**Study of the ceramics and pigments in Late Bronze Age painted Canaanite pottery using ceramic petrography and microbeam methods: An Example from Tel Esur**

**Highlights**

* The ceramics and pigments in LBA painted Canaanite pottery at Tel Esur were studied.
* Compositions, technologies, raw materials, origin and cultural issues were obtained**.**
* The painted vessels were produced in workshops along the Levantine coastal plain.
* For black and red decorations ferromanganese and ferric-iron pigments were utilized.
* The results imply on Cypriot-Canaanite interactions and on import-trade in pigment**s**.

**Abstract**

The ceramics and pigments of Late Bronze Age (LBA) painted Canaanite pottery were analyzed using ceramic petrography and microbeam methods: EPMA, pXRF and LA-ICP-MS. The study focuses on painted vessels from Tel Esur, which has yielded a well-preserved LBA assemblage. The studied pottery is consisted mainly of jars and "biconical"-jugs decorated with black, red or bicolored geometric patterns. The compositions, technologies, raw materials, origin and cultural issues were obtained. The painted vessels were produced in workshops along the Levantine coastal plain. For black and red decorations ferromanganese and ferric-iron pigments were utilized. The use of manganese-based pigment facilitates the black decoration process by firing at oxidizing atmosphere and seems to be a LBA Canaanite technological progress. The use of manganese-based pigment on the LBA painted Canaanite pottery parallel to the use of this technology on painted Cypriot ware such as on Cypriot White Slip-II ware import to Tel Esur. The analogous uses of ferromanganese pigment and the Cypriot trade with Canaan that time match the possibility of Cypriot trade with Canaan also in ferromanganese pigment for the use in black decoration at the LBA Canaanite workshops.

**1. Introduction**

**1.1. Tel Esur and its Late Bronze Age Pottery**

Tel Esur (Tell el-Assawir) is located on the Mediterranean coastal plain of Israel (for location map see Shalvi et al., 2019a). It is a small, five-acre site, of which fewer than two acreswereinhabited during the LBA. It seems to have been a rural LBA settlement at the western entrance to the Nahal ʻIron (Wadi ʻAra) pass, which constituted part of the historical Via Maris leading from Egypt to Mesopotamia. The most significant LBA remains were excavated in Area B1, in the northern part of the site; where in Stratum 2, the LBA is represented by an unusually well-preserved domestic building (Bar, 2016; Shalvi, 2016). Judging from its pottery, the house must have been functional in late LB IB and early LB IIA, circa 1400–1350 BCE. The ceramic assemblage found in the structure is very well preserved, lay mostly in primary deposits and is restorable. It consists of objects primarily of local Canaanite form, some Egyptianizing vessels, and several fragments of standard imported Late Cypriot II pottery such as white slip, base ring, etc. (Shalvi et al., 2019a). The Canaanite pottery includes plain and painted vessels for household use as well as many large ones for storage.

**1.2 Microbeam methods in the study of pottery**

In the present study we use microbeam methods in analyzing of painted Canaanite pottery. Microbeam analyses refer to any microanalytical methods used for compositional analyses, as defined by the Microbeam Analysis Society (MAS). Here we use EPMA (Electron Probe Micro-Analyzer)**,** pXRF (Portable X-Ray Fluorescence Spectroscopy) and LA-ICP-MS (Laser-Ablation Inductively Coupled Plasma Mass Spectrometry) in direct (dry) analysis of the ceramic-body and the pigments.

The EPMA method allows microprobe analysis of ancient ceramics (Ionescu et al., 2011; Ionescu and Hoeck, 2016) and of paints on pottery (Ashkenazi et al., 2017; Shalvi et al., 2019b; Shoval, 2018). This method provides SEM (Scanning Electron-Microscopy) images, WDS (Wavelength Dispersive Spectroscopy) elemental mapping, as well as EDS (Energy-Dispersive X-ray Spectroscopy) analyses. The EPMA-SEM method provides microstructural images of the pottery fabric (Tschegg et al., 2008, 2009). The EPMA-WDS elemental maps present visually the distribution pattern of the detected elements and their degree of homogeneity in the scanned specimens (Panighello et al., 2012). The EPMA-EDSmethod provides chemical analysis of ancient ceramics and discerns mainly the concentrations of major elements (Ionescu and Hoeck, 2016).

