Una Arqueometria del Canvi Tecnològic: Producció i consum d'àmfores durant el canvi d'Era en la zona nord de la costa catalana

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Technological Change Archaeometry:

Production and consumption of Roman amphorae around the change of the Era in the north Catalan coast

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-English summary-

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To Alícia and Noemi

The scientific method consists of the use of procedures designed to show not that our predictions and hypotheses are right, *but that they might be wrong*. It forces us to confront our self-justifications and put them on public display for others to puncture. As its core, therefore, science is a form of arrogance control.

Tavris and Aronson, *Mistakes were made (but not by me)*, pp. 108, 2007

Summary

This dissertation has been implemented within the PRODIFAN Research project funded by DGIMCYT (Spain) and ERDF (European Union) (contract number BHA2003-04589). The main goal of the project was the archaeometrical characterization of the first Roman amphorae designs produced between the 1st century BC and the 1st century AD along the coast of the Citerior Roman province –renamed *Tarraconensis* after Augustus' political reorganization, and which area roughly corresponds to the nowadays coast of Catalonia (Spain).

During the change of the Era, most of the coastal territory in the north-east of the Iberian Peninsula was devoted to the mass production of wine and, likewise, to the production of amphorae to serve as wine containers in overseas trade. As a substitution of the previous Iberian amphorae, whose design had been derived from Phoenician models, the first type to be produced was an imitation of the typical Roman amphorae design, Dressel 1. Its production began in the middle of the 1st century BC, but shortly aftermath was replaced by two new designs peculiar to the Catalan area: Laietana 1 (also called Tarraconense 1) and Pascual 1. Yet, the archaeological evidence shows a wider distribution for the latter type as well as a longer life span, until the first third of the 1st century AD (Figure 1) (Buxeda i Garrigós *et al.* 2008; Martínez Ferreras 2008; Revilla Calvo 1995, 2002; Vila Socias 2005; Vila Socias *et al.* 2005, 2006; Vila Socias *et al.* 2009).

