COUPLING LEAD ISOTOPE ANALYSIS AND PETROGRAPHY TO CHARACTERIZE FABRICS OF STORAGE AND TRADE CONTAINERS FROM HALA SULTAN TEKKE (CYPRUS)*

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Lead isotopes, thin- and sherd-section analyses are coupled on pottery-vessel fragments excavated from the Late Bronze Age site of Hala Sultan Tekke (south-east Cyprus) and representing fabrics used for the production of storage and trade containers. The fabrics of the sherds are first described according to general macroscopic observations. Based on the different fabrics identified, a petrographic analysis is carried out on thin sections and compared to lead isotope results on the same samples. This study shows that a specific fabric corresponds to a specific lead isotopic composition and proposes different sources for the various groups of associated sherds/fabrics. It also demonstrates the compatibility and complementarity of petrography and lead isotopes within pottery provenance study.

KEYWORDS: LEAD ISOTOPES, THIN SECTION, SHERD SECTION, CYPRUS, CANAANITE FABRICS

INTRODUCTION

Recently, the effectiveness of using lead isotope signatures in pottery provenance study was established using a set of samples from the Late Bronze Age site of Hala Sultan Tekke (henceforth, HST) in south-east Cyprus (Renson et al. 2011). This previous research showed that the lead isotopic composition of 20 sherds corresponding to various HST Canaanite fabrics displayed a large variability both in $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios. This variability was interpreted to probably reflect the different provenances of these sherds (Renson et al. 2011). For four fragments, the similarity in lead isotope signature with sherds likely to originate from HST suggested a Cypriote origin, perhaps even a local HST production.

In HST, thousands of sherds were inventoried as Canaanite (Åström 1986, 1992). Canaanite jars are identified according to their shape; that is, a short neck, an ovoid body, a carinated shoulder, a pointed or ‘button-shaped’ base and two or four vertical handles. However, in Cypriote archaeology, the term ‘Canaanite’ is a misleading collective term. It indicates either a specific morphology related to Canaanite or Levantine prototypes of storage and transport jars or...
pointing to specific fabrics used for the manufacturing of storage vessels that can originate from Egypt, Syria, Palestine, Cyprus and possibly Cilicia (Åström 1991a, 149). In this paper, the term ‘Canaanite fabric’ or ‘Canaanite’ corresponds to its broad sense used in Cypriote archaeology (Åström 1991a). Canaanite jars have been studied within their Eastern Mediterranean context (e.g., Pedrazzi 2007). Yet, this type of pottery has not received much scholarly attention in Cyprus, despite its fairly common occurrence in the archaeological records of Late Bronze Age polities (Hadjicosti 1988). A few studies have proposed that Canaanite jars found in Cyprus originated from different parts of the Eastern Mediterranean region (Gunneweg et al. 1987; Eriksson 1995). However, several examples could also have been directly produced on the island (Raban 1980; Hadjicosti 1988; Jones and Vaughan 1988; Serpico 2008). Previous studies have shown that the ‘Canaanite ware’ of HST consisted of various fabrics (Åström 1991b; Fischer 1991; Eriksson 1995) and some were hypothesized to be local or imports from Ugarit, Cilicia (Raban 1980) and Egypt (Eriksson 1995). So, despite the ambiguity related to the term ‘Canaanite’ in HST, due to their multiple fabrics and possible origins, these HST pottery fragments form an ideal case study to investigate the coupling of petrography and lead isotopes as a provenance tool for Canaanite jars.

In this study, the fabrics of the sherds are first described by low-magnification observations directly on sherd sections. The detailed petrography analysis is then realized on thin sections of the same samples subjected to lead isotope analyses. The results of the petrography are finally compared to those of the isotopic analyses. The main purpose of this study is to further explore the possibilities of lead isotope analyses in pottery provenance research by coupling it with classical petrography, using HST Canaanite sherds as a case study. More specifically, the aims are: (1) to define whether a specific fabric presents a specific lead isotopic composition; (2) to propose potential raw materials and provenances for the different fabrics, to confirm or negate the possibility that the isotopic variability previously observed could be explained by different provenances; and (3) to demonstrate or rule out the hypothesis of a local production for the Canaanite. It must be emphasized that the goal of this study is to compare the groupings of the petrography and lead isotopes results rather than to compare the suggested definitive geographical provenances. Although further pottery raw material and provenances are proposed for different fabrics, these are not comprehensively studied at this stage.

SAMPLES AND MACROSCOPIC DESCRIPTIONS

Samples and procedure for macroscopic descriptions

For this study, 24 sherds representing different Canaanite fabrics excavated at HST were selected. They all originate from LC IIIA contexts (c. 1190–1110 BCE). Due to their small size, the sherds analysed here are not identified morphologically, but according to their fabric. Part of the lead isotopic data is already published (Renson et al. 2011) but additional measurements are included here. To provide a local HST fabric reference, petrographic analyses on thin sections were also carried out on eight Plain White Wheel-made sherds and one Coarse fragment demonstrated to originate from HST (Renson et al. 2011).