The pXRF analysis allows chemical analysis of ancient ceramics (Goren et al., 2011; Frahm and Doonan, 2013; Hunt and Speakman, 2015; Holmqvist, 2016; Speakman et al., 2011) and of paints on pottery (Aloupi et al., 2000, 2001a, 2001b; Aloupi-Siotis and Lekka, 2017; Attaelmanan and Yousif, 2012; Centeno et al., 2012; Shalvi et al., 2019b; Shoval and Gilboa, 2016). This method is often utilized for provenance studies of ceramic vessels (Hein et al., 2004; Maritan et al., 2013). The pXRF discerns the concentration of most of the major elements and some of the trace elements. It is an inexpensive, rapid and non-destructive method, which can be used on a large scale (Ferguson et al., 2015; Goren et al., 2011; Pappalardo, et al., 2010). However, this method has some analytical limitations (Hunt and Speakman, 2015). The pXRF analysis does not detect several “light” major elements such as C and O, and regularly not Na and Mg as well. As for the detection of the elements Al, Si, S and P, the analysis has to be performed under vacuum conditions. The pXRF method is less accurate in detection of elemental concentrations than EPMA-EDS and LA-ICP-MS analyses.

The LA-ICP-MS permits a high-resolution and high-accuracy quantitative chemical analysis of ancient ceramics (Giussani et al., 2009; Golitko and Dussubieux, 2016; Resano et al., 2010; Robertson et al., 2002; Wallis and Kamenov, 2013) and of paints on pottery (Neff, 2003;Porter and Speakman, 2008; Shalvi et al., 2019b; Shoval, 2018; Speakman and Neff, 2002). The combination of ICP with LA discerns the identification of the concentrations of all major elements and detectable trace elements (Neff, 2012; Porat et al., 1991; Speakman and Neff, 2005).However, this method is expensive and therefore cannot be use in large scale. It uses here to supports the pXRF results and in detection of the trace elements.

In the present study we use also ceramic petrography (polarized light microscopy). This method allows an optical examination of thin sections of pottery under a polarized microscope (Maggetti, 1982, 1994). The ceramic petrography enables identification of the ceramic fabric and the coarse particles within the ceramic material. This method is often utilized for provenance studies of pottery (Hein et al., 2004; Maritan et al., 2005, 2013; Porat et al., 1991; Shoval et al., 2006). However, the layers of the painted decoration are usually too thin for examination by polarized light microscopy, which eliminates pigment analysis by this method in the present study.

**1.3 Aims of the study**

Studies ofLBA and Iron Age painted pottery from the Eastern Mediterranean has been the subject of several articles (Aloupi et al., 2000, 2001a, 2001b; Aloupi-Siotis and Lekka, 2017; Diebold et al., 2005; Kaplan et al., 2014; Noll, 1981; Porter and Speakman, 2008). In the present study, we performed for the first time detail compositional analysis of an assemblage of pre-Iron Age painted Canaanite pottery. We choose painted pottery from the Canaanite site of Tel Esur, which has recently yielded a well-preserved LBA assemblage dating to ca. 1400-1350 BC, a period in which trade between the Levant and Cyprus was established. Analyses were conducted on the ceramic-body, the black and the red decoration of these vessels using ceramic petrography and microbeam methods.

The present study is an integral part of a wider, comprehensive research project about Bronze and Iron Age paint-decorated pottery in the Eastern Mediterranean (Shalvi et al., 2019b; Shoval, 2018; Shoval and Gilboa, 2016). It designed to facilitate further comparative studies of paint-decorated pottery in the Levant and resulting cultural inferences. We generally expect that painted pigments and the technology may reveal hitherto unknown facets of Canaanite-Cypriot interaction in the LBA. The compositions, technologies, raw materials, origin and cultural issues were obtained.

**2. Experimental Design and Methods**

**2.1 The studied painted Canaanite pottery**

The list of the studied painted Canaanite pottery from Tel Esur is presented in **Table. 1.** The analyzed specimens are from complete vessels and from several pottery fragments (Shalvi et al., 2019a). These consisted mainly of painted jars and "biconical"-jugs in good contexts (Shalvi, 2016). Typological illustrations of the complete vessels studied are demonstrated in **Fig. 1**. Photographs of the studied pottery are given in **Fig. 2**. The painted Canaanite ceramics are typically decorated with black, red or bicolored geometric patterns over the ceramic-body or white slip layer **(Fig. 2)**. The analyzed segments from the ceramic-body, the black decoration and the red decoration of each pottery sample are marked respectively with the prefix C, B and R (e.g. Esur-115B referred to specimen from the black decoration on pottery Esur-115). Particular analyses were conducted on select specimens who considered being representative for the Tel Esur's pained Canaanite assemblage.

