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DIPARTIMENTO DI SCIENZE DELL'ANTICHITÀ — MUSEO DELLE ORIGINI

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Proceeding of the session held at the 24th Meeting of the European Association of Archaeologists, Barcelona 2018

PETROGRAPHY-BASED DISCRIMINATION OF PRODUCTION AREAS WITHIN SOUTHERN MESOPOTAMIA: NEW DATA ON THE UBAID POTTERY FROM TELL ZURGHUL (DHI QAR, IRAQ)

Luca Volpi*, Pamela Fragnoli**

Abstract – This article presents new results on the Ubaid pottery production from Tell Zurghul/ Nigin (Dhi Qar, Iraq). Through thin-section petrography and comparison with edited data we identified intra- and inter-site differences in the raw material procurement patterns and paste preparation modes employed to produce Ubaid vessels across South Mesopotamia. At Tell Zurghul, these variations do not specifically correlate with distinct vessel shapes, suggesting a household organisation of the pottery production. At an inter-site level, these variations are powerful tools to discriminate possible pottery production zones within the Mesopotamian alluvium. These production zones can be distinguished by the proportion of heavy minerals and especially of epidotes and amphiboles, which appear in increased amounts in the Tigris sedimentological zones of influence.

Keywords – *Tell Zurghul; Ubaid pottery production; thin-section petrography; petrographic production areas in Southern Mesopotamia*

Riassunto - *L'articolo presenta nuovi risultati sulle modalità di produzione della ceramica Ubaid dal sito di Tell Zurghul/Nigin (Dhi Qar, Iraq). Attraverso l'analisi petrografica di sezioni sottili ceramiche ed il confronto con i dati editi, sono state identificate alcune differenze intra- e inter-sito nei modelli di approvvigionamento delle materie prime e nelle modalità di preparazione degli impasti per la produzione della ceramica Ubaid in Mesopotamia meridionale. A Tell Zurghul queste variazioni non sono specificamente correlate a forme vascolari distinte, suggerendo un'organizzazione domestica della produzione ceramica. Nel confronto fra più siti, queste variazioni sono strumenti potenti per discriminare possibili zone di produzione della ceramica all'interno dell'alluvio mesopotamico. Queste zone di produzione possono essere distinte in base alla concentrazione di minerali pesanti (specialmente epidoti e anfiboli), che appaiono in quantità maggiori nelle aree con sedimenti fluviali provenienti dal Tigri.*

Parole chiave - Tell Zurghul; ceramica Ubaid; petrografia in sezione sottile; zone di produzione della ceramica della Mesopotamia meridionale

INTRODUCTION[1]

In Southern Mesopotamia the earliest pottery dates back to the end of the 7th millennium BCE and pertains to the so-called Ubaid horizon. The black-on-buff painted pottery defined by the term 'Ubaid', after

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1 LV and PF wrote the introduction and the parts on the geological setting, the archaeometric state of the art, methods and sampling strategies as well as the discussion. LV wrote the parts on the archaeological context and the results on macroscopic fabrics. PF wrote the petrographic results and conclusions.

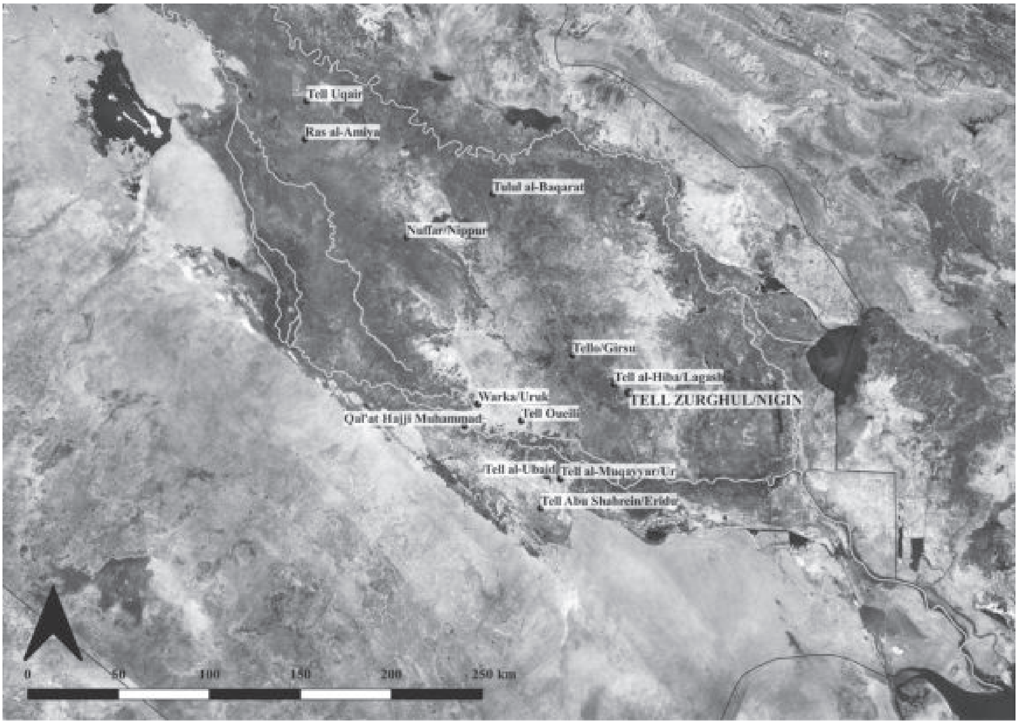

Fig. 1 - Sites with Ubaid pottery in Southern Mesopotamia with the location of Tell Zurghul/Nigin.

the name of one of the two type-sites, was discovered in the 1920s by R.C. Thompson at Tell Abu Shahrein/Eridu and by H.R. Hall at Tell al-Ubaid (Hall 1930; Hall, Woolley 1927; Thompson 1920; see also Potts 1986: 17-22). Afterwards, the term was used to define a similar black-on-buff painted repertoire diffused from the Persian-Arabic Gulf to Northern Mesopotamia and South-Eastern Anatolia between the late 6th and early 5th millennia BCE (for a critical discussion of the term 'Ubaid', see Carter, Philip 2010). This phase was linked with the emergence of a settlement hierarchisation, temple architecture, intensive agriculture, and social stratification (Adams 1981: 52-60; Frangipane 2007; Sievertsen 2010; Stein 1994).

Whereas archaeologists have traditionally focused on the morphological and stylistic aspects of Ubaid ceramics, only a few archaeometric studies have attempted to distinguish production centres and reconstruct exchange networks. This is mainly due to the geological features of the region (van As, Jacobs 2014: 77), i.e. the large-scale homogeneity typical of alluvial plains, which makes it challenging to distinguish production areas through petrographic and geochemical tools. However, systematic petrographic studies performed in similar geological settings such as that of the Nile in Egypt have managed to detect mineralogical variations through which production areas can be distinguished (Ownby 2016: 462; Warden 2021: 25-29). These achievements are far from being realised in Southern Mesopotamia, as a systematic and standardised way of collecting petrographic data is still needed to allow interpretations beyond the single-site level.

This paper is an attempt to pave the way towards large-scale petrographic comparative studies in Southern Mesopotamia aiming at identifying ceramic production areas and reconstructing regional and superregional exchange networks of ceramics and/or shared technological know-hows and stylistic models involving prehistoric Ubaid pottery as well as later ceramic productions. On a smaller scale, we intend to reconstruct the strategies adopted for selecting and processing the ceramic raw materials available at Tell Zurghul in southern Iraq (province of Dhi Qar; fig. 1) to gain initial insights into the organisation of the local pottery production.

UBAID POTTERY FROM SOUTHERN MESOPOTAMIA

Providing a general definition for the entire Ubaid pottery assemblage of Southern Mesopotamia is a difficult task for many reasons, not least of all due to the lack of both extensive excavations and comprehensive pottery studies anchored to stratigraphic data. Archaeological levels associated with Ubaid pottery have been mainly brought to light through deep soundings and small-scale excavations carried out in a very few sites in Southern Mesopotamia (fig. 1). A distinction into six phases (Ubaid 0 – Ubaid 5 phases) has been proposed, based in particular on the excavations conducted at Tell Abu Shahrein/Eridu and at Tell Oueili (Calvet 1987; Forest 1996; Oates 1960, 1987, 2010).

Further observations on the Ubaid pottery concern pastes, decorations, morphological shapes, and technological aspects. Pastes are generally mineral tempered, while vegetal inclusions are less frequent and only attested together with mineral inclusions in mix-tempered pastes. This holds for the entire sequence (Baldi 2020: 120; Safar *et alii* 1981: 173). Although the repertoire is defined as 'black-on-buff', the fabric colour varies from reddish-pink to greenish-grey.

Although scholars' interest has mainly focused on painted decorations, the repertoire is mostly comprised of unpainted vessels, e.g. at Qal'at Hajji Muhammad the painted repertoire is about 40% of the total (Ziegler 1953: 12); at Tell Oueili (Ubaid 4 phase) the percentage is around 12% (Huot 1987: 296), and the same can be said for Tell Abu Shahrein/Eridu Temple VI, where the painted assemblage is attested at 13% (Safar *et alii* 1981: 160). At Tell Zurghul, the percentage is around 22% of the total. As suggested by Karsgaard (2010: 53), the earliest repertoire (phases Ubaid 1–2) is mainly composed of large shallow bowls with plain or flaring rims characterised by all-over decoration. The repertoire of phases 3–5 loses the all-over decorations in favour of simpler motifs (horizontal bands, zigzag or wavy lines, etc.). Moreover, the bowls are generally smaller than the shallow bowls of the previous phases, and they present plain, thinned, flattened, and thickened-outside rims (see the so-called 'assiettes à marli' bowls; Lebeau 1983: 81, pl. III). In contrast to the previous phases there is also an increasing number of open cups with ring bases as well as the appearance of bell-shaped bowls and beakers. As for closed shapes, the typical jars with double-rims persist for a long time throughout several phases (Lebeau 1983: pl. XX; 1991: pl. X; Safar *et alii* 1981: fig. 72), while necked jars with vertical or slightly everted neck can be considered one of the most frequent shape for the latest phase of the period.