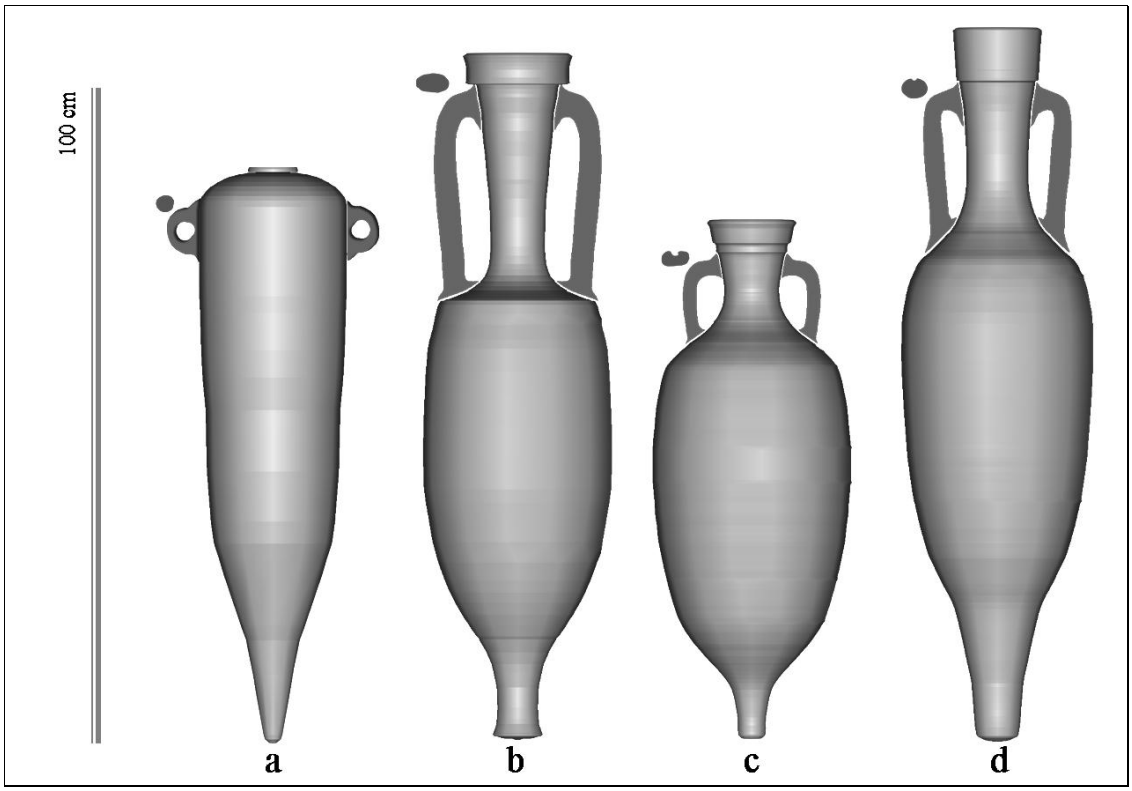

Figure 1. Representative 3D models of Iberian amphorae (a) and the first Roman designs: Dressel 1 (b), Laietana 1/Tarraconense 1 (c), and Pascual 1 (d).

Both archaeological and historical sources available have traditionally been used to fashion explanatory narratives about the economic phenomenon represented by this Roman trade of wine, but few words have been written about the technological change stemmed from the so-called *Romanization* process — at least concerning these amphorae productions. In trying to bridge this gap, **this dissertation suggests a theoretical and methodological framework to study technological change processes which is finally illustrated with the Roman amphorae case**.

The theoretical model is built upon a critical review of the literature concerning technological change and suggest to consider cognitive processes that take part in decission making processes. Specifically, **we suggest a reformulation of several propositions from the cognitive dissonance theory** (Festinger 1957). This theory states that there is a tendency for individuals to seek consistency among their cognitions. When there is an inconsistency between attitudes or behaviors, something

must change to eliminate the dissonance; in the case of a discrepancy between attitudes and behavior, it is most likely that the attitude will change to accommodate the behavior.

On the other hand, **methodological procedure is based on archaeometrical characterization of ceramic materials**. In this study, a set of 345 amphorae have been sampled for archaeometrical characterization. Shards were recovered at 6 main production centres located along the north Catalan coast (Can Notxa (Argentona, El Maresme), El Mujal (Calella, El Maresme), C/ de Guillem de Palafolls (Malgrat de Mar, El Maresme), Fenals (Lloret de Mar, La Selva), Collet de Sant Antoni (Calonge, Baix Empordà), and Llafranc (Palafrugell, Baix Empordà)), and 3 consumption centres located in that area (*Emporiae* (Empúries, Alt Empordà), *Iluro* (Mataró, Maresme), and *Palma* (Palma, Balearic Islands)). Criteria for the sampling of the individuals included representativeness of the range of macroscopic fabrics and the different amphora types recovered at the sites. Specifically, the Roman amphorae designs analyzed are Dressel 1, Laietana 1/Tarraconense 1, Pascual 1, and Dressel 2-4. Additionally, Greco-itàlica, Laboglia, Dressel 7-11, and Oberaden 74 types have also been included in this study, although in a residual manner.

Chemical composition of the individuals has been determined by X-Ray Fluorescence (XRF) and mineralogical characterization has been achieved by X-Ray Diffraction (XRD). In some cases Scanning Electron Microscopy (SEM) has been used to characterize the microstructure and the stage of sintering of the ceramic matrix. Additionally, a series of mechanical properties tests have been devised in order to study the rupture strength and Hertzian strength of the materials. Furthermore, material properties have been evaluated taking into account the different shapes of these amphorae, by Finite Element Methods (FEM). This methodology enables to evaluate the mechanical performance of the whole vessels under different kind of loads and simulating transport conditions.

Analytical programme has been carried out at the Scientific-technical Services of the University of Barcelona (Catalonia, Spain), and at the Laboratory of Archaeometry of NCSR "*Demokritos"* (Athens, Greece).

The structure of the dissertation is as follows: First, a state of the art of

technological change models concerning archaeological ceramics is presented (Chapter 1). The theoretical and methodological framework used in this work is exposed (Chapter 2), followed by the case study (Chapter 3). Then, the state of the arts about the Roman amphorae designs considered in this work is presented (Chapter 4), as well as an introduction to the archaeological evidences of the production and consumption centres from which the ceramic samples have been recovered (Chapter 5). Afterwards, the analytical techniques and routines implemented are exposed (Chapter 6), followed by the results and discussion (Chapters 7-9), as well as the provenance study of the materials (Chapter 10). Finally the conclusions of the reserach are presented (Chapter 11). The set of tables (Annex 1), figures (Annex 2), and maps legend (Annex 3) are attached in CD-ROM format.

