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A compositional and technological reassessment of the function of potters' marks on Early Bronze Age sherds from Tell el-'Abd, Syria

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ABSTRACT

A highly distinctive feature of the Early Bronze Age ceramic assemblage of the site of Tell el-'Abd in northern Syria is the presence of large numbers of pots that were incised with a diverse range of symbols prior to firing. Several hypotheses have been proposed to explain the function of such ceramic "potters' marks". One is that they functioned as a signature or trademark used by potters or workshops to identify their work. Another possibility is that they were used for quality control or accounting purposes during manufacture. Alternatively, they may have signified vessels intended for specific customers, or the size or contents of the vessels. In the case of the Tell el-'Abd potters' marks, distinguishing between these possibilities has proven difficult based upon their macroscopic examination and archaeological context alone. The present research, therefore, attempts to shed further light on the function of the potters' marks by studying the clay paste recipes of 33 ceramic samples using scientific methods. Thin section petrography, instrumental geochemistry and scanning electron microscopy have been used to characterise and classify sherds according to their raw materials and manufacturing technology. This has been compared to the type of potters' mark and other archaeological information in order to test the hypotheses that the distinctive ceramic markings signified ceramics made at different production centres or distinguished between different artisans operating at the same workshop.

1. Introduction

Ceramic markings are isolated symbols, numbers, letters or representations on the surface of pottery vessels or other objects such as bricks and tiles, that are likely to have served a non-decorative function. They can be stamped or incised into the moist clay before firing, in which case they can be referred to as potters' marks. Alternatively, they may also be scratched into the fired piece after production, as a 'graffito', or painted onto it. Such marks have been reported on objects from a wide range of archaeological periods and geographic regions, including the prehistoric Aegean (Lindblom, 2001; Papadopoulos, 2017), Anatolia (Glatz, 2012; Derin, 2013), the Near East (Potts, 1981; Hirschfeld, 1990; London, 1991; Lapp, 1995; Genz, 2001; Feldbacher and Fischer, 2008; Paz, 2011; Sconzo, 2013), Classical, Hellenistic and Roman Mediterranean (Peacock, 1977; South and Steele, 2007; Hirschfeld, 2011; Betina and Skaltsa, 2018; Nagy et al., 2018; Empereur and Abdel Gawad, 2020) and Europe (Trzeciecki, 2018; Ollich et al., 2020; Coto-Sarmiento and Rubio-Campillo, 2021; Hartely and Dickinson, 2008), the Far East (Quinn et al., 2020; Womack and Wang, 2020) and Islamic world (Golombek et al., 2001), as well as South America (Donnan, 1971; Bernier, 2010), ancient Egypt (Lasken, 1993; Bréand, 2009) and sub-Saharan Africa (Ogundiran and Saunders, 2011).

These modifications to the exterior, interior or base of a vessel or other ceramic object may have been indicators of the artisan (Papadopoulos, 2017, p. 91), supervisor or workshop (Quinn et al., 2020) that produced it, or their family/clan membership. They could also have recorded the date an item was produced (Golombek et al., 2001), its volume or contents (Beller, 2014), or the intended owner or customer for which the ceramic object was made (Cambi, 1989). Some may have been as a mark of quality control during manufacture (Li et al., 2016) or were left during accounting procedures (Tassie et al., 2008). Alternatively, they could have served some sort of social function between potters (Ogundiran and Saunders, 2011), encouraged success in the production process, or gave the user of the ceramic object good luck

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(Derin, 2013, p. 94). Hirschfeld (1999) summarised these functional explanations as being associated with either 'Production', 'Trade' or 'Use'.

Some ceramic markings contain letters or symbols that can be related to ancient script (e.g. Caskey, 1970), meaning that they can be deciphered, and may even be used to study the evolution of early writing systems (e.g. Kenoyer, 2020). However, understanding the specific meaning of markings that are not related to any known literary or numeric system is much more difficult. Nevertheless, by assessing the probable function(s) that the marks served, including those listed above, it is possible to reveal important insights into the activities that necessitated them, such as the organisation of ceramic production, the trade, exchange and consumption of pottery and the commodities that transport vessels contained (Coto-Sarmiento and Rubio-Campillo, 2021), as well as systems of administration and the realisation of large scale building projects (Li et al., 2016).

Determining the function(s) of ceramic markings requires the use of multiple lines of evidence (Hirschfeld, 1999; 2002; 2008), including: the motif and its relation to others within a suspected marking system; whether it was applied while the clay object was moist; dry or fired; the marking location; whether the marking was intended to be visible or hidden; what type(s) of object were marked; the frequency and distribution of markings in time and space; as well as the occurrence of similar symbols on other artefact types (Li et al., 2016). Unfortunately, the function of markings on pottery and other ceramic objects might not be readily apparent based on traditional archaeological evidence (e.g. Papadopoulos, 2017, pp. 88–91). This calls for the use of ethnographic analogy from traditional pottery making in the present day or recent past (Donnan, 1971; Arnold, 1972; Kramer, 1985, p. 117), as well as the application of scientific techniques from the field of materials science (Giacomini, 2001; Golombek et al., 2001; Kurzmann, 2006; Gliozzo et al., 2020). The latter provides additional evidence with which to investigate the role(s) of ceramic markings, such as in a recent study of the Terracotta Army in China, in which a chemical difference was detected between the clay paste of statues marked with the names of two suspected workshops (Quinn et al., 2020). In another archaeometric study on building materials from the Roman period, a difference in the geochemical composition could be detected on stamped bricks associated with two pottery production areas (Gliozzo et al., 2020). Despite this potential, scientific information on the geological raw materials and the ceramic recipes of sherds has been utilised in only a handful of cases.

The present pilot study adopts a compositional and technological approach to selected samples from a large and unique corpus of Early Bronze Age potters' marks from the site of Tell el-'Abd in northern Syria (Sconzo, 2013) (Fig. 1). The complementary techniques of thin section petrography, instrumental geochemistry and scanning electron microscopy have been applied to these sherds to form compositional groupings, interpret their ceramic raw materials and assess the production origin or provenance of the material. The results are cross-referenced against the morphology of the potters' marks in order to determine whether these distinctive pre-firing symbols could have been associated with the ceramic production process in some way, particularly as a means of 'intra-workshop' notation or potters' signature, or as a trademark to identify and/or advertise the products of different production centres ('inter-workshop'). Supporting or ruling out one or more of these possible theories will shed much-needed additional light on the function of the enigmatic markings, which are a key characteristic of the early stage of the settlement of Tell el-'Abd and the lower Big Bend region of the Euphrates during the first half of the third millennium BC, but diminish in the later phase and are conspicuously absent elsewhere in Syria.

1.1. The Potters' marks of Tell el-'Abd

The site of Tell el-'Abd was once located on a limestone cliff overlooking the Euphrates River at a crossing between Jebel Sin and Jebel

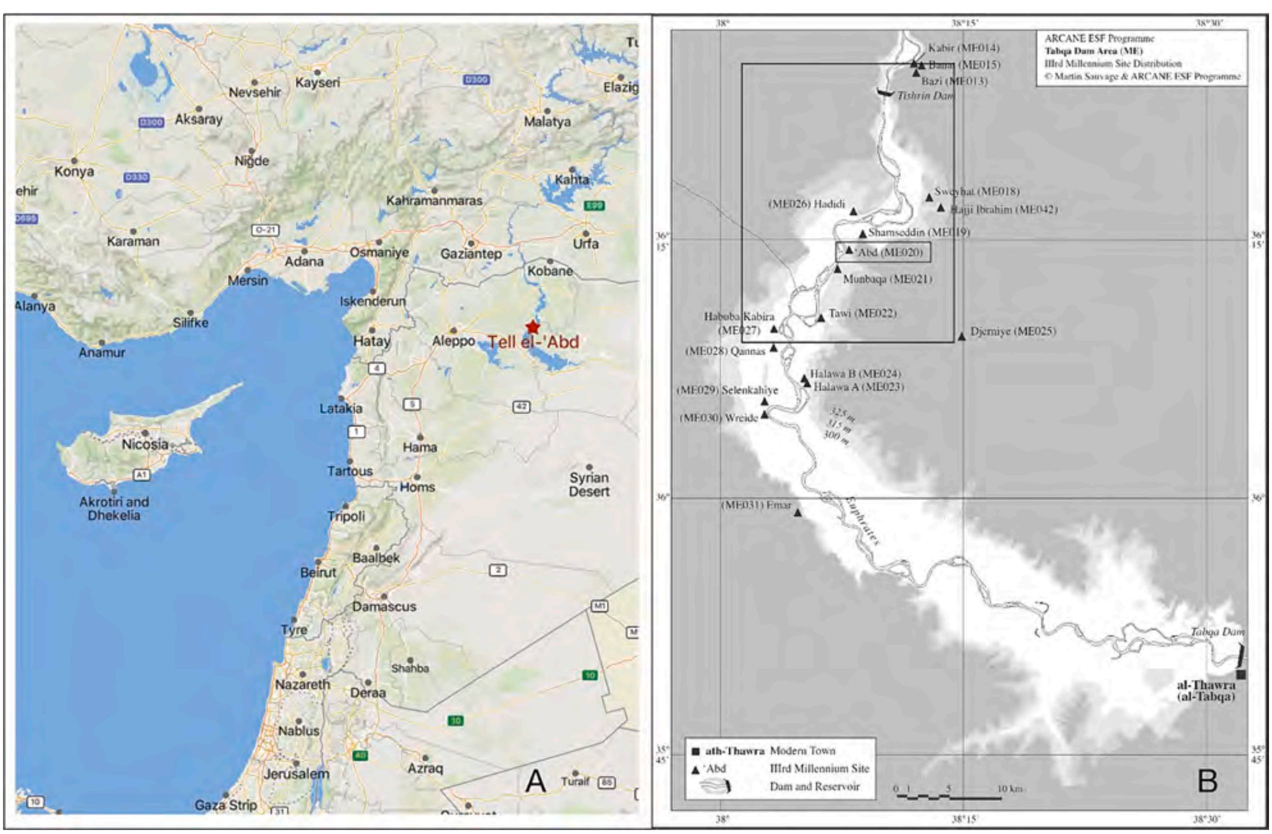

Fig. 1. (A) Geographical location of Tell el-'Abd within Syria (after MapCarta). (B) Tabqa Dam district (after Sconzo, 2013, fig.2.1).