Regarding technological aspects, Ubaid vessels are generally hand-made, specifically with the use of the coiling technique. As a later development, there was probably the introduction of a 'rotative platform' used as a support for joining the coils, refining the shape of the vessels, and realising horizontal parallel painted lines (Nissen 1989: 248; 2001: 168-169; Safar *et alii* 1981: 158).

THE MOUND B OF TELL ZURGHUL: FIELD RESEARCH AND UBAID CERAMICS

The site of Tell Zurghul is located in the province of Dhi Qar in southern Iraq, about 7 km south-east of ancient Lagash, i.e. present-day Tell al-Hiba (fig. 2, *a*). The site is currently being excavated through a joint project between Sapienza University of Rome and Perugia University, co-directed by Davide Nadali and Andrea Polcaro. The settlement of Tell Zurghul covers a surface of about 76 hectares, which comprises two principal mounds, called Mound A and Mound B. The first one corresponds to the main occupational phases of the acropolis of the ancient Nigin, one of the three main cities of the ancient Sumerian State of Lagash. Some meters south-west from Mound A is Mound B, which is the focus of this paper. Mound B, about 0.7 ha and 4 m high, was first partially explored in 1887 through a deep trench made by R. Koldewey in 1887 (Koldewey 1887) and then systematically excavated in 2015, 2017 and 2019 by the Italian archaeological team (fig. 2, *b*).

The excavations have brought to light three architectural phases (1–3) probably related to a templar sequence (Nadali 2020; Nadali, Polcaro 2016; 2018; fig. 3, *a*), which can be dated to the Ubaid 4 phase (5300–4500 BC). The deliberate deposition of a peculiar class of pottery vessels (the so-called 'incense burners') below the walls of the second and third architectural phase suggests a voluntary rebuilding of the structures over time, as in the case of the temple sequence at Tell Abu Shahrein/Eridu (fig. 3, *b*; fig. 4: *r*; see also Nadali 2020; Safar *et alii* 1981: 156-160, fig. 74; Volpi 2020: 54). The sporadic, out-of-context presence of sherds ascribable to the earlier phases Ubaid 2/3 indicates that Mound B had probably a longer occupation (Vacca in press).

The pottery from Mound B consists of 1038 diagnostic vessels and sherds. The repertoire is characterised by open bowls with plain, thinned, bevelled and thickened-outside (the so-called 'assiettes à marli' bowls) rims (fig. 4: *a-h*), open cups with flat and ring bases, and 'bell-shaped' beakers (fig. 4: *j-l*). Closed shapes are mainly characterised by hole-mouth jars, neckless rounded jars with thickened rims, and necked jars with short vertical or flaring necks (fig. 4: *m-q*). Some peculiar shapes, attested in limited numbers, are also present: bowls with a protrusion in the inner wall, large bowls (or basins) with bevelled-inside rim, and the so-called 'clay cones' (fig. 4: *i, s-t*). The pottery assemblage allows us to assign the levels excavated in Area B of Tell Zurghul to the Ubaid 4 phase (Volpi 2020: 53), with some qualifications: the so-called 'assiettes à marli' bowls occur only in the third architectural phase. Other shapes, in particular the so-called 'bottom bases' and the pointed bases, which can be assigned to a later Ubaid 5 phase, have been found only in the filling of the 'Koldewey's trench' (fig. 4: *u*).

GEOGRAPHIC AND GEOLOGICAL SETTING OF SOUTH MESOPOTAMIA

As defined by Sissakian and colleagues the Southern Mesopotamian Plain is a vast lowland between the Tigris and the Euphrates and delimited by the Makhoul Mountains to the north and the Hamrin Mountains to the east, the Wadi Al-Tharthar and the Al-Tharthar Lake to the northwest, the Western and Southern Deserts to the southwest, and the Persian-Arabic Gulf to the southeast (Sissakian *et alii* 2020: 29; Yacoub 2011: 8). In geological terms, the Mesopotamian Foreland Basin is located between the Arabian and the Eurasian Plate, and it belongs to the Zagros Fold-Thrust Belt (Festa *et alii* 2019: 3; Saura *et alii* 2015: 381-382). Most of the area is covered

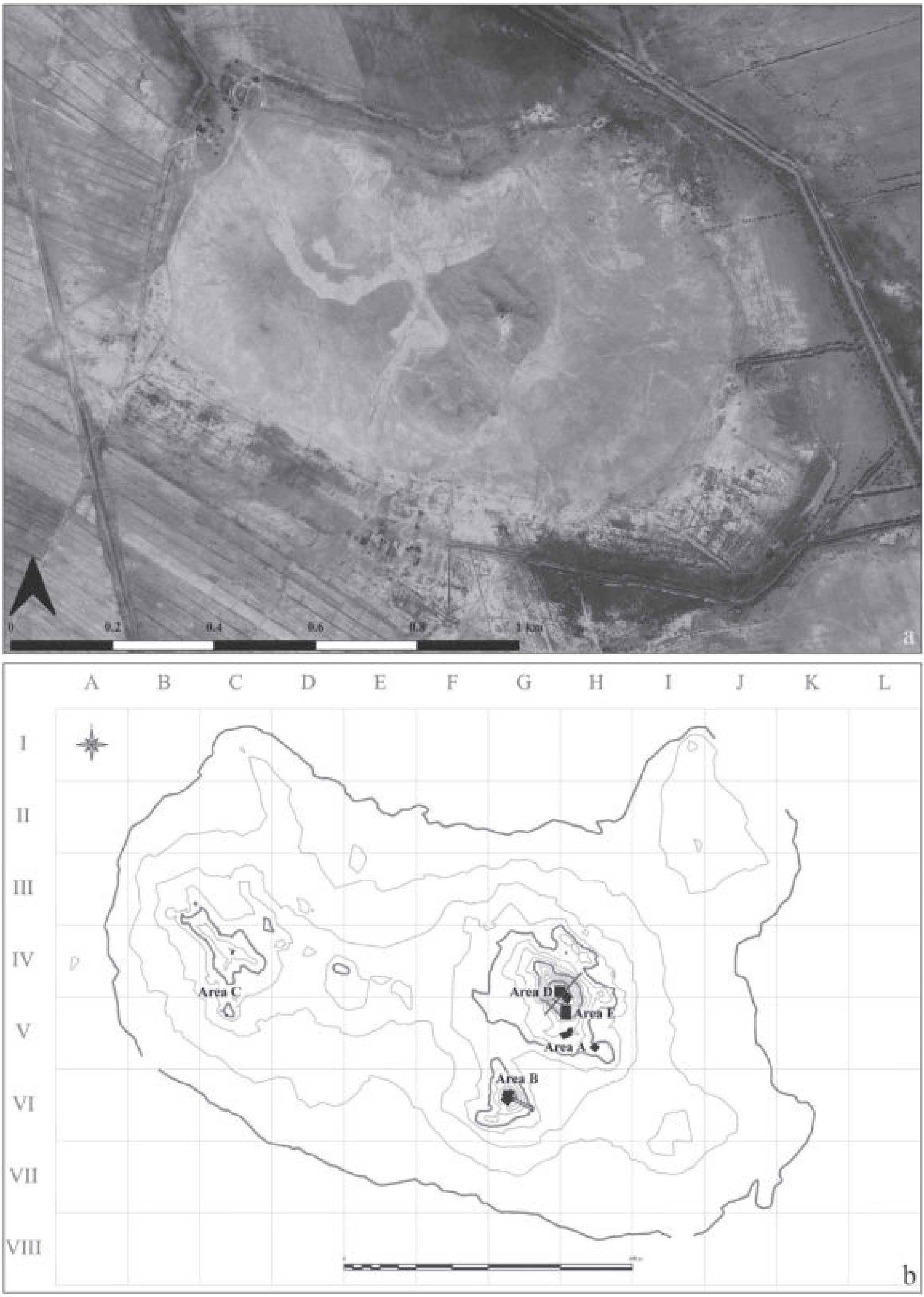

Fig. 2 - a) Satellite image of Tell Zurghul/Nigin, © Missione Archeologica Italiana a Nigin; b) Topographic contour map of Tell Zurghul/Nigin with the placement of excavation areas, © Missione Archeologica Italiana a Nigin.

