The development of pottery production, specialisation and standardisation in the Late Neolithic and Transitional Chalcolithic periods in the Central Plateau of Iran

Armineh K. Marghussian*, Robin A. E. Coningham
Department of Archaeology, Durham University, South Road, Durham DH1 3LE, UK and
Hasan Fazeli
Department of Archaeology, University of Tehran, Tehran, Iran
*Author for correspondence: e-mail a.k.marghussian@durham.ac.uk

Abstract

The prehistoric pottery recovered from Sialk, Ebrahimabad and Pardis sites, the Central Plateau of Iran was studied using the XRF, XRD and SEM/EDX analyses, as well as typological classification. These studies showed the occurrence of a gradual evolution in pottery making in each site from the Sialk I type fragile buff pottery of Late Neolithic period to the dense, strong and more impermeable Sialk II type red pottery in the final phase of Transitional Chalcolithic period. The relative similarity of compositions, and the presence of high- temperature minerals demonstrated a high degree of specialisation in the selection of raw materials and control of the firing temperature and atmosphere in the potters of the three sites in the final phase of Transitional Chalcolithic period.

On the other hand, the pottery forms of different sites and historical periods show a great variety of types with astonishing similarities, very little changes are detected in pottery forms from the earliest Sialk I Neolithic pottery of Sialk site to the latest Transitional Chalcolithic pottery of Pardis site for nearly 600 years. However, despite the similarity of most of the vessel types the potters by producing new vessels differing in size or quantity tried to fulfil the changing needs of their communities, ascertaining the existence of specialisation in the three sites.

Based on the evidence concerning similarities in the overall evolution pattern of pottery production technology as well as some of the characteristics of pottery such as form the existence of cultural/technical interactions and exchanges between the prehistoric communities living in this region in the specified time period seems to be extremely likely.

Keywords: Neolithic pottery, Central Iranian Plateau, Pottery typological classification, Pottery production evolution, Specialized pottery making, Pottery chemical composition

Introduction

The present study introduces new approaches into the understanding of chronology and cultural-technological development of the Neolithic and Chalcolithic settlements within the Central Plateau of Iran through the study of the evolution of ceramic craft specialisation between ca. 5700-4800 BC by analysing newly excavated pottery from the different three areas of this region: the Tehran, Qazvin and Kashan plains utilizing scientific analysis techniques such as X-ray Diffraction (XRD), X-ray fluorescence (XRF), scanning electron microscope (SEM) and typological classification.

The Central Plateau has played a prominent role in Iranian cultural, technological and political development as well as functioning as an important trade route connecting Mesopotamia, northern Iran and central Asia, with a number of settlements dating from the Neolithic to the historic period. Hence, the Central Plateau is one of the most important regions in Iran for studying the prehistory of the region and that of its neighbours more widely. The societies of this region have been at the centre of at least three millennia of sustained and continuous change from the sixth millennia BC onwards, playing an active role in cultural and technical-economic development through their intraregional and interregional interactions. The deep cultural deposits of archaeological remains, reaching to over 10 metres at some sites, along with the sustained progress and advancement in technology and innovation, make this region very attractive for prehistoric studies.

Based on the results of scientific analyses as well as the archaeological data this research will provide valuable information on the course of evolution and the origin of the changes observed in ceramic technology, and will determine the level of specialisation and standardisation in the pottery-making, as well as the mode of production in these prehistoric sites. Through comparison of the pottery characteristics from different sites of the same tradition it will also assess the similarity of sources of raw materials and the techniques of shaping and firing the pottery. Utilising the valuable information gathered by the aforementioned methods this study represents a more comprehensive and reliable information concerning the economic and cultural connections and interactions of the prehistoric communities living in this region in the Late Neolithic and the Transitional Chalcolithic periods.

As the aim of this study concentrated on the excavated pottery from three prominent sites located in the plains of the Central Plateau of Iran - Pardis on the Tehran plain, Ebrahimabad on the Qazvin plain and Sialk on the Kashan plain (Fig. 1) - the geographical and geological background of the major plains of the Central Plateau of Iran are presented here.

Geographical and geological background of the Central Plateau of Iran

Iran is located in the Middle East and borders the Caspian Sea, Persian Gulf and Arabian Sea. Its geography is characterised by high mountain ranges that enclose several broad basins or plateaus on which major agricultural and urban settlements are located. The centre of Iran consists of several closed basins that collectively are referred to as the Central Plateau of Iran that is a popular description for this region as both a cultural zone and geographical area. The Central Plateau with an average elevation of about 900 metres covers nearly one third of Iran, and defined by the Zagros Mountains from the northwest to the southeast, the Alburz

Mountains in the north and the Kopet Dagh in the northeast. The eastern part of the Central Plateau is covered by two salt deserts, the Dasht-i-Kavir (Great Salt Desert) and the Dasht-i-Lut and, apart for some scattered oases they are uninhabited.

The plains are the most important regions for studying the prehistory of the Central Plateau of Iran as major agricultural and urban settlements dating from the Neolithic to the historic period were located in this region. Noting that the plains are mostly covered by water- transported alluvial sediments, alluvial fans were identified as the most extended sediments in the plains, representing fan-shaped deposits which are formed where a fast-flowing stream flattens, slows down and spreads, as at the exit of a valley onto a flatter plain. They are the main site of deposition in areas, in which mountains gradually wear away, through geological time and basins were filled with sediments (Wilkinson 2003, 80). The water permittivity of alluvial fans is usually high, hence alluvial fans are often the principle groundwater source for farming and the possibility of creation of sustainable communities in arid and semiarid regions. They also contain rich soils, suitable for agriculture.

Archaeological studies of the plains of Central Plateau have shown that settlement patterns varied locally and were distinct to each plain (Marshall 2012: 446). Indeed, it appears that environmental factors probably contributed to differences in settlement patterns between the three plains and the most important aspect of prehistoric settlement was identified as instability of settlement sustainability. Fluctuations in the abandonment of sites, the emergence of new sites and increases and decreases of population were regularly repeated on the Tehran, Qazvin and Kashan plains throughout the Mid-Late Neolithic (ca. 6500-5500 BC) and Chalcolithic periods (ca. 5500-3000 BC). Very few long-lived settlements are known from the Central Plateau, the exceptions being Cheshmeh Ali, Tepe Pardis and Mafinabad on the Tehran Plain and Tepe Sialk on the Kashan Plain. Significantly, all of these are or were associated with permanent water sources. For example, a spring has been located in the vicinity of Tepe Sialk and there is direct evidence of the existence of an artificial water channel at Tepe Pardis, which appears to be the earliest use of irrigation technology in Iran (Gillmore et al. 2007, 2009, 2011). This undoubtedly played a major role in the location of a highly specialised settlement at this point, in addition to the proximity to the clay resources for ceramic production. Manuel et al. (2014) also suggested that contrary to some theoretical models in archaeology that consider the external factors as the only causes of the past cultural changes in societies, in the modern archaeology the focus has shifted from external factors to internal factors based on the continuity and sustainability of societies instead of change. They also commented that rather than considering the past societies as victims of environmental, social and political factors, we should try to see the attempts of past societies to survive by management of their landscape, development of new technologies and finding new resources and when necessary abandonment of their living areas. According to the authors, the most important obstacle in the development, continuity and sustainability of the early societies living in Central Plateau of Iran has been access to permanent water sources.

The existence of an artificial irrigation channel at Pardis, as explained above, and discovery of changing pattern of river management during the Chalcolithic at Sialk, as evidenced by the existence of successive layers of deposits comprising the natural alluvial deposits at the bottom and alternating phases of cultural occupation and finer alluvial deposits at top, possibly representing phases of reduced river flow during which occupation is evident, demonstrate that how past human communities have attempted to preserve their long-term survival by trying to manipulate their environment.

The history of archaeological research in the Central Plateau of Iran

Since the 1930s, many archaeologists have been engaged in the study of historical, cultural, technological and socio-political development of the Central Plateau and a number of chronological models have been proposed. The earlier studies of Ghirshman (1938), McCown (1942), Dyson (1965, 1987), Majidzadeh (1976) were largely culture-historical and focused predominantly on stylistic changes in ceramics. They relied almost exclusively on colour and decoration, whilst shape and basic technology were largely ignored.

For example, Ghirshman (1938) who conducted systematic archaeological investigations on the Central Iranian Plateau and excavated the Sialk site for the first time, used similarities between pottery colour and decoration to define four main phases at the site. He divided the North Mound, one of the two mounds of Sialk, which contained the earlier cultural deposits of the Late Neolithic period, into two main phases, Sialk I and Sialk II. Sialk I, Late Neolithic period (ca. 6000-5200 BC) mostly contained pottery possessing a buff body with black painted decoration whilst Sialk II, Transitional Chalcolithic period (ca. 5200-4600 BC), comprised red pottery, painted in black (Fig. 2). Ghirshman's chronological differentiation, and the periodisation of pottery on the basis of their colour and decoration at Sialk, has had a strong and long-lasting influence on the work of subsequent researchers and even today continues to be a key cultural and chronological marker for the interpretation of the late prehistoric chronology of the Central Plateau of Iran.

Negahban also divided the prehistoric chronology of Iran on the basis of the "pottery", as defined by appearance, into eight stages (Negahban 1996, 350) as did Majidzadeh (1981) who also attributed the changes in two distinct phases at the site of Ghabristan to the arrival of new people who produced two "types of pottery" as defined by the colour of the excavated wares. These, he named the "Plum-Ware people" and the "Grey-Ware people" (Majidzadeh 1981, 144,146).

Malek Shahmirzadi (1995) also attempted to find the origins of culture on the basis of ceramic diversity. He linked the change of ceramic appearance to the migration of people into the region who imported different types of ceramic manufacture to these areas.

The aforementioned traditional methods associated with the study of Iranian Central Plateau's pottery have led to confusion and misunderstandings. For example, as pottery of a similar

colour and decoration is usually classified and named with a single common term, such as Sialk I or II, the exact nature of similarity or difference between different vessels or the discussion of the movement of products, cultural interaction or technology transfer is seldom discussed. This could also result in misunderstandings regarding the nature of
socio- economic exchanges between various prehistoric societies, such as the assumption intrusive elements bringing about change in society and the abandonment of settlements (Majidzadeh 1981) or the migration of people into the Central Plateau, importing ceramic manufacture to the region (Malek Shahmirzadi 1995).

Indeed, during almost 90 years colour and decoration have been the main criteria used for identification, characterisation, and comparison between the various pottery types of the region with little attention paid to form, technology, and production.

However, more recently a number of researchers re-excavated the prehistoric sites, zagheh, located in the Qazvin Plain (Fazeli and Djamli 2002; Fazeli and Abbasnejad 2005; Fazeli, et al. 2005); Sialk located in Kashan plain re-excavated in 2008 and 2009 (Fazeli, et al. 2013), Cheshmeh Ali located in the Tehran plain (Fazeli, et al. 2004), Ebrahimabad located in Qazvin Plain (Fazeli et al., 2009, 2007a), Pardis located in the Tehran plain (Coningham et al. 2006, Fazeli, et al. 2007b, 2010). In these studies the researchers attempted to provide additional, more accurate and reliable information with the stricter control on stratigraphy combined with the use of radiocarbon analyses for absolute dating, that could be utilised for scientific analyses methods for better understanding the chronology and cultural- technological development of this region as well as the economic and cultural connections and interactions between prehistoric communities living in the Central Plateau at that period.

Moreover, in 2003 a joint project was launched with the collaboration of the University of Bradford, University of Tehran and the Cultural Heritage Organisation of Iran (CHOI) aiming to study the socio-economic transformation of the Neolithic and the Chalcolithic settlements in the Central Plateau of Iran. One of the main objectives to fulfil the aim of the project was the study of evolution of craft specialisation and settlement patterns of pre-urban societies within the Central Plateau by conducting multidisciplinary research work to provide more precise stratigraphic information using radiocarbon analyses for absolute dating, as well as utilising petrographic studies and various analytical methods to characterise the excavated pottery. In this context three sample sites on the Central Plateau were excavated, namely Pardis, Ebrahimabad and Sialk, located on the Tehran, Qazvin and Kashan plains, respectively.

Sialk site

Tepe Sialk is located in the Kashan plain and consists of two mounds, North and South, some 600 metres apart. This site was first excavated by Ghirshman (1938) as stated above and then re-excavated by Fazeli and Coningham, in 2008 and 2009. In these excavations which aimed to provide absolute dates for the earliest occupation levels at the site, one stratigraphic stepped trench was excavated into the west section of Ghirshman’s original trench (Fazeli, et al. 2013). During these excavations first one main trench (Trench I), then five more trenches (trench II to VI) were dug, the main trench reaching virgin soil in a depth of 16.15 metres, The study of recovered pottery collected during the re-excavation process exhibited the presence of both buff pottery group decorated with black-painted simple geometric motifs, and Sialk II samples from the excavated red pottery group decorated with black-painted simple or composite geometric motifs (Marghussian, et al. 2017a).

Ebrahimabad site

Tepe Ebrahimabad that is located in the Qazvin plain was excavated in 2006 (Fazeli et al., 2009) during which three stratigraphic trenches were excavated (Trenches I-III) and Trench I was reached virgin soil some 11.25 metres from the top.

The study of collected pottery demonstrated the presence of both Sialk I type buff pottery group (Ebrahimabad I) and Sialk II type red pottery group (Ebrahimabad II) that belonged to two main cultural periods, Late Neolithic (c. 5641-5121 BC) and Transitional Chalcolithic

(5198-4875 BC), respectively (Marghussian, et al. 2017b).

Pardis site

Tepe Pardis is located in the Tehran plain and comprises a mound of some seven metres in height above the surrounding ground level. Three seasons of excavations at Tepe Pardis were undertaken in 2004, 2006 and 2007 (Coningham et al. 2004, 2006; Fazeli et al. 2004, 2007b). In 2004 two stepped trenches I and II were excavated (Coningham et al. 2006) and in the excavations carried out in 2006 and 2007 seasons several trenches including two horizontal trenches I and II as well as one deep trench were excavated. Most of the pottery sherds recovered belonged to the Transitional Chalcolithic period with relatively fewer Middle and Late Chalcolithic examples.

The deep trench (Trench VII) revealed the evidence of the Transitional Chalcolithic occupation at the depth of 7 metres and the Late Neolithic deposits at its base. The presence of collapse material associated with kiln structures, suggested that the Transitional Chalcolithic settlements at Tepe Pardis were engaged in the pottery production (Fazeli et al. 2007b). The three seasons of excavations at Tepe Pardis exposed over 60 square metres of mudbrick structures dating to the Transitional Chalcolithic, (Fazeli et al. 2007b), including five multi-chambered kilns, as well as a terracotta slow wheel (Fazeli, et al. 2007b, 2010).

