Odyssey Papers 40

Chemical Analysis of Pottery from the Tortugas Shipwreck (1622) by Plasma Spectrometry (ICPS)

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The excavation of the deep-sea Tortugas shipwreck at a depth of 400m in the Straits of Florida recovered 2,309 olive jar, tableware and cooking pots from intact vessels to potsherds. The wreck is interpreted as the Portuguese-built and Spanish-operated 117-ton *Buen Jesús y Nuestra Señora del Rosario* from the 1622 Tierra Firme fleet, which was returning from Havana to Seville when it succumbed to a hurricane on 5 September.

The pottery assemblage was subjected to Inductively-Coupled Plasma Spectrometry (ICPS) analysis in 2012 with the objective of determining vessel origins. A representative selection of 57 vessels was analyzed, comprising olive jars, tin-glazed pottery (Seville and Morisco wares) and colonoware cooking pots. This project is the first to undertake chemical analyses of Spanish olive jars, significant numbers of Seville Blue on Blue tin-glazed pottery, as well as Seville Polychrome wares.

All the Tortugas ship's pottery, apart from Type 1 olive jars from the Cordoba region of Andalusia and Merida-type unglazed coarsewares from Portugal or northern Spain, proved to derive from Seville and its environs. The ICPS results revealed significant unexpected deviations in chemical concentrations, emphasizing the presence of a number of different sources for Seville ceramics. A further Seville pottery was identified for the first time as containing high levels of magnesium, seemingly indicative of production in a rural pottery industry 18-24km west of Seville. The chemical groups for early 17th-century Seville pottery corresponding to a number of workshops is now seen to be more diverse than for the 16th century.

1. Introduction

The pottery found on the Tortugas shipwreck, today owned and curated by Odyssey Marine Exploration of Tampa, USA, makes an ideal subject for a scientific investigation into its place of production because, unlike the land-based archaeological recovery of pottery, the underwater record forms a sealed deposit of ceramics of single date. Relatively few such investigations using chemical analysis of ceramics' body fabrics from a shipwreck have been published, and those undertaken included only a partial sampling: for example, luster and other Spanish tin-glazed pottery found on a wreck in Studland Bay, Dorset, UK, which proved to be of Seville production (Gutiérrez, 2003). Previous investigations into the analysis of Spanish pottery in the New World have concentrated on the 15th-16th centuries (Olin *et al.*, 1978; Olin and Blackman, 1969; Maggetti *et al.*, 1984; Myers *et al.*, 1992; Rodriguez-Alegria *et al.*, 2003).

The Tortugas shipwreck pottery assemblage comprises 209 olive jars (86 intact jars, 123 individual rims and 1,344 sherds), 1,477 tin-glazed sherds, 554 unglazed coarseware and lead-glazed sherds, and 278 Afro-Caribbean colonoware cooking vessels sherds. This collection included many intact or near intact examples (Figs. 1-5). A provenance in Seville has been suggested out of tradition for most of the wares. English, rather than American terminology, is used to classify the tin-glazed pottery examined in this study following the system adopted for the main pottery report (cf. Kingsley, 2014; Table 3).

To try to investigate as many aspects of the collection as possible, a need existed for each sub-type to be analyzed (defined by differences in decorative scheme since vessel shapes are uniform). A representative selection was chosen for analysis, totalling 57 examples, including principally olive jars, presumed made in Seville; tin-glazed wares also assumed to be from Seville; 'Morisco' wares; and colonoware cooking vessels of Afro-Caribbean form (Figs. 1-5; Tables 1-2).

In total, three of the four olive jar types from the Tortugas shipwreck were sampled (the rare Type 3 is no longer present within the collection; cf. Kingsley *et al.*, 2012: 81, fig. 9), all eight tin-glazed types, four of the ten coarse earthenware and lead-glazed wares preserved within the collection, and both Type 9 and Type 10 styles of colonoware cooking products.

Regarding sampling strategy, for several types of pottery from the wreck (such as Type 1 olive jars and Type 1 Seville Blue on Blue tin-glazed products) many examples were available, so multiple examples were sampled for analysis. For others, the types were rare and only a few samples could be taken. To avoid problems of identification based on procurement from small examples, where possible sampling was taken from discrete positions (and only those vessels that were not intact and displayed breakage points).

Fig. 1. Olive jars from the Tortugas shipwreck sampled for ICPS analysis. A-F: Type 1. G-J: Type 2. K: Type 4.

A. TOR-90-00116-CS; B. TOR-90-00117-CS; C. TOR-90-00118-CS; D. TOR-90-00135-CS; E. TOR-90-00136-CS; F. TOR-90-00138-CS; G. TOR-90-00011-CS; H. TOR-90-00130-CS; I. TOR-90-00132-CS; J. TOR-90-00328-CS; K. TOR-90-00018-CS

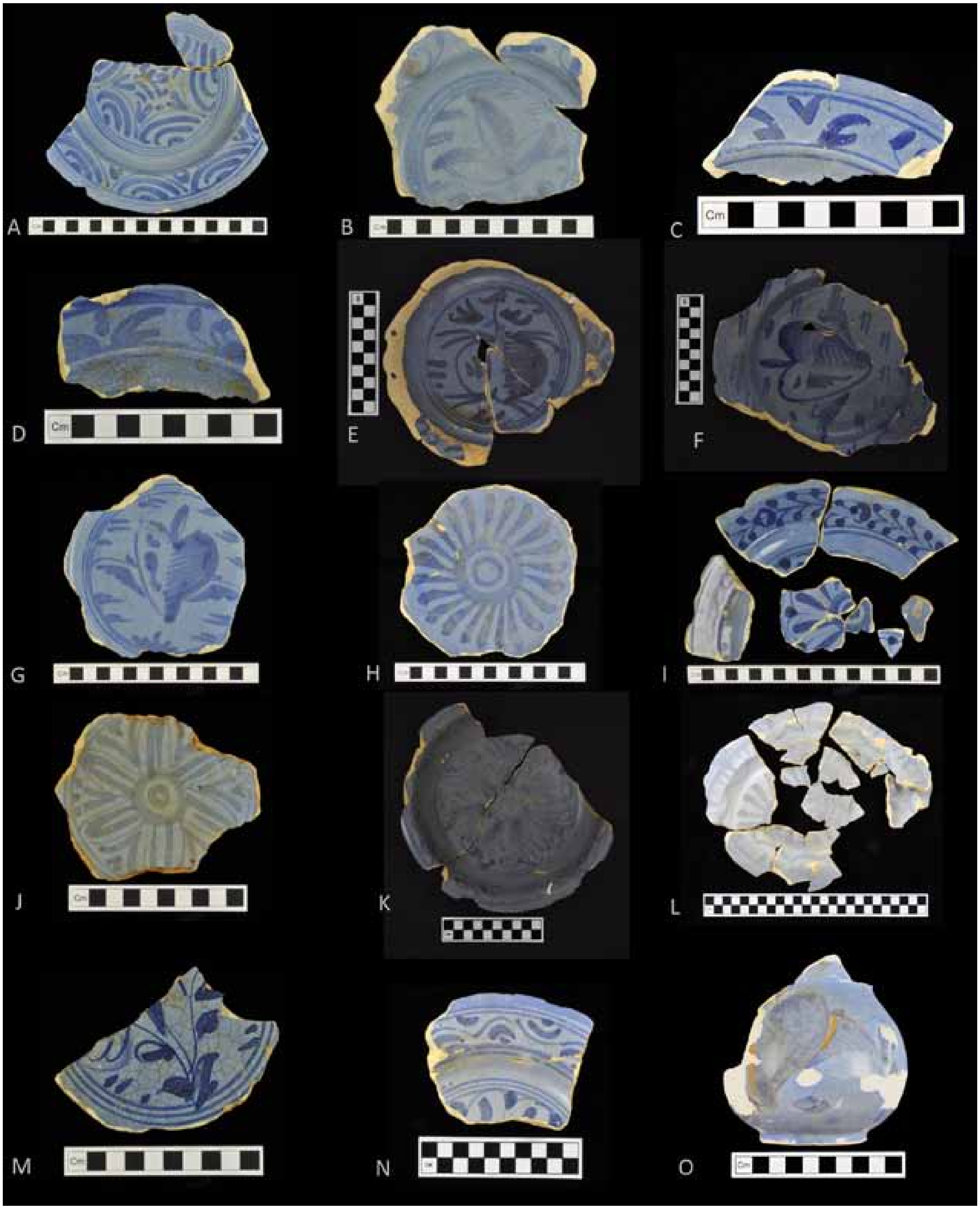

Fig. 2. Tin-glazed Seville Blue on Blue wares from the Tortugas shipwreck sampled for ICPS analysis. A-J, L-N: Type 1A. K: Type 1B. O: Type 1D.

A. TOR-90-00041-CS; B. TOR-90-00044-CS; C. TOR-90-00081-CS; D. TOR-90-00054-CS; E. TOR-90-00084-CS; F. TOR-90-00085-CS; G. TOR-90-00052-CS; H. TOR-90-00045-CS; I. TOR-90-00061-CS; J. TOR-90-00053-CS; K. TOR-90-00086-CS; L. TOR-90-00058-CS; M. TOR-90-00088-CS; N. TOR-90-00046-CS' O. TOR-90-00035-CS.

Fig. 3. Tin-glazed wares from the Tortugas shipwreck sampled for ICPS analysis.
A-D: Type 1C Seville Blue on Blue bowls. E-H: Type 2A Seville Blue on White plates.
I-L: Type 3B-3D Plain White Morisco plates and bowl. M-N: Type 4B-4C Seville White cup and bowl.

A. TOR-90-00049-CS; B. TOR-90-00051-CS; C. TOR-90-00048-CS; D. TOR-90-00056-CS;
E. TOR-90-00015-CS; F. TOR-90-00017-CS; G. TOR-90-00057-CS; H. TOR-90-00090-CS;
I. TOR-90-00013-CS; J. TOR-90-00030-CS; K. TOR-90-00047-CS; L. TOR-90-00073-CS;
M. TOR-90-00065-CS; N. TOR-90-00036-CS.

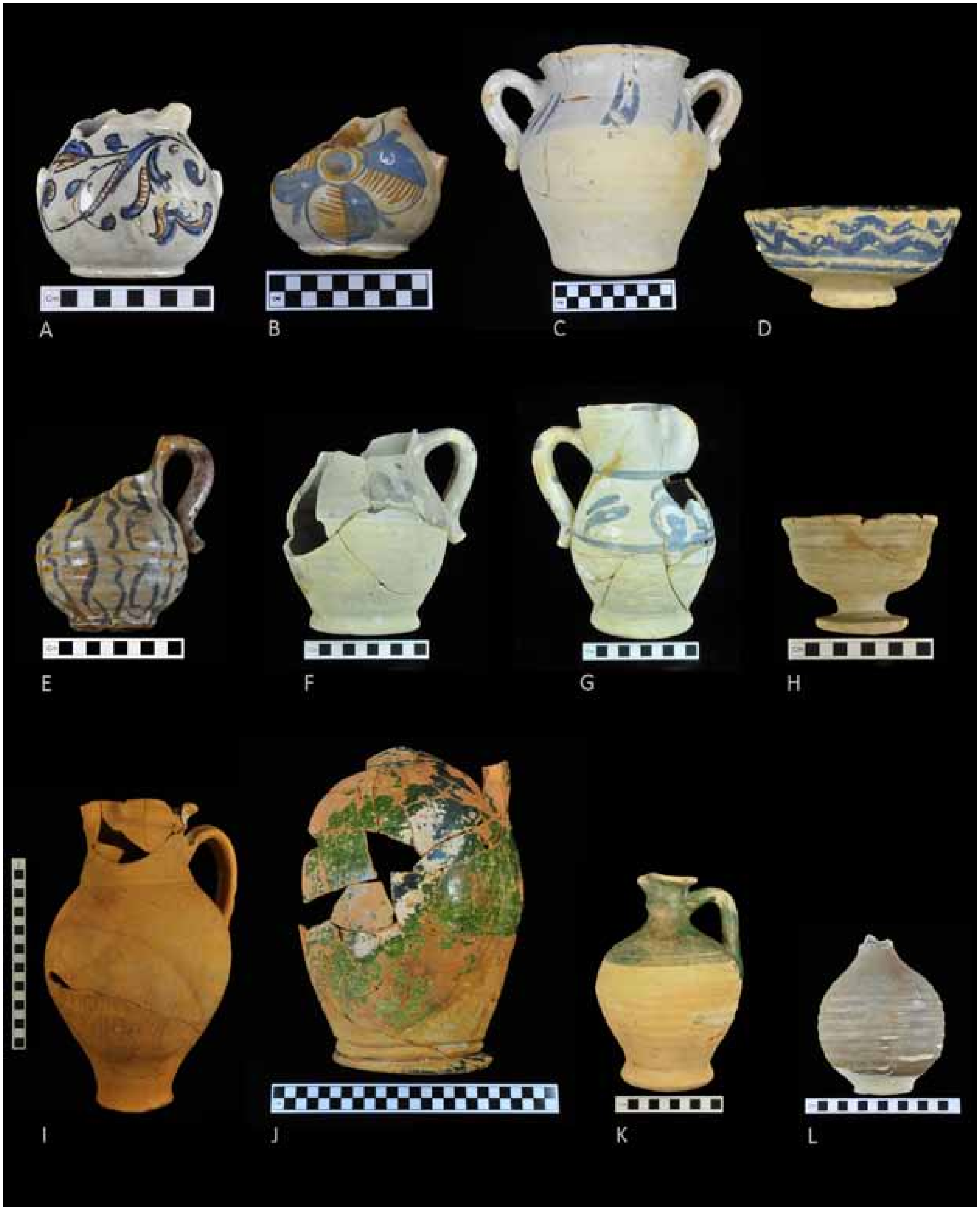

Fig. 4. Tin-glazed wares, unglazed coarsewares and lead-glazed wares from the Tortugas shipwreck sampled for ICPS analysis. A-B: Type 5A Seville Polychrome jugs. C-E: Type 6A, 6C, 6D Linear Blue Morisco jar, bowl and jug. F-G: Type 7 Decorated Blue Morisco pitchers. H: Type 8A Mottled Blue Morisco cup. I: Type 12 Merida jug. J-L: Types 19B, 20, 21 lead-glazed costrel and jugs.

A. TOR-90-00032-CS; B. TOR-90-00070-CS; C. TOR-90-00069-CS; D. TOR-90-00009-CS; E. TOR-90-00023-CS; F. TOR-90-00019-CS; G. TOR-90-00068-CS; H. TOR-90-00038-CS; I. TOR-90-00031-CS; J. TOR-90-00071-CS; K. TOR-90-00016-CS; L. TOR-90-00040-CS.

Fig. 5. Afro-Caribbean Type 9D colonoware cooking pot (A: TOR-90-01207-CS) and Type 10A colonoware griddle (B: TOR-90-00164-CS) from the Tortugas shipwreck sampled for ICPS analysis.