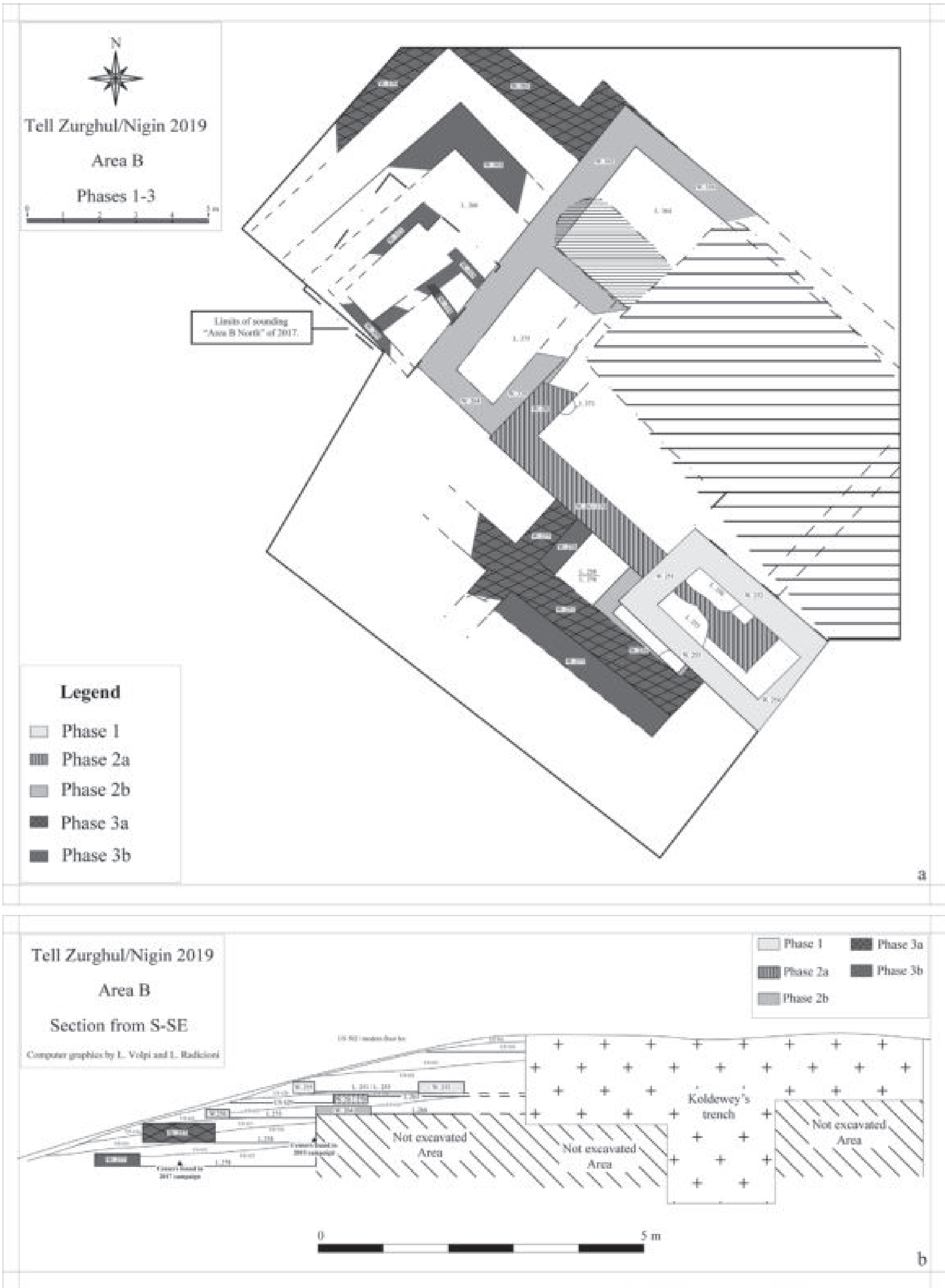

Fig. 3 - a) Composite plan of architectural phases (1–3) from Tell Zurghul, area B, © Missione Archeologica Italiana a Nigin; b) Reconstructive section from S-SE of the architectural phases (1–3) from the site of Tell Zurghul, area B, © Missione Archeologica Italiana a Nigin.

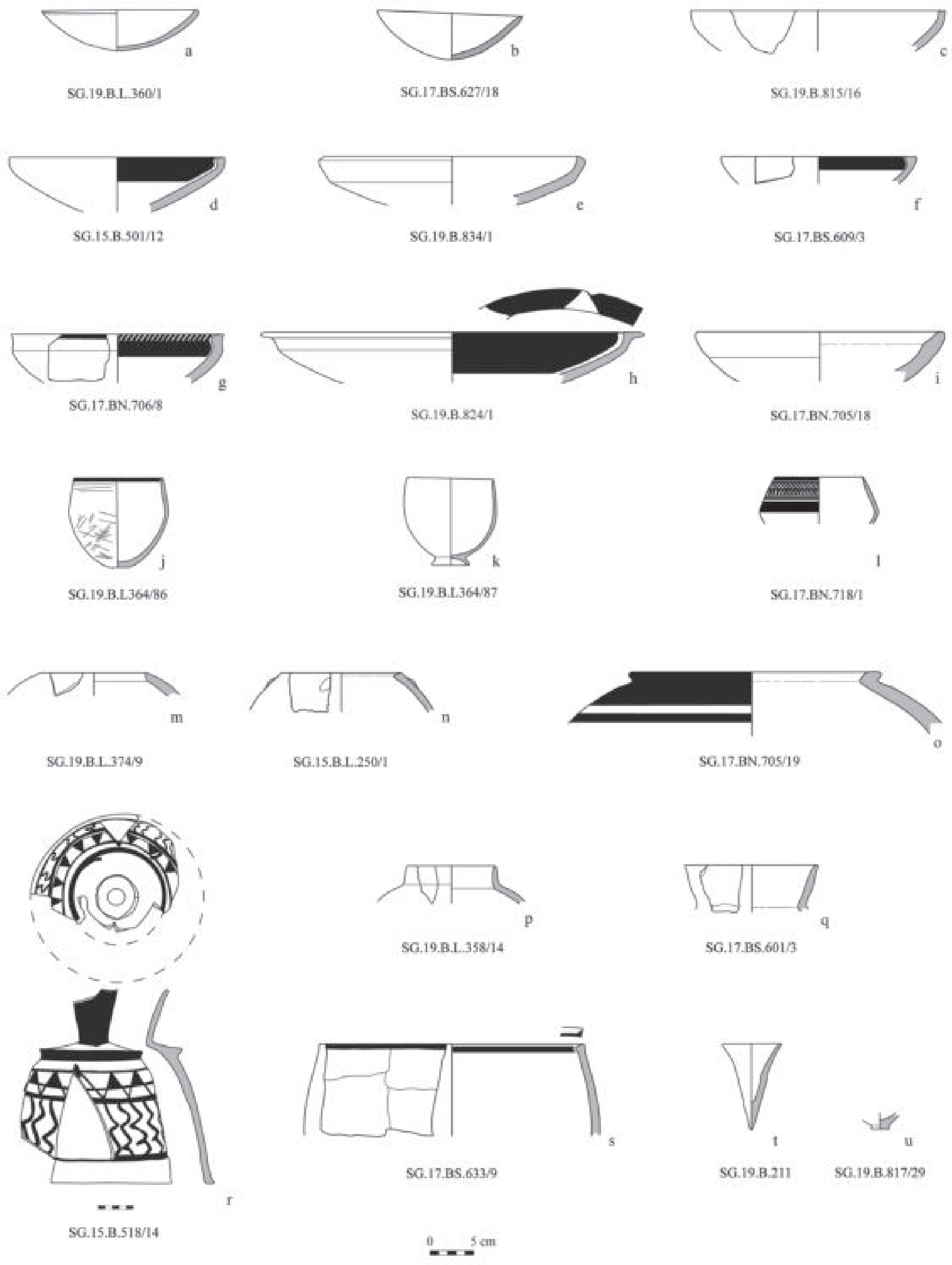

Fig. 4 - Common morphological types of Ubaid pottery from Tell Zurghul, © Missione Archeologica Italiana a Nigin.

by Holocene sediments (starting *c.* 11,700 BP), mainly of fluvial, lacustrine and aeolian origin (Sissakian *et alii* 2020: 29; Yacoub 2011: 11).

The Tigris and the Euphrates rivers deposit their sediments in their own drainage area (Buringh 1986: 15). The two rivers 'drain different geological domains in different proportions, but largely within the same Anatolia-Zagros orogen. Thus, the compositional signatures of their sediments differ, but not markedly [...]' (Garzanti *et alii* 2016: 123). The sediments to the northwest and to the southeast are dominated respectively by the contribution of the Euphrates and Tigris (Garzanti *et alii* 2016: 118). According to Sissakian *et alii* (2018a; 2018b), the Euphrates River intercepts in its basin mainly sedimentary rocks (i.e. carbonates, marl, claystone, and sandstone, and to a lesser extent gypsum and conglomerate), while igneous and metamorphic rocks might occur alongside sedimentary rocks within the Tigris' deposits.

Many studies have investigated the heavy mineral composition of the Euphrates and Tigris sediments, evidencing interesting variations. Scholars have analysed both recent (alluvial) and old sediments, taken respectively from the modern rivers and shallow boreholes (Abdul Wahab 1983; Al-Bassam, Al-Mukhtar 2008; Al-Mukhtar 2015; Philip 1968; Sissakian *et alii* 2020). Especially informative concerning the older sediments is the research conducted by Sissakian and colleagues, according to whom 'the Euphrates River sediments are richer in altered heavy minerals and monoclinic pyroxene, while the Tigris sediments have more rock fragments, minerals of zoisite – epidote group, hornblende and garnet' (Sissakian *et alii* 2020: 33). Boreholes of older sediments have also allowed researchers to distinguish the west bank from the east bank of the Euphrates river (Al-Mukhtar 2015), based on the respective larger amounts of ultra-stable (e.g. zircon, rutile, and tourmaline) and non-stable minerals (e.g. pyroxene, hornblende, and epidote).

Interesting contributions come also from the analyses of the recent Euphrates and Tigris sediments. As cited by Al Mukhtar: 'a review of previous study by Abdul Wahab (1983) for the recent sediments of Tigris, Diyala and Adhaim rivers, indicates that the sediments of the Tigris river and their major tributaries contain heavy minerals represented by predominant amphibole group (including common horneblende with a mean value of 25.49%, brown hornblende with 2.87%, tremolite-actinolite with 0.55% and glaucophane with 0.33%), then epidote group (including epidote with 8.96%, zoisite with 0.95% and clinozoisite with 1.96%) and pyroxene group (including clinopyroxene with 8.05%, brown pyroxene with 2.63% and orthopyroxene with 0.8%)' (Al-Mukhtar 2015: 71).

It is worth mentioning that the main river channels of the Tigris and Euphrates have significantly shifted their course over time (Aqrawi *et alii* 2006; Yacoub 2011). For instance, it is assumed that the sites of the Lagash region (al-Hiba/Lagash, Tello/Girsu and Tell Zurghul) laid on the Tigris alluvial sediments at the end of the 3rd millennium BCE, although they are today closer to the Euphrates (Al-Hamdani 2015: 124; Geyer, Sauvage 2020: 9; fig. 5).

