



THE MINISTRY OF NATIONAL
INFRASTRUCTURES
GEOLOGICAL SURVEY OF ISRAEL

**AN ANALYTICAL STUDY OF CERAMICS FOUND IN
CRUSADER ACRE: LEVANTINE PRODUCTION AND IMPORTS
FROM THE BYZANTINE WORLD**

S.Y. Waksman, I. Segal, N. Porat, E.J. Stern and J. Yellin



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ABSTRACT

As the main harbor of the Latin Kingdom of Jerusalem, Acre is a site of particular interest for the study of commercial and cultural exchanges between the Levant and Mediterranean area at the Crusader period (12th – 13th centuries). Ceramics excavated in several parts of the Medieval city, including the Hospitallers complex of the knights of the order of St. John, were investigated by petrography and chemistry (ICP-AES and -MS). This archaeometric program fits into the general framework of provenance studies in the Medieval Eastern Mediterranean area.

Its first aim was to characterize Levantine ceramic productions, in order to get an insight into the organization of the production and to be able to recognize these ceramics in further provenance studies on sites where they were exported to. Acre is attested as a production center since wasters of a simple bowl named "Acre bowl" were found in the excavations in addition to bowls of this type. Chemical analysis of "Acre bowls" constituted a local reference and enabled to investigate the range of products manufactured in Acre. This chemical reference together with the petrographic characteristics pointed to the importation of most of the typical Levantine ceramics (sgraffito, slip-painted and reserved-slip bowls, glazed cooking wares) into Acre. The analyses also indicated that the slip-painted ware correspond to a specific production, whereas sgraffito ware and cooking wares have similar characteristics. Petrography showed that the raw material used for manufacture of these wares derived from the Lower Cretaceous formations that are not found in the close neighborhood of Acre.

Another scope of the study was to investigate several groups of imports from the Byzantine world all related to the type named "Zeuxippus Ware". "Zeuxippus Ware" is remarkable for the high quality of its fabric and for the extent of its diffusion in a large part of the Mediterranean world and of the Black Sea. It seems that this type of ceramics inspired several "derived" productions of the 13th century, thus clear distinction between prototype" and "derived" productions based on analysis is interesting.

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INTRODUCTION

During the Crusader Period (12th-13th century AD), Acre was the main harbour of the Latin Kingdom of Jerusalem and became its capital after the seizure of Jerusalem by Salah-el-Din in 1187. Military supplies arrived through Acre's port, merchandise was imported and exported and pilgrims began their tour of the Holy Land. It is thus seen as a site of particular interest for the study of material and cultural exchanges between the Levant and the Western and Byzantine worlds.

Recent excavations were undertaken by the Israel Antiquities Authority in the Hospitallers Complex (*Avissar and Stern, 1994*) built in the 12th century by the knights of the order of St. John, in part of a 13th century AD wall and moat (*Hartal, 1997*), and in some other sites throughout the old city in dwellings and commercial areas (forthcoming in *Excavations and Surveys in Israel*). The excavations uncovered abundant ceramic material which is currently studied by E.J. Stern (*Stern, 1995; Stern, 1997*). A sampling of these ceramics has been analysed by Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES), by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) and by petrography in order to classify them according to their elemental and mineralogical characteristics and, when proper reference material is available, to attribute them to their respective source.

Our analytical program focused on two main aims. The first aim was to characterise the Levantine types and especially define which ones of them had been manufactured in Acre. Acre is attested as a production site since ceramics wasters of a simple, unglazed type of bowl (named "Acre bowl"; see *Stern, 1997:38*, Fig. 4: 1-5) have been found in the excavations. These wasters are used as local reference and enable the definition of a new analytical reference. This was seen as a particularly important task, as very little is known about the ceramics production centres of the late Byzantine/ Crusader period, and especially about the Levantine ones.

Our second aim was to investigate specific imports related to the Byzantine world. Typologically, imported ceramics we have studied are associated with the type known as "Zeuxippus ware" (*Megaw, 1968*), which correspond to fine, glazed ceramics decorated with the sgraffito technique. It is of particular interest for the period both because of the extent of its diffusion from Italy to the Levant, from the Black Sea to Egypt (*François, 1997*), and because its decorative patterns have been a main source of inspiration for the 13th century

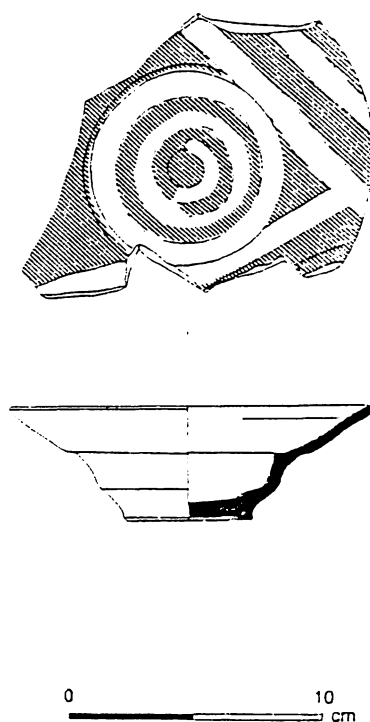


Figure 1. Regional types of ceramics: example of slip-painted ware excavated in Acre (typological group "P")

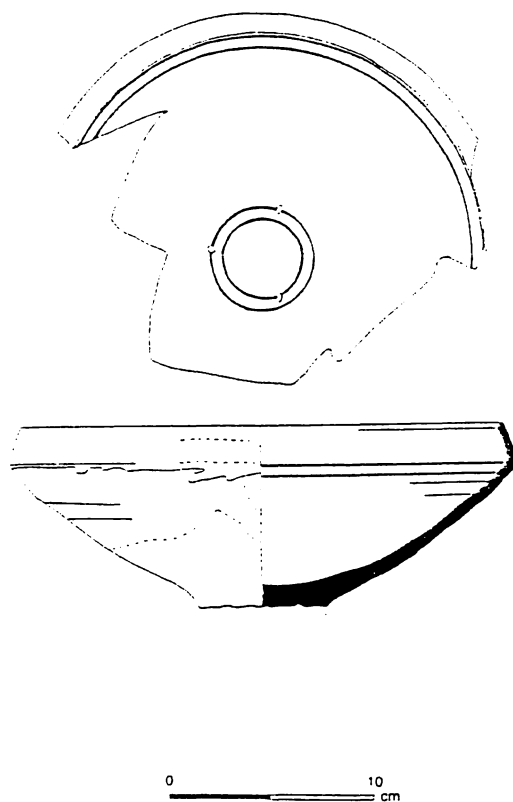


Figure 2. Imported types: example of ceramics of the Zeuxippus ware family (typological group n°1)

visibly contains some micas. The fourth group (4) is quite different. A rouletting decoration is occasionally seen on the exterior of the bowls. The general appearance of the fabric, glaze and the rouletting reminds of Italian glazed bowls from a slightly later period, and for that reason may be of an Italian origin (*Gelichi, 1986*).

Six categories of amphorae, some presumably regional and some presumably imported, were also included in the sampling on an exploratory basis (only four samples of each type were analysed).

Forty-two samples, from the mentioned above groups, were sampled for petrography (Table 1).

METHODS

Thin sections were made from samples selected for petrography and examined under a polarising microscope.

Elemental analysis was performed by ICP-AES on samples prepared according to the following protocol (*Beyth et al., 1988*): 250 mg of powdered ceramics paste was mixed with 1g of Na_2O_2 in Zr crucibles and fused for 30 to 40 minutes in a furnace at a temperature of 550°C . The samples were subsequently dissolved in water with HNO_3 addition ($\sim 3\text{HNO}_3/50$ v/v solution). HNO_3 was used instead of HCl (*Beyth et al., 1988*) to enable the use of the same initial solution both for ICP-AES and ICP-MS, as interferences due to chlorine are to be expected in ICP-MS analysis. Minor quantities of HCl were however occasionally added to dissolve the remaining iron oxides. Sc spike served as internal standard in ICP-AES for the controlling of physical effects in the plasma. Several rock standards were used either as drift monitors (BHVO-1, NIM-L) or as calibration controls and eventual recalibration tools (GS-N, BE-N, Soil-7, CFA-1633a, NIM-S, NIM-G, NIM-N) (*Geostandard Newsletters, 1989*). The elements determined were minor and trace elements Mn, V, Cr, Co, Ni, Cu, Zn, Sr, Y, Ba, La, Ce, Eu, Yb, and all the major elements of ceramic pastes (Mg, Al, Si, Ca, Ti, Fe) except for Na and K, which were analysed by INAA at the Archaeometry Laboratory of the Hebrew University of Jerusalem (*Perlman and Asaro, 1969*). The analysis of additional elements Nb,

Table 1. Comparison of typological, elemental and petrographic classifications.