Aruda, in the Tabqa Dam area of northern Syria (Figs. 1 and 2). Its rescue excavation in 1992–1994 by a German mission from the Altorientalisches Seminar of Tübingen University brought to light a collection of 1,376 marked sherds, the most extensive recovered anywhere in Syria. This impressive corpus was the subject of detailed typological study and archaeological interpretation by Sconzo (2013).

Almost half of the Tell el-'Abd markings were recovered from stratified contexts of Area III, dating to the beginning of the third millennium B.C. (Sconzo, 2013, p. 227) (Fig. 3). They were all applied before firing, during the process of vessel production, most likely the drying or stacking stage. This means that they can be thought of as potters' marks. Most were incised, though some were created via excision, plain impression, punching, or a combination of techniques. The markings occur mainly on plain medium or large 'Simple Ware' jars, followed by small hemispherical cups and storage jars (Fig. 4: 1–4), as well as on smaller numbers of 'Cooking-Pot Ware' (Fig. 4: 5–6). The Tell el-'Abd potters' marks displays a high degree of morphological variability and have been classified by Sconzo (2013, pp. 230–266) into 185 types and varieties belonging to 17 broad groups. These range from simple linear patterns (e.g. Group II Linear Pattern – Fig. 5A) to more complex signs (e.g. Group XIII Multiple stroke figures – Fig. 5D) and zoomorphic (Group XV Stylised animals – Fig. 5F) and human representations (Group XVI Anthropomorphic figures – Fig. 5H).

Many of the recorded marking types are also attested at several localities in the immediate neighbourhood of the site, or elsewhere in the Tabqa Dam district (Hempelmann, 2005; Holland, 2006), while the other half remains a unicum in the region, suggesting that Tell el-'Abd may have served as either a production or re-distribution centre. Certain potters' marks, such as the 'man with raised arms' (Fig. 5H) have also been reported as engravings on stones and in wall paintings (Sconzo, 2013, pp. 263–264), suggesting that they could have meaning beyond more functional needs such as differentiation, accounting, advertisement or identification.

Despite the detailed typological analysis conducted on the marked sherds from Tell el-'Abd, along with investigations into their contextual occurrences and associations with markings found on ceramics from various sites, periods, and objects (Sconzo, 2013), the precise function(s) they served remains elusive.Through a comprehensive study of the potters' marks of Tell el-'Abd, in terms of their morphological characteristics, the relative abundances of the different types, the shape, size and probable function of the parent vessels, the position of the markings on the ceramics, the contexts from which the sherds were recovered and their relationship to markings on other objects at the site and in the surrounding region, several possible explanations for why pots were

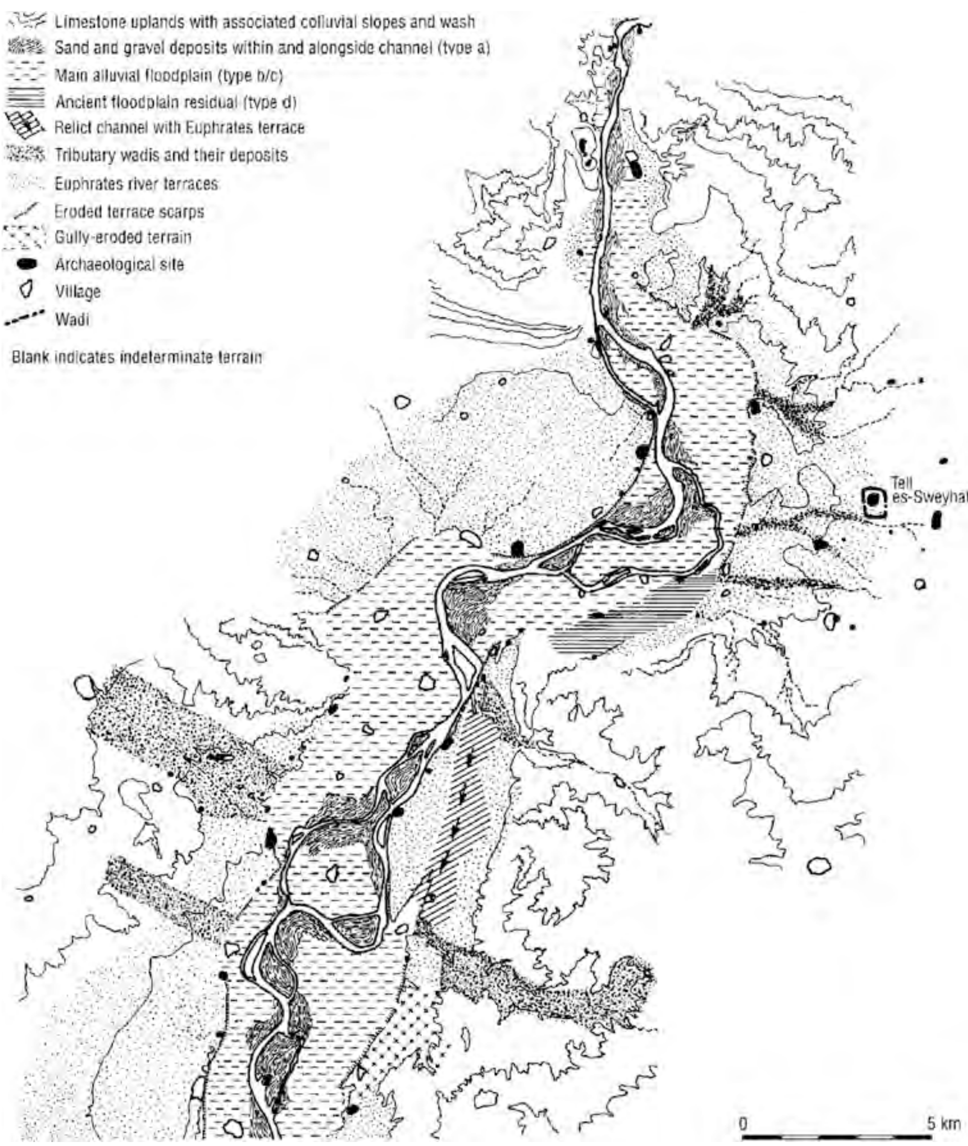

Fig. 2. Geomorphological map of the Tabqa Dam district (after Wilkinson, 2004, fig.2.2).

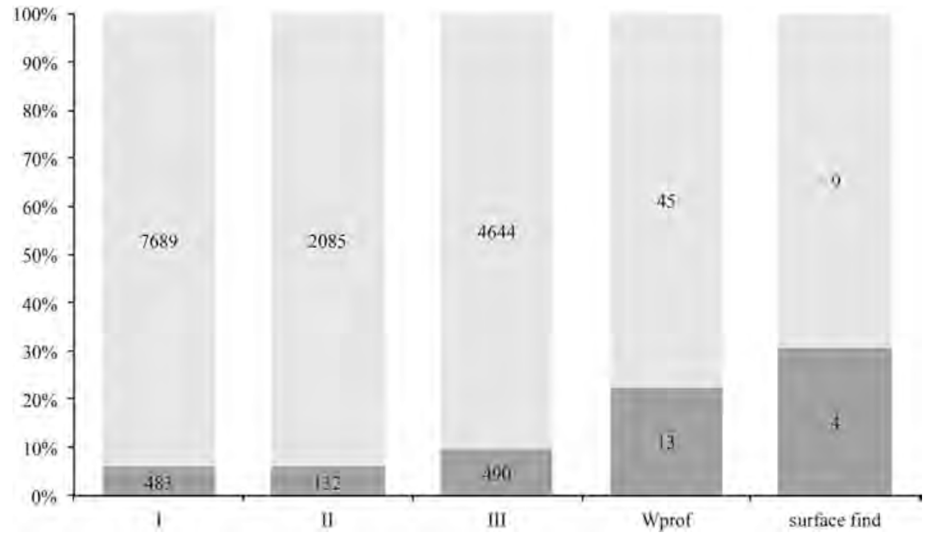

Fig. 3. Frequency of potmarks according to the total number of diagnostic sherds (of all periods) per Area (Sconzo, 2013, fig. 7.17, p. 277).

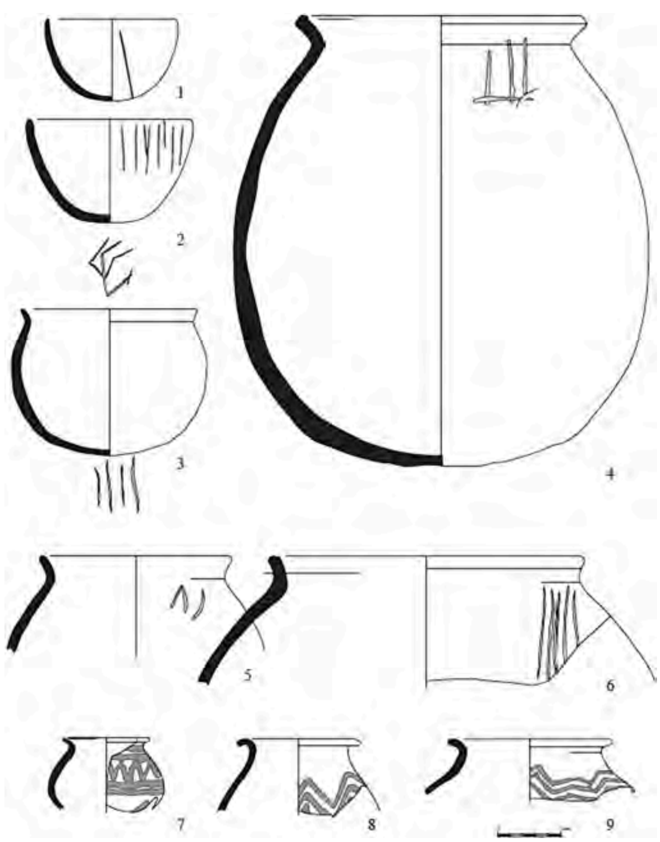

Fig. 4. Most common vessel shapes bearing potmarks: nos. 1–4 Simple Ware; nos. 5–6 Cooking Pot Ware. Nos. 7–9 show examples of Euphrates Monochrome Painted Ware sherds also mentioned in the text. Scale 1:4.

