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Domestic food practice and vessel-use at Salūt-ST1, central Oman, during the Umm an-Nar period

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Abstract

Investigations into everyday food practices during the Umm an-Nar period (c.2700–2000 BC) in the Oman Peninsula are limited. We studied lipid residues in pottery from Salūt-ST1, an Umm an-Nar stone tower in central Oman, to understand domestic practices and vessel use in locally-produced Sandy Wares, regionally-produced Fine Red Omani Wares and imported Indus Black-Slipped Jars between c. 2460–2150 BC. Degraded animal fats were found in a majority of the vessels, and we report the first direct detection of dairy products in Umm an-Nar vessels. The use of non-ruminant fats, plants and/or mixtures of different products is also suggested. Variations in lipid concentrations and contents of Fine Red Omani Wares and Sandy Wares suggest different uses for these vessel categories. Finally, the detection of a range of products (ruminant meat, dairy fats, non-ruminant fats and mixtures) in Indus Black-Slipped Jars from the site indicates vessel multifunctionality and reuse of the vessels.

KEYWORDS

domestic practice, Indus Black-Slipped Jars, lipid residue analysis, Salūt-ST1, Umm an-Nar, vessel use

1 | INTRODUCTION

During the Early Bronze Age (EBA) in south-eastern Arabia, the Umm an-Nar period (c. 2700–2000 BC) marked the development of many 'firsts' in the region. Increasing sedentism and the establishment of settlements with monumental stone or mudbrick 'towers' and associated mudbrick constructions (Cable & Thornton, 2013; Cleuziou & Tosi, 2007, 2020; Frifelt, 1969, 1995) developed in combination with the growth of oasis agriculture (al-Jahwari, 2009; Charbonnier et al., 2017; Tengberg, 2012) and the rise of a shared regional material culture and local pottery, stone and copper industries (David, 1996; Méry, 2000, 2013; Weeks, 2022). Additionally, there was also an increase in the scale and intensity of long-distance exchange networks throughout the Persian Gulf in which Umm an-Nar communities played an important role (Potts, 1990, 1993).

1.1 | Umm an-Nar settlements and domestic lifeways

Umm an-Nar sites with multiple stone or mudbrick 'towers' or dwellings with associated occupation and tombs stretching over several hectares or dozens of hectares have been discovered particularly in central Oman as well as west of the al-Hajar mountains, suggesting a density of settlement, likely centred around oasis agro-systems, where cereals and pulses were cultivated in date palm gardens (al-Jahwari, 2009; Tengberg, 2012). These include sites such as Hili (Cleuziou, 1989), Bat (Frifelt, 1976, 1985; Thornton et al., 2016), al-Khashbah (al-Jahwari & Kennet, 2010; Schmidt & Döpper, 2017), Bisya (Orchard & Orchard, 2007), Salut (Degli Esposti, 2014) and several others. Several Umm an-Nar settlements with or without monumental 'towers' have evidence of domestic activities or architecture associated with them (e.g., al-Jahwari et al., 2018; Azzarà, 2018; Cleuziou, 1989; Cleuziou & Tosi, 2020; Döpper, 2018), while others have evidence of other possible functions: as defensive structures to control access to water; symbolic markers in the landscape; or elite residences (Swerida, 2022; Swerida & Thornton, 2019). Despite a renewed interest in the domestic lifeways of inhabitants of settlements (Swerida, 2022), available information on agricultural practices and the management of animals is limited by the poor preservation of archaeobotanical and faunal material (Uerpmann & Uerpmann, 2008; Willcox & Tengberg, 1995). There are several outstanding questions concerning everyday diet and food practices that research is now beginning to address, including how crops and plant resources were grown (e.g., Deckers et al., 2019); how groundwater or irrigation for cropping was managed (Charbonnier, 2008); what types of animals were raised or hunted (Uerpmann & Uerpmann, 2008); and how pottery was used in domestic practice and food production (Suryanarayan et al., 2022).

1.2 | Dietary evidence through mortuary remains

Evidence related to the diet of Umm an-Nar communities has also been studied through the analysis of dental health and stable isotopic analysis of dental enamel from human mortuary remains from large communal tombs (Blau, 2007; Gregoricka, 2013; Littleton & Frohlich, 1993; Munoz, 2017). The study of oral health conditions of individuals during the Umm an-Nar period (Minimum Number of Individuals is ~250), suggests an increase in the consumption of agricultural products, and is more marked for individuals buried inland than on the coast (Littleton & Frohlich, 1993; Munoz, 2017). Stable carbon isotopic analysis of human dental enamel from EBA contexts from the foothills of the al-Hajjar mountains and coastal sites ($n = 100$) indicate $\delta^{13}C$ values with a wide range, indicative of a diet with mixed C_3–C_4 plant input, with the value spectrum generally weighted towards C_3-based plant sources, except at Umm an-Nar island (Gregoricka, 2013). Unfortunately, reconstructions of diet from human remains in EBA contexts are severely limited due to preservation conditions, postdepositional disturbances and fragmentary and commingled remains (Munoz, 2017). Additionally, the poor preservation of collagen in bones and teeth (Gregoricka, 2013) limits the assessment of the protein input into the human diet through $\delta^{15}N$ values. Such challenges suggest that the study of the contents of pottery, along with supporting bioarchaeological data, can provide a valuable lens into past dietary practices of Umm an-Nar populations.

1.3 | Pottery traditions and pottery from the Indus Civilisation

Indigenous pottery production in the Oman peninsula is documented from c. 3000 BC (Cleuziou 1989, p. 52), specifically that of black-on-red fine ware or Fine Red Omani ware, and by c. 2500 BC, domestic pottery with sandy pastes and black-painted geometric decorations were also produced at settlements (Blackman et al., 1989; Méry, 2000, 2013). Imported vessels from Sistan and Makran (south-east Iran and south-west Pakistan) together with southern Mesopotamian pottery and pottery from the Indus region are also found at settlements and tombs in the Oman Peninsula throughout the EBA (Blackman et al., 1989; Cleuziou & Tosi, 2007; Méry, 2000).