Sample id.	Typological group	Compositional group	Petrographic group
ACR44	Acre bowl (B)	B	1
ACR46	Acre bowl (B)	B	1
ACR47	Acre bowl (B)	B	1
ACR80	Acre bowl (B)	B	1
ACR20	sgraffito (S)	S+C1?	2
ACR22	sgraffito (S)	S+C1	2
ACR26	sgraffito (S)	S+C1	2
ACR72	reserved-slip (R)	R	2
ACR76	reserved-slip (R)	R	3
ACR77	reserved-slip (R)	unclassified	2
ACR37	slip-painted (P)	P	3
ACR64	slip-painted (P)	P	3
ACR68	slip-painted (P)	P	3
ACR51	cooking pot (C)	S+C1	2
ACR52	cooking pot (C)	S+C1	2
ACR56	cooking pot (C)	C2	2
ACR82	cooking pot (C)	C2	3
ACR83	cooking pot (C)	unclassified	2
ACR85	cooking pot (C)	S+C1	2
ACR86	cooking pot (C)	C2	2
ZW1	Zeuxippus type 1 (1)	unclassified	3
ZW3	Zeuxippus type 1 (1)	Z1	5b
ZW6	Zeuxippus type 1 (1)	Z1	5b
ZW10	Zeuxippus type 1 (1)	Z1	5b
ZW11	Zeuxippus type 2 (2)	Z2	5b
ZW13	Zeuxippus type 2 (2)	Z2	5b
ZW15	Zeuxippus type 2 (2)	Z2	5b
ZW18	Zeuxippus type 2 (2)	unclassified	5b
ZW20	Zeuxippus type 3 (3)	Z2	5b
ZW22	Zeuxippus type 4 (4)	Z4	5b
ZW23	Zeuxippus type 4 (4)	unclassified	5b
ZW25	Zeuxippus type 4 (4)	Z4	5b
ACR122	amphora type 1 (A1)		4
ACR123	amphora type 1 (A1)		5a
ACR126	amphora type 2 (A2)		5a
ACR127	amphora type 2 (A2)		5a
ACR129	amphora type 3 (A3)		5a
ACR134	amphora type 4 (A4)	B??	1
ACR138	amphora type 5 (A5)	B??	1
ACR139	amphora type 5 (A5)	B??	1
ACR141	amphora type 6 (A6)		4
ACR143	amphora type 6 (A6)		4

Nd, Sm, Tb, Lu, Ta, Th, U and the more precise determination of Ce, Eu and Yb, have been achieved by ICP-MS, and the results are presented in this report. ICP-MS was performed on the solutions prepared for ICP-AES, further diluted to reach a dilution factor of 1000. 10 ppb of both Rh and Tl was added as internal standard and standard BE-N was used as drift monitor. A flow injection system was used for sample introduction to the ICP-MS.

The analysis of Si was not considered to be reliable on a general basis since some of the solutions showed anomalous Si values, probably related to observed white redepositions. The elements Co, Cu and Zn were also discarded in subsequent statistical treatments of the data, since tests showed they could be brought as contamination coming from the tungsten carbide drill used to sample the ceramics (Co) and from the binder holding the drill bit to the steel axis (Cu, Zn).

Multivariate statistical treatments were applied to the data using the STATGRAPHICS-UNISTAT software (*STATGRAPHICS, 1988*). Samples were grouped according to their elemental composition by Hierarchical Clustering Analysis (HCA), with Ward's method, applied on the standardised data (zero mean, variance unity). The standardisation procedure enables all the elements - major, minor and trace - to play an equivalent role in the classification. Principal Component Analysis (PCA) was also used, mainly as a tool for interpretation and display of the sampling along its main axes of variance.

RESULTS AND DISCUSSION

Petrography

The pottery from Acre can be divided into 5 groups, each related to a major geological association:

1. *Coastal*

Samples: ACR-44, 46, 47, 80, 134, 138, 139.

Temper: Well-sorted quartz, subrounded to subangular, 0.3-0.1 mm, comprising 5-10% of the volume of the sherd. Most samples (except 134) contain up to 2% decomposed carbonate grains, usually larger than the quartz. Accessory minerals are feldspars, epidote, hornblende and chert.

Matrix: Clay-rich, with some fine silty quartz. In some samples (138, 139) it appears to have been slightly calcareous.

Firing temperature: The presence of oxyhornblende and decomposed carbonates points to a temperature of 850-950°C.

Source: Well-sorted quartz sands with carbonates are found along the entire coast of Israel. The source of the clay could be in clayey soils found in between the Kurkar ridges.

2. *Mature siliclastics*

Samples: ACR-20, 22, 26, 51, 52, 83, 85, 86, 56, 72, 77.

Temper: Medium to poorly sorted quartz, subrounded to subangular, 0.4 to 0.05 mm, comprising 10-15% of the volume of the sherds. Many samples contain a few large, slightly decomposed carbonate grains. In poorly fired samples (20) the carbonate grains appear to be of biogenic origin. No feldspars and only a few stable heavy minerals such as epidote, zircon and tourmaline are observed. Some samples contain shale fragments (51, 52, 85) and some contain rare chert grains (52, 83, 85, 86).

Matrix: The matrix is clayey, non calcareous, with poorly sorted silty quartz which may be a continuous population with the quartz in the temper.

Firing temperature: For most samples the firing temperature exceeded 850°C, as shown by the partially decomposed carbonates.

Source: The absence of feldspars and unstable heavy minerals point to a mature siliclastic formation. Such a formation would include sandstone, shale and perhaps siltstone. The Lower Cretaceous formations cropping out at the southern foothills of the Hermon and Lebanon mountains are made of such rocks. Pottery production has taken place in this area, using the Lower Cretaceous shale and sandstone, since the Early Bronze Period (*Greenberg and Porat, 1996; Hartal, 1997*). The source of the vessels from Acre could be in that region.

3. *Red, glassy fragments*

Samples: ACR-82, 76, 37, 68, 64; ZW-1.

Temper: The most prominent component of the temper in all samples, although not the dominant one, is glassy red/brown/orange fragments. They are sometimes finely banded, isotropic or with a chalcedony, fibrous, radiating texture, and comprise up to

5% of the sherd.

The major temper in the samples is quartz. In samples 82 and 76 it is rounded, medium sorted, comprising 10-15% of the volume of the sherd, ranging from 0.3-0.05 mm.

These samples do not contain any other components in the temper.

In samples 37 and 68 the quartz is rounded, well to medium sorted, comprising 2-5% of the volume of the sherd, 0.2-0.05 mm. These sample also contain ~2% partially decomposed carbonates, some from a biogenic source, some shale fragments containing silty iron oxides, oölites, highly weathered basalt fragments and perhaps weathered metamorphic rocks. Sample 64 contains the same accessory fragments however the quartz is poorly sorted and comprises 10% of the sherd.

Matrix: The matrix is clayey, with rare carbonates and poorly sorted silty quartz.

Firing temperature: Varies from sample to sample, in the range of 700° to 850°C.

Source: Apart from the glassy fragments, the components of these groups are similar to the previous group. However, the presence of these fragments suggests that the pottery is from elsewhere.

4. *Dolomitic clay ± basaltic association*

Samples: ACR-123, 141, 143.

Temper: Rounded, micritic carbonate grains, forming 2-5% of the sherd, in the range of 0.3-0.05 mm, sorting varying from sample to sample, often decomposed. Some of the carbonate fragments are the remains of foraminifera. Sample 141 contains quartz with minor plagioclase, mica and heavy minerals such as pyroxene, perhaps derived from basalt. Large, oval and opaque fragments, perhaps shale fragments, are also found in the temper of samples 141 and 143.

Matrix: Calcareous, with fine silty dolomite crystals, rare silty quartz. Samples 141 and 143 also contains some mica laths.