The theoretical model (TCA)

This PhD presents a theoretical model that is used as interpretative framework of the analytical data obtained from the archaeometrical characterization of amphorae shards. The model, called Technological Change Archaeometry (TCA), focusses on behavioral features studied by social psychology within cognitive consistency theory (Cooper 2007). Specifically, several propositions stemmed from cognitive dissonance theory (Aronson 1999; Festinger 1957) are reformulated in terms of technological change and decission making processes. As far as we know, this is the first attempt to bring to the attention of scholars that behavioral psychology concepts could be used to understand some changes that do not follow a linear-simplistic trend in archaeological issues.

The model is based upon five propositions.

1. **Any technology is finally shaped by compromises among different features,** that can be ideological, economic, social, political, or technical in nature. Moreover, it is important to bear in mind that the set of compromises have not necessary to be logical from the researcher point of view. The final resolution of compromises stems from the individual choices.

2. **Choices are taken based on preferences.**
3. **Individuals have preferentes over the state of the world, but also over their own beliefs about the state of the world.** The behaviour of the individuals more often than not go beyond the effects of behavioral model based on reward and punishment. Behaviorists use to argued that anything thas is associated with reward would become more attractive, and anything associated with pain or something pejorative would become noxious and undesirable. Nevertheless it has been demonstrated that individuals' behavior transcends the effects of the latter model and often contradicts them (Akerlof i Dickens 1982; Aronson 1992, 1999; Bawa i Kansal 2008; Cooper 2007; Keith Chen 2007; Lévy-Garboua i Blondel 2002; Oxoby 2004; Schlicht 1983; Steele 1988; Stone i Cooper 2000; Westen *et al.* 2006). Therefore, it should be understood that the set of performance characteristics an artifact show are, in great measure, potentially conferred by the same actors that take part in production, distribution and consumption processes.
4. **Individuals do have some control over their system of beliefs.** They not only are able to exercise some choice about beliefs given available information, but they can also manipulate their own beliefs by selecting sources of information likely to confirm previous and already existing beliefs.
5. **Once assumed, beliefs over the state of the world can persist over the time and be long-lasting.** This latter propostition is a function of the normal expectation existing around the technology, so the more the efforts involved in the specific activity, the higher level of dissonance experienced by individuals, and the more they will seek means to exaggerate the desirability of the outcome of the activity.

Assuming these propositions about technological change, the archaeometrical approach is considered necessary since it is the only mean to shape the whole set of compromises that finally shape an specific technology. Only with this apporach would be possible to evaluate how those compromises vary in time and space, and what is the specific weight of the behavioral mechanisms exposed along the whole process.

RESULTS AND DISCUSSION

Following the statistical approach proposed by Atchison (1986), Buxeda (1999), and Buxeda & Kilikoglou (2003), total variation is used as an estimation of the existing chemical variability of the whole data set of the production centres. As expected, the resultant value (*vt*=2.10) might be considered high as a reflection of the heterogeneous nature of the assemblage, representing different workshops and production centres. As shown in Figure 2, the chemical elements that introduce most of the existing variability are mainly calcium, phosphorous, copper, lead, sodium, and magnesium. This is due, in a lesser extent, to several contamination and alteration processes usually observed in this kind of productions, but it is mainly the result of different technical choices during pottery-making. Whereas some workshops seemingly change from using low calcareous to calcareous pastes during its activity period and roughly in parallel to the change of shape designs, others made up all the amphora types from low calcareous pastes.

Furthermore, if attention is focussed on individual workshops, total variation still provides high values despite all individuals were recovered either inside the same kiln or in its immediate surrounds and, therefore, a monogenic assemblage should be assumed. The general trend seems to be represented by chemical groups delimitated by end-members with an array of intermediate compositions through a continuum. The reason for these relative high chemical spread even within the same workshop can be traced up to the situational factors in which the production of these vessels were embodied. In this regard, the normal expectation (Kingery 2001; Kingery i Aronson 1990) of these containers must be kept in mind. These Roman amphorae were primarily designed for shipping goods (wine) in one-time use. Hence, the main value of the trade would not be the vessel itself but its content. It would be the final selling of the wine

what would produce the benefit for all actors involved in this long chain, of wine and amphorae production and distribution. Moreover, it must be noticed that that shipping, of this great volume of trade, would be restricted to few months along the Mediterranean Sea, as mentioned by classical sources. Thus, taking into account the constraints imposed by the wine production-schedule (Paterson 1982), this would also contribute to this hurried fashion production. As a consequence of the previous considerations, the chemical trend observed in these productions might be the result, at some extent, of a paste preparation not following rigorously standardized processes.