Aims and Objectives

The aim of the present study is to introduce new insights and approaches into the study of the socio-economic transformation of the Late Neolithic and the Transitional Chalcolithic settlements within the Central Plateau of Iran through the study of evolution of craft specialisation in the production of pottery utilising more advanced and novel methods.

It is proposed that the analysis of data collected utilising a number of scientific techniques on the pottery of each individual site at different time periods and identifying similarities and differences between the pottery of different locations, will help better understand the chronology and cultural-technological development of this region, as well as the economic and cultural connections and interactions between prehistoric communities living in the Central Plateau in the aforementioned periods.

This aim will be achieved through the study of typological classification, chemical and mineralogical composition of the ceramics collected from the three sample sites within the Central Plateau of Iran.

Experimental Procedure

Sample selection

This study analyses pottery sherds belonging to various types of Sialk I (Late Neolithic) and Sialk II (Transitional Chalcolithic) ware recovered from the three sites of Ebrahimabad (Trenches I, II and III from the excavations in 2006 (Fazeli et.al. 2009), Pardis (Trenches I, II, III, IV, V and VII from the excavations in 2003, 2005 & 2006 (Coningham et al. 2006; Fazeli et al. 2007b) and Sialk (Trenches V and VI from the excavations in 2008 & 2009 (Fazeli et al. 2013). Table 1 depicts the sequences and dating of the selected pottery of the three sites of Central Plateau. As a preliminary stage of the project, the entire assemblages of some 12,000 sherds were inspected and the diagnostic pottery sherds information entered in a database. The recorded information includes sherd thickness, diameter of rims, weight and Munsell colour coding of the surfaces and core, the linear measurements were taken with a caliper. The data set contained 1619 decorated pottery sherds that were classified in six assemblages on the basis of the pottery of the three sites and their periods (Neolithic

Pardis and Transitional Chalcolithic) as recognised by their appearance (buff or red). The pottery samples used in various analyses were randomly selected from the corresponding assemblages.

Chemical analysis

There are many different techniques that can be used for the chemical analysis of materials and the fluorescence (XRF) technique is one of the most widespread and convenient methods that is useful for investigating about 80 elements present in major quantities (Rice 2015, 394; Pollard, et al. 2007, 101). In this study we used X-ray fluorescence (XRF) technique for chemical analysis of the sherds (Oxford ED2000 spectrometer). The total number of 46 Sialk I type pottery sherds comprising 22, 12 and 12 sherds from the Sialk, Ebrahimabad and Pardis sites, respectively and 40 Sialk II type pottery from the three sites comprising 14 sherds from Sialk, 10 sherds from Ebrahimabad and 16 sherds from Pardis sites were subjected to chemical analysis. The samples of each site and period were randomly selected from the collection of corresponding groups of the excavated pottery.

Sample preparation

The most common form of sample preparation for XRF analysis is to make pressed powder pellets. In order to prepare them, the sherds after crushing and grinding into a very fine powder (weighing 12 grams) and addition of a binder were pressed into pellets using a Specac’s Atlas series hydraulic press operating at 5 -7 ton/in2.The pellets after drying in an oven at 110 °C for one hour were placed in the sample holder of the XRF spectrometer. Running a series of standards or known samples helps confirm that the chosen procedure results in accurate, reproducible data. The analysis was carried out in the conservation laboratories of the Department of Archaeology at Durham University on Oxford Instrument ED2000.

A Principal Component Analysis (PCA) was also carried out on the XRF chemical composition data utilising the statistical package SPSS v.21. For the statistical analysis

silicon oxide (SiO_2), aluminium oxide (Al2O_3), iron oxide (Fe_2O_3), magnesium oxide (MgO), calcium oxide (CaO), potassium oxide (K_2O) and sodium oxide (Na_2O) have been used. In SPSS v.21 analysis a correlation matrix is created and a plot is drawn representing the variation of the second principal component against the fist component using the analysis results.

Mineralogical analysis

X-ray Diffraction (XRD) is one of the most popular techniques for identifying the minerals present in ceramics (Rice 2015, 382-386; Pollard, et al. 2007, 103).).

Because the mineralogical composition of clays changes during firing process at certain specific temperatures XRD analysis by identifying the type of the minerals present in the body upon firing can be used to estimate their firing temperature and provide useful information regarding the technology of making and firing of the ancient pottery (Holakooei, et al. 2014).

Sample preparation

In this study, the selected sherds were analysed by powder X-ray diffraction analysis. In order to prepare the samples for analysis a small piece of each body was cut and ground in a Tema Laboratory Disc Mill, with a tungsten carbide barrel. Diffraction data were collected at ambient temperature (295 K) over the range 5-120° (2θ) using a PANalytical X’pert Multi- Purpose Diffractometer equipped with a Cu-Kα1 X-ray source and a PIXcel solid-state detector. The step-scan size was approximately 0.013° in 2θ and the total acquisition time per pattern was 40 minutes.

Diffraction data were collected at ambient temperature (295 K) over the range 5-120° (2θ) using a PANalytical X’pert Multi-Purpose diffractometer equipped with a Cu-Kα1 X-ray source and a PIXcel solid-state detector. The step-scan size was approximately 0.013° in 2θ and the total acquisition time per pattern was 40 minutes. Identification of mineral phases from the XRD patterns was performed using the International Centre for

Diffraction Data File (ICDD). The final plot of the powder patterns were created using Microsoft Excel software on raw data text files and the Powder Diffraction File (PDF) was used to interpret the patterns.

In this study, the selected sherds were analysed by powder X-ray diffraction analysis. Diffraction data were collected at ambient temperature (295 K) over the range 5-120° (2θ) using a PANalytical X’pert Multi-Purpose diffractometer equipped with a Cu-Kα1 X-ray source and a PIXcel solid-state detector. The step-scan size was approximately 0.013° in 2θ and the total acquisition time per pattern was 40 minutes.

Identification of mineral phases from the XRD patterns was performed using the International

Centre for Diffraction Data File (ICDD). The final plot of the powder patterns were created using Microsoft Excel software on raw data text files and the Powder Diffraction File (PDF) was used to interpret the patterns.

Microstructural examinations

Scanning electron microscope (SEM) is a type of microscope that produced images of a sample by scanning the surface with a focused electron beam that interacts with the atoms of the sample and provides detailed high-resolution images of the sample surface topography, as well as elemental identification and quantitative compositional information of the sample via attaching to the Energy Dispersive X-ray Analyser (EDX or EDA), and in some cases, X-ray mapping of specimens were also created in order to demonstrate the elemental composition of the whole surface or a certain area of the sample surface in the form of a false colour compositional map. (Pollard et al. 2007, 109).

In this study Scanning electron microscopy was used to observe and determine the nature and extent of the changes, such as the degree of vitrification, occurred during the firing process in some pottery samples as well as for determination of the elemental compositions of some typical pottery samples.

Typological classification

Typology is used to refer to the classification of a number of objects that make up part of a homogeneous whole by means of the definition of "types". Type has been broadly defined as “an internally cohesive class of items formally defined by consistent association of attributes (or attribute states) and set off from other classes by discontinuities in attribute states” (Rice, 1987, 484).

In the present study we utilised the “lumping” method to classify the pottery by gathering together of ceramics with similar rim and base forms as shown in their illustrations.

To the best of our knowledge, this is the first time that, such an approach has been attempted within the Central Plateau. Indeed, although Ghirshman mentioned some forms such as the high cups of Period II (Ghirshman 1938: pl. XLV S.1552), open bowls (Ghirshman 1938: pl. XLVI S.1747) and a small number of new forms such as bowls with inverted rims (Ghirshman 1938: pl. XLVII A2, C2) and thickened, modelled rims (Ghirshman 1938: pl. XLIV A2, C2), he did not try to group together similar forms of pottery and classify them. Results and Discussion

Chemical composition

As stated above a total number of 86 sherds from the absolute-dated sequences of the three sites were subjected to chemical analysis study.

Tables 2, 3 and 4 illustrate the chemical compositions of the pottery from the three sites. It can be seen that the oxide content of all Sialk I type specimens of each site show relatively low values of standard deviation, while the Sialk II type specimens demonstrated the existence of two different groups of pottery, calcium rich and calcium poor, each group having relatively low standard deviation within themselves. However, the CaO content exhibits relatively high value of standard deviation that has been attributed to the variation

of the content of this oxide in the original clay deposits due to the cation leaching and exchange (Bieber, et al.1976, Hedges and McLellan 1976).

The Principal Component Analysis (PCA) results carried out on the XRF data of the Sialk I and II types of pottery samples of the three sites are depicted in Figures 3 and 4, respectively. In this analysis the multidimensional data sets of interrelated variables are transformed to new sets with lower number of dimensions called principal components (PCs) in such a way that they are uncorrelated and the first few of these PCs retain most of the variation present in the entire data set. For example, the first PC is a combination of all the actual variables in such a way that it has the greatest amount of variation. Second, PC is also a linear combination of the original variables in such a way that it has the most variation in the remaining PCs.

Fig. 3 depicted that the first two principal components account for 61.5 and 12.3 % of the total variance in the dataset, respectively and the conjunction of these two PCs accounts for 73.8 %

of the total variance, while Fig. 4 indicated that the first principal component explains 69.6% of the total variance of the data set and second PC explains 14.1 %, and the conjunction of these to PCs accounts for 83.7 % of the total variance.

Fig. 3 also reveals that the three groups of samples comprising the Sialk I type pottery of each site, exhibited distinct clustering of the pottery compositions within themselves, while each pottery group was noticeably separated from the pottery of other sites, with some exceptions and Fig. 4 depicts that the compositions of six groups of samples comprising calcium poor and calcium rich pottery types of each site, exhibited distinct aggregation within each group that was distinguishable from the aggregate of same type of pottery from other sites.

Mineralogical analysis

Table 5 summarises the mineralogical analyses of some typical Sialk I and II type samples from the three sites. As can be seen in the table minerals such as quartz card number (001-0649), and esseneite (Calcium Iron Aluminum Silicate, $Ca (Fe_{1.4} Al_{0.6}) SiO_6$ (25-0143) were the major minerals of the Sialk I and calcium rich Sialk II type specimens of the Sialk site. In comparison, the low calcium Sialk II specimens of this site were mainly composed of quartz, hematite (01-1053) and augite (Calcium Aluminum Iron Magnesium Silicate), $Ca (Mg, Al, Fe) Si_2O_6$ (24-0202) minerals (Marghussian, et al. 2017a).

Table 5 also demonstrates that minerals such as quartz and augite (Calcium Aluminum Iron Magnesium Silicate, $(Al_{0.42} Ca_{0.818} Fe_{0.269} Mg0._{792\ 0.6} Si_{1.751})$ (071-0721) are the major minerals present in almost all pottery sherds of the Ebrahimabad I. It is interesting to note that Ebrahimabad II specimens are also composed of the same quartz and augite minerals as the Ebrahimabad I pottery sherds, plus hematite mineral in some sherds (Marghussian, et al. 2017b).

As can be seen in Table 5 minerals such as quartz and augite (Aluminium Iron Magnesium Silicate), $(Al_{0.42} Ca_{0.818} Fe_{0.269} Mg0._{792\ 0.6} Si_{1.751})$ (071-0721) are the major minerals present in almost all Sialk I type pottery sherds of Pardis (Pardis I), as well as calcium rich specimens of

Sialk II type (Pardis II). However, the specimens poor in calcium possessed, hematite and another major mineral, structurally similar to an orthopyroxene mineral (Iron Magnesium Calcium Silicate) with the following formula: ($Ca_{0.043} F_{0.802} Mg_{1.155} O_6 Si_2$, CPDS card No. 01-086-0163).

More detailed results on the mineralogical composition of Sialk and Ebrahimabad pottery have been depicted in (Marghussian, et al. 2017a) and (Marghussian, et al. (2017b), respectively.

Effect of heat on pottery and estimation of the firing temperature

Because the mineralogical composition of clays changes during firing process at certain specific temperatures the identification of the type of the minerals present in the ceramics can provide useful information regarding the technology of making and firing of ancient pottery. These changes normally include the loss of water from various minerals, e.g. clay minerals, the decomposition of carbonates, and the formation of new crystalline minerals. Upon the firing of pottery containing calcareous clays at 850 °C or above because of the decomposition of $CaCO_3$ particles and formation of free CaO some problems such as cracking and spalling may occur in the resulting pottery. This is due to the formation of quicklime upon absorption of moisture by calcium oxide particles over time which is accompanied by volume expansion and stresses (Rye 1976).

However, in the pottery fired at higher temperatures (850-900 °C) or above the rehydration process may not occur, since at these temperatures calcium in clays usually participates in the process of liquid formation (vitrification) and formation of calcium containing minerals (Tite and Maniatis 1975a). Moreover, the iron oxide which is responsible for the generation of red colour in pottery may be incorporated into the crystal structures of the aforementioned calcareous silicate and aluminosilicate minerals and, consequently, the generation of a red colour in the calcium rich pottery may be inhibited (Rice 1987, 336). El-Didamony et al. (1998), studying the firing behaviour of calcareous clays, also observed distinct firing shrinkages at the 1050–1150 °C temperature range, which were attributed to the formation of a liquid phase in compositions located in the vicinity of the major eutectic of the SiO_2– CaO– Al_2O_3 system. The eutectic temperature is the lowest possible melting temperature over all of the mixing ratios for the involved component species. The eutectic temperature of this system has CaO/SiO_2 and Al_2O_3/SiO_2 molar ratios of 0.402 and 0.140, respectively, and a melting point of 1165 °C. Obviously, the most efficient densification and vitrification process should occur at the above temperature range.

It has also been reported that the calcium compounds, such as diopside, wollastonite and calcium ferrosilicates, are mainly formed at high temperatures of 900–1100 °C (Tite and Maniatis 1975b). El-Didamony et al. (1998) have also shown that during the firing of calcareous clays, the content of the mineral diopside gradually increased up to 1150 °C, and Eftekhari Yekta and Alizadeh (2001) detected the formation of diopside at the 930-1080 °C temperature range during the firing of a clay containing MgO and CaO with similar composition to the present study.