Firing temperature: Not very high, in the range of 700-800°C.

Source: These samples are not from Israel.

5. *Micaceous-metamorphic*

Samples: ACR-122, 126, 127, 129; ZW-3, 6, 10, 1, 15, 13, 11, 18, 20, 22, 25, 23.

Temper: Two subgroups can be defined on the base of temper, one with coarse and the other with fine temper:

a) Coarse-grained temper. Sample 122 is lightly tempered (~2%) with rock fragments of quartz cemented with decomposed carbonate, as well as individual quartz grains and abundant mica laths. The quartz is well-sorted, ~0.1 mm, forming 1% of the sherds, while the mica is ~0.05 mm forming 5% of the sherds. This sample resembles sample 129 which contains the same type of quartz but where the quartz was homogeneously dispersed in the clay and the larger fragments are not observed.

Samples 126 and 127 contain poorly sorted, subangular metamorphic and igneous rock fragments such as mica-schist and large crystals of feldspar, as well as rare decomposed carbonate fragments, all ranging between 1.5 and 0.1 mm. All the finer grains are quartz.

b) Fine-sand quartz. All the remaining samples are lightly tempered with well sorted, subrounded quartz, ~0.1 mm (range of 0.2-0.05 mm), usually forming 1-5% of the volume of the sherds. Other components are mica laths in the same size range as the quartz, larger metamorphic rock fragments, decomposed carbonate grains, feldspar crystals, oxyhornblende, mudballs and microquartz.

Matrix: The matrix of all samples is finely micaceous, with varying amounts of fine silty quartz. Some samples are slightly calcareous (122, 126, 127).

Firing temperature: The partially decomposed carbonate fragments and oxyhornblende point to a firing temperature of 800-900°C.

Source: The geological provenance of this group is in a metamorphic terrain with plutonic rocks such as granite nearby. The clays are probably derived from soils or river deposits, as evident by the fine matrix with quartz and mica.

Elemental analysis

1. Regional types

A general picture of the structure of the compositional groups can be seen on the first planes of a principal component analysis (Fig. 3). Figure 3a represents regional types of bowls on the first planes of PCA based on 16 elements (68% of variance). It illustrates the fact that the repartition of the samples based on the elemental composition broadly supports the typological classification. Two groups are well differentiated, corresponding to the Acre

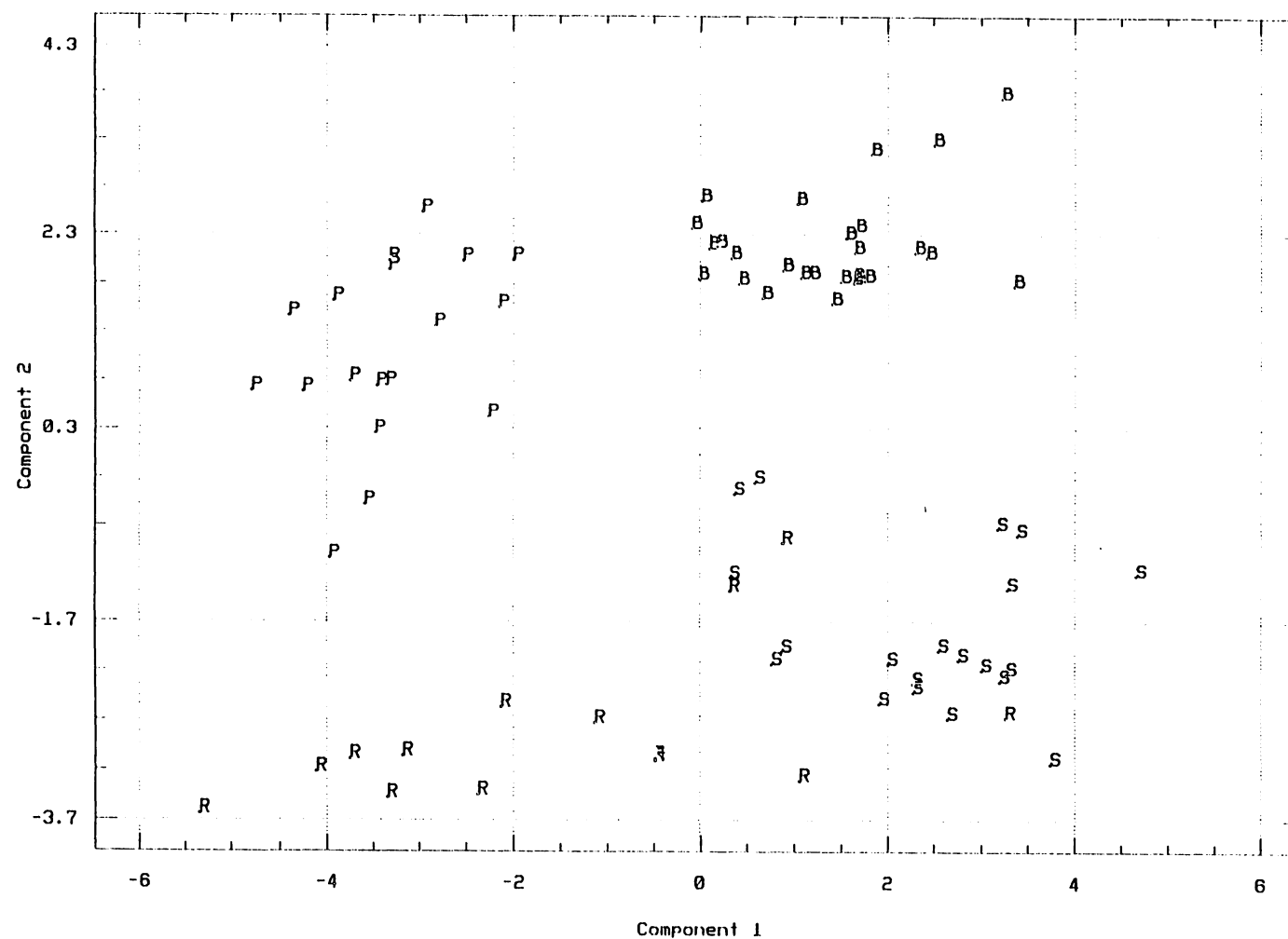


Figure 3a). Glazed and unglazed bowls of local and regional types: first plane of PCA based on 16 variables, expressing 68% of the system variance; additional passive variables - Na_2O and SiO_2 ; representation in the samples space (B: Acre bowls, P: slip-painted ware, R: reserved-slip ware, S: sgraffito).