The selection of samples according to the Tortugas shipwreck typology was as follows (Figs. 1-5):

Assumed Seville Region
- Olive Jars Type 1 (Six Samples)
- Olive Jars Type 2 (Four Samples)
- Olive Jar Type 4 (One Sample)

Assumed Seville Wares
- Seville Blue on Blue Tin-Glazed (Tortugas Type 1A: 14 Plates)
- Seville Blue on Blue Tin-Glazed (Tortugas Type 1B: Four Small Bowls)
- Seville Blue on Blue Tin-Glazed (Tortugas Type 1D: 1 Jug)
- Seville Blue on White Tin-Glazed (Tortugas Type 2A: Four Plates)
- Seville White Tin-Glazed (Tortugas Type 4B: OneBowl)
- Seville White Tin-Glazed (Tortugas Type 4C: One Cup)
- Seville Polychrome Tin-Glazed (Tortugas Type 5A: Two Jugs)

'Morisco' Wares
- Plain White Morisco Tin-Glazed (Tortugas Type 3B: Two Plates)
- Plain White Morisco Tin-Glazed (Tortugas Type 3C: One Flanged Plate)
- Plain White Morisco Tin-Glazed (Tortugas Type 3D: One Bowl)
- Linear Blue Morisco Tin-Glazed (Tortugas Type 6A: One Jar)
- Linear Blue Morisco Tin-Glazed (Tortugas Type 6C: One Bowl)
- Linear Blue Morisco Tin-Glazed (Tortugas Type 6D: One Jug)
- Decorated Blue Morisco (Tortugas Type 7: Two Pitchers)
- Mottled Blue Morisco (Tortugas Type 8A: One Cup)

Lead-Glazed & Undecorated Coarse Tablewares
- Lead-Glazed Ware (Type 20: One Half-dipped Jug)
- Merida-Type Ware (Type 12: One One-Handle Jug)
- Lead-Glazed Ware (Type 19B: One Costrel)
- Lead-Glazed Ware (Type 21: One Jug)

Cooking Wares
- Afro-Caribbean Colonoware (Tortugas Type 9D: Cooking Pot)
- Afro-Caribbean Colonoware (Tortugas Type 10A: Cooking Griddle)

Current literature often presumes that the majority of 17th-century Spanish Type 1 buff-colored olive jars (Fig.1A-1F) were manufactured in the exact geographical area where Dressel 20 Roman olive oil amphoras were produced in the 1st and 2nd centuries AD, the Guadalquivir Valley, where Roman kiln sites and estates have been found, but no 16th- or 17th-century sites are attested. Type 2 redware olive jars (Fig. 1G-1J) are thought to come from a location 75km northeast of Seville.

The Seville Blue on Blue wares (Figs. 2, 3A-3D) comprise the most numerous tableware category (47.5% of all tableware rims, bases and handles and 28.2% by counts of largely intact or unique vessels) found on the Tortugas shipwreck and also include the broadest decorative schemes (Kingsley, 2014: figs. 43-47). These are typically assumed

Tortugas Type	Inv. No.	ICPS Sample Nos.
Type 1	TOR-90-00116-CS	09-0911-44; VB1
Type 1	TOR-90-00117-CS	09-0911-52; VB2
Type 1	TOR-90-00118-CS	09-0911-50; VB3
Type 1	TOR-90-00135-CS	09-0911-46; VB4
Type 1	TOR-90-00136-CS	09-0911-40; VB5
Type 1	TOR-90-00138-CS	09-0911-35; VB6
Type 2	TOR-90-00011-CS	09-0911-45; VB7
Type 2	TOR-90-00130-CS	09-0911-42; VB8
Type 2	TOR-90-00132-CS	09-0911-47; VB9
Type 2	TOR-90-00328-CS	09-0911-58; VB10
Type 4	TOR-90-00018-CS	09-0911-55; VB11

Table 1. Olive jars from the Tortugas shipwreck subjected to Inductively-Coupled Plasma Spectrometry (ICPS) analysis.

to originate from Seville if their fabrics appear coarse and to be Italian if they appear fine. Examples were selected reflecting all the decorative sub-types, even though the clay fabric ought to be identical in theory.

The Type 9-10 colonoware cooking vessels (Fig. 5) originate from outside Europe in Afro-Caribbean contexts (Gerth and Kingsley, 2014). Similar wares were conspicuous on the wreck of the *Atocha*, from the same 1622 Tierra Firme fleet as the Tortugas ship. The fabric required testing because it is was a major anomaly in the collection as the only presumed consistently non-Spanish ceramic ware attested.

2. ICPS Analysis: Inductively-Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

Chemical analysis using Inductively-Coupled Plasma Spectrometry (ICPS) of pottery fabric gives a chemical fingerprint and thus information on its source, reflecting the clay from which it was made. Such analytical investigations show whether ceramics have the same paste as each other, and are therefore made from the same clay source (Orton and Hughes, 2013: 153, 168-82). The atomic emission version of ICPS analyses for all the major elements in the ceramic (except silicon) and a good range of trace elements.

Conclusions drawn from the use of such a wide range of elements from each pottery sample are significantly more secure when so many elements can be taken into consideration. It also considerably lessens the risk that pottery from different origins made from clays of similar age and mineralogical make-up can be confused by chemical analysis. The advantages of ICPS include its straightforward calibration, consistent accuracy, precision of results and ready availability as a technique (cf. Hughes, 2008 for a typical application). Previous projects using ICPS and neutron activation analysis (NAA) have defined the chemical characteristics of Seville-produced pottery, and were compared to the current Tortugas pottery analyses.

Powdered samples were obtained from each example by drilling into a broken edge or inconspicuous part of a pot using a 2mm or 3mm-diameter tungsten carbide drill bit fitted into a hand-held electric drill. In addition, the samples sent to the laboratory for ICPS analysis included several portions of a Certified Reference Material (NBS679 Brick Clay, produced by the US National Institute for Standards and Technology, Washington DC) spaced out in the analysis batch, but not identified as such. These acted as quality control samples. The chemical profiles of these control samples gave entirely satisfactory results.

The powdered samples were analyzed by the Viridian Partnership, Woking, United Kingdom, using their standard technique for ICP-AES. The samples were prepared by fusing weighed portions of each sample powder with lithium metaborate in a furnace to render the components of the clays soluble in dilute acid. The ICPS results are provided fully in Tables 4A-4B, arranged according to Tortugas pottery type. Where the sample was consistent within the type, the average chemical analysis is given in Tables 5A-5B, including averaged analyses for selected comparison groups from published investigations on similar pottery. The same data is presented in Tables 6A-6B for pottery whose analysis did not conform to the main compositional patterns.

3. Seville Clays

Potteries were established in the Triana district of Seville in the early 14th century; artisans were motivated to settle

Tortugas Type	Inv. No.	ICPS Sample Nos.
Type 1A, Seville Blue on Blue Plate	TOR-90-00041-CS	09-0911-43; VB12
Type 1A, Seville Blue on Blue Plate	TOR-90-00044-CS	09-0911-19; VB13
Type 1A, Seville Blue on Blue Plate	TOR-90-00081-CS	09-0911-30; VB 14
Type 1A, Seville Blue on Blue Plate	TOR-90-00054-CS	09-0911-32; VB 15
Type 1A, Seville Blue on Blue Plate	TOR-90-00084-CS	09-0911-56; VB 16
Type 1A, Seville Blue on Blue Plate	TOR-90-00085-CS	09-0911-54; VB 17
Type 1A, Seville Blue on Blue Plate	TOR-90-00052-CS	09-0911-36; VB18
Type 1A, Seville Blue on Blue Plate	TOR-90-00045-CS	09-0911-57; VB19
Type 1A, Seville Blue on Blue Plate	TOR-90-00061-CS	09-0911-49; VB 21
Type 1A, Seville Blue on Blue Plate	TOR-90-00053-CS	09-0911-17; VB22
Type 1A, Seville Blue on Blue Plate	TOR-90-00058-CS	09-0911-38; VB24
Type 1A, Seville Blue on Blue Plate	TOR-90-00088-CS	09-0911-11; VB25
Type 1A, Seville Blue on Blue Plate	TOR-90-00046-CS	09-0911-10; VB26
Type 1B, Seville Blue on Blue Plate	TOR-90-00086-CS	09-0911-48; VB23
Type 1C, Seville Blue on Blue Bowl	TOR-90-00049-CS	09-0911-26; VB27
Type 1C, Seville Blue on Blue Bowl	TOR-90-00051-CS	09-0911-53; VB28
Type 1C, Seville Blue on Blue Bowl	TOR-90-00048-CS	09-0911-41; VB29
Type 1C, Seville Blue on Blue Bowl	TOR-90-00056-CS	09-0911-14; VB30
Type 1D, Seville Blue on Blue Jug	TOR-90-00035-CS	09-0911-13; VB42
Type 2A, Seville Blue on White Plate	TOR-90-00015-CS	09-0911-09; VB31
Type 2A, Seville Blue on White Plate	TOR-90-00017-CS	09-0911-23; VB32
Type 2A, Seville Blue on White Plate	TOR-90-00057-CS	09-0911-29; VB33
Type 2A, Seville Blue on White Plate	TOR-90-00090-CS	09-0911-39; VB34
Type 3B, Plain White Morisco Plate	TOR-90-00013-CS	09-0911-51; VB35
Type 3B, Plain White Morisco Plate	TOR-90-00030-CS	09-0911-31; VB36
Type 3C, Plain White Morisco Plate	TOR-90-00047-CS	09-0911-21; VB37
Type 3D, Plain White Morisco Bowl	TOR-90-00073-CS	09-0911-18; VB38
Type 4B, Seville White Bowl	TOR-90-00036-CS	09-0911-27; VB39
Type 4C, Seville White Cup	TOR-90-00065-CS	09-0911-15; VB41
Type 5A, Seville Polychrome Jug	TOR-90-00032-CS	09-0911-22; VB43
Type 5A, Seville Polychrome Jug	TOR-90-00070-CS	09-0911-08; VB44
Type 6A, Linear Blue Morisco Jar	TOR-90-00069-CS	09-0911-05; VB45
Type 6C, Linear Blue Morisco Bowl	TOR-90-00009-CS	09-0911-03; VB49
Type 6D, Linear Blue Morisco Jug	TOR-90-00023-CS	09-0911-02; VB50
Type 7, Decorated Blue Morisco Pitcher	TOR-90-00019-CS	09-0911-20; VB46
Type 7, Decorated Blue Morisco Pitcher	TOR-90-00068-CS	09-0911-04; VB47
Type 8A, Mottled Blue Morisco Cup	TOR-90-00038-CS	09-0911-06; VB48
Type 9D, Colonoware Cooking Bowl	TOR-90-01207-CS	09-0911-01; VB51
Type 10A, Colonoware Cooking Griddle	TOR-90-00164-CS	09-0911-34; VB52
Type 12, Merida-type Jug	TOR-90-00031-CS	09-0911-07; VB53
Type 19B, Green-glazed Costrel	TOR-90-00071-CS	09-0911-28; VB54
Type 20, Green-glazed Jug	TOR-90-00016-CS	09-0911-12; VB55
Type 21, Lead-glazed Jug	TOR-90-00040-CS	09-0911-24; VB56

Table 2. Pottery from the Tortugas shipwreck subjected to Inductively-Coupled Plasma Spectrometry (ICPS) analysis.

there by the availability of clays in the nearby meadow, on islands in the river, and at the village of Castilleja de la Cuesta, located around 4km west of Triana on the cart road towards Huelva. Coarse earthenwares, including those used for packaging foodstuffs for export, were probably produced in Seville itself or in satellite countryside potteries (Lister and Lister, 1987: 74-5, 80).

Two kinds of clay were used in Seville ceramics in the period under consideration: clay that fired to a red colour, lacking in plasticity but with greater strength and ability to withstand heat, was used for bricks, roofing tiles, cooking pots and heavy objects (Lister and Lister, 1987: 256). It was extracted from pits in the Triana or Tablada meadows or from an island in the river. Light-firing calcareous clay

Tortugas Type	English Terminology	American Terminology	Spanish Terminology
Type 1 (Seville Ware)	Seville Blue on Blue	Ichtucknee Blue on Blue	Sevilla Azul Sobre Azul
Type 2 (Seville Ware)	Seville Blue on White	Talavera-Style Blue on White; Ichtucknee Blue on White	Sevilla Azul Sobre Blanco
Type 3 (Morisco Ware)	Plain White Morisco	Columbia Plain	Blanca Lisa
Type 4 (Seville Ware)	Seville White	Sevilla White	Sevilla Blanca
Type 5 (Seville Ware)	Seville Polychrome	Andalusia Polychrome	Sevilla Polícroma (Estilo Talavera)
Type 6 (Morisco Ware)	Linear Blue Morisco	Yayal Blue on White	Azul Lineal
Type 7 (Morisco Ware)	Decorated Blue Morisco	Santo Domingo Blue on White	Azul Figurativa
Type 8 (Morisco Ware)	Mottled Blue Morisco	Santa Elena Mottled Blue on White	Azul Moteada

Table 3. Types of tin-glazed wares on the Tortugas wreck with comparative English, American and Spanish terminology (after Gutiérrez, 2000: 44).

came from along the riverbanks or from near Castilleja de la Cuesta. Gonzalez Garcia and Garcia Ramos (1964; 1966; 1969) have described these as marls outcropping in the west side of the city near the Triana quarter. This light-firing clay was used by the makers of tin-glazed wares, and Lister and Lister (1987: 257) have suggested it may have been added to the red-firing clay.

The present project has indicated that contrary to this theory a larger proportion of red clay was systematically mixed with a smaller volume of the light-firing clay for tin-glazed pottery dated to the period of the Tortugas shipwreck. This had the result of lowering the percentage of lime in the clay and increasing the proportion of clay (clay minerals). Avery (1997) undertook a small sampling program of Andalusian clays, including his clay no. 7 extracted from around 1m below the surface at Cartuja in Seville, which was red-firing and had a high incidence of quartz temper.

A much more extensive program of systematic sampling and analysis of Andalusian clays was conducted from the 1960s to the 1980s, including measuring the proportions of sand, lime and clay, and examining the effects of firing and chemical analyses of the clay fraction (cf. Gonzalez Garcia and Garcia Ramos, 1964). Significant numbers of the clays in the Seville district were documented and are of direct relevance to the present study. Those clay analyses cannot be directly compared with the current ICPS results, however, because Gonzalez Garcia and Garcia Ramos carried out a chemical separation of the different fractions (sand/lime/clay). The published analyses related to the separated clay fraction alone.

However, it has been possible to reconstruct, with some caution, the probable analysis of the original (unseparated) clays, given the known proportions of the other two components of sand (pure silica, effectively) and lime (pure calcium carbonate). The former clay study also concluded that the two clay types were blended, and suggested a technical reason, namely to modify the high plasticity and shrinkage coefficient of the light-firing clays and therefore to obtain the best fit for the glazes on tin-glazed pottery.

Mineralogically, Seville pottery contains temper of sedimentary origin, specifically an association of quartz with biotite and muscovite (Maggetti *et al.*, 1984: 152, 159). The matrix is very fine grained and calcitic; the coarser particles (max. 0.3mm) are predominantly quartz with a few red oxidized biotites and colorless muscovites; there are some grains of plagioclase and epidote.