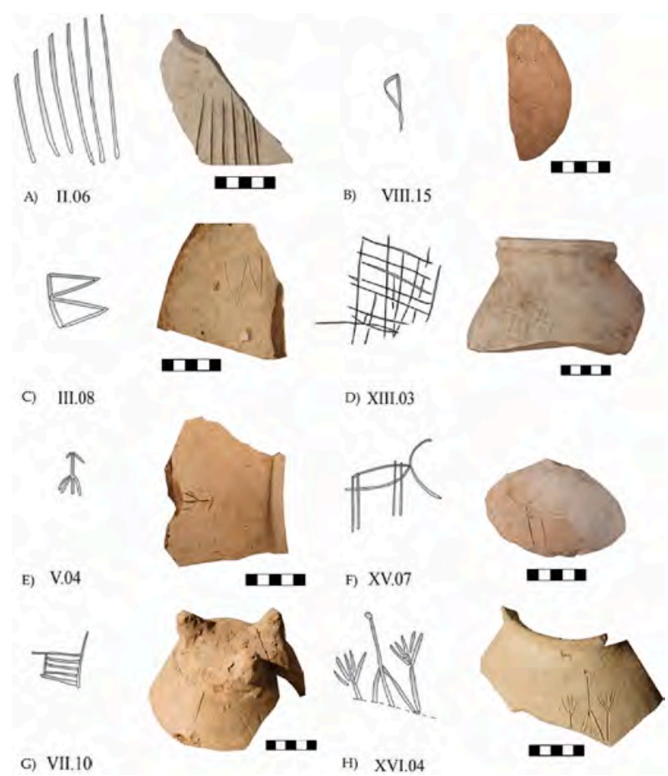

Fig. 5. Examples of potters' marks on ceramics from Early Bronze Age Tell el-'Abd, northern Syria, with their classification according to Sconzo (2013, pp. 230–266). (A) Group II Linear Pattern, (B) Group VIII Crescent-shaped pattern, (C) Group III V-shaped pattern, (D) Group XIII Multiple stroke figures, E) Group V Trident and arrow, (F) Group XV Stylised animals, G) Group VII Frame, H) Group XVI Anthropomorphic figures. Scale bars: 5 cm.

marked at this site in the third millennium BC were explored (Sconzo, 2013). Given that the markings were applied during the production process, before firing, the 'production', 'trade' and 'use' functional categories defined by Hirschfeld (1999) were considered.

Marking practices associated with trade and use may have served to signify the volume (e.g. Fargo, 1980; Helms, 1987), quality (e.g. Oates, 1982; Genz, 2001; Beller, 2014), price (e.g. Kolinski, 1994, p. 12) of the products that the vessels were intended to contain. While potters may have marked their vessels before firing, according to volume, the presence at Tell el-'Abd of identical signs on sherds deriving from vessels of different sizes seems to rule out this explanation (Sconzo, 2013, p. 285). Marking pots during the production process, according to their intended contents, also seems unlikely given that certain forms, such as cooking pots and bowls, were most probably used to process or serve a range of foodstuffs, and potters may not have known in advance what storage vessels were destined to contain. Similarly, the likelihood of the price of the vessels or their contents being decided during the production process is small and is perhaps not supported by the occurrence of similar markings on vessels of different forms and sizes or of different markings on the same type of vessel.

An additional possible explanation in terms of the potential trade of the Tell el-‘Abd marked pots is that their symbols were an indicator of the intended buyer/owner of the vessels (e.g. Cambi, 1989). This may have been known at or before the time of production and was marked on the ceramics to ensure that the correct pots reached their owner once completed. The evidence for this hypothesis is somewhat inconclusive at Tell el-‘Abd and is not helped by the relative lack of primary contexts (Sconzo, 2013, p. 285). In the small southern units of the site, the occurrence of an exclusive set of markings may support the idea of ownership. However, in the domestic context of Area III/Level 4, a much wider range of signs was encountered. This could be seen to indicate that the various markings distinguished the ceramics of a specific individual or family from those of others, in a communal setting during the use-life of the vessels.

Finally, the large size and location of the signs, on the vessel shoulder or above the belly, was used to support the hypothesis that they needed to be easily visible and could therefore be used to distinguish between the products of different workshops or potters. In this view, they could have acted as ‘signature’ that was used by potters to identify their goods at a local and/or regional market. The markings may also have been used to keep track of the objects created by different potters, or groups of potters from the same workshop, that made use of a single communal kiln (Sconzo, 2013, p. 318). However, these hypotheses remained to be tested through a detailed study that considers not only the typology, but also the production technology of the pottery found at the site.

The present pilot study therefore aims to shed additional light on the meaning of the Tell el-‘Abd potters' marks by applying a compositional and technological approach to the diverse corpus for the first time. This is explored in terms of possible compositional variation in the geological raw materials used to fashion the pots and their paste preparation recipes, which are compared to the marking types, vessel forms and wares that they occur on.

2. Materials and methods

A total of 33 sherds from Tell el-‘Abd featuring complete and almost complete potters' marks were chosen for analysis (TEA001–033) as part of a pilot sampling to examine the potential of a multidisciplinary approach to the study of potters' marks. Notably, the sampling strategy was constrained by the limited availability of specific types of marks. These belong to several typological categories previously defined by Sconzo (2013, pp. 230–266) including ‘Linear pattern’ (Group II: n = 15, Fig. 5A), ‘Multiple stroke figures’ (Group XIII: n = 6, Fig. 5D), ‘Anthropomorphic figures’ (Group XVI n = 5, Fig. 5H), ‘V-shaped pattern’ (Group III n = 2, Fig. 5C),‘Stylised animals’ (Group X: n = 2), ‘Trident and arrow’ (Group V: n = 1, Fig. 5E), ‘Frame’ (Group VII: n = 1, Fig. 5G), and ‘Crescent-shaped pattern’ (Group VIII: n = 1, Fig. 5B) (Table 1). Thirty sherds belong to the so-called ‘Simple Ware’ family, while three correspond to the ‘Cooking Pot Ware’. The Simple Ware samples belong to a wide range of shapes, including storage jars and pithoi (n = 3), jars (n = 16) and bowls (n = 10) and undetermined (n = 1). Most of the samples were recovered from Horizon 2 at Tell el-‘Abd, which dates to the Early Bronze Age II (c. 2900–2700/2650 BC), whereas the rest come from disrupted contexts or surface finds.

Notably, some Simple Ware samples have a whitish-coloured surface on the exterior. In addition, five sherds of ‘Euphrates Monochrome Painted Ware’ from the same site were also selected (TEA034-038), for

Table 1
Details of Bronze Age sherds analysed from Tell el-‘Abd in the present study, including context, shape, type of potters' mark.

Code	Sherd Number	House/room	Level	Horizon	Form	Ware type	Potmark type	Ware group
TEA001	20/16–14,35	G-2	III:4	2	Storage Jar	A.3	XVI	Simple Ware
TEA002	20/16–15,108		Unknown	Unknown	Unknown	Unknown	Unknown	Simple Ware
TEA003	16/20–33,8		II:<2	0	Jar	A.8	XVI	Simple Ware
TEA004	20/16–17,22	St2	III:4	2	Unknown	A.4	XVI	Simple Ware
TEA005	22/19–11,17		III:2	2	Bowl	A.10	VII	Simple Ware
TEA006	20/19–11,14	A-1	III:4	2	Jar	A.2	XIII	Simple Ware
TEA007	20/17–19,40	F-1	III:4	2	Bowl	A.4	XIII	Simple Ware
TEA008	20/17–19,155	F-1	III:4	2	Jar	A.2	XIII	Simple Ware
TEA009	20/16–14,27	G-2	III:4	2	Jar	A.3	XIII	Simple Ware
TEA010	20/19–6,151		III:1	3	Bowl	A.8	XIII	Simple Ware
TEA011	16/20–71,8	U-1	Unknown	Unknown	Unknown	A.4	Unknown	Simple Ware
TEA012	20/16–14,27	G-2	III:4	2	Jar	A.3	XIII	Simple Ware
TEA013	17/20–11,1		II:1	0	Jar	A.6	III	Simple Ware
TEA014	20/16–15,107	St1	III:4	2	Bowl	A.3	XVI	Simple Ware
TEA015	20/16–15,102	St1	III:4	2	Bowl	A.1	VIII	Simple Ware
TEA016	20/19–74,25	A-1	III:4	2	Bowl	A.0	XV	Simple Ware
TEA017	16/21–1,16		II:0	0	Jar	A.7	XV	Simple Ware
TEA018	20/16–15,3	St1	III:4	2	Jar	A.4	XIV	Simple Ware
TEA019	20/19–6,165		III:1	3	Jar	A.8	II	Simple Ware
TEA021	20/17–19,156	F-1	III:4	2	Storage Jar	A.7	II	Simple Ware
TEA022	20/17–19,39	F-1	III:4	2	Jar	A.4	II	Simple Ware
TEA023	20/17–19,14	F-1	III:4	2	Jar	A.4	II	Simple Ware
TEA024	20/16–15,30	St1	Unknown	Unknown	Unknown	A.4.1	Unknown	Simple Ware
TEA025	20/19–11,21	A-1	III:4	2	Jar	A.8	II	Simple Ware
TEA026	20/17–19,55	F-1	III:4	2	Jar	A.3	II	Simple Ware
TEA027	20/19–58,174	A-1	III:1	3	Bowl	A.1	II	Simple Ware
TEA028	20/16–13,29	H-1	III:4	2	Bowl	A.9	II	Simple Ware
TEA029	20/16–13,75	H-1	III:4	2	Bowl	A.3	II	Simple Ware
TEA030	20/19–78,26	A-1	III:4	2	Unknown	A.10	II	Simple Ware
TEA031	20/17–19,154	F-1	III:4	2	Cooking Pot	D.2	II	Cooking Pot Ware
TEA032	20/17–19,48	F-1	Unknown	Unknown	Unknown	D.2	II	Cooking Pot Ware
TEA033	20/16–13,50	H-1	III:4	2	Cooking Pot	D.2	II	Cooking Pot Ware
TEA034	20/19–78,26	A-1	III:4	2	Unknown	C.3	Unknown	Euphrates Monochrome Painted Ware
TEA035	20/16–15,92	St1	Unknown	Unknown	Unknown	C.3	Unknown	Euphrates Monochrome Painted Ware
TEA036	–	–	Unknown	Unknown	Unknown	C.3	Unknown	Euphrates Monochrome Painted Ware
TEA037	19/28–11; 19/28–13	–	I:4	2	Jar	C.3	Unknown	Euphrates Monochrome Painted Ware
TEA038	16/20–55,11	–	Unknown	Unknown	Unknown	C.3	Unknown	Euphrates Monochrome Painted Ware