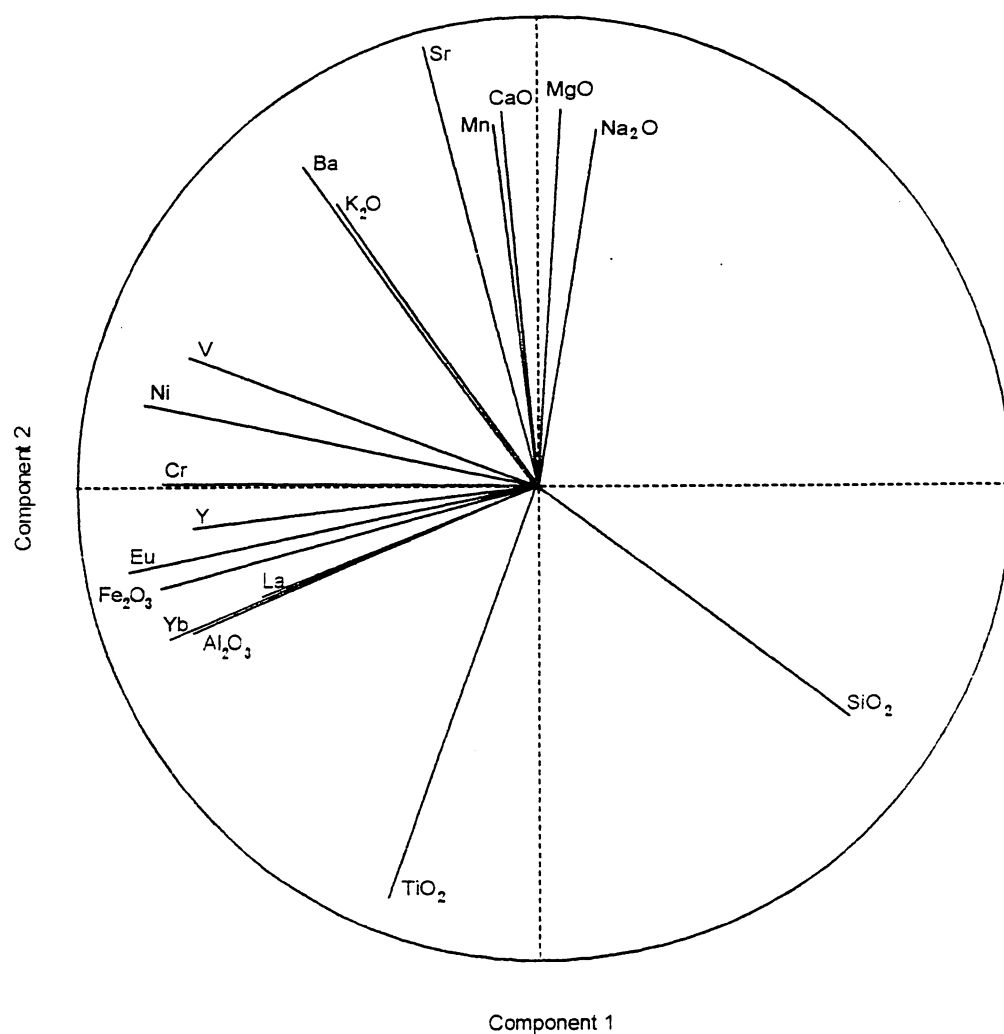


Figure 3b). Glazed and unglazed bowls of local and regional types: first plane of PCA based on 16 variables, expressing 68% of the system variance; additional passive variables - Na₂O and SiO₂; representation in the variables space (B: Acre bowls, P: slip-painted ware, R: reserved-slip ware, S: sgraffito).

bowls (samples "B") and to the slip-painted ware ("P"). The two other categories of bowls, sgraffito ware (samples "S") and reserved-slip wares ("R"), are not clearly separated from each other in Figure 3a and also in the classification by HCA.

Figure 3b represents PCA in the variables' space, which shows the correlation of the initial compositional variables with the principal components, and may thus be used as a guideline to the explanation of the differences between groups. The first axis opposes the groups richer in Al, Fe, transition elements of the Fe series and rare earth: namely, samples "P" and "R", to this of poorer in these elements and/ or richer in Si – samples "S" and "B" (note that Si has been included here as a passive variable only). The second axis is positively correlated with alkalines, alkaline earths and Mn and is negatively correlated with Ti and, less clearly, with Si. It essentially separates the low-Ca, high-Ti samples ("R") and low/variable Ca samples ("S") from the higher-Ca samples "B" and "P" and further isolates samples "B" for their comparatively higher contents in Na, Mg and Mn.

Table 2 gives the elemental compositions of the groups which appear as more stable structures throughout the classification by HCA. The names of the compositional groups were kept as close as possible to the names of the typological groups: when the compositional group closely corresponds to the typological group, it keeps the same name (groups B and P); when it corresponds to part of a typological group or to samples of different typology, the main typological components are specified (e.g., group S+C1, group C2).

Local production

As illustrated in Figure 3, the Acre bowls constitute a well-defined group within the sampling (group B, Table 2, 26 samples). It includes five wasters of this category of bowls; two other wasters have been excluded of the group, one being a noticeable global outlier (higher content in Mg, Cr and Ni, not represented in Figure 3).

Petrographic analyses (see above and Table 1) indicate that these ceramic pastes correspond to the Pleistocene coastal formations of Israel, which occur around Acre. All the evidences give a coherent picture and designate the group as a reference for Acre's production: the distribution of the finds of Acre bowls practically restricted to Acre, the presence of wasters in Acre itself, the distinctive elemental character of the group and the inclusion of most of the wasters in it, and the coastal mineralogical assemblage.

Table 2. Ceramics of local and regional types :
mean composition and standard deviation (sigma) of the main groups and sub-groups; in ppm except (%)

	B		P		R		C2		S+C1	
	mean	sigma	mean	sigma	mean	sigma	mean	sigma	mean	sigma
n	26		17		5		5		24	
Na ₂ O (%)	1.32	0.28	0.36	0.10	0.17	0.05	0.23	0.07	0.15	0.04
MgO (%)	3.19	0.48	1.46	0.20	0.90	0.05	0.93	0.22	0.67	0.13
Al ₂ O ₃ (%)	13.34	1.33	14.92	0.88	18.14	0.49	13.63	1.33	11.40	1.08
K ₂ O (%)	1.70	0.28	1.48	0.25	1.13	0.16	0.84	0.22	0.53	0.12
CaO (%)	8.02	1.74	9.25	1.88	1.50	0.41	1.66	0.37	3.93	2.72
TiO ₂ (%)	1.19	0.08	1.54	0.12	2.03	0.11	1.50	0.13	1.57	0.10
Fe ₂ O ₃ (%)	7.48	0.63	12.81	1.03	11.89	0.60	10.30	0.91	8.19	0.78
Mn	1035	90	721	138	550	27	1073	151	436	138
V	121	12	168	13	131	17	117	15	104	13
Cr	142	12	236	13	184	7	181	13	145	10
Ni	70	7	141	11	99	2	104	7	59	7
Sr	314	52	286	47	134	21	83	9	94	41
Y	40.6	2.2	42.5	5.9	63.8	4.7	66.3	6.1	32.0	3.9
Ba	389	70	639	203	173	36	233	25	145	28
La	41.9	2.9	38.6	2.5	64.0	2.3	55.8	5.1	29.9	4.1
Ce	87	8	66	8	115	8	84	7	66	8
Nd	39	4	38	5	64	4	55	4	30	4
Sm	8.1	0.8	8.2	1.4	13.6	0.9	11.8	0.9	6.3	0.8
Eu	1.88	0.18	2.13	0.37	3.43	0.20	2.86	0.17	1.46	0.19
Tb	1.2	0.1	1.2	0.2	1.9	0.1	1.8	0.1	1.0	0.1
Yb	3.6	0.3	3.5	0.3	4.9	0.4	4.7	0.4	3.1	0.3
Lu	0.54	0.05	0.50	0.04	0.78	0.06	0.76	0.06	0.51	0.04
Th	9.3	1.0	7.1	0.8	10.3	0.9	9.5	1.2	8.9	1.1
U	2.5	0.6	3.2	0.2	2.4	0.1	3.5	0.3	2.5	0.2

The only other samples that may eventually be related to this reference group are five amphorae of regional type. The relation is not direct, since the Fe, Ti, Cr, Ni, Y and REE contents of some of these amphorae fall out of the reference group range [$m-2\sigma$, $m+2\sigma$] (Table 3). We can only observe that the ratios of Fe to the other cited elements in the amphorae and in the Acre bowls are the same. Normalising the amphorae's composition of Fe to the mean of the reference group and keeping the same ratios between Fe and the other cited elements leads to values much closer to those of the Acre bowls. A hypothesis may be that the difference between the samples of amphorae and the reference group is only due to a larger variation of the amount of Fe-bearing minerals, whose contribution for Ti, Cr, Ni, Y and REE would be dominant in the amphorae. Petrography also associates the three amphorae analysed (out of the five submitted to elemental analysis) with a coastal source, but this does not rule out a provenance from another production centre located along the coast.

Our conclusion on the local provenance of all Acre bowls and the only proved local production *stricto sensu* among our sampling, does not quite agree with a previous petrographic study on a sampling including Acre bowls and cooking pots (*Goren, 1997*). That study showed that both typological categories have representatives in a coastal group and in a group related to Lower Cretaceous formation (see below). In our sampling, the two categories are well separated by the analyses and there is no satisfactory explanation at this stage for the apparent disagreement.

Regional production

The remaining glazed bowls and cooking wares of regional types share some common elemental characteristics, such as high Ti and Fe and low alkaline content. However, they are spread by the classification between one well-separated group (group P, Table 2, 19 samples), which closely corresponds to the slip-painted ware, one heterogeneous structure (group S+C1, Table 2, 24 samples) including most of the sgraffito ware and cooking pots, several sub-groups (group R, group C2, Table 2) and some unclassified sherds. All these samples, which correspond typologically to slip-painted ware ("P"), sgraffito ware ("S"), reserved-slip ware ("R") and cooking pots ("C"), will be referred to in the following paragraphs as the "sub-sampling". Petrographic analysis identifies a common "basis" corresponding to mature sandstone and shales, a geological context not quite widespread in Israel. It is probably related

Table 3. Comparison of composition of some regional type amphorae and of Acre bowls (reference group), before and after normalization of the iron value; in ppm except (%).

