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Black-on-Red Pottery in the Levant
A Petrographic Contribution from Tell Keisan

Jacek Michniewicz, Andrzej Szydło, Mariusz Burdajewicz

Abstract: This article focuses on the problem of identifying the possible origin of the so-called Black-on-Red pottery of the Iron Age found at Tell Keisan, a site in southern Phoenicia/Lower Galilee. Sixteen samples were selected for petrographic, chemical, and micropaleontological analyses, representing the entire period of the pottery occurrence (late tenth–fifth century BC) at the site. The results allow the authors to conclude that most of the vessels from which the samples came should be considered imports from southern and western regions of Cyprus. This result aligns with similar studies undertaken on Black-on-Red pottery from other sites on the Levantine coast. Looking at it from a broader perspective, the currently dominant hypothesis of Cyprus as the main production centre of the Black-on-Red pottery in the Iron Age also gains a strong reinforcement from Tell Keisan.

Keywords: Tell Keisan, Black-on-Red pottery, Cyprus, Levant, Iron Age, petrography, micropaleontology

Jacek Michniewicz, Institute of Geology, Faculty of Geographical and Geological Studies, Adam Mickiewicz University, Poznań; *jacekm@amu.edu.pl*; 0000-0002-1110-1494

Andrzej Szydło, Polish Geological Institute-National Research Institute, Carpathian Branch in Cracow, Kraków; *aszy@pgi.gov.pl*; 0000-0002-5193-1986

Mariusz Burdajewicz, Faculty of Archaeology, University of Warsaw, Warsaw; *mburdajewicz@uw.edu.pl*; 0000-0001-8862-0105

Black-on-Red (hereafter BoR) pottery is one of the most recognisable ceramic wares in the Levant during the Iron Age. Discovered at the vast majority of sites in Cyprus and along the Levant coast, it has been the subject of numerous studies since the pioneering research of Einar Gjerstad on Iron Age pottery from Cyprus.[1] In recent decades, among

[1] Gjerstad 1948: 68–73, 242–270, 287–288, 295–296.

several research questions, the origin of BoR pottery has been the most debated. This issue is still well reflected in BoR's other name, Cypriot-Phoenician pottery, which was alternatively used in the past.[2] It is commonly expected that archaeometric and petrographic methods will play a decisive role in identifying potential centres of BoR production.[3]

Although there is a consensus on the Cypriot origin of the majority of BoR vessels discovered outside Cyprus, the question of possible production in mainland Phoenicia has not yet been conclusively resolved. This fact is significant for samples devoid of minerals or elements that are diagnostic of Cypriot ophiolite, especially minerals of the serpentine group or elevated chromium contents typical of rocks of the lithosphere. For example, in Tyre on the northern Levantine coast, among the predominant vessels with Cypriot raw material chemistry, two samples were described as having Syro-Palestinian characteristics.[4]

With regard to Cypriot pottery, the practice of using two primary varieties of raw material, ferruginous clay, based on *terra rossa* (probably levigated), and light-fired clays based on marl, is stressed. The areas of Palaepaphos, Kition, Amathus, and Salamis are indicated as the main centres of BoR production (see discussion below).

The authors of this paper decided to contribute to this discussion by taking the BoR pottery discovered at one of the Levantine sites, namely Tell Keisan, as a case study.[5] The site is located in Lower Galilee, which constituted part of southern Phoenicia (**Fig. 1a**). Two series of excavations in 1971–1976 and 1979–1980 were carried out by the École Biblique et Archéologique Française in Jerusalem under the direction of Jacques Briend and Jean-Baptiste Humbert, respectively.[6] This is one of the key Levantine sites for understanding the transitional period from the Late Bronze to the Iron Age and beyond until the Hellenistic period. The sizable remains of the residential quarter have provided information about urbanism and its almost continuous development through the centuries, as well as the local material culture of the period in the southern Phoenician area. Extremely abundant ceramic finds from well-documented stratigraphic contexts have made it possible to establish the outlines of a typo-chronological ceramic sequence (levels 2–13), which has not lost its relevance despite the passage of years. Keisan's unique geographical location, between the sea and the mountains, on the trade route from the Mediterranean coast via Megiddo inland and Bet-Shean to Transjordan, ensured a key role in foreign trade. The numerous finds of Cypriot and Aegean pottery from the Bronze and Iron Age are a telling example of this phenomenon.[7]

[2] An exhaustive discussion on the meaning and use of the term 'Cypro-Phoenician' pottery was presented by Schreiber 2003: xix–xxx, 1–4.

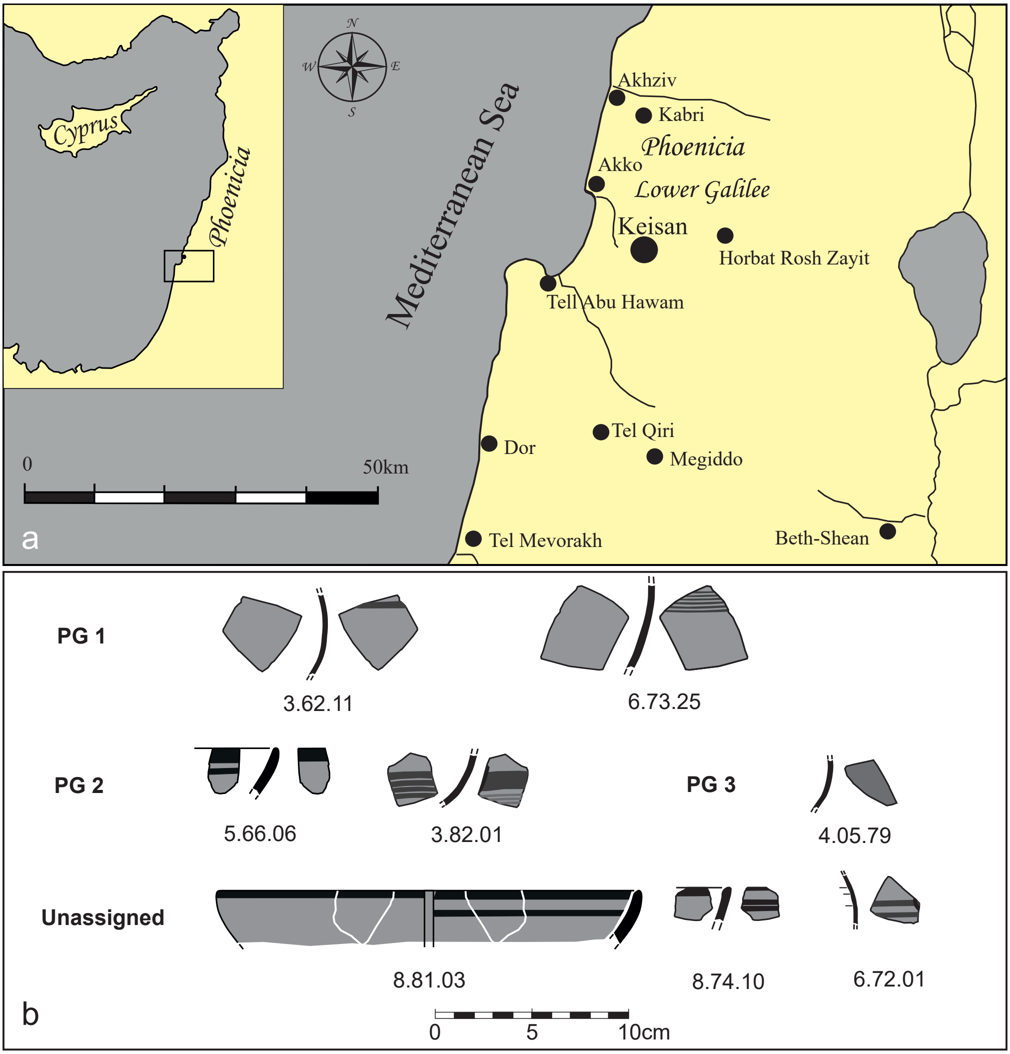
[3] Bieber 1978; Matthers, Liddy, Newton 1983; Brodie, Steel 1996; Kleiman *et al*. 2019; Waiman-Barak, Georgiadou, Gilboa 2021; Waiman-Barak, Bürge, Fischer 2023.

[4] Bieber 1978; Bikai 1978: 53.

[5] The authors contribute to the article as follows: Mariusz Burdajewicz – introduction and archaeological context; Jacek Michniewicz – methodology, petrography, chemical analyses and geological context; Andrzej Szydło – methods, micropaleontological analyses and geological interpretation.

[6] Briend, Humbert (Eds) 1980; Humbert 1981; 1993.

[7] Burdajewicz 2020a.



1a. Map of Levant showing the location of Tell Keisan; b. a selected sample of BoR vessels from Tell Keisan (Drawing: M. Burdajewicz).

A total of 204 BoR sherds were discovered in levels 3–8.[8] The chronological range spans the late tenth down to the end of the fifth century BC. For the convenience of readers, the correlation of relative chronological systems for Tell Keisan, Levant and Cyprus is presented below:[9]

– level 3 – Babylonian and Persian period/Cypro-Classical I and Cypro-Archaic II;
– levels 4 and 5 – Iron Age IIB and C/Cypro-Archaic I;

[8] Burdajewicz 2020b: 40–44, Pl. 2: 2.
[9] Burdajewicz 2020b: Pl. 2: 1.

– levels 6 and 7 – Iron Age IIB/Cypro-Geometric III;
– level 8 – Iron Age IIA/Cypro-Geometric I and II.

Regarding quantity, the apogee of BoR finds at Tell Keisan is in levels 5 and 4 (775–575 BC). The repertoire of vessel forms is minimal. Most are bowls; the rest are closed forms, like small jugs or juglets. Only a few fragments may come from large vessels such as amphorae or craters.

The presented petrographic project has two main stages. The first stage is to determine whether the sampled vessels originated from the coast of Phoenicia or from Cyprus. The second stage aims to identify the specific production centres of these vessels as precisely as possible. The samples come from an unpublished Iron Age pottery assemblage at Tell Keisan (1971–1976, 1979–1980).[10] Of the samples selected for analyses (**Table 1**), ten represent bowls, and the other six samples are from small containers, mostly probably ridged-neck juglets. Typologically, the bowls form a relatively homogeneous group of vessels that differ primarily in size. They feature a rounded profile, a simple rounded or slightly tapered rim, two horizontal handles below the rim, and a base ring. A characteristic feature of the decoration is the combination of thin horizontal lines and/or broader bands on the outside and/or in the interior (**Fig. 1b**). Painted strokes underline the contour of the horizontal handles. The decoration is painted in shades of black on dark brown to brick-red engobe. The same decorative style is found on closed forms such as jugs and amphorae.