Shards were selected on the basis of their fabrics, which were identified by macroscopic observations made on sherd section. The section of the Canaanite sherds was described using a magnifying lens and a binocular microscope (×20). The matrix characteristics (hardness, density and homogeneity) and the inclusions (frequency, roundness and sorting) were examined and qualified using notation scales similar to those of Orton et al. (1993) and Barraclough (1992).
Potential sources were then suggested by comparing the section to that of Canaanite fabrics defined in Arnold and Bourriau (1993), Aston (2000), Bourriau et al. (2000, 2001) and Smith et al. (2004). Sherds that did not correspond to any of these fabrics were qualified as ‘unknown fabrics’. The main goal of the macroscopic observations is to assess, prior to detailed petrographic analysis, if the pottery items investigated here display different fabrics, which could possibly originate from multiple source areas. The macroscopic observations were not carried out on Plain White Wheel-made and Coarse sherds, as is it already established that these fragments originate from HST (Renson et al. 2011).

Description of the fabrics

The set of Canaanite fragments can be divided into five main groups and a few singletons. For reasons of clarity and easier comparison with groups defined by thin-section analyses, the fabrics identified here are reported in the table presenting the petrographic and isotopic results (Table 1). The five fabrics are described below:

- A first group is composed of seven samples (HST 23, HST 47, HST 54, HST 56, HST 57, HST 60 and HST 49) presenting a rather similar fabric (Fig. 1 (a)). The matrix is fine and homogeneous and presents a medium to high hardness. The inclusions are generally well

![Figure 1](https://example.com/figure1.png)

*Figure 1  Examples of sherd sections: (a) example for group 2 (sample HST 56); (b) example for group 3 (sample HST 39); (c) example for group 4 (sample HST 22); (d) example for subgroup 5B (sample HST 40). For sherd numbers, see Table 1. The black bar represents 5 mm. The numbers of the groups mentioned here refer to the thin-section groups.*
<table>
<thead>
<tr>
<th>Sample</th>
<th>Pottery ware</th>
<th>$^{207}$Pb/$^{204}$Pb</th>
<th>2se</th>
<th>$^{206}$Pb/$^{204}$Pb</th>
<th>2se</th>
<th>TS group</th>
<th>Thin-section sources</th>
<th>Sherd-section sources</th>
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<tr>
<td>HST 6b</td>
<td>Plain White Wheel-made II</td>
<td>15.6776</td>
<td>0.0008</td>
<td>18.8756</td>
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</tr>
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<td>18.8707</td>
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<td>18.8362</td>
<td>0.0008</td>
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<td>Cyprus?</td>
<td>Unknown fabric d</td>
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<td>19.0606</td>
<td>0.0012</td>
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<td>Cyprus?</td>
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<td>0.0014</td>
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<td>19.2814</td>
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<td>Unknown fabric c</td>
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Note: 2se refers to two standard errors (internal error); pottery ware, petrographic group, sources suggested by thin-section analysis and sherd-section observation or by a previous study (Renson et al. 2011) are indicated for each sample; additional measurements are indicated in bold in the table.
sorted. These inclusions are clay pellets (1 mm), fine to coarse rounded or angular quartz, limestone up to 2 mm, grey grids of various sizes and vegetal skeletons. The inclusions can vary from one sherd to another. This fabric does not correspond to any known Canaanite fabric or fabric from Egypt described in the literature. These samples are reported in Table 1 as ‘unknown fabric a’.

- Four samples (HST 4c, HST 39, HST 50 and HST 51) presenting a comparable fabric form the second group. Macroscopic observation (Fig. 1 (b)) reveals a light reddish brown core (2.5Y 6/4) and a red external zone (2.5YR 5/8). The sherds also present a cream slip. The matrix is dense and presents a very high hardness. The fabric displays fine and well-sorted limestone particles (moderate to abundant), fine semi-angular quartz (moderate), fine dark rock (sparse) and coarse (1 mm) limestone particles (sparse). In terms of possible provenance, this fabric is similar to an Egyptian mixed Nile/marl fabric described by Bourriau et al. (2000) as Subgroup G6b.

- Three other samples (HST 22, HST 37 and HST 44) represent a third fabric group. The macroscopic examination of the sherd sections (Fig. 1 (c)) reveals a uniform reddish yellow colour (2.5YR 5/3). The fabric is crumbly, presents very low hardness and very well-sorted inclusions (0.1–0.5 mm) of rounded quartz (abundant), fine translucent pebbles and black grids (sparse to moderate). The fabric of sample HST 48 resembles that of this group, but this affiliation is uncertain according to the sherd observation. This fabric is comparable to those reported in the literature as the Group 1 described by Bourriau et al. (2001). It was interpreted as originating from the seaward portion of the Jezreel Valley, approximately between Haifa and Akko (Smith et al. 2004).

- Samples HST 24 and HST 38 share a similar fabric and present a dark grey inner section (5YR 4/1), a yellow outer section (5YR 6/6) and no slip. They form a fourth fabric. The hardness of the fabric is high. The inclusions are well sorted and composed of angular and semi-angular limestone fragments from very fine to 0.5 mm in size (abundant), shells of 0.5 mm (moderate), angular fine quartz (moderate) and vegetal inclusions of 1 mm coated or not (sparse). Compared to the literature, this fabric is similar to the one of Subgroup 5.1.1 described by Bourriau et al. (2001, 132) that reveals high limestone and low contents in quartz. This fabric was suggested to originate from the coastal region of Lebanon and Syria because it presents a large abundance of limestones, marls and dolomite from the Upper Cretaceous to the Eocene combined with a poor development of Quaternary sediments including coastal sands (Bourriau et al. 2001). More precisely, this fabric could originate from the coastal region between Akko and Sidon (Smith et al. 2004, 73).