Indus pottery appears to have been imported to the Oman Peninsula mostly from c. 2500–2000 BC. It is represented by a variety of different forms, such as pedestalled dishes, perforated vessels, cooking pots and jars, and is found at several coastal and inland sites in south-eastern Arabia (Cleuziou & Méry, 2002; Méry, 2000; Thornton & Ghazal, 2016, pp. 204–208). Black-Slipped Jars (BSJs), however, are one of the most common vessel types, found more widely in coastal and interior settlements in the Omani peninsula than they are within the Indian subcontinent (Méry & Blackman, 2004). Geochemical analyses of several examples from different sites have indicated that these vessels were produced either along the Ravi River or the Indus River, but those reaching the Oman Peninsula came from the southern Indus basin area (Méry & Blackman, 1999, 2004). Indus BSJs are unmistakably transport or storage vessels, shaped not unlike amphoras from classical antiquity (Méry & Blackman, 2004). Although there are variations in size and capacity, ranging between 19 and 22 cm in external rim diameter, and estimated volumes vary from 30 to 80 litres, most BSJs appear to have been made to be transported by boat; their bases are tapered which makes them easy to stack and ship (possibly down the Indus river and then the Arabian Gulf), and they are slipped on both the interior and exterior surfaces (Méry & Blackman, 1999, 2004). It has been suggested that Indus BSJs were used to transport a specific foodstuff from the Indus region to south-eastern Arabia (Méry & Blackman, 2004); however, it is possible that upon their arrival in the Omani peninsula, they were emptied and refilled with different foodstuffs or for the transport of other commodities. It is also possible that BSJs were used to transport/store multiple foodstuffs and had secondary or multiple uses.

Apart from BSJS, other imported Indus pottery appear to mostly feature vessels related to food preparation or presentation (Méry, 2000). Several sites across the Oman Peninsula also have examples of characteristic Umm an-Nar pottery which are produced with typical shapes inspired by Indus pottery (termed as 'Indus-related' or 'Indus-style' pottery types) (Frenez et al., 2016; Méry, 2000, p. 238). These vessels often have characteristic everted rims (Frenez et al., 2016; Méry et al., 2017). The presence of a large and diverse assemblage of Indus and Indus-related material culture at different sites has led to the suggestion that people from the Indus region or Indus-trained craftspeople were settled in central Oman by *c*. 2500 BC (Frenez et al., 2016; Méry et al., 2017). This is particularly true for the site of Salūt-ST1, the focus of this paper.

2 | SALŪT-ST1

Located at the convergence of two major wadis, Wadi Sayfam and Wadi Bahla, in the vicinity of Bisya, south of Bahla, the area of Salut hosts at least three large circular EBA 'towers' built of massive stone blocks (Degli Esposti, 2016). The 'towers' were identified by different surveys (de Cardi et al., 1976, p. 164; Humphries, 1974, p. 50; Orchard & Orchard, 2007, p. 158) and are all located on low terraces adjacent to the main wadis and sometimes built around a low natural rock outcrop (Degli Esposti, 2016). One of these 'towers', now known as Salūt-ST1 (but previously identified as 'Building 5' by Orchard & Orchard, 2007) was excavated from 2010 to 2015 by the Italian Mission to Oman (IMTO) at the request of the former Office of the Adviser to His Majesty the Sultan for Cultural Affairs (Figure 1). The site is now included in the Bisya and Salut Archaeological Park, established by the Ministry of Heritage and Culture, and a new research project led by the University of Milan (Salut and Bisya Archaeological Mission) in 2020 is currently ongoing.

Excavations at Salūt-ST1 revealed a 22m circular stone tower with a central well, surrounded by a large ditch (11–13m wide and upto 3m deep) comprising two connected, concentric channels (Figure 1). The deposits inside the main ditch support the identification of three main phases within the EBA occupation of the site (Degli Esposti, 2016). During the first phase, the ditch was filled with water at least in its lower portion. The second phase is represented by a gradual silting of the ditch with waterborne sediments. Anthropic activity occurred inside the ditch during this phase, as witnessed by fireplaces and dumps interspersed with thin water-laid deposits. The third phase corresponds to the final filling up of the ditch, no longer in

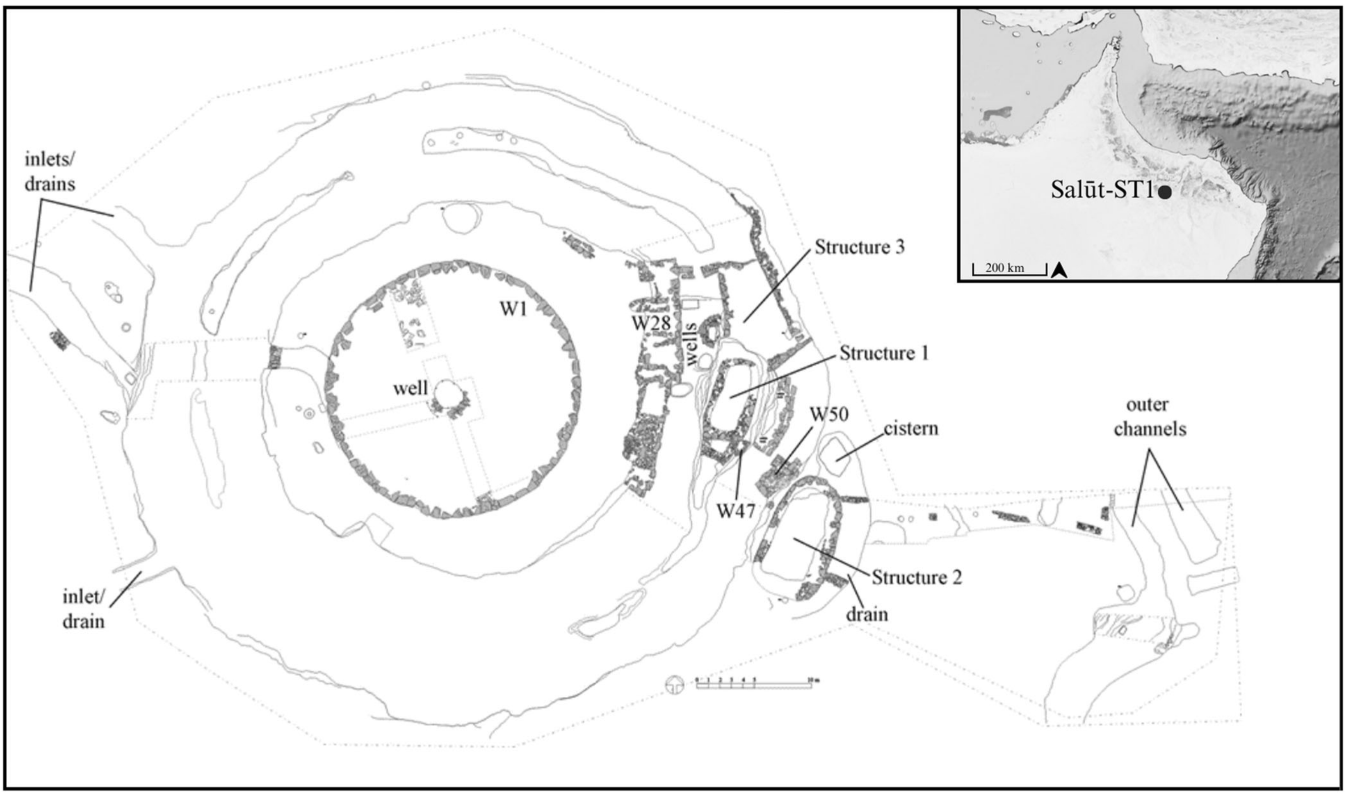

FIGURE 1 Plan of Salūt-ST1 and location of the site within Oman (inset).