4. Interpretation of ICPS Analyses Using Principal Components Analysis & Discriminant Analysis

Detailed interpretation of the analyses of the Tortugas pottery was carried out using multivariate statistics, which simultaneously considers the concentrations of many elements in each sample. For this investigation, Principal Components Analysis (PCA) and Discriminant Analysis (DA) were used (Tabachnick and Fidell, 2007). Descriptions of their application to archaeology are described elsewhere (Baxter, 1994; 2003; Shennan, 1997). The SPSS version 15 statistical package was used for this work (Pellant, 2007).

A. Discriminant Analysis

Discriminant analysis is a means of testing whether there are significant measured differences between pre-defined groups of items. Applied in this case, the type categories of the Tortugas pottery were used as the groups' identifier,

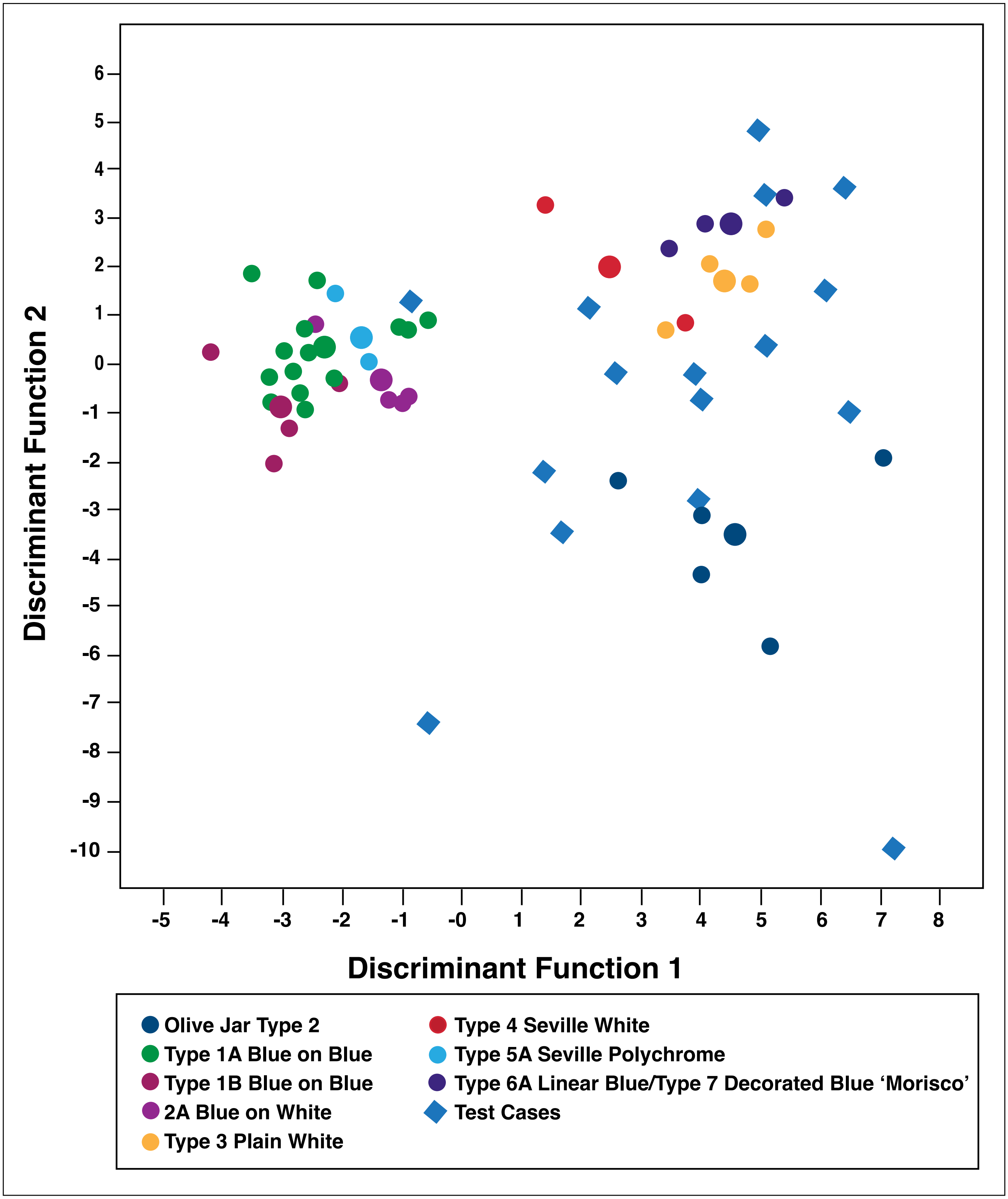

Fig. 6. A plot of the first and second discriminant scores arising from discriminant analysis of the ICPS study of Tortugas ceramics, using as defined groups only tableware Types 1-7 and olive jars Types 1-2. The rest were treated as 'test' samples (the program assigned them to whichever defined group they were most similar to chemically). Associations and systematic differences between types in their clay chemistry are clearly indicated. Group centroids are depicted as larger symbols.

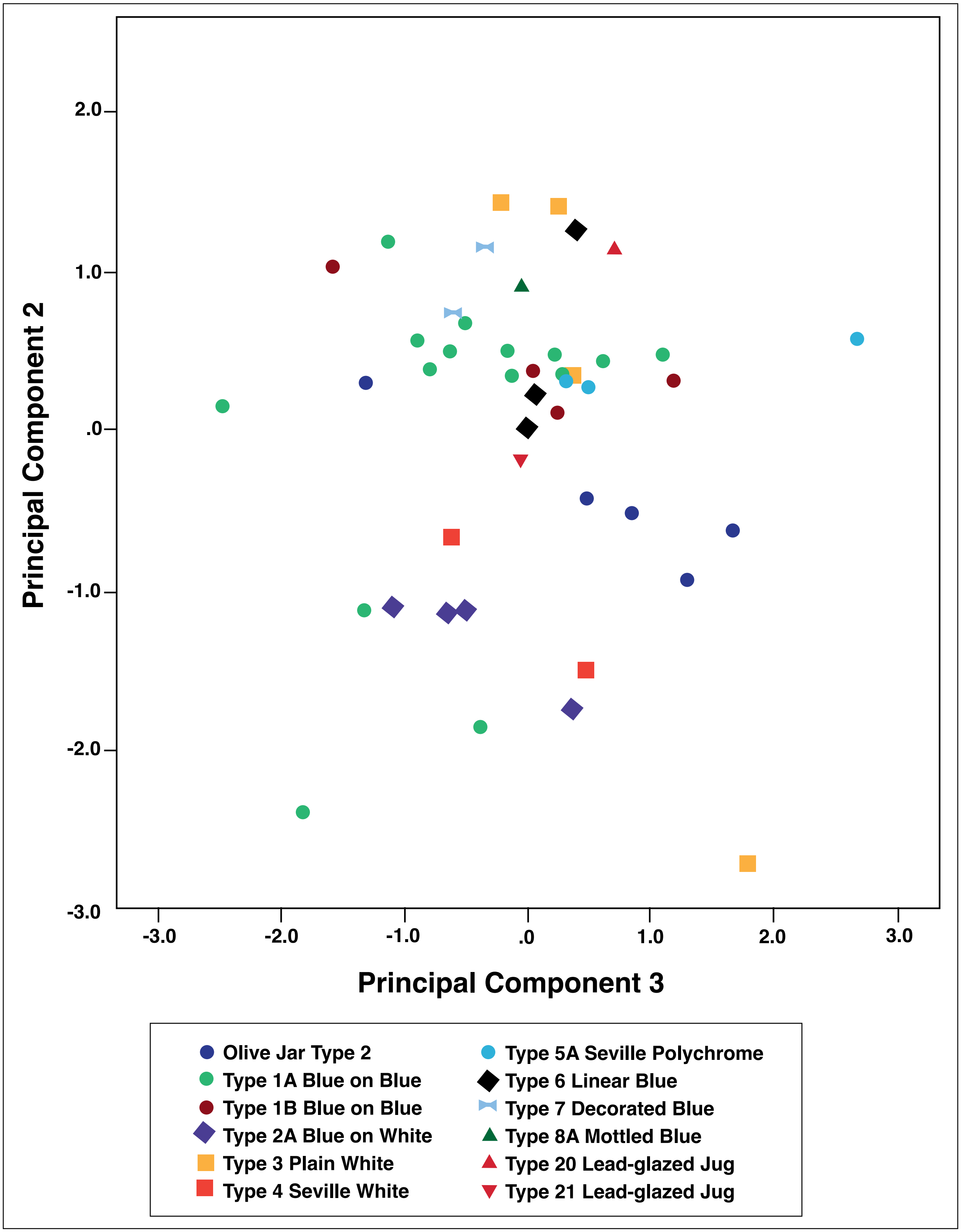

Fig. 7. A plot of the second and third principal components arising from principal components analysis of the ICPS study of ceramics, excluding olive jars Type 1 and tableware Types 10A, 10B, 12, 19B (which were 'outliers' significantly different in clay analysis).

and those chemical elements that show differences between types were looked for. Discriminant analysis produces discriminant functions, which are linear combinations of those elements that best separated the identified groups. Fourteen of the ICP-AES elements shown in Tables 4A-4B were included in the tests (aluminium, iron, sodium, potassium, calcium, magnesium, manganese, titanium, chromium, scandium, strontium, zirconium, lanthanum, and cerium), chosen for the reliability of measurement and because they are not subjected to post-depositional effects (such as barium and phosphorus, which can change).

Before carrying out the tests, the results were first converted to logarithms to remove large element-to-element differences in numerical values. This is very common in archaeological and other studies; it does not affect the between-element ratios, which are important provenance indicators. For ease of interpreting the results, plots are drawn up of pairs of the resulting discriminant functions for each sample (Fig. 6), where each sample analyzed is shown by the appropriate symbol for its type. Such plots create a type of sample 'map' where items that have the same chemical analysis will group together: each point represents one sample of pottery on this composition map. For a detailed explanation of the operation and significance of discriminant analysis, see Baxter (1994).

Discriminant analysis was carried out on all the samples analyzed in this project, but only Types 1-7 tin-glazed wares and olive jar Types 1 and 2 were defined as groups; all the rest were treated as 'test' samples (i.e. the program assigned them to whichever of the defined groups they were most similar to chemically). The plot of the first two discriminant scores is shown in Fig. 6. The results demonstrate that with a few exceptions the clay chemistry was consistent within each type. Thus, they had been made from the same clays or clay mixtures, and perhaps all derived from the same workshop. It was clear from the analyses, however, that the types fell into two major chemical groups, apart from the Type 1 olive jars, which had a rather different chemistry.

These two groups corresponded to 'Seville' wares (Fig. 6, left) and 'Morisco' wares (Fig. 6 right) respectively (Seville wares are tin-glazed varieties produced in Spain in response to Italian influence; 'Morisco' continue the influence of earlier indigenous wares; Lister and Lister, 1987). Comparison with previous ICPS and NAA results confirmed both main chemical groups as Seville products, but made of slightly different clay mixtures. This appears to be the first occasion when this chemical difference in the fabric of the two series of wares has been recognized, probably because few of the later period Seville wares have been analyzed until now. Substantial numbers of earlier Morisco Spanish wares have been analyzed previously, including those found in the Caribbean and Venezuela and excavated from a kiln site in Seville (Olin *et al*., 1978; Myers *et al*., 1992). Support for the conclusions about the two clay mixtures also came from previous extensive analyses made in the 1980s of raw clays from the Seville region and throughout Andalusia – clay matching the Tortugas pottery can be found for specific clays in the Seville area.

A large proportion of the Seville wares analyzed from the Tortugas shipwreck formed one of the two major chemical groups. Discriminant analysis (Fig. 6) demonstrated that all the Seville Blue on Blue tin-glazed wares (Types 1A and 1B) were very similar to each other chemically (and seemed almost identical in chemistry), as well as to the Seville Blue on White tin-glazed wares (Type 2A). Seville Polychrome (Type 5A) does not appear to have been previously analyzed, but this study determined that it is chemically part of the Seville wares group. Similar chemically, but not identical to the Seville Blue on Blue wares, the Type 2 olive jars bear the chemical signature of Seville clays (unlike the Type 1 jars). Two Seville White Wares (Type 4) were both similar chemically to the Seville Blue on White tin-glazed pottery (Type 2A) and the Type 2 olive jars.

The Morisco wares formed the second major clay chemical group, which was higher in lime (calcium oxide) and lower in the percentage of clay-related chemical elements, suggesting a higher percentage of quartz sand temper relative to the Seville wares.

Discriminant analysis revealed that the Type 1 olive jars were unlike any of the other groups of pottery, suggesting manufacture at some distance from all the other types. During the Roman period Dressel 20 amphoras were produced in the Guadalquivir Valley between the cities of Cordoba and Seville at a number of production sites (Tyers, 1996: 87, 88, fig. 53), and ICPS analyses appear to confirm the proposal that the Type 1 Tortugas olive jars were similarly made in the region of Cordoba from clays chemically different to the rest of the pottery analyzed for the current project, which represents production in and around Seville.