ARCHAEOMETRIC STATE OF THE ART IN SOUTHERN MESOPOTAMIA

Previous archaeometric studies conducted in various chrono-cultural contexts of Central-Southern Mesopotamia mainly aimed at distinguishing locally-produced from imported vessels through both petrographic and geochemical tools. In most of the cases the results identify the local provenance of ceramics on the basis of the so-called 'criterion of abundance', according to which the most represented petrograph-

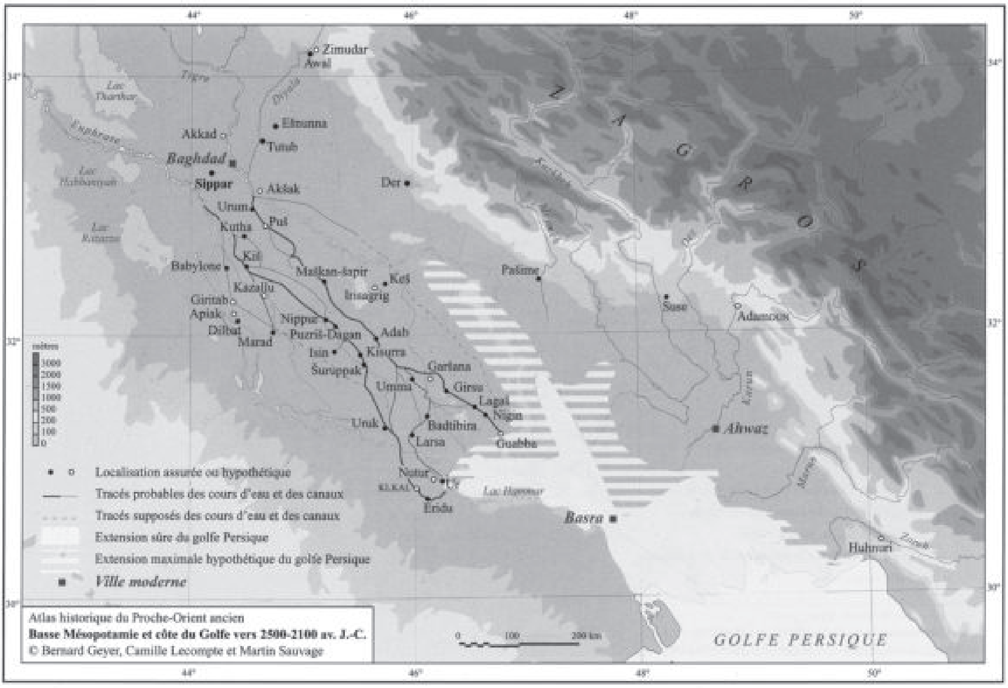

Fig. 5 - Probable extension of the Persian-Arabic Gulf coastline and probable course of the Euphrates and Tigris rivers around the second half of the 3rd Millennium BC (from Geyer, Sauvage 2020: 9).

ic group at one site is considered to have originated locally (Quinn 2013: 119; Rice 2015: 341). In Southern Mesopotamia, this criterion was first used by Mynors for the third millennium BC pottery from a series of sites (Al Kaissi, Mynors 1987; Mynors 1983; 1987), and more recently by Daszkiewicz *et alii* (2012) and Festa *et alii* (2019) for Late Uruk to Seleucid vessels from Warka/Uruk and third millennium BC pottery from Tell Abu Tbeirah, respectively.

Once the local production has been established singularly at each site, only very few studies have attempted to define the compositional features by which production zones can be distinguished from each other within the Southern Mesopotamian alluvial plain. At a geochemical level, the possibility of a distinction emerged from the analysis of Ubaid sherds imported from Southern Mesopotamia to Dosariyah (Saudi Arabia) on the coast of the Persian Gulf (Magee, Karacic 2018; Oates *et alii* 1977). Indeed, ICP analysis clearly evidenced two distinct geochemical groups based on variations related to potassium and sodium as well as a series of trace elements such as Ba, Rb, Sc, Sr, and V. These geochemical groups were interpreted as originating from two distinct Ubaid production centres operating in Southern Mesopotamia (Magee, Karacic 2018: 203). Comparable outcomes have been obtained through pXRF analyses on the ceramic assemblage from Bahra 1 (Kuwait; Ashkanani *et alii* 2020). Ubaid pottery belongs here to a distinct geochemical group, further distinguished into two sub-groups based on Ba, Nb, Rb, Sr, Y, and Zr content (Ashkanani *et alii* 2020: 10-12).

Far more promising were the results obtained through thin-section petrography; here those related to the Ubaid materials from Tell Oueili are our main reference due to the chronological and cultural affinities with Tell Zurghul (Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996). For a broader regional evaluation, the petrographic results produced by Mynors on third millennium BC pottery from Central and Southern Mesopotamia are crucial as well (Al Kaissi, Mynors 1987; Mynors 1983, 1987). By analysing ceramic samples from several sites located in Central-Southern Mesopotamia, in the Diyala and Hamrin basins, the author was able to distinguish two groups based on both the incidence of mineral inclusions (i.e. amphibole, biotite, epidote, muscovite, and pyroxene) and the roundness of quartz grains. The vessels produced in Southern Mesopotamia (group 1) typically contain minerals of biotite, epidote, pyroxene and to a lesser extent muscovite; the rounded to sub-rounded shapes of quartz grains is also diagnostic. The vessels from the Diyala and Hamrin basins (group 2) are lacking in amphibole, biotite, epidote, muscovite, and pyroxene, while quartz exhibits angular shapes (Al Kaissi, Mynors 1987: 144, tab. 1; Mynors 1983: 383, tab. 4; see also Méry, Schneider 1996: 86-87).

MATERIALS, METHODS AND SAMPLING STRATEGIES

For the purpose of this paper, 40 pottery samples from the Area B of Tell Zurghul were examined through thin-section petrography. The samples were selected based on a preliminary autoptic evaluation, considering the following parameters: colour of the fabric in fresh broken section; shape, size, colour, and frequency of mineral and/or vegetal inclusions (Tab. 1). In most of the cases only non-diagnostic sherds could be sampled for laboratory analyses due to the Iraqi SBAH rules for the export of archaeological materials. The representativeness of the selected sampling is therefore based on the macroscopic classification into fabrics rather than on morphological and typological criteria.

Thin-section petrography was selected as a privileged tool due to its discriminating potential, its comparability with edited data, and the larger geographic representativeness in the region under study. The inclusions, clay matrix, and porosity of the 40 thin sections were examined under a standard polarising microscope, i.e. LEICA DM 2700P. The aim was to group the ceramic thin sections according to common strategies in the procurement and manipulation of raw materials. The resulting petro-groups were described and documented through photomicrographs at different magnifications. Comparative charts were used to quantify the main components (Rice 2015: 269). The obtained results were interpreted within a wider reference database including most of the petrographic data previously published on the ceramic assemblages from Southern Mesopotamia, in order to assess whether petrographic tools are able to distinguish production zones within this widespread alluvium plain.

RESULTS

Macroscopic fabrics

The macroscopic classification into fabrics was performed on a total of *c.* 4500 sherds, 1038 of which are diagnostic. The fabric classification aimed at selecting a representative sampling for petrographic analyses, as we could hardly rely on typological criteria due to local restrictions on the export of diagnostic material. The sherds were firstly grouped by the naked eye and then further observed with an USB handheld digital microscope (© Celestron Digital Microscope PRO) at 20x to 200x magnification.

The discriminant criteria for fabric classification were colour in a fresh section of the clay matrix as well as the type (e.g. mineral vs. vegetal), colour, amount, and size of inclusions. Colours, amount, and

Sample N. (Tell Zurghul)	SU (Area B)	Vessel N.	Shape	Macro-fabrics	Petro-groups
SG_001	633			Group 2	Gr. 1c
SG_002	625			Group 1	Gr. 5
SG_003	706			Group 2	Gr. 1b
SG_004	703			Group 1	Gr. 5
SG_005	620-L.266			Group 1	Gr. 5
SG_006	627			Group 1	Gr. 2
SG_007	635			Group 1	Gr. 6
SG_008	706	SG.17.BN.706/1	Bowl	Group 1	Gr. 6
SG_009	629			Group 2	Gr. 1a
SG_010	709			Group 1	Gr. 2
SG_011	703			Group 2	Gr. 1c
SG_012	627			Group 2	Gr. 1c
SG_013	713	SG.17.BN.713/3	Cup	Group 2	Gr. 1a
SG_014	706			Group 2	Gr. 1a
SG_015	L.263			Group 2	Gr. 1a
SG_016	624			Group 2	Gr. 1b
SG_017	703			Group 1	Gr. 2
SG_018	627			Group 2	Gr. 1c
SG_019	633			Group 2	Gr. 1c
SG_020	627			Group 2	Gr. 1b
SG_022	706		Bowl	Group 2	Gr. 1a
SG_024	705			Group 1	Gr. 4
SG_025	604			Group 3	Gr. 3
SG_026	706			Group 3	Gr. 7
SG_027	705			Group 1	Gr. 4
SG_028	706			Group 1	Gr. 4
SG_029	718			Group 1	Gr. 3
SG_030	705	SG.17.BN.705/19	Holemouth jar	Group 1	Gr. 4
SG_031	627			Group 1	Gr. 5
SG_032	720			Group 1	Gr. 3
SG_033	610	SG.17.BS.610/un2		Group 1	Gr. 5
SG_034	627	SG.17.BS.627/18	Bowl	Group 1	Gr. 3
SG_035	627			Group 2	Gr. 1b
SG_036	627		Cup	Group 2	Gr. 1b
SG_037	706	SG.17.BN.706/32	Cup	Group 1	Gr. 2
SG_038	630	SG.17.BS.630/4	Bowl	Group 1	Gr. 6
SG_039	804	SG.17.BE.804/3	Bowl	Group 1	Gr. 4
SG_040	703/705		Bowl	Group 1	Gr. 6
SG_041	L.263	SG.17.BS.L.263/un1	Bowl	Group 2	Gr. 1a
SG_042	L.263	SG.17.BS.L.263/un2	Bowl	Group 2	Gr. 1b

Tab. 1 - Analysed samples from Tell Zurghul with the indication of the stratigraphic unit (SU), the vessel number, the shape (when identified), macroscopic fabrics and petrographic groups identified.

size have been evaluated (colour and size) and quantified (amount) with the © Munsell Soil Color Charts. Accordingly, three main groups could be recognised. The first is characterised by the reddish-cream colours of the clay matrix and the recurrent (10 to 30%) presence of white, reddish, and black mineral inclusions of >1 to 2 mm size. The second group exhibits a greenish matrix containing orange and black mineral inclusions of the same size as in the first group (15 to 30% of frequency). Both group 1 and 2 present compact fabrics with few (around 3%) visible voids (around >1-1 mm size) derived from the presence of vegetal inclusions burnt out during the firing process. The third group was mainly distinguished by the predominance of vegetal inclusions (10-15%, 2-3 mm size), while the clay matrix invariably shows reddish, cream, and greenish colours. Mineral inclusions are less visible (white, orange, and black) and they are attested in lower frequencies (2-5%).