use. Two dates obtained from charcoal from contexts located at the bottom and the top of the stratigraphic sequence of phase 2 span 2455–2147 and 2464–2294 cal BC, respectively, thus suggesting a relatively short life span and the abandonment of the site before the beginning of the Wadi Suq period (Méry et al., 2017; Degli Esposti & Cremaschi in preparation; Table 1). Six wells dug into the ditch's cemented marl in phase 2 were also discovered; the excavation of three of them suggests that inhabitants were tapping into a lower water table than the one exploited in the earlier phases of occupation of the site (Degli Esposti, 2016, p. 672). The central well was reused in the Iron Age when it was probably re-dug and enlarged, as indicated by Iron Age pottery within the well and a partially surviving wellhead (Degli Esposti, 2011, 2016). Pottery dating to the early Islamic period and Iron Age were also discovered in several contexts above the EBA deposits. Despite the mixing and redeposition of material in several parts of the site, certain EBA contexts within the main ditch were sealed and were stratigraphically reliable (Degli Esposti, 2016, p. 672). Materials from these contexts were prioritised for scientific studies of pottery and other objects.

2.1 | Local, regional and imported material culture

Umm an-Nar pottery, such as globular open-mouth jars and pots with typical motifs of horizontal and undulated lines on the shoulder, were the most common types of pottery found at Salūt-ST1 (Degli Esposti, 2016). The fabric of this pottery has been classified as ST1 Sandy Ware (divided into ST1 Beige Sandy Ware and ST1 Red Sandy Ware) and was probably locally-produced at Salūt-ST1, used for domestic purposes (Méry et al., 2017, Figure 2a–f). Indus-type cooking pots and exceptionally, one BSJ, were also associated with this type of ware (Méry et al., 2017, pp. 177–178). Fine Red Omani pottery, corresponding to other types found in other sites around the Oman Peninsula (Méry, 2000) was also represented at Salūt-ST1, possibly produced and distributed at a regional scale (Méry et al., 2017, p. 176; Figure 2g–i). A wide range of Indus pottery, including utilitarian pottery and specific forms used for food production, presentation, and storage were recovered from the stratigraphic levels associated with the second phase of the ditch at Salūt-ST1, such as micaceous fabric BSJs (Figure 2j–m), Indus-type cooking pots, perforated vessels, pedestalled dishes and small globular jars with black-on-red decorations (Degli Esposti, 2016; Frenez et al., 2016; Méry et al., 2017). Indus seals and carnelian beads possibly manufactured with non-Indus raw materials were also recovered from another part of the ditch (Frenez et al., 2016; Méry et al., 2017). The diversity of Indus pottery types; the presence of numerous Indus-style but locally produced pottery such as cooking pots and other specific types used for food preparation and presentation; as well as the presence of Indus beads, figurines and seals has led to the suggestion that 'Indus merchants and/or crafts-people' and/or 'Indus-related communities' were settled at Salūt-ST1 (Frenez et al., 2016, p. 118).

2.2 | Bioarchaeological evidence

Several quern stones, as well as some grinding/crushing stones, were found from EBA contexts at Salūt-ST1, indicating that plant foods were prepared. However, only macrobotanical remains of *Ziziphus* sp. were identified, perhaps indicating the consumption of the fruit (Degli Esposti, 2016), and limited charcoal analysis from two contexts suggested the presence of Acacia-type plants (cf. *Leguminosae Acacia*), possibly used as firewood. Faunal remains were retrieved from many contexts (Strolin 2018). A total number of 1534 bones (5674g) were studied and 861 (4380g) were identified (56%). The faunal spectrum at Salūt-ST1 is mainly represented by domestic taxa: goats and sheep (727 remains) represent 84.4% of the total number of identified specimens (NISP), and cattle bones (130 bones) represent 15.1% of this total. Equids and camels represent less than 1% of the NISP. Archaeozoological data thus suggest that animal exploitation mainly relied on domestic ruminants, which matches the evidence available from other inland Bronze Age sites of south-eastern Arabia (Uerpmann & Uerpmann 2008).

2.3 | Aim of the present research

This paper presents the results of lipid residue analysis from local, regional and imported pottery ($n = 69$) from Salūt-ST1 to address what foodstuffs were contained in pottery as part

TABLE 1 Radiocarbon dates obtained from contexts from Salūt-ST1.

US	Phase	Context	Type of material dated	^{14}C Date (BP)	Calibrated date (2σ)	Calibrated date (σ)
55	Phase 2 (final)	Dumped pottery with charcoal and burnt matter	Charcoal	3830 ± 35	2455 (6.3%) 2417 BC 2410 (85%) 2196 BC 2170 (4.2%) 2147 BC	2342 (11.4%) 2316 BC 2310 (56.9%) 2204 BC
419	Phase 2 (early)	Fireplace	Charcoal	3890 ± 25	2464 (95.4%) 2294 BC	2456 (39.8%) 2394 BC 2389 (28.5%) 2344 BC