	MgO, %	Al ₂ O ₃ , %	CaO, %	Mn	V	Sr	Ba	TiO ₂ , %	Fe ₂ O ₃ , %	Cr	Ni	Y	La	Eu	Yb
<u>ACRE BOWLS (n=26)</u>															
mean (m)	3.19	13.34	8.02	1035	121	314	389	1.19	7.48	142	70	40.6	41.9	1.7	3.2
sigma (s)	0.48	1.33	1.74	90	12	52	70	0.08	0.63	12	7	2.2	2.9	0.1	0.3
m-2s	2.24	10.68	4.55	856	96	209	249	1.04	6.23	117	55	36.3	36.1	1.4	2.7
m+2s	4.15	16.01	11.49	1214	145	419	530	1.34	8.74	167	84	45.0	47.6	2.0	3.7
<u>AMPHORAE</u>															
ACR138	3.35	11.78	8.14	925	97	337	364	0.98	6.24	108	52	30.8	32.9	1.5	2.5
ACR137	2.88	12.76	9.94	863	102	347	333	1.07	6.87	126	57	33.5	35.8	1.6	2.9
ACR136	3.89	11.70	8.08	894	115	330	306	0.94	5.48	99	51	29.3	29.4	1.3	2.4
ACR134	3.53	12.92	6.45	1031	114	251	349	1.16	7.08	127	62	33.8	35.8	1.5	2.9
ACR139	3.54	12.91	9.02	1141	108	330	392	1.16	7.06	130	62	33.7	36.1	1.7	3.0

Renormalized to Fe=average Fe of the Acre bowls group

	TiO ₂ , %	Fe ₂ O ₃ , %	Cr	Ni	Y	La	Eu	Yb
ACR138	1.18	7.48	130	63	37.0	39.4	1.8	3.0
ACR137	1.16	7.48	137	62	36.5	39.0	1.7	3.1
ACR136	1.28	7.48	135	70	40.0	40.2	1.8	3.3
ACR134	1.22	7.48	134	65	35.8	37.8	1.6	3.1
ACR139	1.23	7.48	138	66	35.7	38.3	1.8	3.2

to the Lower Cretaceous formation which crop out in large occurrences on the slopes of the mount Hermon in the Northern Israel and across Lebanon, and in Trans-Jordan. Ferruginous clays derived from these type of formations are known to have been used for the manufacture of pottery since the Neolithic Period (see *Greenberg and Porat, 1996* and *Goren, 1995* for details and for location of major and minor occurrences in Israel), and we will discuss further below the parallels with previous studies.

The best-differentiated group is the one which (strictly) corresponds to the slip-painted ware (group P). These samples are distinguished by petrography as they are the only ones which include iron oölites and probably (very degraded) basalt fragments. They also include red glassy fragments, sometimes banded, which are unknown in ceramics associated with the Lower Cretaceous formations in Israel. Group P is characterised by a quite high Fe content - more than 12% Fe₂O₃, higher contents in transition elements of the Fe-series (V, Cr, Ni), and a somewhat higher content in MgO within the sub-sampling, which may be related to the presence of basalts. The concentration of Ca is also higher within the sub-sampling, most of the other samples are noticeably low in Ca.

As the group P shares some common characteristics with a few of the other sherds of the sub-sampling, it could have been seen as a variant of a larger group: high Fe is also observed in group R, and Fe is globally rather high in the sub-sampling. Besides, the red glassy fragments are present in two other samples, one reserved-slip bowl (in group R) and one cooking pot (in group C2) (see groups below). However, the non-ambiguous elemental separation (see Figure 4, where the group is opposed to the other sherds of the sub-sampling which seem to be part of a "continuum") and the homogeneity of the group on one hand, and the additional petrographic features on the other hand point to a distinct production.

The situation is more ambiguous for the remaining sherds of the sub-sampling. In spite of the "continuous" aspect seen in Figure 4 and of the common petrographic characteristics (except for the 2 samples just mentioned), the following structures may be distinguished (cf. Table 2):

- group S+C1 (24 samples), including most of the sgraffito ware, some cooking pots and one sample of reserved-slip ware. Its coefficients of variation are high, the Ca content being particularly variable but generally low. A low Ca content is consistent for the cooking pots with the thermal properties expected from these categories of ware (*Picon, 1995*).
- group R (5 samples), characterised by high Fe and Ti, low Ca, and especially much

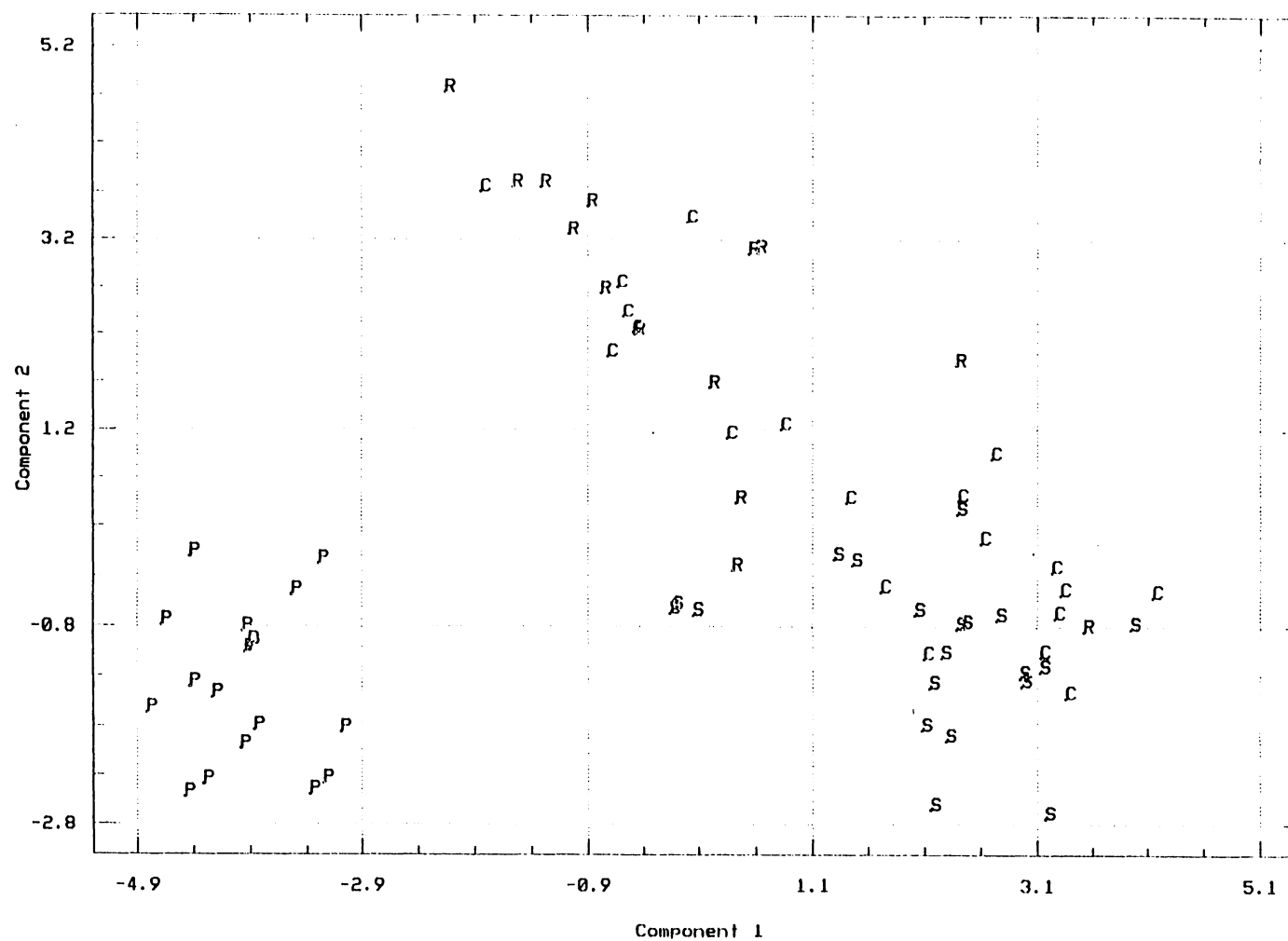


Figure 4. Regional types of ceramics: glazed bowls and cooking pots ("sub-sampling", see text); first plane of PCA based on 15 variables, expressing c. 74% of the system variance, representation in the samples space (C: cooking pots, P: slip-painted ware, R: reserved-slip ware, S: sgraffito).

higher Y and REE content (nearly twice as much as in group S+C1). Group R contains exclusively reserved-slip samples, but does not include all of them. The reserved-slip samples which, at this stage of the study, have not been included in the group share some of the above features, but do not have such high REE content and have a more variable Ca concentration. Two of them are well apart from the others and from group R and may, when the size of the sampling is increased, form a distinct group.

