PERIODICO di MINERALOGIA
established in 1930

Dipartimento
di Scienze della Terra
Sapienza
Università di Roma

An International Journal of
Mineralogy, Crystallography, Geochemistry,
Ore Deposits, Petrology, Volcanology
and applied topics on Environment, Archaeometry and Cultural Heritage

Khirbet al-Batrawy ceramics: a systematic mineralogical and petrographic study for investigating the material culture

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ARTICLE INFO

Submitted: September 2016
Accepted: November 2016
Available on line: December 2016

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DOI: 10.2451/2016PM665

How to cite this article:
Medeghini L. and Nigro L. (2017)
Period. Mineral. 86, 19-35

ABSTRACT

The present paper reports the results of a mineralogical and petrographic study focused on the archaeometric characterization of Early Bronze Age pottery from the archaeological site of Khirbet al-Batrawy (Jordan), dated between 3000 and 2000 BC. Optical microscopy (OM) and X-ray powder diffraction (XRPD) analyses are used to define the nature of the raw material, the technology of the ceramic production and their developing during the centuries. The results allow us to identify 12 petrographic *fabrics* in which the nature of the inclusions is consistent with the geological surrounding of Khirbet al-Batrawy. The variability observed in the *fabrics* suggests a technological evolution during the centuries, characterized by a first start-up phase in the ceramic production, followed by a diffuse experimentation in the choice of the starting raw material and a last standardization phase. The co-occurrence of primary calcite, illite, gehlenite and diopside allows hypothesizing a firing temperature lower than 950 °C. A moderate increasing in the firing temperature is observed in the last phases of Batrawy history, suggesting a development of knowledge connected to the firing process.

Keywords: Early Bronze Age ceramic; technology; Khirbet al-Batrawy; OM; XRPD.

INTRODUCTION

This research is an outcome of the *Archaeological Expedition to Palestine & Jordan* project coordinated by Sapienza-University of Rome and directed by Prof. Lorenzo Nigro, under the aegis of the Department of Antiquities, the Hashemite Kingdom of Jordan, and with the support of the Italian Ministry of Foreign Affairs and International Cooperation. This project, studying the material culture of the ancient Near-East, aims to provide information about the development of the technological aspects of pottery production in the Bronze Age (Nigro, 2010, 2011, 2013, 2014a, 2014b, 2015, 2016a, 2016b; Nigro and Sala, 2013).

Indeed, the investigation of pottery technology provides an overall picture about ancient societies through the use and the level of pottery production knowledge (Scarpelli et al., 2010; De Vito et al., 2014; Raneri et al., 2015a). Potters engage in a series of action from the choice of a particular material to the firing of the pottery that reflects the level of technological skill and states social identities (Nigro, 2014c; Santacreu et al., 2016). Potters can decide to use unique clay or a mix of different clays on the basis of the properties of the material or the destination of use of the ceramic. They can also add tempers to increase the workability of the raw material or to decrease the firing temperature or in connection to the shape and dimensions of the final product. Also, the choice of particular inclusions rather than others can give information about the technological skills or preferences of ancient cultures. Firing conditions are analyzed to infer the maximum firing temperature reached during the production at that time and provide information about the typology of kiln where pottery was fired (Maggetti et al., 2015).

For these reasons, the characterization of such ancient artifacts has a cultural relevance; however, it is a complicated task due to the heterogeneity of raw materials and to the mineralogical changes driven by heating process.

The mineralogical and petrographic characterization of pottery plays a main role in the study of archaeological ceramic in which optical microscopy (OM) analysis combined with X-ray powder diffraction (XRPD) is a traditional approach (Turbanti Memmi, 2004). These kinds of analyses can give information to define how the pottery was made in the past. In particular, the definition of the mineralogical composition can provide information about the provenance of the pottery; the percentage, grain size and distribution of the inclusions can allow reconstructing the technique used to produce the pottery. Finally the presence of high temperature minerals, as well as the occurrence or absence of primary calcite and the optical activity of the matrix allow estimating the firing temperature (Trindade et al., 2009; Tschegg et al., 2009; Barone et al., 2012).

The aim of this paper is to discuss and highlight the relevance of the mineralogical and petrographic analysis in the reconstruction of the knowledge and the level of the ceramic production technology reached by ancient populations. In particular, here are pointed out the advantages of this analytical approach in the definition of mineralogical and petrographic composition of the Batrawy pottery to determine potential differences in composition or technology, their correlation with various time periods and evolution over time.

GEOGRAPHICAL AND GEOLOGICAL SETTING

Khirbet al-Batrawy is located in the surroundings of the city of Zarqa (north-central Jordan) on the top of a limestone cliff, from where it dominates a large part of the Upper Wadi az-Zarqa.

Jordan is a region characterized by a succession of sandstones and limestones lying on a Pre-Cambrian basement consisting of metamorphic rocks of the Aqaba Granite Complex, and conglomerates of the Saramuj Series (Burdon, 1959).

The Amman Zarqa Basin is characterized by the presence of the Zarqa river which is connected to the formation of Jordan Rift Valley. The outcrops in this Basin include: basalts in the north-east, limestones in the centre/centre-north, limestones and marls in the west/north-west with Kurnub sandstone and two different outcrops of marls and sandstones in the south (Figure 1).

In the north-western part of the basin, the Amman Formation (Upper Cretaceous) is composed of limestone, chert, chalky and phosporite. The Wadi Umm Ghundran Formation (Coniacian) outcrops in the area between the modern cities of Amman and Zarqa. It is composed by chalky-marl and marl. The Shuayb Formation (Turonian age), belonging to the Aijlun Group, consists of different type of limestones, phosphorite marl and chert (Margane et al., 2002).

Limestones in the centre/centre-north belong to various formations. The Wadi As Sir Formation (Cretaceous)

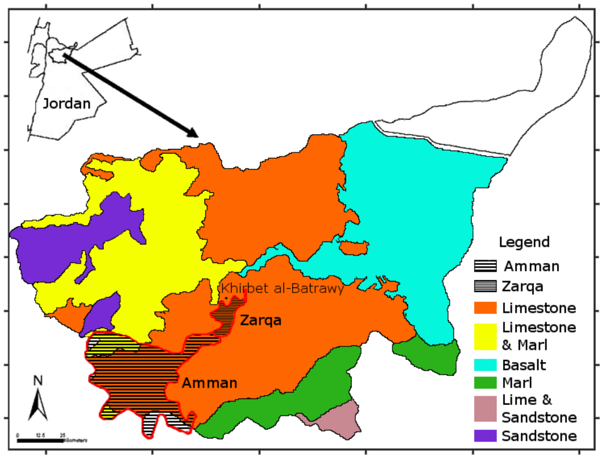

Figure 1. Schematic geological map of Amman Zarqa Basin (modified from Medeghini et al., 2013b).

is diffusely exposed and consists mainly of dolomitic limestone, chalky limestone with occasional chert nodules (Bender, 1974). Moreover, vesicular basalt of Holocene age is exposed in the eastern part of the studied area.

The formation exposed in the north eastern part of the plateau consists of limestone interbedded with chert veins and fossiliferous beds (Margane et al., 2002).

The marlstone, typical of the Khirbet al-Batrawy area, outcropping in the slopes of the wadi beds, is usually intercalated within the limestone and appears as a hardened rock composed by clay, mud, sand and abundant calcareous material (shells) and outcrops along the slopes and in the wadi beds (Khrisat, 2005).

ARCHAEOLOGICAL SETTING

Archaeological excavations allowed defining the history of Batrawy from the end of the 4th millennium BC to the development of a fortified city during the 3rd millennium BC (Nigro and Sala, 2013; Nigro, 2013, 2014a, 2014c, 2015 and reference therein).

The earliest processes of sedentarization in the Zarqa Valley started in the last centuries of 4th millennium BC when a group of semi-nomadic herders and farmers settled along the Zarqa River and began to practice agricultural activities. At the beginning of the 3rd millennium BC, the rural communities in the Upper Wadi az-Zarqa decided to move from the river banks to a protected site leading to the foundation of the fortified city of Batrawy.