Gonzalez Garcia and Garcia Ramos (1969) examined ceramic clays from around Cordoba, of which clays Co-27 and Co-29 on the south side of the Guadalquivir were closest to the city and also contained more than 55% clay. These comprised blue marls used for brickmaking that were similar to clay located near the river in Seville. Their analyses were recalculated as described above for comparison with the Tortugas Type 1 olive jars. The alumina was about 12%, iron around 3%, lime some 15% and titanium 0.4%, but magnesium, potassium and sodium were quite low. Given that the laboratory processing of the clay

TOR Inv. No.	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
TOR-90-00116-CS	47.0	11.9	4.92	5.17	8.00	0.60	2.30	0.59	0.17	0.06	314	281	20.0	266	70	30.6	62.6
TOR-90-00117-CS	47.5	12.4	4.85	5.92	7.66	0.63	2.28	0.64	0.16	0.07	336	80	14.3	273	101	26.7	55.8
TOR-90-00118-CS	47.8	12.6	5.09	5.62	9.25	0.58	2.31	0.64	0.18	0.07	336	87	16.4	436	100	32.4	57.5
TOR-90-00135-CS	53.2	13.7	5.61	6.38	8.49	0.62	2.33	0.67	0.20	0.07	345	80	18.8	310	95	26.2	53.2
TOR-90-00136-CS	52.4	14.1	5.90	3.29	12.80	0.76	2.98	0.71	0.21	0.06	369	91	15.5	405	113	30.3	60.8
TOR-90-00138-CS	51.6	13.6	5.79	4.61	11.76	0.87	2.84	0.67	0.23	0.06	313	82	16.2	649	109	28.5	57.3
TOR-90-00011-CS	56.9	9.3	4.17	4.19	10.13	0.97	1.28	0.54	0.15	0.03	321	76	16.4	349	111	21.7	47.9
TOR-90-00130-CS	51.4	12.6	5.18	2.89	13.20	0.85	2.60	0.65	0.20	0.08	333	73	16.9	366	110	26.4	57.8
TOR-90-00132-CS	51.4	12.7	5.27	2.83	11.92	0.86	2.83	0.65	0.17	0.07	349	70	18.1	349	113	25.7	57.6
TOR-90-00328-CS	63.6	9.7	7.06	1.26	6.76	0.48	1.67	0.54	0.29	0.02	171	90	16.1	219	127	20.5	46.3
TOR-90-00018-CS	59.1	14.5	5.10	2.52	8.76	1.03	3.11	0.69	0.20	0.05	417	86	18.5	332	112	28.0	59.4
TOR-90-00041-CS	51.4	15.6	6.49	3.65	15.85	1.77	1.37	0.79	0.25	0.11	405	91	19.5	475	147	33.6	70.6
TOR-90-00044-CS	52.2	14.8	6.03	3.19	16.95	1.24	2.02	0.76	0.22	0.11	378	161	17.9	461	160	34.6	71.9
TOR-90-00081-CS	54.4	15.8	6.21	3.59	21.23	1.81	1.60	0.79	0.23	0.12	445	90	19.8	523	132	35.4	70.3
TOR-90-00054-CS	50.5	14.7	5.88	3.62	19.37	1.28	1.56	0.73	0.23	0.12	398	82	18.3	493	133	33.1	67.1
TOR-90-00084-CS	49.2	13.7	6.88	3.31	16.96	0.97	2.10	0.70	0.25	0.11	352	88	15.9	418	149	32.7	65.6
TOR-90-00085-CS	44.2	13.0	4.95	4.08	19.77	1.01	1.76	0.64	0.19	0.10	345	79	14.6	507	127	30.9	61.9
TOR-90-00052-CS	56.0	15.4	6.17	3.43	17.54	1.38	1.70	0.83	0.23	0.11	412	84	18.3	479	159	33.7	69.0
TOR-90-00045-CS	48.3	12.4	4.56	1.86	16.78	1.11	1.86	1.02	0.31	0.03	286	93	14.3	333	141	31.9	68.6
TOR-90-00061-CS	42.1	11.8	4.98	2.96	15.56	1.24	1.01	0.64	0.21	0.09	317	74	14.2	526	65	28.8	59.5
TOR-90-00053-CS	53.8	14.8	7.03	3.21	14.64	0.96	2.00	0.83	0.30	0.12	424	82	17.7	434	187	34.1	71.8
TOR-90-00086-CS	43.9	11.7	4.04	2.03	15.51	1.06	1.66	0.87	0.22	0.03	246	80	12.9	308	60	26.0	55.6
TOR-90-00058-CS	50.9	14.7	6.59	3.14	15.89	1.21	2.22	0.76	0.31	0.11	372	78	15.8	600	151	32.5	67.7
TOR-90-00088-CS	50.8	14.7	5.92	5.02	18.86	1.28	1.12	0.74	0.25	0.12	367	84	15.8	510	152	34.4	68.2
TOR-90-00046-CS	55.7	17.0	6.84	3.70	17.27	1.87	1.68	0.86	0.25	0.11	478	110	19.8	517	157	35.8	74.5
TOR-90-00064-CS	47.9	11.6	4.43	3.36	19.10	0.90	1.66	0.92	0.28	0.03	275	71	13.3	368	131	24.3	52.6
TOR-90-00049-CS	55.9	15.4	6.74	3.31	14.98	1.40	1.85	0.84	0.26	0.11	442	85	18.6	428	137	32.1	70.6
TOR-90-00051-CS	50.5	14.4	6.04	3.11	13.38	1.09	1.98	0.76	0.21	0.11	397	79	20.7	416	149	53.0	68.6
TOR-90-00048-CS	54.5	15.6	6.56	3.54	14.97	1.65	1.72	0.87	0.21	0.13	468	72	20.4	451	165	29.5	66.8
TOR-90-00056-CS	48.7	14.6	6.16	3.77	16.91	1.78	0.93	0.74	0.23	0.11	392	84	16.7	528	140	32.7	67.7
TOR-90-00015-CS	51.7	13.5	4.95	2.64	17.71	0.95	1.64	0.89	0.28	0.04	258	83	14.0	328	142	29.4	61.9
TOR-90-00017-CS	50.8	13.3	5.39	1.94	14.80	1.11	2.34	0.88	0.41	0.03	317	83	14.4	276	130	27.8	61.1
TOR-90-00057-CS	52.2	14.0	4.85	2.89	19.96	1.36	1.66	0.86	0.25	0.04	280	77	16.4	355	130	26.7	59.3
TOR-90-00090-CS	52.8	13.8	4.81	2.87	15.47	1.22	1.54	0.81	0.24	0.03	305	79	14.2	250	130	27.4	58.9
TOR-90-00013-CS	47.4	11.7	6.31	3.02	14.46	1.03	1.83	0.68	0.32	0.06	314	78	18.0	452	164	30.8	63.4
TOR-90-00030-CS	49.9	11.1	4.78	11.65	8.65	0.67	1.35	0.62	0.25	0.07	280	69	13.9	229	161	28.3	54.6
TOR-90-00047-CS	56.1	15.5	4.49	1.35	12.55	0.84	3.06	0.86	0.36	0.03	441	49	14.2	280	118	45.8	90.8
TOR-90-00073-CS	46.3	10.3	4.06	10.68	6.36	0.75	1.16	0.56	0.19	0.06	237	62	11.9	231	152	26.4	53.4
TOR-90-00036-CS	53.9	13.9	4.72	2.80	14.73	1.04	2.48	0.83	0.23	0.03	323	73	15.7	290	140	30.4	65.9
TOR-90-00065-CS	51.2	13.2	5.02	3.06	19.14	1.47	1.57	0.82	0.35	0.04	304	81	14.7	341	173	33.1	70.6
TOR-90-00035-CS	52.5	15.4	6.39	3.26	16.06	1.09	1.86	0.78	0.23	0.11	405	83	18.0	475	151	32.7	69.1
TOR-90-00032-CS	55.6	14.3	5.79	3.04	15.27	1.17	1.90	0.81	0.23	0.10	389	80	17.6	442	191	33.2	71.0

Analysis results: SiO2 silicon; Al2O3 aluminium; Fe2O3 iron; MgO magnesium; CaO calcium; Na2O sodium; K2O potassium; TiO2 titanium; P2O5 phosphorus; MnO manganese (all in weight percent). Ba barium; Cr chromium; Sc scandium; Sr strontium; Zr zirconium; La lanthanum; Ce cerium (all in parts per million).

Table 4A. Descriptions of samples analyzed by ICPS from the Tortugas shipwreck and full set of results.

TOR Inv. No.	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
TOR-90-00070-CS	54.4	13.8	11.65	2.68	9.08	0.91	1.94	0.78	0.36	0.08	355	73	14.9	343	183	42.5	66.3
TOR-90-00069-CS	49.4	11.1	4.70	3.63	17.71	0.76	2.45	0.62	0.23	0.06	283	69	12.7	456	160	29.0	57.7
TOR-90-00019-CS	48.2	11.3	4.48	4.88	14.20	1.05	1.77	0.66	0.23	0.06	302	74	14.7	571	179	30.2	62.3
TOR-90-00068-CS	48.2	10.7	4.43	7.98	10.73	0.91	1.55	0.60	0.25	0.06	274	61	12.6	355	170	28.3	58.5
TOR-90-00038-CS	46.8	10.3	4.14	7.11	10.97	0.50	1.76	0.58	0.21	0.06	249	64	11.5	375	148	28.2	55.8
TOR-90-00009-CS	55.0	13.4	5.46	3.12	16.40	1.20	1.76	0.75	0.26	0.07	357	85	15.3	435	195	33.6	67.5
TOR-90-00023-CS	47.2	10.2	5.90	7.85	11.29	0.57	1.71	0.58	0.20	0.06	275	85	11.3	317	159	26.9	55.4
TOR-90-01207-CS	67.3	16.9	4.73	1.20	2.20	2.33	2.14	0.53	0.10	0.06	1018	114	12.9	336	121	11.8	28.7
TOR-90-00164-CS	62.8	18.3	4.93	1.26	3.18	2.84	1.72	0.62	0.14	0.07	972	58	15.0	430	174	43.8	71.3
TOR-90-00031-CS	68.6	18.0	5.19	1.66	<LLD	0.49	3.95	0.74	0.09	0.02	342	43	11.2	81	199	37.8	75.9
TOR-90-00071-CS	63.6	18.1	5.24	1.78	0.75	0.87	3.84	0.80	0.18	0.03	453	97	17.1	90	183	31.6	69.1
TOR-90-00016-CS	49.8	10.9	5.20	8.15	10.10	0.48	1.75	0.62	0.29	0.06	239	71	13.7	334	166	28.3	57.8
TOR-90-00040-CS	51.4	11.0	4.37	3.04	16.59	0.98	2.19	0.67	0.21	0.06	330	65	14.0	406	177	31.0	60.0

Analysis results: SiO2 silicon; Al2O3 aluminium; Fe2O3 iron; MgO magnesium; CaO calcium; Na2O sodium; K2O potassium; TiO2 titanium; P2O5 phosphorus; MnO manganese (all in weight percent). Ba barium; Cr chromium; Sc scandium; Sr strontium; Zr zirconium; La lanthanum; Ce cerium (all in parts per million).

Table 4B. Descriptions of samples analyzed by ICPS from the Tortugas shipwreck and full set of results.

Tortugas Type	Key *	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
Olive Jar Type 1	Mean	49.9	13.0	5.36	5.16	9.66	0.68	2.51	0.65	0.2	0.07	336	117	16.9	390	98	29.1	57.9
	S.D.	2.8	0.9	0.46	1.10	2.12	0.12	0.32	0.04	0.0	0.01	21	80	2.1	145	15	2.4	3.4
	C.V.	5.6	6.7	8.6	21	22	17	13	6.5	14	9.8	6.2	69	13	37	16	8.3	5.8
Olive Jar Type 2	Mean	56.5	11.8	5.36	2.74	10.2	0.84	2.30	0.62	0.2	0.05	318	79	17.2	323	115	24.5	53.8
	S.D.	5.2	2.2	1.05	1.05	2.54	0.21	0.78	0.07	0.1	0.02	90	8	1.0	59	7	3.2	6.2
	C.V.	9.2	19	20	38	25	25	34	11	26	45	28	11	6.1	18	6	13	11
Compare: Clay SE-2 (GG & GR 1964) (recalc analysis)			11.2	6.34	1.37	10.5	0.68	0.52	0.84									
Compare: Clay SE-24 (GG & GR 1988) (original analysis)		55.5	11.5	5.80	3.05	10.4	0.57	2.77	0.57									

* Mean = average; S.D. = one standard deviation about the mean; C.V. = coefficient of variation: standard deviation expressed as a percentage of the mean.
Analysis results: SiO2 silicon; Al2O3 aluminium; Fe2O3 iron; MgO magnesium; CaO calcium; Na2O sodium; K2O potassium; TiO2 titanium; P2O5 phosphorus; MnO manganese (all in weight percent). Ba barium; Cr chromium; Sc scandium; Sr strontium; Zr zirconium; La lanthanum; Ce cerium (all in parts per million).

Table 5A. Average compositions of olive jars Type 1 and 2 with comparative published analyses of Seville clays.

Tortugas Type	Key *	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
Type 1A Seville Blue on Blue	Mean	50.1	14.1	5.80	3.34	17.4	1.27	1.69	0.79	0.20	0.10	367	90	16.5	463	137	32.1	66.3
	S.D.	4.2	1.7	0.97	0.75	1.9	0.31	0.34	0.10	0.0	0.04	65	22	2.4	79	34	3.3	6.3
	C.V.	8.4	12	17	22	11	25	20	13	15	37	18	24	14	17	25	10	9.4
Type 1B Seville Blue on Blue	Mean	52.4	15.0	6.37	3.43	15.1	1.48	1.62	0.80	0.2	0.11	424	80	19.1	456	148	36.8	68.4
	S.D.	3.4	0.6	0.33	0.29	1.4	0.31	0.47	0.06	0.0	0.01	37	6	1.9	50	12	10.8	1.6
	C.V.	6.4	3.8	5.2	8.3	9.6	21	29	7.9	8.7	7.9	8.6	8	9.7	11	8	29	2.4
Type 2A Blue on White	Mean	51.9	13.7	5.00	2.58	17.0	1.16	1.80	0.86	0.3	0.04	290	80	14.7	302	133	27.8	60.3
	S.D.	0.9	0.3	0.27	0.44	2.3	0.17	0.37	0.04	0.1	0.00	26	3	1.1	48	6	1.1	1.5
	C.V.	1.7	2.2	5.4	17	14	15	20	4.3	26	4.0	9.0	3	7.6	16	4	4.0	2.4
Type 4 Seville White	Mean	52.5	13.5	4.87	2.93	16.9	1.25	2.02	0.82	0.3	0.03	313	77	15.2	315	157	31.7	68.3
	S.D.	1.9	0.5	0.21	0.19	3.1	0.30	0.65	0.01	0.1	0.00	14	6	0.7	36	23	1.9	3.3
	C.V.	3.6	3.5	4.3	6.3	18	24	32	1.4	29.6	11	4.3	8	4.7	11	15	6.1	4.9
Type 5A Seville Polychrome	Mean	54.2	14.5	7.94	2.99	13.5	1.06	1.90	0.79	0.3	0.10	383	78	16.8	420	175	36.2	68.8
	S.D.	1.6	0.8	3.22	0.29	3.8	0.13	0.04	0.02	0.1	0.01	25	5	1.7	69	21	5.5	2.4
	C.V.	3.0	5.7	41	9.7	28	13	2.1	2.1	29	15	6.7	7	9.9	16	12	15	3.5
Compare: Clay SE-4 (GG and GR 1966) (recalc analysis)		59.7	13.5	2.25	0.84	10.1	1.91	1.79	0.27									
Compare: Clay SE-45 (GG and GR 1966) (recalc analysis)		56.7	11.2	2.88	0.58	18.2	2.05	1.67	0.20									
High Magnesium Group	Mean	48.0	10.6	4.75	8.90	9.68	0.65	1.55	0.59	0.23	0.06	259	69	12.5	307	159	27.7	55.9
	S.D.	1.6	0.4	0.71	1.81	1.88	0.16	0.24	0.02	0.04	0.00	20	9	1.1	63	8	0.8	1.9
	C.V.	3.2	3.5	14.9	20	19	25	16	3.9	15.3	6.0	7.6	13	9.1	20	5	3.1	3.4
Type 6-8 Pottery with a 'Seville' Clay Composition	VB45	49.4	11.1	4.70	3.63	17.7	0.76	2.45	0.62	0.23	0.06	283	69	12.7	456	160	29.0	57.7
	VB46	48.2	11.3	4.48	4.88	14.2	1.05	1.77	0.66	0.23	0.06	302	74	14.7	571	179	30.2	62.3
	VB49	55.0	13.4	5.46	3.12	16.4	1.20	1.76	0.75	0.26	0.07	357	85	15.3	435	195	33.6	67.5
	VB56	51.4	11.0	4.37	3.04	16.6	0.98	2.19	0.67	0.21	0.06	330	65	14.0	406	177	31.0	60.0

* Mean = average; S.D. = one standard deviation about the mean; C.V. = coefficient of variation: standard deviation expressed as a percentage of the mean.
Analysis results: SiO2 silicon; Al2O3 aluminium; Fe2O3 iron; MgO magnesium; CaO calcium;
Na2O sodium; K2O potassium; TiO2 titanium; P2O5 phosphorus; MnO manganese (all in weight percent).
Ba barium; Cr chromium; Sc scandium; Sr strontium; Zr zirconium; La lanthanum; Ce cerium (all in parts per million).