Considering the lack of high temperature minerals such as diopside and wollastonite in these pottery and the presence of oxides such as R_2O (alkali oxides), Fe_2O_3 and TiO_2 in their composition that could be acted as fluxes lowering their fusion point, as well as the presence of esseneite mineral in Sialk I pottery it can be expected that these pottery had lower sintering and vitrification temperatures than the 1050–1150 °C range as reported by El- Didamony et al. (1998). Esseneite mineral owing to its very low content of SiO_2 (23.2 wt %) and high content of Fe_2O_3 (43.3 wt%) and CaO (21.65 wt %), is a low melting point mineral, that can be formed at relatively lower temperatures. Hence, on the basis of the above discussion it can be suggested that Sialk I pottery was fired at the 850-900 °C temperature range. On the other hand, Considering the higher refractoriness of the raw materials used in the production of the low calcium Sialk II pottery, owing to their higher content of SiO_2 and Al_2O_3 and much lower content of CaO, a much higher firing temperature should be anticipated for this pottery in comparison to the Sialk I pottery. On the other hand, considering the technical difficulties involved in construction and handling of high- temperature kilns in prehistoric times and the absence of the aforementioned high- temperature phases in the sherds studied in this study, the temperatures range of 1050-1100 °C can be assigned to the firing of the low calcium Sialk II pottery investigated. It should be noted that the other type of Sialk II type pottery with a red coating, owing to their similarity in chemical and mineralogical compositions to the Sialk I (buff) pottery of the same site, were probably fired at lower temperature ranges, perhaps at the midway between the Sialk I and II pottery.

The Sialk I type pottery of Ebrahimabad (Ebrahimabad I), because of their higher content of SiO_2, Al_2O_3 and lower content of CaO, are more refractory in comparison with Sialk I pottery from the site of Sialk and thus require higher temperatures for sintering and vitrification. On the other hand, the major silicate mineral appearing on the firing of Ebrahimabad’s pottery is augite with higher content of SiO_2 and lower content of CaO (see above) and much lower content of Fe_2O_3 (10.62 wt%), which could be formed at relatively higher temperatures in comparison with the esseneite mineral of Sialk I pottery of Sialk site, hence, a higher temperature range such as 950-1000 °C could be suggested for their firing.

On the other hand, the Ebrahimabad II pottery possesses similar major mineral phases as Ebrahimabad I pottery (quartz and augite minerals), plus a hematite phase.

As hematite crystals responsible for the red colour of pottery can only be formed within an oxidising atmosphere, the mastering of firing techniques such as the accurate control of firing temperature and atmosphere the production of the red pottery was necessary at Ebrahimabad. Meanwhile, the use of a more oxidising atmosphere in the process of firing of pottery usually elevated the temperature of firing. On the basis of the above facts and observations, the temperature range of 1000-1050 °C can be assigned to the firing of Ebrahimabad II pottery. In the case of Pardis pottery the mineralogical analysis also revealed the presence of quartz and augite minerals in the Pardis I pottery that was similar to the major minerals of Ebrahimabad I pottery as discussed above. Hence, a temperatures range of 950-1000 °C can be estimated for the firing of Pardis I pottery, which is the same temperature range as suggested for the firing of Ebrahimabad I pottery.

On the other hand, the calcium rich pottery of Pardis II were mainly composed of the same phases as the Pardis I pottery, whereas specimens poor in calcium possessed quartz, hematite and another major phase, structurally similar to a orthopyroxene. The latter pyroxene phase is structurally similar to diopside which usually becomes a major phase of pottery above 1000- 1050 °C temperature range (El-Didamony et al. 1998, Eftekhari Yekta & Alizadeh, 2001). It should also be noted that the aforementioned specimens containing less calcium, because of their higher content of SiO_2 and lower CaO, are more refractory in comparison with Pardis I and Ebrahimabad II pottery. Considering the above points, the range of 1050-1100 °C, which is similar to the firing temperature range of Sialk II pottery from the site of Sialk, can be suggested for the firing of Pardis II pottery.

It should be noted that in non-industrial firing, there might be considerable fluctuations in firing temperatures. Even in kiln firing, temperature differences of as much as 100 °C may exist between different sections of the kiln (Mayes 1961, 1962). Under these conditions, the determination of the exact firing temperatures is impossible.

The origin of red colour in Sialk II type pottery

As stated above the Sialk I and II types of pottery has been solely defined on the basis of their colour and decoration, buff pottery decorated with black-painted simple geometric motifs (Sialk I type) and red pottery decorated with black-painted simple or composite geometric motifs (Sialk II type).

In the case of the Sialk I type buff pottery which are calcium rich the aforementioned process of fixation of iron in the network of newly formed calcium ferrosilicate minerals prevented the generation of red couler, as discussed above. However, in the case of the red- surfaced calcium rich pottery of Sialk II type, two different methods could be used to generate the red colour, either the application of a red iron rich coating to the interior and outer surfaces of pottery, such as pottery from Sialk (Marghussian, et al. 2017a), or other means such as the replacement of raw materials or refinement of the firing technology.

It has been shown that the difference observed between the content of iron on the exterior surface and core of the specimens, as determined by SEM elemental map of different sections is a good criterion to show the existence or absence of a red coating or slip on the surface of the pottery (Marghussian, et al. 2017a).

On the basis of the aforementioned criterion two Sialk II pottery samples from Sialk site, a calcium rich pottery, with red surface and buff core (Fig. 5) and a low calcium pottery which was red both on surface and core (Fig. 6) subjected to the SEM elemental analysis. Figure 5 shows that there is a large difference between the content of iron on the core and outer surface of a calcium rich sample from the Sialk site, indicating the existence of a red coating on its surface. Whereas, there is almost no difference between the content of iron on the core and outer surface of the low calcium pottery sample of the same site (Fig. 6) that revealed the absence of a red coating on its surface. This criterion was also applied to the calcium rich red pottery from Ebrahimabad and Pardis that revealed no difference between the content of iron on the core and outer surface of these pottery, indicating the absence of a red coating on their surface (results are not shown here).

Hence, it seems that the ancient potters used an alternative route to produce red pottery. It is well known that the clays used as one of the prominent raw materials in pottery making may contain iron in several forms. Some clays may contain hematite (Fe_2O_3) crystals, or more often iron may be present in the lattice structure of some clays. During the firing of pottery in an oxidizing atmosphere, the lattice structure of the clays is collapsed liberating some iron ions that may take part in the crystallization of some iron compounds such as hematite crystals which is responsible for the generation of the red colour of pottery.

Therefore, it can be postulated that the potters of Ebrahimabad and Pardis in some stage of their production process by better mastering of the firing techniques, by exercising a more precise control on the firing temperature, time and atmosphere, have succeeded in producing red surface pottery despite using calcium rich raw materials. This was only possible by constructing relatively advanced kilns, however in addition to using more refined firing techniques the application of alternative resources of raw materials (low calcium clays) was necessary to produce the aforementioned Pardis II pottery in the later stages of the Transitional Chalcolithic period. The pottery that was red both on surface and core exhibited denser, highly vitrified structures, and much improved properties such as high impermeability hardness, and strength. (Fig. 7).

Typological study

The ceramics from the individual sites were split into broad categories: Jars (form J), Bowls (Form B), Beakers (Form BE), Trays (Form T), Bases (Forms F and R) and Dishes (Form D). Each of these categories has been further subdivided, generally along the lines of having open or closed mouths (i.e. B1 and B3). A further subdivision was then made depending on steep or shallow sides (i.e. J1a, J1b).

Following the conventions outlined by Coningham and Ali (2007), jars were defined as having heights usually in excess of maximum diameters and orifice diameters less than the maximum body diameters. Bowls and dishes have heights less than maximum diameters, with the maximum diameters usually at the rim. Dishes are significantly less in height and shallower than bowls.

Table 6 demonstrates the detailed definition of various forms and Figure 8 depicts the drawings of selected pottery forms.

Vessel form types

The assemblages from the three sites within the Central Plateau of Iran contained 1087 rims belonging to 5 broad categories and 26 different vessle types.

Table 7 shows the relative quantity of the pottery in each category, it can be seen that the category of bowl in general has the highest percentage (86%) of all rims recovered from the aforementioned three sites in Late Neolithic, and Transitional Chalcolithic periods.

Figures 9 and 10 show the relative quantity of the vessel types in the Late Neolithic and Transitional Chalcolithic periods.

These figures reveal that the type B3b has the highest percentage of vessel types in the Late Neolithic, with 28.8 % of all sherds found in this period, and also the highest percentage of vessel types in the Transitional Chalcolithic, with 12.9 % of all sherds found in the latter period. Table 8 demonstrates the distribution of vessel types between the three sites during the Transitional Chalcolithic and Late Neolithic periods. It revealed that during the Sialk I period (Neolithic) the Sialk site had been quite active in the production of pottery. Indeed, the assemblage of Sialk I type pottery recovered from the site presents a very wide range of forms (n=21), and 7 vessel forms are specific to this period, while 2 forms are specific to Sialk II period. Also it was found that 12 pottery vessel forms out of the 14 forms of the Sialk II pottery have similar counterparts in the Sialk I pottery. It can be concluded that Sialk II pottery, insofar as the forms are concerned, offers a continuation of the Sialk I tradition with a narrower range of forms. However, it appears that the potters of Sialk in Period II experienced a higher level of specialisation and, by limiting or abandoning the production of certain vessels and producing new vessels, were trying to fulfil the changing needs of their communities.

Table 8 also revealed that contrary to the Sialk site the Pardis site demonstrated little activity in producing pottery during Pardis I period (Neolithic). Indeed, only 5 Sialk I type vessel types were recovered from Pardis site (Pardis I pottery), while 24 different vessel forms were recovered from Pardis II period (Transitional Chalcolithic, Pardis II pottery) which encompasses all of the 5 forms of Pardis I period. It was also demonstrated that Ebrahimabad has not been a prominent pottery making site, especially in the Neolithic period, indeed, only 7 vessel forms of Sialk I type (Ebrahimabad I pottery) were collected from the site, from which one form was exclusive to this period, while 14 different vessel forms were recovered from Ebrahimabad II (Transitional Chalcolithic) period (Ebrahimabad II pottery) out of which 6 forms were common with Ebrahimabad I period (Table 8).

With consideration of the pottery vessel forms of different sites and periods the following conclusions can be drawn regarding the common vessel forms between them:

1. Three Sialk I form types of Pardis (Pardis I) pottery were common with Sialk I type pottery of the Sialk site (Vessel types: B2b, B3b, B3c).

2. Out of the 24 different Silk II form types of Pardis (Pardis II) pottery, 5 (Vessel types: J1b, J2, B1a, B1d, B2a) and 2 (Vessel types: D1, BE1) forms were exclusively common with Sialk I and Sialk II form types of the Sialk site, respectively, while 10 vessel forms were simultaneously common with both Sialk I and Sialk II forms of the Sialk site (Vessel types: J1a, B1b, B1e, B3a, B3d, B4a, B4b, B5, T1, T3).

3. Three pottery vessel forms out of 7 Ebrahimabad I pottery were common with the Sialk I type pottery of the Sialk site (Vessel types: J2, B3a, B3d). and simultaneously with vessel forms of the Pardis site (both Pardis I and Pardis II), while the remaining 3 vessel forms were shared between the Neolithic pottery of all three sites (Vessel types: B2b, B3b, B3c).

4. Out of the 14 different vessel forms of Ebrahimabad II period, 4 (Vessel types: J1b, B1a, B2a, B2b) and 1 (Vessel type: D1) were exclusively common with the Sialk I and Sialk II type pottery of the Sialk site, respectively and 8 forms were simultaneously common with both Sialk I and II pottery (Vessel type: B1c, B1e, B3a, B3b, B3c, B3d, B5, T1) .

5. Ebrahimabad II pottery has 13 common form types with Pardis II (Vessel types: J1b, B1a, B1e, B2a, B2b, B2c, B3a, B3b, B3c, B3d, B5, T1, D1), however only 1 (Vessel type:B1c) form was specifically shared between the aforementioned two types of pottery and the remaining

vessel forms had a counterpart from the Sialk site (Sialk I, Sialk II or both).

Based on the results of this study it can be inferred that the Sialk I and II types of pottery from Ebrahimabad and Pardis, insofar as the forms are concerned, were developed under a strong influence from Sialk site. This can be attributed to the much older and far more developed and extended tradition of pottery-making in Sialk in the period of Late Neolithic and that have been spread to Pardis and Ebrahimabad and possibly replaced the less developed traditions of these sites. In the subsequent stages of their development, in the Transitional Chalcolithic period, the pottery-making tradition of Pardis and Ebrahimabad were under the strong influence of Sialk.

It is interesting to note that despite the existing evidence, concerning the occurrence of some radical changes concerning the firing technology and resources of the raw materials in the aforementioned sites in the Late Neolithic and Transitional Chalcolithic periods, as discussed above, very little changes were detected in pottery forms from Sialk I to Pardis II pottery for nearly 600-700 years.

However, it seems that despite the similarity of most of the vessels produced during the Sialk I and II periods, the potters of region changed the size of the produced vessels, limited or abandoned the production of certain sizes of vessels and produced new vessels differing in size with the existing ones.

Fig. 11 indicated the existence of two distinct groups of vessel forms for Sialk I type pottery, from Sialk site, small and large, in the group of small sizes the greatest number of bowls is located in the narrow range of 24-26 centimetres, while in the large size group the bowls are almost evenly distributed in the broad range of > 30 < 40 centimetres.

Figure 12 depicts that the rim sizes of Sialk II type pottery from Sialk site are mostly located in two major ranges of 22-24 and 26-28 centimetres, and very small number of bowls exist in other size ranges.

Figure 13 indicates that the rim sizes of Pardis II type pottery in Transitional Chalcolithic period are mostly distributed in four size ranges namely, very small bowls in the range of 15-

17, the most abundant small bowls in the size range of 21-23 centimetres, a limited number of intermediate size bowls, located mostly within the broad range of 27-32 centimetres and after a break in the size range of 33-38 centimetres the smaller number of large bowls mostly in the size range of 39-44 centimetres.

Therefore, it seems that in spite of the relative similarity of vessel forms discovered from different sites and periods the quantity and size of each vessel form differs in various locations and periods depending on the size (population) and emerging needs.

Craft specialisation and standardisation of pottery-making

Background

Cross defined specialisation as “a situation in which a relatively large portion of the total production of a given item or class of items is generated by a small segment of the population” (Cross 1993: 65).

It is known that the patterns of craft activities within segmentary societies will usually be organised in a self-sufficient mode of household production, while the more complex societies generally are more centralised (Rice 2015; Costin 1991; Wason 2004).

It has been proposed that there is a relationship between craft specialisation and cultural complexity and a number of different theoretical approaches have been suggested by archaeologists to study this relationship (Childe 1951; Tosi 1984; Arnold and Nieve 1992 ; Costin 1996; Hirshman, et al. 2010.

Mode of production

A mode of ceramic production represents a distinct set of social relations between producers and between producers and consumers. Modes differ in terms of scale of production, or quantities of labour and resources used, as well as quantities of vessels produced (Rice 2015: 80-6). Therefore, they differ in degree of intensification of production, or increased efficiency in production for the purpose of increased yields (Rice 2015, 190).