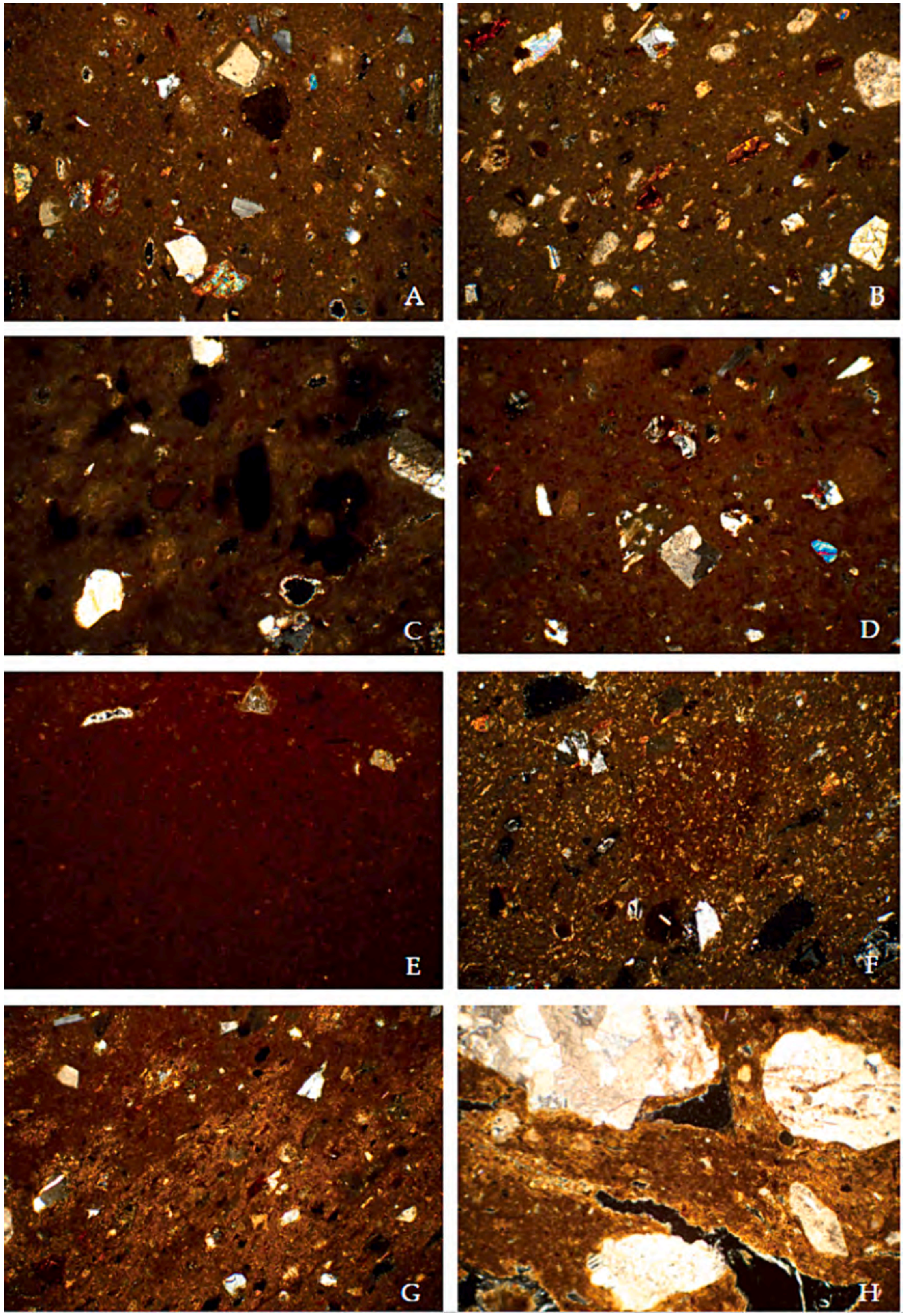

Fig. 6. Thin section petrographic micrographs of selected Bronze Age ceramic specimens from Tell el-‘Abd analysed in this study. A–G. Calcareous Polymict Sand-Tempered Fabric. A. Simple Ware belonging to sub-fabric 1. B. Simple Ware belonging to sub-fabric 2. C. Simple Ware belonging to sub-fabric 3. D. Euphrates Monochrome Painted Ware belonging to sub-fabric 1. E. Area of base clay that did not receive temper. F. Poorly hydrated lumps of powdered based clay. G. Post-depositional secondary calcite in sample TEA030. H. Cooking Pot Ware sample belonging to Calcite-tempered Calcareous Fabric. Images taken in crossed polars. Image width = 1.5 mm.

Table 2
Petrographic classification and modal and textural petrographic data collected on Bronze Age sherds analysed from Tell el-‘Abd in the present study.

			(%)			(mm)		
Code	Petrographic fabric	Sub-fabric	Inclusions	Matrix	Voids	Mean	STDev	Mode
TEA001	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	6–10 %	76–80	11–15 %	0.10–0.15	0.05–0.10	Very fine sand
TEA002	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	6–10 %	81–85	6–10 %	0.26–0.30	0.21–0.25	Fine sand
TEA003	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	6–10 %	0.16–0.20	0.11–0.15	Very fine sand
TEA004	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	0–5 %	0.16–0.20	0.16–0.20	Fine sand
TEA005	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	76–80	0–5 %	0.21–0.25	0.21–0.25	Fine sand
TEA006	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	10–15 %	81–85	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA007	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	10–15 %	81–85	6–10 %	0.10–0.15	0.05–0.10	Very fine sand
TEA008	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	10–15 %	81–85	0–5 %	0.10–0.15	0.11–0.15	Fine sand
TEA009	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	6–10 %	81–85	6–10 %	0.16–0.20	0.11–0.15	Fine sand
TEA010	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	6–10 %	81–85	6–10 %	0.10–0.15	0.05–0.10	Very fine sand
TEA011	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	76–80	6–10 %	0.26–0.30	0.31–0.35	Fine sand
TEA012	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	10–15 %	81–85	0–5 %	0.16–0.20	0.16–0.20	Fine sand
TEA013	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	10–15 %	76–80	6–10 %	0.26–0.30	0.21–0.25	Medium sand
TEA014	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	0–5 %	0.16–0.20	0.05–0.10	Fine sand
TEA015	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	21–25 %	71–75	0–5 %	0.10–0.15	0.16–0.20	Fine sand
TEA016	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA017	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	6–10 %	81–85	6–10 %	0.16–0.20	0.05–0.10	Fine sand
TEA018	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	10–15 %	86–90	0–5 %	0.26–0.30	0.41–0.45	Fine sand
TEA019	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	6–10 %	81–85	6–10 %	0.10–0.15	0.16–0.20	Very fine sand
TEA021	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	10–15 %	76–80	6–10 %	0.21–0.25	0.41–0.45	Very fine sand
TEA022	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	26–30 %	65–70	0–5 %	0.16–0.20	0.21–0.25	Fine sand
TEA023	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	71–75	6–10 %	0.10–0.15	0.11–0.15	Fine sand
TEA024	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	21–25 %	71–75	0–5 %	0.10–0.15	0.11–0.15	Very fine sand
TEA025	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	16–20 %	76–80	0–5 %	0.10–0.15	0.16–0.20	Coarse silt
TEA026	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	21–25 %	71–75	0–5 %	0.10–0.15	0.05–0.10	Coarse silt
TEA027	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA028	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	16–20 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA029	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	21–25 %	71–75	0–5 %	0.10–0.15	0.11–0.15	Very fine sand
TEA030	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 3	21–25 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA031	Calcite-Tempered Calcareous Fabric	N/A	10–15 %	76–80	0–5 %	0.56–0.60	0.41–0.46	Coarse sand
TEA032	Calcite-Tempered Calcareous Fabric	N/A	16–20 %	76–80	0–5 %	0.61–0.65	0.46–0.50	Coarse sand
TEA033	Calcite-Tempered Calcareous Fabric	N/A	31–35 %	60–65	6–10 %	0.56–0.60	0.46–0.50	Coarse sand
TEA034	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	71–75	6–10 %	0.10–0.15	0.11–0.15	Fine sand
TEA035	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 2	16–20 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand
TEA036	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	71–75	6–10 %	0.10–0.15	0.11–0.15	Fine sand
TEA037	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	21–25 %	71–75	0–5 %	0.10–0.15	0.11–0.15	Very fine sand
TEA038	Calcareous Polymict Sand-Tempered Fabric	Sub-fabric 1	16–20 %	76–80	0–5 %	0.10–0.15	0.05–0.10	Very fine sand

comparison with the 33 marked ceramics. Samples of this ware were recently analysed scientifically by Russo et al. (2018), who interpreted them as being locally produced.

The ceramic paste of all sherds (n = 38) was analysed by a combination of thin section petrography and instrumental geochemistry. Standard 30 μm thin sections (Humphries, 1992; Quinn, 2022, pp. 23–36) were prepared at Tübingen University and studied under the polarising light microscope at magnifications of x40–400 in PPL and XP. The samples were classified into petrographic fabrics based on the nature of their inclusions, matrix and voids, then described in detail (Quinn, 2022, pp. 91–97, 98–124) and interpreted in terms of their probable raw materials and paste preparation recipes. Quantitative textural data was also collected on selected thin sections using a PETROG digital stepping stage and point counting software in order to characterise their grain size distribution. The petrographic characteristics of the fabrics were compared to geological maps of the environment around Tell el-‘Abd (e.g. Wilkinson et al., 2014, Fig. 1B), as well as further afar. The ceramics were also compared to the analysis of contemporaneous painted and plain sherds including Euphrates Monochrome Painted Ware from Tell el-‘Abd analysed by Russo et al. (2018).