Table 5B. Average compositions of main 'Seville' chemical groups among the Tortugas shipwreck pottery samples, with single examples of other Types matching these patterns and comparative published analyses of Seville clays.

	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
Pureza Street Kiln: Plain White Morisco (Myers *et al.*, 1992)																	
Mean			4.70		22.7	0.77	1.74				409	75	11.3	497		34.1	59.4
Standard Deviation			0.22		5.1	0.17	0.27				76	8	0.6	69		1.7	3.2
Coefficient of Variation			4.9		23	22	16				19	11	5.3	14		4.9	5.4
Santa Catalina de Guale: Plain White Morisco (Myers *et al.*, 1992) – Mean																	
Mean			5.30		16.7	0.94	1.32				448	88	13.1	465		41.2	71.3
Standard Deviation			0.24		2.6	0.14	0.26				45	5	0.6	90		1.9	3.6
Coefficient of Variation			4.5		15.5	14.5	21.3				10.0	5.9	4.8	19.3		4.5	5.1
Seville (Inanez *et al.*, 2008) – Mean																	
Mean		11.2	4.59		20.7	0.88	1.72	0.57		0.084	343	72	11.2	456	135	30.9	61.9
Standard Deviation		1.1	0.00		1.7	0.23	0.43	0.06		0.018	130	7	1.0	64	16	1.8	3.5
Seville Lustreware Workshop (Polvorinos del Rio and Castaing, 2009) – Mean																	
Mean	49	11.6	3.80	3.50	22.0	0.90	1.80	0.50	0.20	0.07	281	75		423	155		
Standard Deviation	1.7	0.4	0.24	0.42	2.2	0.21	0.7	0.03	0.04	0.01	33	30		13	32		
Seville White, Mexico City (Rodriguez-Alegria *et al.*, 2003) – Mean																	
Mean		14.1	4.10		17.7	0.71	2.49	0.61		0.06	405	42	10.7	327	189	40.6	80.6
Standard Deviation		0.8	0.22		0.7	0.08	0.48	0.06		0.01	50	3	0.6	40	19	3.1	3.7
Coefficient of Variation		6.0	5.4		3.9	11	19	9		8	12.3	6.0	5.3	12.1	9.9	7.7	4.6

Note: a blank in the analysis Table indicates element/s not measured.

Table 6A. Comparative published analyses of pottery not fitting the general chemical pattern for the Tortugas Seville wares.

	Si02	Al203	Fe203	MgO	CaO	Na20	K20	TiO2	P205	MnO	Ba	Cr	Sc	Sr	Zr	La	Ce
	50.1	14.1	5.80	3.34	17.4	1.27	1.69	0.79	0.2	0.10	367	90	16.5	463	137	32.1	66.3
Standard Deviation	4.2	1.7	0.97	0.75	1.9	0.31	0.34	0.10	0.0	0.04	65	22	2.4	79	34	3.3	6.3
Coefficient of Variation	8.4	12	17	22	11	25	20	13	15	37	18	24	14	17	25	10	9.4
Tortugas Olive Jar, Type 2 (Redware) – Mean																	
	56.5	11.8	5.36	2.74	10.2	0.84	2.30	0.62	0.2	0.05	318	79	17.2	323	115	24.5	53.8
Standard Deviation	5.2	2.2	1.05	1.05	2.54	0.21	0.78	0.07	0.1	0.02	90	8	1.0	59	7	3.2	6.2
Coefficient of Variation	9.2	19	20	38	25	25	34	11	26	45	28	11	6.1	18	6	13	11
Tortugas Single Pottery Vessels of Unusual Analysis																	
VB45	49.4	11.1	4.70	3.63	17.7	0.76	2.45	0.62	0.23	0.06	283	69	12.7	456	160	29.0	57.7
VB46	48.2	11.3	4.48	4.88	14.2	1.05	1.77	0.66	0.23	0.06	302	74	14.7	571	179	30.2	62.3
VB56	51.4	11.0	4.37	3.04	16.6	0.98	2.19	0.67	0.21	0.06	330	65	14.0	406	177	31.0	60.0
Tortugas Pottery High Magnesium Group																	
VB36	49.9	11.1	4.78	11.65	8.65	0.67	1.35	0.62	0.25	0.07	280	69	13.9	229	161	28.3	54.6
VB38	46.3	10.3	4.06	10.68	6.36	0.75	1.16	0.56	0.19	0.06	237	62	11.9	231	152	26.4	53.4
VB47	48.2	10.7	4.43	7.98	10.7	0.91	1.55	0.60	0.25	0.06	274	61	12.6	355	170	28.3	58.5
VB48	46.8	10.3	4.14	7.11	11.0	0.50	1.76	0.58	0.21	0.06	249	64	11.5	375	148	28.2	55.8
VB50	47.2	10.2	5.90	7.85	11.3	0.57	1.71	0.58	0.20	0.06	275	85	11.3	317	159	26.9	55.4
VB55	49.8	10.9	5.20	8.15	10.1	0.48	1.75	0.62	0.29	0.06	239	71	13.7	334	166	28.3	57.8
Tortugas Pottery Redware (Non-Calcareous Clay) with Very High Aluminium & High Potassium																	
VB54	63.6	18.1	5.24	1.78	0.75	0.87	3.84	0.80	0.18	0.03	453	97	17.1	90	183	31.6	69.1
VB53	68.6	18.0	5.19	1.66	<LLD	0.49	3.95	0.74	0.09	0.02	342	43	11.2	81	199	37.8	76
Portugal Pottery (Inanez *et al*., 2009) – Mean of Two Vessels																	
		10.9	3.96		27.9	1.00	1.16	0.75		0.03	160	80	10.0	359	146	27.0	56.0
Standard Deviation		0.8	0.11		1.1	0.32	0.42	0.03		0.01	0	4.0	1.0	16	11	2.0	4.0
Tortugas Colonoware Cooking Wares																	
VB51	67.3	16.9	4.73	1.20	2.20	2.33	2.14	0.53	0.10	0.06	1018	114	12.9	336	121	11.8	28.7
VB52	62.8	18.3	4.93	1.26	3.18	2.84	1.72	0.62	0.14	0.07	972	58	15.0	430	174	43.8	71.3

Note: a blank in the analysis Table indicates element/s not measured.
Al to Al2O3: 1.889; Fe to Fe2O3: 1.431; Ca to CaO: 1.399; Mg to MgO: 1.658; Na to Na2O: 1.348; K to K2O: 1.205; Ti to TiO2: 1.668; Mn to MnO: 1.291.

Table 6B. Analyses of pottery not fitting the general chemical pattern for Seville wares, including single vessels from the Tortugas shipwreck.

before analysis probably removed significant amounts of these components, the comparison with the olive jars are of limited value: the proportions of alumina, iron and lime are approximately the same, but not sufficient as proof of comparable origins.

B. Principal Components Analysis (PCA)

By contrast, in Principal Components Analysis the source identifications do not form part of the statistical tests themselves, but for ease of interpreting the PCA plots (Fig. 7) the type for each sample analyzed is shown by the appropriate type symbol. In this method of analysis the elements that contribute towards the principal component scores (i.e. which determine the 'shape' of plots, such as Fig. 7) are those with the largest spread (standard deviation) among all the samples analyzed – these may well not be the elements that best show differences between groups, which discriminant analysis seeks out for a set of analyses. Variations between in this case different types are particularly highlighted. If the types were essentially all the same in the chemistry of the clay fabric, no systematic differences in their principal components would result. Principal components analysis used the same elements as for the Discriminant Analysis on the ICPS results, and again each point represents one sample of pottery on this composition 'map'.

Some types show a clear patterning (Fig. 7). For example, all the Tortugas Type 2 olive jars apart from one lie in the center right of the plot. The Type 1A Seville Blue on Blue tin-glazed wares split into two groups: the main group lies in the upper part of the plot, overlapping with the Type 5A Seville Polychrome and the Type 1B bowls, which form a single compact group of points. The smaller group of three Type 1A-1B Seville Blue on Blue plates (TOR-90-00045, TOR-90-00046-CS and TOR-90-00086) lies at the bottom left of the distribution of items, next to the group of Type 2A Seville Blue on White plates. The split in the Type 1A tin-glazed pottery may indicate production at two different Seville workshops (one of which also made the Type 2A vessels), or perhaps slightly different chronological periods of manufacture at the same workshop.

The Plain White Morisco tin-glazed pottery clearly splits into three groups. The 'high magnesium' group of ceramics plots at the extreme top of the scatter of points. The Type 7 Decorated Blue Morisco wares and the single Type 8A Mottled Blue Morisco plot just below the 'high magnesium' group at the top of the distribution of points, and show some separation of the Morisco from the Seville wares, which occupy the area below them. The differences between the broad Seville and Morisco types seen in the discriminant analysis are rather less evident in this principal components plot (Fig. 6). The first three principal components account for 67% of the chemical variation in this selection of the pottery, so the plot pattern accurately represents relationships between the different types (the first component contained 41%, the second 15% and the third 11%).

Of the components used to plot Fig. 7, the second component has higher levels towards the top of the figure for magnesium, manganese and zirconium, but lower levels of titanium and potassium. Pottery with this pattern of analysis will plot towards the top. The third component has higher levels to the right of potassium and iron, but lower levels of calcium and sodium. Pottery with this pattern of analysis will plot towards the right of the figure.

5. ICPS Results: Main Seville Chemical Group

The ICPS analysis of the Tortugas shipwreck pottery clearly revealed that numbers of different types seem to fall into two major chemical groups as previously described, with the Type 1 olive jars having a rather different chemistry. First, a fairly clear main chemical group was identified, which only contained Seville wares (Fig. 6). Second, a smaller number of tin-glazed types are closely related chemically to each other: one Type 3B Plain White Morisco plate is very similar to the Type 6 Linear Blue Morisco jar, Type 6C Linear Blue Morisco bowl and one of two Type 7 Decorated Blue Morisco pitchers, and only slightly different to them are the Type 2 olive jars. Intermediate in clay chemistry between the pair (Type 3 and Type 6 on the one hand, and the Type 2A Seville Blue on White tin-glazed plates on the other) is the Type 4 Seville White ware. The provisional hypothesis is that the second series of types, as well as the first, represent production in Seville, and that the separate 'first' and 'second' groups of types reflect slightly different blends of clay sources used by Seville potters.

Not all the remaining types conformed to these patterns. All individual types are listed below with comments on their homogeneity and chemical characteristics.

The main Seville composition group (Fig. 6) in fact comprises all the 'Sevilla Wares' defined by Lister and Lister (1982: 57-61), which are tin-glazed pottery varieties produced in Spain in response to Italian influences. But as these authors point out, the wares have not been reported formerly from Seville itself. The present analytical project has shown that the fabric of the analyzed examples of 'Sevilla wares' bear all the chemical characteristics of Seville products, including Seville clays (Gonzalez Garcia *et al.*, 1964).

However, they show a recognisable difference to chemical analyses of earlier Morisco wares produced in Seville, such as Isabela Polychrome (Blue and Purple Morisco ware) and Columbia Plain (Plain White Morisco) (Olin *et al.*, 1978). While the clay used for the later 'Sevilla Wares' is generally comparable to the previous Morisco series of wares, the later pottery appears to have been a blend of light-firing clay mixed with material from a different origin. The clay remains light in color, but tends more often to a buff or pinkish tone rather than oyster white, and is fine grained and denser than the paste used earlier (Lister and Lister, 1982: 57).

These observations are borne out in the present study by the chemical differences found between the 'Sevilla' and 'Morisco' wares shown in the two groupings of pottery in the discriminant analysis of the chemical examination (Fig. 6). These differences amount to a greater proportion of plastic clay in the later Seville wares and lower proportion of lime. This appears to be the first occasion when this chemical difference in the fabric of the two series of wares has been identified, probably because previously few of the later 'Sevilla' wares have been analyzed, which could be compared against the much larger number of 'Morisco' wares studied especially from New World sites (Olin *et al.*, 1978). Clays similar in chemistry to the Tortugas types listed above have been found by Gonzalez and Garcia Ramos near Seville (1966: clays SE-4 at La Panoleta; SE-45 and SE-46 at Castilleja de Guzman; Table 5B).

From the discriminant analysis and principal components analysis, a series of types have a very close chemical relationship, with overlapping chemistry, indicating manufacture from the same single clay type, allowing for small natural variations caused by slightly different batches and clay preparation. These groups are:

A. Tortugas Type 1A/1B (Seville Blue on Blue Plates) (Figs. 2A-2N)

All 14 samples of the Type 1A-1B Seville Blue on Blue tin-gazed wares analyzed (Figs. 2A-2N; Table 2) were very similar chemically to each other and to four Seville Blue on Blue Type 1C bowls and to Seville Blue on White 2A plates, with the exception of three exemplars, which discriminant and principal components analysis showed were more similar chemically to the Type 2A Blue on White examples than to the other group Type 1A-1B wares, namely:

- VB19: Seville Blue on Blue Plate (TOR-90-00045-CS; Fig. 2H)
- VB23: Seville Blue on Blue Plate (TOR-90-00086-CS; Fig. 2K)
- VB24: Seville Blue on Blue Plate (TOR-90-00058-CS; Fig. 2L)

The Seville Blue on Blue type category appeared in the New World on sites dating after *c.* 1550, peaked about 1600 and fell into disuse around 1630-40 (Deagan, 1987, 63). In a system devised by Goggin, the type was formerly named Ichtucknee Blue on Blue. These wares can be difficult to identify and classify because they can be confused with contemporaneous, extremely similar Italian prototypes that provided the inspiration for the Spanish versions (Deagan, 1987, 61). The confusion is most apparent for the blue-ground wares. However chemical analysis is able to distinguish between the fabric of Italian, Spanish and Mexican versions of 'Sevilla wares'.

The present ICPS investigation appears to be the first in which significant numbers of Seville Blue on Blue wares have been chemically analyzed. Although substantial numbers of sherds of Spanish pottery have been examined in the past, including those found in the Caribbean and Venezuela (Olin *et al.*, 1978), and from a kiln site in Seville (Myers *et al.*, 1992), the Tortugas pottery is later in date. For example, no Isabela Polychrome (Blue and Purple Morisco ware) was recovered from the Tortugas shipwreck, a class of tin-glazed pottery that is firmly dated in the Americas between the late 15th and first third of the 16th century (Hurst *et al.*, 1986: 54). It is not encountered after 1550 and does not occur off Ireland in the Armada wrecks of 1588.

In contrast, Blue on Blue tin-glazed wares were produced between the end of the 16th century and through the 17th century. In earlier analytical projects, relatively few examples were analyzed. Previous studies did not reveal the presence of more than one chemical pattern among the results, demonstrating the difficulty in correctly identifying this ware on consumer sites. By appearance this ware may be easily confused for Ligurian Blue on Blue ware (Italian *berettino*), which was copied by Spanish potters under the influence of migrant Italian tin-glazed potters (Hurst *et al.*, 1986, 53). However chemical analysis easily distinguishes the original Ligurian from the Spanish copies: the Ligurian material has substantially higher chromium concentrations than the Spanish wares (Hughes, 1991: 57-8; Myers *et al.*, 1992: 26, quoting data obtained by the present author).