Peacock (1981, 1982, 8-10) and Van der Leeuw (1977, 1984) have suggested four modes of ancient pottery production:

Household production, household industry, individual workshop industry, and nucleated workshop industry

Three of the four modes of production are applicable to the prehistoric chiefdoms: household, household industry, and individual workshop industry, but the nucleated workshop industry, is usually associated with urbanism and fully developed market economies Arnold (1991 92).

Standardisation

One of the most common and effective ways in the archaeological studies to recognise the goods produced in mass quantities by specialists is their high degree of standardisation. Standardisation reflects the reduction of variability; hence ceramics within each category of pottery exhibit little heterogeneity in composition and appearance, however, standardisation has many diversified aspects such as homogeneity in ceramic materials, vessel shapes and decoration. It also encompasses all aspects of manufacturing process, such as resource selection, processing, forming, finishing, and firing, as well as the organisational aspects of production like scale and mode. Hence, in the archaeological studies the increased scale of specialised production can be detected by examining the manufacturing facilities, exchange pattern and the degree of standardisation in the physical and stylistic characteristics of the goods (Blackman et al. 1993).

Specialisation and standardisation of pottery-making at the three sites

Specialisation and standardisation at Sialk

Mode of production

Considering the course of evolution in pottery-making at Sialk, it can be speculated that the first stage of the development in pottery-making industry at the oldest phase of Late Neolithic, characterised by the low quality and quantity of pottery produced using rather primitive shaping and firing techniques could be assigned to the household production mode. While, the second stage of development between the earlier and later phases of the Late Neolithic period, before entering the Transitional Chalcolithic period, characterised by higher quality and quantity of the pottery produced by more refined techniques can be ascribed to the "simple household industry".

However, the pottery industry witnessed a very distinct change from the Sialk I to Sialk II period by producing the high quality bulk red pottery, the production of which must have been accompanied by a quite high degree of specialisation in the selection of materials and mastering of the firing techniques by the potters of Sialk during this time period. This event that can be evaluated as a breakthrough in the process of evolution of the pottery- making at Sialk.

Despite the facts that no specific areas or workshops were recognised, and the direct evidence of use of complex pottery-making technology such as kilns, moulds, wheels, etc. was not found at Sialk, but the large quantity and high quality of the Sialk II type pottery recovered from the site, all witnessing the existence of a certain degree of specialisation in pottery-making, the mode of complex household industry could be assigned to the pottery production at Sialk in the Transitional Chalcolithic period.

Standardisatation

On the basis of the results of this study that revealed the existence of a very large quantity of Sialk II type pottery (Transitional Chalcolithic) exhibiting quite remarkable resemblance with each other regarding their form and decoration as well as similarity of the chemical/ mineralogical compositions between pottery of this period the existence of a certain degree of standardisation in pottery-making can be envisaged in Sialk in the Transitional Chalcolithic period.

Specialisation and standardisation at Ebrahimabad

On the basis of the experimental results obtained in this study, the occurrence of an apparently gradual development in pottery-making technology at the site of Ebrahimabad can be ascertained in the late Neolithic through the Transitional Chalcolithic periods (from ~ 5500 to ~5000 BC). The potters of Ebrahimabad finally produced high quality wares, which were red both on surface and core between 5060 and 4882 BC. This indicated the existence of considerable specialisation in the field of the selection of materials and mastering of firing techniques, more efficient control of the temperature and time in order to maintain the required degree of oxidising atmosphere within an appropriate schedule.

However, considering the relatively small size of the mound of Ebrahimabad, the limited extent of the excavations carried out on the site and relatively low number of the studied samples, despite the observation of the aforementioned continuous and gradual development of pottery production and the similarity of the products belonging to each period regarding their chemical/ mineralogical compositions, it is not possible to draw solid, precise conclusions regarding the mode of pottery-making and standardisation at Ebrahimabad.

However, pottery production modes at Ebrahimabad could tentatively be evaluated as household production and simple household industry in the late Neolithic and Transitional Chalcolithic periods, respectively.

Specialisation and standardisation at Pardis

Mode of production

It has been discovered that during the Transitional Chalcolithic period (5200-4600 BC), the residential part of the Pardis site or domestic space was separated from the workshop area and the whole workshop area of 400 square metres was constantly used for making vessels. Indeed, all the excavated layers contained kiln remains and other artefacts related to ceramic manufacturing (Fazeli et al. 2007b).

This would imply a permanent ceramic production centre from the end of sixth into the first half of fifth millennium BC. Another example of direct evidence for the mass production and specialisation of ceramic production is the use of multi-chambered kilns in the firing process, which is very important for studying the standardisation of ceramic production (Fazeli et al. 2010, 2014). Tepe Pardis also exhibited a diversified range of different pottery forming techniques, it seemed that the combination of different techniques such as SSC (sequential slab construction, and fast wheel throwing might have coexisted for a long period (Manuel et al. 2014).

Positive evidence was found at Pardis for the use of fast potters' wheels (Fazeli et al. 2007b, 2010) indicating the familiarity of potters of Tepe Pardis with this specialised technique and utilised it with clay mixtures of variable texture and also with different forms.

On the basis of the above points it can be suggested that Tepe Pardis functioned as a specialised pottery-producing centre, performing at a level of "individual workshop industry", as defined above, in Transitional Chalcolithic period.

Standardisatation

The large quantity and high quality of the Pardis II pottery recovered from the site, exhibiting quite remarkable resemblance with each other on their form, decoration and chemical/ mineralogical compositions, as well as regarding the variation in quantity and size of the produced vessels with similar forms in different periods all evidenced the high degree of specialisation and standardisation practiced by the potters of Pardis during the Transitional Chalcolithic period.

Conclusions

This study introduced new approaches into the understanding of chronology and cultural-technological development of the Neolithic and Chalcolithic settlements within the Central Plateau of Iran through the study of the evolution of ceramic craft specialisation between ca. 5700-4800 BC by analysing newly excavated pottery from the different three areas of this region: the Tehran, Qazvin and Kashan plains. Despite having been investigated for almost 90 years, the prehistoric ceramics of the Central Iranian Plateau have mainly been studied in a basic manner, based on the study of colour and decoration of pottery as the criteria to identify, characterise, and compare the various pottery types of the region with little attention to technology and production.

In the present study a multidisciplinary research method has been adopted by utilising scientific analysis techniques such as X-ray Diffraction (XRD), X-ray fluorescence (XRF) and scanning electron microscope (SEM) as well as typological classification in studying and characterisation the pottery.

The results of the analyses demonstrated the occurrence of a gradual change in pottery- making at these sites in the aforementioned periods, commencing with the coarse, fragile buff pottery of the Neolithic period, and eventually culminating in the high-quality, fine and quite strong, bulk red pottery in the later stage of the Sialk II period (Early Chalcolithic) that can be evaluated as the critical point of entering into the transitional Chalcolithic era.

Since, the comparison of pottery from different sites with the same tradition revealed no distinct similarities in chemical composition and the details of the technology of pottery-making, the possibility of long distance trade and direct exchange of ceramic articles or production technology, as well as resources between the studied sites in the Late Neolithic and Transitional Chalcolithic periods should be ruled out.

Hence, the general chromatic change of the pottery from the Late Neolithic to the Transitional Chalcolithic periods should be ascribed to the replacement of raw materials and refinement of the firing technology, the precise control of the firing temperature and atmosphere. This indicated the existence of a high degree of skill and experience in the potters of region, concerning the techniques of selection of raw materials and mastering of the firing techniques.

Regarding the typological characteristics of the pottery recovered from the three sites the following conclusions can be drawn:

The pottery assemblage of Sialk I recovered from Sialk site presents a very wide range of forms and the Sialk II pottery, offer a continuation of the Sialk I tradition with a narrower range of forms.

It is also apparent that most of the vessel forms of Ebrahimabad I and Pardis I pottery resemble Sialk I pottery vessel froms the site of Sialk, and during the Sialk II period, this influence was continued, most of the pottery forms from Ebrahimabad and Pardis were developed under the strong influence from Sialk.

This can be attributed to the much older and far more extended tradition of pottery- making in Sialk in the period of Late Neolithic that possibly was shared with potters at Pardis and Ebrahimabad and replaced the local traditions of these sites.

Despite the occurrence of some radical changes concerning the firing technology and resources of the raw materials in the aforementioned sites in the Transitional Chalcolithic periods, very few changes were detected in pottery forms from Sialk I to Pardis II pottery. However, it should be noted that the quantity and size of each vessel form differs in various locations and periods depending on the population of sites and their needs.

Finally, considering the large quantity and high quality of the Sialk II type pottery recovered from the three sites (especially, Sialk and Pardis) the pottery of each site exhibiting quite remarkable resemblance with each other regarding their form, decoration as well as their chemical/ mineralogical compositions, a high degree of specialisation and standardation can be assigned to these sites during the Transitional Chalcolithic period. Moreover, based on the existing evidence concerning the resemblance of some characteristics of the pottery of the three sites (such as form) with each other the cultural/technical interactions and exchanges between the prehistoric communities living in this region in the specified time period seems to be very likely.

References

Arnold , P.J., 1991. Dimensional standardization and production scale in Mesoamerican ceramics. Latin American Antiquity, 2(4), pp. 363-370.

Arnold, D.E., Nieves, A.L., 1992. Factors affecting ceramic standardization. In: Bey,G.J., III, Pool, C.A. (Eds.), Ceramic Production and Distribution: An Integrated Approach. Westview Press, Boulder, Colorado, pp. 113–214.

Bieber, A. M. Jr., Brooks, D. W., Harbottle, G., and Sayre, E. V., 1976, Application of multivariate techniques to analytical data on Aegean ceramics, Archaeometry, 18,59– 74.

Blackman, M.J., Stein, G.J. & Vandiver, P.B., 1993. The standardization hypothesis and ceramic mass production: technological, compositional, and metric indexes of craft specialisation at Tell Leilan, Syria. American Antiquity, 58(1), pp. 60-80.

Childe, V.G., 1950. Magic Craftsmanship and Science. Liverpool University Press. Childe, V.G., 1951. Man Makes Himself. New York: New American Library.

Coningham, R.A.E., Fazeli, H., Young R. L. and Donahue R. E., 2004. Location, location, location: A pilot survey of the Tehran Plain in 2003. Iran, 42, pp.1-12. Coningham, R.A.E., Fazeli, H., Young, R.L., Gillmore, G.K., Karimian, H., Magshoudi, M., Donahue, R.E. and Batt, C.M., 2006. Socio-economic transformations: settlement survey in the Tehran Plain and excavations at Tepe Pardis. Iran, 44, pp.33-62.

Coningham, R.A.E. & Ali, I., 2007. Charsadda: The British-Pakistani excavations at the Bala Hisar of Charsadda. B.A.R. International Series. Oxford: Archaeopress.

Costin, C.L., 1991. Craft Specialisation: Issues in Defining, Documenting and Explaining the Organization of Production. Archaeological Method and Theory, 3, pp. 1-55.

Costin, C.L., 1996. Craft Production and Mobilization Strategies in the Inka Empire. In Wailes, B. (ed.) Craft Specialization and Social Evolution, Philadelphia, pp. 211-225.

Cross, J.R., 1993. Craft specialisation in nonstratified societies. Research in Economic Anthropology, 14, pp. 61-84.

Dyson, R.H. and Howard, S.M., (eds.) 1989. Tappeh Hesar: Reports of the Restudy Project, 1976. Firenze: Casa Editrice Le Lettere.

Dyson, R. H. Jr., 1965, Problems in the relative chronology of Iran 6000–2000 BC, in Chronologies in Old World archaeology (ed. R. W. Ehrich), 216–256, University of Chicago Press, Chicago.

Eftekhari Yekta, B. and Alizadeh, P., 2001. Abnormal shrinkage during firing of an iron- bearing alcareous clay. Industrial ceramics, 21(3), pp.159-162.

El-Didamony, H., Assal, H. H., Hassan, H. S., and Abd El-Ghafour, N. G., 1998, The thermal behaviour of clay and calcareous clays containing different lime contents, Industrial Ceramics, 18, 91–98.

Fazeli Nashli, H, and Djamali, M; 2002. The Process of Specialised Ceramic production at Zagheh Prehistoric site Based on the archaeological evidence and Petrography result, in M. Azarnush (ed.). The First Symposium of Archaeology in Iran: The Role of Sciences in Archaeology, Cultural Heritage Organization Press, 203-224 (in Persian).

Fazeli, H., Coningham, R.A.E. & Batt, C.M., 2004. Cheshmeh-Ali revisited: towards an absolute dating of the Late Neolithic and Chalcolithic of Iran's Tehran Plain. Iran, 42, pp.13- 23.

Fazeli, H., and Abbasnejad, R., 2005, Social transformations and interregional interaction in the Qazvin plain during the 5th, 4th and 3rd millennia BC, Archäologische Mitteilungen aus Iran und Turan, 37,7–26.

Fazeli, H., Wong, E. H. & Potts, D.T., 2005. The Qazvin Plain revisited: A reappraisal of the chronology of the Northwestern Central Plateau, Iran, in the 6th to the 4th millennium BC, Ancient Near Eastern Studies, 42, pp. 3-82.

Fazeli, N.H., Marghussian, A.K., Ilkhani, H., Beshkani, A., 2007a. Preliminary report of Ebrahimabad Excavation 2006. Archaeological Reports 7. Iranian Centre for Archaeological Research, Tehran, pp. 376-406.

Fazeli, H., Coningham, R. A. E., Young, R.L., Gillmore, G.K., Maghsoudi, M., & Raza, H., 2007b. Socio-economic transformations in the Tehran Plain: final season of settlement survey and excavations at Tepe Pardis. Iran 45, pp. 267-286.

Fazeli, N.H., Beshkani, A., Marghussian, A., Ilkhani, H., Abbasnegad Seresty, R. & Young, R., 2009. The Neolithic to Chalcolithic transition in the Qazvin Plain, Iran: chronology and subsistence strategies. Archäologische Mitteilungen Aus Iran and Turan 41, pp. 1-21.

Fazeli, N. H., Vidale, M., Guida, G., and Coningham, R. A. E., 2010, The evolution of ceramic manufacturing technology during the Late Neolithic and Transitional Chalcolithic periods at Tepe Pardis,Iran, Archäologische Mitteilungen aus Iran und Turan, 42,87–112.

Fazeli, N. H., Coningham, R. A. E., Marghussian, A., Manuel, M., Azizi, H., and Pollard, M., 2013, Mapping the Neolithic occupation of the Kashan, Tehran and Qazvin plains, in the Neolithisation of Iran: the formation of new societies(eds. R. Matthews and N. H. Fazeli), 114–135, Oxbow Books, Oxford.