- The last group contains three samples (HST 40, HST 42 and HST 45) with a similar fabric and presenting a light yellowish brown core (2.5Y 6/4), a red external zone (2.5YR 5/8) and no slip (Fig. 1 (d)). The hardness of the fabric is medium. The inclusions are well sorted and composed of mica, vegetal inclusions 1 mm coated or not (abundant), limestone fragments of 0.5 mm (moderate), rounded quartz (moderate), 0.1 mm red grids (sparse) and grey grids from fine to 0.5 mm (sparse). The important amount of rounded sand and vegetal inclusions could mean that these fabrics are silt clays from Egypt (Arnold 1980; Nordström 1985; Arnold and Bourriau 1993).

Finally, three more samples (HST 21, HST 35 and HST 52) could not be linked to any group according to their macroscopic descriptions. These samples are reported in Table 1 as ‘unknown fabric’ b, c and d, respectively.

Although it cannot be used to unambiguously distinguish a provenance or source for the sherd fragments, this macroscopic description identifies different fabrics, which could originate from...
different areas. This preliminary approach indicates that the HST sherds assemblage forms a good case study to investigate the coupling of petrography to lead isotopes as a discriminative tool for pottery provenance.

METHODS

Petrographic thin-section analysis

Petrographic thin-section analysis was realized on 33 pottery samples (Nikon and Zeiss, for photography microscope models were used, under magnifications of $\times25$–$\times400$). The petrographic grouping is based on the global structure of the matrix, and the types, distribution and texture of the inclusions (size, shape, roundness etc.). The proportions of coarse particles, fine particles and voids observed in the thin section are indicated by a ratio (c:f:v$_{20\mu m}$ = coarse:fine:void), the limit between coarse and fine fractions corresponding to 20 $\mu$m (see Whitbread 1995, 379–86). Samples having a similar matrix and general types of inclusions but presenting variations in only specific types or textures of inclusions are often characterized as different subgroups of the same petrographic group. The complete petrographic procedure is detailed in Ben-Shlomo (2006).

Lead isotope analyses

The acid digestions and lead isolation were realized following the procedure described in Renson et al. (2011). Lead isotope ratios were measured using a Nu Plasma multi-collector – inductively coupled plasma – mass spectrometer (MC–ICP–MS), in operation at the Département des Sciences de la Terre et de l’Environnement of the Université Libre de Bruxelles, Belgium. The analytical conditions were described in Renson et al. (2011) and the measured values were corrected using the Tl doping method as well as the sample-standard bracketing method (White et al. 2000; Weis et al. 2006). Lead isotopic values for SRM981 published by Galer and Abouchami (1998) were used for standard bracketing. A total of 83 analyses were carried out on the SRM981 standard and the following mean values were obtained: 36.714 $\pm$ 0.006 (2SD), 15.497 $\pm$ 0.002 (2SD) and 16.940 $\pm$ 0.003 (2SD) for $^{208}$Pb/$^{204}$Pb, $^{207}$Pb/$^{204}$Pb and $^{206}$Pb/$^{204}$Pb ratios, respectively.

RESULTS

The Canaanite fragments, together with the reference Plain White and Coarse samples, are divided into five groups on the basis of petrographic observations and isotopic compositions. A few remaining sherds cannot be clearly linked to any of the groups and are discussed separately.

Group 1 (Fig. 2 (a)) is composed of four Plain White Wheel-made samples (HST 1a, HST 1b, HST 6b and HST 33) and one Coarse sample (HST 6c). All samples from this group (including two misfired Plain White Wheel-made) are sherds previously identified as being part of the HST pottery production (Renson et al. 2011). According to thin-section analysis, the matrix is characterized by a c:f:v$_{20\mu m}$ ratio that ranges from 40:38:12 to 55:35:10, and is dark to reddish under regular polarized light and dark under crossed polarized light. It probably corresponds to a calcareous fabric and is characterized by a microfossil-packed matrix (Fig. 2 (a)). Inclusions are composed of very rounded coarse silt-fine sand-sized microfossils (15–30% of slide area, 0.05–0.35 mm) and quartz (5–20%, sized at 0.04–0.25 mm), as well as smaller proportions of chalk.
(0.15–0.45 mm), feldspar (0.1–0.2 mm) and mica (0.06–0.12 mm). Dolomite also appears occasionally (a few, 0.06–0.15 mm). The five sherds identified as group 1 display relatively homogeneous lead isotopic composition that varies from 15.675 ± 0.0008 (2se) to 15.687 ± 0.0008 (2se) and 18.823 ± 0.0009 (2se) to 18.908 ± 0.0009 (2se) for 207Pb/204Pb and 206Pb/204Pb, respectively (Table 1 and Fig. 3).