Stratigraphic data allowed dividing the Batrawy history in four periods from 3000 BC to 2000 BC, when this site was completely abandoned. During the first phase, Early Bronze II (EB II), dating between 3000 and 2700 BC, the city-wall was built all around the hill and the monumental temple and other buildings have been erected on the Acropolis. In 2700 BC a violent earthquake stopped the growth of the city and during the other two phases, Early

Bronze IIIA (EB IIIA, 2700- 2500 BC) and Early Bronze IIIB (EB IIIB, 2500-2300 BC), Batrawy was reconstructed and grew up in a more monumental way. In EB IIIA the city-wall was erected again and the temple was rebuilt. Trade activities developed extensively, giving a diffuse wealth in Batrawy until the enemy raids around 2500 BC that set on fire the city. During EB IIIB Batrawy was rebuilt with a strong defensive system including towers and bastions. In this period a big palatine complex, centre of administrative and productive function and collection of luxury goods, was erected. The final destruction of the city took place around 2300 BC, when the whole city was set on fire.

The hill was abandoned between 2300 and 2200 BC (Bronze Age IV A, EB IVA) and used as a burial area. It was resettled around 2200 BC (Bronze Age IV B, EB IVB) by a rural village, but it had a short life and around 2000 BC the site was completely abandoned (Nigro, 2010, 2012, 2013, 2014a, 2014b, 2015; Nigro and Sala, 2013).

Archeological excavations carried out so far at Khirbet al-Batrawy were focused on seven areas, with monumental finds illustrating the whole life of the ancient city (Figure 2).

- Area A where the acropolis was built with a major building (probable temple) and the remains of the small EB IVB village were set;
- Area B in the northern spur of the cliff where the main EB II-III city-wall, the city-gate and a round bastion were discovered; in the south part a EB III public building, the so called "Palace of copper axes", and remains of EB IVB rural village were brought to light;
- Area C including the north-western Tower in the north-western spur;
- Area D in the south-western spur where a big tower was located to control the Wadi az-Zarqa;
- Area E along the southern side of the hill, where a portion of the earliest EB II city-wall was uncovered;
- Area F at the centre of the easternmost terrace of the site, where the EB II-III temple of the city was located;
- Area G where inside the southern fortification line a secondary entrance was discovered, called the 'Water Gate' as it led straight to the ford across the Zarqa River, with a stairway connected to the city (Nigro, 2013, 2014a, 2015; Nigro and Sala, 2013).

EXPERIMENTAL

Materials

Ninety-one ceramic samples from four functionally differentiated stratigraphic contexts dated between 3000 and 2000 BC have been analyzed. The investigated samples represent a diversified inventory of pottery productions such as Simple and Simple Painted Ware, Storage Ware, Kitchen Ware, Khirbet Kerak Ware a specialized pottery production characteristic of Southern Levant (Medeghini et al., 2013a) and Metallic Ware. Two other productions are distinguished on the basis of the related superficial treatments, i.e., Red Burnished Ware and Red Polished Ware (Table 1).

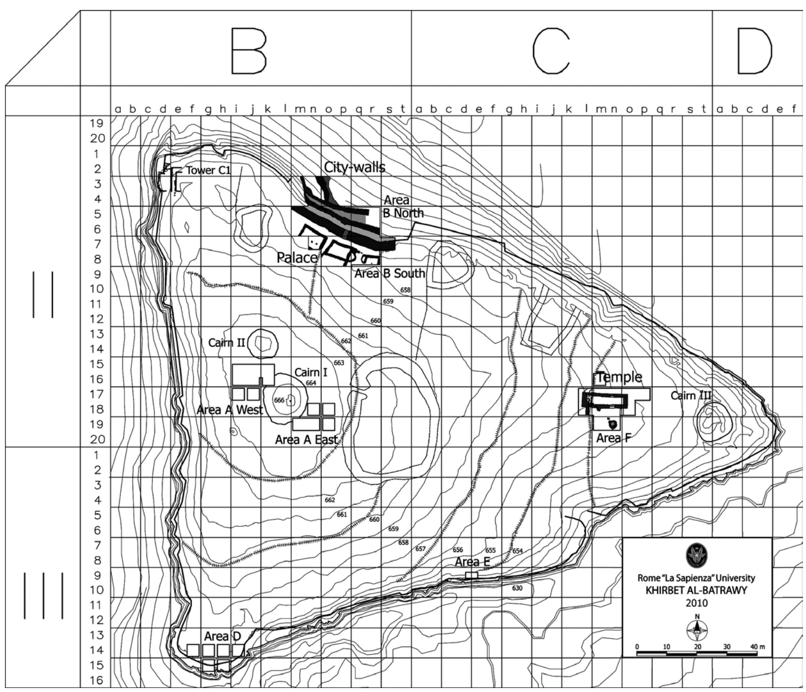

Figure 2. Topographical plan of Khirbet al-Batrawy, with the indications of excavated areas (courtesy of Rome "La Sapienza" Expedition to Palestine & Jordan).

Table 1. Analyzed sample from Khirbet al-Batrawy.

Samples	Class	Pottery Type	Area	Date
KB.06.B.392/8	Storage Ware	jar	B	EB II 3000-2700 BC
KB.06.E.702/10	Red Polished Ware	jug	E	EB II 3000-2700 BC
KB.06.E.703/5	Simple Ware	jar	E	EB II 3000-2700 BC
KB.06.E.703/6	Storage Ware	jar	E	EB II 3000-2700 BC
KB.06.E.704/1	Red Burnished Ware	platter	E	EB II 3000-2700 BC
KB.06.E.704/6	Red Burnished Ware	bowl	E	EB II 3000-2700 BC
KB.06.E.706/2	Red Burnished Ware	platter	E	EB II 3000-2700 BC
KB.06.E.706/1	Red Burnished Ware	platter	E	EB II 3000-2700 BC
KB.05.A.52/8	Storage Ware	hole-mouth jar	A	EB IIIA 2700-2500 BC
KB.05.A.58/1	Red Polished Ware	jug	A	EB IIIA 2700-2500 BC
KB.05.A.64/1	Red Burnished Ware	platter	A	EB IIIA 2700-2500 BC
KB.05.A.64/13	Storage Ware	jar	A	EB IIIA 2700-2500 BC
KB.05.B.110/15	Red Polished Ware	jug	B	EB IIIA 2700-2500 BC
KB.05.B.126/1	Red Polished Ware	jug	B	EB IIIA 2700-2500 BC
KB.05.B.126/3	Red Burnished Ware	platter	B	EB IIIA 2700-2500 BC
KB.05.B.126/4	Simple Painted Ware	bowl	B	EB IIIA 2700-2500 BC
KB.05.B.136/1	Simple Painted Ware	jar	B	EB IIIA 2700-2500 BC
KB.05.B.136/3	Simple Ware	jar	B	EB IIIA 2700-2500 BC
KB.05.B.136/5	Storage Ware	pithos	B	EB IIIA 2700-2500 BC
KB.05.B.146/1	Red Burnished Ware	platter	B	EB IIIA 2700-2500 BC
KB.05.B.146/3	Simple Painted Ware	jar	B	EB IIIA 2700-2500 BC
KB.05.B.146/4	Simple Ware	jar	B	EB IIIA 2700-2500 BC
KB.05.B.146/5	Simple Ware	juglet	B	EB IIIA 2700-2500 BC
KB.05.B.146/6	Simple Ware	juglet	B	EB IIIA 2700-2500 BC
KB.05.B.146/7	Red Polished Ware	jug	B	EB IIIA 2700-2500 BC
KB.05.B.146/8	Red Burnish Ware	platter	B	EB IIIA 2700-2500 BC
KB.05.B.146/15	Simple Painted Ware	bowl	B	EB IIIA 2700-2500 BC
KB.05.B.146/20	Kitchen Ware	hole-mouth pot	B	EB IIIA 2700-2500 BC
KB.05.B.146/24	Simple Ware	juglet	B	EB IIIA 2700-2500 BC
KB.05.B.146/30	Red Polished Ware	jug	B	EB IIIA 2700-2500 BC
KB.06.B.167/4	Storage Ware	jar	B	EB IIIA 2700-2500 BC
KB.06.B.376/4	Red Polished Ware	jug	B	EB IIIA 2700-2500 BC
KB.06.B.413/2	Kitchen Ware	hole-mouth pot	B	EB IIIA 2700-2500 BC
KB.06.B.427/1	Khirbet Kerak Ware	jug	B	EB IIIA 2700-2500 BC
KB.08.B.805/6	Khirbet Kerak Ware	jug	B	EB IIIA 2700-2500 BC
KB.09.B.820.10	Khirbet Kerak Ware	bowl	B	EB IIIA 2700-2500 BC
KB.09.B.820.12	Khirbet Kerak Ware	bowl	B	EB IIIA 2700-2500 BC
KB.09.B.820/13	Khirbet Kerak Ware	jug	B	EB IIIA 2700-2500 BC
KB.06.E.701/2	Simple Painted Ware	jar	E	EB IIIA 2700-2500 BC
KB.06.E.703/3	Simple Ware	juglet	E	EB IIIA 2700-2500 BC
KB.05.A.46/8	Storage Ware	pithos	A	EB IIIB 2500-2300 BC
KB.05.A.216/4	Storage Ware	jar	A	EB IIIB 2500-2300 BC
KB.05.A.204/2	Storage Ware	hole-mouth jar	A	EB IIIB 2500-2300 BC
KB.05.A.204/3	Kitchen Ware	hole-mouth pot	A	EB IIIB 2500-2300 BC
KB.05.A.220/5	Storage Ware	pithos	A	EB IIIB 2500-2300 BC