Some Blue on Blue tin-glazed pottery has been attributed to production in Talavera, Spain, but chemical analysis (Inanez, 2007; Inanez *et al.*, 2007; 2008; 2009) confirms that Talavera tin-glazed ceramics have quite distinctive differences to Seville wares (see below under Seville Blue on White). None of the Tortugas Type 1 pottery bears the signature of Talavera (or of Liguria). All the Tortugas Blue on Blue pottery analyzed is of Seville manufacture. The absence on the Tortugas shipwreck of pottery from Ligurian and Talaveran sources may be of some historical significance and interest.

B. Tortugas Type 1C & Type 1D (Seville Blue on Blue Bowls & Jug) (Figs. 2O, 3A-3D)

All four Tortugas Type 1C Seville Blue on Blue bowl samples formed a consistent chemical composition group, overlapping with the Type 1A Seville Blue on Blue plates and Type 5A Seville Polychrome jugs:

- VB27: Seville Blue on Blue Bowl (TOR-90-00049-CS; Fig. 3A)
- VB28: Seville Blue on Blue Bowl (TOR-90-00051-CS; Fig. 3B)
- VB29: Seville Blue on Blue Bowl (TOR-90-00048-CS; Fig. 3C)
- VB30: Seville Blue on Blue Bowl (TOR-90-00056-CS; Fig. 3D)

These analyzed wares are of Seville manufacture, possibly from the same workshop(s) as the Type 1A products given their close chemical similarity in clay fabric (Fig. 6, Table 5B).

Analysis of a single Tortugas Type 1D Seville Blue on Blue jug (VB42: TOR-90-00035-CS; Fig. 2O) displayed the same chemical profile as Types 1A and 1B.

C. Tortugas Type 2A (Seville Blue on White Plates) (Fig. 3E-3H)

All four examples of Tortugas Type 2A Seville Blue on White plates (Figs. 3E-3H) formed a consistent chemical composition group, similar chemically to the three Type 1A plates discussed above, and to the two examples of Type 4 Seville White wares (see their position in Fig. 6):

- VB31: Seville Blue on White Plate (TOR-90-00015-CS; Fig. 3E)
- VB32: Seville Blue on White Plate (TOR-90-00017-CS; Fig. 3F)
- VB33: Seville Blue on White Plate (TOR-90-00057-CS; Fig. 3G)
- VB34: Seville Blue on White Plate (TOR-90-00090-CS; Fig. 3H)

This variety of tin-glazed pottery has been suggested to be a Talavera-style product of a genre originally manufactured in the town of Talavera de la Reina in the western province of Toledo in central Spain. Assigning this type to its origin when found on New World sites is difficult because the style was copied in Seville (Deagan, 1987: 64-5).

The current chemical analysis clarifies that the four samples from the Tortugas wreck were all produced in Seville and not Talavera, since they share the same chemical analysis of body fabric as definite Seville products. In addition to their similarity to the Type 1A Seville Blue on Blue plates, they exhibit different analyzed profiles to examples of Talaveran tin-glazed wares, such as those recently published by Inanez *et al.* (2008: table 3). Average concentrations are compared in Table 5B with the average for the four Tortugas Type 2A Blue on White plates.

Cluster analysis and principal components applied to the Seville and Talavera tin-glazed pottery has identified two chemically distinct groups by site (Inanez *et al.*, 2010: 282, fig. 2). There were clear chemical differences between the products of the two sites: higher concentrations in Seville wares of sodium, strontium, manganese, vanadium and chromium, but lower concentrations of caesium, rubidium and potassium. Talaveran-style products were also manufactured in Puebla, Mexico, but these products are different again from the Seville products (typical analyses of the Mexican variety are presented in Olin and Blackman, 1989) and none of the Tortugas examples show similarities to the Mexican variety.

D. Tortugas Type 3 (Plain White Morisco Ware) (Fig. 3I-3L)

The Tortugas wreck's Type 3 Plain White Morisco tin-glazed wares show a mixture of chemical compositions. Four examples were analyzed. One Type 3B plate (VB35: TOR-90-00013-CS; Fig. 3I) overlapped chemically with the Type 1A Seville Blue on Blue plates and is thus indicative of production within Seville.

However, another two examples formed part of the 'high magnesium' chemical group originating in a rural context west of Seville (see section 6A below): a Type 3B plate (VB36: TOR-90-00030-CS; Fig. 3J) and a Type 3D bowl (VB38: TOR-90-00073-CS; Fig. 3L). These two vessel samples are very similar to some Type 6-8 Linear, Decorated and Mottled Blue Morisco wares (Fig. 6), and only slightly different to the Type 2 olive jars.

Finally, the Type 3C flanged plate (VB37: TOR-90-00047-CS; Fig. 3K) proved to be an 'outlier' (i.e. chemically not like other items), containing high potassium (3.0%) and rare earths (lanthanum and cerium), and low magnesium (1.35%), chromium (49 ppm) and zirconium (118 ppm). It does not appear to be consistent with Seville pottery in its chemical composition. Plain White wares produced in Mexico, and excavated at Mexico Cathedral, were analyzed by the Smithsonian (Olin *et al.*, 1978, table IV), but are significantly different in clay chemistry to the Tortugas plate, which does not seem to have been made of Valley of Mexico clays. The question of whether it may have been made in Lisbon cannot be confirmed or denied due to the lack of comparative material. However, it is not chemically like two published examples of Portuguese faience (Inanez *et al*., 2009). The lack of published comparative analyses means its origin is not answerable at present based on the current analysis.

There is archaeological evidence that Plain White Morisco pottery comprised the basic table product on Spanish ships. Numerous examples are known from vessels dating between 1559 off Florida, 1588 off Ireland and of course 1622 (Kingsley, 2014: 63, table 7). If this ware was so prevalent, production at multiple locations might be expected. The Plain White Morisco wares found at the site of Santa Catalina de Guale, St Catherine's Island, Georgia, showed a variety of chemical patterns, including those closer to the Seville products analyzed from the Tortugas shipwreck (Myers *et al*., 1992).

E. Tortugas Type 4 (Seville White Ware) (Fig. 3M-3N)

Two examples of Tortugas Type 4 Seville White wares were analyzed, a Type 4B bowl (VB39: TOR-90-00036-CS; Fig. 3N) and a Type 4C cup (VB41: TOR-90-00065-CS; Fig. 3M). Both were similar to each other chemically and close to Type 2A Seville Blue on White plates and the Type 2 olive jars, but lay between the Seville Blue on White, the Linear/Decorated/Mottled Blue Morisco Seville varieties and one Type 3B Plain White Morisco plate. They contain more lime and alumina than the Type 2 olive jars, which could be the result of the mixing of some 'fat' clay of the Triana district with the 'short' clay used for the latter. Fat (long) clay has a high plasticity and strength (high percentage of clay minerals); short (lean) clay has a lower plasticity and strength and lower percentage of clay minerals (Hamer and Hamer, 2004).

The separation from the main Tortugas Type 1 and Type 2 suggests a closer affinity to the 'long' clay end of the spectrum. Seville White ware is one of the 'Sevilla wares' identified by Lister and Lister, and is distinguished from the earlier Plain White Morisco products by its fabric color and forms (Deagan, 1987: 61). While the Plain White Morisco wares analyzed in this project had divergent compositions, the Seville White pair are chemically very similar, like the other 'Sevilla Wares' examined, suggesting closer control over their production and manufacture in limited numbers of workshop(s) located in Seville itself.

They differ slightly in chemical profile from ten examples of Seville White found in Mexico City, whose average is specified in Table 6A (Rodriguez-Alegria *et al*., 2003; analyses MTM293-298, 305-308 available on-line from the Missouri University Research Reactor (MURR) website). The Mexico City examples differ in having lower levels of sodium, titanium, chromium and scandium, but slightly higher lanthanum and cerium. A different workshop may have been responsible for their production.

F. Tortugas Type 5A (Seville Polychrome Jugs) (Fig. 4A-4B)

The two samples of Tortugas Type 5A Seville Polychrome jugs (VB43: TOR-90-00032-CS, Fig. 4A; VB44: TOR-90-00070-CS, Fig. 4B) formed a consistent chemical composition group, overlapping with Seville Blue on Blue Type 1A and Type 1B. The author is not aware of any previous analyses of Seville Polychrome. The Tortugas shipwreck project, therefore, has for the first time indicated that this type has the most common later-period chemical composition found for Seville-produced tin-glazed pottery.

Although no Isabela Polychrome (Blue and Purple Morisco) pottery was found on the Tortugas wreck, previous analyses of this type by different research groups have shown that its chemical composition corresponds to the earlier Morisco pattern for Seville pottery, but differs from the later Seville Polychrome. Examples of analyses of the Isabela type include Spanish imports found in the New World in the Dominican Republic and Venezuela (Olin *et al*., 1978).

G. Tortugas Types 6-8 (Linear, Decorated & Mottled Blue Morisco Ware) (Fig. 4C-4H)

Six examples of Tortugas Types 6-8 Linear, Decorated and Mottled Blue Morisco wares were analyzed for this project. Of these, three are identifiable as Seville clays. The Type 6A Linear Blue Morisco jar (VB45: TOR-90-00069-CS; Fig. 4C) proved to be close to Type 1B Seville Blue on Blue bowls. The Type 6C Linear Blue Morisco bowl (VB49: TOR-90-00009-CS; Fig. 4D) is closely similar to Seville Blue on Blue Types 1A and Seville Polychrome 5A, so is a 'regular' Seville composition. A Type 7 Decorated Blue Morisco pitcher (VB46: TOR-90-00019-CS; Fig. 4F) was close to Type 1A Seville Blue on Blue plates.

Although principal components analysis shows the similarity of these two samples to the Type 1 tin-glazed ceramics, their analysis has a lower percentage of alumina than the latter. This suggests a significant proportion of 'lean' clay in the clay mixture, like the Type 4 Seville White ware.

A further three of these Morisco tin-glazed wares proved to relate to the 'high magnesium' chemical group (see section 6A below): Type 6D Linear Blue Morisco jug (VB50: TOR-90-00023-CS; Fig. 4E), Type 7 Decorated Blue Morisco pitcher (VB47: TOR-90-00068-CS; Fig. 4G), Type 8A Mottled Blue Morisco cup (VB48: TOR-90-00038-CS; Fig. 4H). The co-production of Type 7 pitchers at different sources is an especially important trend.

H. Tortugas Type 2 Olive Jars (Botijas) (Fig. 1G-1J)

The four Tortugas Type 2 red-ware olive jars analyzed (VB1-VB6; Fig. 1G-1J) form a consistent chemical group, not overlapping with any other Seville type, but lying chemically between the 'Main Seville' group and the two examples of Type 4 Seville White ware. Lister and Lister (1987: 80-82) reviewed the production of Andalusian olive jars and similar containers used for foodstuffs export. As during the Roman period, the containers may have been made in the same place where the content was processed, or urban workshops may have provided shipping containers for agricultural goods sent in bulk to the port.

A red-firing clay with mica and metamorphic rock inclusions is widespread in southern Spain and was used in Seville to make many heavy duty objects and tiles (Lister and Lister, 1987: 81). This analysis (Table 5A) shows that the characteristic feature of the Tortugas wreck's Type 2 olive jars is relatively low alumina (average 11.8%) and lime (average 10.2%) compared to the finer tin-glazed ceramics. Gonzalez Garcia and Garcia Ramos (1964) published profiles of clays found very close to Seville, which produced clay that is very similar to these olive jars (clay SE-2). This is a sample of the 'Arcilla magra' (lean clay with a high percentage of sand: 65% total) of the Vega of Triana, usually mixed with the 'Arcilla grasa' (fat clay, lower sand percentage: 25% total) used in modern local industry. Its high percentage of sand, however, would make it very suitable for heavy olive jars.

Its published analysis has been recalculated for comparison with the Tortugas Type 2 olive jars (Table 5A). The published chemical analysis was of the clay fraction of the clay alone. However, the percentages of clay, sand and lime were given (Gonzalez Garcia and Garcia Ramos, 1964: 498, table V) and from this it is possible to 'reconstitute' the overall chemical analysis.

Comparing the results in Table 5A, there is a very close similarity for all the major elements, including the characteristic low alumina and lime, compared to other Tortugas types, except potassium and magnesium, strongly suggesting that the 'lean clay' deposits found in Seville itself were used for the Tortugas Type 2 olive jars. The lower percentages of the two elements in the 'reconstituted' analysis of the clay fraction could well result from the laboratory processing of the original clay prior to analysis: the clay fraction was probably separated by acid dissolution (although details were not published). Some of the magnesium present as carbonate would definitely be dissolved, while potassium is a soluble element and may have been lost too in the same process.

The published clay was collected from the Vega del Triana, 400m west of the riverbed of the Guadalquivir River near the cart road from La Panoleta to San Juan of Aznalfalache. The analysis of this local Seville clay demonstrates that suitable clay matching that used for the Tortugas Type 2 olive jars was available within Seville itself, close to the potter's quarter. The selection of the sand-rich clay for these containers seems technically appropriate. It suggests that of the two rural/urban location modes for production of these jars in Andalusia (Lister and Lister, 1987: 80), urban workshops in the Triana district produced these containers for agricultural goods sent in bulk to Seville.

Blue marl clay matching the Tortugas Type 2 olive jars was also found further downstream in the new channel of the Rio Guadaira near Dos Hermanas, some 8km southwest of Seville in a 2m-thick layer (Gonzalez Garcia *et al.*, 1988: 216, 217, table 1, sample 24) (recalculated analysis cited in Table 5A). These marls outcrop at different points on the banks of the Guadalquivir River from the vicinity of Seville to over 100km northeast of Seville.

This may well represent a further deposit of the red-firing 'lean' clay. In this case, the reported analysis is of the whole sample (fraction less than 0.12mm) without treatment to remove the carbonates, so is directly comparable to the Tortugas analyses without further calculations. Its mineral proportions were determined and are instructive: the clay minerals were smectite (less than 5%), illite (37%) and kaolinite (5%); it also contained quartz (24%), plagioclase feldspar (9%) and lime (19%). The clay minerals (total 47%) were thus about twice the proportion of quartz (24%). The Dos Hermanas clays were generally employed in the making of tiles from historical times (Gonzalez Garcia *et al.*, 1988: 223).

I. Tortugas Type 4 Jars (Fig. 1K)

The single example of the flat-based Tortugas Type 4 jar analyzed (VB11: TOR-90-00018-CS; Fig. 1K) is close in chemistry to the Type 2 olive jars (Fig. 7). Its body fabric contains a comparable amount of lime and is similar in all other chemical elements. A comparable Seville origin is indicated.