- sub-group of cooking pots C2 (5 samples), close to group R by its high Y and REE and low Ca content. It is distinguished from group R by lower Al, Ti and higher Mn.

Figure 5 shows how the samples of groups R and C2 are separated from the rest of the sub-sampling mainly by their higher REE contents (principal component 2), and are separated from each other by their Al, Ti and Mn contents (principal component 3).

Among the previous studies of ceramics that have been related to the Lower Cretaceous formations, a rather large range of compositions was observed. Some of these results have little in common with our data: one analysis of a Chalcolithic sherd gives a content of 7.5 % Fe_2O_3 comparable to the lowest values in the sub-sampling but much lower Ti and higher K and Mg (*Edwards and Segnit, 1984; Goren, 1995*); the Fe content of Bronze age Metallic ware found in Abydos is even lower (*Porat, 1989*). On the other hand, Metallic ware uncovered in Tel Dan and other sites have Fe and Ti contents comparable to our results (10% or more Fe_2O_3 , around 1.9% average TiO_2) (*Porat, unpublished analyses, and Greenberg and Porat, 1996*); Roman ceramics from the Kefar Hananya workshop and clays from the nearby Hananya valley, where soils are developed on the Lower Cretaceous sediments, also show compositions which resemble less calcareous, more REE-rich samples of our groups (*Adan-Bayewitz and Perlman, 1985; Wieder et al., 1994*).

Even if no close correspondence between our results and the above data is observed, similar trends with some of them strengthen the hypothesis that our regional sub-sampling has been manufactured in workshop(s) using raw materials derived from the Lower Cretaceous formations. Besides, the variations in composition between the different sets of data indicate that some distinction may be found within these clays. Also, the relative homogeneity of the ceramics corresponding to the only located workshop (Kefar Hananya), and especially of the surrounding clays, suggests that, at least in this case, the geochemical variability around a specific location is restricted. If these two factors seem to indicate a favourable geochemical context, the location of

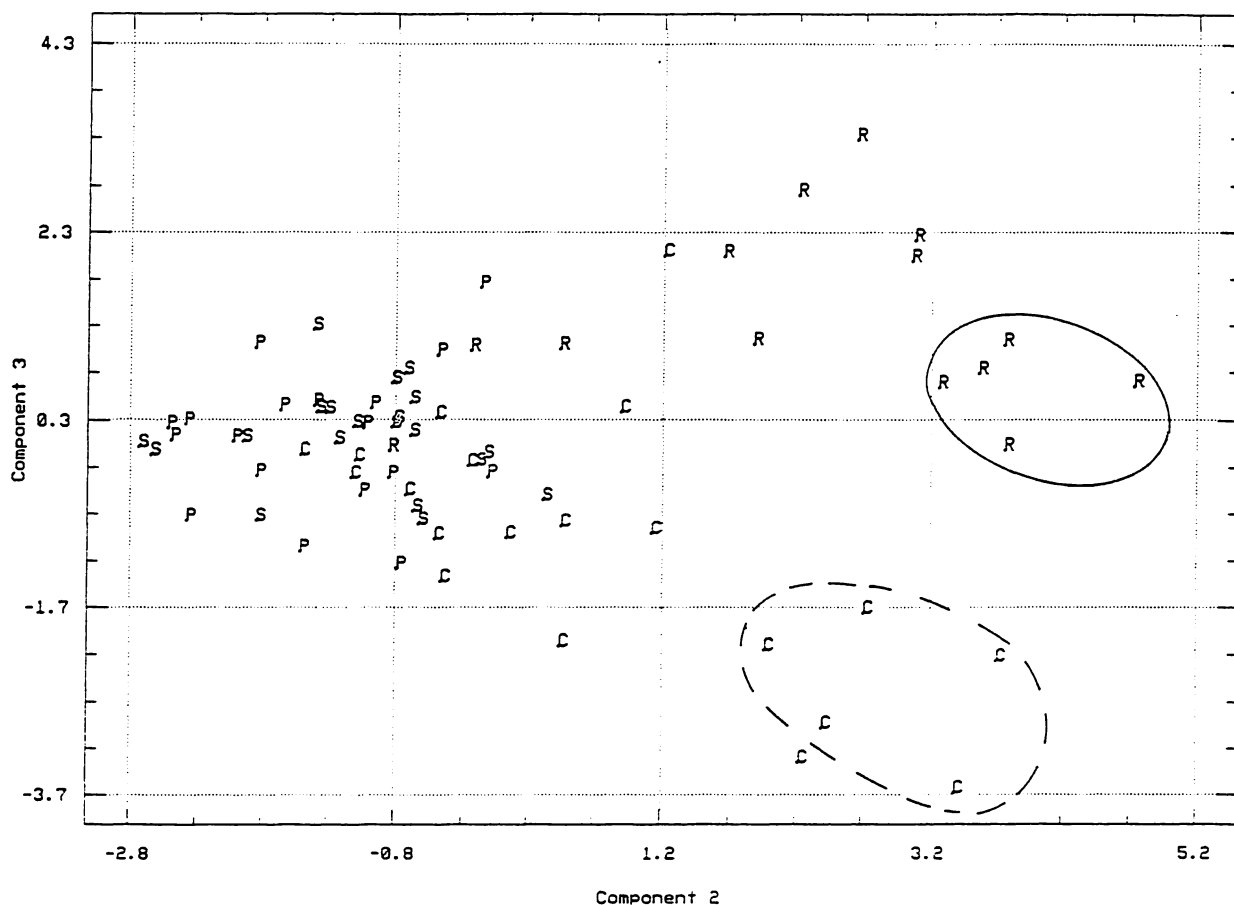


Figure 5a). Regional types of ceramics: glazed bowls and cooking pots ("sub-sampling", see text); plane defined by the 2nd and 3rd principal components of PCA based on 15 variables, expressing c. 34% of the system variance; representation in the samples space (C: cooking pots, P: slip-painted ware, R: reserved-slip ware, S: sgraffito). Compositional groups are underlined: solid line for group R, dotted line for group C2.