Table 1. Continued ...

Samples	Class	Pottery Type	Area	Date
KB.05.A.224/2	Storage Ware	pithos	A	EB IIIB 2500-2300 BC
KB.06.A.120/6	Red Polished Ware	jug	A	EB IIIB 2500-2300 BC
KB.05.B.111/3	Simple Ware	jar	B	EB IIIB 2500-2300 BC
KB.10.B.1040/8	Storage Ware	pithos	B	EB IIIB 2500-2300 BC
KB.10.B.1054/6	Simple Ware	vat	B	EB IIIB 2500-2300 BC
KB.11.B.1054/12	Simple Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1054/13	Red Burnished Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1054/21	Metallic Ware	pattern combed jar	B	EB IIIB 2500-2300 BC
KB.10.B.1054/22	Red Burnished Ware	jar	B	EB IIIB 2500-2300 BC
KB.10.B.1054/24	Storage Ware	pithos	B	EB IIIB 2500-2300 BC
KB.10.B.1054/62	Simple Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/3	Storage Ware	hole mouth jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/8	Storage Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/10	Storage Ware	pithos	B	EB IIIB 2500-2300 BC
KB.11.B.1124/15	Storage Ware	hole mouth jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/22	Simple Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/24	Storage Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/29	Storage Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1124/33	Red Burnished Ware	juglet	B	EB IIIB 2500-2300 BC
KB.11.B.1128/1	Storage Ware	jar	B	EB IIIB 2500-2300 BC
KB.11.B.1128/50	Storage Ware	pithos	B	EB IIIB 2500-2300 BC
KB.11.B.1128/51	Storage Ware	pithos	B	EB IIIB 2500-2300 BC
KB.11.B.1128/52	Storage Ware	hole-mouth jar	B	EB IIIB 2500-2300 BC
KB.11.B.1128/65	Red Burnished Ware	juglet	B	EB IIIB 2500-2300 BC
KB.05.5/D200	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.6b/1	Kitchen Ware	hole-mouth pot	A	EB IV 2300-2000 BC
KB.05.A.18/5	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.21/27	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.34/2	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.62/1	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.68/2	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.82/4	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.84/3	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.8b/3b	Kitchen Ware	hole-mouth pot	A	EB IV 2300-2000 BC
KB.05.A.88/1	Storage Ware	hole-mouth jar	A	EB IV 2300-2000 BC
KB.05.A.96/1	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.98/1	Kitchen Ware	hole-mouth pot	A	EB IV 2300-2000 BC
KB.05.A.210/2	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.210/4	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.212/6	Simple Ware	jar	A	EB IV 2300-2000 BC
KB.05.A.216/12	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.06.A.248/2	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.06.A.256/1	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.06.A.ø/18	Storage Ware	jar	A	EB IV 2300-2000 BC
KB.05.B.128/3	Kitchen Ware	hole-mouth pot	B	EB IV 2300-2000 BC
KB.06.B.383/7	Storage Ware	jar	B	EB IV 2300-2000 BC

The EB II layer is still under excavations and therefore it was possible to study only 8 pottery samples. The limited number of samples is due to the antiquity of EB II phase and to the fact that it has been under investigations only in a small area of the archaeological site. These samples were found in the areas B (near the main EB II-III city-wall and the city gate) and E (southern fortification line with the secondary entrance). Thirty-two pottery samples of the EB IIIA phase from the areas A (Acropolis), B (near the city wall and public building) and E (southern fortification line) have been investigated. The phase EB IIIB is represented by 29 samples, found in the areas A (Acropolis) and B (Palace). Finally, the sherds analyzed for the EB IV phase include 22 samples, found in the areas A (rural village) and B (the remains of the palace). From the archaeological point of view, the latter phase (EB IV) marks a drastic change in the settlement, after the destruction of the earlier city, and the occupation of its ruins by a rural village.

Methods

Pottery samples have been first analyzed by OM in thin-section under polarizing microscopy (Zeiss D-7082 Oberkochen) to define homogeneous petrographic groups in terms of microstructure, groundmass, composition of inclusions and textural features at the Department of Earth Sciences, Sapienza University of Rome, following the Whitbread's criteria (Whitbread, 1986, 1995). Twenty-six representative potsherds have been analyzed by XRPD to identify the mineralogical assemblage and in particular the newly formed mineralogical phases using a Siemens D5000 automatic powder diffractometer (Department of Earth Sciences, Sapienza University of Rome). The instrument was equipped with a graphite monochromator using Cu Kα radiation, operating at 40 kV and 25 mA. The XRPD data were collected from 3° to 70° 2θ with a step-size of 0.02° and counting time of 2 s.

RESULTS

Optical microscopy analysis

For the first time, a very detailed mineralogical and petrographic characterization of Khirbet al-Batrawy ceramics is reported; considering the nature of the inclusions, their packing and the mean size, twelve petrographic *fabrics* were distinguished in the analyzed samples. A detailed description of the *fabrics* is summarized in Table 2 and Figure 3.

These groups have almost the same mineralogical composition; however, *Fabric A* is characterized by the presence of micritic and sparry calcite as sand-sized inclusions with a spatial distribution of quite uniform, good sorting, in a fine calcareous matrix with vesicles as pores. The inclusions and pores do not exhibit a preferred alignment parallel to each other and to the margins of the sections.

Samples of *Fabric B* show a predominance of clay pellets and fragments of grog as inclusions in a calcareous groundmass with big pores that can exhibit a preferred alignment parallel to each other and to the margins of the sections, whereas inclusions do not show any preferred alignment.

The *Fabric C* is characterized by the presence of diffuse medium sand-sized fragments of calcite, clay pellets and iron oxides in a calcareous matrix characterized by a heterogeneous color with mega-*vughs*, not aligned to the margin of sample.

The main feature of *Fabric D* is the prevalence of calcite crystals in a calcareous red-orange colored clay matrix with mega-*vughs*. All the inclusions do not show any preferred alignment, whereas pores can exhibit a preferred alignment parallel to each other and to the margins of the sections.

Fabric E is represented by the presence of fine micritic calcite in a calcareous matrix with low porosity. The shapes of the voids are usually meso-vesicles that do not exhibit an alignment parallel to each other and to the margins of the sections. Differently, *Fabric F* is characterized by the presence of fragments of fossils and sedimentary rocks as medium coarse-sized inclusions without any preferred alignment in a calcareous reddish-brown colored clay matrix. The samples contain mainly meso- and macro-elongated *vughs,* meso and micro-vesicles that in some cases exhibit a lightly preferred alignment parallel to the margins of the sections.