**Table 1:** The list of the Tel Esur's painted Canaanite pottery studied.

**2.2 Experimental**

Ceramic petrography was performed here by examination of thin sections of the painted pottery with a BX51-P Olympus polarizing microscope equipped with a camera (Fabbri et al., 2014; Shoval et al., 2006). Microbeam analyses of the pottery specimens were preformed with the following instruments (Shalvi et al., 2019b). EPMA analysis was conducted with a high-resolution JEOL SuperProbe JXA-8230 EPMA apparatus equipped with SEM and four WDS spectrometers for microanalysis (Shoval, 2018). For pXRF analysis was a handheld Bruker Tracer III-V XRF spectrometer was used (Shoval and Gilboa, 2016). LA-ICP-MS analysis was preformed with an ICP-MS AGILENT Technologies 7500 CX series ORS quadrupole mass spectrometer designed for high-precision measurement of elemental concentration (Shoval and Paz, 2015). For the detailed experimental protocol in our experiments see references of our previous works quote above.

**Fig. 1:** Typological illustrations of the Tel Esur's complete painted Canaanite vessels studied.

**Fig. 2:** Photographs of the Tel Esur's painted Canaanite pottery studied.

**3. Results**

**3.1 Ceramic petrography analysis**

**Fig. 3** illustrates ceramic petrography photomicrographs of thin sections analyzed from several complete painted Canaanite vessels at Tel Esur. The major coarse particles are quartz grains derive from quartz sand and fragments of carbonate rocks and *kurkar* (a local term for aeolianite). The ceramic matrix is calcareous and contains some quartz silt. Based on the nature of the coarse particles and the characteristics of the ceramic matrix, four major petrographic groups were identified (data is summarized in **Table 5)**.

**Fig. 3:** Ceramic petrography photomicrographs of thin sections analyzed from several complete painted Canaanite vessels at Tel Esur (cross-polarized light). Major coarse particles are quartz grains (Qu), fragments of carbonate rocks (CR) and *kurkar* (Ku), iron concretions (IC), calcareous algae (CA) and foraminifera (Fo).

**3.2 The EPMA-SEM** **images**

**Fig. 4** illustrates the EPMA-SEM images scanned on the ceramic-body, the black decoration and the red decoration on samples Esur-106C, Esur-115B and Esur-103R, respectively. Two types of SEM images are presented in the figure: secondary electron (SEI) and backscattered (COMPO) images. The former shows the microstructures of the scanned specimen **(Fig. 4a, c, e)** while the latter contrasts components consisting of light-metals against those consisting of heavier-metals **(Fig. 4b, d, f)**. In the backscattered images, the areas assigned a darker shade of grey represent materials composed of light-metals while the lighter areas represent materials composed of heavier-metals. The ceramic-body is characterized by pseudo-platy microstructure of the fired-clay **(Fig. 4a)**. The fired-clay was formed by the firing of the clay raw material (Shoval et al., 2011). The backscattered image of the ceramic-body **(Fig. 4b)** displays darker grey shaded areas, indicating light-metals (Si and Al; see below). The black and the red decorations are composed of small pigment particles **(Fig. 4c, e)**. The backscattered image of these pigments **(Fig. 4d, f)** displays whiter shaded indicating heavier-metals (Fe and Mn; see below).

**Fig. 4:** EPMA-SEM images scanned on specimens of the ceramic-body (a, b), the black decoration (c, d) and the red decoration (e, f) in samples Esur-106C, Esur-115B and Esur-103R, respectively. (a, c, e) secondary electron images; (b, d, f) backscattered images.