The BoR pottery from Keisan, in terms of typology, closely resembles the BoR assemblages found at numerous Levantine coastal sites. Both the forms and decorative methods mirror those observed elsewhere in this region. While the analogies are too numerous to list exhaustively, comparable pottery assemblages are found at sites including Akhziv, Kabri, Akko, Horbat Rosh Zayit, Tel Dor, Tel Qiri, and Megiddo, among others.[11]

Only a rough chronological framework can be proposed for the absolute dating of individual samples. In many cases, the excavators could not clearly distinguish between stratigraphic layers. Hence, terms such as, for example, level 4/5/6, 5/6, and so on. This obstacle automatically forced a sometimes rather broad chronological framework for specific finds, whether ceramic or other artefacts. For this article, however, this is not the primary issue. The important thing is that the samples selected for the present analysis generally represent almost the entire period of BoR occurrence at Tell Keisan.

APPLIED METHODS

A set of sixteen samples from several different vessels was subjected to petrographic and chemical analysis to determine their possible origin.[12] In addition, a thin-section micro-

[10] The final publication, including the BoR finds, is currently being prepared by Burdajewicz. No archaeometric analyses have yet been conducted on Keisan's BoR finds, except for an unpublished petrographic analysis of two bowls from level 8 by Charles Wilson (Wilson 2021).

[11] Burdajewicz 2020b: 40–44, with references.

[12] Samples were taken from randomly chosen BoR fragments. The only criterion was that all stratigraphic/chronological levels with BoR finds were represented. Level 3 (580–380 BC) was excluded because the few BoR

paleontological analysis was also carried out, something which has not previously been applied in scientific studies on the provenance of BoR pottery.

The texture and mineral composition of each sample were examined using a polarising optical microscope, Olympus AX 70 Provis, in both transmitted and reflected light. The age of the raw material was studied by fossil content. The analysis was performed using a ZEISS Stereo microscope V12.

The degree of sintering and chemical composition of the ceramics and selected non-plastic components were determined using a Hitachi 3700N scanning electron microscope coupled with a NoranSIX energy dispersive spectrometer (Institute of Geology, Adam Mickiewicz University in Poznań). The analyses were conducted under low vacuum conditions (25Pa), with an accelerating voltage of 20kV and a constant working distance of 10.0mm.

RESULTS

The principal petrographic characteristics of the examined ceramics are outlined in **Table 2**. The petrographic features allow for the distinction of three Petrographic Groups (PG). The key to this classification was the mineral content and distribution, as well as other petrographic data (**Figs 3–9**, **Tables 3–6**). Six samples are mutually distinct and have been designated as 'unassigned'.

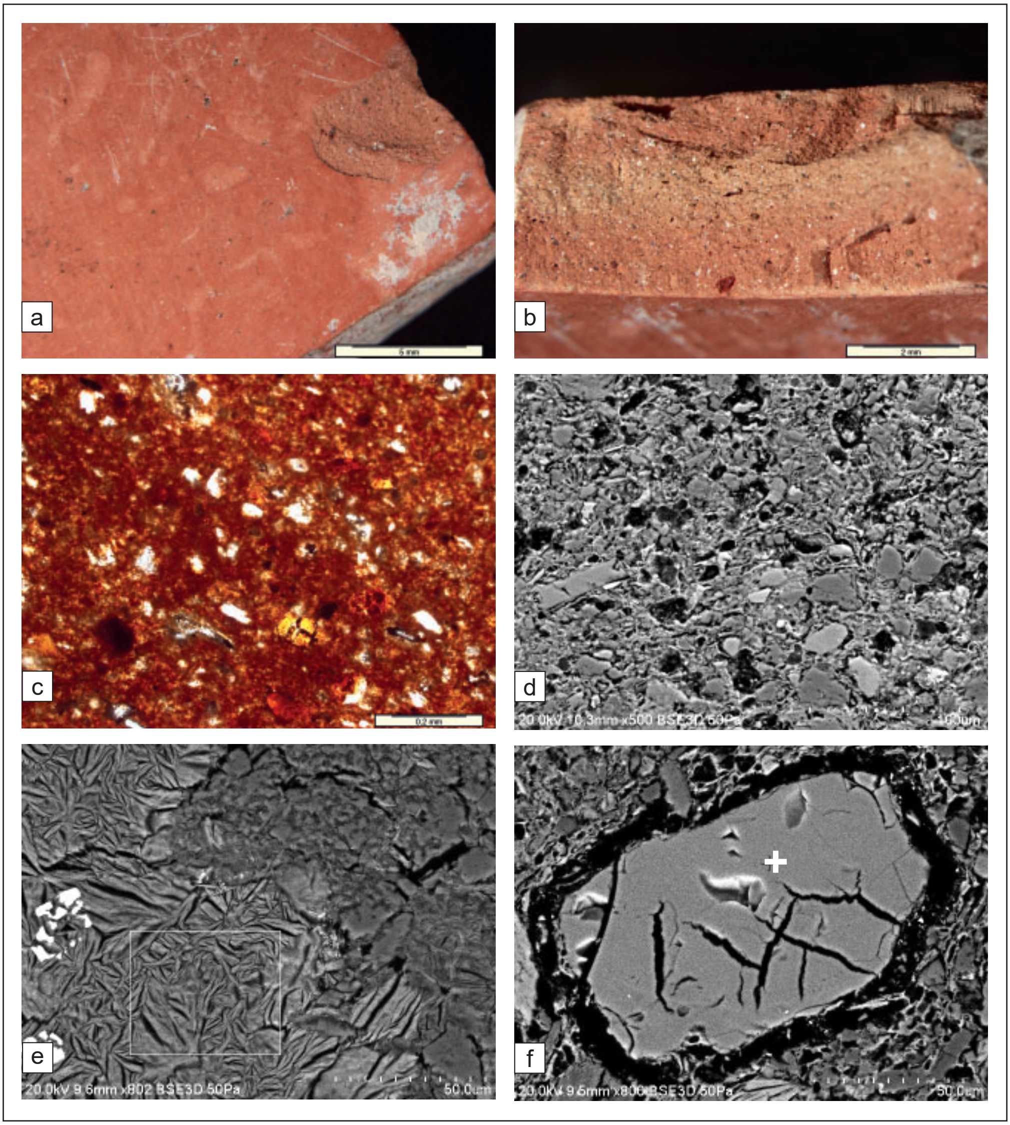
At the macroscopic level, samples from individual groups show considerable similarity, particularly in terms of engobe color. Light brown/brick red is characteristic of PG 1; brown/light brown for PG 2; and brown/dark gray for PG 3. At the same time, the colour of their interior varies significantly, from brick red through various shades of brown to light gray. The unassigned samples are characterised by great diversity: the color of the engobe ranges from light brick red to orange, brown, and dark grey.

Ceramic fragments contain calcareous (foraminifera) and siliceous (radiolaria) microfossils. They are observed mainly in cross-sections, the taxonomy of which could sometimes be determined based on the number, shape and configuration of chambers (**Fig. 10**). Their stratigraphic range and provenance allow for correlation with deposits of similar mineralogical composition (**Figs 11–12**). This method has been proven and is widely used in geological stratigraphic studies, also concerning Paleogene sediments; it is also effective in the study of ceramics, especially those fired at lower temperatures.[13] The presented results are based on similar studies conducted in the Mediterranean region, particularly in its eastern part, including the Middle East and Cyprus.[14]

finds there were likely residual. The number of samples was limited to 16 because of restrictions on the number that could be used for petrographic analysis.

[13] Pessagno 1960; Postuma 1971; Quinn, Alaimo, Montana 1998; Quinn 2000; 2007a; 2007b; Michniewicz 2009; Baliniak, Malata 2017; Shalem *et al*. 2019.

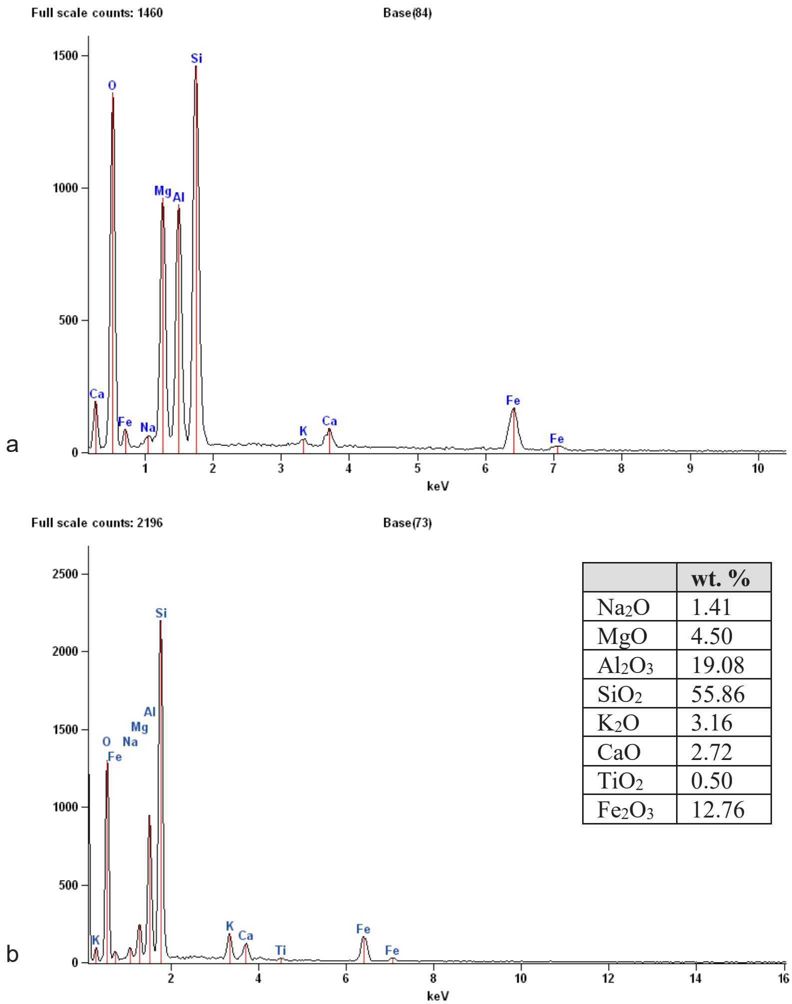
[14] Morgiel *et al*. 1980; Toumarkine *et al*. 1985; Kähler 1994; Olsson *et al*. (Eds) 1999; BouDagher-Fadel, Clark 2006; Sanfilippo, Kagan Tekin, Hakyemez 2015; Michniewicz, Młynarczyk 2017; Wade *et al*. (Eds) 2018.