Fabric G contains inclusions of basaltic rocks and fragments of fossils in a matrix ranging in color from red to beige-brown and with meso-vesicles and meso- and macro-elongated *vughs* that do not exhibit a preferred alignment. In all the samples ferriferous nodules have been often observed in variable quantity and size. Clay pellets appear to represent lumps of the base clay used to produce these ceramics.

The sherds belonging to *Fabric H* shows the same inclusions of *Fabric G* associated to large-sized of clay pellets and iron oxides in a calcareous fine matrix with color ranging from red, beige to dark brown and optical activity. Pores are mainly represented by meso- and macro/mega-elongated *vughs*, meso-vesicles and rare micro-vesicles that exhibit a preferred alignment parallel to each other or to the margins of the sections.

Large-sized fragments of fossils and fragments of shells are the main features of *Fabric I* in a calcareous red-brown colored clay matrix with big pores aligned to the margin of the sample.

Fabric L with a calcareous groundmass, ranging from orange to dark, is distinguished on the basis of coarse inclusions of calcite. Irregular shape pores are observed, without alignment to the margin of the sample.

Fabric M shows crystals of calcite associated to micritic calcite and fragments of sedimentary rocks in a calcareous fine clay matrix with color ranging from beige to brown showing optical activity. Porosity is represented by macro- and meso-elongated *vughs* that exhibit a preferred alignment parallel to the margins of the sections.

Ceramic samples included in *Fabric N* show diffuse clay pellets and rare inclusions of calcite in calcareous matrix with a variable color ranging from red to beige-grayish. Fragments present a high porosity mainly represented by large-sized *vughs* (macro-) and rare meso-vesicles showing a preferred alignment parallel to each other or to the margins of the sections.

Finally, one sample (KB.05.A.212/6) has been considered as petro-graphic 'loner' not showing similar features respect the other samples. It shows equant and elongate, from angular to sub-rounded medium sand-sized inclusions in low percentage (5%), in a calcareous fine clay matrix with beige-green color. There is a medium abundance of coarse-sized micritic calcite (0.6-1.8 mm), iron oxides nodules and fine quartz (0.1-0.05 mm) as inclusions that do not show any preferred alignment. Rare fragments of grog (1.0-1.5 mm) are also present. The samples contain macro-*vughs* that exhibit a lightly preferred alignment parallel to each other or to the margins of the sections. The clay matrix of the samples is not optically active.

X-Ray Powder Diffraction analysis

XRPD results show that quartz and calcite are ubiquitous and the most abundant mineral phases in all samples with extremely variable amounts. The XRPD patterns of the analyzed samples present high and large peaks which make difficult the identification of other minerals present in minor amounts. However, minor amounts of gypsum, illite, K-feldspar, plagioclase, gehlenite and hematite have been identified as shown in Table 3 where the results by Medeghini et al. (2013b) are reported for comparison.

DISCUSSIONS

Technological level of production

According to the results of the mineralogical and petrographic characterization, the ceramic from the archaeological site of Khirbet al-Batrawy seems to have a similar mineralogical and petrographic composition over the different historical periods and among the different types of pottery. However, some observations are possible in individual samples indicating the existence of specialized wares.

Potsherds are mainly composed by different amounts of quartz and calcite.

Quartz is a very common constituent of numerous rocks types and, being very resistant to weathering, generally occurs in small amounts in natural clay deposits and in archeological ceramic made from them (Quinn, 2013); therefore, its addition by potters as temper is difficult to be confirmed (Papachristodoulou et al., 2006).

OM analysis of Batrawy ceramic allowed us to identify different forms of calcite (i.e., crystalline, micritic and sparry calcite); moreover, fragments of fossils (shells) and fragments of sedimentary rocks (marl and chert) have also been observed. Probably calcite was present in clays as inclusions, deriving by the weathering process of limestones and marls outcropping in the area, as well as tempers added by the potters. In this view, the abundant fragments of fossils observed in thin sections suggest a probable use of marls in the raw material.

Calcite was preferred as a temper over quartz, especially in the manufacturing of tableware (Papachristodoulou et al., 2006), as calcium carbonate temper generally ensures a thermal shock resistance necessary for objects exposed to repeated heating and cooling cycles during use (Tite et al., 2001; Papachristodoulou et al., 2006). Calcite also plays an important role in the flux decreasing of the refractory nature of clay, allowing the reduction of the firing temperature. In particular, high percentages of calcite inclusions have been observed in fragments of Kitchen Ware and local Khirbet Kerak Ware suggesting that the pottery from Khirbet al-Batrawy presented high thermal shock resistance and was probably fired at low temperatures.

Alkali feldspar, deriving from igneous and metamorphic rocks outcropping in the Khirbet al-Batrawy area, occurs in the studied pottery. The low abundance and diffusion of this mineral phase support the hypothesis that K-feldspar crystals were naturally included in the original clays.

The occurrence of hematite in the ceramic matrix was related to the mineralogical composition of the starting clay minerals used (e.g., Hradil et al., 2003), or as the result of reactions that take place during firing in oxidizing atmosphere (Nodari et al., 2007). The diffuse presence of hematite in the studied pottery has been confirmed by the identification in thin sections of diffuse iron nodules.

Gypsum, pyroxenes and epidote have been identified as rare mineral phases and represent natural aplastic inclusions in clays. Furthermore, the occurrence of rare crystals of olivine could be related to the basaltic rocks of the Jordan area (Burdon, 1959). Gypsum can be considered as accessory mineral of the raw material, being a common mineral in sedimentary rocks, and evaporitic sequences (Freyer and Voigt, 2003). The gypsum, decomposed during firing, in post-heating processes is formed after rehydration of anhydrite via bassanite (Medeghini et al., 2013a). Another possibility is connected to degradation processes as a result of the interaction of the sherds with sulfate-rich fluids in the burial environment. Among the inclusions identified in thin section, grog and fragments of basaltic rocks also occur in ceramic sherds of the different historical periods.

Table 2. Microscopic features of petrographic *fabrics* identified.