6. ICPS Results: Pottery with Divergent Chemistry

A. 'High Magnesium' Group

The ICPS results for the Tortugas shipwreck identified a series of individual pots with a very distinctive high percentage of magnesium in their clay (Tables 4A-4B, 5B), very unlike the regular and fairly consistent levels found in the rest of the sampled pottery (typically 2-3%). This is accompanied by lower levels of calcium, which suggests that there may be a source of dolomitic limestone (a calcium/magnesium carbonate) distantly involved in the material that eventually formed the clay. Dolomitic limestone occurs either where magnesium-bearing solutions have acted upon limestone or as a gangue mineral in hydrothermal veins associated particularly with galena.

There are extensive deposits of galena within southern Spain not far distant to the west of Seville, which might be the original source of the extra magnesium incorporated into the clay, which otherwise has features common to other Seville pottery. The unusual feature of the 'high magnesium' pottery found among the assemblage analyzed (Table 5B) is that they represent a diversity of pottery types, as follows:

- Type 3B, Plain White Morisco Plate (VB36: TOR-90-00030-CS; Fig. 3J)
- Type 3D, Plain White Morisco Bowl (VB38: TOR-90-00073-CS; Fig. 3L)
- Type 7, Decorated Blue Morisco Pitcher (VB47: TOR-90-00068-CS; Fig. 4G)
- Type 8A, Mottled Blue Morisco Cup (VB48: TOR-90-00038-CS; Fig. 4H)
- Type 6D, Linear Blue Morisco Jug (VB50: TOR-90-00023-CS; Fig. 4E)
- Type 20, Lead-Glazed Half-Dipped Jug (VB55: TOR-90-00016-CS; Fig. 4K)

These sampled vessels plotted close together in a principal components analysis (Fig. 7), which included almost all the samples analyzed, suggesting their chemistry was similar, as well as having unusual magnesium and calcium concentrations. Among the clays of the Seville region studied by Gonzalez Garcia and Garcia Ramos (1966), examples from two locations stood out as 'high magnesium' clays, namely to the west of Seville close to the Rio Guadiamar (Benacazón: clays SE33-35) and Aznalcazar (SE36), located about 18km and 24km respectively from the center of Seville. These towns lie at the west end of the Aljarafe region, well known for wine making, so the existence of pottery workshops within this busy region would not be unusual. Gonzalez Garcia and Garcia Ramos (1966) concluded that the high magnesium represents a predominance of the iron-magnesium rich clay mineral montmorillonite.

B. Tortugas Type 21 (Lead-Glazed Ware) (Fig. 4L)

The single Type 21 lead-glazed jug analyzed (VB56: TOR-90-00040-CS; Fig. 4L) is chemically intermediate between the Type 6A Linear Blue Morisco jar (TOR-90-00069-CS, itself close to Type 1A Seville Blue on Blue examples) and the Seville Type 2 olive jars. This points to another source in Seville.

C. Olive Jars Type 1 (Figs. 1A-1F)

The Tortugas Type 1 olive jars had a rather different chemistry to the rest of the Tortugas ceramics, and it was concluded they were made near Cordoba, where Dressel 20 amphoras were manufactured in the Roman period (see section 4A above).

7. ICPS Results: Anomalous Samples

The Tortugas Type 12 unglazed coarseware jug (VB53: TOR-90-00031-CS; Fig. 4I) is an outlier, which is very different to anything else analyzed in this project. It has been identified stylistically as a Merida-type product, a brick-red fabric with quartz and mica inclusions believed to originate in the High Alentejo extending inland from Lisbon and to the east into Spain (Gutiérrez, 2007). Chemical analyses of Portuguese ceramics are fairly few. Two Portuguese faience fragments were analysed by Inanez *et al.*, (2009; the average profiles are specified in Table 6B), but the ICPS analysis of this jug revealed very low calcium (it is a redware, lime-free clay) that is very different to these faience examples. Its chemical analysis, therefore, cannot as yet confirm or deny the suggestion of a Portuguese origin.

Tortugas Type 19B green-glazed standing costrel (VB54: TOR-90-00071-CS; Fig. 4J) is a redware (non-calcareous clay) with very high aluminium and high potassium that displays the same chemistry as the Type 12 jug, which suggests a comparable Merida source. It also has some chemical similarity to the Type 20 lead-glazed half-dipped jug, although it is somewhat different to the other samples within the high magnesium chemical group. Its nearest major group is the Type 2 olive jar series.

The Tortugas colonoware cooking vessels sampled are represented by a Type 9D cooking pot (VB51: TOR-90-01207-CS; Fig. 5A) and Type 10A griddle (VB52: TOR-90-00164-CS; Fig. 5B). Both are chemical outliers, but have rather different chemical analyses to each other, so they do not share the same origin. Compared against the published analyses of Valley of Mexico pottery, both items have the characteristic very high sodium content of that region's pottery (1-2%), and other general chemical similarities (Olin *et al.*, 1978; Maggetti *et al.*, 1984; Rodriguez-Alegria *et al.*, 2003).

The Type 9D cooking pot is quite similar to Mexico City Red Ware (Rodriguez-Alegria *et al.*, 2003: analyses published on the Missouri University Research Reactor (MURR) website: analyses MTM021-078). The Type 10A griddle is like the analysis of Puebla pottery (Maggetti *et al.*, 1984: 188-9, appendix C, analyses SD29-37). There is one caution about the comparative analyses from this latter paper: Olin and Blackman (1989: 88) later determined that the 1984 results were flawed by problems encountered with the dissolution of the ceramic samples.

These two Tortugas colonowares require further follow-up analysis in terms of comparison with appropriate datasets of analyses made by American researchers in order to determine whether the tentative links to production of both in Mexico suggested here can be confirmed or not. Historical and typological studies suggest that these wares could have been produced in the Caribbean by African slaves (Gerth and Kingsley, 2014). Comparative analyses of colonoware excavated across the Caribbean have not been conducted.

8. Seville Ceramics Analyses Studies

It is quite striking that the variety of chemistry found among the Tortugas shipwreck pottery contrasts strongly with the very consistent chemical composition published by Olin *et al.* (1978) for imports into five sites in the Dominican Republic, one in Venezuela and from the Carthusian monastery at Jerez in Spain. The sherds from Nueva Cadiz, Venezuela, only differed slightly in concentration for the alkali metals rubidium, sodium and caesium compared to the sites in the Dominican Republic and from Jerez. Their research also showed that Yayal Blue on White (Linear Blue Morisco), Isabela Polychrome (Blue and Purple Morisco) and Caparra Blue (Plain Blue Morisco) from the same sites, like the Plain White Morisco wares, conformed to the same compositional pattern, which by consensus characterizes Seville tin-glazed ware.

Inanez *et al.* (2008) analyzed by neutron activation a range of Mujedar and Renaissance ceramics from Seville as part of a larger study into Spanish glazed ceramics, which included X-ray fluorescence analysis (XRF) on the body fabric and analyses of the glazes (Inanez, 2007; Inanez *et al.,* 2009). Pottery and tiles were examined by NAA from three excavations and one museum in Seville: Pureza, 16th-17th centuries, three blue, five plain white; Valladares, three blue and two white; Plaza de Armas, 16th-17th centuries, one blue, eight blue on blue; and Museo Arqueologico de Sevilla, 15th-16th centuries, two blue, one luster and three polychrome.

The average concentration they found for Seville pottery is presented in Table 6A, after converting their element data into oxides. The results show a low-alumina, high calcium (lime) clay composition, typical of some of the Morisco wares analyzed here, and including the Type 2 olive jars. But it contrasts with the averages found in this project for the 'Sevilla type' wares (Tortugas Types 1, 2, 4 and 5). None of their samples apparently showed this composition, although this is not possible to confirm definitively because they published only the Seville average, not data for individual samples. The authors concluded that their Seville data is homogeneous: there appeared to be no chemical sub-groups among the samples, unlike other centers such as Leida, Muel and Barcelona. This conclusion is at odds with the results from the Tortugas shipwreck, and may arise from the selection of samples analyzed by Inanez *et al.* (2008) covering mainly earlier Seville pottery (Morisco wares) rather than the generally later, main types examined here.

Polvorinos del Rio and Castaing (2009) studied a small number of tin-glazed lusterwares found at a 15th to 16th-century workshop in Triana, Seville, using a variety of techniques including PIXE (Proton Induced X-ray Emission; Table 6A). Given that their samples derived from a single workshop, it is not surprising that their results showed a single chemical composition profile. Their analyses of the lusterware compared well with the results on Sevillian luster sherds analyzed by neutron activation and ICPS from the Spanish shipwreck in Studland Bay, Dorset, England (Gutiérrez *et al.*, 2003). The products from this workshop showed general similarity for many chemical elements to the average for the Tortugas shipwreck's Type 1 Seville Blue on Blue ceramics, although the calcium (lime) is lower in the Type 1A (average of 17.4% in Type 1A and 15.1% in Type 1B; in relation to 22% in the workshop sherds), while the aluminium is higher (Type 1A: 14.1%, Type 1B 15.0% compared to 11.6% in the workshop), as is the iron (Type 1A: 5.8%, Type 1B: 6.4% compared to 3.8%). This workshop appears to have used a different clay mixture, with a fabric containing more lime and less clay component (indexed by aluminium and iron).

9. Discussion

Among the many dozens of Plain White Morisco and Yayal Blue on White (Linear Blue Morisco) sherds of Spanish origin analyzed by neutron activation analysis by Olin *et al.* (1978) from sites in the Dominican Republic and Venezuela, and from Jerez in Spain, there was a remarkable uniformity in clay chemistry. The same chemical composition was also found among ten specimens of Isabela Polychrome (Blue and Purple Morisco ware) and four Caparra Blue (Plain Blue Morisco) from these sites. This data led to the conclusion that the sherds from all five sites suggested manufacture from a single clay or at most a few closely related clays, and archaeological evidence pointed to Seville, most likely the Triana district (Olin *et al.*, 1978: 205).

The implication for the present project is that significant deviation in chemical concentrations was not

Tortugas Type	Inv./Sample No.	Source
Type 1	TOR-90-00116-CS; VB1	Cordoba Region
Type 1	TOR-90-00117-CS; VB2	Cordoba Region
Type 1	TOR-90-00118-CS; VB3	Cordoba Region
Type 1	TOR-90-00135-CS; VB4	Cordoba Region
Type 1	TOR-90-00136-CS; VB5	Cordoba Region
Type 1	TOR-90-00138-CS; VB6	Cordoba Region
Type 2	TOR-90-00011-CS; VB7	Seville
Type 2	TOR-90-00130-CS; VB8	Seville
Type 2	TOR-90-00132-CS; VB9	Seville
Type 2	TOR-90-00328-CS; VB10	Seville
Type 4	TOR-90-00018-CS; VB11	Seville

Table 7. ICPS results for olive jars from the Tortugas shipwreck.

expected for such wares. The Plain White Morisco pottery analyzed here, for example, showed just one example that conformed to the main pattern of Seville wares, two were of the 'high magnesium' group and the fourth did not seem to be similar to the Seville composition. The Tortugas ship's Plain White Morisco pottery therefore appears to show divergent origins, among the very limited number analyzed. Olin *et al.* (1978) did not subject their data to full multivariate analysis, so it was not clear whether chemical sub-groups are concealed within their overall average chemical concentrations. However, the consistent average composition across different wares and find sites showed no correspondence analytically with the sub-groups found for the Tortugas pottery.

Analyses by ICPS atomic emission spectrometry of sherds excavated from beneath the Metropolitan Cathedral in Mexico City included small numbers of Seville White and Plain White Morisco Gun Metal pottery (Maggetti *et al.*, 1984), which revealed an interesting pattern. Their data is directly comparable to the Tortugas results as the same technique (and element suite) was used. The results for the Seville White (four examples) and Plain White Morisco Gun Metal pottery (five samples) significantly showed that the two types had very similar, though slightly different, overall clay chemistry to the single chemical composition pattern found in their previous publications.

The Seville White from Mexico City contained slightly higher alumina (average around 16%) than the Plain White Morisco Gun Metal pottery (approx. 12.3%) and slight differences in other elements. These chemical differences correspond to the 'main Seville' clay chemistry found among the Tortugas pottery and the slightly different types (e.g. the different clusters shown in the discriminant analysis; Fig. 6). This is an example where the chemical distinctions for Seville wares found on the Tortugas shipwreck have been paralleled elsewhere for small numbers of pottery analyzed.

The analyses of the Tortugas ceramics have revealed distinct differences in chemical composition of Seville wares by period. Up to the present date, the majority of previous analyses of Seville pottery discussed here mainly covered the period 1500-1600, predating the Tortugas wreck. Seville ceramics of this period, analyzed from a number of 'consumer' sites mainly in the New World, showed a fairly consistent chemistry that reflects the use of a relatively high percentage of lime (typically over 20% calcium oxide) and a correspondingly diminished percentage of plastic clay. By contrast, the Tortugas pottery of significantly later date shows a general pattern whereby Seville potters used a mixed clay preparation based on rather less lime (range of 10-17% lime) and a correspondingly higher percentage of plastic clay.

Lister and Lister (1987) noted that the later period pottery of Seville, associated with the introduction of Italian influences on pottery making, resulted in clay bodies which were finer and slightly pinker in color than the earlier pottery. The relative scarcity of analyses of later period pottery probably accounts for the non-recognition of the change in clay chemistry. In fact, earlier work contained hints of this change. Further examples are evident from the study of pottery produced at a kiln site at Pureza Street in Seville and another elsewhere in Seville (Myers *et al.,* 1992).

A very consistent chemical composition pattern was found, corresponding to the chemistry of many of the earlier Spanish ceramics identified on New World sites. This seemed to establish a single, relatively narrow chemical pattern for Seville ceramics. Small numbers of later period pottery from the Pureza Steet kiln and from a lusterware kiln also in Triana have been analyzed (Polvorinos del Rio and Castaing, 2009), but these showed the same chemical pattern as the earlier period, probably indicating continuity of potters' practices in those particular workshops.