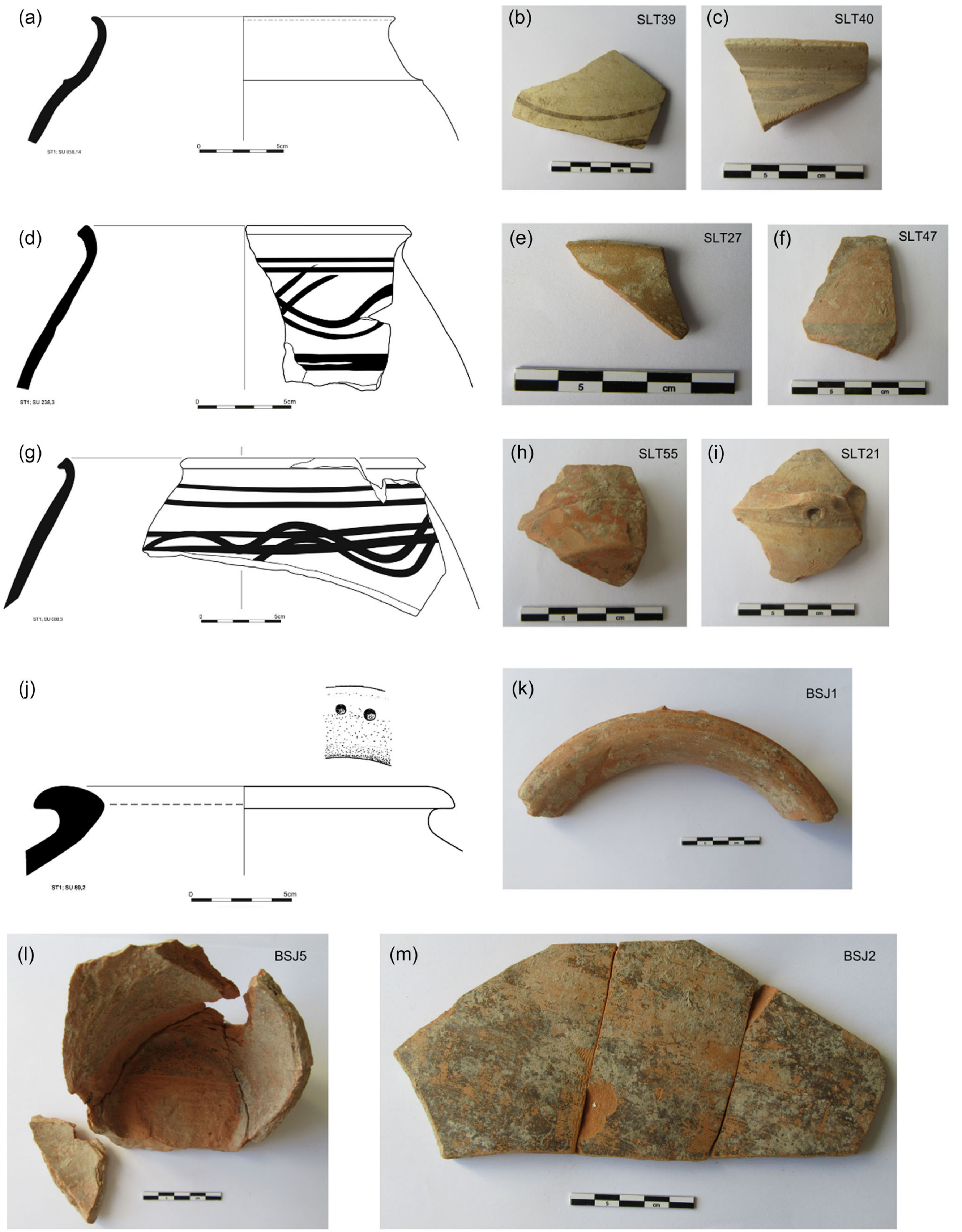

FIGURE 2 Drawings and photographs of (a–f) ST1 Sandy Ware (a–c: Beige Sandy Ware, d–f: Red Sandy Ware); g–i, Fine Red Omani Ware; j–m, Micaceous Red Indus Black Slipped Jar fragments from Salūt-ST1.

of everyday domestic practice, as well as to identify if specific products were used or stored in imported Indus pottery, specifically BSJs, at the site. Ceramic lipid residue analysis provides a means to extract, identify and reconstruct the contents of ancient vessels, enabling an understanding of foodstuffs that were cooked or stored in ceramic vessels (Evershed, 2008; Roffet Salque et al., 2017). The presence of specific organic products in imported vessels may also provide an indication of the 'invisible' products that were transported via exchange networks (e.g., Rageot et al., 2019). This method has been applied in several different archaeological contexts around the world, revealing the presence of organic products that do not usually survive in the archaeological record, such as animal fats and dairy products (e.g., Craig et al., 2005; Evershed et al., 2008), aquatic substances (Craig et al., 2013; Cramp & Evershed, 2014), leafy vegetables, plant oils (Charters et al., 1993, 1997; Copley et al., 2005; Dunne et al., 2016) and apicultural products such as beeswax (Roffet-Salque et al., 2015). Not only do lipid residues absorbed within the potsherd reflect the types of products processed within the vessels; isotopic analyses ($\delta^{13}C$) of fatty acids extracted from potsherds also reflect the source of the animal fats and the foraging environment or extent of C_3 or C_4 plants consumed by animals (Copley et al., 2003; Dunne et al., 2018; Mukherjee et al., 2008). This can provide valuable information about the past isoscapes of the region of study (Dunne et al., 2022). Within the context of the archaeology of south-eastern Arabia, this method has huge potential in addressing questions about domestic lifeways and the use of pottery in food production and storage, and, at the same time, opens up new ways to investigate the movement of organic products through exchange networks.

3 | METHODS

3.1 | Sample selection

Potsherds for lipid residue analysis from Salūt-ST1 were collected directly from the field during excavations in December 2015. The selected fragments were stored unwashed, wrapped in aluminium foil, and packed into polypropylene bags to avoid sample contamination.

Potsherds were chosen from two contexts located within the main ditch that contained evidence of ephemeral occupation, demonstrated by hearths in sandy fills and concentrations of pottery. Crucially, both these contexts probably represent a relatively narrow period of occupation, roughly between c. 2460 and 2150 cal. BC, providing an understanding of pottery use within a restricted chronological phase. A total of 69 vessel fragments were selected: 14 fragments of Fine Red Umm an-Nar or Omani Ware (FR-OM), 36 fragments of ST1 Sandy Ware (ST1-SW), which were further classified as Red Sandy Ware ($n = 23$) and Beige Sandy Ware ($n = 13$), 18 fragments of Micaceous Red Indus Black-Slipped Jars (MR-IN BSJs) and one indeterminate vessel (Table 1, Figure 2). Most of the vessel fragments were body sherds ($n = 48$), with some base ($n = 10$) and rim fragments ($n = 11$). See Supporting Information S1 for full details. The vessel forms represented included pots ($n = 11$), jars ($n = 19$), pot/jars ($n = 2$), suspension vessels ($n = 2$), Black Slipped-Jars ($n = 18$) and indeterminate forms ($n = 17$). A rim fragment of a Beige Sandy Red jar (SLT40) had evidence of graffiti marks. None of the analysed potsherd fragments showed evidence of charring or burning on the interior or exterior surfaces.

Due to the targeted nature of sampling, state of vessel preservation and colour of the interior and exterior slip of Indus BSJs at Salūt-ST1, it was possible to determine through visual examination that the assemblage contained at least five individual Black-Slipped Jars. Fragments from other vessel fabrics did not fit together, and thus it was assumed that every other fragment analysed represented an individual vessel. Fourteen of the 18 BSJ fragments could be assigned to individual vessels, and three BSJs had multiple fragments (Figure 2j–m). One of the BSJ rim fragments (SLT74) had two small perforations, made by partial drilling. Termed 'house-marks' or 'potter's marks', there are several examples of drill marks on the rims of vessels of different fabric types at the site (Degli Esposti, 2014).