Samples	Microstructure	Groundmass	Inclusions	
Fabric A - micritic and sparry calcite with vesicles				
KB.06.E.706/1, KB.06.E.706/2	Common: *meso*- and micro-vesicles, Rare: macro-elongated *vughs*	calcareous light-brown color optical activity	20% sand-sized equant-elongate from angular to sub-rounded	Dominant: micritic and sparry calcite (0.5-1.3 mm) Common: fragments of chert (0.4-2.0 mm), fine quartz (0.1-0.5 mm), iron oxides nodules
Fabric B - clay pellets and fragments of grog				
KB.06.B.392/8, KB.06.E.703/5 KB.06.B.703/6 KB.05.A.64/13, KB.05.B.136/5 KB.05.B.146/4 KB.05.A.204/3, KB.05.B.111/3 KB.10.B.1040.8, KB.11.B.1124/24	Common: macro- and mega-elongated *vughs* Rare: micro-vesicles	calcareous from orange-beige to dark brown optical activity	10-20% coarse-sized equant-elongate from very-angular to sub-rounded	Dominant: grog (0.5-2.0 mm), clay pellets (0.3-2.2 mm) Common: micritic and sparry calcite (0.3-1.5 mm), fragments of sedimentary rocks (0.5-1.0 mm), fine quartz (0.05-0.1 mm), iron oxides nodules Rare: fragments of basaltic rocks (~0.5 mm) and olivine (0.2-0.5 mm)
Fabric C - calcite and clay pellets				
KB.06.E.702/10 KB.05.B.146/7, KB.05.B.146/8	Common: macro- and mega-*vughs* Rare: *meso-vughs*	calcareous from light red to dark gray optical activity	20% medium sand-sized equant and elongate from angular to sub-rounded	Dominant: micritic and sparry calcite (0.2-2.0 mm), clay pellets (0.7-0.9 mm) Common: fragments of grog (1.0-2.0 mm) and iron oxides nodules Rare: quartz (0.1-0.4 mm) and olivine (~0.5 mm)
Fabric D - crystals of calcite				
KB.06.E.704/1, KB.06.E.704/6 KB.11.B.1054/13	Common: *meso*- and macro-elongated *vughs* and *meso*-vesicles	calcareous from orange to brown optical activity	20-30% medium sand-sized equant-elongate from sub-angular to sub-rounded	Dominant: crystals of calcite (0.5-1.1 mm) Common: micritic calcite (0.3-1.0 mm), iron oxides nodules Rare: fragments of fossils (0.3-2.0 mm), fragments of sedimentary rocks (0.5-1.0 mm), quartz (0.1-2.0 mm)
Fabric E - fine calcite				
KB.05.A.58/1, KB.05.B.126/1 KB.05.B.136/1, KB.05.B.146/6 KB.05.B.146/24, KB.06.E.703/3 KB.10.B.1054/21, KB.10.B.1054/22, KB.11.B.1124/33, KB.11.B.1128/65	Rare: *meso*-vesicles	calcareous orange-brown optical activity	10-20% fine-grained equant from sub-angular to well-rounded	Dominant: micritic calcite (0.2-0.3 mm) Common: fragments of fossils (0.2-1.2 mm), fragments of sedimentary rocks (0.5-0.9 mm), iron oxides, clay pellets (0.3-1.2 mm) Rare: quartz (0.1-0.5 mm) and coarse calcite (0.2-1.9 mm)
Fabric F - fossils and sedimentary rocks				
KB.05.A.64/1, KB.05.B.126/3 KB.05.B.146/1, KB.05.B.146/30 KB.06.B.376/4, KB.06.B.427/1 KB.09.B.820/12 KB.05.5/D200, KB.05.A.82/4 KB.05.A.96/1	Common: *meso*- and macro-*vughs*, *meso*- and micro-vesicles	calcareous from beige to brown-red optical activity	10-30% coarse-sized equant-elongate from very-angular to well-rounded	Dominant: fragments of fossils (0.2-2.3 mm), sedimentary rocks (0.3-1.3 mm), diffuse micritic calcite (0.1-1.5 mm), calcite (0.2-2.0 mm) Common: iron oxides nodules and clay pellets (0.5-2.2 mm) Rare: fine quartz (0.05-0.1 mm), pyroxene (~0.2 mm), fragments of basaltic rocks (0.5-0.9 mm)
Fabric G - basaltic rocks and fragments of fossils				
KB.05.B.110/15, KB.05.B.126/4 KB.05.B.136/3, KB.05.B.146/3 KB.05.B.146/5, KB.05.B.146/15 KB.08.B.805/6, KB.09.B.820/10 KB.09.B.820/13, KB.06.E.701/2 KB.05.A.18/5, KB.05.A.34/2	Common: *meso*-vesicles Rare: *meso*- and macro-elongated *vughs*	calcareous from red to beige-brown optical activity	20-30% coarse sized equant-elongate from very-angular to well-rounded	Dominant: fragments of basaltic rocks (0.2-2.5 mm), fragments of fossils (0.2-0.8 mm) Common: fragments of sedimentary rocks (0.5-2.5 mm), micritic and sparry calcite (0.2-2.1 mm), iron oxides nodules and clay pallets (0.6-1.2 mm) Rare: olivine (0.2-0.5 mm), quartz (0.3-0.9 mm)

Table 2. Continued ...

Samples	Microstructure	Groundmass	Inclusions	
Fabric H - clay pellets, calcite and iron oxides				
KB.05.A.52/8, KB.06.B.167/4 KB.10.B.1054/24, KB.11.B.1124/8 KB.11.B.1124/10 KB.05.A.62/1, KB.05.B.128/3	Common: *meso*- and macro/mega-*vughs*, *meso*-vesicles Rare: micro-vesicles	calcareous from red, beige to dark brown optical activity	10-30% equant-elongate from angular to rounded	Dominant: fragments of basaltic rocks (0.2-2.5 mm), fragments of fossils (0.2-1.8 mm), iron oxides, clay pellets (0.1-2.1 mm) Few: micritic and sparry calcite (0.1-2.0 mm), quartz (0.05-0.1 mm)
Fabric I - shells				
KB.06.B.146/20, KB.06.B.413/2	Common: *meso*- and mega-*vughs*	calcareous red-brown optical activity	40% coarse-sized from very-angular to angular	Dominant: fragments of fossils (0.5-3.0 mm)
Fabric L - calcite and micritic calcite				
KB.05.A.204/2, KB.11.B.1054/12 KB.05.A.6b/1 KB.05.A.21/27, KB.05.A.68/2 KB.05.A.8b/3b, KB.05.A.88/1 KB.05.A.98/1, KB.06.A.248/2 KB.06.ø/18	Common; *meso*- and macro-vesicles	calcareous from orange to dark optically active	20-30% coarse-grained inclusions	Dominant: calcite (0.1-2.2 mm), micritic calcite (0.1-2.0 mm) Common: fragments of fossils (0.1-2.0 mm), fragments of sedimentary rocks (0.8-1.1 mm) Rare: fragments of basaltic rocks (~0.6 mm), fragments of fossils (0.2-1.0 mm), quartz (0.05-0.1 mm) Iron nodules, dark clay pellets (0.1-1.0 mm)
Fabric M - micritic, calcite and sedimentary rocks				
KB.05.A.46/8, KB.05.A.216/4 KB.06.A.220/5, KB.05.A.224/2 KB.06.A.120/6, KB.10.B.1054/6 KB.10.B.1054/62, KB.11.B.1124/ KB.11.B.1124/15, KB.11.B.1224/22 KB.11.B.1124/29, KB.11.B.1128/1 KB.11.B.1128/50, KB.11.B.1128/51 KB.11.B.1128/52	Common: macro- and *meso*-elongated *vughs*	calcareous from beige to brown optical activity	40% coarse grains equant-elongate from very-angular to well-rounded	Dominant: micritic calcite (0.1-2.1 mm), calcite (0.1-2.0 mm) Common: fragments of fossils (0.1-2.0 mm), fragments of sedimentary rocks (0.5-2.1 mm), clay pellets (0.5-1.8 mm), grog (0.4-1.0) and iron oxides nodules Rare: fragments of basaltic rocks (0.5-1.2 mm), quartz (0.1-0.5 mm)
Fabric N - clay pellets and rare calcite				
KB.05.A.84/3, KB.05.A.210/2 KB.05.A.210/4, KB.05.A.216/12 KB.06.A.256/1, KB.06.B.383/7	Common: macro-elongated-*vughs* Rare: *meso*-vesicles	calcareous from red to beige-grayish	10-30% equant-elongate from very-angular to well-rounded	Dominant: clay pellets (0.1-1.0 mm), iron oxides nodules Few: fragments of fossils (0.5-2.0 mm), fragments of basaltic rocks (0.2-1.0 mm), fragments of sedimentary rocks (1.0-2.0 mm) Rare: fragments of grog (0.5-1.0 mm), calcite (0.7-2.0 mm), micritic and sparry calcite (0.2-2.2 mm), quartz (0.1-0.05 mm)

In the majority of the sherds, minor amounts of illite have been found indicating a starting raw material mainly composed by illitic calcareous clay, containing quartz, calcite, feldspars and minor amounts of iron oxides and hydroxides. Therefore, the mineralogical composition of the used clay, the prevalence of calcareous inclusions and the presence of fragments of basaltic rocks are consistent with the geological surrounding of Khirbet al-Batrawy, suggesting a local supply of the raw material.