However, the analysis of pottery from the later (consumer) site of Santa Catalina de Guale, St. Catherine's

Tortugas Type	Inv/Sample No.	Source
Type 1A, Seville Blue on Blue Plate	TOR-90-00041-CS; VB12	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00044-CS; VB13	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00081-CS; VB14	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00054-CS; VB15	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00084-CS; VB16	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00085-CS; VB17	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00052-CS; VB18	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00045-CS; VB19	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00061-CS; VB21	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00053-CS; VB22	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00058-CS; VB24	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00088-CS; VB25	Seville
Type 1A, Seville Blue on Blue Plate	TOR-90-00046-CS; VB26	Seville
Type 1B, Seville Blue on Blue Plate	TOR-90-00086-CS; VB23	Seville
Type 1C, Seville Blue on Blue Bowl	TOR-90-00049-CS; VB27	Seville
Type 1C, Seville Blue on Blue Bowl	TOR-90-00051-CS; VB28	Seville
Type 1C, Seville Blue on Blue Bowl	TOR-90-00048-CS; VB29	Seville
Type 1C, Seville Blue on Blue Bowl	TOR-90-00056-CS; VB30	Seville
Type 1D, Seville Blue on Blue Jug	TOR-90-00035-CS; VB42	Seville
Type 2A, Seville Blue on White Plate	TOR-90-00015-CS; VB31	Seville
Type 2A, Seville Blue on White Plate	TOR-90-00017-CS; VB32	Seville
Type 2A, Seville Blue on White Plate	TOR-90-00057-CS; VB33	Seville
Type 2A, Seville Blue on White Plate	TOR-90-00090-CS; VB34	Seville
Type 3B, Plain White Morisco Plate	TOR-90-00013-CS; VB35	Seville
Type 3B, Plain White Morisco Plate	TOR-90-00030-CS; VB36	HMG: 18-24km west of Seville *
Type 3C, Plain White Morisco Plate	TOR-90-00047-CS; VB37	High Potassium Outlier **
Type 3D, Plain White Morisco Bowl	TOR-90-00073-CS; VB38	HMG: 18-24km west of Seville
Type 4B, Seville White Bowl	TOR-90-00036-CS; VB39	Seville
Type 4C, Seville White Cup	TOR-90-00065-CS; VB41	Seville
Type 5A, Seville Polychrome Jug	TOR-90-00032-CS; VB43	Seville
Type 5A, Seville Polychrome Jug	TOR-90-00070-CS; VB44	Seville
Type 6A, Linear Blue Morisco Jar	TOR-90-00069-CS; VB45	Seville
Type 6C, Linear Blue Morisco Bowl	TOR-90-00009-CS; VB49	Seville
Type 6D, Linear Blue Morisco Jug	TOR-90-00023-CS; VB50	HMG: 18-24km west of Seville *
Type 7, Decorated Blue Morisco Pitcher	TOR-90-00019-CS; VB46	Seville
Type 7, Decorated Blue Morisco Pitcher	TOR-90-00068-CS; VB47	HMG: 18-24km west of Seville *
Type 8A, Mottled Blue Morisco Cup	TOR-90-00038-CS; VB48	HMG: 18-24km west of Seville *
Type 9D, Colonoware Cooking Bowl	TOR-90-01207-CS; VB51	Valley of Mexico?
Type 10A, Colonoware Cooking Griddle	TOR-90-00164-CS; VB52	Valley of Mexico?
Type 12, Merida-type Jug	TOR-90-00031-CS; VB53	Portugal/N. Spain ?
Type 19B, Green-glazed Costrel	TOR-90-00071-CS; VB54	Portugal/N. Spain ?
Type 20, Green-glazed Jug	TOR-90-00016-CS; VB55	HMG: 18-24km west of Seville *
Type 21, Lead-glazed Jug	TOR-90-00040-CS; VB56	Seville

** HMG = High magnesium chemical group: rural production near the Rio Guadiamar, Benacazón and Aznalcazar, about 18-24km west of Seville.*

*** Seemingly not Seville, Mexico or Lisbon.*

Table 8. Summary of Tortugas shipwreck tablewares' origins based on Inductively-Coupled Plasma Spectrometry (ICPS) analysis.

Island, Georgia, dated to 1576-1680 (Myers *et al.*, 1992) found that the majority of this pottery, including Plain White Morisco, Yayal Blue on White (Linear Blue Morisco), Decorated Blue on White, Santa Elena (Mottled) Blue on White, Seville Blue on Blue, Seville Blue on White, and San Luis Blue on White (Spanish variant), showed compositions outside the range of the Pureza Street kiln. They speculated that this indicated multiple sources within Seville supplying Santa Catalina, implying a change over time in the organisation of Seville's tin-glazed pottery industry. They also observed that this hypothesis was consistent with documentary records indicating a major expansion in Seville's ceramic industry to over 30 workshops at the end of the 16th century, which increased the need for raw materials to the point that legal disputes resulted over access to potting clays on the isle off the Cartuja land (near Triana) and along the east banks in front of San Jeronimo to the north of the city (cf. Lister and Lister, 1987: 160, 334, note 362).

The Tortugas shipwreck's ceramic analyses now provides much firmer evidence of a change in the pattern of clay mixing by the Seville potters, and confirmation of the earlier indications that there were numbers of different workshops using different blends than attested in the Pureza Street kiln.

10. Summary & Conclusions

Many 16th-century Seville ceramics conform to a consistent chemical pattern, showing a high percentage of lime and relatively low percentages of aluminium and iron (associated with the clay minerals). The pattern reverses for the later period, corresponding to the chronology covered by the Tortugas ceramics. The earlier potters appear to have used directly just the light-firing lime-rich clays of the Seville district, while the later potters, under the influence of Italian styles, clay technology and the emergence of the 'Sevilla' types of tin-glazed pottery, seem to have mixed some red-firing clay with the white.

In this later period different workshops seem to have used slightly different blends of white- and red-firing clays, leading to small but analytically detectable differences in the chemical composition of the resulting tin-glazed wares. The future challenge is to expand the numbers of analyses of these later wares of the 17th century to try to refine the picture still further. One of the chief new findings of the present project has been to analyze a sufficiently large number of later Seville ceramics that a pattern previously hinted at on the basis of relatively small numbers of analyses is now seen to form a coherent pattern.

The current project has also emphasized the presence of a number of different chemical patterns for Seville ceramics. This is not entirely surprising since previous analytical studies of 16th-century tin-glazed pottery from major centers in northern Europe, including Antwerp (Hughes and Gaimster, 1999) and London (Hughes, 2009), have shown precisely such individual clay chemistry patterns for an individual workshop, and systematic chemical differences between workshops.

Considering the results for individual types, the Tortugas Type 1 olive jars are confirmed as products of the region around Cordoba, whereas the Type 2 olive jars have the chemical signature of Seville ceramics. This project in fact appears to be the first to undertake chemical analyses of Spanish olive jars, while only small numbers have previously been studied by thin-section analysis.

The Tortugas shipwreck project has also discovered for the first time the existence of a Seville pottery featuring high levels of the element magnesium (very probably present in the source clay as the clay mineral montmorillonite). Initial indications are that they were produced by a previously unrecognized rural pottery workshop/s west of Seville, close to the Rio Guadiamar and near Benacazón and Aznalcazar, about 18km and 24km respectively from the center of Seville.

This has also highlighted a feature of the less well represented Morisco wares on the Tortugas shipwreck, which, unlike the Seville wares, show a mixture of clay compositions. The Tortugas Type 3 Plain White Morisco ware and the Type 6-8 Linear, Decorated and Mottled Blue Morisco wares all include examples of both 'high magnesium' and clay compositions related to the Seville products, though with lower percentages of aluminium they are more in common with the 15th to 16th-century chemical pattern for Seville pottery established previously by analysis of ceramics from many locations in the New World.

In contrast, many of the Seville pottery types are chemically homogeneous within each type, with slight distinctions between types suggesting production at different workshops within Seville. Can we say whether any of the Tortugas pottery types examined were made in the same workshop using the same clay mixture? Identity of chemistry for pastes implies the same clay mixture; subtle chemical differences, however, could reflect production in a different workshop or chronological period in the same workshop. The case is strongest for the Type 1A and Type 1B Blue on Blue wares, which are sufficiently close chemically to be consistent with production in the same workshop. The Type 2A Blue on White wares are slightly different to them and have more in common with the Type 4 Seville White products analyzed, perhaps revealing production in a further workshop.

Bibliography

Avery, G., *Pots as Packaging. The Spanish Olive Jar and Andalusian Transatlantic Commercial Activity, 16th-18th Centuries* (PhD Thesis, University of Florida, 1997).

Baxter, M. *Exploratory Multivariate Statistics in Archaeology* (Edinburgh University Press, 1994).

Baxter, M., *Statistics in Archaeology* (London, 2003).

Deagan, K., *Artifacts of the Spanish Colonies of Florida and the Caribbean, 1500-1800. Vol. 1 Ceramics, Glassware and Beads* (Washington, 1987).

Gerth, E. and Kingsley, S., *The Deep-Sea Tortugas Shipwreck, Florida (1622): Afro-Caribbean Colonoware & Maritime Slavery* (OME Papers, Tampa, 2014).

Gonzalez Garcia, F. and Garcia Ramos, G., 'Arcillas ceramicas de Andalucia: 1. yaciamentos de las Vegas de Guadalquivir y Corbones en la provincia de Seville', *Bolletin de la Socieded Espanola de Ceramica* 3.5 (1964), 481-502.

Gonzalez Garcia, F. and Garcia Ramos, G., 'Arcillas ceramicas de Andalucia: 3. Yaciamentos terciarios de la margen derecha del Guadalquivir, en la provincia de Sevilla', *Bolletin de la Socieded Espanola de Ceramica* 5.2 (1966), 229-45.

Gonzalez Garcia, F. and Garcia Ramos, G., 'Arcillas ceramicas de Andalucia: 7. Yaciamentos terciaros de la Campina de Cordoba (b) Yaciamento terciarios y cuarternarios de la margenas del Guadalquivir (Cordoba)', *Bolletin de la Socieded Espanola de Ceramica* 8.1 (1969), 17-46.

Gonzalez Garcia, F., Garcia Ramos, G., Romero Acosta, V. and Gonzalez Rodriguez, M., 'Arcillas empleadas en la fabricacion del azulejo artisico de Sevilla. Propiedades y transformaciones por coccion. 1. Materiales que contienen carbonato de calcio', *Bolletin de la Socieded Espanola de Ceramica y Vidrio* 27.4 (1988), 215-23.

Gutiérrez, A., *Mediterranean Pottery in Wessex Households (13th to 17th Centuries)* (BAR British S306, Oxford, 2000).

Gutiérrez, A., 'Portuguese Coarsewares in Early Modern England: Reflections on an Exceptional Pottery Assemblage from Southampton', *Post-Medieval Archaeology* 41.1 (2007), 64-79.

Gutiérrez, A., Williams, D. and Hughes, M.J., 'A Shipwreck Cargo of Sevillian Pottery from the Studland Bay Wreck, Dorset, UK', *International Journal of Nautical Archaeology* 32.1 (2003), 24-41.

Hamer, F. and Hamer, J., *The Potter's Dictionary* (London, 2004).

Hughes, M.J., 'Provenance Studies of Spanish Medieval Tin glazed Pottery by Neutron Activation Analysis'. In B. Budd, B. Chapman, C. Jackson, R. Janaway and B. Ottaway, (eds.), *Archaeological Sciences 1989* (Oxbow Monograph 9, Oxford, 1991), 54-68.

Hughes, M.J., 'Scientific Analysis'. In I.M. Betts, 'Spanish Tin-glazed Tiles from Woking Palace and other Sites in South-east England', *Surrey Archaeological Collections* 94 (2008), 66-7.

Hughes, M.J. and Gaimster, D., 'Neutron Activation Analyses of Maiolica from London, Norwich, the Low Countries and Italy'. In D. Gaimster (ed.), *Maiolica in the North: The Archaeology of Tin-glazed Earthenware in North-west Europe c. 1500-1600* (British Museum Occasional Papers 122, London, 1999), 57-89.

Hurst, J.G., Neal, D.S. and van Beuningen, H.J.E., *Pottery Produced and Traded in North-west Europe 1350-1650* (Museum Boymans, Rotterdam, 1986).

Iñañez, J.G., *Caracteritzacio Arqueometrica de la Ceramica Vidrada Decorada de la Baixa Edat Mitjana al Renaixement als Centres Productors de la Peninsula Iberica* (PhD Thesis, University of Barcelona, 2007).

Iñañez, J.G., Buxeda i Garrigós, J., Speakman, R.J., Glascock, M.D. and Suárez, E.S., 'Characterization of 15th-16th Century Majolica Pottery Found on the Canary Islands'. In M.D. Glascock, R.J. Speakman and R.S. Popelka-Filcoff (eds.), *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation* (American Chemical Society, Washington, 2007), 376–98.

Iñañez, J.G., Buxeda I., Garrigós, J., Glascock, M. and Speakman, R.J., 'Archaeometric Characterization of Renaissance Tin-lead Glazed pottery from Talavera de la Reina, Puente del Arzobispo and Seville (Spain)', *36th International Symposium on Archaeometry, ISA 2006* (Universite Laval, Quebec, 2009).

Iñañez, J.G., Speakman, R.J., Buxeda I., Garrigós, J. and Glascock, M., 'Chemical Characterization of Majolica from 14th-18th Century Production Centers on the Iberian Peninsula: a Preliminary Neutron Activation Study', *Journal of Archaeological Science* 35 (2008), 425-40.

Iñañez, J.G., Speakman, R.J., Buxeda I., Garrigós, J. and Glascock, M., 'Chemical Characterization of Tin-lead Glazed Pottery from the Iberian Peninsula: Initial Steps toward a Better Understanding of Spanish Colonial Pottery in the Americas', *Archaeometry* 51.4 (2009), 546-67.

Kingsley, S., *The Deep-Sea Tortugas Shipwreck, Florida (1622): the Ceramic Tablewares* (OME Papers, Tampa, 2014).

Kingsley, S., Gerth, E. and Hughes, M., 'Ceramics from the Tortugas Shipwreck. A Spanish-Operated Navio of the 1622 Tierra Firme Fleet', *Ceramics In America*

(Chipstone Foundation, 2012).

Lister, F.C. and Lister, R., *Sixteenth Century Majolica Pottery in the Valley of Mexico* (University of Arizona Press, Tucson, 1982).

Lister, F.C. and Lister, R., *Andalusian Ceramics in Spain and New Spain. A Cultural Register from the Third century B.C. to 1700* (University of Arizona Press, Tucson, 1987).

Maggetti, M., Westley, H. and Olin, J.S., 'Provenance and Technical Studies of Mexican Majolica using Elemental and Phase Analysis. In J. Lambert (ed.), *Archaeological Chemistry III* (American Chemical Society Advances in Chemistry Series 205, 1984), 151-91.

Myers, J.E., de Amores Carredano, F., Olin, J.S. and Pleguezuelo Hernandez, A., 'Compositional Identification of Seville Maiolica at Overseas Sites', *Historical Archaeology* 26.1 (1992) 131-47.

Olin, J.S. and Blackman, M.J., 'Compositional Classification of Mexican Majolica Ceramics of the Spanish Colonial Period'. In R.O. Allen (ed.), *Archaeological Chemistry IV* (American Chemical Society, Washington, 1989), 87-112.

Olin, J.S., Harbottle, G. and Sayre, E.D., 'Elemental Composition of Spanish and Spanish Colonial Majolica Ceramics in the Identification of Provenience'. In G.F. Carter (ed.), *Archaeological Chemistry II* (American Chemical Society Advances in Chemistry Series 171, Washington, 1978), 200 29

Orton, C. and Hughes, M., *Pottery in Archaeology* (Cambridge University Press, 2013).

Polvorinos del Rio, A. and Castaing, J., 'Lustre-decorated Ceramics from a 15th to 16th Century Production in Seville', *Archaeometry* 52.1 (2009), 83-98.

Pellant, J., *SPSS Survival Manual* (McGraw Hill/Open University Press, Maidenhead, 2007).

Rodriguez-Alegria, E., Neff, H. and Glascock, M., 'Indigenous Ware or Spanish Import? The Case of Indigena Ware and Approaches to Power in Colonial Mexico', *Latin American Antiquity* 14.1 (2003), 67-81

Shennan, S. *Quantifying Archaeology* (Edinburgh University Press, 1997).

Tabachnick, B. and Fidell, L.S., *Using Multivariate Statistics* (Pearson, London, 2007).

Tyers, P., *Roman Pottery in Britain* (London, 1996).