**3.3 The EPMA-WDS** **elemental maps**

**Figs. 5-7** illustrate the EPMA-WDS elemental maps scanned from the ceramic-body, the black decoration and the red decoration on samples Esur-106C, Esur-115B and Esur-103R, respectively. The color tones in each map represent the concentration range of the detected element as determined according to the color scale. The elemental maps **(Figs. 5-7)** reveal non-homogeneous distribution patterns of the detected elements, which reflect compositional variations of the components in the scanned areas. The elemental maps of the ceramic-body **(Fig. 5)** display high concentrations of SiO2 and Al2O3, attesting to the composition of the fired-clay ceramic in the specimens. The patches with higher SiO2 content reflect contribution from accessory quartz particles within the fired-clay **(Fig. 5a)**. Some concentrations of Fe2O3 and traces of MnO are also observed for the ceramic-body **(Fig. 5c-d)**. The content of CaO **(Fig. 5e)** demonstrates the presence of fine calcite within the ceramic material (Shoval, 2003; Fabbri et al., 2014). The elemental maps of the black decoration **(Fig. 6)** illustrate prominent concentrations of Fe2O3 and MnOattesting to the ferromanganese composition of the black paint. The non-homogeneous distribution patterns of the detected elements in the maps reflect the granular microstructure of the pigment grains. The elemental maps of the red decoration **(Fig. 7)** show higher concentrations of Fe2O3 and only traces of MnO with respect to those of the black decoration.

**3.4 The EPMA-EDS analysis**

**Table 2** presents results of the EPMA-EDS analysis of the major elements (presented as oxides) in the ceramic-body and the black and the red decoration on select Tel Esur's painted Canaanite pottery. Both pigments contain Fe2O3; the black decoration comprises also MnO.

**Table 2:** EPMA-EDS analysis of the major elements (oxides, in mass%) in black (B) and the red (R) decorations on select Tel Esur's painted Canaanite pottery (for several specimens results of two analyses are presented.

**Fig. 5:** EPMA-WDS elemental maps (oxides; color scale in mass%) scanned from the ceramic-body on sample Esur-106C: (a) SiO2; (b) Al2O3; (c) Fe2O3; (d) MnO; (e) CaO and (f) MgO.

**Fig. 6:** EPMA-WDS elemental maps (oxides; color scale in mass%) scanned from the black decoration on sample Esur-115B: (a) SiO2; (b) Al2O3; (c) Fe2O3; (d) MnO; (e) CaO and (f) MgO.

**Fig. 7:** EPMA-WDS elemental maps (oxides; color scale in mass%) scanned from the red decoration on sample Esur-103R: (a) SiO2; (b) Al2O3; (c) Fe2O3; (d) MnO; (e) CaO and (f) MgO.

**3.5 pXRF analysis**

**Table 3** presents the pXRF analysis of the major elements in the ceramic-body, the black decoration and the red decoration of all specimens from the Tel Esur's painted Canaanite pottery. As there is significant overlap in the Al and Si peaks in the pXRF spectra of ceramics, we present in **Table 3** the sum of the concentrations of SiO2+Al2O3. Furthermore, due to some analytical limitations of the pXRF method (Hunt and Speakman, 2015; Liritzis and Zacharias, 2011), we present in the table the sum of the trace elements concentrations rather than each one individually. The pXRF results confirm that the ceramic-body is rich in SiO2+Al2O3, with some Fe2O3 and poor in MnO; the black decoration consists of pronounced concentrations of Fe2O3 and MnO, and the red decoration is rich in Fe2O3 and poor in MnO. In our pXRF analyses, larger amount of Fe2O3 are detected with respect to those of the EPMA-EDS and LA-ICP-MS analyses.

**Table 3:** pXRF analysis of the major elements (oxides, in mass%) in the ceramic-body (C), the black (B) and the red (R) decorations of the Tel Esur's painted Canaanite pottery (The whole pXRF analysis of each specimen is normalized to 100%).

**3.6 LA-ICP-MS analysis**

**Table 4** presents results of the LA-ICP-MS analysis of the major and trace elements in the black decoration on select Tel Esur's Canaanite pottery. Some differences in the results obtained by the line analysis and by the spot analysis are related to the different scanned areas by the two methods and the heterogeneity within the pigment layers. The analysis confirms the composition of the major elements and shows the levels of the concentrations of the trace elements Cu, Zn, Ni, Co and V.

**Table 4**: LA-ICP-MS analyses (major elements, oxides, in mass%; trace elements in ppm) of the black decoration (B) in select Tel Esur's painted Canaanite pottery. The symbol < is used to report when the concentration of an individual element is below its limit of detection. (LA = line analysis; SA = spot analysis).