All sherds were also characterised geochemically via portable X-ray fluorescence spectroscopy (pXRF). An Olympus Innox-X Delta Premium hand-held portable X-ray fluorescence spectrometer (‘UCL IoA pXRF3′) with a Rhodium source and a 2 mm aluminium filter was used with the

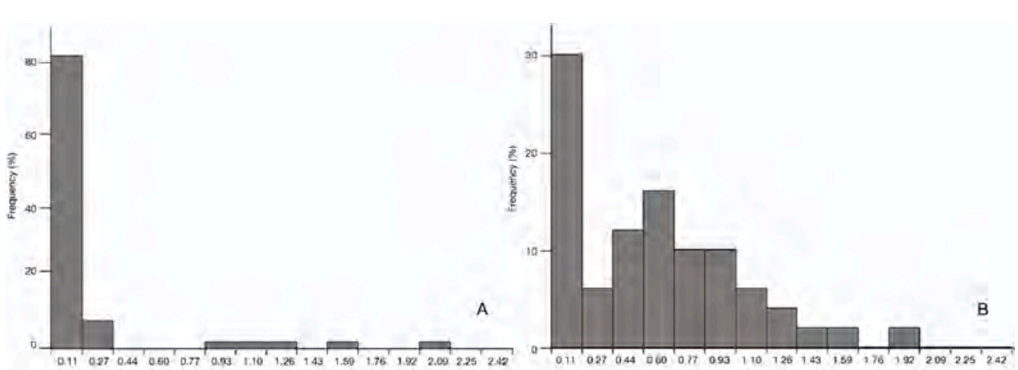

Fig. 7. Grain size distribution histograms of the long-axis of inclusions in selected Bronze Age ceramic samples from Tell el-‘Abd analysed in this study. A. Plain ware sample TEA021 from the Calcareous Polymict Sand-Tempered Fabric. B. Cooking Pot Ware sample TEA031 from the Calcite-tempered Calcareous Fabric.

manufacturer's 'Soil' mode. This uses the 'Compton Normalisation' algorithm to determine the concentration of 30 elements (As, Ag, Au, Bi, Ca, Cd, Cl, Co, Cr, Cu, Fe, Hg, K, Mn, Mo, Ni, Pb, Rb, S, Se, Sb, Sn, Sr, Ti, Th, U, V, W, Zn and Zr) using three beams (Beam 1—0.15 mm Cu filter, 40 kV; Beam 2—2 mm Al filter, 40 kV; Beam 3—0.1 mm Al filter, 15 kV). The three beams were set to record for 60, 120 and 60 s live time respectively, resulting in a real time of several minutes per analysis. Three circular spots of c. 9 mm in diameter were measured on each sample, then averaged in order to avoid inaccuracies due to the natural heterogeneity of ceramics (Shackley, 2010; Tykot, 2016). The measurements were taken on a fresh fracture in order to characterise the composition of the body of the ceramics and avoid a light coloured surface layer that occurred on many sherds.

The quality of the pXRF data was assessed using 14 powdered certified reference materials (CRMs) of rock, ore, sediment, soil and ceramics, held in a sample cup or 'cuvette' with a 4 µm prolene film. All certified reference materials were measured five times and the averaged value then compared to the certified concentrations of 12 elements (K, Ca, Ti, Mn, Fe, Co, Cu, Zn, Rb, Sr, Zr and Pb) to determine accuracy. A single standard was analysed at the start of each session in order to determine the precision of the pXRF for each element. Data for elements with poor accuracy and/or precision were disregarded and the averaged values were then explored descriptively and via multivariate statistics (Baxter, 2003; 2015; Quinn, 2022, pp. 348–353, 365–380), both before and after various data transformation techniques. The geochemical patterning within the dataset was compared to that detected in thin section, as well as the marking type and ware of the analysed samples in order to reveal any correlations.

Selected samples were analysed via scanning electron microscopy coupled with energy-dispersive X-ray spectrometer detector (SEM-EDS) in order to examine their microstructure and the chemical composition of the clay matrix, specific inclusions and the surface coating. A total of 14 samples, chosen from the petrographic and geochemical groupings and including Simple Ware, Cooking Pot Ware and Euphrates Monochrome Painted Ware sherds, were prepared as resin mounted polished blocks and studied using a Carl Zeiss EVO 25 scanning electron microscope coupled with an attached Oxford Instruments X-max 80 energy-dispersive X-ray spectrometer detector at the UCL Institute of Archaeology. Three analyses were made of each feature at a magnification of x100 and x250 before averaging. Data was interpreted and extracted using Aztec 4.1 software. The SEM operated in high vacuum, at accelerating voltage of 20 kV with a beam current of 180pA and at a working distance of 8.5 mm. A cobalt standard was used for internal calibration of the instrument and it was regularly measured to check beam stability. The standardisation dead time was kept at 40–45 %. The default factory calibration was kept as a calibration method. Area scans were taken at a magnification of x100 and x250. Imaging was acquired in both secondary electron mode and in backscattered electron mode. The X-Ray count time was kept at 750,000 counts per second. The concentration of elemental oxides was measured by stoichiometry and reported in wt%. Two basalt standards (BHVO-2 -Basalt, Hawaiian Volcanic Observatory, and BCR-2 - Basalt, Columbia River) were analysed at the beginning of each session and used to assess the accuracy and precision of the SEM-EDS data.

3. Results

The 33 marked ceramic samples from Tell el-'Abd could be classified

Table 3
Geochemical characterisation of Bronze Age sherds analysed from Tell el-'Abd in the present study via portable X-ray fluorescence spectroscopy. Including elements with accuracy of < 30 % relative error. Concentration expressed as wt% (K-Fe) and parts per million-ppm (Cu-Pb).

Code	K	Ca	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Zr	Pb
TEA001	2.57	17.07	0.38	0.09	4.87	37	63	54	1303	109	14
TEA002	1.89	14.01	0.37	0.08	4.95	31	57	65	1729	114	6
TEA003	3.58	14.81	0.41	0.10	4.70	30	73	56	698	107	14
TEA004	2.99	12.76	0.35	0.09	5.18	38	57	69	1034	112	17
TEA005	2.79	15.58	0.35	0.08	4.57	35	71	50	797	101	13
TEA006	2.92	16.85	0.36	0.09	4.46	38	74	53	1993	104	13
TEA007	3.13	14.02	0.33	0.08	4.08	34	72	46	1148	106	11
TEA008	2.84	16.49	0.38	0.07	4.55	35	96	54	925	109	14
TEA009	2.38	14.64	0.28	0.07	3.91	27	67	48	987	96	13
TEA010	2.04	13.62	0.39	0.09	5.11	36	52	61	848	118	13
TEA011	2.90	14.35	0.36	0.08	4.42	37	87	40	605	97	12
TEA012	2.39	16.65	0.31	0.07	4.01	31	64	53	935	99	13
TEA013	2.62	15.04	0.35	0.08	4.63	35	69	52	972	104	13
TEA014	2.71	10.72	0.45	0.09	5.28	34	65	67	1258	118	17
TEA015	2.50	13.79	0.40	0.09	5.51	45	54	78	2006	127	18
TEA016	2.73	13.46	0.42	0.13	5.17	41	92	65	1349	127	17
TEA017	2.43	19.95	0.36	0.12	4.69	38	54	42	860	105	12
TEA018	2.56	13.64	0.38	0.08	4.70	36	83	57	1355	109	16
TEA019	1.78	16.47	0.40	0.09	5.37	40	64	45	792	115	6
TEA021	1.39	17.34	0.37	0.09	4.97	38	63	39	980	111	7
TEA022	2.94	17.62	0.36	0.08	4.40	32	76	42	1281	98	12
TEA023	2.74	13.18	0.33	0.09	4.57	28	64	50	1030	109	15
TEA024	2.39	17.37	0.35	0.08	4.32	35	73	54	1348	100	14
TEA025	2.58	13.82	0.37	0.09	4.73	33	66	57	1030	120	10
TEA026	2.92	14.82	0.38	0.09	4.71	41	89	55	1374	111	14
TEA027	2.56	16.68	0.36	0.09	4.88	34	67	63	1345	117	16
TEA028	2.63	15.40	0.39	0.10	5.00	35	63	62	927	113	14
TEA029	3.19	12.96	0.41	0.08	5.02	29	58	61	1069	110	16
TEA030	1.69	51.18	0.72	0.05	2.02	44	56	27	740	43	9
TEA031	2.68	23.23	0.43	0.08	4.63	22	72	65	7252	192	13
TEA032	2.98	20.61	0.40	0.06	4.41	46	83	54	3050	136	14
TEA033	3.05	17.97	0.51	0.08	4.77	32	82	75	6736	245	12
TEA034	2.64	15.38	0.41	0.11	5.81	46	55	80	1911	126	20
TEA035	1.93	14.19	0.36	0.08	4.53	40	69	46	1717	114	14
TEA036	2.80	16.97	0.38	0.09	4.87	37	60	55	974	113	12
TEA037	2.01	13.96	0.36	0.10	4.84	39	72	44	675	115	9
TEA038	2.10	19.19	0.44	0.09	4.98	38	64	60	1563	106	16

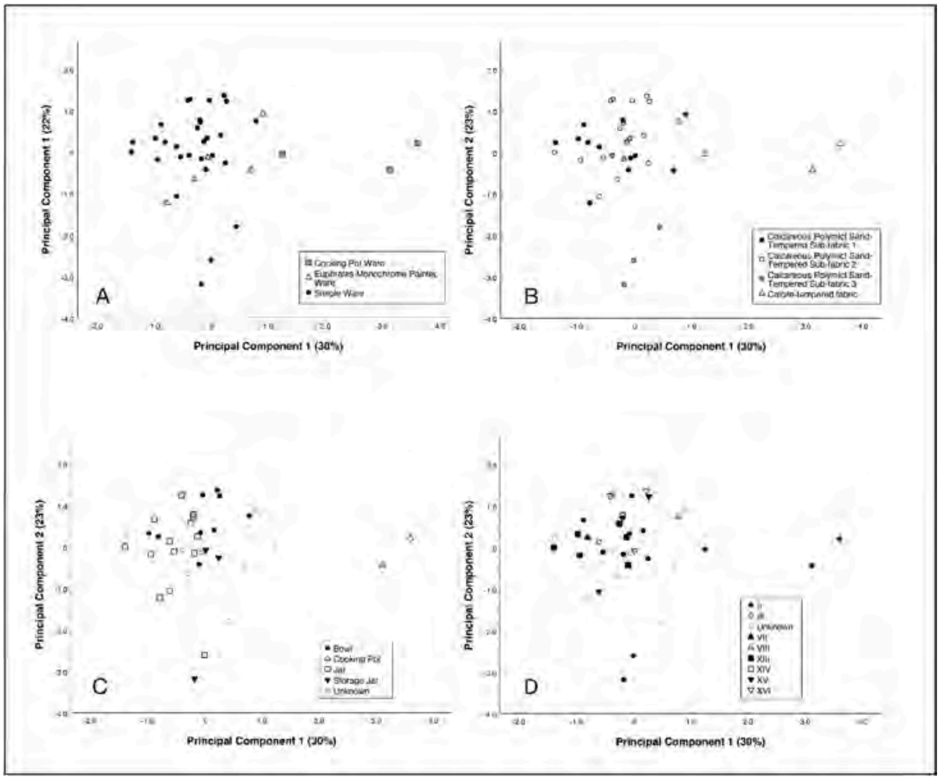

Fig. 8. Score plots for components 1 and 2 from principal components analysis of the geochemical dataset in Table 1, transformed to base-10 logarithms and omitting sample TEA030. A. Samples labelled by ware. B. Labelled by petrographic fabric/sub-fabric. C. Labelled by vessel form. D. Labelled by potters' mark group.