Petrographic grouping

The thin sections were classified into six petrographic groups (Tab. 2). The most represented group includes 17 thin sections and is distinguished by greenish-beige vitrified clay matrices, typically conferred by the high carbonate content, dominated by plant inclusions and quartz minerals. Iron oxides/hydroxides and biotites (altered by firing) also frequently appear, while plagioclases, K-feldspars, clinopyroxenes, muscovites, and bone fragments are rarer. In some cases, the alteration by firing of microfossils such as foraminifera left typical voids in the matrix. The high firing temperatures caused further changes in the clay matrix, which is vitrified and often shows degassing voids. The use of marine marls fired at temperatures above 900°C can be assumed based on the above-mentioned features of both the clay matrix and inclusions. The unimodal grain-size distribution concentrated in relatively fine fractions (up to 0.3 mm) of the mineral inclusions suggests that they were naturally present in the clay matrix and not added as temper. By contrast, vegetal components were intentionally added to the clay paste and then left typical voids due to their combustion during the firing process. The morphological variability of these voids and the absence of typical imprints of spikelets, glumes, caryopses, and straw allow us to exclude the use of cereal by-products as pottery temper. The inclusions are unevenly distributed and tend to cluster in cloudy spatial arrangements within the clay matrix, which indicates incomplete mixing processes during the paste preparation.

This main petrographic group is divided into the three subgroups based on the incidence and size of mineral and vegetable inclusions.

In *Subgroup 1a* (fig. 6: *a*: total of 6 samples) the plant inclusions, which predominate over the mineral fraction, reach a maximum incidence of 7%, have a polymodal grain-size distribution ranging between 0.2 and 6.5 mm and follow discordant or spiraliform orientations (at the joints between different coils). The size and incidence of the mineral fraction reach 0.08 mm (very fine sands) and 3%, respectively. The surface of most of the samples is covered by a reddish-black clay slipping layer of variable thickness, optically inactive and without inclusions.

Subgroup 1b (fig. 6: *b*: total of 6 samples) differs from the previous subgroup 1a in the increased and decreased sizes and amounts of the mineral (0.28 mm/5%) and vegetal fraction (3 mm/5%), respectively. Clay slipping layers occurs less often and show reddish-brown colours, a slight optical activity and inclusions up to 0.1 mm. Compared to Subgroup 1a, inclusions and voids follow a more oriented though not perfectly parallel spatial distribution

Petro-groups		Inclusions					Matrix		Orientation of inclusions, clay matrix and voids
		Type	Incidence	Grain-size distribution	Maximal diameter	Spatial distribution	Optical activity	Colour (PPL and XP)	
1	1a	veg, qu, op, bt, pl, kfds, cpx, mu, bo, for			6.5 mm				random with discordant and spiraliform patterns
	1b	qu, ox, bt, veg, pl, kfds, cpx, mu, bo, for, *chert, amph, qu-fds aggregates, qu-schist*	10%	polymodal-bimodal	3 mm	uneven and clustered	inactive (vitrified)	greenish-beige	slightly imbricated
	1c	qu, pl, kfds, ox, bt, veg, cpx, mu, bo, for, *chert, amph, qu-fds aggregates, qu-schist*			1.6 mm				stongly aligned
2		veg, qu, ox, bt, pl, kfds, cpx, idd/serp, mu, amph, qu-fds aggregates, chert, qu-schist, quartzite, ep, volc, *ca*	10%	bimodal	1.2 mm				weakly-moderately aligned
3		veg, qu, ox, bt, pl, kfds, cpx, idd/serp, mu, amph, qu-fds aggregates, chert, qu-schist, quartzite, ep, volc	30%	polymodal	5.2 mm				either aligned or random
4		veg, qu, ox, bt, pl, kfds, ca, cpx, idd/serp, mu, amph, qu-fds aggregates, chert, qu-schist, quartzite, ep, volc	20%	bimodal	2.6 mm	homogeneous	slightly active	brown to reddish-brown	
5		veg, qu, ox, bt, pl, kfds, cpx, idd/serp, mu, amph, qu-fds aggregates, chert, qu-schist, quartzite, ep, volc	25%	bi-polymodal	4.8 mm				random with discordant and spiraliform patterns
6		veg, qu, ox, bt, cpx, mu, idd/serp, amph, pl, kfds, qu-fds aggregates, chert, qu-schist, quartzite, ep, volc	15%	bimodal	2 mm				
SG_026 (Loner)		veg, ca, qu, mu, amph, kfds, pl, *shells*	35%	polymodal	5 mm		active	beige, brown and reddish-brown lenses + dark core	

Tab. 2 - Main features for each identified petro-group. The types of inclusions are listed in decreasing order of importance and are italicized in case they are not present in each sample. Abbreviations: qu=quartz; ox=iron oxides/hydroxides; bt=biotite; veg=vegetal temper; pl=plagioclase; kfds=K-feldspar; cpx=clinopyroxene; mu=muscovite; bo=bones; for=foraminifera; amph=amphibole; idd/serp=iddingsite/serpentine; ep=epidote; volc=igneous rocks; ca=micritic calcite; op=opaque minerals.

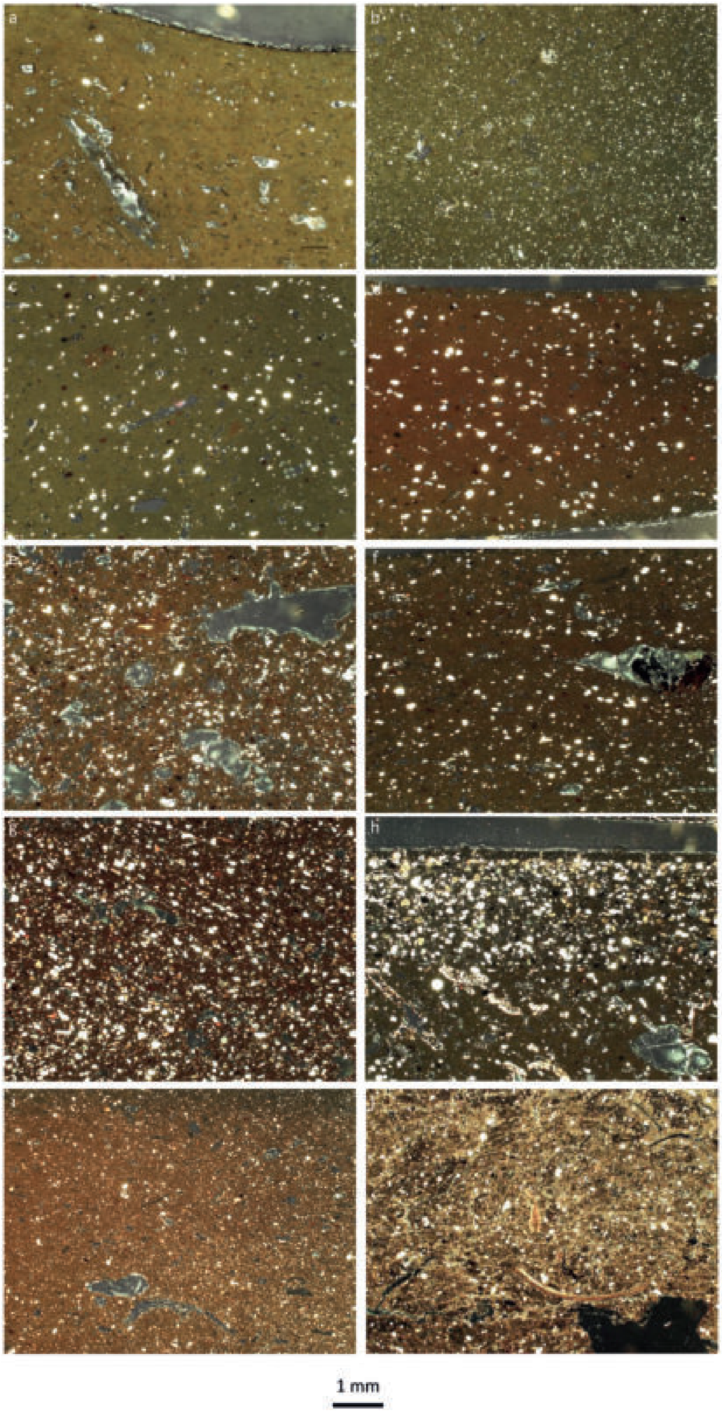

Fig. 6 - Main petrographic groups identified. a) Petro-group 1, subgroup 1a; b) petro-group 1, subgroup 1b; c) petro-group 1, subgroup 1c; d) petro-group 2; e-f) petro-group 3; g) petro-group 4; h) petro-group 5; i) petro-group 6; j) SG_026 (loner).

('imbricated pattern'). More than half of the samples contain chert fragments, while amphiboles appear much more rarely. Lithic quartz-feldspar aggregates and metamorphic rocks (quartz schist) are observed in isolated samples as well.

In the *subgroup 1c* (fig. 6: *c*: total of 5 samples), the size and incidence of the plant fraction further decrease (1.6 mm/3%), while the mineral fraction follows an opposite trend (0.32 mm/7%). The incidence of plagioclases and feldspars, which can form lithic inclusions together with quartz grains (also polycrystalline), is higher and bone inclusions up to 1.2 mm occur as well. Fine grains of brown hornblende were observed in a few samples as well. Porosity and inclusions follow an orientation parallel to the surfaces. The surfaces of most of the samples are covered by a compact blackish-brown to reddish-black optically inactive slip layer containing a few isolated inclusions up to 0.2 mm. Chert, polycrystalline quartz and metamorphic inclusions appear in most of the samples as well. The sample SG_001 is also distinguished by the presence of amphiboles, SG_011 by quartz schists and SG_012 by quartz-feldspathic lithic inclusions.