Fazeli, N.H., Mosapour, N.F. & Firoozmandi, S.B., 2014. Craft Specialisation at Shahdad: Pottery Production during the third millennium BC. Iranian Journal of Archaeological Studies, 2(2), pp. 83-93.

Gillmore, G.K., Coningham, R.A.E., Young, R., Fazeli, H., Rushworth, G., Donahue, R. & Batt, C.M., 2007. Holocene alluvial sediments of the Tehran Plain: sedimentation and site visibility. Reconstructing Human-Landscape Interactions, pp. 37–67.

Gillmore, G.K., Coningham, R.A.E., Fazeli, H., Young, R., Magshoudi, M., Batt, C.M., Rushworth, G. & Ivison, C., 2009. Irrigation on the Tehran Plain, Iran: Tepe Pardis - The site of a possible Neolithic irrigation feature? Catena, 78(3), pp. 285-300.

Gillmore, G.K., Stevens, T., Buylaert, J.P., Coningham, R.A.E., Fazeli, H., Young, R. & Maghsoudi, M., 2011. Geoarchaeology and the value of multidisciplinary palaeo- environmental approaches: a case study from the Tehran Plain, Iran. Human Interactions with the Geosphere: The Geoarchaeological Perspectiv, 352(1), pp. 49-67.

Ghirshman, R., 1938,Fouilles de Sialk, prés de Kashan 1933, 1934, 1937, Vol. 1, Musée du Louvre, Department des Antiquités Orientales, Paris.

Hedges, R. E. M., and McLellan, M., 1976, On the cation exchange capacity of fired clays and its effect on the chemical and radiometric analysis of pottery, Archaeometry, 18, 203– 206.

Hirshman, A.J., Lovis, W.A., Pollard, H.P. 2010. Specialization of ceramic production: A sherd assemblage based analytic perspective, Journal of Anthropological Archaeology 29 (3), 265–277.

Holakooei, P., Tessari, U., Verde, M. and Vaccaro, C., 2014. A new look at XRD patterns of archaeological ceramic bodies. Journal of Thermal Analysis and Calorimetry, 118(1), pp. 165-176.

Majidzadeh, Y., 1976. The early prehistoric cultures of the central plateau of Iran: an archaeological history of its development during the fifth and fourth millennia BC. Thesis, University of Chicago.

Majidzadeh, Y., 1981. Sialk III and the Pottery Sequence at Tepe Ghabristan: The Coherence of the Cultures of the Iranian Central Plateau. Iran 19, pp. 141-6.

Malek Shahmirzadi, S., 1995. The relative chronology of the central Iranian Plateau from the Neolithic to Early States, Journal of Archaeology and History 9(2), pp. 2-18 (in Persian).

Manuel, M.J., Coningham, R.A.E., Gillmore, G. and Fazeli, H., 2014. Societal change and sustainability within the Central Plateau of Iran: an archaeological viewpoint. In Sillitoe,

P. (ed). Sustainable Development: an appraisal from the Gulf Region. New York, pp. 38- 61.

Marghussian, A.K., Coningham, R.A.E., Fazeli, H., 2017a. The evolution of pottery production during the Late Neolithic period at Sialk on the Kashan Plain, central plateau of Iran. Archaeometry, 59, (2) 222–238.

Marghussian, A.K., Coningham, R.A.E., Fazeli, H., 2017b. Investigation of Neolithic pottery from Ebrahimabad in the central plateau of Iran, utilising chemical–mineralogical and microstructural analyses. Journal of Archaeological Science: Reports.

Marshall, J., 2012. Missing Links: Demic Diffusion and the Development of Agriculture on the Central Iranian Plateau, Unpublished doctoral dissertation, Durham University.

McCown, D., 1942. The Comparative Stratigraphy of Early Iran. Studies in Ancient Oriental Civilization, Chicago: University of Chicago Press.

Negahban, E.O., 1996. Marlik: the complete excavation report, Vol. 87. UPenn Museum of Archaeology.

Peacock, D.P., 1981. Archaeology, ethnology and ceramic production. Production and distribution: A ceramic viewpoint, pp.187-194.

Peacock, D.P., 1982. Pottery in the Roman world: An ethnoarchaeological approach. London: Longman.

Pollard, A.M., Nashli, H.F., Davoudi, H., Sarlak, S., Helwing, B. and Saeidi, F., 2013. A new radiocarbon chronology for the North Central Plateau of Iran from the Late Neolithic to the Iron Age. Archäologische Mitteilungen aus Iran und Turan, 45, pp.27-50.

Pollard, A.M., Davoudi, H., Mostafapour, I., Valipour, H.R. and Fazeli Nashli, H., 2012. A New radiocarbon chronology for the late Neolithic to Iron age in the Qazvin plain, Iran. The International Journal of Humanities, 19(3), pp.110-151.

Pollard, A. M., Batt, C., Stern, B., and Young, S. M. M., 2007. Analytical chemistry in archaeology, Cambridge University Press, Cambridge.

Rice, P. M., 1987, Pottery analysis: A source book. first ed. University of Chicago Press, Chicago.

Rice, P.M., 1991. Specialisation, standardization, and diversity: A retrospective. In Bishop,

R. L., and Lange, F. W. (eds.). The ceramic legacy of Anna O. Shepard, The University Press of Colorado, pp. 257-279.

Rice, P.M., 2015. Pottery analysis: A sourcebook. Second ed. University of Chicago Press. Rye, O.S., 1976. Keeping your temper under control: materials and the manufacture of Papuan pottery. Archaeology and Physical Anthropology in Oceania, 11(2), pp. 106-107.

Tite, M.S., and Maniatis, Y., 1975a. Scanning electron microscopy of fired calcareous clays. Transactions of the British Ceramics Society, 74, pp. 19-22.

Tite, M.S., and Maniatis, Y., 1975b. Examination of ancient pottery using scanning electron microscope. Nature, 257, pp. 122-123.

Tosi, M., 1984. The Notion of Craft Specialization and its Representation in the Archaeological Record of Early States in the Turanian Basin. In Spriggs, M. (ed.). Marxist Perspective in Archaeology. Cambridge, pp. 22-53.

Van der Leeuw, S.E., 1977. Towards a study of the economics of pottery making. Ex horreo, 4, pp. 68-76.

Van der Leeuw, S.E., 1984. Dust to Dust: A Transformational View of Ceramic Cycle. In Leeuw, S., Van der, E. & Pritchard, A.C. (eds.). The Many Dimensions of Pottery: Ceramics in Archaeology and Anthropology, Amsterdam, pp. 709-766.

Wason, P.K., 2004. The archaeology of rank. Cambridge University Press.

Wilkinson, T., 2003. Archaeological Landscapes of the Near East. Arizona: The University of Arizona Press.

Figure Captions

Fig. 1. Map of the Central Plateau of Iran showing the location of sites discussed in this research.

Fig. 2 Pardis pottery sherds: (a) Pardis II red Ware; (b) Pardis I buff Ware.

Fig. 3 PCA of Sialk I, Pardis I and Ebrahimabad I pottery samples. The site abbreviations are as follows: ■ Pardis I (n = 12), ○ Sialk I (n = 22), ●Ebrahimabad I (n=8).

Fig. 4 PCA of Sialk II, Pardis II and Ebrahimabad II pottery samples. The site abbreviations are as follows: ● Ca-rich Pardis II samples (n = 8), ▼ Ca-rich Sialk II samples (n = 6), ■ Ca-poor Pardis II samples (n= 8), ○ Ca-poor Sialk II samples (n = 8), □ Ca-rich Ebrahimabad II samples**,** (n = 5), ▽Ca-poor Ebrahimabad II samples, (n = 5).

Fig. 5 A typical elemental spectrum of Sialk II pottery with a red coating. (a) Core. (b) Exterior surface

Fig. 6 A typical elemental spectrum of Sialk II Sample which is in red colour both on exterior and core. (a) Exterior surface. (b) Core.

Fig.7 A typical SEM micrograph of a calcium poor Pardis II pottery (Transitional Chalcolithic period) exhibiting a highly vitrified microstructure.

Fig. 8 The typology of vessel forms.

Fig.9 Relative quantity of the vessel types in the Neolithic period.

Fig.10 Relative quantity of the vessel types in the Transitional Chalcolithic period.

Fig. 11. Distribution of rim diameters of vessel type B3a for Sialk site in Neolithic period.

Fig. 12 Distribution of rim diameters of vessel type B3a for Sialk site in Transitional Chalcolithic period.

Fig. 13 Distribution of rim diameters of vessel type B3a for Pardis site in Transitional Chalcolithic period.

Table 1. Calibrated and modelled dates for Tepe Sialk North, Tepe Pardis and Tepe Ebrahimabad (cal BC) (Pollard et al. 2012; 2013)

Site	Period	Trench	Phases	Modelled date with 95% probability (cal BC)
Sialk	**Sialk I** **Late Neolithic (Early)**	**VI**	**I_1-I_3**	**5841–5679 to 5742-5674**
Sialk	**Sialk I** **Late Neolithic (Late)**	**V**	**I_4-I_5**	**5449 5323 to 5280 5221**
Sialk	**Sialk II** **Transitional Chalcolithic (Early)**	**V**	**II_1-II_2**	**5316-5206 to 5025–4743**
Ebrahimabad	**Ebrahimabad I** **Late Neolithic (Late)**	**II-III**		**5641 -5480 to 5295 -5121**
Ebrahimabad	**Ebrahimabad II** **Transitional Chalcolithic (Early)**	**II-III**		**5198 -5044 to 5191 -4875**

Pardis	**Pardis I** **Late Neolithic** **(Late)**	**VII**		**5848 5066 to 5212 5017**
Pardis	**Pardis II** **Transitionl** **Chalcolithic (Early)**	**VII**		**5280-5050 to 4830-4680**

Table 2. Chemical compositions of some Sialk I and II pottery samples, wt%

(after Marghussian, et al., 2017a).

Oxide/ Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3
S1y	0.75	2.3	9.75	44.6	0.16	3.54	19.2	1.29	16.36
S1z	0.59	2.62	10.94	45.1	0.45	2.34	17.3	1.38	17.56
S1v	0.44	2.83	10.02	43.2	0.32	2.08	23.4	1.26	15.33
S1h	0.32	2.4	9.82	47.7	0.18	3.51	18.8	1.28	14.24
S1q	0	1.87	9.53	47.5	0.25	4.23	18.7	1.25	14.63
S1ae	0.27	2.27	10.33	47.0	0.22	2.42	19.9	1.21	15.03
S1aa	0.33	2.49	10.7	48.0	0.22	4.14	16.8	1.23	14.42
S1g	0.73	1.89	10.16	47.6	0.25	2.51	20.8	1.27	13.69
S1f	0.21	1.99	8.59	43.6	0.5	4.23	25.3	1.2	12.62
S1j	0.58	2.48	9.09	44.0	0.51	3.88	22.6	1.17	13.93
S1d	0	2.2	9.25	45.7	0.36	3.68	22.6	1.21	13.41
S1o	0.18	2.18	8.71	42.1	0.47	3.75	26.7	1.19	13.23
S1m	0.15	2.34	9.09	42.9	0.24	3.32	26.1	1.15	13.46
S1e	0.37	2.42	9.06	43.2	0.4	3.24	24.6	1.12	14.11
S1a	0.32	1.97	9.37	45.1	0.3	3.72	22.7	1.2	13.98
S1l	0.13	1.39	8.33	44.4	0.3	3.51	24.1	1.19	14.85
S1b	0.42	2.3	9.71	44.8	0.25	3.72	22.4	1.18	14.03
S1c	0.69	2.25	9.88	45.9	0.28	4.04	20.3	1.18	14.34
S1ab	0.44	2.26	9.45	46.2	0.73	4.04	20.4	1.2	14.02
S1ac	0.31	2.26	9.2	43.8	0.6	3.51	22.6	1.2	14.97
S1r	0	2.07	8.15	40.3	1.38	3.55	29.3	1.18	12.13
S1ad	0.39	2.37	9.19	43.9	0.66	1.96	25.6	1.12	13.7
Average	**0.35**	**2.23**	**9.47**	**44.8**	**0.41**	**3.41**	**22.3**	**1.21**	**14.27**
SD	**0.23**	**0.30**	**0.71**	**1.99**	**0.27**	**0.70**	**3.22**	**0.06**	**1.17**
S2m	0.52	2.28	10.15	46.2	0.27	4.26	18.8	1.19	15.01
S2b	0.56	2.42	8.51	50.4	0.26	4.72	17.8	1.19	12.88
S2e	0.69	2.35	9.37	44.0	0.23	4.13	22.5	1.2	14.07
S2c	0.59	2.4	10.09	49.1	0.26	4.7	15.3	1.18	15.07
S2n	0.21	2.13	8.96	42.2	1.23	3.56	24.5	1.24	13.92
S2f	0.33	2.11	8.81	41.0	0.28	4.49	27.2	1.17	13.2
Averagge	**0.48**	**2.28**	**9.32**	**43.8**	**0.42**	**4.31**	**22.7**	**1.20**	**14.03**
SD	**0.18**	**0.13**	**0.68**	**3.34**	**0.40**	**0.44**	**4.91**	**0.02**	**0.90**
S2a	0.69	1.46	10.67	62.3	0.22	5.15	3.67	1.42	13.56
S2i	0.34	1.56	10.78	58.6	0.2	5.5	8	1.47	12.54
S2p	0	1.54	11.02	57.4	0.22	5.15	2.88	1.41	18.97
S2k	0.35	1.45	12.19	60.1	0.24	4.77	2.53	1.44	15.95
S2d	0.36	1.75	11.06	59.7	0.26	5.42	6.17	1.43	12.93
S2h	0.42	1.62	10.33	59.8	0.34	4.72	4.73	1.49	14.91
S2g	0.36	1.53	11.66	60.5	0.16	4.42	3.13	1.47	15.88
S2j	0.78	1.43	11.7	54.0	0.29	4.43	8.35	1.61	16.3
Average	**0.36**	**1.56**	**11.10**	**59.8**	**0.23**	**5.02**	**4.44**	**1.45**	**14.96**

SD	**0.20**	**0.10**	**0.63**	**1.54**	**0.06**	**0.40**	**2.01**	**0.03**	**2.23**

Table 3 Chemical compositions of some Ebrahimabad I and II pottery samples, wt% (after Marghussian, et al., 2017b).

Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
E1s	0.87	1.77	9.44	46.71	0.32	4.54	18.7	1.37	13.24
E1c	0.3	1.55	11.33	49.2	0.32	5.19	12.1	1.42	16.48
E1t	1.43	1.62	11.05	48.6	0.5	4.35	14.9	1.34	15.72
E1f	0.96	1.66	10.93	47.46	0.56	5.27	14.9	1.3	14.86
E1g	0.59	1.68	11.51	49.84	0.47	4.84	12.1	1.26	15.75
E1r	2.75	2.29	10.35	48.1	0.45	4.86	13.0	1.31	15.05
E1k	0.56	1.69	11.71	51.19	0.37	5.58	12.5	1.38	13.29
E1l	0.41	1.64	10.6	48.81	0.55	5.19	16.5	1.39	13.46
E1p	1.29	1.84	9.69	48.22	0.38	4.58	18.5	1.39	12.28
E1n	0.2	1.67	10.08	47.04	0.41	4.99	20.8	1.29	11.89
E1o	0.44	1.53	8.81	41.65	0.99	5.29	27.2	1.4	10.32
E1u	0.45	1.72	10.03	48.04	0.4	4.32	20.1	1.2	12.43
Average	**0.89**	**1.72**	**10.5**	**47.89**	**0.48**	**4.97**	**16.5**	**1.35**	**13.85**
SD	**0.73**	**0.21**	**0.92**	**2.43**	**0.19**	**0.38**	**4.63**	**0.05**	**1.9**
Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
E2a	0.43	1.53	10.37	48.01	0.38	4.25	17.4	1.54	14.86
E2b	0.03	1.26	10.37	47.04	0.32	4.3	18	1.65	15.78
E2d	0.3	1.55	10.34	45.97	0.29	4.01	19.9	1.61	14.82
E2e	0	1.54	10.63	50.79	0.55	4.8	12.6	1.59	16
E2n	0.79	1.53	10	46.93	0.47	4.41	19.8	1.34	13.43
Average	**0.31**	**1.48**	**10.34**	**47.75**	**0.40**	**4.35**	**17.5**	**1.55**	**14.98**
SD	**0.32**	**0.12**	**0.22**	**1.85**	**0.11**	**0.29**	**2.98**	**0.12**	**1.02**
Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
E2f	1.08	1.82	10.93	61.51	0.27	4.22	2.79	1.33	14.95
E2j	0.38	1.11	10.9	60.25	0.53	4.51	4.35	1.27	15.97
E2c	0.42	1.51	11.33	54.78	0.34	4.19	8.51	1.65	16.35
E2h	0.3	1.45	11.89	57.12	0.31	4.37	2.81	1.93	18.8
E2i	0.18	1.01	11.27	55.2	0.36	4.37	8.6	1.93	15.88
Average	**0.472**	**1.38**	**11.26**	**57.77**	**0.36**	**4.33**	**5.41**	**1.62**	**16.39**
SD	**0.35**	**0.33**	**0.40**	**3.00**	**0.10**	**0.13**	**2.94**	**0.32**	**1.44**

Table 4 Chemical compositions of some Pardis I and II pottery samples (wt%)

Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
P1b	0.04	1.8	9.3	48.12	0.31	3.82	18.63	1.2	15.05
P1c	0.29	1.89	9.83	49.63	0.37	3.21	19.44	1.26	12.93
P1d	0.38	1.69	9.68	52.62	0.43	4.39	15.09	1.29	13.31
P1f	0.46	1.59	9.44	50.58	0.37	4.17	17.71	1.24	12.51
P1l	0.44	1.83	9.4	48.31	0.28	3.95	19.78	1.21	13.61
P1j	0.46	2.02	9.99	52.29	0.48	3.44	13.68	1.3	14.98
P1g	0.62	1.53	10.17	52.05	0.49	4.39	14.01	1.26	14.01
P1h	0.56	1.83	10.59	48.85	0.28	4.2	17.13	1.23	14.08
P1a	0.12	1.85	10.63	48.26	0.31	4.57	17.25	1.45	14.48
P1e	0.23	1.76	9.75	49.96	0.35	3.89	17.73	1.35	13.87
P1i	0.18	1.51	8.23	51.09	0.22	4.8	18.55	1.11	13.75
P1k	0.36	1.85	10.41	51.47	0.4	4.21	14.52	1.28	14.17
Average	**0.34**	**1.74**	**9.92**	**50.01**	**0.36**	**4.08**	**16.96**	**1.29**	**13.78**
SD	**0.21**	**0.13**	**0.5**	**1.67**	**0.07**	**0.43**	**2.12**	**0.08**	**0.83**
Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
P2c	0.44	1.74	10.35	54.71	0.23	4.54	10.79	1.32	14.77
P2f	0.77	1.79	9.51	50.15	1.36	4.6	16.31	1.23	12.77
P2h	0.34	1.74	10.1	50.43	0.27	4.71	15.14	1.28	14.8
P2i	0.11	1.67	10.81	53.54	0.36	4.59	10.29	1.21	16.21
P2v	0.27	1.69	11.03	52.37	0.23	5.07	13.44	1.77	13.61
P2z	0.52	1.73	10.24	51.37	0.65	4.75	14.87	1.63	13.55
P2t	0.43	1.62	9.53	53.11	0.41	4.78	14.37	1.54	13.76
P2j	0.22	1.65	9.99	54.57	0.53	4.63	11.91	1.28	13.44
Average	**0.39**	**1.70**	**10.20**	**52.53**	**0.51**	**4.71**	**13.4**	**1.41**	**14.11**
SD	**0.19**	**0.05**	**0.51**	**1.65**	**0.35**	**0.16**	**2.04**	**0.20**	**1.02**
Oxide/ Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
P2a	0.57	1.18	12.02	62.39	0.25	4.49	3.07	1.42	14.41
P2b	0.06	1.26	11.48	60.37	0.3	3.82	7.01	1.94	13.07
P2d	0.44	1.36	12.16	61.97	0.26	4.68	3.17	1.38	14.73
P2g	0,22	1.49	11.49	62.27	0.2	4.69	3.21	1.4	14.88

P2e	0.63	1.06	10.88	60.45	0.63	4.44	4.86	1.3	15.69
P2k	0.13	1.15	12.25	62.53	0.65	3.18	4.02	1.58	14.06
P2s	0.42	1.28	12.74	61.26	0.41	4.11	4.66	1.67	14
P2m	0.32	1.11	12.56	63.07	0.59	3.96	5.39	1.44	11.43
Average	**0.37**	**1.24**	**11.95**	**61.79**	**0.41**	**4.17**	**4.4**	**1.52**	**14.04**
SD	**0.20**	**0.13**	**0.58**	**0.93**	**0.17**	**0.48**	**1.27**	**0.19**	**1.30**

Table 5. Major crystalline phases present in the typical pottery sherds of the three sites

Site	Type	Major phases (JCPDS card No.)
Sialk	Sialk I	Esseneite (25-0143), Quartz (001-0649), Hematite (01-1053)*
Sialk	Sialk II (calcium rich)	Esseneite (25-0143), Quartz (001-0649)
Sialk	Sialk II (calcium poor)	Augite (24-0202), Quartz (001-0649), Hematite (01-1053)
Ebrahimabad	Sialk I	Augite (071-0721), Quartz (001-0649)
Ebrahimabad	Sialk II (calcium rich)	Augite (071-0721), Quartz (001-0649, Hematite (001-1053)
Ebrahimabad	Sialk II (calcium poor)	Augite (071-0721), Quartz (001-0649, Hematite (001-1053)
Pardis	Sialk I	Augite (071-0721), Quartz (001-0649)
Pardis	Sialk II (calcium rich)	Augite (071-0721), Quartz (001-0649)
Pardis	Sialk II (calcium poor)	Orthopyroxene (086-0163), Quartz (001-0649), Hematite (001-1053)

*Only present in some samples

.

Table 6. Detailed definition of various vessel forms.

Vessel forms of pottery	Description
J1a	A jar with a shallow shoulder (45-75^{o} angle) with an everted rim.
J1b	A jar with a steep shoulder (<45^{o} angle) leading to an everted rim.
J1c	A Jar with a steep shoulder (75^{o} to ~90) with an everted rim.
J2	A jar with a flared rim and curved neck.
B1a	A closed bowl with a curved body and a low shoulder (45-75^{o} angle).
B1b	A closed bowl with a curved body and a steep shoulder (75^{o} to near vertical angle).
B1c	A closed bowl with a steep and straight shoulder (75^{o} to near vertical angle) leading to a pronounced curving body.
B1d	A closed bowl with a steep shoulder to globular body leading to a narrow flat base.
B1e	A closed bowl with a steep and virtually straight shoulder (75o- near vertical angle) leading to a gently curving body.
B2a	A closed bowl with a shallow shoulder (45-75^{o} angle) with a flattened rim.
B2b	A closed bowl with a steep shoulder (<45^{o} angle) with a flattened rim.
B2c	A closed bowl with a steep shoulder (75^{o} to near vertical angle).
B3a	An open bowl with a shallow, inwardly sloped (45-75^{o} angle) straight-sided body.
B3b	An open bowl with a rounded and flared rim and a straight or slightly concave neck.
B3c	An open bowl with a shallow inwardly sloped (45-75^{o} angle) gently curving body.
B3d	An open bowl with a steep shoulder and vertical straight shoulder (75^{o} to near vertical angle).
B3e	An open Bowl with a rounded and flared rim inwardly sloped (45-75^{o} angle) and a curved neck leading to a Flat-bottomed base.
B4a	An Open bowl with a steep and straight shoulder (75^{o} to near vertical angle) leading to a pronounced curving body with flat base.
B4b	An open bowl with a steep, inwardly sloped (75^{o} to near vertical angle) gently curving body.
B5	An open bowl with a steep, inwardly sloped (75° to near vertical angle) straight-sided body.
T1	A tray bowl with a slightly rounded and inwardly flaring rim and thick angular carination in the middle of its body.
T2	A tray bowl with a vertical wall rising to slightly flattened and rounded rim.
T3	An open tray bowl with a straight and inwardly sloping body to flat base.
BE1	A beaker with a steep and vertical straight shoulder (75^{o} to near vertical angle) leading to a Flat-bottomed base.
D1	A shallow dish with a very shallow inwardly sloped (<45^{o} angle) straight-sided body.

Table 7. The number of main categories of all vessel forms in Sialk, Pardis and Ebrahimabad.

Vessel type/quantity	Jar	Bowl	Tray	Dish	Beaker	Total number of vessel forms
Number of Sialk I*	16	430	10	0	0	456
Number of Sialk II	3	138	12	2	16	171
Number of Pardis I	3	9	0	4	0	16
Number of Pardis II	45	251	12	6	4	318
Number of EB. I	3	33	0	0	0	36
Number of EB. II	2	83	2	3	0	90
Total	72	944	36	15	20	1087

* I and II denote the periods.

Table. 8 Percentage of vessel forms of the three sites.

Vessel Type	Numbers in Sialk I (%)	Numbers in Sialk II (%)	Numbers in Pardis I (%)	Numbers in Pardis II (%)	Numbers in Ebrahim-abad I (%)	Numbers in Ebrahim-abad II (%)
J1a	15.5	23	0	61.5	0	0
J1b	19	0	0	69	0	12
J1c	0	0	16	84	0	0
J2	46	0	0	42	12	0
B1a	17	0	0	66	0	17
B1b	9	13	0	78	0	0
B1c	37.5	25	0	0	0	37.5
B1d	33	0	0	67	0	0
B1e	18	16	0	53	0	13
B2a	30	0	0	40	0	30
B2b	59	0	5	15	9	12
B2c	0	0	0	54	14	32
B3a	46	18.5	0	21	5	9.5
B3b	59	17	2	9	5	8
B3c	30.5	13.5	3	29	5	19
B3d	60	19.5	0	13.5	3.5	3.5
B3e	100	0	0	0	0	0
B4a	46	32.5	0	21.5	0	0
B4b	18	18	0	64	0	0
B5	64	10	0	22.5	0	3.5
B6	0	0	0	100	0	0
T1	28	32	0	32	0	8
T2	0	0	0	100	0	0
T3	33	44.5	0	22.5	0	0
D1	0	13.5	26.5	40	0	20
BE1	0	80	0	20	0	0

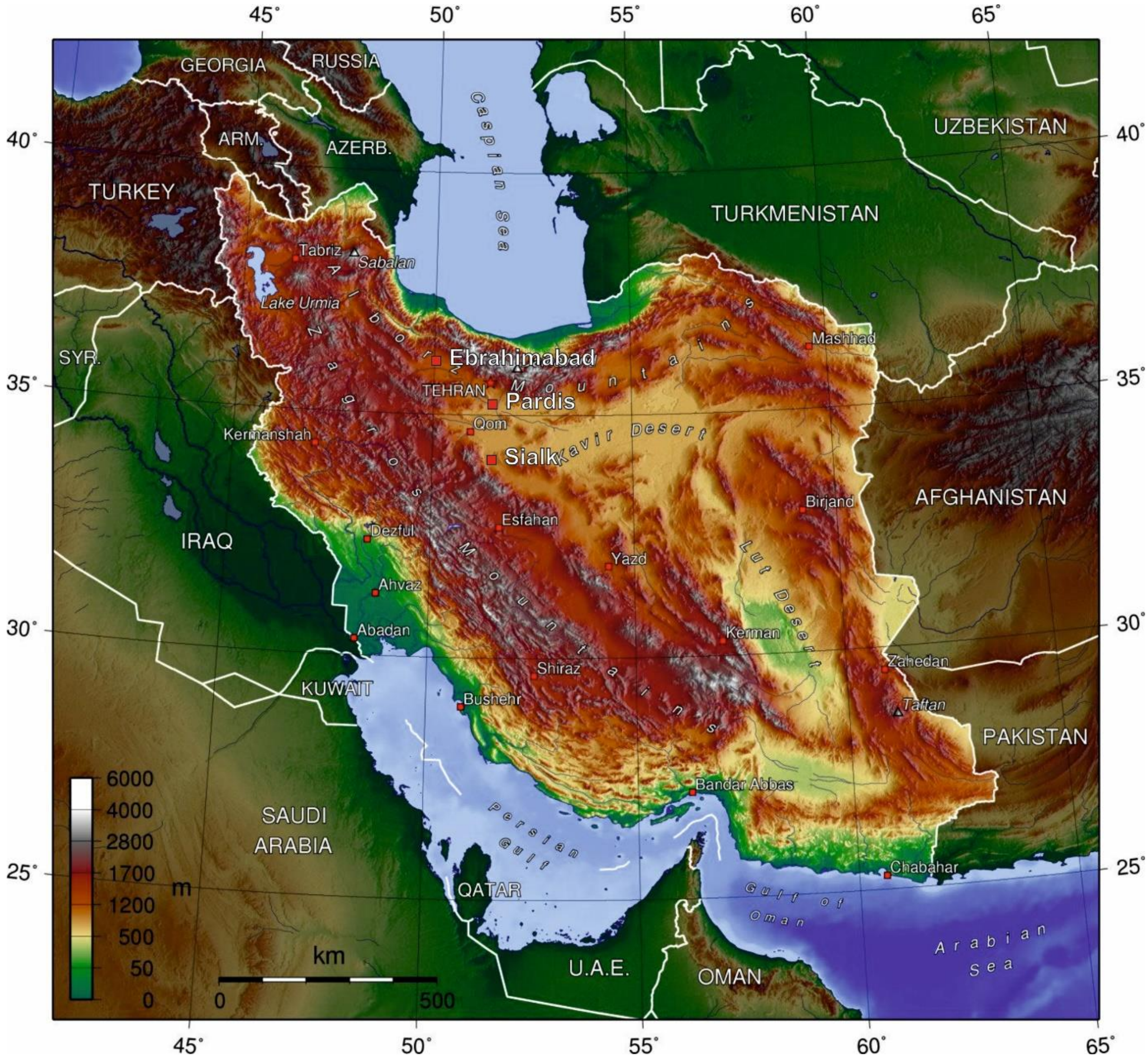


Fig. 1. Map of the Central Plateau of Iran showing the location of sites discussed in this research.