into two petrographic fabrics in thin section (Fig. 6; Table 2). The Calcareous Polymict Sand-Tempered Fabric is characterised by the presence of moderately to poorly-sorted sub-rounded to rounded sand-sized inclusions of quartz, carbonate sedimentary rock, metamorphic and basic igneous rock inclusions, opaques and iron-rich clay pellets in a calcareous clay matrix (Fig. 6A–C). The metamorphic rock includes fragments of serpentinite, as well as inclusions composed of interlocking quartz, biotite and muscovite mica with weak metamorphic foliation,

Table 4
SEM-EDS elemental data of selected Bronze Age ceramic specimens from Tell el-'Abd analysed in this study. All data normalised to a total of 100 and displayed in atomic %. Abbreviations: CPST = Calcareous Polymict Sand-Tempered fabric; CTC Fabric = Calcite-tempered Calcareous fabric. BDL: Below limits of detection.

Sample	Feature	Petrographic Fabric	Na_2O	MgO	Al_2O_3	SiO_2	SO_2	ClO_2	K_2O	CaO	TiO_2	Fe_2O_3	SrO	BaO
TEA001	Clay matrix	CPST Sub-fabric 1	2.15	7.63	15.88	54.21	0.39	0.47	3.05	12.63	0.32	3.27	BDL	BDL
TEA003	Clay matrix	CPST Sub-fabric 2	2.26	12.76	14.54	44.12	0.34	0.25	9.05	10.51	3.33	2.85	BDL	BDL
TEA006	Clay matrix	CPST Sub-fabric 3	1.49	12.19	13.89	45.77	0.32	0.5	7.94	9.23	4.67	4	BDL	BDL
TEA006	Argillaceous inclusion	CPST Sub-fabric 3	1.5	13.78	15.7	49.55	0.23	0.75	3.94	4.57	5.38	4.61	BDL	BDL
TEA006	Clay matrix	CPST Sub-fabric 3	1.49	12.19	13.89	45.77	0.32	0.5	7.94	9.23	4.67	4	BDL	BDL
TEA006	Celestine inclusion	CPST Sub-fabric 3	BDL	BDL	BDL	0.52	BDL	0.45	BDL	BDL	63.86	BDL	34	1.07
TEA008	Clay matrix	CPST Sub-fabric 2	2.34	10.97	12.5	43.27	0.33	1.01	10.4	12.08	3.83	3.29	BDL	BDL
TEA008	Slip layer	CPST Sub-fabric 2	1.95	12.55	14.3	53.2	0.36	0.99	4.12	4.79	4.17	3.57	BDL	BDL
TEA011	Clay matrix	CPST Sub-fabric 1	1.56	11.52	13.13	45.41	0.3	BDL	9.31	10.81	4.29	3.68	BDL	BDL
TEA011	Slip layer	CPST Sub-fabric 1	1.36	12.83	14.62	43.34	0.27	0.27	8.81	10.24	4.45	3.81	BDL	BDL
TEA015	Clay matrix	CPST Sub-fabric 2	1.58	11.89	13.54	48.38	0.24	0.52	7.26	8.44	4.39	3.76	BDL	BDL
TEA015	Argillaceous inclusion	CPST Sub-fabric 2	2.54	6.08	6.93	40.4	0.45	3.7	10.32	11.98	9.48	8.12	BDL	BDL
TEA015	Clay matrix	CPST Sub-fabric 2	1.58	11.89	13.54	48.38	0.24	0.52	7.26	8.44	4.39	3.76	BDL	BDL
TEA015	Celestine inclusion	CPST Sub-fabric 2	BDL	BDL	0.32	1.22	BDL	1.05	0.37	BDL	62.43	BDL	34	0.41
TEA018	Argillaceous inclusion	CPST Sub-fabric 1	1.03	11.28	12.85	44.42	0.39	0.18	9.2	10.68	5.37	4.6	BDL	BDL
TEA018	Clay matrix	CPST Sub-fabric 1	1.17	10.63	12.11	44.81	0.39	0.18	10.22	11.87	4.64	3.98	BDL	BDL
TEA022	Clay matrix	CPST Sub-fabric 2	1.92	11.05	12.59	41.16	0.5	0.57	11.81	13.72	3.6	3.09	BDL	BDL
TEA022	Slip layer	CPST Sub-fabric 2	2.48	11.56	13.17	40.02	0.69	1.23	11.29	13.11	3.47	2.97	BDL	BDL
TEA025	Argillaceous inclusion	CPST Sub-fabric 3	1.14	11.59	13.21	49.22	0.19	0.44	7.23	8.4	4.62	3.96	BDL	BDL
TEA025	Clay matrix	CPST Sub-fabric 3	1.32	11.78	13.42	44.23	0.18	0.44	9.34	10.84	4.55	3.9	BDL	BDL
TEA031	Clay matrix	CTC Fabric	2.12	16.73	19.06	47.11	0.12	0.47	2.9	3.37	4.37	3.74	BDL	BDL
TEA032	Clay matrix	CTC Fabric	1.22	13.49	15.37	54.63	0.25	0.65	1.77	2.05	5.7	4.88	BDL	BDL
TEA032	Celestine inclusion	CTC Fabric	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	64.07	BDL	34	2.17
TEA033	Clay matrix	CTC Fabric	2.36	13.3	15.15	47.88	BDL	0.31	5.96	6.92	4.37	3.75	BDL	BDL
TEA033	Celestine inclusion	CTC Fabric	BDL	BDL	0.29	0.31	BDL	0.27	0.34	BDL	63.27	BDL	35	0.54
TEA035	Clay matrix	CPST Sub-fabric 2	1.55	11.99	13.66	43.95	0.3	0.12	8.85	10.28	5.01	4.29	BDL	BDL
TEA035	Argillaceous inclusion	CPST Sub-fabric 2	1.24	11.41	13	49.21	0.23	BDL	6.33	7.36	6.04	5.18	BDL	BDL
TEA035	Slip layer	CPST Sub-fabric 2	1.34	12.01	13.69	52.9	0.21	0.24	6.03	7.01	3.53	3.03	BDL	BDL
TEA038	Clay matrix	CPST Sub-fabric 1	1.57	13.18	15.02	47.85	0.28	0.21	7	8.13	3.64	3.12	BDL	BDL

that seem to have derived from schist. The basic igneous rock fragments are composed of fine, randomly-oriented laths of plagioclase feldspar and clinopyroxene, which probably derived from basalt. Less common inclusions include polycrystalline quartz, amphibole, plagioclase feldspar, calcite, orthoclase feldspar and quartz arenite rock fragments composed of well-sorted quartz grains.

The inclusions have a bimodal grain size distribution (Fig. 6A–D; Fig. 7A–B) suggesting the sand-sized grains were probably added as temper. Other evidence for tempering in one thin section is an area of probable base clay that is devoid of sand grains (Fig. 6E). The clay pellets observed in a few samples are likely to be natural phenomena, formed during the deposition of the clay or its bioturbation by organisms, as they are rounded and spherical with sharp boundaries (Quinn, 2022, pp. 76, 111). Incompletely hydrated clay particles with ring voids, visible in two samples (Fig. 6F), can be taken as evidence for the use of powdered clay that was ground during preparation (Quinn, 2022, p. 235). The base clay was calcareous and contained naturally occurring silt-sized quartz inclusions. It appears to have derived from the use of ancient marine marl. The samples contain thin, elongate, planar voids which seem to have been produced by the differential shrinkage of the wet clay body where it was restricted by the sand sized inclusions. Their moderate alignment to margins of the samples seems to confer with macroscopic evidence for shaping on a slow wheel (Russo et al., 2018). All samples were fired in an oxidising atmosphere and the clay matrix is vitrified in some sherds. Evidence for post-depositional alteration by groundwater is visible in many samples in the form of dispersed, amorphous patches of micrite parallel to the sherds margins or fine micrite deposited in voids.

The Calcareous Polymict Sand-Tempered Fabric displays some variation in terms of the size and amount of sand temper and the specific combinations of inclusion types between samples. This has been used to visually subdivide the samples into three sub-fabrics. Sub-fabric 1 is characterised by a higher relative abundance of igneous rock fragments (Fig. 6A and D), sub-fabric 2 by more metamorphic and carbonate sedimentary rock fragments (Fig. 6B) and sub-fabric 3 a higher proportion of opaques (Fig. 6C).