The remaining samples (fig.6: *d-i*) – i.e. 22 out of a total of 40 samples – differ from the above-mentioned petrographic subgroups in the brown- to reddish-brown-coloured matrixes; the greater incidence of chert, mafic inclusions – such as amphiboles, clinopyroxenes, iddinsgite, and serpentine – micas, feldspars (K-feldspars and plagioclases) and quartz-feldspar lithic aggregates; the presence of metamorphic traits (quartz-schists, quartzites, epidote, metamorphic and polycrystalline quartz), and igneous rocks; the absence of microfossils and bone fragments; the lower degree of alteration by firing of biotites; the slight optical activity of the matrix (firing temperature about 800°C); and the more homogeneous spatial distribution of inclusions. As seen in group 1 for the vegetal fraction, the mineral fraction shows here relatively low sorting degrees, high incidences, and large grain sizes, which point to its intentional addition as paste temper. Based mainly on grain-size criteria, 6 petrographic groups can be distinguished.

In *petro-group 2* (fig. 6: *d*: total of 4 samples) inclusions are weakly to moderately aligned to vessel surfaces, reach a maximum diameter and incidence of 1.2 mm and 10% and exhibit a bimodal grain-size distribution. The fine fraction (< 0.6 mm) predominates over the coarse one (0.6-1.2 mm), which exclusively consists in vegetal temper. Very few samples (SG_037 and SG_017) also contain micritic calcite.

In *petro-group 3* (fig. 6: *e-f*: total of 4 samples) the maximum size and incidence of inclusions are 5.2 mm and 30%. The grain-size distribution is polymodal with equally represented fine (< 0.6 mm), medium (0.6-1.8 mm) and coarse modes (> 1.8 mm). While mineral inclusions are only present in the finer fractions, vegetal inclusions dominate all the fractions. Some of the voids left by the burnt vegetal matter like in the sample SG_029 are attributable to anatomical parts of cereal plants. Firing times in most of the cases were not long enough to allow a complete oxidation of the vegetal matter. In half of the samples (e.g. SG_034 and SG_029) inclusions are aligned parallel to the surfaces, while in the other half (e.g. SG_025 and SG_032) they show a random distribution with spiraliform and discordant patterns. SG_029 presents a superficial layer, which is finer-grained and lacking in any inclusions, with a more reddish colour and darker shade compared to the underlying ceramic body. This could indicate both peculiar surface treatments (intense burnishing or wet smoothing) and firing procedures (change of atmospheres at the end of the firing process).

In *petro-group 4* (fig. 6: *g*: total of 5 samples) the inclusions amount to 20% of the total paste mixture and do not display any preferential orientation within the matrix, but rather show discordant and spiral-like patterns. The grain-size distribution is bimodal, with a predominance of the fine fraction (< 0.8 mm) – which creates closed spaces between the various grains – over the coarse one (0.8-2.6 mm). As observed in the previous petro-groups, the coarse fraction consists exclusively of vegetal temper, while the fine fraction is dominated by minerals. Micritic calcite occurs abundantly in all samples.

The inclusions of *petro-group 5* (fig. 6: *h*: total of 5 samples) reach sizes and incidences of 4.8 mm and 25% and mostly follow random and discordant spatial arrangements. The inclusions present a bi- to polymodal grain-size distribution with an equal incidence of the finer and coarser fraction. This latter only consists, as observed so far, of vegetal components. The sample SG_004 is distinguished by the higher incidence of vegetal temper and the peculiar double-layered surface treatment: the underlying layer is 2 mm thick and rich in mineral especially calcareous inclusions; the superficial layer is thinner (0.2 mm) and without inclusions.

In *petro-group 6* (fig. 6: *i*: total of 4 samples) the inclusions follow random and discordant spatial patterns and reach a maximum size and incidence of 2 mm and 15%. The mineral fraction is concentrated in the finest fractions, between silts and very fine sands. One can assume the use of a naturally silty clay with a granular texture, to which vegetal temper was added. In terms of mineral-petrographic associations, petro-group 6 is distinguished by the lower amount of feldspar-based lithic and mineral inclusions and the higher content of mica, both biotite and muscovite.

The sample SG_026 (fig. 6: *j*) shows peculiar features and has to be considered a petrographic loner. SG_026 has a calcareous matrix, crossed by a dense network of thin cracks, optically active, with a dark core and colours unevenly distributed into beige, brown and reddish-brown lenses. The bimodally-distributed inclusions reach a maximum size and incidence of 5 mm and 35% and are randomly oriented. The grain-size distribution is polymodal but with a predominating coarse fraction (> 1.2 mm), which only consists of vegetal inclusions that were often not fully oxidised during the firing process. The grain size of mineral inclusions falls into the range of very fine silts and sands composed, in decreasing order of incidence, of micritic calcite, quartz, muscovite, brown hornblende, K-feldspar, plagioclase, and shells (bivalves and gastropods).

DISCUSSION OF THE RESULTS

Comparison between the macroscopic and petrographic grouping in relation to the morphological ceramic repertoire

Petrographic groups and macroscopic fabrics correlate quite well (fig. 7, *a*). The carbonate-rich and high-fired petro-group 1 dominated by quartz and vegetal inclusions consistently corresponds to the second fabric. However, the slight distinctions observed within petro-group 1, i.e. between subgroups 1a, 1b and 1c, are not tangible at a macroscopic level. The first macro-fabric is comprised of several petro-groups (2, 3, 4, 5 and 6), which, nevertheless, share a series of features, such as a low-fired and non-calcareous clay matrix as well as the presence of igneous and metamorphic components. The calcareous low-fired sample SG_026 (loner) tempered with vegetal matter fits with the third main fabric.

As previously stated, the main aim of the fabric classification was to correlate, though indirectly, the analytical results with vessel shapes and types, as sampling could be performed almost exclusively on undiagnostic sherds. If we assume the

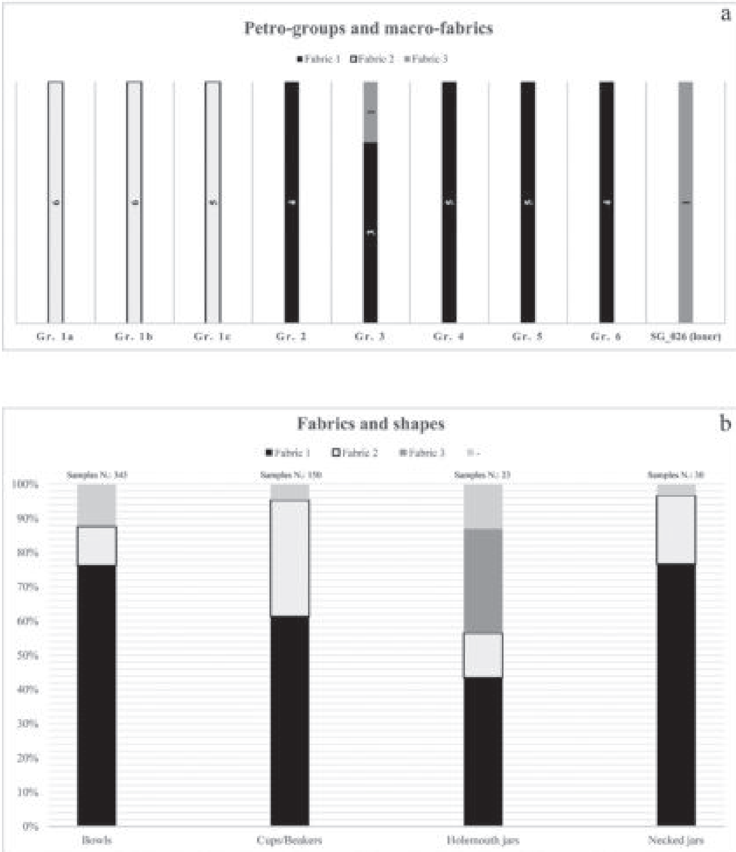

Fig. 7 - a. Ratio between petrographic groups identified and macroscopic fabrics; b. ratio between macroscopic fabrics and morphological shapes.

above-mentioned matches to be representative, no close relations emerge between vessel shapes/types and fabrics, i.e. petro-groups (fig. 7, *b*). In other words, the same shape could be produced with distinct raw materials and paste preparations, while distinct shapes can share the same recipes. Only bowls and necked jars show a clear predominance of the first fabric, which, however, might correspond to a series of distinct petro-groups (2 to 6).

Local supply strategies and production organisation of the Ubaid pottery

All the minero-petrographic associations identified in the Ubaid vessels from Tell Zurghul point to a local production based on both the compatibility with the formations reported on geological maps (fig. 8) and the criterion of abundance. Distinctions within petro-group 1 (i.e. between sub-groups 1a, 1b and 1c) and between petro-groups 2–6 mainly concern the grain-size distribution of inclusions, namely the different ways of processing the same raw material. The differences between petro-group 1 and petro-groups 2–6 indicate instead the use of at least two local basins, one of calcareous-fossiliferous nature and one non-calcareous exhibiting metamorphic and igneous traits. The catchment area of both deposits is located in close proximity to the site: calcareous-fossiliferous clays come from the marshes or marine areas of the Persian-Arabic Gulf, the shoreline of which was located immediately south of the site in the Mid-Holocene period (Geyer, Sauvage 2020; Kennett, Kennett