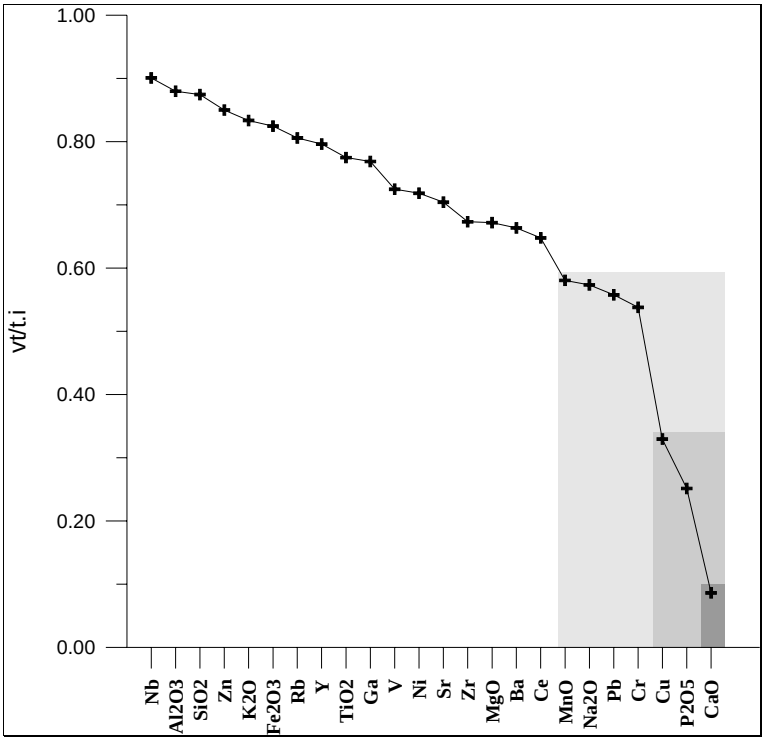

Figura 1. Elements and vt/τ_i values.

In spite of this, one of the basic performance requirements in amphora technology is avoidance of failure. Otherwise, catastrophic cracking would cause the content to spill out, resulting in a partial lost of the investment, or affecting boat's buoyancy at worst. For that reason, some mechanical properties of the ceramic material have been studied.

First of all, equivalent firing temperatures (EFT) of the individuals were estimated. In that sense, the mineralogical characterization reveals a tendency to achieve high temperatures (950-1000ºC), which is especially clear in Pascual 1 productions. In the case of calcareous productions, a fair amount of vitreous phase is produced at this range of temperature and remains stable between 850-1050ºC. Thus, if a higher strength associated with and extensive vitrification is to be produced, the control over the firing process would be less critical than in low-calcareous productions, something that might be desirable in pottery-making in a hurried fashion.

Furthermore, mechanical properties of fracture strength and toughness have also been estimated. The results show a typical unstable crack propagation mode (Kilikoglou i Vekinis 2002; Kilikoglou *et al.* 1995; Kilikoglou *et al.* 1998) in most of the individuals tested. The general trend is high fracture strength values but lower energy dissipation from crack initiation until final failure. This behaviour is the result of a combination of factors, but it has to be stressed that, in any case, the high EFT of the individuals analyzed is certainly playing an important role.

In studying technological change, it is crucial to discern among the properties of the material the artefact was made of, and the performance characteristics that should be evaluated in the context of an specific activity (Schiffer 2001). For this reason, a quantitative model of each amphorae type has been created using the FEM approach (Vila Socias *et al.* 2008). By using FEM, different mechanical loads can be applied to the each model in a computer simulation and predict which conditions would cause vessel failure. Following this approach, the loading conditions of common activities have been simulated. In the case of filled amphora lifted by the two handles, the results show a maximum strain at the joint of the handles and the body of the vessel, representing just 3% of the total fracture strain of the material for the Dressel 1 type, and 6% for the Laietana 1 and Pascual 1 types. As expected, these results are not critical in any case and, therefore, all designs considered could have been lifted by the handles without failing. Conversely, the loading conditions for the amphora at the bottom, when stacked for shipping or storage, appear to be critical for Dressel 1 type (maximum strain corresponding about 86% of fracture strain), but neither do for Laietana 1, nor for Pascual 1 (maximum strain representing 49% and 48% of the fracture strain,

respectively). These results certainly reveal great differences in the mechanical performance of the three shape designs. Further investigation will provide more criteria for assessing the role played by these different performances in driving forward shape design changes.