The Calcareous Polymict Sand-Tempered Fabric includes all 30 Simple Ware sherds, which occur in all three sub-fabrics (Fig. 6A–C). The five Euphrates Monochrome Painted Ware samples were petrographically closely related to the Simple Ware sherds in thin section, occurring as Sub-fabrics 1 and 2 (Fig. 6D). The three Cooking Pot Ware sherds included in the analysed sample set have a different petrographic composition in thin section, which is characterised by poorly-sorted generally angular calcite fragments in a calcareous clay matrix (Fig. 6H). The dominant inclusions are likely to have been added as crushed rock temper based on their size and shape. Less abundant silt and sand-sized inclusions of quartz, basalt, quartz arenite, serpentinite, schist, limestone, amphibole and opaques are also present in the samples, which seem to have been naturally occurring. The Calcite-tempered Calcareous Fabric and the Calcareous Polymict Sand-Tempered Fabric share some similarities, notably their calcareous clay matrices and similar intrinsic inclusions, but they differ in terms of the types of temper used. No correlation exists between the petrographic fabric classification of the ceramics and their vessel shape or type of potters' marks (Table 2). The modal and textural petrographic data, recorded via point-counting, also revealed little meaningful distinction between the sherds, except for the larger mean and modal grain size of the inclusions in the three Cooking Pot Ware/Calcite-tempered Calcareous Fabric sherds/ and their higher standard deviation/degree of sorting (Fig. 7).

The analysis of the 14 CRMs revealed that the pXRF data for 11 elements (Ca, Cu, Fe, K, Mn, Pb, Rb, Sr, Ti, Zn, Zr) had an accuracy of < 30 % relative error. Based upon this quality assessment, elements with $>$ 30 % relative error were excluded from the archaeological data as they could introduce unwanted bias. Simple Ware sherd TEA030 was removed from the dataset as it has abnormally high Ca (>50 %), which is caused by the deposition of secondary calcite during burial (Fig. 6G) (Buxeda i Garrigós and Cau, 1995; Buxeda i Garrigós, 1999; Buxeda i Garrigós et al., 2001; Cau Ontiveros et al., 2002). Principal component analysis (PCA) was performed on the raw multivariate dataset of 37 samples and 11 elements (Table 3) and after log transforming the values to base-10 logarithms (Quinn, 2022, p. 362). A plot of components 1 and 2, which projects 52 % of the total variation in two dimensions, reveals the presence of three chemical groups (Fig. 8). The main group is composed of the majority of the Simple Ware sherds and the Euphrates Monochrome Painted Ware sherds (Fig. 8A), all of which belong to the Calcareous Polymict Sand-Tempered Fabric (Fig. 8B). Two of the Cooking Pot Ware sherds form a small distinct chemical group due to their high Sr, Ti and Zr (Table 3), which affect principal component 1. These sherds belong to the Calcite-tempered Calcareous Fabric and it is likely that their high Ca and Sr can be explained by the addition of calcite temper, which is not present in the sherds of the main chemical group. Their elevated values for the elements Ti and Zr, and also Rb and Mn, on the other hand, may indicate that they were manufactured with a different base clay to the Calcareous Polymict Sand-Tempered Fabric. Three Simple Ware/Calcareous Polymict Sand-Tempered Fabric samples (TEA002, 019 and 021) plot away from the main chemical group due to their low values for K and Pb, which affect principal component 2, as well as their high Fe (Table 3). These belong to the Calcareous Polymict Sand-Tempered Sub-fabric 3, which contains less igneous inclusions and more opaque iron material, though other sherds of this sub-fabric plot in the main chemical group. The other two Calcareous Polymict Sand-Tempered sub-fabrics are not chemically distinct in terms of the eleven elements, even when the Cooking Pot Ware/Calcite-tempered

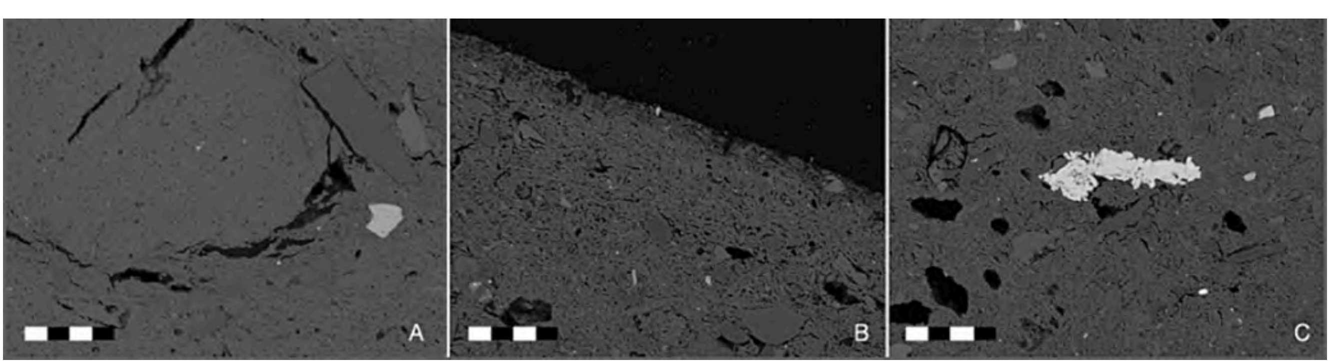

Fig. 9. Scanning electron micrographs of selected Bronze Age ceramic specimens from Tell el-'Abd analysed in this study. A. Argillaceous inclusion in Simple Ware sherd of Calcareous Polymict Sand-Tempered Sub-fabric 1 consisting of area of base clay that did not receive temper. B. External 'layer' on Simple Ware sherd of Calcareous Polymict Sand-Tempered Sub-fabric 2. C. Aggregate of the mineral celestine in Simple Ware sherd of Calcareous Polymict Sand-Tempered Sub-fabric 1 that may have precipitated during burial. See Table 2 for corresponding geochemical data specific features collected via SEM-EDS. Scale bar = 250 μm.

Calcareous Fabric samples were excluded from the PCA.

The five Euphrates Monochrome Painted Ware sherds, which are petrographically closely related to the Simple Ware samples, also overlap chemically with these sherds, but plot in on the edge of the main chemical group, perhaps suggesting a slight chemical difference. There appears to be no correlation between the chemical composition of the 37 sherds and the form of the parent vessel from which they came, save for the two Cooking Pot Ware samples (Fig. 8C). Finally, labelling the samples in the PCA plot according to the broad group to which their specific potters' mark can be classified (Fig. 8D), does not reveal any chemical correspondence, as sherds with the same marking (e.g. Type II) are compositionally different and some samples with different potters' marks are chemically related.

The SEM-EDS data had an accuracy of < 3 % or less for the major and minor elements Al, Ca, Fe, K, Na, Si and Ti, which can be used to study the chemical composition of the base clay, argillaceous inclusions and surface layers of the 14 analysed sherds (Table 4). Variation in the major and minor element composition of the base clay in the analysed samples may suggest the use of a different base clay for the Calcite-tempered Calcareous Fabric, which has higher Al_2O_3 and MgO and lower CaO, and K_2O compared to the Calcareous Polymict Sand-Tempered Fabric. A comparison of the plastic clay component of the ceramics with examples of the aplastic–semi plastic argillaceous inclusions (Fig. 9A) seen in thin section confirms that these are likely to be areas of poorly hydrated base clay.

The whitish material that is visible on the surface of several of the sherds (Fig. 5F) appears in the SEM as a thin zone, rather than a separate well-defined layer with a sharp boundary (Fig. 9B). This seems to rule out that it is a slip coating. Its light colour does not seem to be explained by the precipitation of salts from the body during drying as an external 'scum coat' (Quinn, 2022, p. 264) due to similar range of Cl, Na and S values in the zone/layer compared to the underlying clay. Given the comparable major and minor chemical composition of the thin zone to that of the base clay and argillaceous inclusions (Table 4) it is possible that it could be a self-slip produced by wiping the ceramics with excess water before drying. However, this does not explain the white colour. Another possibility is that soluble material such as calcite has been selectively leached from the surface during burial to create a less porous zone that appears lighter coloured and is referred to as the 'espresso crema effect' (Tschegg, 2009a; Tschegg et al., 2009b), though this is not supported by its chemical composition (Table 4). The presence of small amounts of the evaporitic mineral celestine (SrSO4) in some samples (Fig. 9C) may indicate post-depositional alteration. The site was located beneath the water of the Tabqa Dam, however, the archaeological strata was not found to have been waterlogged during its excavation.

4. Discussion

4.1. Pottery technology, raw materials and provenance

Two distinct paste preparation recipes have been identified among the 33 sampled specimens via petrographic and geochemical analysis, the Calcareous Polymict Sand-Tempered Fabric and the Calcite-tempered Calcareous Fabric. These correlate well with two fabrics recorded within 19 Early Bronze Age sherds of painted and plain ceramics from Tell el-'Abd by Russo et al., (2018, pp. 363–364, Fig. 5, table 1). The Pyroxene Fabric (Fabric A) of these authors, which contains samples of unmarked Plain Ware/Simple Ware as well as Euphrates Monochrome Painted Ware and Miscellaneous Painted Ware, has a similar mixture of basic igneous and metamorphic rock and related mineral inclusions to the Calcareous Polymict Sand-Tempered Fabric in this study, as well as a calcareous clay matrix. Similarly, the Calcite Tempered Fabric (Fabric B) matches the Calcite-tempered Calcareous Fabric due to the presence of crushed sparry calcite temper. As in the present study, this recipe was used for the manufacture of Cooking Pot Ware sherds.

The bedrock geology of the Middle Euphrates River Valley near Tell el-'Abd is dominated by Tertiary chalk and thin-bedded limestone (Wilkinson, 2004, figs. 2.2 and 2.3, p. 18 and 19) and therefore calcite would have been widely available. However, the well-formed crystalline shape of the temper added to the Calcite-tempered Calcareous Fabric may suggest the exploitation and crushing of calcite veins. Igneous and metamorphic bedrock is absent in the study area, though clasts of "basic and acidic igneous rocks, metamorphics, lavas, and a wide range of sedimentary rocks" of Anatolian origin occur in a cemented conglomerate that forms part of the Pleistocene river terrace (Wilkinson, 2004, p. 19). This compositionally diverse material could have been the source of the temper added to the ceramics of the Calcareous Polymict Sand-Tempered Fabric. The sub-fabrics detected in the ceramics of this group may reflect natural geological variation within the utilised river sediments and the procurement of sand from different layers or specific locations within the deposit. In both ceramic recipes, temper was added to a calcareous base clay. This is likely to have been derived from marly layers within the chalky limestone or local floodplain sediment containing a mixture of clay and eroded calcareous material.

Based on the petrographic characteristics of the analysed samples and their comparison to the geology around Tell el-'Abd and the Middle Euphrates River Valley, it is possible that the ceramics were manufactured at or close to the site. While it is not possible to rule out production at another location along the river, the presence of over-fired waster sherds of Euphrates Monochrome Painted Ware at Tell el-'Abd (Russo et al., 2018, p. 361) seems to indicate that pottery was made at the site.