2. Representatives of PG 1. Sample 3.62.11: a. the surface; b. fresh fracture; c. thin section petrographic image (PPL); d. micromass in SEM-BSE mode, magnification x500; e. Mg-chlorite, SEM-BSE image. Sample 3.62.17: f. orange glassy fragment in SEM-BSE mode (Phot. J. Michniewicz).

Petrographic group 1

This group (samples 3.62.11, 3.62.17, 6.73.25, 6.74.18, 6.79.11) could be macroscopically characterised as bright red, a fine ware-type pottery with smooth fracture. Grey and white carbonate grains are common, as are a few oval dark reddish-brown inclusions of red soil admixture or Fe-Mn pedogenic concentrations (**Fig. 2a-b**).



	wt. %
Na_2O	1.41
MgO	4.50
Al_2O_3	19.08
SiO_2	55.86
K_2O	3.16
CaO	2.72
TiO_2	0.50
Fe_2O_3	12.76

3. Representatives of PG 1: a. sample 3.62.11, Mg-chlorite, EDS spectrum, cf. Fig. 2e; b. sample 3.62.17, EDS spectrum and chemical composition of orange glassy fragment, cf. Fig. 2f (Processing: J. Michniewicz).

The micromass under a microscope in plane-polarised light (PPL) is reddish-brown (**Fig. 2c**), mottled red in cross-polarised light (CPL), partly anisotropic and rich in fragmentarily preserved foraminifers. Sparse oval centres of carbonates have been decomposed. Several textural concentration features (Tcf), such as iron-rich clay granules or Fe-pedogenic nodules have also been observed.

Silt-sized particles are less than 10% by volume (**Fig. 2c, d**), and are predominantly quartz. There are frequent isotropic orange fragments representing palagonite-like glasses (**Figs 2c, f, 3b**), polygonal orange biotite/glauconite, oxidised Mg-chlorite (**Figs 2e, 3a**), and amphibole fragments. Rare and very rare fresh plagioclase (An: 72-85), epidote (including zoisite and clinozoisite), K-feldspars (found in the sample 6.79.11), serpentinite (detected in sample 6.79.11).

Only single, fine sand-size grains are observed: chert, lithics, andesite (plagioclase-biotite overgrows), quartz-plagioclase, quartz-plagioclase epidote and quartz-epidote overgrows, quartzitic mudstone. A red algae fragment is present in sample 3.62.11.

The glassy fragments comprise magnesium and iron aluminosilicates, and their chemical composition is typical for all specimens of PG 1 (**Table 3**, **Figs 2f, 3b).**

Micropaleontology

The ceramic fragments belonging to this petrographic group contain the highest rate of foraminifers. Among them, early Paleogene (Paleocene-Eocene) forms similar to *Globigerina* predominate (samples: 6.73.25, 6.79.11). Most of them resemble species belonging to the genera *Parasubbotina/Subbotina sp.* (**Fig. 10a, f, k**). Some specimens are classified as: *Parasubbotina varianta*, *Parasubbotina* cf. *inaequispira* (**Fig. 10d**), *Parasubbotina pseudobulloides*, *Subbotina eoceana, Subbotina linaperta, Subbotina velascoensis* and also *Turborotalia* cf. *frontosa* (**Fig. 10c**) – which are known from the late Paleocene-early Eocene or Eocene.[8] The taxa of the genera: *Chiloguembelina* (sample 6.79.11); *Chiloguembelina morsei/Chiloguembelina midwayensis* (**Fig. 10b**); *Chiloguembelina crinita*, *Dipsidripella* (sample 6.73.25); *Dipsidripella danvillensis*, *Globanomalina* (sample 6.73.25) have also been recorded. There are also rare cross-sections of specimens that probably belong to the genera *Acarinina* (sample 6.79.11) and *Morozovella* (sample 6.73.25), *Catapsydrax* (sample 6.73.25): *Catapsydrax* ex gr. *unicavus* (**Fig. 10g**). Some of the identified specimens resemble species that became extinct in the Eocene or survived into the early Oligocene (**Fig. 12**). Worth noting is the unusual co-occurrence with planktonic siliceous microorganisms belonging to radiolarians (samples 6.73.25, 4.05.79; **Figs 10h**, **12**).

Petrographic Group 2

Semi-fine ceramics (samples 3.82.01, 4.04.44, 5.66.06) covered with a slip of various colours: brown (3.82.01), black and red (4.04.44), black (5.66.06). Brownish and grey body, rough at the fracture (**Fig. 4a-b**).

Micromass is light brown and grey (PPL), partially isotropic (CPL).

Among fine inclusions fresh plagioclase and quartz silt, many amphibole and epidote group minerals, are common. The diagnostic is the presence of tiny brownish-red and orange mineral phases of different chemistry and origin (**Fig. 4c**), scattered brown oxy-actinolite, automorphic approximately hexagonal biotite or glauconite. Similar coloured glass fragments are isotropic and often devitrify, being replaced by rosettes of aluminosilicates. Plagioclase composed of albite, bytovnite and andesine – mostly automorphic, fresh – post volcanic. In comparison to PG 1, the paste is more calcareous (15–19% CaO; see **Table 6**).

Fine sand-size inclusions contain a few monocrystalline quartz with sharp extinction, fresh plagioclase, lithics: plagioclase-biotite and plagioclase-amphibole-biotite aggregates (andesite/dioritoide), automorphic amphibole, epidote, lathwork volcanoclastics.

Sample 5.66.06 is somewhat different due to numerous foraminifera, including *Globigerina*-like forms, imbedded within grey mottled red (PPL) micromass.

The orange glassy fragments comprise magnesium and iron aluminosilicates, and their chemical composition is typical for all specimens of the PG 1 and 2**.**

Micropaleontology

The planktonic foraminiferal fauna is preserved only in sample 4.04.44. It contains foraminifera species that are diagnostic for the Eocene: *Subbotina eoceana* and *Parasubbotina* cf. *hagni* (**Figs 10e, j, 12**). Unspecified forms of the genera *Parasubbotina/Subbotina* were also recorded from the Paleogene (**Fig. 12**).[15]

Petrographic Group 3

The group (samples 3.70.40, 4.05.79) is distinguished by the presence of serpentine-group minerals. Semi-fine, cream-coloured (3.70.40) and light red (4.05.79) ceramic body is covered with a dark and light brown glaze (**Fig. 4e-f**).

Sample 3.70.40 has grey micromass in PPL, highly sintered, isotropic, almost free of quartz silt and sand-size admixtures. Some scattered fine orange fragments are of magnesium-silicate composition diagnostic for serpentine group minerals (**Figs 4g, 5**). Very few fine alkaline feldspars, Na plagioclase (albite An 9%), Ca plagioclase (An 74%), K feldspar, amphibole and Mg-chlorite (identified by SEM-EDS).

Sample 4.05.79 has brownish grey matrix (in PPL), mostly anisotropic, rich in scattered golden secondary carbonates, almost devoid of silt-sized quartz, with single greywacke fragment. Very few fine silt-sized orange serpentine, epidote, lathwork volcanite, phyllosilicates with chemistry similar to Mg-chlorite.

Petrographically, both fragments are similar to PG 2: high inclusion of marl (18–23% CaO), with scattered small reddish and orange serpentine group minerals (**Table 6**).

Micropaleontology

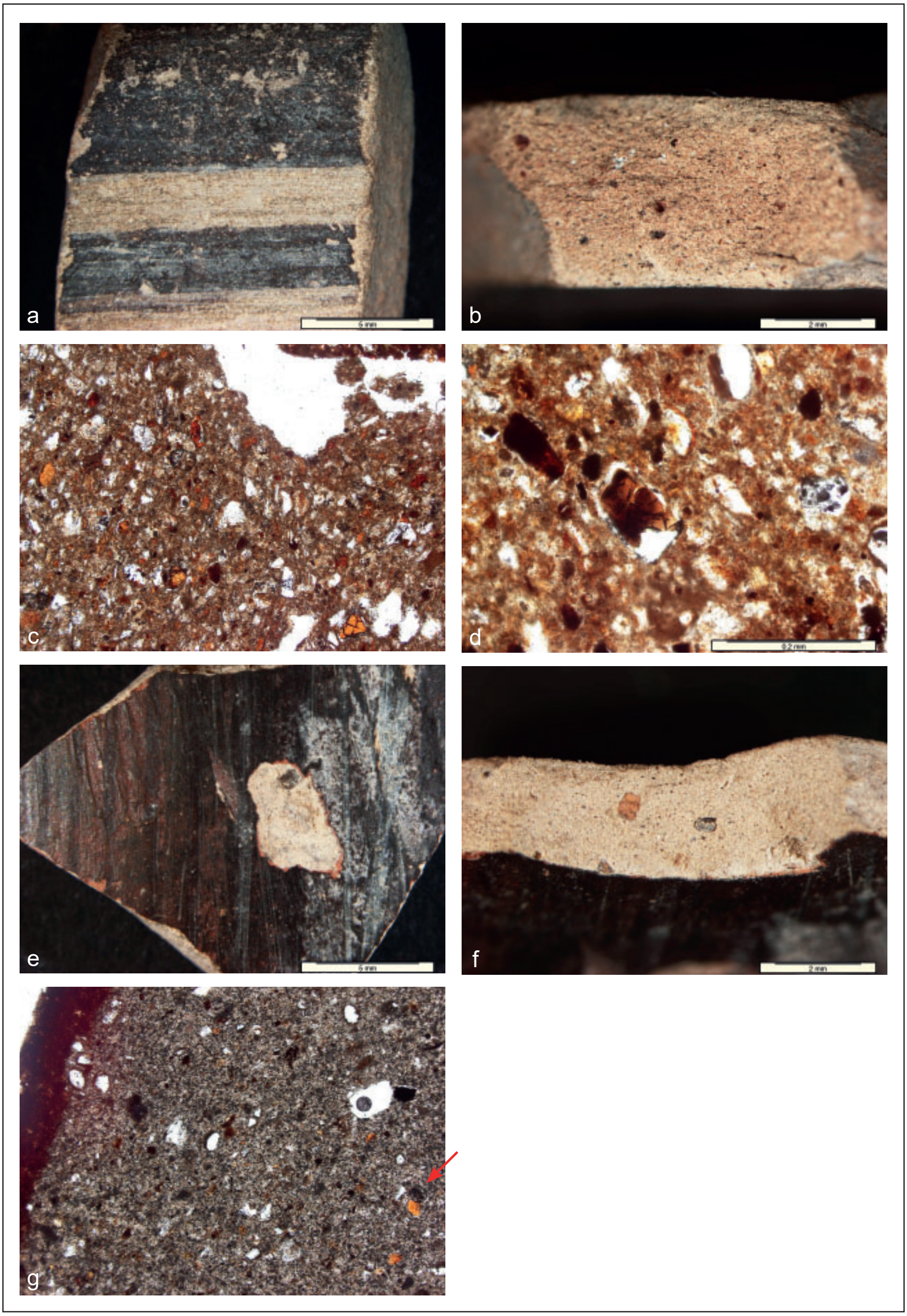
Sample 4.05.79 contains unspecified foraminifera. As in the case of the sample 6.73.25 assigned to PG 1, the co-occurrence of radiolarians is noteworthy.