**Group 2** (Figs 2 (b) and 2 (c)) is composed of four Plain White Wheel-made samples (HST 2, HST 6f, HST 6g and HST 6h) and six Canaanite (HST 21, HST 23, HST 47, HST 54, HST 56 and HST 60). According to the thin-section study, the matrix presents a c:f:v_{20\mu m} ratio that ranges from 25:70:5 to 40:50:10, a reddish to dark colour under regular polarized light and is often ferruginous, occasionally micaceous. The main inclusions are ferruginous to argillaceous rounded to sub-rounded tcf s (textural concentration features; see Whitbread 1995, 386) or

shales: fine to coarse sand-sized particles (0.2–1.0 mm) are common in this fabric. Other common inclusions are microfossils (0.1–0.65 mm) in various shapes and sizes, opaque minerals and serpentine (0.08–0.6 mm), quartz (sub-angular to rounded, 0.04–0.3 mm), limestone fragments (0.3–0.8 mm), mica (0.5–0.25 mm) and feldspar (angular 0.2–0.45 mm). Group 2 is divided into five subgroups (2A–2E, Figs 2 (b) and 2 (c)), according to the occurrence of some specific accessory minerals compared to the regular assemblage of subgroup 2A (Fig. 2 (b)). In subgroup 2B (Fig. 2 (c)), quartz is more abundant (reaching 10–15% of the slide area in comparison to around 5% in group 2A) and tcf/shale fragments are coarser (reaching 1.2–1.8 mm). Subgroup 2C presents frequent chert inclusions (sub-angular to sub-rounded, 0.25–0.6 mm), not appearing at all in other samples, 2D presents more microfossils (reaching 25% of the slide area, in comparison with up to 2% in other subgroups) and 2E presents basalt fragments (sub-rounded, 0.5–0.8 mm) and olivine (sub-rounded, 0.25–0.5 mm). Notwithstanding the differences between the subgroups, the clay of every sample from this group presents an ophiolithic, slightly micaceous component that could originate from southern or central Cyprus (see, e.g., Whitechurch et al. 1984; Gorzalczy 1999, 186–9; Goren et al. 2004, 60–1). However, this type of lithology is not diagnostic, as it also occurs in various locations in northern Syria or along the southern Aegean Turkish coast. Serpico (2008, Fabric Group 6, figs 27 and 28) described a somewhat equivalent fabric with a similar suggested provenance on the southern coast of Cyprus. Fabrics of group 2 could represent more than one workshop or production line using relatively similar clays, due to the variability in quantities of the different

Figure 3  The $^{207}$Pb/$^{204}$Pb versus $^{206}$Pb/$^{204}$Pb three-isotope plot for petrographic groups. The three lead isotopic subgroups of group 2 are surrounded by ellipses.
types of inclusions. According to thin-section observations, samples HST 48, HST 49 and HST 52 probably belong to group 2, as these samples have a darker matrix, are more ferruginous and contain tcfs and silty quartz, similar to group 2. Sample HST 42 also resembles samples from group 2, but presents very dominant large limestone and microfossil inclusions (0.25–0.7 mm, a few 1.8 mm).

On the basis of lead isotope analysis, the 10 sherds identified as group 2 are divided into various subgroups that present slightly different signatures (Table 1 and Fig. 3). A first subgroup composed of samples HST 2, HST 6f, HST 6g and HST 6h (all Plain White Wheel-made sherds) presents a lead isotopic composition that varies from 15.682 ± 0.0008 (2se) to 15.685 ± 0.0008 (2se) and from 18.850 ± 0.0008 (2se) to 18.931 ± 0.0010 (2se) for 207Pb/204Pb and 206Pb/204Pb, respectively (Table 1 and Fig. 3). For samples HST 48 and HST 49 (Canaanite fragments), their lead isotopic compositions, of 15.687 ± 0.0007 (2se) and 18.894 ± 0.0007 (2se) and 15.685 ± 0.0006 (2se) and 18.893 ± 0.0007 (2se), respectively (Table 1 and Fig. 3), clearly corroborate their affiliation to this first subgroup. The lead isotope values of sample HST 48 also clearly invalidate the sherd-section observation that linked it to a fabric of Levantine origin, more precisely from the Jezreel Valley. Moreover, sample HST 52 (Canaanite) presents an isotopic composition of 15.693 ± 0.0007 (2se) and 18.836 ± 0.0008 (2se) for 207Pb/204Pb and 206Pb/204Pb, respectively, close to that of the first subgroup described here above, an argument in clear favour of its affiliation to it. The isotopic composition of this subgroup perfectly fits that of group 1, representative of the local HST production and made from clay units available in the surroundings of the site (Renson et al. 2011). In this case, there is good agreement between thin-section observation and lead isotopes to support this local HST origin.

Another subgroup (samples HST 21, HST 54, HST 56 and HST 60, all Canaanite sherds) presents an isotopic composition that varies from 15.688 ± 0.0007 to 15.691 ± 0.0009 and from 19.010 ± 0.0008 to 19.065 ± 0.0008 for 207Pb/204Pb and 206Pb/204Pb, respectively (Table 1 and Fig. 3). Sample HST 42, with 15.698 ± 0.0010 (2se) and 19.061 ± 0.0012 (2se) for 207Pb/204Pb and 206Pb/204Pb, respectively, plots close to the second lead isotopic subgroup (Fig. 3). This argues in favour of its affiliation to this subgroup and contradicts the sherd-section observation that again proposed different fabric of Egyptian origin. This second subgroup includes only Canaanite sherds and presents slightly higher values, mostly in 206Pb/204Pb, than those of group 1. Finally, sherds HST 23 (15.680 ± 0.0008, 19.088 ± 0.0009) and HST 47 (15.681 ± 0.0010, 19.087 ± 0.0011) are isolated and differ from the values of group 1 (Table 1 and Fig. 3). The Quaternary sediments proposed as raw material by thin-section observation for group 2 can present a variable mineralogy across the island, which could explain the variable lead isotopic composition among the 14 sherds of this group.