3.2 | Lipid extractions: Acidified methanol and solvent extractions

A small portion (~5 cm diameter) of each selected pottery fragment ($n = 69$) was broken off and exterior surfaces were removed with a modelling drill. The pottery piece was then ground into a fine powder to obtain ~1 g using a mortar and pestle. The drill bits and mortar and pestle were cleaned three times with HPLC-grade dichloromethane between uses to avoid cross-contamination.

Lipids from the pottery powder were extracted via the one-step acidified methanol protocol (Craig et al., 2013; Correa-Ascencio & Evershed, 2014) and analysed via gas chromatography coupled to a mass spectrometer (GC-MS) (Supporting Information S2).

A selection of fragments with relatively higher lipid concentrations or unusual lipid profiles ($n = 10$) were also analysed via solvent extraction (Evershed et al., 1990) to test for the preservation of triacylglycerols and wax esters (Supporting Information S2). These extracts were analysed via gas chromatography-flame ioniser detection (GC-FID) and GC-MS.

3.3 | Instrumental analyses: GC-FID, GC-MS and GC-C-IRMS

GC-FID analyses were performed for the solvent extracts on an Agilent Technologies 7890A device. One microliter of the sample was introduced using an on-column injector into a 15 m × 0.32 mm i.d. fused silica capillary (DB5-MS, 0.1 µL film thickness, Agilent JandW), with helium used as the carrier gas. The GC temperature programme was as follows: increased from 50°C to 100°C at 15°C min^{-1}, then from 100°C to 375°C at 10°C min^{-1}. Quantification and calculation of the TLE were done by calculating the total peak area in the GC-FID chromatographic profile in relation to the peak area of the internal standard, the amount of internal standard added during sample preparation and the mass of the powdered sample.

GC-MS analysis of both solvent and acidified methanol extracts was performed using a Shimadzu GC 2010 PLUS chromatograph coupled to a Shimadzu QP 2010 ULTRA mass spectrometer, fitted with a high-temperature nonpolar column (DB5-HT, 15 m × 0.32 mm i.d., 0.1 µm film thickness, Agilent JandW). The injection was performed using a splitless injector. The temperature programme consisted of a 1 min isothermal hold at 50°C followed by an increase to 150°C at 20°C min^{-1}, then to 250°C at 10°C min^{-1} and to 350°C min^{-1} and a final isothermal hold for 10 min. The GC-MS interface was maintained at a temperature of 300°C and the mass spectrometer was run in electron ionisation mode (EI, 70 eV). Mass spectra were acquired over the range m/z 50–950.

Gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS) was conducted on a selection of the acidified methanol extracts. Nineteen samples from specific vessel types (e.g., BSJs) and with relatively high concentrations of fatty acids were selected. Differences in fatty acid biosynthesis between ruminant adipose and mammary tissues, as well as those of non-ruminants, create differences in the stable carbon isotope values of fatty acids (Copley et al., 2003; Dudd & Evershed, 1998). Fats from animals raised on a C_4 plant/marine diet also have enriched $\delta^{13}C$ values compared to those from animals raised on C_3 plants (Dunne et al., 2012). Plotting the difference between $C_{16:0}$ and $C_{18:0}$ fatty acids ($\Delta^{13}C = \delta^{13}C_{18:0}–\delta^{13}C_{16:0}$) against the $\delta^{13}C_{16:0}$ values highlights metabolic and physiological variations enabling the distinguishing of ruminant (meat and dairy) and non-ruminant fats and also enables the detection of any C_4/marine dietary component into the animals' diet (e.g., Craig et al., 2005; Dunne et al., 2012; Lucquin et al., 2016; Outram et al., 2009).

Stable carbon isotope values of methyl palmitate ($C_{16:0}$) and methyl stearate ($C_{18:0}$), derived from precursor fatty acids, were measured by GC-C-IRMS following existing procedures (Craig et al., 2013). Results were plotted against $\delta^{13}C$ values of modern reference terrestrial fats from Africa and Asia and C_3 plant oil references published elsewhere (Craig et al., 2005; Dunne et al., 2012; Lucquin et al., 2016; Outram et al., 2009; Steele et al., 2010). Fatty acid $\delta^{13}C$ values of modern reference fats from the study region are not yet available.

4 | RESULTS AND INTERPRETATIONS

Interpretable concentrations of lipid (above 5 µg g^{-1}) were found in all the potsherds analysed via acidified methanol extraction from Salūt-ST1 ($n = 69$; Table 2. Figure 3). Of these, 10 samples were also extracted via solvent extraction, of which only three (SLT30, SLT35 and SLT53) yielded total lipid extracts (TLEs) above 5 µg g^{-1} (Supporting Information S1).

4.1 | Lipid yields from different groups of pottery

Lipid concentrations of vessels from Salūt-ST1 ranged from 5.6 to 741.4 µg g^{-1}, with FR-OM vessels indicating higher lipid concentrations (mean: 187.9 µg g^{-1}; Kruskal–Wallis test ($\chi^2[4] = 14.705$, $p = .005$) than the other vessel fabrics. Lipid yields from ST1-Sandy Ware vessels and Indus BSJs had similar median values, but Red Sandy Ware vessels exhibited a narrower range with three exceptions (SLT18, SLT35 and SLT37) (Figure 3).

TABLE 2 Range, average and median lipid concentrations from different groups of pottery analysed from Salūt-ST1.

Fabric Type	Number of samples	Lipid concentration range (µg g^{-1})	Mean lipid concentration (µg g^{-1})	Median lipid concentration (µg g^{-1})
FR-OM	14	18.9–740.6	187.9	81.2
ST1-SW	36	5.6–741.4	77.9	25.8
Red Sandy Ware	23	7.1–741.4	86.6	26.2
Beige Sandy Ware	13	5.6–381.4	62.7	25.4
MR-IN (BSJs)	18	5.7–85.2	35	28.4
Indeterminate	1		76	
Total	69	5.6–741.4	89	35.5

Note: Red and Beige Sandy Wares fall under the ST1 Sandy Ware category.

Abbreviations: BSJ, Black-Slipped Jars; FR-OM, Fine Red Omani Ware; MR-IN, Micaceous Red Indus Ware; ST1-SW, ST1 Sandy Ware.