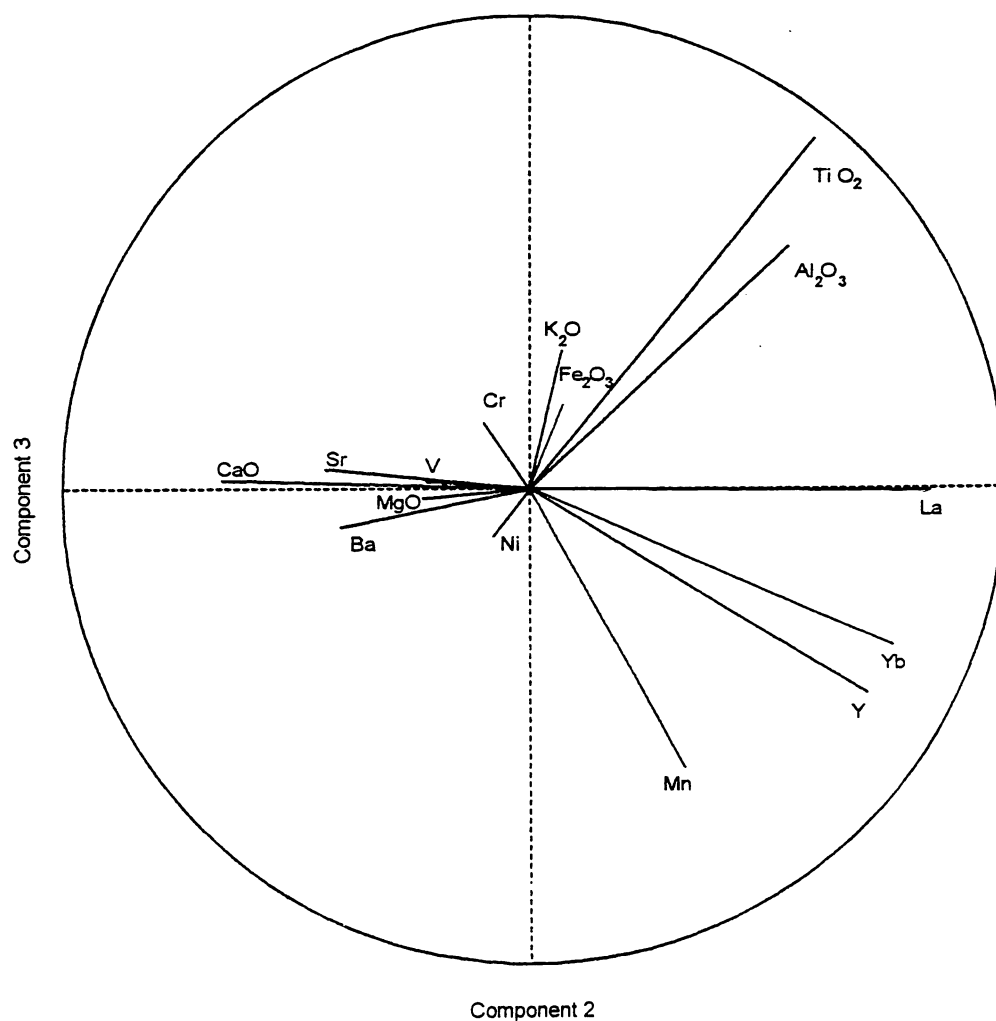


Figure 5b). Regional types of ceramics: glazed bowls and cooking pots ("sub-sampling", see text); plane defined by the 2nd and 3rd principal components of PCA based on 15 variables, expressing c. 34% of the system variance; representation in the variable space, (C: cooking pots, P: slip-painted ware, R: reserved-slip ware, S: sgraffito).

the medieval workshop(s) remains to be identified, in the absence of their vestiges, through the acquisition of precise, located clay references. The distribution of the regional types of wares considered gives little clues since it extends from mid-Israel to northern Lebanon and "parallels" the large outcrops of Lower Cretaceous formations from the border northwards.

Besides the question of the location of the workshops, the analyses give some information - and raise further questions - about the organisation of production and trade. Regarding the sampling of regional wares imported in Acre, and considering that this sampling is representative, different cases may be distinguished.

The homogeneity of composition of the slip-painted ware (group P) and its good separation from the other categories suggest a single site of manufacture, which was specialised in this ware, or used a specific raw material for its manufacture. Or, as suggested by M. Picon (*pers. comm.*), this workshop may have manufactured several types of wares, of which only the slip-painted bowls reached Acre. This would mean that Acre was not part of the "local market" of the workshop, where all the different products would be represented. It may imply that the workshop was located further away and that only part of its production was distributed on a wider scale.

For the other categories of regional wares analysed, the spread in composition may be due to their production in several workshops and/or to the indifferent use of raw materials having distinct elemental characteristics - which would imply a quite important variability in REE in the vicinity of a workshop in the case of the cooking pots. Whether such a variability is possible can not be told from our analyses, and petrography does not identify minerals whose presence/absence or relative abundance would be correlated with the elemental variations. If this variability can exist, it would explain the splitting of the cooking pots on one hand, and of the reserved slip group on the other hand, between samples with high and low REE content. In any case, the grouping of sgraffito wares, cooking pots and one reserved-slip sample in compositional group S+C1 points to the use of similar clays to manufacture cooking wares as well as different kind of table wares, and the presence of a distinct group of reserved-slip ware suggest the existence of several workshops.

2. Imports

Three main compositional groups can be distinguished out of the four typological categories of ceramics related to the Zeuxippus ware examined in this study (Table 4). They are clearly differentiated chemically from the local and regional types, of the latter readily by their much higher concentration of alkalines and alkaline-earths. They are also clearly separated between themselves, as illustrated for instance in the biplot (La, CaO) (Fig. 6). Petrographic analysis confirms their imported status, as the metamorphic elements present in their paste are alien to Israel and exclude a regional provenance.

Except for one outlier, the analyses confirm that typological group n°1 is a well defined, homogeneous group (group Z1, Table 4, 9 samples), with coefficients of variations far below 10% for most elements except Ca and Sr. Although the sample amount (9 sherds) can not be considered to be quite satisfactory for statistical representativity, the consistent results give some confidence in the figures as good estimates of the average composition. From its finer fabric, this group is a potential prototype for the other categories of wares of the Zeuxippus family examined.

This hypothesis is somewhat supported by the compositional similarity of the group to one sample considered to be a "genuine" Zeuxippus ware which was found in the distant site of Pergamon (Turkey) and was previously analyzed by PIXE and INAA (*Spieser, 1996; Waksman, 1995*: sample M107). In spite of the little significance of comparing, one sherd with a small compositional group, this clear, rather expectable result is quite noticeable. It was obtained through an intercalibration which was found to be workable for 11 elements out of the 15 determined by ICP-AES (Al, Ca, Ti, Mn, Fe, Cr, Ni, Sr, Ba, La, Eu; intercalibration batch: 10 samples).

Pergamon has also been a production site of Zeuxippus ware derivatives, but as the composition of the latter does not match any of the categories found in Acre, it does not appear that this ware was exported to Acre.

A quite interesting feature of group Z1 is its distinctive slip. All the sherds belonging to this group have a slip constituted of pure clay showing an almost perfect orientation under the polarizing microscope, whereas the slip of all the other samples considered is a more or less quartz-rich material. The information available on slips, and furthermore on slips of

Table 4. Main groups of ceramics of the Zeuxippus ware family :
mean composition and standard deviation (sigma), in ppm except (%)

Z1		Z2		Z4	
mean	sigma	mean	sigma	mean	sigma
9		17		9	
1.04	0.07	0.56	0.12	1.64	0.20
3.51	0.25	4.17	0.39	2.24	0.30
14.89	0.62	19.13	0.95	18.82	1.51
2.48	0.17	3.30	0.26	4.26	0.34
8.33	1.15	11.48	1.13	1.70	0.91
0.83	0.02	0.71	0.03	0.77	0.02
7.09	0.28	8.01	0.46	5.66	0.40
1,210	91	1,015	162	397	40
129	12	130	11	101	11
245	13	303	33	106	11
152	8	224	33	48	4
297	50	295	39	112	16
29.4	0.8	37.6	1.8	39.6	2.4
439	31	436	32	690	99
32.4	1.1	44.1	2.7	50.1	3.2
61	4	76	5	96	5
29	1	36	2	43	3
5.7	0.3	7.2	0.5	8.7	0.5
1.30	0.06	1.54	0.11	1.66	0.13
0.8	0.0	1.0	0.1	1.2	0.1
2.8	0.1	3.3	0.2	3.6	0.2
0.39	0.03	0.47	0.03	0.53	0.02
10.6	0.3	14.4	1.6	16.8	2.4
2.8	0.1	3.9	0.7	3.2	0.2