Unassigned ceramics

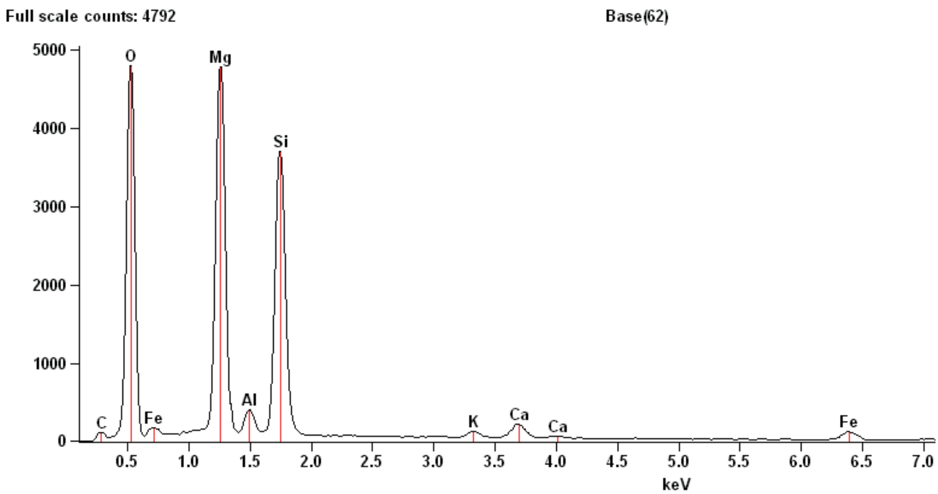
Sample 8.74.10

Light orange, semi-fine ceramics rich in fine sand-sized inclusions and covered with red smooth slip (**Fig. 6a-b**). Micromass is orange in PPL, highly calcareous, foraminiferous (**Fig. 6c**), sporadically mottled with red iron oxides, especially concentrated around the centre of the Globigerina ooze. Silt-sized inclusions states less than 1% by volume, a little quartz and feldspars. Coarse inclusions are dominated by medium-size monocrystalline quartz, usually subangular, angular clasts of micrite and biomicrite limestone, mollusk

[15] Toumarkine, Luterbacher 1985.



4. Sample 5.66.06, representative of PG 2: a. the surface; b. fresh fracture; c-d. thin section (PPL) with diagnostic orange and brownish-glassy fragments. Sample 3.70.40, representative of PG 3: e. the surface; f. fresh fracture; g. thin section (PPL) with orange serpentine group mineral fragment (Phot. J. Michniewicz).



5. Sample 5.66.06, EDS spectrum of the serpentine mineral marked with an arrow on Fig. 4g (Processing: J. Michniewicz).

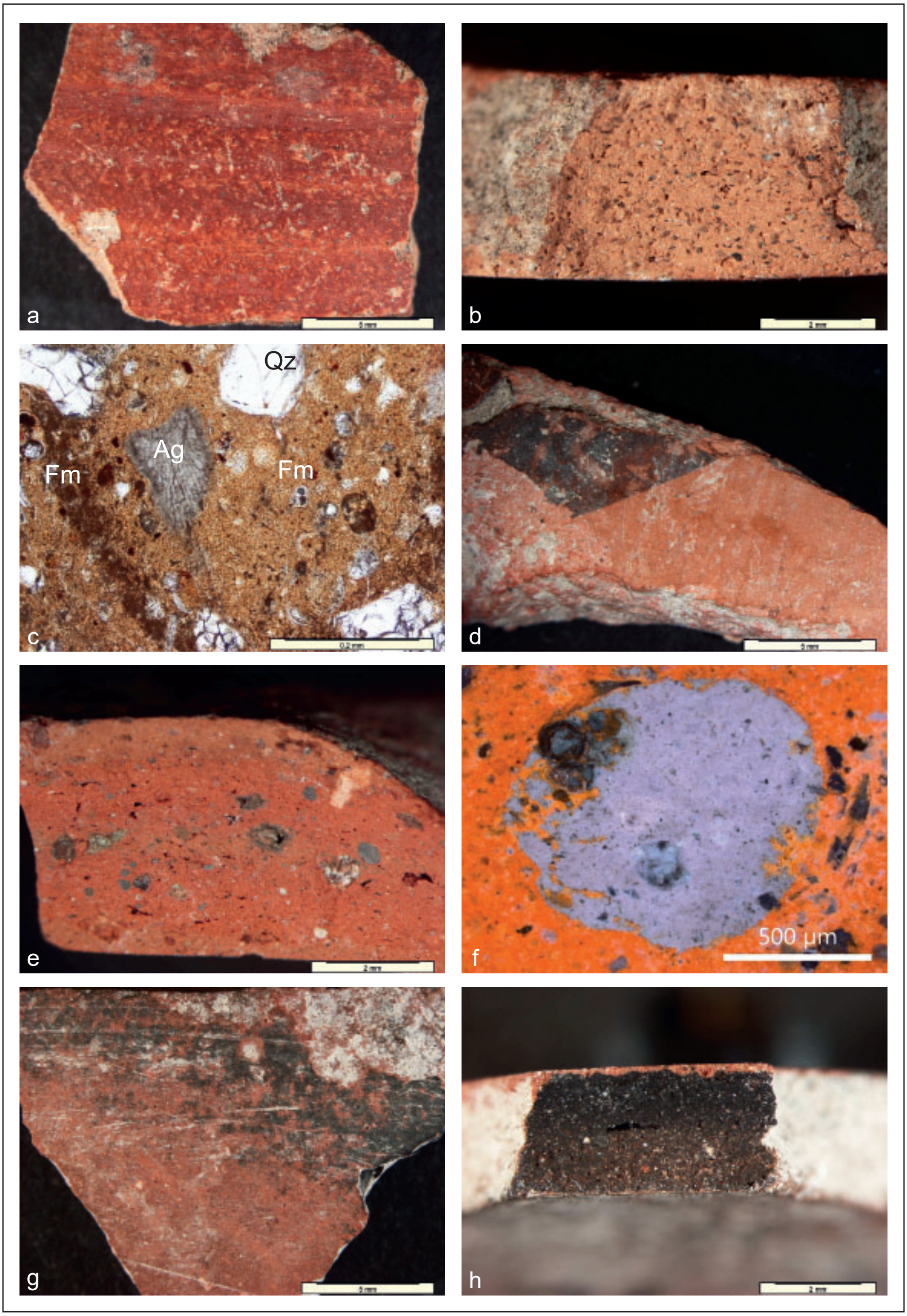
and echinoid fragments. The presence of red algae is diagnostic. Isolated K-feldspars and calcareous sandstone (kurkar?) are also present. The sample contains *Pseudohastigerina wilcoxensis* (**Fig. 10i**) and *Subbotina eoceana*, unspecified species of genera *Parasubbotina/ Subbotina* (**Fig. 10k**) from the Eocene (**Fig. 12**).

SAMPLE 6.73.15

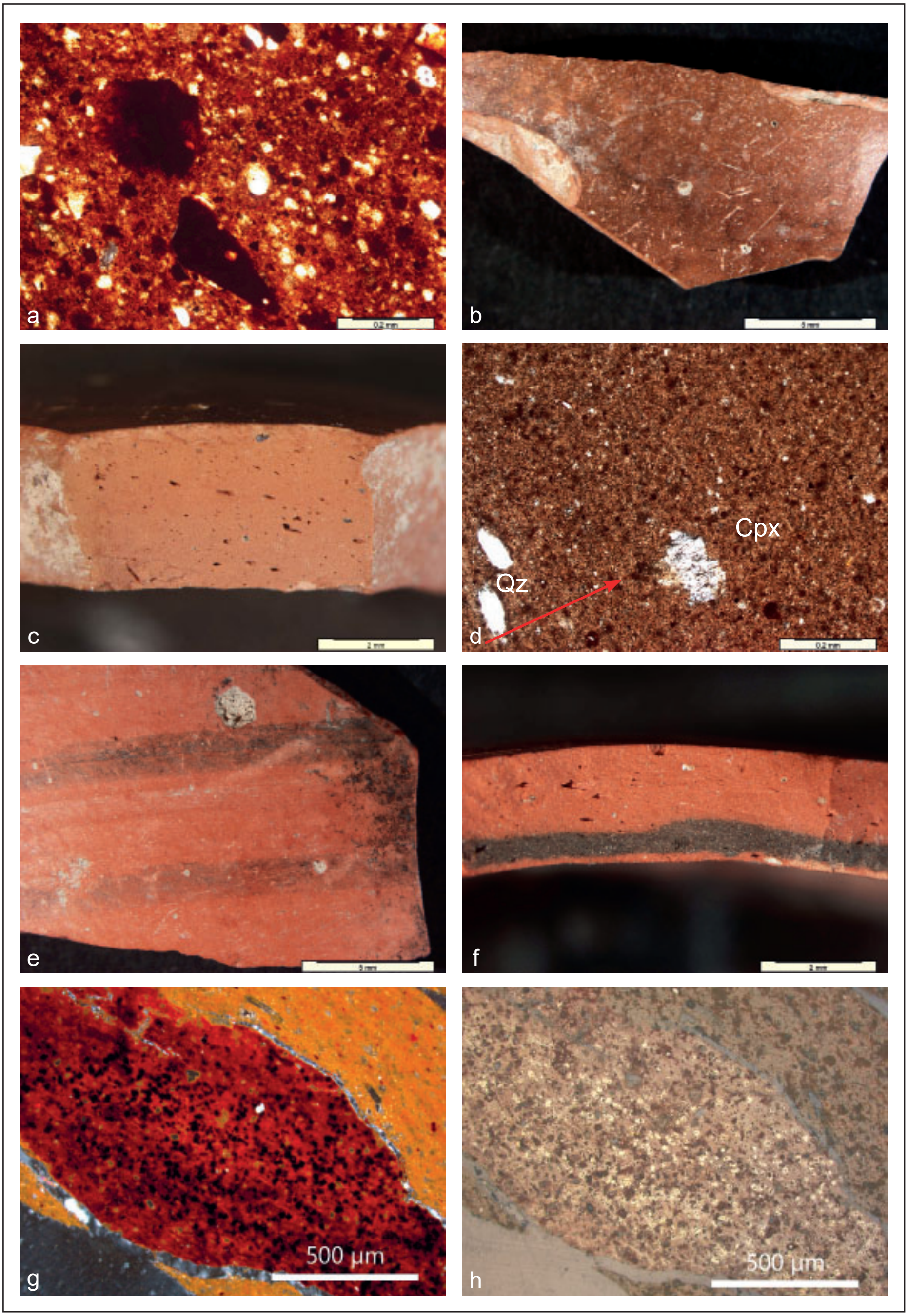
Dark red, semi-fine ceramics with light red slip and black ornaments (**Fig. 6d-e**). The micromass is dark red, inactive – highly sintered, enriched in oval black, light grey in reflected, crossed polarised light fragments of tephra(?) or Fe concentration forms of pedogenic origin (**Fig. 6f**). Sand-sized inclusions cover about 10% of the thin section area. They include: subrounded quartz, mosaic chert, cloudy-kaolinised feldspar, angular quartz-epidote, quartz-feldspar-oxybiotite lithics, some colourless pyroxene and lathwork vulcanite. Chemically, the sample is characterised by an almost complete absence of carbonates (**Table 6**). Due to high sintering, no microorganisms were found.