(a)

Fig. 2. Pardis pottery sherds: (a) Pardis II red Ware; (b) Pardis I buff Ware.

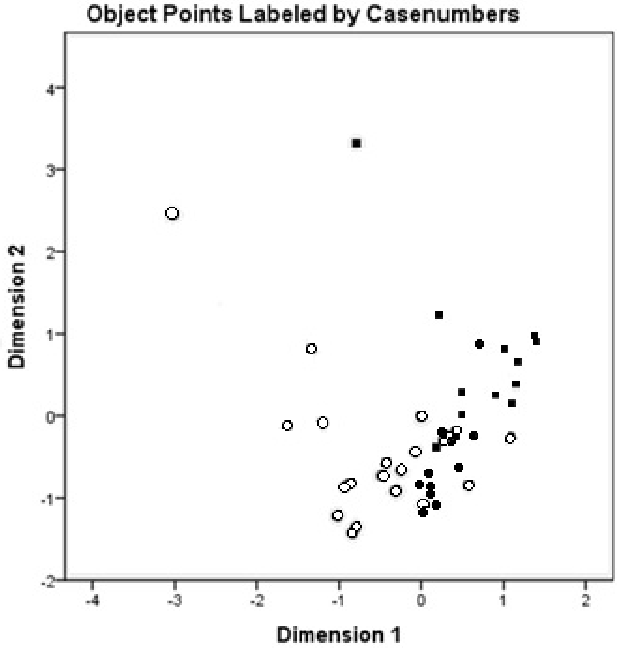


Fig. 3 PCA of Sialk I, Pardis I and Ebrahimabad I pottery samples. The site abbreviations are as follows:

■ Pardis I (n = 12), ○ Sialk I (n = 22), ●Ebrahimabad I (n= 8).

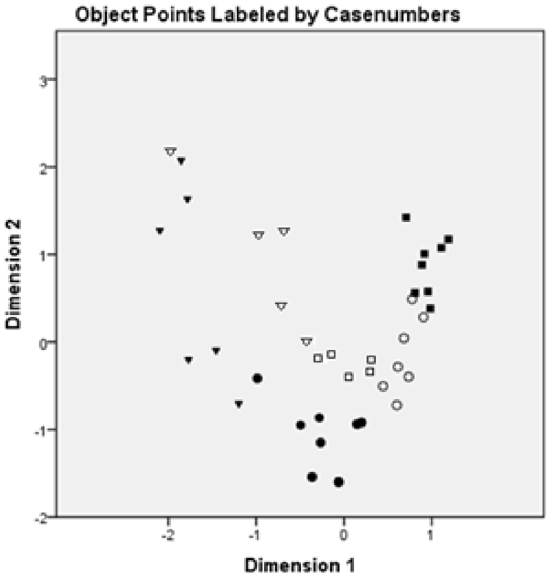
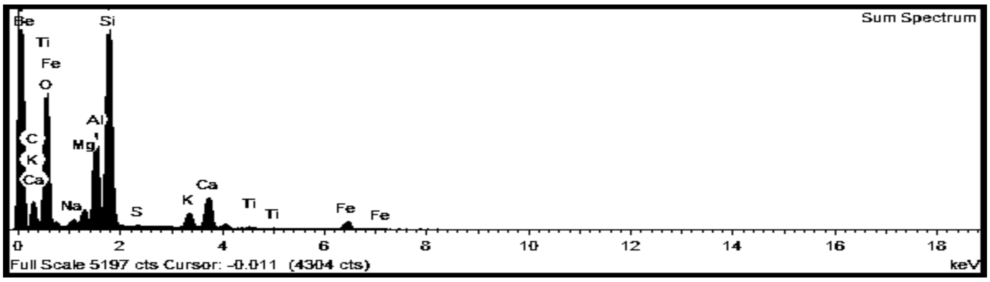


Fig. 4 PCA of Sialk II, Pardis II and Ebrahimabad II pottery samples. The site abbreviations are as follows:

● Ca-rich Pardis II samples (n = 8), ▼ Ca-rich Sialk II samples (n = 6), ■ Ca-poor Pardis II samples (n= 8), ○ Ca-poor Sialk II samples (n = 8), □ Ca-rich Ebrahimabad II samples, (n = 5), ▽Ca-poor Ebrahimabad II samples, (n = 5).

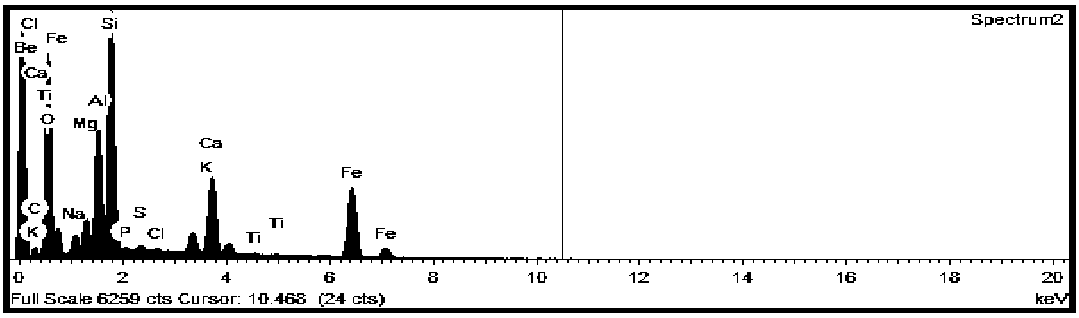


Summary results

Element	Weight %	Weight %	Atomic %	Compound %	Formula
Sodium	0.958	0.080	0.807	1.291	Na_2O

Magnesium	2.403	0.130	1.914	3.985	MgO
Aluminum	5.116	0.247	3.671	9.666	Al2O3
Silicon	16.133	0.745	11.123	34.512	SiO2
Potassium	1.976	0.111	0.979	2.381	K2O
Calcium	8.093	0.383	3.910	11.324	CaO
Iron	4.782	0.268	1.658	6.152	FeO
Oxygen	51.788	2.249	62.682		

(a)

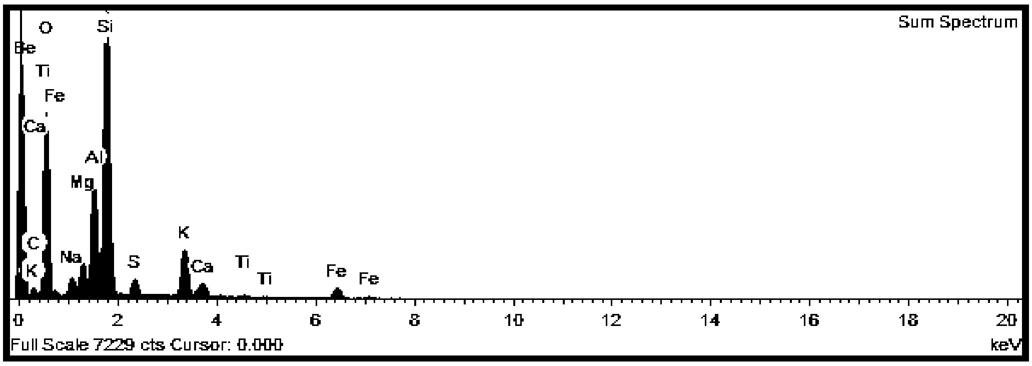


Summary results

Element	Weight %	Weight % σ	Atomic %	Compound %	Formula
Sodium	1.728	0.074	1.849	2.330	Na2O
Magnesium	2.553	0.068	2.583	4.233	MgO
Aluminum	7.483	0.087	6.823	14.138	Al2O3
Silicon	15.036	0.114	13.170	32.166	SiO2
Potassium	1.794	0.058	1.129	2.161	K2O
Calcium	7.904	0.092	4.851	11.059	CaO
Iron	24.810	0.207	10.929	31.918	FeO
Oxygen	37.695	0.198	57.963		

(b)

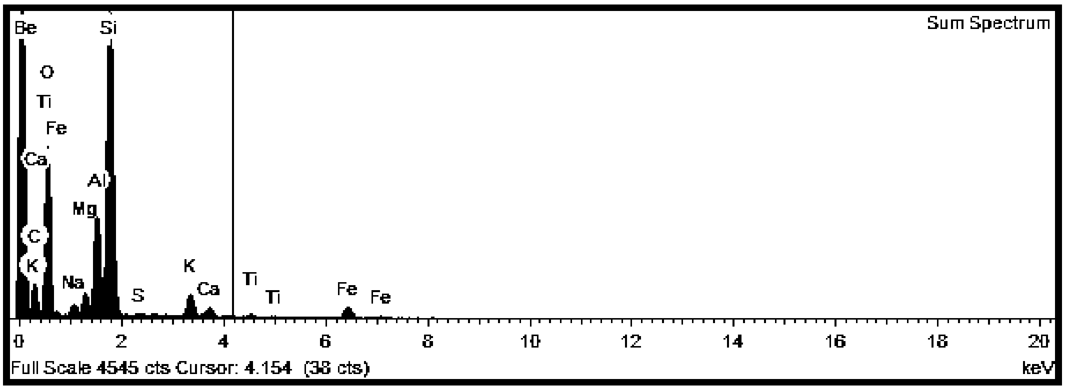
Fig. 5 A typical elemental spectrum of Sialk II pottery with a red coating. (a) Core. (b) Exterior surface



Summary results

Element	Weight %	Weight % σ	Atomic %
Sodium	1.846	0.075	1.673
Magnesium	2.426	0.071	2.079
Aluminum	7.463	0.098	5.762
Silicon	22.177	0.169	16.450
Calcium	1.648	0.068	0.856
Iron	5.109	0.152	1.906
Oxygen	51.348	0.287	66.863

(a)



Summary results

Element	Weight %	Weight % σ	Atomic %
Sodium	1.020	0.083	0.828
Magnesium	1.507	0.087	1.156
Aluminum	6.276	0.230	4.337
Silicon	21.335	0.717	14.164
Potassium	2.397	0.113	1.143
Calcium	1.079	0.079	0.502
Iron	4.823	0.245	1.610
Oxygen	47.914	1.587	55.841

(b)

Fig. 6 A typical elemental spectrum of Sialk II Sample which is in red colour both on exterior and core. (a) Exterior surface. (b) Core.

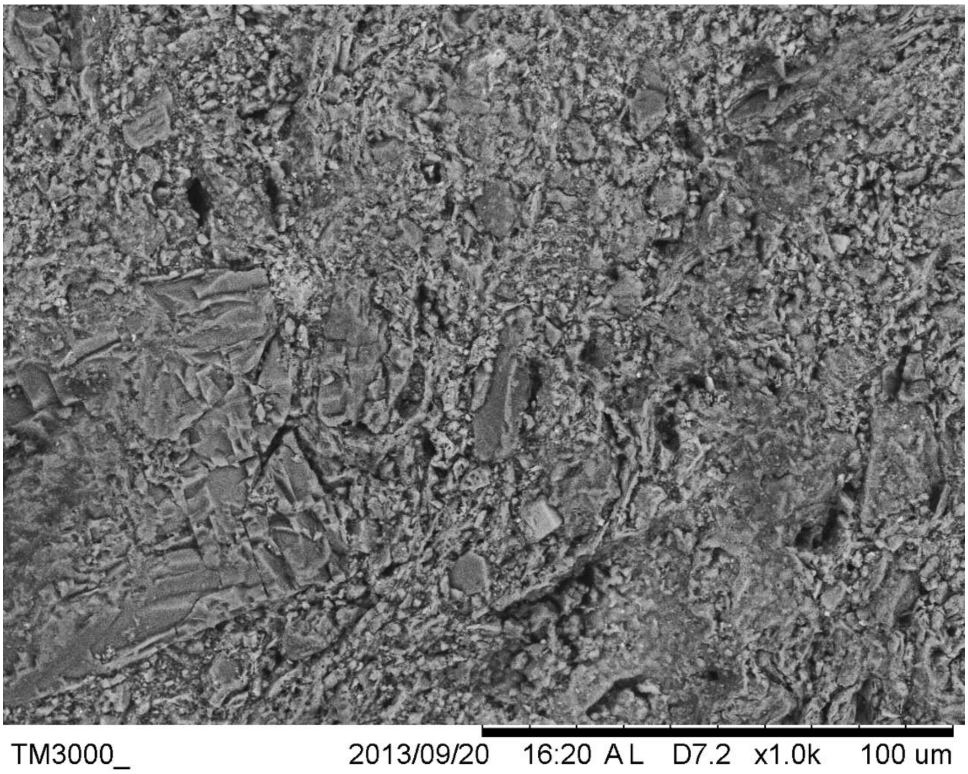
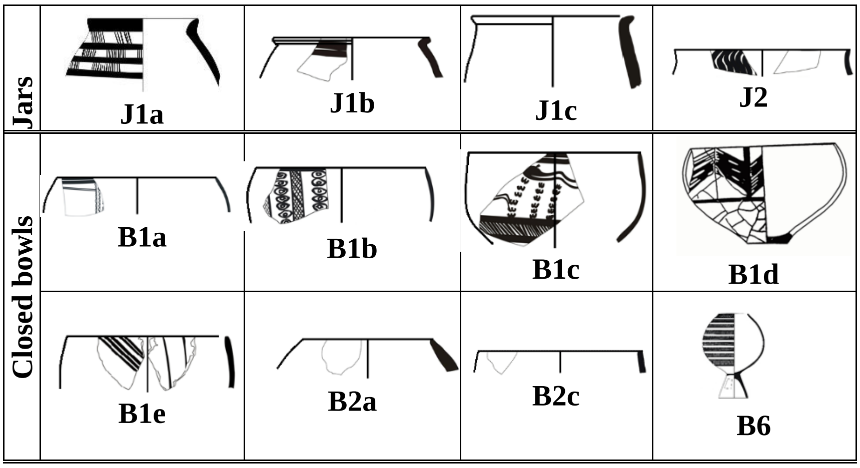


Fig.7 A typical SEM micrograph of a calcium poor Pardis II pottery (Transitional Chalcolithic period) exhibiting a highly vitrified microstructure.