In the studied pottery, microscopic analysis shows that the inclusions are usually coarse sized and are distributed in an unimodal grain size suggesting no evidences of purification process or selection of the raw material by the potters. Furthermore, the high variability of manufacturing, supported by the identification of twelve differentiated *fabrics*, suggests that the raw clayey materials used to produce the Batrawy pottery did not undergo any purification before the use. Indeed, the final result of the purification process is a sort of standardized matrix, without coarse inclusions that prevent the possibility to identify the provenance of pottery. The absence of purification in the preparation of the raw

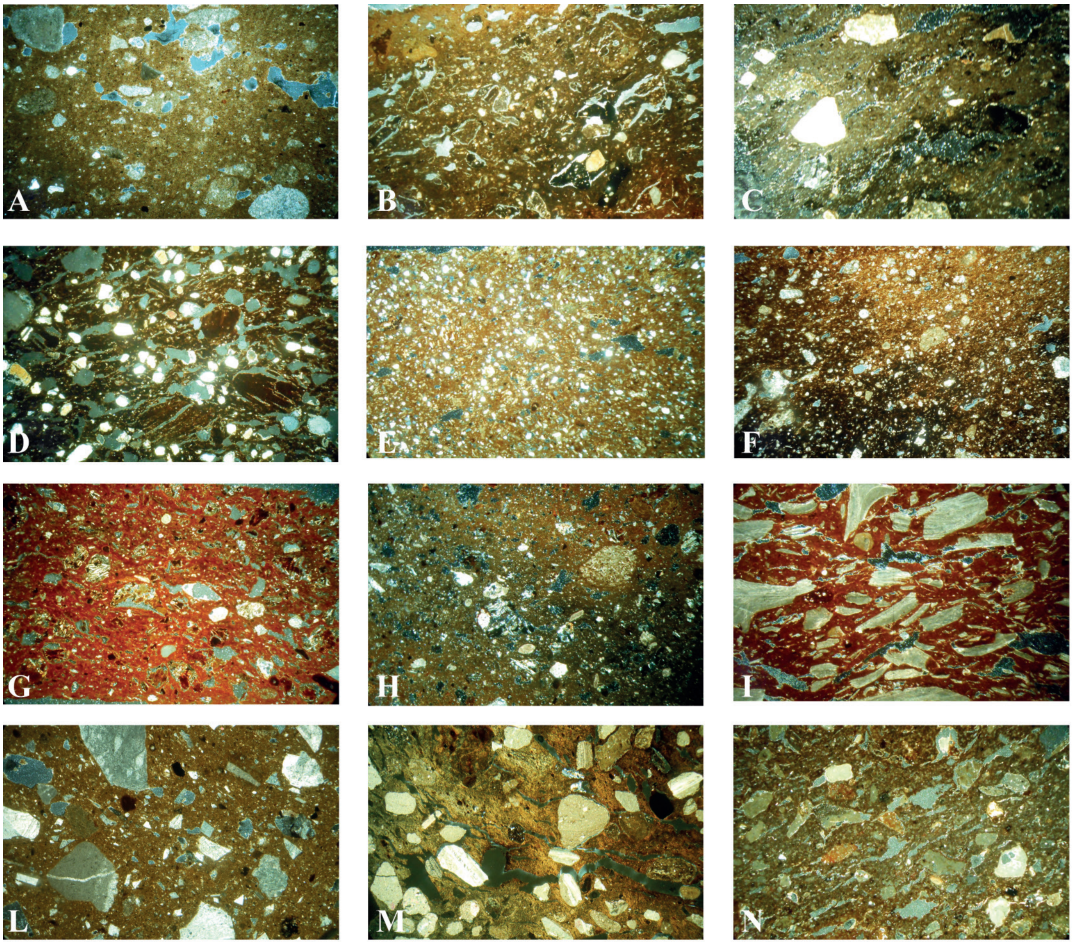

Figure 3. Thin section photomicrographs of representative samples belonging to the 12 different *fabrics* (mag 2.5x and crossed polarizers). *Fabric A*: sample KB.06.E.706/2; *Fabric B*: sample KB.05.B.111/3; *Fabric C*: sample KB.05.B.146/7; *Fabric D*: sample KB.06.E.704/1; *Fabric E*: sample KB.05.A.58/1; *Fabric F*: sample KB.05.B.146/30; *Fabric G*: sample KB.05.B.146/3; *Fabric H*: sample KB.05.B.136/3; *Fabric I*: sample KB.06.B.413/2; *Fabric L*: sample KB.06.A.248/2; *Fabric M*: sample KB.10.B.1054/6; *Fabric N*: sample KB.05.A.210/4.

material denotes a low quality of manufacturing. This hypothesis is further supported by the diffuse presence of clay pellets representing lumps of the base clay used to produce these ceramics and not adequately mixed in the phase of forming. *Fabric E-fine calcite* represents an exception as the predominance of fine inclusions suggests the application of a purification process connected to the production of specific classes, such as Red Polished and Red Burnished Ware.

Porosity of the ceramic body is similar among the *fabrics* and it is probably due to a low time of mixing and modeling which prevented the removal of air from the clay (Fiaccavento, 2014). On the contrary, a low porosity is observed in *Fabric E-fine calcite* suggesting a major accuracy in the phase of mixing and forming for specific classes of ceramics.

The shape of the voids is usually irregular, both vesicles and *vughs* are observed without any alignment to the walls of the samples. However, in *Fabric D-crystals of calcite*, *Fabric H-clay pellets, calcite and iron oxides, Fabric I-shells, Fabric M-micritic, calcite and sedimentary rocks,* and *Fabric N-clay pellets and rare calcite* the pores can exhibit a preferred alignment parallel to each other and to the margins of the sections, which might be related to the phase of forming (Grifa et al., 2015). The contemporary presence of *vughs* and vesicles and their position, in the external and internal parts of the section respectively, support the hypothesis of mixed technique of hand and potter’s wheel, as regards special ceramic productions, such as the palatial one (Medeghini et al., 2016). Furthermore, the absence of any orientation of the minerals in thin section confirms that the intensity of shaping the pot on the potters’ wheel was low. The care in the modelling and the use of the wheel are related to specific ceramic classes in *Fabric D* and *Fabric I* (Red Polished Ware, Red Burnished Ware and Metallic Ware);

whereas common shape (Simple Ware and Storage Ware) are included in *Fabric H*, *Fabric M* and *Fabric N* (Figures 4 and 5). However, these *fabrics* are attested in the final phases of Batrawy urbanization, suggesting in this case, an improvement in the modelling phases over the time.

The relationship among different *fabrics*, pottery type and different phases of Batrawy history allows speculating about the developing of pottery production (Figures 4 and 5).

Charting *fabrics* by periods results a minor variability in the *fabrics* has been observed during the first phase EB II, suggesting a start-up of the pottery production in Batrawy. In particular, *Fabric A-calcite, micritic and sparry calcite with vesicles*, *Fabric C-calcite and clay pellets* and *Fabric D-crystals of calcite* are observed in the Red Burnished and Polished Ware, whereas *Fabric B-clay pellets and fragments of grog* in Simple and Storage Ware. The major variability in *fabrics* observed in EB IIIA can be explained with the diffuse experimentation of materials and procedures applied in this phase. In this view, the difficulties to correlate *Fabric E-fine calcite*, *Fabric F-fossils and sedimentary rocks* and *Fabric G-basaltic rocks and fragments of fossils* to a specific pottery types can be explained as a diffuse experimentation of material and technology. The *Fabric I-shells*, with its particular features very different respect to the others, is included in this context of experimentation and testing

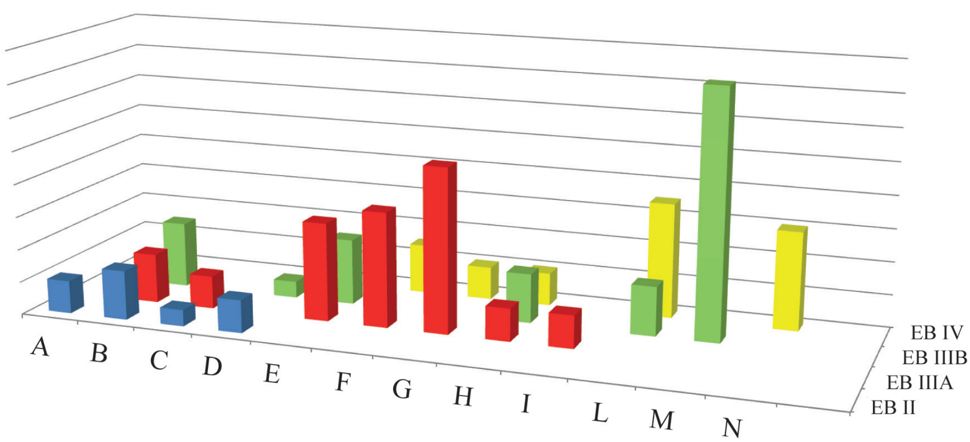

Figure 4. Diagram showing the distribution of the *fabrics* identified by OM in the four phases of Khirbet al-Batrawy urbanization.