SAMPLE 6.74.08

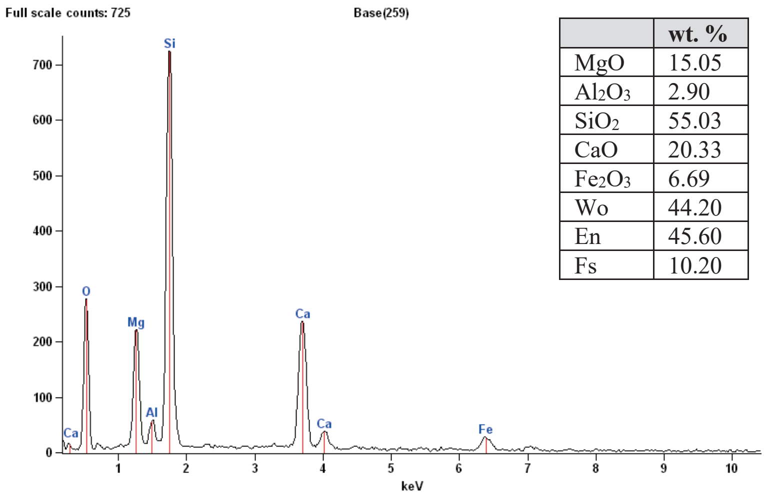
Red slip with black ornamentation, black and dark brown fired body on section (**Fig. 6g-h**). Micromass is reddish-brown in PPL, black-brown in CPL, almost free of carbonates (<1 wt. % CaO), about 15% quartz silt. Coarse inclusions, about 25–30% by volume, are dominated by monocrystalline angular and sub-angular quartz with sharp extinction, oval cherts and quartzites in equal proportions. Diagnostic is the presence of black, sharp-edged chamotte clasts (**Fig. 7a**), which are fragments of sintered ferruginous clay. A few colourless Ca-pyroxenes (augite, Wo 43.4; En 36.2; Fs 20.4) are also observed. No microorganisms were detected.



6. Unassigned samples. Sample 8.74.10: a. the surface; b. fresh fracture; c. thin section PPL image. Sample 6.73.15: d. the surface; e. fresh fracture; f. thin section (reflected CPL), tephra(?) fragment. Sample 6.74.08: g. the surface; h. fresh fracture (Phot. J. Michniewicz).



7. Unassigned samples. Sample 6.74.08: a. thin section (PPL) with dark red chamotte fragments. Sample 3.62.22: b. the surface; c. fresh fracture; d. thin section, image obtained in PPL, clinopyroxene (Cpx), quartz (Qz). Sample 6.72.01: e. the surface; f. fresh fracture; g. thin section, shale fragment CPL; h. as above, but in reflected PPL (Phot. J. Michniewicz).



	wt. %
MgO	15.05
Al_2O_3	2.90
SiO_2	55.03
CaO	20.33
Fe_2O_3	6.69
Wo	44.20
En	45.60
Fs	10.20

8. Unassigned sample 3.62.22, EDS spectrum and chemical composition of clinopyroxene marked with an arrow on Fig. 7d (Processing: J. Michniewicz).

Sample 3.62.22

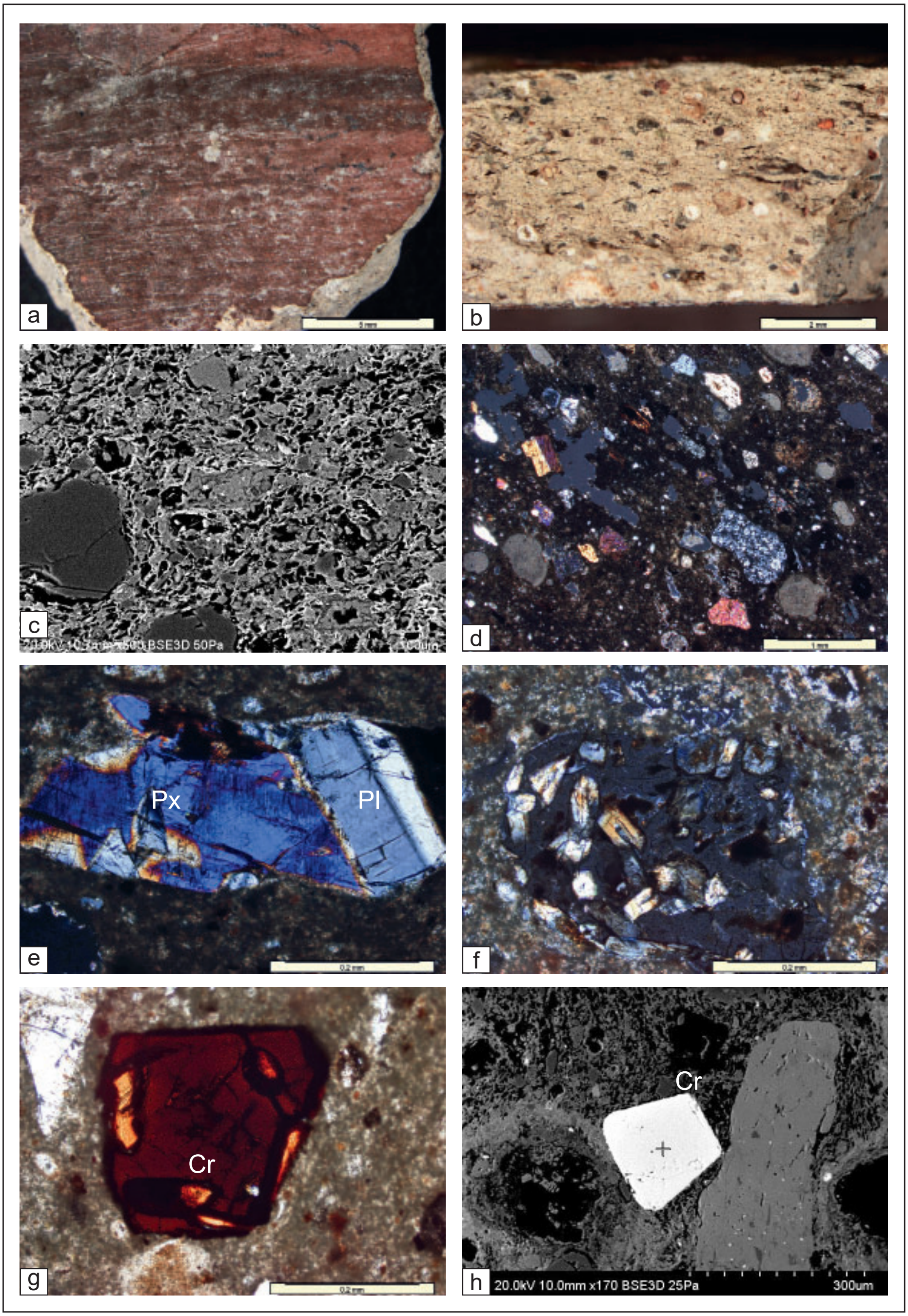
The fine, light red ceramic body is covered with a light brown smooth and lustrous slip (**Fig. 7b-c**). Matrix is pale brown, massive, optically inactive, and almost free of non-plastic components, including quartz silt. The ceramic is characterised by a low calcium carbonate content (CaO = 1.2%). The coarse admixture include single sand-size grain of colorless pyroxene, augite (**Figs 7d, 8**). No microorganisms were detected.