**Group 3** (Fig. 4 (a)) is composed of four Canaanite samples (HST 4c, HST 39, HST 50 and HST 51). According to thin-section analysis, the matrix presents a c:f:v20m ratio that ranges between 35:55:10 and 50:45:5 and is dark to opaque in crossed polarized light (XPL) and dark red to dark brown in regular polarized light (PPL). The clay was fired at high temperature (probably over 850°C). This fabric (Fig. 4 (a)) represents clay material derived from a coastal alluvial soil, rich in rounded and angular sand-sized quartz (beach sand, sized at 0.1–0.8 mm, represents 20–30% of the slide area). Other distinctive non-plastic coarse inclusions are mica (0.05–0.12 mm), feldspar (0.1–0.35 mm), opaque minerals (0.05–0.25 mm), limestone fragments (0.2–1.3 mm, a few) and hornblende (0.1–0.28 mm). The mineralogy of this clay is comparable to that of the loess and brown soil clays of the southern Levant coast (probably south of Ashkelon; see Goren et al. 2004, 112–13; Ben-Shlomo et al. 2009, 2268, and more references therein).
Interestingly, the four sherd samples identified as group 3 by petrography present a quite narrow lead isotopic range between 15.638 ± 0.0011 (2se) and 15.643 ± 0.0007 (2se) and between 18.692 ± 0.0011 (2se) and 18.827 ± 0.0009 (2se) for $^{207}$Pb/$^{204}$Pb and $^{206}$Pb/$^{204}$Pb ratios, respectively (Table 1 and Fig. 3). This narrow range clearly supports a homogeneous and uniform provenance. The $^{207}$Pb/$^{204}$Pb values are distinctively less radiogenic than those of the local HST groups (groups 1 and part of 2), supporting a different raw material source.

**Group 4** (Fig. 4 (b)) is composed of three Canaanite sherds (HST 22, HST 37 and HST 44). According to the thin-section analyses, the matrix presents a c:f:v$_{20\mu m}$ ratio that ranges from 60:35:5 to 40:50:10 and is either grey–brown or reddish under parallel polarized light, and dark to reddish under crossed polarized light. This clay consists of an alluvial soil rich in rounded beach sand presenting a large amount of quartz (25–40% of the slide area, 0.1–0.6 mm, sub-angular or mostly rounded) and limestone fragments (15–35% of the slide area, 0.15–1.0 mm, sub-rounded). There are a few tcf/shale fragments (0.1–0.4 mm) as well as mica grains (0.05–0.15 mm). This clay (Fig. 4 (b)), rich in beach sand and presenting similar amounts of quartz and limestone fragments, probably comes from a coastal source somewhere in the Eastern Mediterranean, either in the Levant or in Cyprus. A Levantine source may be more likely due to the almost total lack of mica and serpentine (or any igneous inclusions), which is a common

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**Figure 4** Thin sections: examples of non Cypriote fabrics: (a) example for group 3 (sample HST 4c) (XPL); (b) example for group 4 (sample HST 22) (LS = limestone, XPL); (c) example for subgroup 5A (sample HST 24) (A = Amphiroa algae, PPL). For sherd numbers, see Table 1.
mineralogical characteristic in most Cypriote clays. More precisely, the source area could be located in the region between the north of Tel Aviv and the south of Akko. This fabric is quite similar to Serpico Fabric Group 1, an origin for which is proposed seaward of the Jezreel Valley (Serpico 2008, fig. 6, see below sherd section): although basalt is lacking, a similar fabric was also identified for Canaanite jars from Kommos, Crete (Day et al. 2011, Fabric 1).

The three sherds identified as group 4 present a homogeneous lead isotopic composition, which varies from $15.718 \pm 0.0011$ (2se) to $15.725 \pm 0.0010$ (2se) and $18.936 \pm 0.0014$ (2se) to $18.957 \pm 0.0011$ (2se) for $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$, respectively (Table 1 and Fig. 3). These samples form an isolated cluster of lead data with $^{207}\text{Pb}/^{204}\text{Pb}$ values that are more radiogenic than those of the local HST groups. This is indicative of a third possible source of raw material.