**4. Discussion**

**4.1 The origin of the painted pottery**

Ceramic petrography data of the Tel Esur's complete painted Canaanite vessels is summarized in **Table 5**. The identification of quartz grains within the ceramic materials **(Fig. 3)** reveals an origin of the painted vessels from raw material consisted quartz sand, which is characteristic of the Levantine coastal plain region (Gilboa and Goren, 2015). The observation of four major petrographic groups specifies an origin in several provenances of this region. The content of a large amount of quartz grains in the ceramic without other fragments of calcareous rock (Groups A1 and A2 in **Table 5**) identifies an origin from raw material rich in quartz sand in the Sharom coastal plain area. The combination of quartz grains with coarse fragments of carbonate rocks (Groups B1 and B2) specifies raw material in the eastern coastal plain, closer to the hill country in which carbonate rocks are exposed. The combination of quartz grains with coarse *kurkar* particles rich in quartz sand (Groups C1 and C2) identifies raw materials in the Sharon or Carmel coast, west of the *kurkar* ridges (Gvirtzman *et al*., 1998). The combination of few quartz grains with coarse *kurkar* particles consist of fossil fauna (Groups D1 and D2) specifies raw material in the Northern coast (Western Galilee-Lebanon coast), west of the *kurkar* ridges.

In all the petrographic groups the ceramic matrix contains fine calcite, which reflects an origin from calcareous raw materials. In the coastal plain region, calcareous raw materials are found in local clay-alluvia, river beds and marshland sediments. It should be noted that the red *Hamra soil* which is common in the coastal plain region has non-calcareous composition (Gvirtzman *et al*., 1998), and thus exclude it use for raw material in production of these vessels.

**Table 5:** Ceramic petrography data of the Tel Esur's complete painted Canaanite vessels.

**4.2 The composition of the painted pottery**

**Fig. 8** illustrates diagrams comparing the results of the pXRF analysis for select elements in the ceramic-body, the black decoration and the red decoration of the Tel Esur's painted Canaanite pottery. Three different compositions are observed for these pottery segments**.** The ceramic-body is rich in SiO2+Al2O3 and contains CaO **(Fig. 8a)**, which characterize calcareous ceramic consists of fired-clay and fine calcite (Shoval, 2003; Fabbri et al., 2014). The use of calcareous raw material allows production of ceramic at lower firing temperature (Shoval, 2003). In addition, the calcareous raw material has lighter colors which enable accentuating of the painted decorations on lighter substrate **(Fig. 2)**, instead of covering with light slip for this purpose (Shoval, 2018). The distributions of the elements (oxides) in the compositions of the ceramic-body on different pottery **(Fig. 8)** are related to variations in the compositions of the raw materials utilized.

The black decoration on the painted Canaanite pottery contains Fe2O3 and MnO **(Fig. 8b)**, which characterize ferromanganese pigment (Shalvi et al., 2019b; Shoval and Gilboa, 2016). The red decoration contains Fe2O3 almost without MnO **(Fig. 8b)**, which typify ferrous-iron pigment (Sabbatini, et al., 2000; Shoval, 2018). The distributions of Fe2O3 and MnO in the compositions of the black decoration on different pottery are related to the origin of the pigment and to the quality of the pigments on the pottery. In each pottery sample, the highest concentrations of these oxides are detected on painted segments in which the pigment layers are thicker and consecutive and the painted decorations have been better preserved. Both, the black and the red pigments contain also some SiO2+Al2O3, which reflects some content of fired-clay (Shalvi et al., 2019b).

**Fig. 8:** Diagrams comparing the results of the pXRF analysis for select elements (oxides, in mass%) in the ceramic-body, the black decoration and the red decoration of the Tel Esur's painted Canaanite pottery (data in **Table 3**): (a) CaO versus SiO2+Al2O3 and (b) MnO versus Fe2O3.

Although some differences in the concentrations of the elements are observed in the pXRF analysis **(Table 3)** with respect to those obtained by the EMPA-EDS **(Table 2)** and LA-ICP-MS **(Table 4)**, similar trends in the results are observed. The differences might be caused for several reasons: the accuracy of each analyzing method, inhomogeneity of the object analyzed, different locations on the object targeted by each apparatus, different sizes of the scanned area and different penetration depths of the analysis. Although the similar trends, larger amounts of Fe2O3 are detected in our pXRF analysis with respect to those obtain by the EPMA-EDS and LA-ICP-MS, due to less accurate of the former in detection of iron.