Lipid concentrations of Indus BSJs ($n = 18$) ranged from 5.7 to 85.2 μg g^{-1}. Of the 18 fragments, 14 fragments could be assigned to one of five individual jars that were identified within the assemblage (see Section 3.1). Lipid concentrations from fragments belonging to the same vessel were compared to (1) assess the reliability of lipid concentration values obtained and (2) measure the gradient of lipid concentration across the vessel profile to make inferences about vessel use, if possible (Table 3). Such work has previously been carried out on ethnographic ceramic vessels from Senegal (Drieu et al., 2022). Table 3 shows that fragments belonging to the same Indus BSJ demonstrate a relatively constrained range of values for lipid yields. Figure 4 demonstrates the limited variability for similar types of fragments from the same vessels. For BSJ 2, the lipid yields of the body fragments were higher than those obtained for rim fragments and fragments from the top of the body, whereas the lower part of the vessel had a very low lipid yield. Body fragments of BSJ 3 had relatively higher lipid concentrations than BSJ 2, and finally, the base and funnel fragments of BSJ 5 had relatively higher lipid concentrations than most other fragments. Hypotheses about the relationship between lipid concentrations

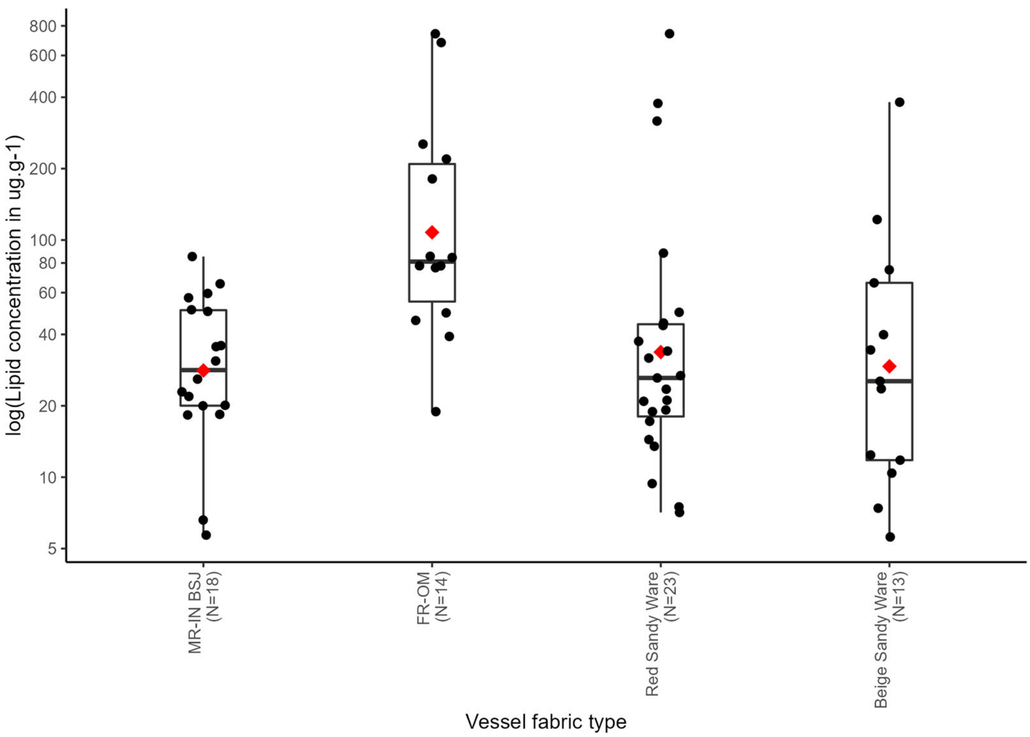

FIGURE 3 Boxplots of lipid concentrations obtained from Indus BSJs, FR-OM and ST1-Sandy Ware (Red Sandy Ware and Beige Sandy Ware) vessels from Salūt-ST1 (excluding the single indeterminate vessel). Red diamonds represent mean values. FR-OM: Fine Red Omani Ware; MR-IN BSJ, Micaceous Red Indus Black-Slipped Jars.

TABLE 3 Details of individual vessels of Indus BSJs identified at Salūt-ST1 including the number of fragments, fragment type/s, lipid concentration range and mean lipid concentration.

Individual BSJ #	Number of fragments	Fragment type/s	Lipid concentration range (in μg g^{-1})	Mean lipid concentration (in μg g^{-1})
BSJ 1	1	Rim (SLT1)	85.2	
BSJ 2	7	Rim (SLT74), Body-top (SLT04), Body (SLT05, SLT08, SLT09, SLT62), Between body and funnel (SLT03)	6.6–35.9	21
BSJ 3	3	Body (SLT38, SLT60, SLT63)	30.9–59.5	42
BSJ 4	1	Body (SLT73)	20.1	
BSJ 5	2	Base (SLT79), funnel (SLT78)	50–65.4	57.7

Note: Four other BSJ fragments that could not be assigned to any individual vessel are not included in this table.

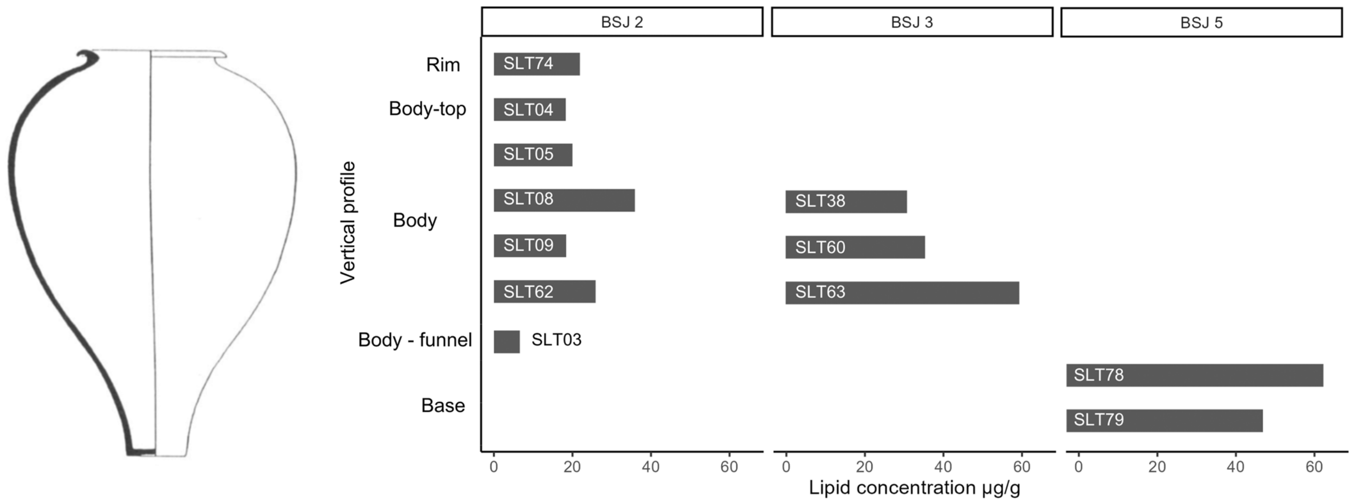

FIGURE 4 Lipid yields of fragments corresponding to three Indus Black Slipped Jars after acidified methanol extraction. Note that the exact location of the body fragments on the body of vessels is unknown. Representative drawing of Black-Slipped Jar (left) from Méry and Blackman (1999) after Bouquillon et al. (1996).

along the profile and vessel use are explored in the Discussion (Section 5.3).