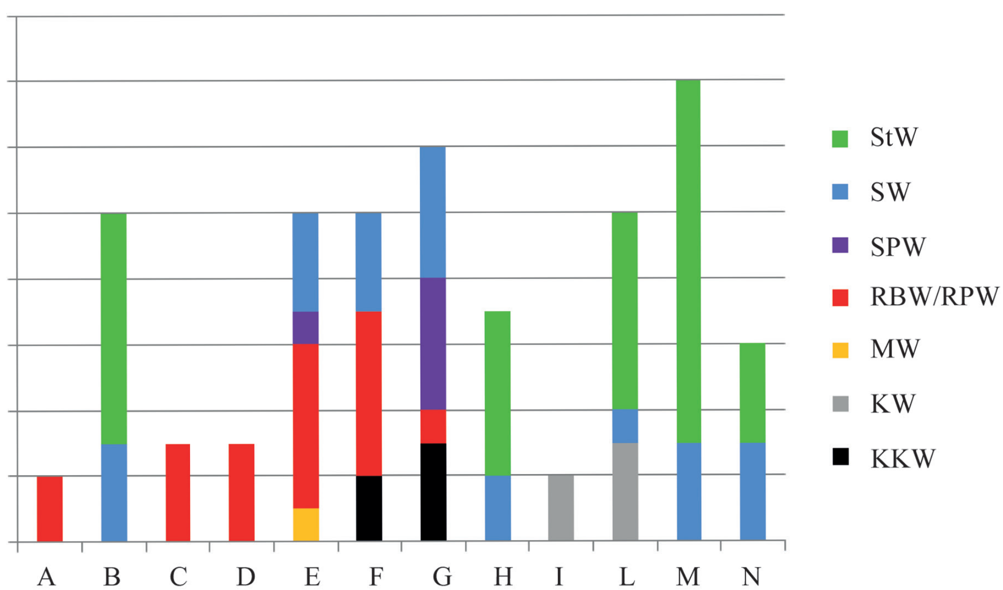

Figure 5. Diagram showing the distribution of the *fabrics* identified by OM respect to the type of pottery (StW: Storage Ware; SW: Simple Ware; SPW: Simple Painted Ware; RBW: Red Burnished Ware; RPW: Red Polished Ware; MW: Metallic Ware; KW: Kitchen Ware; KKW: Khirbet Kerak Ware).

that characterized this period. In the EB IIIB a sort of standardization and selection was observed, as a minor number of *fabrics* have been identified and connected to specific pottery types. *Fabric E-fine calcite*, present in different pottery types in EB IIIA, is associated only to Red Burnished Ware. Fabric H-*clay pellets, calcite and iron oxides*, *Fabric L-calcite and micritic calci*te and in particular *Fabric M-micritic, calcite and sedimentary rocks*, the typical *fabric* of EB IIIB production, are associated to the diffuse production of Simple and Storage Ware shapes. In the post-urban EB IV phase, no evidence of experimentation has been observed and the number of *fabrics* sharply decreases, though maintaining a certain association between *fabrics* and pottery types noticed in EB IIIB phase.

The distinction of different *fabrics* allows us to discriminate the coarser pottery usually used for storage function from the finer pottery typical of small jars, jugs or fine ceramic, suggesting an aware choice due to the final destination. Moreover, Storage Ware fragments present a major compositional variability respect to the Simple Ware fragments, suggesting a minor care in the choice of the used material and proportion between clay and inclusions.

Furthermore, even if no changes in the supply of raw material, the high variability of *fabrics* suggests that the raw materials (clay and inclusions) were selected based on the pottery function and destination.

Firing

The color of pottery is strictly connected to the atmosphere conditions of firing as red-orange matrix is usually related to an oxidizing atmosphere, whereas black-gray to reducing firing condition; where the presence of $CaCO_3$ crystals could play an important role (Nodari et al., 2007). Jordan pottery presents a great variability in the color of matrix, suggesting different atmosphere conditions. The extreme variability of the color in the numerous studied samples suggests that they were incompletely oxidized probably due to a short firing duration, or reduced and rapidly cooled in air. The heterogeneous results indicate uncontrolled firing conditions, which were frequent in open kiln where the control of temperature and the diffusion of oxygen were difficult to monitor and keep constant. Moreover, no evident relationship has been recognized between the redox state of the atmosphere and phases of Batrawy urbanization or the different types of pottery.

Information about the maximum firing temperatures has been obtained taking into account the presence or absence of primary calcite, hematite, illite, diopside and gehlenite in the studied samples.

Calcite is an important indicator of firing temperature as its thermal decomposition into CaO and CO_2 begins around 650 °C and it is completed at about 900-950 °C (Duminuco et al., 1998).

The identification of primary calcite in the ceramic samples allows estimating the firing temperature below the temperature of thermal decomposition of calcite, supported by the optical activity of clay matrix. Moreover, minor amounts of illite have been identified. Clay minerals, such as illite, are dehydrated at temperature ranging between 459 and 900 °C (Guarino et al., 2016). At the upper limit temperature, at about 850-950 °C (Riccardi et al., 1999; Trindade et al., 2009) the free CaO from carbonates reacts with silica and alumina from the breakdown of clay minerals resulting in the formation of calcium silicate or calcium aluminum silicates (Aras, 2004; Barone et al., 2011; Raneri et al., 2015b). These reactions take place in a temperature range influenced by the SiO_2 concentration in the system. When the amount of SiO_2 is low, the thermal stability is reached at 850 °C, while at higher content of SiO_2 the equilibrium temperature reduces to 800 °C (Riccardi et al., 1999; Rathossi et al., 2004). Moreover, if the clay component is mainly illite, the temperature range increases up to 800-1050 °C (Duminuco et al., 1998).

In the case of the coarse-grained and Ca-enriched pottery of Batrawy, the occurrence of illite indicates an incomplete collapse of clay minerals, driving to the formation of gehlenite (1)

$$2CaO + Al_2O_3 + SiO_2 \rightarrow Ca_2Al_2SiO_7 \qquad (1)$$

Diopside was observed in ceramic sherds dated to EB III phases (Table 3) and included in *Fabrics G* and *H*. These *fabrics* show the predominance of fragments of basaltic rocks. In this case, diopside is considered a primary phase which does not interfere in the definition of firing temperature as it starts to be unstable at temperatures above 1000 °C (Cultrone et al., 2001).

In sample belonging to EB IV phase, the lack of fragments of basaltic rocks in samples containing diopside allows us to hypothesize that diopside results from reactions between clay minerals, quartz and calcium carbonates at temperature close to 900° C (Dondi et al., 1995; Trindade et al., 2009). In these samples, the occurrence of diopside in the ceramic contributes to estimate the firing temperature as its crystallization starts at temperatures higher than 850 °C (Cultrone et al., 2001).

The small quantities of gehlenite in the analyzed samples seems to suggest its initial formation in the temperature range between 800 and 950 °C; this range can be limited between 850-950 °C in the sherds in which diopside has been detected, excluding samples of *Fabrics G* and *H*. Conversely, for the samples in which gehlenite has not been found, the estimated temperature was lower than 800 °C.

This finding draws to the hypothesis that during the

Table 3. Mineralogical phases and relative abundances of analyzed samples (+++=abundant; ++=present; +=scarce; tr=traces) identified by XRPD analysis. Cal: calcite; Qtz: quartz; Gp: gypsum; Ill: illite; Kfs: K-feldspar; Pl: plagioclase; Hem: hematite; Gh: gehlenite; Di: diopside; Ep: epidote (* data from Medeghini et al., 2013b).