**Group 5** (Fig. 4 (c)) is composed of five Canaanite sherds (HST 24, HST 38, HST 40, HST 43 and HST 45). According to thin-section analyses, the matrix presents a c:f:v$_{20\mu m}$ ratio that ranges between 25:63:12 and 40:55:5, and is silty and dark brown to light brown coloured. This fabric reflects calcareous clays rich in microfossils. According to petrography, the main inclusions are microfossils (5–15% of the slide area, mostly rounded or elongated, sized at 0.08–0.8 mm) including the *Amphiroa* algae (0.3–0.8 mm), quartz (7–15% of the slide area, mostly sub-rounded to rounded, 0.1–0.4 mm) and limestone fragments (5–15% of the slide area, 0.1–0.75 mm sub-angular to rounded). Other elements are ferruginous to argillaceous rounded to sub-rounded tcf or shale fragments (0.15–0.65 mm), opaque minerals (0.05–0.15 mm) and chert (a few, 0.08–0.25 mm). This group can be divided into two subgroups: 5A (HST 24, HST 38 and HST 43) and 5B (HST 40 and HST 45). Subgroup 5B contains more sand-sized chalk (0.15–0.8 mm) and is especially rich in quartz (25%, 0.2–0.4 mm, mostly rounded) in comparison with subgroup 5A (Fig. 4 (c)). The fabric of group 5 probably corresponds to Neogene marl clay mixed with beach sand, and could originate from the northern Levantine coast, probably north of Akko and south of Latakia (see, e.g., Buchbinder 1975; Sivan 1996, 48–53; Walley 1997; Goren and Halperin 2004, 2558). This fabric is quite similar to Serpico Fabric Group 5, an origin for which is proposed along the Lebanese coastal plain (Serpico 2008, figs 23 and 24), and probably also to a fabric defined for Kommos Canaanite jars (Cohen-Weinberger and Goren 2004, 73, Group B; Day et al. 2011, Fabric 2).

The five sherds identified as group 5 (A and B) present a narrow range of lead isotopic compositions that vary from $15.699 \pm 0.0007$ (2se) to $15.707 \pm 0.0008$ (2se) and $19.281 \pm 0.0006$ (2se) to $19.369 \pm 0.0008$ (2se) for $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$, respectively (Table 1 and Fig. 3). The values for both $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios are more radiogenic than those of the local HST groups but do not plot together with group 4 (Fig. 3).

**Isolated sherd samples**

On the basis of the petrography, sherds HST 35 and HST 57 cannot be related to a specific group described above. Sample HST 35 presents a highly micaceous fabric and is probably from a metamorphic source (with angular mica schist, basalt, pyroxene and other minerals, 0.3–0.9 mm in size). The sherd-section description reveals a brown (7.5YR 5/4) to greyish brown (7.5YR 4/1) colour. The hardness of the fabric is very high and the inclusions are well sorted. Inclusions are irregular limestone and quartz particles from 0.5 to 1 mm (abundant), very fine limestone fragments and mica. No precise source within the Eastern Mediterranean can be suggested so far on the basis of petrography. However, the lead isotopic composition (Table 1 and Fig. 3) is similar to that of groups 1 and 2 ($15.675 \pm 0.0007$ (2se) to $18.795 \pm 0.0008$ (2se)). This similarity suggests that this sample shares a local HST Cypriote origin.
In thin section, sample HST 57 displays very abundant reddish rounded limonite (?) inclusions (20% of the slide area, 0.1–0.75 mm in size). It is somewhat similar to group 2 and a Cypriote origin is possible. The sherd-section description reveals a uniform light red (2.5YR 6/6) colour and no slip. The hardness of the fabric is high and the matrix is very fine and homogeneous. Inclusions are black grids from 0.2 to 2 mm (abundant), limestone from 0.2 to 2 mm (moderate), angular quartz from 0.2 to 2 mm (moderate), vegetal debris of 2 mm (sparse to moderate), clay pellets of 2 mm (sparse), vegetal skeletons (sparse) and rounded sand (sparse). However, the lead isotopic data do not confirm a Cypriote origin, as it plots alone in the lead isotopic diagram of Figure 3. Its lead isotopic composition (Table 1) differs from any other group composition (15.718 ± 0.0007 (2se) to 19.718 ± 0.0008 (2se)) and it is more radiogenic than HST production.

It is worth mentioning that except for a few sherds, most of the groups identified according to thin-section analyses are similar to the subdivisions based on sherd-section observations. The sources identified by the two methods are similar for groups 4 and 5A but differ for groups 3 and 5B. For a few samples (HST 42 and HST 48), thin-section analyses and sherd-section observations proposed different sources. The use of lead isotope further discriminated between these sources. Moreover, lead isotope analyses confirmed the affiliation of a few sherds (HST 42, HST 48, HST 49 and HST 52) to a fabric, although this link was not clearly visible by thin-section analyses.

DISCUSSION

The sherd assemblage representing the local HST pottery production (Plain White Wheel-made and Coarse fragments) has a homogeneous lead isotopic composition (Renson et al. 2011) and ranges over two fabrics (groups 1 and 2) according to petrography. Group 1 contains only pottery fragments characterizing the HST production (Plain White Wheel-made and Coarse samples) and, according to petrography, the original raw material used for the making of group 1 is most probably a marl. Group 2 contains four samples representing the HST production (Plain White Wheel-made sherds) as well as 10 Canaanite sherds; and the raw material proposed for the making of group 2, according to petrography, corresponds to Quaternary sediments. Marls and Quaternary sediments occur in abundance around the site of HST and in south-east Cyprus and central Cyprus more generally. Moreover, it was demonstrated that the lead isotopic composition of the HST pottery production precisely matches that of these marls and Quaternary sediments (Renson et al. 2011). Consequently, the confluence of the petrography and isotopic data demonstrates a local HST production for the three Canaanite fragments HST 48, HST 49 and HST 52. These three samples present a lead isotopic composition indistinguishable from the local HST Plain White Wheel-made.