Sample 6.72.01

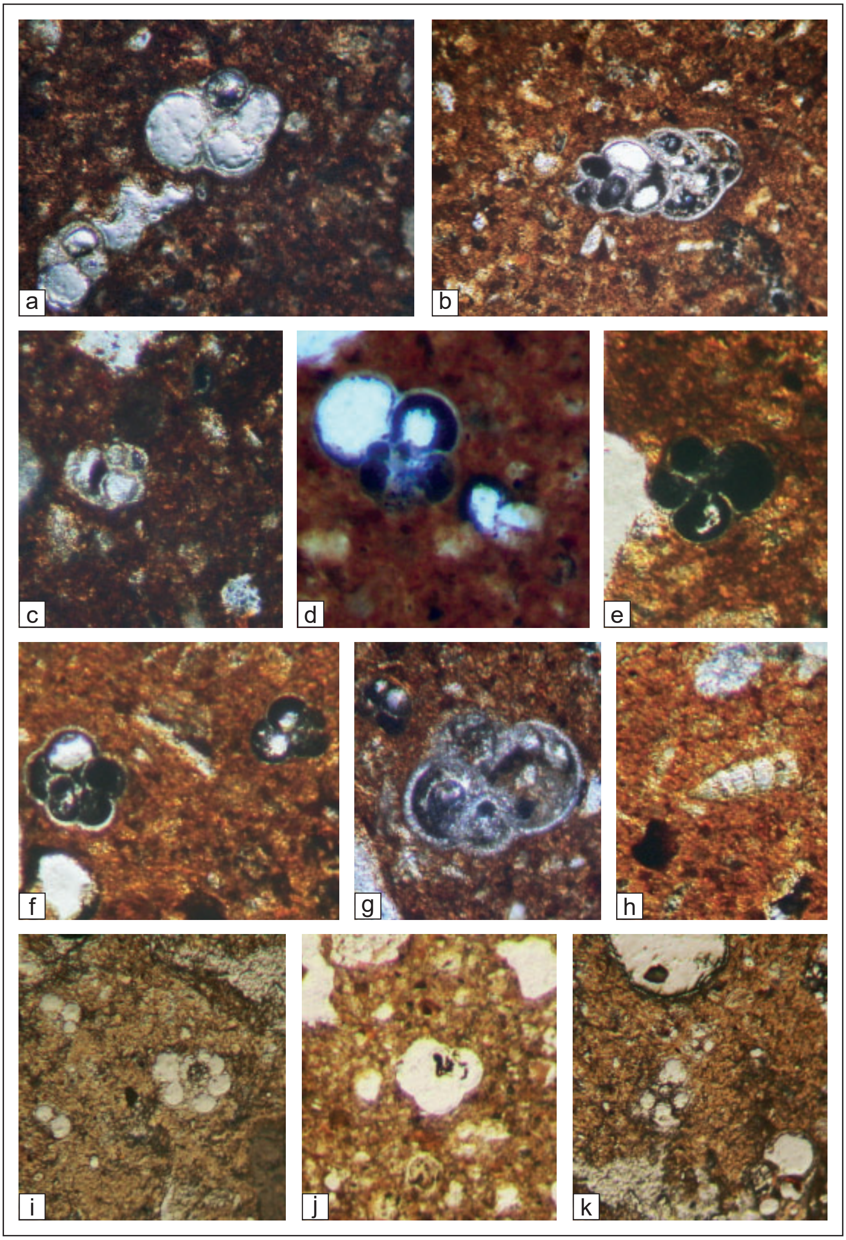
Sample red and smooth on the surface, red on the fracture with black lamellae – the effect of interrupted firing processes (**Fig. 7e-f**). The matrix is slightly active in CPL, generally highly sintered, bright red and mottled with milky discolouration due to carbonate components (CaO = 9 wt. %). Diagnostic is the presence of cherry red shale fragments characterised by the presence of rhomboid pseudomorphs of hematite after dolomite (**Fig. 7g-h**). Unspecified specimens of foraminifera were detected.

Sample 8.81.03

Semi-fine type ceramic, fired to creamy-white colour, covered with reddish-brown slip. Fine black and white sand grains are visible in the cross-section (**Fig. 9a-b**). Marl-type micromass, greenish-grey in PPL, goldish-green in CPL (lens x10), inactive, rich in thermally decomposed microorganisms, mainly foraminifers, currently replaced by secondary carbonates, almost devoid of silt-size quartz, highly porous (**Fig. 9c**). Sand-size admixture (20% of the volume): composed predominantly of monomineral clinopyroxene, mostly augite (cf. **Table 4**, **Fig. 9d**), minor gabroides (**Fig. 9e**), oxy-amphibole, oval micrite limestones (<5 %), some (10%) angular quartz with sharp extinction (volcanogenic), plagioclase



9. Unassigned sample 8.81.03: a. the surface; b. fresh fracture; c. thin section (CPL) image; d. micromass at magnification x500 in SEM-BSE mode; e. gabbro fragment composed of pyroxene and plagioclase; f. boninite fragment (natural glass with embedded phenocrysts) in CPL; g. chromite in transmitted PPL; h. chromite (Cr), image obtained in SEM-BSE mode (Phot. J. Michniewicz).



10. Microfossils from some sampled BoR vessels from Tell Keisan: a. sample 6.79.11, *Parasubbotina/Subbotina* sp. shells modified by temperature, x150; b. sample 6.73.25, *Chiloguembelina morsei/Ch. midwayensis*, x100; c. sample 6.79.11, *Turborotalia* cf. *frontosa*, x75; d. sample 6.73.25, *Parasubbotina* cf. *inaequispira*, x150; e. sample 4.04.44, *Subbotina eocaena* shell filled with dark material, x150; f. sample 6.73.25, *Parasubbotina*, x100; g. sample 6.73.25, *Catapsydrax ex* gr. *unicavus*, x150; h. sample 6.73.25, *Radiolaria* sp., x50; i. sample 8.74.10, *Pseudohastigerina wilcoxensis*, x80; j. sample 4.04.44, *Parasubbotina* cf. *hagni*, x80; k. sample 8.74.10, *Parasubbotina/Subbotina* sp. shells modified by temperature, x80 (Phot. A. Szydło, J. Michniewicz).

of variable composition: An: (5–97%), lathwork volcanites, very few (2–5%) hyaloclastite, quartz-feldspar lithics, serpentine after olivines, boninite (**Fig. 9f**), ilmenite. Diagnostic is the presence and composition of red (PPL), isotropic Cr-spinels (chromites) (**Fig. 9g-h**, **Table 5**). Unspecified species of genera *Parasubbotina/Subbotina* were detected (**Fig. 12**).

DIFFERENCES IN THE CHEMICAL COMPOSITION OF CERAMIC PASTES

The EDS study of the chemical composition of the raw material was carried out excluding the admixture of the sand-size fraction, but with the presence of grains of the silt-size fraction, at 500x magnification. The results are presented in **Table 6**.

In particular, the differences in CaO content are pronounced, being extremely low (0.9–1.3 wt. %) in the unassigned samples 6.73.15, 6.74.08 and 3.62.22, moderate (10–12 wt. %) in samples belonging to PG 1 and in the unassigned sample 6.72.01, and high (15–21 wt. %) in samples obtained from marly raw material (15–27 wt. %), PG 2 and 3. Sample 8.74.10 is extremely calcareous (42 wt. %). The Al_2O_3 and SiO_2 contents vary with changes in the CaO content. The Fe_2O_3 content is similar. Noteworthy is the elevated magnesium content in PG 2 samples, which may be related to the presence of dispersed biotite lamellae. Surprisingly, the MgO content is low in PG 3 samples, which contain serpentinite fragments.

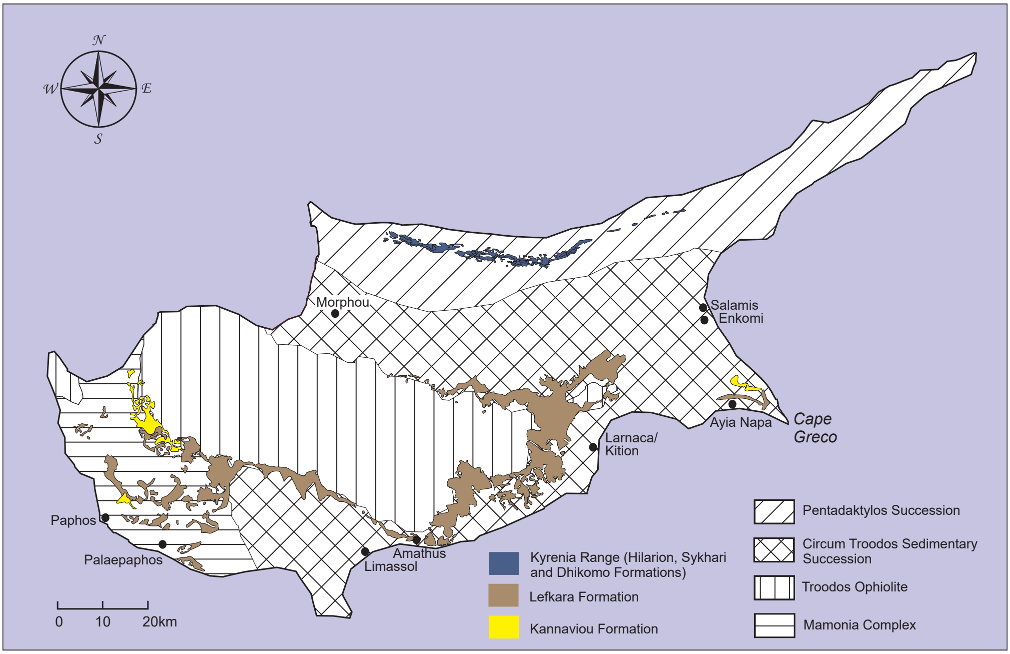
DISCUSSION AND CONCLUSIONS

The results of the micropaleontological investigations indicate that the ceramics of petrographic groups PG 1, PG 2, and PG 3, as well as the three unassigned samples (8.74.10, 6.72.01, 8.81.03), were made from Paleogene (Paleocene-Eocene) clays and marls or soils formed on Paleogene bedrocks (**Fig. 12**). As the outcrops of Paleogene are found throughout the Levant, both in Israel, Lebanon, and Cyprus,[16] micropaleontology does not allow us to prove where the BoR pottery studied here was made, whether it is a Cypriot import or a local Tell Keisan product, or more generally a continental Phoenician.

Regarding the further search for markers of provenance for the vessels studied, the presence of silt-sized orange glazes among the BoR samples studied deserves special attention. Their presence has not been recorded or discussed in detail, nor did it form the basis of the systematics of the vessels analysed.

The composition of the glass fragments from Tell Keisan BoR pottery shows SiO_2: 57–59 wt. %, Al_2O_3: 14–17, MgO about 6–10 wt. %, and a small amount of CaO (2 wt. %). The Fe_2O_3 content is high (10–14 wt. %), while the TiO_2 content is negligible (< 0.5 wt. %). While low CaO and high SiO_2 contents are typical of acid lavas, large amounts of MgO and iron oxide (Fe_2O_3) are characteristic of basaltic rocks. In the case of the PG 1 orange glass fragments, the high magnesium content is disproportionate to the low calcium content.

[16] Hernández-Molina *et al*. 2022.



11. Simplified geological sketch indicating the geological units mentioned in the text (Processing: M. Burdajewicz; based on: Pentazis 1979).

Such a composition does not correspond to natural basalts[17] and is closer to the composition of submarine volcanic glass alteration products – palagonite.[18]

Similar 'orange fragments' have been recorded by the Jacek Michniewicz and Jolanta Młynarczyk team[19] in the Phoenician wine/oil jar ceramic pastes discovered at Sha'ar-Ha'Amakim (the easternmost fringe of the Akko plain) and in a (single) jar fragment from Tell Keisan (sample TK-221). Compared to the chemical composition of the BoR ceramics currently under analysis, the composition of the glass from the Galilee jars differs.