**4.3 Technological choice in black decoration**

On ancient pottery black decoration was achieved with ferrous-iron pigment or with manganese-based pigment (Barnett et al., 2006; Aloupi et al., 2000, 2001a; Shoval, 2018; Shoval and Gilboa, 2016). The former pigment requires firing of the pottery in a reduction atmosphere (Maggetti and Schwab, 1982) while the latter pigment enables firing in an oxidizing atmosphere (Schweizer and Rinuy, 1982; Uda et al., 1999; Shalvi, 2016). In periods early to the LBA, the black decoration was obtained with ferrous-iron (Noll et al., 1975; Noll, 1981). In this case, the bicolored decoration required firing twice, once in a reducing atmosphere for the black decoration, and then in oxidizing atmosphere for the red decoration (Maggetti and Schwab, 1982; Schweizer and Rinuy, 1982; Uda et al., 1999). On the other hand, the combination of ferromanganese pigment for black decoration and ferric-iron pigment for red decoration enables simultaneously bicolored decorations under a single firing in an oxidizing atmosphere (Shalvi et al., 2019b; Shoval, 2018; Shoval and Gilboa, 2016).

In the present study we show that ferromanganese pigment consists of Fe2O3 and MnO (**Fig. 6; Tables 2-4)** was utilized for the black decoration. The use of manganese-based pigment seems to be an LBA technological progress in the Canaanite workshops. This may be the reason for the sharp increase in production of bicolored Canaanite pottery during the LBA (Bonfil, 2003; Choi, 2016; Panitz-Cohen, 2006).

**4.4 The use of ferromanganese pigment on Canaanite and on Cypriot ware**

In the Cypriot workshops the source of manganese-based pigment was the Cyprus umber ore (Aloupi et al., 2000, 2001a; Aloupi-Siotis and Lekka, 2017). In Cyprus this ore appears in the Upper Turonian pelagic sediments over the ophiolite pillow basalts (Constantinou and Govett, 1972; Robertson, 1975; Robertson and Hudson, 1973, 1974). Indeed, Cyprus umber ore was identified in the black decoration on LBA Cypriot White Slip-II ware imports at Tel Esur (Shalvi et al., 2019b) and of Cypro-Geometric and Cypro-Archaic Bichrome ceramics imports at Tel Dor (Shoval and Gilboa, 2016).

**Fig. 9** shows comparison between the major element compositions of the black decoration on the Canaanite pottery and those on LBA painted Cypriot White Slip-II ware imports at Tel Esur**.** The figure demonstrates that the concentration points of the major elements (presented as oxides) in the black decoration on both pottery groups are generally coincide. The black decorations on the two pottery groups contain Fe2O3 and MnO of ferromanganese pigments **(Fig. 9a),** SiO2 and Al2O3 from clay **(Fig. 9b)**, CaO from fine calcite **(Fig. 9c)** and TiO2 and K2O **(Fig. 9d)**. In both pottery groups, the black decoration on each specimen contains higher concentrations of Fe2O3 than MnO **(Fig. 9a)**. Some dispersion of the concentration points of the major elements in the black decoration of the two pottery groups can be explained by the content of some local clay with the black pigment. The results demonstrate that ferromanganese pigment was used in both, the Canaanite and the Cypriot workshops (Shalvi et al., 2019b).

For the black decoration in the Canaanite workshops an available source of ferromanganese ore was required, whereas such large ore sources are rare in the Canaan region (Ilani et al., 1990) and absent from the coastal plain area. Therefore, the ferromanganese pigment for black decoration must have been imported to the Canaanite workshops from an outside ore source. The analogous uses of ferromanganese pigment on LBA painted Cypriot ware match the possibility of Cypriot trade with Canaan also in ferromanganese pigment for the use in black decoration at the LBA Canaanite workshops.

**Fig. 9:** Diagrams comparing the LA-ICP-MS analyses of select major elements (mass %) in the black decoration on the Tel Esur's painted Canaanite pottery (data in **Table 4**) to those on LBA Cypriot White Slip-II ware imports at Tel Esur and to that of Cyprus umber ore (data of the latters from Shalvi et al., 2019b)**:** (a) MnO versus Fe2O3; (b) Al2O3 versus SiO2, (c) CaO versus SiO2+Al2O3 and (d) TiO2 versus K2O.