Finally, and as far as provenance is concerned, it has to be stressed that discrimination at the inter-regional level is possible by chemical analysis despite the fact that many workshops were located in a very similar geological environment and that the reference groups of the production centres are not tightly homogeneous, as has already been pointed up. However, the chemical trend discussed above points to the definition of reference groups of the production sites as an essential starting point in provenance studies concerning these vessels. In this sense, the cluster analysis of the chemical data reveal different distribution patterns concerning the Roman cities of *Emporiae*, *Iluro*, and *Palma*. The amphorae recovered at the city of *Iluro* seems to be mainly produced in workshops located in its surrounds, while the city of *Emporiae* seems to be supplied by many of the production centres that operated along the coast. In any case, again it is hoped that further investigation will shed light on these seeming distribution patterns, specially in the case of *Palma* where an increase of the sample size is needed.

Conclusions

In the following pages six propositions are stated as conclusions of the dissertation. All of them are indeed interrelated and draw a general conclusion of the technological change phenomena concerning Roman amphorae.

1. The amphorae productions studied represent a production model characterized by a non-standardized treatment of raw materials and recipes along the activity period of the kilns. The results obtained from the statistical analysis on the chemical subcomposition of the ceramic pastes suggest that the first Roman amphora types recovered in the north-east of the Iberian Peninsula did not follow a highly standardized paste preparation process. The general trend seems to be represented by chemical groups delimitated by end-members with an array of intermediate compositions through a continuum. Nevertheless, it has been demonstrated that it is possible to discriminate representative productions from different kilns, although they are located close to each other in a very similar geochemical context. This is the case, for instance, of the productions of C/ de Guillem de Palafolls site (Malgrat de Mar) and El Mujal site (Calella), which are located less than 7 Km away.

In this regard, it has also been observed in several cases higher variability in chemical composition whithin the same kiln production than beetwen different production centres. This permits to explain the relatively great number of individuals that do not fit in any cluster, and also points the necessity of increasing sample size in order to achieve a better understanding of the real production diversity representing each site. This observations ought to be considered valid in the reception centres as well.

Random sampling experiment from Monte Carlo and Jacknife procedures has been shown to be of special utility in chemical variability assessment. More

specifically, it has been shown very useful (i) in assessing the specific weight of each element in the whole chemical variation of the individuals, (ii) in comparing chemical variability between amphorae sets recovered from production and consumption centres, and (iii) in comparing chemical variability with other types of ceramic (in this case, *terra sigillata*).

A very relevant utility of the methodology implemented is the identification of individuals forming every generated subset. Taking into consideration that several causes that introduce variability in the whole chemical data set have been identified —not only those related with the low-standardized paste preparation process, and with the great diversity of productions that increase the number of the characterized sites, as well as different alteration and contamination processes—, specific identification of individuals which most contribute to the chemical variability of the generated subset facilitates the research of the causes that can explain that variation. The combination of these random resampling procedures provides a useful tool in order to easily recognise those concurrent individuals that most contribute to the subset variability and, therfore, to check out whether the atypical observations can be explained by some kind of alteration and/or contamination processes or by relevant diferences in the whole chemical composition profile, which might be related with different technical choices and/or different provenances. Likewise, this methodology enables to identify specific individuals the retrieval of which results in an increase in the subset chemical variability, to wit, those individuals that show greater chemical similarities with the others.

Another important feature that has also been pointed out is the special sensibility of sample size when considering total variation as a quantitative measure of the total chemical variability of this kind of pottery. It has been observed that considering up to 30, and most specially up to 50 individuals, improves the apparent representativeness of the general chemical variability of production centres. This result stresses that the-more-the-better as far as the sample size of this kind of ceramic technology is concerned, specially in trying to stablish reference groups for every production centre. Furthermore, it has also been shown that the evaluation of box and whispers plots shape provides information that can be correlated with the proportion of chemical clusters in the whole

data set.