Also different from the BoR is the composition of volcanic glasses taken from natural outcrops in the northern Galilee, the Carmel region, and the Zevulun Plain.[20] In Cyprus, the occurrence of volcanic glass can be attributed to the following units (cf. **Fig. 11**):

1) Lavas belonging to the upper pillow lava unit of the Troodos Ophiolite complex, comprising basaltic andesite (52–56% SiO_2), andesite (56–62% SiO_2), and dacite (62–66% SiO_2).[21]

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[17] Cf. Thy, Brooks, Walsch 1985; Taylor *et al*. 2022.

[18] Cf. Fonseca *et al*. 2017: Table S2. When looking for analogies to the data on the composition of Cypriot glazes, it is essential to bear in mind the disparities due to transformations caused by the firing of the ceramics, in particular the dehydration of the glazes, and measurement errors due to the semi-quantitative nature of the analysis.

[19] Michniewicz, Młynarczyk 2017.

[20] Michniewicz, Młynarczyk 2017: 132, Table 14.

[21] As documented by Thy, Brooks, Walsch 1985; Cameron 1985; Rautenschlein *et al.* 1985; Fonesca *et al*. 2017.

Paleogene						Petrographic Group/Sample no.	Microfossils (Foraminifera/ Radiolaria)
Paleocene		Eocene			Oli-gocene		
late	late	early	mid.	late	early		
						1/6.73.25	*P. pseudo-bulloides*
						3/4.05.79	*P. hagni*
						1/6.73.25	*P. inaequispira*
						1/6.73.25	*P. varianta*
						1/6.73.25, 3/4.05.79, un./8.74.10	*S. eocaena*
						1/6.73.25	*S. linaperta*
						un./8.74.10	*S. velascoensis*
						1/6.73.25	*Ch. morsei/ Ch. midwayensis*
						1/6.74.18	*Ch. crinita*
						1/6.73.25	*T. frontosa*
						un./8.74.10	*P. wilcoxensis*
						1/6.73.25	*D. danvilensis*
						1/6.73.25	*C. unicavus*
						1/6.73.25	*Globanomalina*
						1/6.79.11	*Acarinina*
						1/6.73.25	*Morozovella*
						2/5.66.06, un./6.72.01, 8.74.10	*Parasubbotina/ Subbotina*
						1/6.73.25, 3/4.05.79	*Radiolarians*

12. Foraminifer taxa and their temporal ranges identified in BoR ceramics from Tell Keisan (based on: Cohen *et al*. 2025; Toumarkine, Luterbacher 1985; Olsson *et al*. (Eds) 1999; Sanfilippo, Kagan Tekin, Hakyemez 2015).

2) Campanian-age volcanoclastic sediments of the Kannaviou Formation (Circum Troodos sedimentary succession), represented by an andesite-dacite-rhyolite (<69% SiO_2) assemblage.[22] The Kannaviou Formation is exposed both in the western coastal region of Cyprus, particularly in the Paphos area, and in the zone of authigenic sedimentary rocks covering the Mesoaria area, including the southern coast.

3) Early Miocene tuffaceous deposits of the Kyrenia Range.[23]

4) The lower marls of the Lefkara Formation, representing deep-sea sediments composed of chalks, marly chalks, marls, radiolarian-rich calcilutites.[24] According to Alastair H.F. Robertson the lowest parts of Lefkara Formation contains clasts (less than 0.5mm) of altered occasionally fresh volcanic glass.[25] The lower Lefkara Formation unit commonly fills depressions along the volcaniclastic ophiolite palaeosurface of the Troodos Massif.[26] It is noteworthy that the Paleogene age of the Lefkara Formation corresponds to the age of the raw material of the BoR ceramics analysed. Lefkara Formation outcrops both near Kition, Amathus, as well as on the west coast – near Palaepaphos.[27]

PROVENIENCE OF POTTERY BELONGING TO PETROGRAPHIC GROUPS

The ceramics of PG 1 are similar to those of the Tel Dor BoR ceramics recognised by Paula Waiman-Barak as Salaminian,[28] thus linking them to the Pliocene Nicosia Formation or *terra rossa* exposed in the area.[29] From the perspective of the currently established Paleogene age of the raw material, it is more likely that the BoR fragments assigned to PG 1 are associated with marls of the Lefkara Formation (Lower Marl Unit?), which is better exposed to the south and east of the Troodos Massif, e.g. near Kition (**Fig. 11**).[30] Therefore, the Kition/Ayia Napa(?) area is a more likely production region for the analysed BoR vessels than the Salamis region (Mesaoria Plain).

Analogous to PG 1, pottery assigned to PG 2 contains orange glazes, the main difference between PG 2 and PG 1 being the higher CaO content within the raw clay in PG 2. Thus, their provenance may be similar to that of PG 1 vessels.

In the case of PG 3, the presence of serpentine group minerals indicates a relationship with ophiolite rocks, most likely Cypriot Troodos Massive. The presence of foraminifera species *Parasubbotina hagni* and *Subottina eoceana* dates the raw material to the Eocene.

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[22] Robertson 1977; Chen, Robertson 2019.

[23] Chen, Robertson 2021.

[24] Kähler 1994; Kähler, Stow 1998; Sanfilippo, Kagan Tekin, Hakyemez 2015.

[25] Robertson 1976: 1012.

[26] Hernández-Molina *et al*. 2022.

[27] Cf. Pentazis 1979; see also *Levantine Ceramics Project* (*LCP*): Petrographic sample HST 2_6; Robertson 1976; Garzanti, Andò, Scutellà 2020; Waiman-Barak, Bürge, Fischer 2023: Fig. 4.

[28] Based on the work of Waiman-Barak, Bürge, Fischer 2023; a similar suggestion of a link between two BoR samples (nos 6.517, 6.864) from Tell Keisan, with the Salamis furnaces appears in Wilson's study (Wilson 2021).

[29] Waiman-Barak, Georgiadou, Gilboa 2021: Fig. 5.

[30] Kähler 1994; Kähler, Stow 1998; Papadimitriou *et al*. 2018.

The copresence of lathwork volcanic lithic grains suggests this group's association with the Paphian products.[31]

PROVENIENCE OF UNASSIGNED SAMPLES

Sample 8.74.10 is similar to the Phoenician paste pottery produced mainly on the south coast of Lebanon. This similarity applies to the marly micromass, the globigerinid ooze, the presence of fragments of red algae and the medium-size quartz admixture.[32] However, a Cypriot origin is equally likely, especially with the Miocene globigerinid marls of the Pakhna Formation (Terra Member).[33] Cypriot coastal sands rich in limestone and red algal fragments are documented in the west – Mamonia Province,[34] and in the south-east of Cyprus – Ayia Napa, Cape Greco,[35] so the origin of this sample remains an open question.

The composition of the sand-size temper of sample 6.73.15 corresponds to the Troodos Massif,[36] and the cooccurrence of epidote and cherts would indicate the Mamonia Province (western Cyprus), or the Morphou region.

The high proportion of chert and volcanogenic quartz, Ca-pyroxene, suggests that also in case of sample 6.74.08 the Mamonia Province is a likely source area.[37]

Sample 3.36.22 is characterised by low CaO content and lack of non-plastic admixtures (except for one grain of amphibole), making it impossible to determine provenance.

For sample 6.72.01 diagnostic are cherry-red shale fragments, which make the ceramics similar to Paphian(?) BoR bowl.[38]

In case of sample 8.81.03 the raw material is marl containing black sand composed of minerals of plutonic and volcanogenic rocks. The presence of Ca-pyroxenes, amphiboles, volcanic glazes, serpentinised olivines, and especially Cr spinel (chromite) is a diagnostic for the Cyprus ophiolite.[39] The highest percentage of heavy transparent minerals in the sandy fraction is diagnostic for the sands of the beaches of southern Cyprus, especially Limassol/Amathus (69%), as well as northern Cyprus, i.e. Morphou region (45%).[40]

To sum up, the studies carried out do not confirm the Phoenician provenance of the analysed fragments of black-on-red pottery discovered at Tell Keisan. However, the diverse origins of the analysed samples are clearly evident. The petrographic composition of the non-

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[31] Waiman-Barak, Georgiadou, Gilboa 2021: 246–247; Garzanti, Andò, Scutellà 2000: Table 1.

[32] Cf. Bettles 2003: Fabric Class 1A; Eliyahu-Behar *et al*. 2008; Michniewicz, Młynarczyk 2017: Petrographic Group 1A.

[33] Cf. Follows 1992; Eaton, Robertson 1993; Goren, Bunimovitz, Finkelstein 2003.

[34] Cf. Follows 1992; Garzanti, Andò, Scutellà 2000: 209.

[35] Cf. Follows 1992; Nir 1993: 19–23, Appendix V; Garzanti, Andò, Scutellà 2000: 209; Waiman-Barak, Bürge, Fischer 2023: Fig. 4.

[36] Garzanti, Andò, Scutellà 2020: 215.

[37] Cf. Garzanti, Andò, Scutellà 2000: 209–210.

[38] Documented by Weiman-Barak *et al*. 2021: Fig. 11.

[39] Cameron 1985: 241–244, Table 5; Tschegg, Hein, Ntaflos 2008: 1141; Tschegg, Ntaflos, Hein 2009: 1109.

[40] Cf. Garzanti, Andò, Scutellà 2000.

plastic components, the proportions between them, the presence of minerals diagnostic of rocks associated with the ophiolite and the products of its weathering, in conjunction with the results of the micropaleontological analyses, point to a Cypriot origin. The differences found prove that they were made in different areas, especially southern and western Cyprus (cf. **Table 1**). A sampled bowl, 5.66.06, is exciting since it was found in level 8 (late tenth century BC), along with five other BoR vessels. These are the earliest examples of BoR pottery at Tell Keisan and in Palestine, alongside BoR finds from Megiddo.[41] The petrography of two more bowls from the same level 8 also indicates Cypriot origin.[42] Then, the fact that at least three BoR vessels from level 8 reveal Cypriot provenance is highly significant and reinforces the theory that BoR vessels found on the Levantine coast, especially in southern Phoenicia, were mainly Cypriot imports. The provenance of sample 8.74.10, whose petrography corresponds to Cypriot clays and Phoenician ceramics from southern Lebanon/northern Israel, is ambiguous.

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[41] Kleiman *et al*. 2019.

[42] Nos 6.517 and 6.864, published in Briend, Humbert (Eds) 1980: Pl. 56: 1–2. For petrographic analysis, see Wilson 2021.