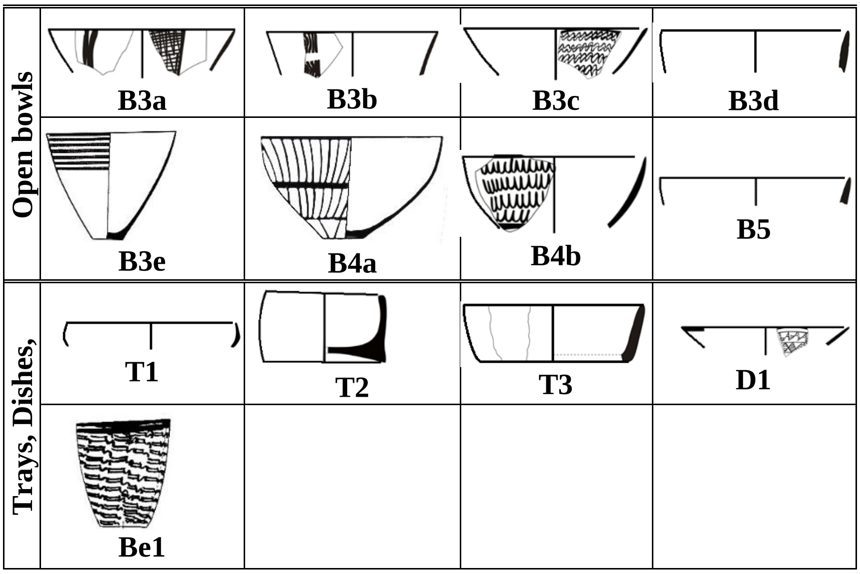


Fig. 8 Rim typology of the selected pottery.

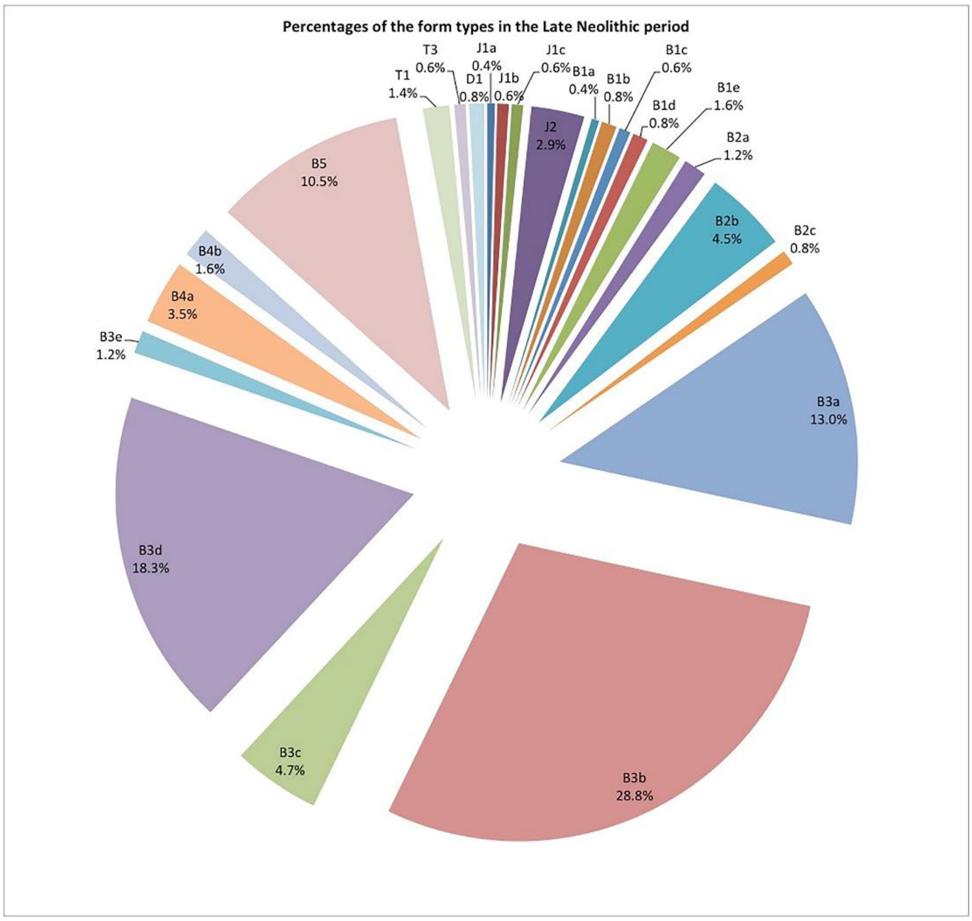


Fig.9 Relative quantity of the vessel types in the Neolithic period.

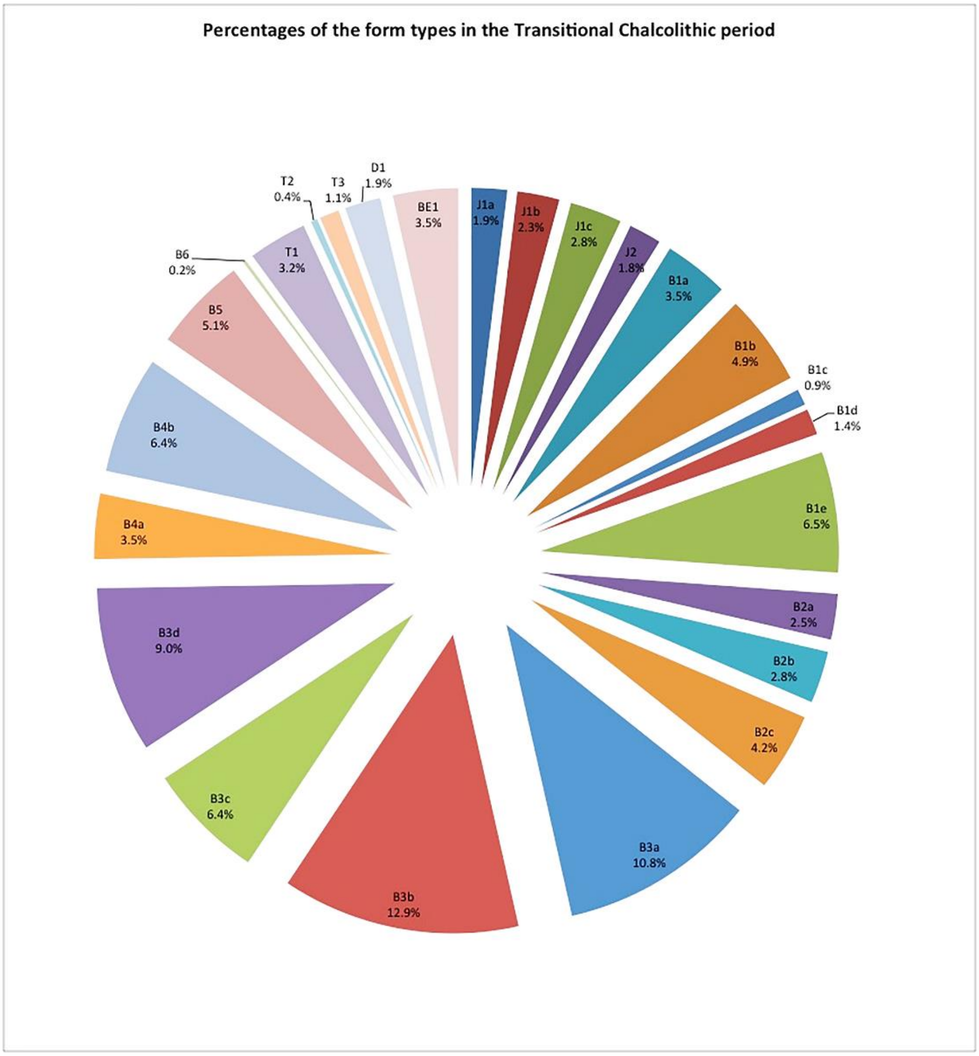


Fig.10 Relative quantity of the vessel types in the Transitional Chalcolithic period.

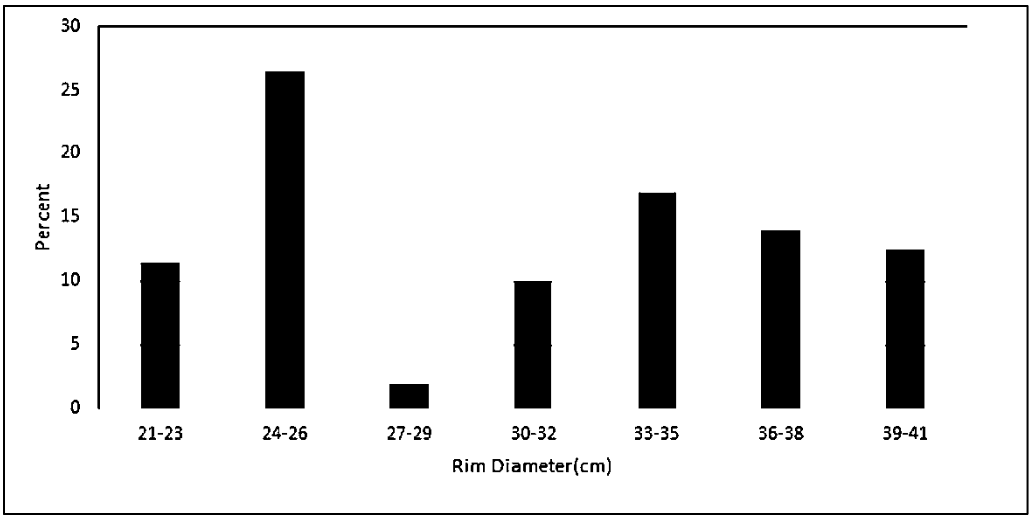


Fig. 11 Distribution of rim diameters of vessel type B3a for Sialk site in Neolithic period.

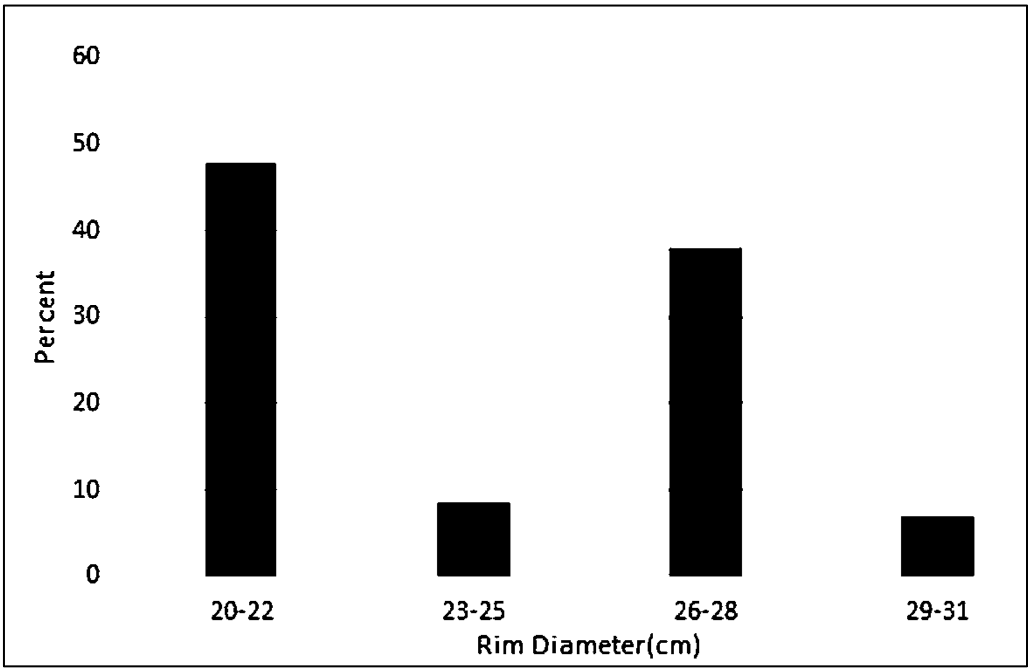


Fig. 12 Distribution of rim diameters of vessel type B3a for Sialk site in Transitional Chalcolithic period.

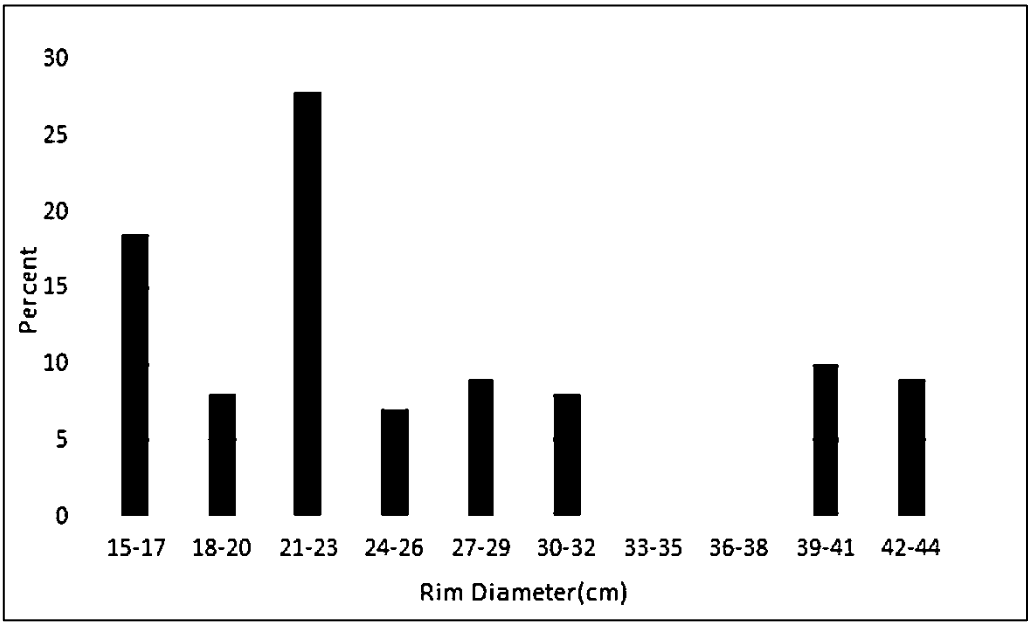


Fig. 13 Distribution of rim diameters of vessel type B3a for Pardis site in Transitional Chalcolithic period.