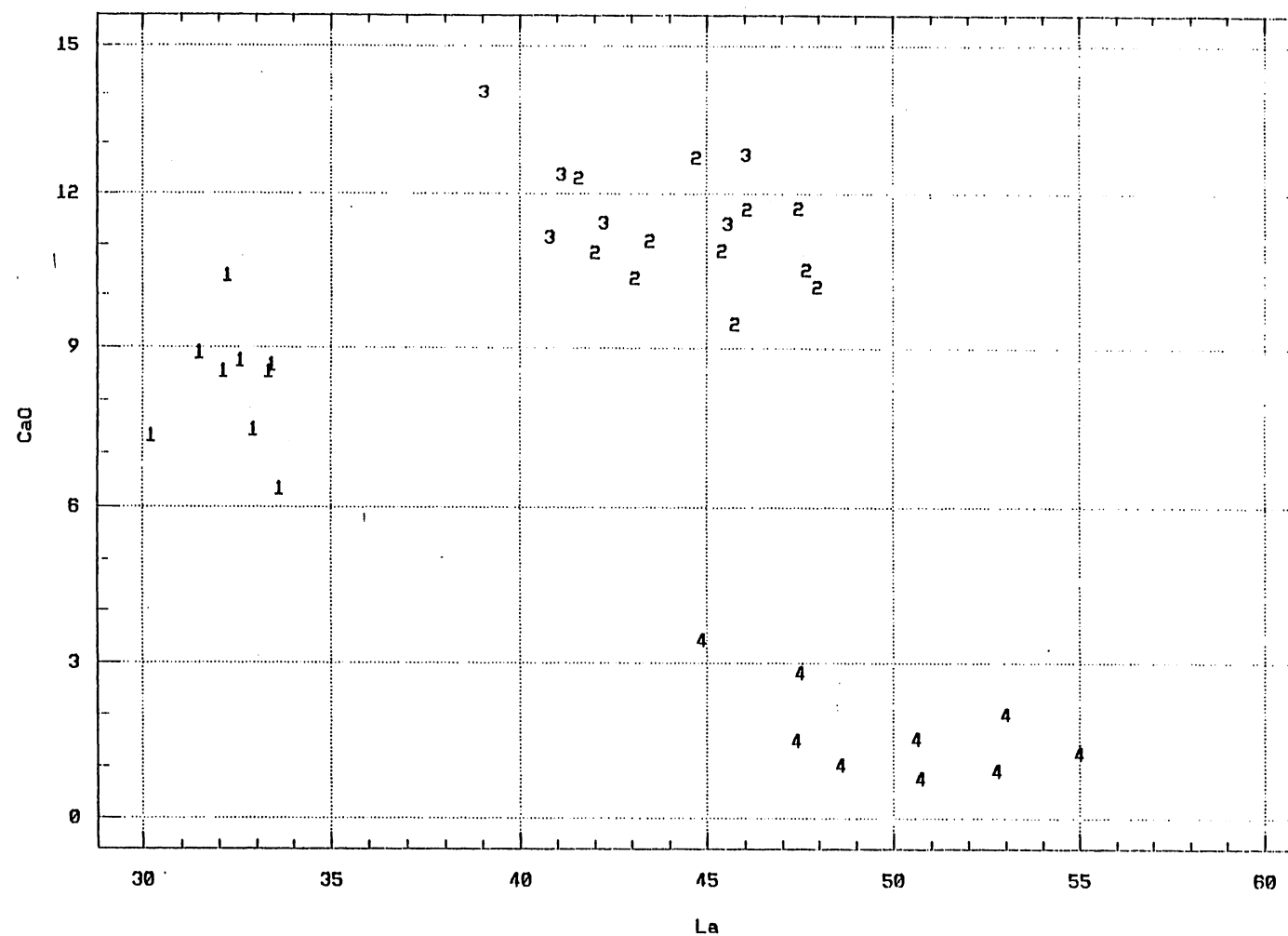


Figure 6. Ceramics of the Zeuxippus ware family: binary plot (CaO/La), typological groups 1 to 4; unclassified samples were excluded.

ceramics of the Byzantine Period, is still very scarce. This particularity is certainly worth noticing, and one may wonder if it could be considered as a possible key for the attribution of a ware to the "genuine" Zeuxippus ware. As a matter of fact, the one "outlier" of typological group 1, which is a global outlier by composition and is related to petrographical group 3 due to the presence of red glassy fragments in the paste, also has this kind of clay slip. In itself, the existence of these outlier questions, the unicity of the "prototype" of the Zeuxippus ware, already pointed out by Boas who distinguished two compositional groups out of a sampling attributed to the genuine Zeuxippus ware (*Boas, 1994*).

Most of the samples in the typological groups 2 and 3 belong to a second compositional group (group Z2, Table 2; 17 samples). It corresponds to rather calcareous ceramics (c. 12% CaO), bearing the highest concentrations in Fe (c. 8% Fe₂O₃), Cr (c. 300 ppm), Ni (c. 220 ppm) and REE of the Zeuxippus family's sampling. The singularity of the samples of group n°3 is thus not confirmed by analysis, though small differences can be observed in the Cr and Ni concentrations.

Ongoing analyses at the Research Laboratory for the Archaeology and History of Art of wares from Cypriot workshops, including Lemba, and of ceramics from Sparta (*Armstrong and Hatcher, 1997*) should enable us to test the identity of our group Z2 with these products and to confirm - or not - the Cypriot provenance. In this perspective, a batch of 13 samples and standards already analyzed by ICP-AES in Oxford was included in our sampling and intercalibration is in progress.

Typological group n°4 appears as a clearly separated group (group Z4, Table 4, 9 samples), with a quite distinctive feature in its low Ca (1-2% CaO) and Sr (c. 100 ppm) contents (whereas Ba remains at a relatively high level, c. 600 ppm). Cr and Ni are also the lowest of the Zeuxippus family's sampling (c. 100 and 50 ppm, respectively).

Analytical data corresponding to comparative material will be sought among the studies developed on medieval ceramics from Italy. An ongoing analytical study (*A. Mignucci, pers. comm.*) concerning the local productions and imports of Medieval Venice is of particular interest since one of the close typological parallel to group 4 is thought to come from this city (*Gelichi, 1986*).

CONCLUSIONS

This study has enabled to constitute a new analytical reference group corresponding to a production centre of ceramics in Acre at the Crusader Period, at a time when its harbour was of particular importance in the Eastern Mediterranean area. The picture that emerges from our sampling is that only the "Acre bowls", simple unglazed bowls that do not seem to have been diffused much further than the close surroundings of Acre, proved to have been locally manufactured. However, some of the amphorae of regional types have composition which resembles the ones of the reference group, but still another coastal production centre can not be ruled out. Other types of vessels (jars, jugs, plates) found in Acre, which present to the naked eye the same clays as the Acre bowls, were not considered in this study and further research may prove them to be local as well.

Though we cannot tell at this stage whether other workshops, using different raw materials, may have existed in Acre at the time, the other categories of wares of regional type examined - sgraffito, slip-painted and reserved-slip wares, cooking bowls - belong to elemental groups which have little in common with our reference group. They are related by petrography either to the Lower Cretaceous formation which do not crops out close to Acre, or to formations that do not occur in Israel. It is thus probable that these wares were manufactured at some distance from Acre. If we consider our sampling to be representative for the "Levantine" wares of the Crusader Period, this result would mean that the range of products made in Acre itself was quite limited and that most of the ceramics of regional type were imported to it.

Among these, the slip-painted wares are clearly distinguished from the other categories, pointing to a specific production or to the specific export of this category to Acre. Sgraffito bowls and cooking pots are less distinctive, and the latter show a quite noticeable variability in their REE content that suggests either their manufacture in several workshops and/or the use of raw materials having a natural variability in these elements. A similar variability is observed in the reserved-slip ware, which is somehow apart except for one sherd related to the previous categories. The data attest to the use of similar clays to manufacture cooking wares and table wares and suggest several places of manufacture.

The locations of the manufacturing sites of the regional types of ceramics remain a

subject for further research. The pastes of some of them are identified as materials derived from the Lower Cretaceous formation, but the main extent of these nearly overlaps the area of diffusion of the wares in the Levant. Very few of the ceramics previously analysed and related to the Lower Cretaceous formation correspond to precisely provenanced material, and thus a more precise location would probably have to be sought through a fieldwork program. Such a program would moreover enable an evaluation of our data which would take into account the natural geochemical variability of the clays within these formations.

The present study has also presented information about some categories of imported ceramics related to the Byzantine type "Zeuxippus ware" - a type which was widely diffused in the 13th century. Three compositional groups have been defined and characterized, one being a potential prototype for the other categories. The samples of this potential prototype found in Acre appear to be analytically similar to a sample of Zeuxippus ware found in Pergamon (Turkey), and present distinctive characteristics in their slip made of pure clay.

Other analytical comparisons with typological parallels analyzed in other laboratories, based on intercalibration procedures, have been planned and are ongoing. The identification of the provenance of these imported wares relies on the availability of appropriate analytical data corresponding to reference groups of known origin. The development of databases specific to late Byzantine and Crusader material is directed towards constituting a basis for such research.

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