**5. Technology Transferring**

Aloupi et al. (2001a, 2001b) and Aloupi-Siotis and Lekka (2017) show a chronological interplay on the use of different black decoration techniques (iron reduction technique, manganese black technique) which ties up with the archaeological views towards an Aegean influence in Cyprus during the Middle and Late Bronze Age. They have reported that in painted Cypriot ware the manganese-based pigment became preferable for black decoration at the end of the LBA and onwards (1050-325 BC). Whereas, in earlier periods from the Neolithic to the Middle Bronze Age (5000-1625 BC), the black decoration on Cypriot pottery was obtained with ferrous-iron pigment (Aloupi et al., 2001a; Jones, 1986). The period between 1625-1050 BC was a transitional one, in which both techniques were used for black decoration.

The use of manganese-based pigment on the LBA painted Canaanite pottery parallel to the use of this technology on painted Cypriot ware (Aloupi et al., 2000, 2001a; Aloupi-Siotis and Lekka, 2017) such as on Cypriot White Slip-II ware import to Tel Esur (Shalvi et al., 2019b) reflects Canaanite-Cypriot technology transferring. The manganese-based technology may have arrived to the Canaanite workshops by exchange of ideas associated with the LBA maritime trade circulation in goods between Cyprus and Canaan. Indeed, the LBA Canaanite assemblage from Tel Esur accords with the period when sea route trade between the Levant and Cyprus was relatively intense (Kassianidou, 2013; Panitz-Cohen, 2014; Steel, 2002, 2014; Sherratt, 2014). Such maritime distribution of dozens of archaeologically invisible commodities, including minerals, is a well-known phenomenon in the Bronze Age Mediterranean (e.g. Altenmüller and Moussa, 1991; Knapp, 1991; Marcus, 2008). The exported of goods from Cyprus to ancient eastern and southern Mediterranean markets was reported by Gittlen, 1981; Gomez et al., 2002; Grave et al., 2014; Maguire, 1995; Tschegg et al., 2008.

Aloupi et al. (2001a) also propose that the manganese-based technique arrived on the Syro-Palestinian coast between 1200-1000 BC through Cypriot cultural influences. Their claim is based solely on the visual examination of a small number of examples.

However, since the LBA Canaanite pottery from Tel Esur was dated to the late LB IB and early LB IIA (circa 1400–1350 BCE) the present study suggests that the manganese-based technology was used in Canaan at least 150 years earlier than that reported before for the transition to the Syro-Palestinian coast.

**6. Summary**

1. The applying of ceramic petrography and microbeam methods in analyzing of LBA painted Canaanite pottery at Tel Esur provides useful information and a multi-analytical database regarding their compositions, ceramic technologies, raw materials, origin and cultural issues.

2. The ceramic petrography demonstrates production of the painted Canaanite vessels in workshops at the Levantine coastal plain region. The identification of four major petrographic groups specifies an origin in several provenances at this region.

3. The microbeam analyses reveal the use of ferromanganese pigment for the black decoration and ferric-iron pigment for the red decoration. The black pigment contains also some clay.

4. The use of manganese-based pigment facilitates the black decoration process by firing at oxidizing atmosphere and seems to be a LBA technological progress in the Canaanite workshops. Moreover, the combination of ferromanganese pigment for black decoration and ferric-iron pigment for red decoration enables simultaneously bicolored decorations under a single firing in an oxidizing atmosphere.

5. The transition to the manganese-based technology in the Canaanite workshops may be the reason for the sharp increase in production of bicolored Canaanite pottery during the LBA.

6. The use of manganese-based pigment on the LBA painted Canaanite pottery parallel to the use of this technology on painted Cypriot ware such as on Cypriot White Slip-II ware import to Tel Esur. This may reflect transition of Technology between Canaan and Cyprus.

7. For black decoration in the Canaanite workshops an available source of ferromanganese ore was required, whereas such large ore sources are rare in the Canaan region and absent from the coastal plain area. The analogous uses of ferromanganese pigment on LBA painted Cypriot ware and with the Cypriot trade with Canaan that time match the possibility of Cypriot trade with Canaan also in ferromanganese pigment for the use in black decoration at the LBA Canaanite workshops.

8. As the LBA Canaanite pottery from Tel Esur was dated to the late LB IB and early LB IIA (circa 1400–1350 BCE) it appears that the manganese-based technology was used in Canaan at least 150 years earlier than that reported before for the transition to the Syro-Palestinian coast.

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