4.2 | Lipid composition: All vessel fabrics

Lipid extracts of pottery fragments from Salūt-ST1 were characterised by saturated fatty acids ranging from $C_{12:0}$ to $C_{26:0}$. Most vessel fragments had GC-MS profiles dominated by palmitic acid ($C_{16:0}$) (43 extracts, 62%); however, stearic acid ($C_{18:0}$) had the highest peak in 12 extracts, 17%), and myristic acid ($C_{14:0}$) had the highest peak in six extracts (9%). Most profiles were typical of degraded animal fats (Dudd & Evershed, 1998; Dudd et al., 1999; Whelton et al., 2018); however, mid-chain fatty acids are ubiquitous in plant and animal products. Forty-seven (68%) of the lipid extracts contained branched-chain fatty acids such as C_{15}, and C_{17} (and on three occasions, C_{14}), which may be indicative of ruminant fats, but also may have bacterial origin (Dudd & Evershed 1998, see Figure 5 and Supporting Information S1).

Unsaturated fatty acids (UFAs) such as $C_{16:1}$ and $C_{18:1}$ were found in half of the extracts, and in some instances, $C_{22:1}$ (seven extracts) were also found, but the relative intensity of these peaks was low. α,ω-dicarboxylic acids (C_8, C_9 and/or C_{10}) were found in 19 extracts (28%) with shorter-chain (C_5, C_6, C_7) moieties found in two extracts (SLT09: Indus BSJ, and SLT35: Sandy Red Omani vessel) that also had UFAs $C_{16:1}$, $C_{18:1}$ and $C_{22:1}$. Dicarboxylic acids are degradation products of UFAs (Regert et al., 1998), which are more predominant in plants or aquatic products. Two extracts (SLT53 and SLT54: Fine Red Omani vessels) had relatively high abundances of even long-chain fatty acids ($C_{20:0}$ to $C_{24:0}$), with $C_{22:0}$ dominating in one extract, and $C_{16:0}$ in the other, along with UFAs and dicarboxylic acids (Figure 5). The presence of long-chain fatty acids in these extracts is likely indicative of leafy plants (Dunne et al., 2022; Kolattukudy et al., 1976; Tulloch, 1976). Only a single sample (SLT73: Indus BSJ) had very small peaks of odd-chain *n*-alkanes (C_{25}–C_{29}, C_{27} dominating) possibly indicating the presence of plant waxes (Kolattukudy, 1970), while 8 samples had low concentrations of a nonspecific pattern of *n*-alkanes, indicative of contamination from petroleum products. As *n*-alkanes are also common lipid components of soils (van Bergen et al., 1997), their low presence in the pottery could be related to the burial context and is not particularly diagnostic.

Despite the presence of a large proportion of ST1 Sandy Ware pots and jars that were likely used for domestic practices or cooking, mid-chain ketones or other heat markers indicative of the heating or boiling of products were not detected in any of the extracts. These results are consistent with the above-mentioned absence of visible burning traces on the pottery surfaces.

In the three samples from which solvent extracts had interpretable lipid concentrations (SLT30, SLT35: ST1-Sandy Ware vessels and SLT53: FR-OM vessel), the presence of fatty acids ($C_{12:0}$ to $C_{18:0}$); UFAs ($C_{16:1,}$ $C_{18:1}$), branched-chain fatty acids (C_{15} and C_{17}) and monoacylglycerols (M_{16} and M_{18}) were detected, indicating degraded animal fats and matching the lipid profiles obtained via acidified methanol extractions (see Supporting Information S1).

4.3 | Lipid composition: Individual Indus BSJs

The lipid profiles of fragments of Indus BSJs that could be assigned to the same vessel were compared. Three fragments (SLT38, SLT60 and SLT63) belonging to BSJ 3 had lipid profiles very similar to each other and their