On the other hand, the random resampling method implemented has been useful to compare the chemical variability characteristic of both amphoare and *terra sigillata* productions. The results show that, even when several alateration and contamination processes are present in a great number of TSI and TSH individuals, the chemical variability exhibited by *terra sigillata* sets is clearly lower than the characteristic variability of Roman amphorae. This results are due to the great chemical homogeneity observed in TSI and TSH productions as a result, at least partially, of technical processes where the recipies are kept constant along the activity period of the production centres unlike the amphorae case. The interpretation of these differences focusses on the situational factors in which production, distribution and consumption is embedded. Certainly, *terra sigillata* represents a kind of pottery technology that is worthy by itself, to wit, it has an inherent market value, unlike the amphora technology which market value is only a very small proportion of its content value. Furthermore, it has also to be stressed that the normal expectation of both technologies is quiet different, although both belong to the symbolic framework of the Roman empire. Whereas *terra sigillata* was considered to be long-lasting tableware, Roman amphorae were primarily designed for shipping goods (wine) in a single use fashion. Hence, the main value of the trade would not be the vessel itself but its content. It would be the final selling of the wine what would produce the benefit for all actors involved in this long chain of wine and amphorae production and distribution. Moreover, it must be noticed that shipping, of this great volume of trade, would be restricted to few months along the Mediterranean Sea, as mentioned by classical sources. Thus, taking into account the constraints imposed by the wine production-schedule, this would also contribute to this hurried fashion production. As a consequence of the previous considerations, the chemical trend observed in the amphorae productions might be the result, at some extent, of a paste preparation not following rigorously standardized processes.

In spite of this, one of the basic performance requirements in amphora technology is avoidance of failure. Otherwise, catastrophic cracking would cause the content to spill out, resulting in a partial lost of the investment, or affecting boat's

buoyancy at worst. For these reasons a trade-off considering, on one hand, the reduction of the investment neended to produce an amphora and, on the other hand, the need to achieve basic performance requirements to avoid failure is interpreted

Furthermore, different technical models are observed that might be linked with pre-Romans traditions.

2. Most part of the chemical variability observed in production centres can be explained by the existence of two models that used different kind of raw materials in pottery making. There is a model characterized by the exclusively use of low-calcareous pastes (model A) and another that used both low-calcareous and calcareous pastes (model B). Model A is represented by Can Notxa site, El Mujal site, C/ de Guillem de Palafolls site, and Fenals site, whereas model B is represented by the productions recovered at Collet de Sant Antoni de Calonge site and Llafranc site. It should be noted that all these workshops are located in a very similar geochemical context. Moreover, the geochemical context arround the production centres can not explain by itself the differences in CaO content in the pastes used in amphorae production. However, there is an important feature, still related with the specific emplacement of the workshops, that might explain those technological differences; whereas the production centres of Can Notxa, El Mujal, C/ de Guillem de Palafolls, and Fenals are located in the area that previously to the Roman ocupation was ruled by Laietanii (pre-Roman Iberians who inhabited this region), the workshops of Collet de Sant Antoni de Calonge and Llafranc are located within the territory previously ruled by the Indiketes Iberian tribe. Therefore, taking into consideration that, as far as we know, there is no other sign that could be traced up, we do interpret that the differences concerning technical choices in pottery making might be linked either with a deliberate attempt to achieve different performances characterisitcs or with different pre-Roman technological traditions. The latter option would be consonant with the results recently obtained by Tsantini (2007) in her PhD about Iberian amphoare.

Moreover, the amphorae production models established show quite interesting differences. Model A workshops', representing exclusively low-calcareous productions, did use different pastes to make up every amphorae design. Specifically, in the case of

El Mujal six different pastes have been identified; three of them were exclusively used in Laietana 1/Tarraconense 1 production, and the rest in Pascual 1 production. Likewise, the production centre of C/ de Guillem de Palafolls used at least three different pastes; two in Pascual 1 production, and the third exclusively in Dressel 2-4 production. A similar pattern is observed in Fenals; one out of five pastes identified was exclusively used in Dressel 2-4 productions, while the rest were used in Pascual 1 productions. Unfortunately, the small sample size analyzed from Can Notxa do not permit to draw that firm conclusions. Nevertheless, it has been shown that both Laietana 1/Tarraconense 1 and Pascual 1 designs were produced in this workshop.