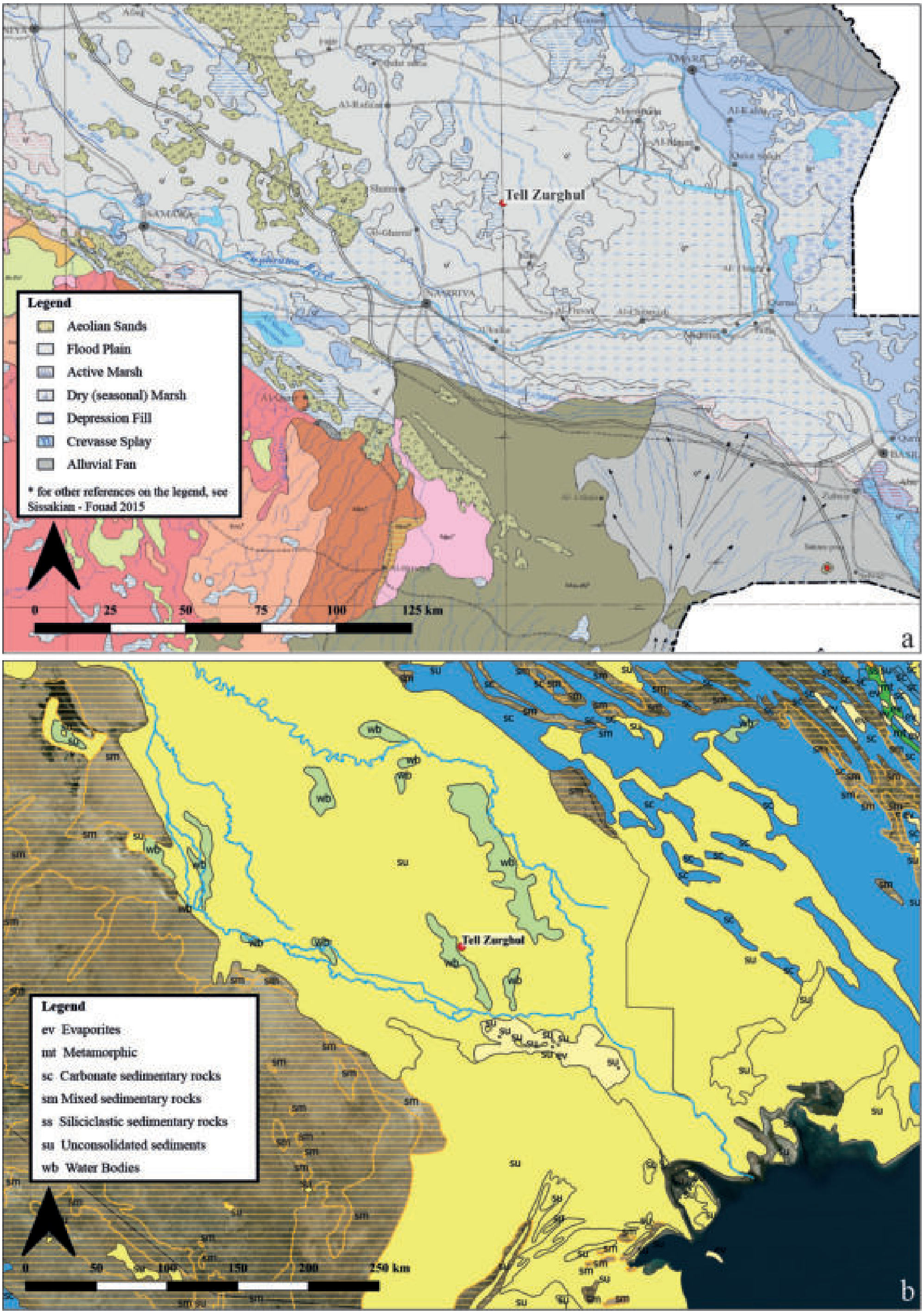

Fig. 8 - a. Geological map of Southern Mesopotamia with the location of Tell Zurghul/Nigin (after Sissakian, Fouad 2015); b. Lithological map of Southern Mesopotamia with the location of Tell Zurghul/Nigin (after Hartmann, Moosdorf 2012).

2006); non-fossiliferous clays with metamorphic, ophiolitic and volcanic traits are instead compatible with the sediments of the Anatolia-Zagros orogen carried by the Tigris (Garzanti *et alii* 2016: 119), which today flows about 80 km from the site but must have been much closer in antiquity (Al-Hamdani 2015: 124; Geyer, Sauvage 2020: 9-10). Furthermore, the amphiboles, epidotes, and pyroxenes observed in petro-groups 2–6 are also reported from local boreholes, which reached the Holocene levels (Al-Kaaby, Albadran 2020: fig. 1, 7).

Similar raw material procurement patterns and paste preparation modes have been identified for the Ubaid vessels from Tell Oueili (Courtois, Velde 1983: 148), where a total of 244 thin sections have been analysed (Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996). According to the authors 'il n'y a pas, dans les séries étudiées, de grand contraste minéralogique d'une poterie à l'autre. Les différences sont essentiellement d'ordre granulométrique, c'est-à-dire dues à la présence ou non et à la proportion de sable (contenu) dans les céramiques. [...] Cependant quelques différences dans l'aspect des fonds de pâte doivent être clairement mises en évidence. [...]. Ces différences visuelles correspondent en fait à l'utilisation de plusieurs terres plastiques diverses tant par leur composition physico-chimique que par leurs caractères granulométriques, et qui sont soit des argiles limoneuses plus ou moins micacées, soit des argiles marneuses « hyper fines », très riches en carbonates.' (Courtois 1983: 143-144). A last common piece of evidence between Tell Zurghul and Tell Oueili is the lack of correlations between paste recipes and morpho-functional shapes, which may be taken as a hint corroborating that the pottery production was organised at a household level, as already proposed by Courtois and Velde (1996: 323).

Petrography-based production zones within Central-Southern Mesopotamia

The ceramic petrographic data from Central and Southern Mesopotamia are compared here to assess if productions zones might be distinguished on a petrographic basis (Al Kaissi, Mynors 1987; Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996; Mynors 1983; 1987). From north to south, the following areas were compared (figs. 9; 10):

- The Middle Euphrates, which refers to the region along the northernmost stretch of the Iraqi Euphrates River valley;
- The Hamrin area;
- The southern Diyala region;
- Upper Southern Mesopotamia, which includes the sites of Kish, Jemdet Nasr, and Abu Salabikh;
- Middle Southern Mesopotamia comprised of the sites of Nippur and Fara;
- Lower Southern Mesopotamia with the sites of Uruk and Tell Oueili;
- Southern Euphrates, represented by the sites of Eridu, Ur and al-Ubaid;
- Mid-Southern Tigris with the sites of Tell al Wilaya, Lagash and Tell Zurghul.

As one can expect in such a homogeneous geological setting, similar minerals and rocks occur across the different sites and areas (Tab. 3). Quartz, feldspars, pyroxenes, calcite, and opaque minerals as well as various sedimentary and igneous rocks are ubiquitous. However, the occurrence of some other minerals such as amphibole, biotite, muscovite, epidote, iddingsite/serpentine, chlorite, and glauconite shows variations according to sites and/or areas.

The Middle Euphrates, Diyala and Hamrin regions (fig. 10, *b*) differ from Southern Mesopotamia, the Southern Euphrates, and Mid-Southern Tigris (fig. 10, *a*) by the absence of amphibole, olivine,

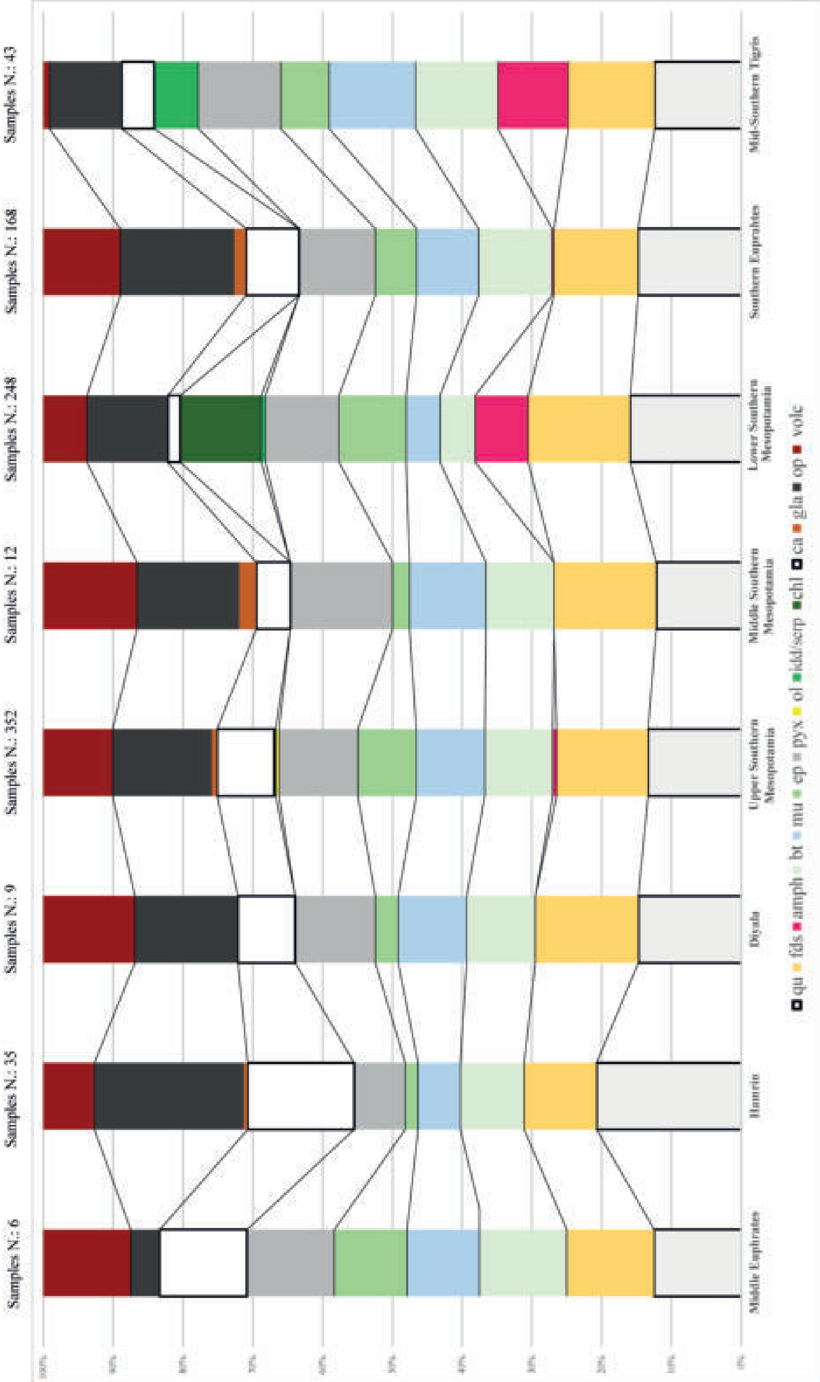

Fig. 9 - Graph of occurrence of main minerals and rocks inclusions in ceramic thin-section petrography according to possible petro-regions within Central and Southern Mesopotamia (data from Tell Zurghul thin-sections and from Al Kaissi, Mynors 1987; Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996; Mynors 1983; 1987).