Although the petrographic results also suggest a Cypriote origin for the Quaternary sediments used for the making of the seven other Canaanites of group 2 (HST 21, HST 23, HST 42, HST 47, HST 54, HST 56 and HST 60), their isotopic compositions differ from that of the local HST pottery fragments or from that of any Quaternary sediment collected around HST, so far. The lead isotopic subgroup composed of samples HST 21, HST 54, HST 56 and HST 60 presents a lead isotopic composition that is close to that of three clay samples of Cypriote Quaternary sediments collected in the Pleistocene Terrace deposits located along the northern coast of Cyprus, the lead isotopic composition of which ranges between 15.670 ± 0.0009 (2se) and 15.705 ± 0.0008 (2se) and between 19.085 ± 0.0010 (2se) and 19.110 ± 0.0010 (2se) for $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$, respectively. Finally, the lead isotopic composition of samples

HST 23 and HST 47 does not correspond to that of any Quaternary sediment in Cyprus so far analysed. Consequently, these seven Canaanite fragments either originate from another site in Cyprus or from outside Cyprus. Because the accessory mineral assemblage varies within sherds from group 2, the raw materials used for their production could indeed originate from various locations. An ongoing study of the Sr isotopic composition of these sherds will hopefully refine this hypothesis.

A Cypriote origin is also proposed on the basis of petrographic observations for sample HST 57—described as an isolated sherd sample. However, the lead isotopic composition of sample HST 57 clearly differs from that of HST production, and presents more radiogenic values for both $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios (Table 1 and Fig. 3). Lead data for sample HST 57 also differ from the isotopic composition observed for the marls from the Palaeogene–Plio-Pleistocene and the Quaternary sediments collected in south-east Cyprus (Renson et al. 2011). Neither does it correspond to any clay source so far investigated in the Kyrenia Range (northern Cyprus) or in the Mammonia Complex (south-western Cyprus). Because only part of the possible clay sources on the island have been characterized for their lead isotopic composition, the hypothesis of a Cypriote origin for sample HST 57 cannot be confirmed or ruled out at this point. According to lead isotopes, sample HST 35 could originate from Cyprus. Because mica-rich clay sources were used for the production of some pottery and clay tablets from Cyprus (Vaughan 1991; Goren et al. 2004), the mineralogy of sample HST 35 is likely to be compatible with some Cypriote raw materials. The lead isotope analysis of further clay sources from Cyprus presenting high mica contents should confirm or negate a Cypriote origin for this sample.

Three other groups (groups 3, 4 and 5) were clearly identified according to their distinct fabrics and contrasted lead isotopic compositions compared to that characteristic for HST (Table 1 and Fig. 3). Neither of these lead isotopic signatures matches the isotopic field of the marls from the Palaeogene–Plio-Pleistocene or Quaternary sediments investigated, so far, in the Circum Troodos Sedimentary Succession in south-east Cyprus. Every fabric corresponds to a specific lead isotopic composition. On the basis of the existing petrographic and isotopic data, a provenance area outside Cyprus is advocated. In more detail, group 3 could come either from the southern Levantine coast, according to thin-section analysis, or eventually from the northern part of Egypt, according to sherd-section observation. Although thin-section analysis proposes an origin related to the southern Levantine coast, an Egyptian source is still possible and the clay used as raw material could correspond to an alluvial soil derived from Nile sediments. The natural lead isotopic composition of Nile sediments results mainly from the mixing of four different sources: the Oligocene Ethiopian basalts (drained by the Blue Nile), the north-eastern Sudan Precambrian rocks (drained by the White Nile), the Sahara dusts and the average of the Upper Continental Crust (A. Veron, pers. comm.). In the absence of lead isotopic measurement for the two potential clay sources proposed by sherd-section and thin-section observations for group 3 production, an attempt is made to compare the signature of sherds from group 3 to those expected for Nile sediments on the basis of a mixing of these four geological sources (Fig. 5). This comparison shows that the signature of group 3 is not incompatible with that of a clay source corresponding to Nile sediments. However, geographically speaking, this does not formerly rule out a Levantine coast origin. Indeed, Nile sediments are also transported and accumulated along the Eastern Mediterranean coast (Krom et al. 1999) and are thus likely to influence the isotopic composition of coastal Levantine sediments as well. Complementary lead isotope analyses of the sediment typical of the southern Levantine coast and/or the alluvial material from the Nile should clearly discriminate between these two sources. Moreover, the fabric G6b described by Bourriau et al.
(2000), which macroscopically resembles the group 3 fabric (see above), was used for specific Egyptian amphorae mainly produced during the 20th Dynasty (Aston 2000). Eriksson (1995) potentially identified this material at HST on the basis of a stylistic comparison of the shapes and a microscopic analysis of the fabrics. The similarities in lead isotope between this material and Egyptian mixed Nile/marl fabric would strongly corroborate the hypothesis of the importation of Egyptian amphorae in HST.

The source area proposed for group 4 is the northern Levantine coast, probably more precisely in the coastal portion of the Jezreel Valley, according to sherd-section observation. The three sherds of group 4 plot together in an isotopic field characterized by more radiogenic $^{207}\text{Pb}/^{204}\text{Pb}$ values than the local HST products (Table 1 and Fig. 3).