The issues discussed above together can be applied to interpred that, assuming a synchronized production based on stratigraphic data, the differences exposed did point to the existence of several actors involved in the production of each amphorae design which would be indicative of different contents.

On the other hand, representative productions of Model B did not follow the same pattern since the change of designs is not linked with a change in pastes. The specific case of Collet de Sant Antoni de Calonge show a minority production of low-calcareous ceramics (exclusively Pascual 1), as well as a clacareous paste used in Laietana 1/Tarraconense 1, Pascual 1 and Oberaden 74 productions. Similarly, a minority production of low-calcareous pastes (Pascual 1) is identified in Llafranc workshop, together with a majority production of calcareous paste used in Pascual 1 and Dressel 7-11 production.

In any case, simple size should be increased in order to corroborate the exposed propositions.

3. Firing temperatures estimated (EFT) also exhibit important variability, however there are relevant differences among production and reception centres. Amphorae as large, heavy and thick-walled vessels, were for the most part fired inside relatively large kilns structures. This accords with the archaeological evidences of the production centres considered in this study as well as those concerning other Roman workshops (Peacock i Williams 1986; Peña 2007; Revilla 1995). So, it was in all likelihood more difficult to achieve an homogeneous firing regime inside a large kiln than it was inside

an small one. Therefore it can be assumed that in an effort to ensure that most of the vessels in a load of amphorae set inside a large kiln were subjected to a minimally adequate firing temperature it may have been necessary to expose some portion of the load to excessively high firing temepratures, resulting in a relatively high proportion of wasters. This assumption permits to explain the obtained results in EFT estimations. In the specific case of production centres, a wide spread of EFT is observed together with an important number of overfired individuals. On the other hand, amphorae recovered from consumption centres show great variability too, but it should be noted that there are very few individuals fired at high temperatures (>1000ºC). This brings about the fact that during the production process, not only the amphorae fired at relatively proper firing regimes (850/950-1000ºC) were considered as suitable containers, but also those fired at clearly low firing temperatures (<850ºC). Conversely, those individuals that were exposed to excesively high temperatures somehow were identified as non suitable vessels for wine transport.

If attention is focussed on production centres, different patterns are observed. Most of the individuals fired at high temperatures correspond to calcareous productions of Model B, whereas EFT of low-calcareous productions of Model A are placed in the lower range. For instance, El Mujal productions show a different pattern as far as the amphorae designs are concerned. Most of Pascual 1 were fired at 850-950 ºC, while virtually all Laietana 1/Tarraconense 1 were clearly fired at lower temperatures. This would explain that Laietana 1/Tarraconense 1 design shows finer granulometry and, therefore, with relatively lower EFT appropiate mechanical performances would be obtained, which accords with the results obtained from the fracture and Hertzian strenght tests carried out.

In any case, it does not seem to be a deliberated effort in order to keep constant the mechanical properties of the ceramic body. Moreover, we understand that these mechanical properties were assumed to fluctuated in a relatively wide range which would explain that individuals from reception centres, which succesfully overcame the suitablilty evaluation, show great variability in fracture strenght values —from very low to very high values. In any case, it should be pointed out that all of these considerations concern the physical properties of the ceramic but not the performance chartacteristics

of the whole vessel which should be approached by Finite Element Methods.

4. Amphorae designs show different mechanical performance when used as transport vessels. By means of computer simulation it has been demonstrated that Roman designs would perform better than Iberian amphorae design. Likewise, it has been shown that Dressel 1 design would not perform as correctly as expected under the simulated load conditons. Conversely, Laietana 1/Tarraconense 1 and Pascual 1 designs show a very succesful performance from the engeneering point of view. From the obtained results it is clear that these latter designs would entail greater mechanical advantatges in comparison to Dressel 1. Furthermore, the overall results permit to consider Laietana 1/Tarraconense 1 as some kind of ideal vessel as far as maritime transport is concerned. Besides the extraordinary performance from the engeneering point of view, this amphora type was produced from ceramic materials that turn to show the highest resistance values. Plus, the granulometric characteristics exhibited implies that lower firing temperatures would be needed in order to obtain such materials. Moreover, this design show the best empty-weight/volume ratio which might be considered an important feature in an overseas trade context. Finally, it should be pointed that this design, together with Pascual 1, represent the typical amphorae types from the conquered territories of Tarraconensis province that struggled for marked share along the western provinces. Certainly, these two new designs implied the entrance of new vessels which performance characteristics (from the engeneering point of view) superseded the typical Roman design Dressel 1. Besides, from the FEA results we do interpret that the poor mechanical performace of Dressel 1 under transport conditions would have been a key factor in boat sinking, specially in those cases where thouand of Dressel 1 were pilled up in several layers.