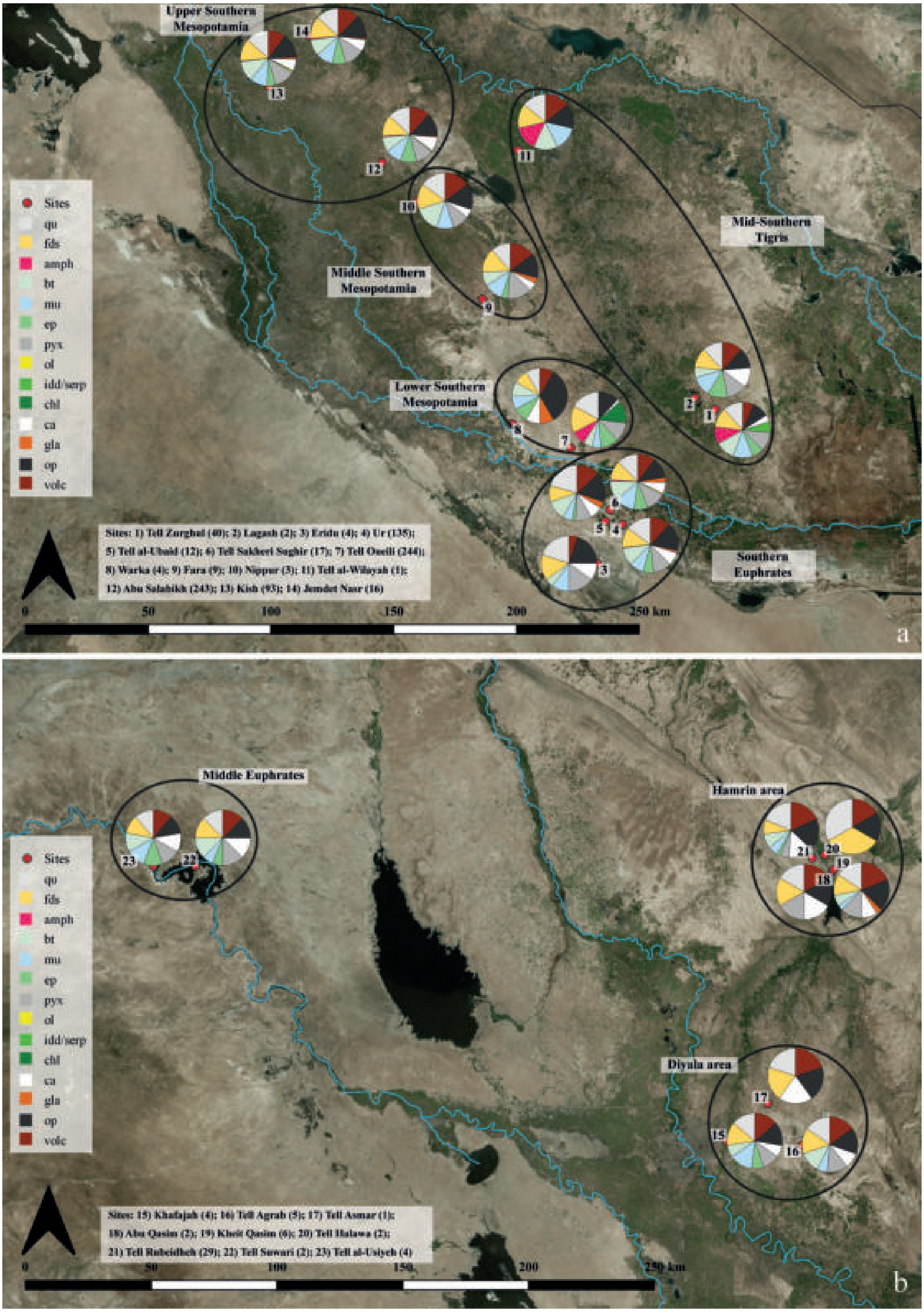

Fig. 10 - Location of the main sites from Central and Southern Mesopotamia with the occurrence of main minerals and rocks inclusions in ceramic thin-section petrography site-by-site. Close to site names, in bracket ( ) the number of analysed samples (data from Tell Zurghul thin-sections and from Al Kaissi, Mynors 1987; Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996; Mynors 1983; 1987).

Area	Minerals													
Middle Euphrates	qu	fds		bt	mu	ep	pyx				ca				op
Diyala	qu	fds		[bt]	[mu]	[ep]	pyx				ca				op
Hamrin	qu	fds		[bt]	[mu]	[ep]	pyx				ca	[gla]			op
Upper southern Mesopotamia	qu	fds	[amph]	bt	mu	[ep]	pyx	[ol]	[idd/serp]		ca	[gla]	[sil]	[chr]	op
Middle southern Mesopotamia	qu	fds		bt	mu	[ep]	pyx				ca	[gla]			op
Lower southern Mesopotamia	qu	fds	[amph]	bt	mu	[ep]	pyx		[idd/serp]	chl	ca	[gla]			op
Southern Euphrates	qu	fds	[amph]	bt	mu	[ep]	pyx	[ol]			ca	[gla]			op
Mid-Southern Tigris	qu	fds	amph	bt	mu	ep	pyx		[idd/serp]		ca				op

Tab. 3 - Main minerals for each possible petro-region. Abbreviations: qu=quartz; fds=feldspars; amph=amphibole; bt=biotite; mu=muscovite; ep=epidote; pyx=pyroxene; ol=olivine; idd/serp=iddingsite/serpentine; chl=chlorite; ca=micritic calcite; gla=glauconite; sil=sillimanite; chr=chronodronite; op=opaque minerals. In brackets [ ], minerals attested only in few samples of each region (after Al Kaissi, Mynors 1987; Courtois 1983; 1996; Courtois, Velde 1983; 1987; 1991; 1996; Mynors 1983; 1987).

iddingsite/serpentine, and glauconite. As a result of this absence the minero-petrographic associations of the Middle Euphrates, Diyala and Hamrin are less variegated, being almost exclusively dominated by quartz, feldspars, calcite, pyroxene, muscovite, biotite, and epidote. Within these two macro-areas further distinctions emerge. While muscovite, biotite, and epidote occur in almost each vessel from the Middle Euphrates, they become more sporadic and even absent (e.g. Abu Qasim and Tell Halawa) in the vessels from the Diyala and Hamrin areas. Diyala and Hamrin are further distinguished by the presence of angular-shaped quartz, absent in the Middle Euphrates area (Al Kaissi, Mynors 1987: 144, tab. 1; Mynors 1983: 383, tab. 4).

The ceramic samples from the Mid-Southern Tigris differ from the Southern Mesopotamian ones by the absence of glauconite and olivine as well as by the occurrence of iddingsite/serpentine and the higher incidence of amphiboles and epidotes. This is consistent with sedimentological studies performed in the region at the end of the 1960s, which found that amphiboles and epidotes are transported through the Upper/Lower Zab and Adhaim rivers, respectively, into the Tigris (Philip 1968: 39-41). By contrast, vessels from Central Mesopotamia do not differ from each other by their minero-petrographic composition. The only exception is the site of Tell Oueili, which is distinguished by the presence of chlorite in more than 70% of the analysed vessels, generally in association with amphiboles and iddingsite/serpentine.

The occurrence of chlorite in the surroundings of the site is further confirmed by modern boreholes that drilled more and less recent fluvial sediments of both the Euphrates and the Tigris rivers (Al-Mukhtar 2015; Garzanti *et alii* 2016; Philip 1968).

The above-mentioned differences are possibly due to the distinct mineralogical and lithological nature of the sediments transported within this complex hydrographic system. Amphiboles are mainly carried by the Tigris and most of its tributaries, while they are almost lacking in the Middle and Southern Euphrates area as well as in Upper, Middle, and Lower Mesopotamia. In contrast, glauconite does not occur in the Mid-Southern Tigris area, while it is attested in Southern Mesopotamia and in the Southern Euphrates area. Finally, the more variegated minero-petrographic associations observed in the ceramics from Central Mesopotamia are possibly due to the contribution in the sediment formation of both the Euphrates and Tigris rivers.

CONCLUSION

Consistently with the evidence from other coeval sites, Ubaid ceramics were locally produced at Tell Zurghul as well, where at least two distinct supply sources were exploited. The raw materials available were then processed in different ways, which led to a relatively large number of recipes, i.e.

petro-groups. Surface treatments, shaping techniques (Volpi in press) and firing procedures point to a certain degree of variability as well. This variability does not at all correlate with vessel shapes and types, which suggests a non-specialised production probably organised at a household level. A similar hypothesis has already been proposed by Courtois and Velde (1996: 323) for the Ubaid repertoire from Tell Oueili on the basis of the archaeometric evidence.

Despite the widespread geological homogeneity of the Southern Mesopotamian alluvial plain, a distinction into production areas appears to be possible based on some mineral inclusions identified both in modern geological boreholes and ancient ceramic assemblages. Sites like Tell Zurghul can be therefore located within the Tigris's sedimentological zone of influence (at least from the Ubaid period until the 3rd millennium BCE), which is distinguished by the higher incidence of some heavy minerals such as of amphiboles and epidotes. Distinctive of the nearby site of Tell Oueili is the recurrent presence of chlorite among ceramic inclusions.

Future research aiming at reconstructing ceramic exchange networks within Mesopotamia should integrate the petrography-based distinctions identified in this work with geochemical methods. The success of large-scale petrographic comparative studies also depends on collecting data according to standardised procedures and terminologies, which has not always been the case so far. To this end, a more precise quantification of the different components and fractions would be very much needed. Last but not least, the potential of heavy mineral and grain-size analyses should be further explored both on ancient ceramics and recent sediments taken along the Euphrates and Tigris basins.

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