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Table 1. Black-on-Red pottery samples from Tell Keisan

Sample no.	Level	Form	State of preservation	PG	Provenance
3.62.11	5	bowl	body-sherd	1	Cyprus, Kition/Ayia Napa
3.62.17	4/5/6	bowl	body-sherd	1	
6.73.25	5	bowl	body-sherd	1	
6.79.11	4	bowl	body-sherd	1	
6.74.18	5/6	juglet	body-sherd	1	
3.82.01	4/5/6	bowl	body-sherd	2	Cyprus, Kition/Ayia Napa
4.04.44	4/5/6	bowl	body-sherd	2	
5.66.06	8b	bowl	rim	2	
3.70.40	4/5/6	closed form	body-sherd	3	Cyprus, Paphos region
4.05.79	5	juglet?/jug?	body-sherd	3	
8.74.10	5	bowl	rim	unassigned	Lebanon/Cyprus, Mamonia Province/ Ayia Napa/Cape Greco
6.73.15	4	bowl	body-sherd	unassigned	Cyprus, Mamonia Province, Morphou region
6.74.08	4/5/6	juglet	body-sherd	unassigned	Cyprus, Mamonia Province
3.62.22	4/5/6	juglet	body-sherd	unassigned	?
6.72.01	4	juglet	body-sherd	unassigned	Cyprus, Paphos region
8.81.03	4	bowl	rim	unassigned	Cyprus, Limasol/Amatus/Morphou region

Table 2. The petrographic data of the BoR pottery from Tell Keisan

Sample no.	Qtz silt (%)	CaCo$_3$ silt	Foraminifera	Terra rosa	Sand (%)	Limestone	Orange glass	Brownish glass	Quartz	Chert	Bioclasts	Feldspars	px/amf+pl±ep	Amphibole	Sandstone	Mudstone	Serpentinite	Pyroxene	Epidote	Cr-spinel	Mica/Chlorire	Kf+Qtz	Dolomite	Plagioclase	Kf	Volcanites	Fd+Biotite	Red algae	Chamotte
3.62.11	0	1	2	1	<5%	1	1	0	1	0	0.5	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0
3.62.17	<2%	1	1	1	<5%	0	1	0	1	0	0	1	1	0	0	0	0	0	1	0	0.5	0	0	1	0	0	1	0	0
6.73.25	<5%	1	2	1	0	0	1	0	1	1	0	1	1	1	0	1	0	1	1	0	0	0.2	0	1	0	1	0	0	0
6.74.18	<2%	1	1	0	<5%	0	1	0	1	1	0	1	0.5	0	0	0	0	0	1	0	0	0	?	1	0	1	0	0	0
6.79.11	0	0.5	1	0	0	2!	1	0	1	0	0	1	1	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0	0
3.82.01	0	2!	1	0.2	0	0	1	1	1	0	0	1	0	1	0	0	0	0	1	0	Chl	0	0	1	0	0	0	0	0
40.04.44	0	2!	1	1	0	0	1	1	1	1	0	1	1	1	0	0	0	1	1	0	Chl	1	0	1	0	1	1	0	0
5.66.06	<2%	1	2	0	<5%	0	1	1	1	0	1	2	0.2	1	0	0	0	1?	1	0	Chl	0	0	1	0	?	1	0	0
3.70.40	<1%	2!	?	0.2	<1%	0	0	1	1	0	0	1	0	1	0	0	1	0	1	0	Chl	0	0	1	0	1	1	0	0
4.05.79	<2%	2!	1	0	0	1	0?	0	1	0	0	0	0	0	1	0	1	1?	1	0	0	1	0	1	0	1	1	0	0
8.74.10	<1%	2!	2	0	0	2	0	0	1	0	1	0	0	0	1	0	0	0.2	1	0	0	0	0	0	0	0	0	1	0
6.73.15	<2%	2!	1	1	0	0	0	0	1	2	0	1	1	0	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0
6.74.08	5-7%	0	0	0	0	0	0	1	2	2	0	0.2	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	1
3.62.22	<1%	0	0	0	<2%	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6.72.01	<1%	?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.81.03	<2%	2!	1	0	0	2	0	0	0.2	0	1	1	0.2	1	2!	0	1	1	0	1!	0	0	0	1	0	1	0	0	0

Table 3. Major element composition (wt. %) of the orange glazes of Petrographic Groups 1 and 2

Oxide Compound	PG 1										PG 2					
	Sample no.															
	3.62.11	**SD**	**3.62.17**	**SD**	**6.73.25**	**SD**	**6.74.18**	**SD**	**6.79.11**	**SD**	**3.82.01**	**SD**	**40.04.44**	**SD**	**5.66.06**	**SD**
Na_2O	1.21	0.26	1.48	0.41	0.99	0.07	0.92	0.25	1.43	0.30	2.09	0.69	1.50	0.53	1.64	0.38
MgO	7.65	1.58	6.12	1.00	6.73	1.01	6.00	0.68	9.68	3.23	5.50	0.98	9.10	5.84	8.96	3.14
Al_2O_3	13.98	2.39	17.22	1.38	14.60	1.95	14.33	0.37	15.87	2.54	14.11	2.60	12.49	1.73	14.40	2.07
SiO_2	57.65	0.55	59.15	2.62	58.35	0.92	58.18	1.65	58.17	3.32	51.48	1.97	59.23	4.55	56.38	1.72
K2O	3.40	0.89	2.90	0.91	3.35	0.47	3.41	0.84	1.95	0.85	3.34	0.94	3.19	0.87	2.65	1.05
CaO	2.66	0.43	2.26	0.28	2.71	0.27	2.81	0.23	2.61	0.17	2.10	0.27	2.50	0.36	2.86	1.05
TiO_2	0.28	0.20	0.39	0.23	0.16	0.24	0.31	0.22	0.18	0.20	0.17	0.29	0.11	0.20	0.00	0.00
Fe_2O_3	13.18	2.44	10.33	2.54	13.00	1.47	14.04	1.23	10.05	2.82	10.09	1.86	11.88	0.87	13.12	3.23
Number of analyses	n=4		n=6		n=6		n=4		n=10		n=8		n=4		n=6	

Table 4. Sample 8.81.03: chemical composition (wt. %) and mineral group name of pyroxenes

Pyro-xene	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	Mg#	En	Wo	Fs	Px mineral group
px1	54.28	0.41	2.41	<	6.07	<	17.14	19.69	<	0.68	49.4	40.8	9.8	augite
px2	56.37	<	3.96	<	11.06	0.54	19.55	7.53	<	0.57	62.7	17.4	19.9	pigeonite
px3	54.36	<	2.20	0.40	4.90	<	19.00	19.14	<	0.75	53.5	38.7	7.7	augite
px4	55.16	<	1.58	<	5.48	<	16.23	21.55	<	0.69	46.7	44.5	8.8	augite
px5	53.29	<	3.52	0.56	7.12	<	16.65	18.85	<	0.70	48.7	39.6	11.7	augite
px6	56.46	<	3.24	<	9.19	<	19.68	10.61	0.41	0.62	60.6	23.5	15.6	augite
px8	53.44	<	3.55	<	3.73	<	18.25	21.02	<	0.79	51.5	42.6	5.9	augite
px9	55.65	<	3.18	<	4.80	<	18.11	17.98	<	0.74	53.7	38.3	8.0	augite
px10	54.12	<	2.45	<	6.74	<	16.58	20.12	<	0.65	47.6	41.5	10.9	augite
px11	54.67	<	1.84	0.71	3.54	<	19.84	19.40	<	0.81	55.5	39.0	5.6	augite

Table 5. Sample 8.81.03: chemical composition (wt. %), chromium and magnesium number (#) of chromites

Oxide Compound	Cr1	Cr2	Cr3	Cr4	Cr5
MgO	11.09	12.00	11.35	11.73	10.76
Al_2O_3	16.08	13.40	19.31	19.86	12.57
SiO_2	3.12	2.76	3.82	5.96	4.29
TiO_2	0.23	<	0.67	<	<
Cr_2O_3	48.94	50.82	39.17	42.62	48.49
MnO	0.52	0.37	<	0.67	0.49
FeO	20.02	20.64	24.16	15.13	19.41
CaO	<	<	1.02	2.36	1.67
V_2O_5	<	<	0.49	<	<
Cr#	0.80	0.83	0.72	0.73	0.83
Mg#	0.30	0.31	0.27	0.37	0.35

Table 6. Semi-quantitative EDS composition (wt. %) of the ceramic pastes of the BoR pottery, excluding grains of the sand-size fraction

Oxide Compound	PG 1					PG 2			PG 3		Unassigned					
	Sample no.															
	3.62.11	3.62.17	6.73.25	6.79.11	6.74.18	3.82.01	4.04.44	5.66.06	3.70.40	4.05.79	8.74.10	6.73.15	6.74.08	3.62.22	6.72.01	8.81.03
Na_2O	1.75	1.21	1.93	1.84	1.14	1.99	1.67	1.34	0.54	0.54	0.57	0.65	0.56	0.67	0.00	1.30
MgO	5.63	3.18	4.91	4.16	3.15	5.17	7.06	5.45	2.76	3.05	1.43	1.59	0.56	1.68	2.62	3.93
Al_2O_3	14.52	16.92	14.43	12.94	15.78	13.43	13.08	13.47	12.93	12.76	12.02	15.45	24.17	14.57	19.28	13.23
SiO_2	56.49	58.61	57.15	58.72	58.56	50.96	50.20	54.08	56.06	50.71	33.71	70.28	61.05	73.14	54.24	49.76
K_2O	1.77	1.82	1.81	1.64	1.76	1.05	1.71	0.29	1.85	1.57	1.75	1.66	1.30	1.85	5.87	2.19
CaO	10.83	10.56	11.11	12.25	11.12	19.26	15.99	15.14	18.81	23.23	42.17	1.29	0.90	1.20	9.74	21.74
TiO_2	0.72	0.53	0.00	0.83	0.90	0.00	0.50	1.25	0.62	0.79	0.65	0.92	1.76	0.84	1.22	1.05
Fe_2O_3	8.29	7.17	8.65	7.64	7.58	8.13	9.80	8.97	6.41	7.35	6.09	7.73	9.69	6.06	7.03	6.79
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00

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Contact address concerning product safety (GPSR):
Fabryka Druku sp. z o.o.
6, Zgrupowania AK “Kampinos” st., 01-943 Warszawa
fabrykadruku@fabrykadruku.pl

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Table of contents