritage of Apulia), for having authorized this research (register numbers 6074 dated May 17 2012 and 8520 dated July 11 2012) and are grateful to Dr. Antonietta Dell'Aglio and Dr. Amelia d'Amicis (National Archaeological Museum of Taranto—M.Ar.Ta) for providing archeological samples and for their scientific support and fruitful discussion. The authors would like to thank Sr. Amelia d'Amicis also for the stylistic attribution of the samples analyzed and Dr. Italo Muntoni (Superintendence for Archaeological Heritage of Apulia) for the continuous and constant contribution to the research, in particular during the discussion of results in view of archeological implications and manuscript processing.

This study was financed by the "Laboratorio per lo Sviluppo Integrato delle Scienze e delle Tecnologie dei Materiali Avanzati e per dispositivi innovativi (SISTEMA)" of the University of Bari.

References

Aruga R, Mirti P, Casoli A (1993) Application of multivariate chemometric techniques to the study of Roman pottery (terra sigillata). Anal Chim Acta 276:197–204

Beazley JD (1963) Attic red-figure vase-painters, 2nd edn. Oxford University Press, Oxford

Bruno P, Caselli M, Curri ML, Favia P, Laganara C, Lamendola R, Mangone A, Traini A (1994) XPS, ICP and DPASV analysis of medieval pottery. Statistical multivariate treatment of data. Fresenius J Anal Chem 350:168–177

Castoldi M (2006) I vasi a figure rosse del periodo protoapulo e apulo antico: Taranto e le officine ceramiche. In: G Sena Chiesa, Slavazzi F (eds) Ceramiche attiche e magnogreche, collezione Banca Intesa, Electa, Milano, 178–181

Dell'Aglio A (2002) La forma della città: aree e strutture di produzione artigianale. In: Taranto e il Mediterraneo, Proceedings of the 41st convegno di studi sulla Magna Grecia, 12–16 october 2001. Taranto, Istituto per la storia e l'archeologia della Magna Grecia, Taranto, 171–193

Fontannaz D (2005) La céramique proto-apulienne de Tarente : problèmes et perspectives d'une recontextualisation, in La céramique apulienne Bilan et perspectives, Actes de la table ronde organisée par l'Ecole française de Rome en collaboration avec la Soprintendenza per i Beni archeologici della Puglia et le Centre Jean Bérard de Naples, 30 novembre-2 décembre 2000. In: M Denoyelle, E Lippolis, M Mazzei, C Pouzadoux, (eds) Collection du Centre Jean Bérard, 21, Napoli, 2005, 125–142

Giannossa LC, Acquaviva M, De Benedetto GE, Acquafredda P, Laviano R, Mangone A (2014) Methodology of a combined approach: analytical techniques to identify technology and raw materials of thin walled pottery from Herculaneum and Pompeii. Anal Method 6(10): 3490–3499

Graves P, Robinson E, Barbetti M, Yu Z, Bailey G, Bird R (1997) Analysis of south Italian pottery by PIXE-PIGME. Meditarch 9(10):113–125

Heimann RB, Maggetti M (1981) Experimental of calcareous terra sigillata (mineralogical change). Preliminary results. Brit Muse Occasion Pap 19:163–177

Ingo GM, Bultrini G, de Caro T, Del Vais C (2000) Microchemical study of the black gloss on red and black-figured Attic vases. Surf Interface Anal 30:101–105

Jones RE (1986) Greek and Cypriot pottery: a review of scientific studies. British school of Athens, Athens

Kingery WD (1991) Attic pottery gloss technology. Archeomaterial 5: 47–54

Kretz R (1983) Symbols for rock-forming minerals. Am Mineral 68: 277–279

Mangone A, Giannossa LC, Ciancio A, Laviano R, Traini A (2008) Technological features of Apulian red figured pottery. J Archaeol Sci 35:1533–1541

Mangone A, Giannossa LC, Laviano R, Fioriello CS, Traini A (2009a) Late Roman lamps from Egnatia: from imports to local production. Investigations by various analytical techniques to the correct classification of archaeological finds and delineation of technological features. Microchem J 91:214–221

Mangone A, Giannossa LC, Colafemmina G, Laviano R, Traini A (2009b) (a) Use of various spectroscopy techniques to investigate raw materials and define processes in the overpainting of Apulian red figured pottery (4th century BC) from southern Italy. Microchem J 92:97–102

Mangone A, Giannossa LC, Laganara C, Laviano R, Traini A (2009c) (b) Manufacturing expedients in medieval ceramics in Apulia. J Cult Herit 10:134–143

Mangone A, De Benedetto GE, Fico D, Giannossa LC, Laviano R, Sabbatini L, van der Werf I, Traini A (2011) Multianalytical study of archaeological faience from Vesuvian area as a valid tool to investigate provenance and technological features. New J Chem 35: 2860–2868

Mangone A, Caggiani MC, Giannossa LC, Eramo G, Redavid V, Laviano R (2013) Diversified production of red figured pottery in Apulia (Southern Italy) in the late period. J Cult Herit 14:82–88

Mirti P, Gulmini M, Perardi A, Davit P, Elia D (2004a) Technology of production of red figure pottery from Attic and southern Italian workshop. Anal Bioanal Chem 380:712–718

Mirti P, Gulmini M, Pace M, Elia D (2004b) The provenance of red figure vases from Locri Epizephiri (southern Italy): new evidence by chemical analyses. Achaeometr 46:183–200

Noble JV (1960) The technique of Attic vase-painting. Am J Archaeol 64:307–313

Robinson E (2013) New Pixe-Pigme analyses for South Italian pottery. Mediterranean Archaeol 26:15–41

Robinson E (2014a) (a) Archaeometric analysis of Apulian and Lucanian red-figure pottery. In: Carpenter TH, Lynch KM, Robinson EGD (eds) The Italic people of ancient Apulia: new evidence from pottery for workshops, markets and customs. Cambridge University Press, New York, pp 243–264

Robinson E (2014b) (b) The early phases of Apulian red figure. In: Schierup S, Sabetai V (eds) The regional production of red-figure pottery: Greece, Magna Graecia and Etruria. Aarhus University Press, Aarhus, pp 217–233

Tang CC, MacLean EJ, Roberts MA, Clarke DT, Pantos E, Prag AJNW (2001) The study of Attic black gloss sherds using synchrotron X-ray diffraction. J Archaeol Sci 28:1015–1024

Thorn J (2009) The invention of 'Tarentine' red-figure. Antiquity 83: 174–183

Thorn J, Glascock M (2010) New evidence for Apulian red-figure production centres. Archaeometr 52:777–795

Tite MS, Bimson M, Freestone IC (1982) An examination of the high gloss surfaces finishes on Greek Attic and Roman Samian wares. Archaeometr 24:117–126

Trendall AD (1967) The red-figured vases of Lucania; Campania and Sicily. Oxford University Press, Oxford

Trendall AD (1989) Handbook of red figure vases of south Italy and Sicily. Thames-Hudson, London

Trendall AD, Cambitoglou A (1978) The red-figured vases of Apulia; early and middle Apulian I. Clarendon, Oxford

Trendall AD, Cambitoglou A (1982) The red-figured vases of Apulia; Late Apulian II. Clarendon, Oxford