In any case, improvement of this technical performance should not be considered the only cause of this technological change process; the very important fact in order to understand the underlying features concerns the specific context this phenomenon took place.

5. The technological change occurs at the periphery of the Empire which agrees

with the predictions of the theoretical model. Our theoretical model states that individuals not only have preferentes about the state of the world but also over their beliefs about the state of the world. Hence, it can be inferred that individuals would avoid to be exposed to new data that contradict the system of beliefs they already have. Without considering whether the mechanical shortcommings of Dressel 1 design were certainly identified by producers, it has to be concluded that the specific situation concerning the colonial pressure reinforced around the change of the Era would had generated the necessary conditions for dissonance arose severely since one of the most disseminated symbols of Rome was at stake. In this regard the situation at the periphery was completely different. The new settlements were established away from the decision-making centre but managed by the same people on social status-basis who had to keep on reproducing the complex system of power and representation along the new territories. And this is precisely the reason by which they had to introduce themselves as something different and achieve good market share in western provinces. This is when the new designs came into play, which additionally represented better performanced vessels.

The theoretical model presented also gives an alternative explanation about the so-called conservative characteristic of traditional pottery technology. The behavioral models use to explain how this conservative feature comes about using the behavioral chain model: once an artifact performs adequately along the behavioral chain there is pressure to keep it as is because changes in on technical choice have ramifications along the behavioral chain and could easily result in inadequate performance in many down-the-line activities; therefore, many artifacts go through long periods of stability until alterations of design are implemented. The model presented in this PhD explains this phenomenon as a phychological mechanism to avoid exposure to data aversive to the current system of beliefs.

Therefore this PhD (at least the theoretical part) is divergent, rather than convergent in nature, and seeks to open up a new area of enquiry. It does not claim to be precise in terms of its comprehensiveness or parsimony in covering all the relevant factors that should be considered with respect to this relationship between the technological change of the Roman amphorae specific case and cognitive dissonance

theory. It has made an attempt to bring to the attention of scholars and practitioners that existing knowledge from another domain, that of behavioral Psychology, could be used to understand some changes that do not follow a linear-simplistic trend

6. The overall data exposed agrees with the patterns observed about distribution and consumption of amphorae. The amphorae recovered at the reception centres represent different technologies too, with low calcareous, calcareous and high calcareous ceramics covering all the characterized designs. However it has been pointed out the necessity to increase the sample size in both production and consumption sites if an accurate image of the amphorae supply is to be obtained, since there remain a lot of individuals not matched with any chemical cluster. Specifically, in *Iluro* case 37 out of 48 individuals have been clustered; 77.08% of the whole set have been grouped, 21.92% remain ungrouped, and only 33.33% have been affiliated to an specific production centre. Concerning *Palma* site, 15 out of 31 individuals have been clustered; 48.38% of the whole set have been grouped, 51.62% remain ungrouped, and just 6.45% have been affiliated to an specific production centre. Finally, in the *Emporiae* case altogether 15 out of 31 individuals have been clustered; 44.68% of the whole set have been grouped, 55.32% remain ungrouped, and 29.78% have been linked to an specific workshop.

As far as provenance is concerned, two different models have been identified. The first one is represented by the case of *Iluro* which would had been supplied by the workshops placed in its surrounds. Conversely, the case of *Emporiae* represents a model of a reception centre that would had received goods from a a greater diversity of production centres, from those located at southern area (Can Notxa and El Vilarenc) to those placed at northern area (Sant Antoni de Calonge). In any case, the amphorae distribution pattern clearly follows a route from south to north.

The specific case of the city of *Palma* is quite different since there are very few individuals that have been grouped with production centres. However it should be noticed that two clear chemical clusters have been identified which groups amphorae recovered at *Palma* and amphorae recovered at *Iluro* with similar chronologies (Dressel 1 and Greco-Italic).

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