The Calcareous Polymict Sand-Tempered Fabric, which corresponds to the main geochemical group in the samples, contains all Simple Ware and Euphrates Monochrome Painted Ware sherds, whereas the Calcite-tempered Calcareous Fabric, which is chemically distinct, relates to the analysed Cooking Pot Ware sherds. This suggests that the same recipe was used to produce at least two distinct pottery wares, whereas a different paste may have been used for the manufacture of the cooking pots, a finding corroborated by the study of Russo et al. (2018). The addition of calcite as temper in cooking pots has a long tradition in the Bronze and Iron Age of Syria and adjacent areas (e.g. Mason and Copper, 1999; Franken and Kalsbeek, 1969; Franken and Kalsbeek, 1974; Beynon et al., 1986; London, 1991; Vilders, 1991; Franken, 1992; Shoval et al., 1993; London and Shuster, 2021) and is still being used in the present day. Calcite has a similar thermal expansion coefficient to fired clay (Rye, 1976; Hoard et al., 1995), thus avoiding stresses that can build up in cooking pots during use (Muller, 2017). A drawback of using calcite as temper is its transformation at c. 750 °C during firing and the subsequent affect this can have on the structural integrity of ceramics (Rice, 1987, p. 81). Potters were clearly aware of this and fired their cooking pots below this level. The optical activity of the clay matrix in many of the analysed samples in thin section (Quinn, 2022, pp. 266–269), seems to support this idea.

The base clay used for both the Calcareous Polymict Sand-Tempered Fabric and the Calcite-tempered Calcareous Fabric seems to have been finely ground then hydrated, leaving argillaceous inclusions in some samples. The geochemical composition of these clay particles matches that of the clay matrix. Whether temper was added before or after hydration is difficult to determine, though the uneven distribution of the sand and crushed calcite in some places might support the latter.

4.2. Function of the potters' marks

When Hirschfeld (1999) addresses the functional category of 'production' in relation to potter's marks, she lists the following explanations: identification of potters/workshop; communal kiln; administrative control; and advertisement. These can also be thought of in terms of inter-workshop and intra-workshop notation. The former refers to marking practices that serve to distinguish the products of different workshops after manufacture, during the process of trade or redistribution or supply of objects to a large-scale project. Such a practice has been interpreted for the marking of ceramics from a diverse range of periods and parts of the world such as Roman Italy (Gliozzo et al., 2020) and Qin Period China (Quinn et al., 2020).

The position of the potters' marks of Tell el-'Abd on their parent vessels, which would have made them highly visible, is in keeping with this type of function rather than some sort of intra-workshop notation or 'trademark'. They could have served to advertise the output of different workshops, that produced ceramics of a specific quality. The large number of marked ceramics, the presence of different symbols on similar vessels and the wide range of forms with the same marking type, all seem to support the idea that the ceramics used at the site were manufactured at several different workshops, each producing a range of overlapping ceramic forms and marking a high proportion of their products to distinguish them from their competitors.

If the markings were meant to signify and/or advertise the products of different workshops, then it might be expected to find compositional differences between the ceramic sherds on which they occur. Separate workshops or production units are perhaps likely to have procured clay and other raw materials themselves, particularly if they were not geographically close by to one another, leading to subtle differences in the petrographic, chemical composition (e.g.Gliozzo et al., 2020; Quinn et al., 2022) and texture of the paste used to make ceramics. Different workshops producing similar ceramics are also known to have employed their own paste preparation recipes, in terms of the addition of temper or not, the type(s) of temper used and whether clay was refined or mixed (e.g. Arnold, 1978). With this in mind, the fact that the ceramics analysed from Tell el-'Abd in this study have a wide range of marking types, yet are petrographically, chemically and texturally very homogeneous and do not display any obvious technological differences in terms of their paste preparation recipes, is particularly informative. However, no correlation exists between the marking type and the paste composition of the sherds. The ceramic body of the 30 Simple Ware sherds and the five Euphrates Monochrome Painted Ware samples therefore seem to have been made using the same raw materials and technology, and the minor petrographic variability defined by the three sub-fabrics does not relate in any way to either the broad groups or more specific types of markings (Table 2).

It is of course possible that ceramics were made by several workshops, at or close to Tell el-'Abd, using a homogeneous and perhaps geographically expansive clay source, and that this was tempered with sand from a deposit that was similarly fairly uniform in terms of its composition. Archaeological and ethnographic evidence from other periods and parts of the world to support such a scenario is fairly scarce, though it has not been rigorously tested in many studies. Nevertheless, the natural mineralogical and chemical variability in natural clay deposits used for ceramic production (e.g. Hein et al., 2004) and pottery produced by several potters utilising the same clay source at a single workshop (e.g. Arnold et al., 1991; Buxeda et al., 2003), as well as the compositional differences between ceramics made at different workshops in the same general area (Arnold, 2000 Fig. 2, p. 351; Fig. 5, p. 359; Fig. 6, p. 360) seems to suggest that this scenario is unlikely, given the homogeneity of the analysed marked ceramics from Tell el-'Abd.

Alternatively, clay could have been procured in a single location and handed out to different workshops to produce similar ceramics. Such an explanation has been proposed for the mass production of ceramics for large scale projects, such as the statues of the Terracotta Army in China, where multiple adjacent units at the First Emperors Mausoleum received clay from a centralised dedicated taskforce that kept the raw material supply chain running and ensured a homogeneous paste throughout the clay figures (Quinn et al., 2017). There seems to be no reason to assume that this was the case at Tell el-'Abd, where ceramics seem to have been manufactured for domestic storage and consumption rather than as part of a rapid mass production for a single project. There also seems to be no evidence that ceramic production was centrally controlled or that clay was scarce and therefore controlled and distributed to separate workshops. The transport of raw materials from one production site to another distant affiliated workshop for the manufacture of similar pottery has been proposed in some instances (e.g. Amicone and Quinn, 2015), though not conclusively proven. While we cannot rule out that there were several related sites producing Simple Ware and Euphrates Monochrome Painted Ware and clay was transported between them, there is at present no need to propose this.

Different raw materials and a distinct recipe were used for the manufacture of the three Cooking Pot Ware samples analysed in this study. While these are small in number, the reasoning behind this seems almost certainly to be driven by their intended function, as reasoned above. They do not stand out from the other 30 sherds in terms of their potters' marks in a way that might suggest that they were made by a specific workshop or potter.

The compositional characterisation and technological reconstruction of the analysed sherds and its comparison to the potters' marks on the sherds therefore does not support the idea that the different symbols or groups of symbols were 'inter-workshop' trademarks that served to differentiate and/or advertise similar ceramics made by distinct production units. Based upon the homogeneity seen in the present study, it is possible that they could be 'signatures' used to distinguish between the output of different potters working at a single workshop, as these might be expected to have been made from similar raw materials and paste preparation technology. Whether ancient potters needed to mark their pots to tell them apart from those of their co-workers is of debate, with some arguing that this can been achieved by subtle differences in style and manufacturing (Hardin, 1977; Vitelli, 1977; Graves, 1981; Longacre, 1981; London et al., 1989; London, 1991), at least in the case of ceramics made by hand. The marked pottery vessels from Tell el-'Abd are likely to have been coil built, then further fabricated on a slow wheel, which could mean that pots made by different potters working at a single workshop may have been fairly standardised and were therefore difficult to tell apart without some sort of notation such as potters' marks. Ethnographic evidence also exists for intra-workshop marking by different artisans working within a shared production context (Donnan, 1971, p. 465; Sillar, 2000, p. 73; Glatz, 2012, p. 29).

A final possible function that might be worth considering is that the potters' marks were in some way symbolic, bringing the potters or their users good luck (Derin, 2013, p. 94), or that they could have served some sort of social role between potters (Ogundiran and Saunders, 2011) or they could have been a reference to the name and main title of the donor or the owner of the vessel and the special occasion at which the vessel was offered (Tassie et al., 2008). Possible evidence to support this is the occurrence of certain potters' marks (e.g. 'man with raised arms' from Group XVI Anthropomorphic figures - Fig. 5H) as engravings on stones and in wall paintings (Sconzo, 2013, pp. 263–264). In the case of a social or symbolic function, we cannot expect to find compositional or technological variability between the ceramic paste of vessels marked with different symbols or groups of symbols, which is in keeping with the results of the present study, but does not in itself necessarily prove such a hypothesis. Thus, after examining several hypotheses, the possibility that Tell el-'Abd potmarks had more than one function and meaning cannot be ruled out.

5. Conclusion

This study has underscored the key role of a multidisciplinary methodology, melding macroscopic observations, geochemistry, and thin section petrography, in reconstructing the *chaîne opératoire* of ceramic artefacts, the determination of their provenance and their compositional characterisation. Integrating archaeometric data into discussions surrounding the significance of potters' marks emerges as pivotal, shedding light on their contextual meaning. Through petrographic and geochemical analyses, the identification of two distinct paste preparation recipes has been achieved. Furthermore, by correlating petrographic findings with geological maps of the region, a compelling case for a local origin, specifically the Middle Euphrates, has been posited for the principal wares found at Tell el-'Abd, namely Simple Ware, Cooking Pot Ware, and Euphrates Monochrome Painted Ware.

While the study's outcomes may not definitively unravel the enigma of Tell el-'Abd potters' marks, they significantly advance our comprehension of these symbols within their socio-productional framework and broader geographical context. Anticipating future archaeometric inquiries into Early Bronze Age ceramics from the Middle Euphrates region, it is envisaged that such endeavors will enrich our understanding of ceramic traditions, technologies, and the distinct phenomenon of potters' marks in this inland Syrian locale.

CRediT authorship contribution statement

Sara Carrión Anaya: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review and editing original and final draft, Visualization. **Patrick Sean Quinn:** Conceptualization, Methodology, Supervision, Investigation, Writing – original draft, Writing – review and editing original and final draft, Visualization, Resources. **Silvia Amicone:** Conceptualization, Methodology, Supervision, Investigation, Writing – review and editing original and final draft, Resources. **Paola Sconzo:** Conceptualization, Methodology, Supervision, Investigation, Writing – review and editing of the original and final draft, Visualization, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article.

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