The raw material used for group 5 is suggested to originate from the northern Levantine coast between Akko and Latakia, according to the thin-section analysis. The same source is proposed by sherd-section observation for two samples (HST 24 and HST 38), while an Egyptian source is suggested for the two other samples of this group (HST 40 and HST 45). Lead isotopic composition of the four samples is very homogeneous (Table 1 and Fig. 3), attesting the common origin of these four samples as suggested by the thin-section work. This example also attests to the effectiveness of lead isotopes to discriminate between two potential sources for the Canaanite production. In the absence of lead isotopic data for the clay source proposed by sherd-section and thin-section observation, a comparison is made between the composition of group 5 and that of two components proposed as the raw materials used for group 5 production according to

Figure 5 The $^{207}\text{Pb}/^{204}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$ three-isotope plot. Black triangles, petrographic group 3 sherds; dashes, Ethiopian basalts (from Pik et al. 1999); empty diamonds, Precambrian rocks from north-eastern Sudan (from Stern and Krömer 1993); plus signs, Upper Continental Crust (from Asmerom and Jacobsen 1993; Hemming and McLennan 2001; Millot et al. 2004); crosses, Sahara dusts (from Biscaye et al. 1997).
the similarities with Fabric 5 of Serpico (2008) and that of Subgroup 5.1.1 described by Bourriau et al. (2001) (Fig. 6). The lead isotopic composition of a sample collected in the Lower Cenomanian limestone (Erel et al. 1997) represents the Upper Cretaceous–Eocene rock assemblage developed in the Levant, proposed as the source of the carbonate fraction of group 5. The lead isotopic composition of group 4 could represent the coastal sediment from northern Israel and Lebanon proposed as the source for the beach sand fraction present in group 5. It appears that the lead isotopic signature of group 5 could indeed result from a mixing between clays derived from Lower Cenomanian Limestone from the Levant and coastal beach sand from northern Israel (Fig. 6). Complementary lead isotope analyses on a larger set of clay sources from this region should allow us to confirm a northern Levantine coastal origin for this Canaanite group found in HST.

The Canaanite sherds analysed in the present study represent several fabrics and various potential sources: (1) a local source in close proximity to Hala Sultan Tekke; (2) possibly two or three other Cypriote sources; (3) two different north Levantine sources; (4) a south Levantine or northern Egyptian source; and (5) possibly an additional source, so far unknown. This is in good agreement with previous studies realized on Canaanite vessels from Hala Sultan Tekke (Raban 1980; Eriksson 1995). The present results show that the lead isotopes are consistent with petrographic observations in most cases, and suggest a same subdivision inside the sherd samples. In several cases, this study showed that lead isotopes further discriminated between potential sources suggested by petrography. For group 3 and subgroup 5B, lead isotope analyses of reference Canaanite pottery fragments and/or on clays from the different source areas should allow us to decipher between the sources proposed by thin-section observation on one hand and sherd-section observation on the other. The comparison of the isotopic composition of the different group of sherds with a few data available for rocks and sediments clearly indicates that lead isotopic composition is an excellent tool to trace the source of Canaanite fabrics.

Figure 6  The 208Pb/206Pb versus 206Pb/207Pb three-isotope plot. Black diamonds, petrographic group 4 sherds; black circles, petrographic group 5 sherds; plus sign, Lower Cenomanian limestone and dolomite bedrock (Israel) (from Erel et al. 1997).

CONCLUSIONS

This study demonstrates that a specific Canaanite fabric presents a specific lead isotopic composition depending on the source region. The multiple sources proposed for the Canaanite sherds excavated at HST explain the isotopic variability observed amongst Canaanite fragments. In addition, it is possible to discriminate between Cypriote ‘Canaanite ware’ and imports. A potential source in close proximity to HST can be recognized that makes it likely that jars of Canaanite fabric were locally produced at this site.

Moreover, the raw materials used for the Canaanite fabrics production presently analysed originate from different Quaternary deposits and Tertiary marls occurring in the Levant and in Cyprus. Petrography allows us to identify the type of clay and often points to potential sources on the basis of a comparison with previous studies realized on Canaanite fabrics. However, this study shows that when petrographic thin-section analysis is coupled with lead isotope analyses, it results in more refined data. Finally, the isotopic composition of the clay sources used for the different fabrics presented here is obviously well preserved in the pottery itself, opening the way to further precise provenance studies if the suggested clay sources are sampled and characterized for lead isotopes.

In future research, it would be expedient to link the current data to a morphological analysis of storage and trade containers. This approach would contribute to a better understanding of exchange patterns and connections in the Eastern Mediterranean region. Moreover, it would specify the role of HST in trade involving containers in Canaanite fabrics.

Using Canaanite fabrics as a case study, this work demonstrates the strong discriminatory effect of coupling petrography and lead isotopes in ceramic provenance studies. When petrography proposes several sources for a type of raw material, lead isotope analyses appear as an efficient discriminative tool that deciphers between the different potential sources. Today, numerous complementary analytical methods are available and multi-proxy approaches provide more precise statements on pottery origins and consequently improve knowledge on exchanges between ancient civilizations. This research demonstrates the effectiveness of determining various characteristics of pottery fragments and clay sources to establish the provenance of pottery.

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