EBII	Cal	Qtz	Gp	Ill	Kfs	Pl	Hem	Di	Gh	Ep
KB.06.B.392/8	+++	++			tr	tr				
KB.06.E.702/10	tr	+++	+	tr	tr	tr	tr			
KB.06.E.706/1	+++	++					tr		tr	
KB.06.E.703/6*	+++	+	+						+	
KB.06.E.703/5*	+++	++	tr	+						
KB.06.E.704/1*	++	+++								
KB.06.E.704/6*	++	+++			tr					
KB.06.E.706/2*	+++	+	+				tr			
EB IIIA	Cal	Qtz	Gp	Ill	Kfs	Pl	Hem	Di	Gh	Ep
KB.05.A.52/8	+++	++		tr	++	++	tr	+		
KB.05.A.58/1	++	+++			tr	tr	tr			
KB.05.B.110/15	+++	+			tr	++		+	tr	
KB.05.B.146/20	+++	+		tr	tr					+
KB.06.B.167/4	+++	++			tr			tr		
KB.06.B.413/2	+++	+							+	
KB.05.A.64/1*	++	+++			tr	+				
KB.05.A.64/13*	++	+++				++			tr	
KB.05.B.126/1*	+++	++								
KB.05.B.126/3*	+++	++					+			
KB.05.B.126/4*	+++	++		tr	+	++		++		
KB.05.B.136/1*	++	+++		tr	+		+			
KB.05.B.136/3*	+++	++		tr	+	+		+		
KB.05.B.136/5*	+++	++				+			tr	
KB.05.B.146/1*	+++	++								
KB.05.B.146/3*	++	+++			++	++	tr	+		
KB.05.B.146/4*	+++	++		tr						
KB.05.B.146/5*	+++	++		tr		+	tr	+		
KB.05.B.146/6*	++	+++		tr						
KB.05.B.146/7*	++	+++				+	tr	+		
KB.05.B.146/15*	++	++		tr		+++		+		+
KB.05.B.146/24*	+	+++				+			+	
KB.05.B.146/30*	++	+++		tr	+				tr	
KB.06.B.376/4*		+++	+			++	+	++		
KB.06.E.701/2*	+	+++		tr	++		+	++		
KB.06.E.703/3*		+++			tr					
KB.06.B.427/1*	+++	++								
KB.08.B.805/6*	+++	++		tr						
KB.09.B.820/10*	+++	++			tr					
KB.09.B.820/12*	+++	++		tr						
KB.09.B.820/13*	+++	++		tr	+		tr		tr	

Table 3. Continued ...

BA IIIB	Cal	Qtz	Gp	Ill	Kfs	Pl	Hem	Di	Gh	Ep
KB.05.A.46/8	+++	++			tr	tr				
KB.05.A.216/4	+++	++		tr						
KB.05.A.220/5	+++	++		tr			tr		tr	
KB.05.A.224/2	+++	++		tr	tr	tr				
KB.06.A.120/6	+++	++		tr	tr		tr		tr	
KB.10.B.1040/8	+++	++			++	++	tr	+	+	
KB.10.B.1054/13	++	+++			tr	tr				
KB.05.A.204/2*	+++	++								
KB.05.A.204/3*	+++	++				tr				
KB.05.B.111/3*	++	+++				+	tr			
KB.10.B.1054/21*	+++	++							tr	
KB.10.B.1054/24*		+++			+				tr	
KB.10.B.1054/62*	+++	+								
KB.11.B.1124/8*	+++	++								
KB.11.B.1124/3*	+++	++								
KB.11.B.1124/15*	+++	++								
KB.11.B.1124/29*	++	+++		tr		+	tr			
KB.11.B.1128/65*	++	+++	+			tr	tr			
KB.11.B.1128/50*	+++	++								
KB.11.B.1128/51*	+++	++		tr						

BAIV	Cal	Qtz	Gp	Ill	Kfs	Pl	Hem	Di	Gh	Ep
KB.05.A/D200	++	+++			+	+	tr		+	tr
KB.05.A.6b/1	+++	++		+	+	+				
KB.05.A.21/27	+++	++			+	+	tr	+		
KB.05.A.34/2	+++	++			+	+	tr	tr	tr	
KB.05.A.68/2	+++	++			+	+				tr
KB.05.A.82/4	+++	++			+	+		tr	+	
KB.05.A.8b/3b	+++	++		tr	+			tr		
KB.05.A.210/2	+	+++		+		++		+		
KB.05.A.210/4	+++	++			+	+		tr	tr	
KB.06.B.383/7		+++	++		++	++	tr		++	+
KB.05.A.18/5*	+++	++			tr					
KB.05.A.62/1*	+++	+			tr	tr	tr			
KB.05.A.84/3*	++	+++		tr	+		tr		+	
KB.05.A.88/1*	+++	++		tr	+					
KB.05.A.96/1*	+++	++		tr						
KB.05.A.98/1*	+++	++		tr						
KB.05.A.212/6*	+++	++							tr	
KB.05.A.216/12*	+++	++			tr				tr	
KB.05.B.128/3*	++	+++		tr	+	++	tr			
KB.06.A.248/2*	++	+++					tr			
KB.06.A.256/1*	++	+++		tr	tr					
KB.06.A.ø/18*	+++	+								++

history of Khirbet al-Batrawy an evolution in the control of firing temperature developed. Indeed, the inferred decrease in the range of temperature of pottery from EB II to EB IV phases suggests a better control of temperature conditions and a longer duration of firing process.

CONCLUSIONS

Ceramics from Khirbet al-Batrawy were produced using calcareous clay with quartz, feldspars, and minor amounts of oxides and hydroxides, consistent with the geological setting. The mineralogical composition of the pottery does not change over time, suggesting that the supply of raw material had the same provenance during the long history of Khirbet al-Batrawy.

Analyzed potsherds from Batrawy have almost all the same mineralogical composition; however, on the basis of the prevalence of particular inclusions, twelve *fabrics* could be distinguished.

The majority of sample shows predominance of coarse-sized inclusions distributed in a unimodal grain size, suggesting that the raw material has not been subjected to purification process; moreover, the presence of clay pellets results from an inadequate mixing of the clays during the preparation. However, the occurrence of grog, voluntarily added as tempers, and the aware choice of raw material suggest a potter's awareness that considered the features of material in the workability and particularly in the pottery production. Furthermore, the variability in size of the tempers, which is directly related to the different shape and use of the vessels, allows hypothesizing an initial differentiation of the material used in the various typologies and functions of the pottery.

In addition, the co-occurrence of *vughs* and vesicles in the external and internal part of the section respectively, supports the archaeological hypothesis that a mixed technique of hand and potter's wheel was applied during the manufacturing of the ceramic. This is especially valid for the neck of big palatial *pithoi*.

The technological evolution of the production in the Jordan pottery is marked by an initial research and study of the raw materials and shape in the EB II phase, which continued through a major and diffuse experimentation in the use of materials and procedures of modeling in EB IIIA phase. The developing finishes in EB IIIB and EB IV with a sort of standardization and selection characterized by a minor number of *fabrics* with specific features to satisfy the request and necessity of a particular production.

The firing temperatures were estimated generally below 950 °C. A limited increase of firing temperature from EB II to EB IV pottery can be inferred, along with a narrowing of the range of the firing temperature between 850-950 °C that suggests a better control of temperature conditions during firing.

Different *fabrics* identified show a marked distribution over pottery types, thus suggesting that in spite of the limited technological advancement reached by the local potters, they indeed had the idea of a certain specialization of *fabrics* in respect of ceramic shapes (dishes, basins, bowls, pots, vats, amphoriskoi, small jars, jugs, hole-mouth jars, transport jars (Metallic Ware), storage jars and *pithoi*), and their specific functions.

ACKNOWLEDGEMENTS

Financial support was provided by Sapienza University of Rome (Project Avvio alla Ricerca 2015).

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