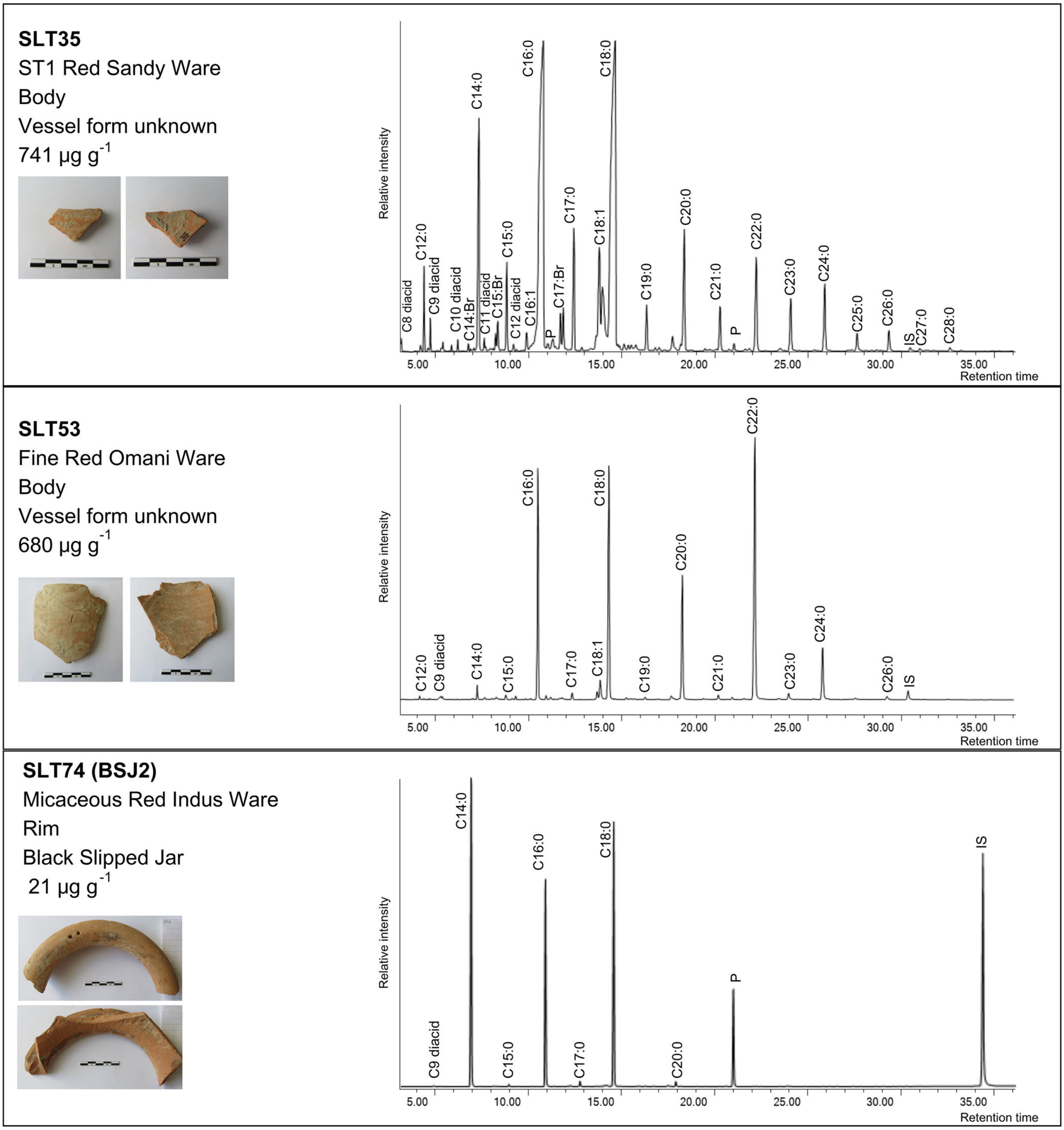

FIGURE 5 Examples of partial total ion chromatograms of lipid extracts from vessel fragments from Salūt-ST1. SLT35 has a profile typical of degraded animal fats with possible plant input. SLT53 has a high abundance of $C_{22:0}$ fatty acid and SLT74 has a high abundance of $C_{14:0}$ fatty acid, possibly indicative of the presence of leafy plants and seed oil, respectively. Cn:x indicates fatty acid with n carbon atoms and x double bonds; IS: Internal Standard; P: phthalate, Br: branched-chain fatty acid; diacid: α,ω-dicarboxylic acids. For SLT74, the internal standard was different to the others; hence there is a difference in the retention time.

$C_{16:0}$/$C_{18:0}$ (P/S) ratios ranged between 1.1 and 1.3. Similarly, two fragments from BSJ 5 (SLT78 and SLT79) also had comparable lipid profiles, with P/S ratios of 0.6 and 0.9, respectively. Together, both these vessels have lipid profiles indicative of degraded animal fats.

For BSJ 2, five out of the seven fragments (SLT03, SLT04, SLT05, SLT08 and SLT62) had very similar lipid profiles, with saturated fatty acids ($C_{12:0}$ to $C_{20:0}$); branched-chain fatty acids (C_{15} and C_{17}), UFAs ($C_{16:1}$, $C_{18:1}$) and diacids (C_8 and/or C_9), which altogether are not highly diagnostic; but likely indicate the presence of degraded animal fats. However, one fragment (SLT09) also had short-chain diacids (C_5–C_{10}); whereas another (SLT74) had very high concentrations of $C_{14:0}$ relative to $C_{16:0}$, possibly indicating the presence of plant products or plant oils (Copley et al., 2005; Dunne et al., 2016). The P/S ratios of all the fragments assigned to BSJ 2 ranged from 0.8 to 1.2. These results highlight that fragments belonging to the same vessel exhibit some variability in their lipid profiles. This may be linked to the differential absorption of lipids from different foodstuffs used in the same vessel, indicating challenges in interpretation based on lipid profiles alone as previously observed in experiments on ethnographic pottery (Drieu et al., 2022).

4.4 | Fatty acid isotopic results and interpretations

Nineteen extracts from Salūt-ST1 were selected for fatty acid isotopic analysis, of which eight belonged to Indus BSJ fragments, six to ST1-Sandy Ware vessels, and five to Fine Red Omani vessels. The $\Delta^{13}C$ ($\delta^{13}C_{18:0}$–$\delta^{13}C_{16:0}$) values from these vessel extracts ranged from –4‰ to 1‰ and $\delta^{13}C_{16:0}$ values ranged from –22.9‰ to –30.1‰ (Figure 6).

Four vessels had $\Delta^{13}C$ values that fell within the reference range for dairy products, including a FR-OM suspension vessel (SLT21), an Indus BSJ (SLT63- BSJ 3) and two ST1-SW vessels (SLT35 and SLT37). The increased negative $\delta^{13}C_{16:0}$ values of these extracts suggest that dairy products were derived from animals consuming more C_4 plants.

At least four of the vessels had $\Delta^{13}C$ values that fell within the reference range for ruminant adipose fats, which include three ST1-SW vessels (SLT20, a Beige Sandy Ware suspension vessel and SLT18 and SLT50, two Red Sandy Ware jars), and one BSJ (SLT73–BSJ 4). One FR-OM vessel (SLT53), and another BSJ (SLT79–BSJ 5) had $\Delta^{13}C$ values that fell at the limits of the range of ruminant adipose fats. The $\delta^{13}C_{16:0}$ values of these extracts suggest the presence of meat in the vessels that originated from ruminants consuming mixtures of C_3 and C_4 plants (Copley et al., 2003; Dudd & Evershed, 1998; Dunne et al., 2012).

The rest of the vessels, which included a Red Sandy Ware pot (SLT13), three FR-OM vessels (SLT46, SLT52 and SLT54) and four Indus BSJ fragments (SLT09, SLT74, SLT62—BSJ 2 and SLT02—BSJ with no individual ID) had $\Delta^{13}C$ values that fell within modern references ranges for non-ruminant resources or those of C_3 plant oils (Figure 6b). Of these eight vessels, half had the presence of a range of α,ω-dicarboxylic acids or a high relative abundance of $C_{14:0}$ which may support the presence of plant products or seed oil, respectively (Dunne et al., 2016); however, other chemical markers for plant products were not detected, and the P/S ratios were not suggestive of plant products in these extracts. These inconsistent results complicate the interpretation of $\delta^{13}C$ values and are discussed in detail in Section 5.2.

5 | DISCUSSION

5.1 | Pastoral food practices at Salūt-ST1

The results obtained from lipid residue analysis of pottery provide unique insight into the use of ceramics as part of everyday food practices by prehistoric communities at Salūt-ST1. As the pottery analysed was from two sealed occupational contexts located within the main ditch, the ceramic lipid extracts likely represent food storage and vessel use restricted to a relatively narrow chronological phase, roughly between c. 2460 and 2150 cal. BC.

Nearly all of the lipid profiles obtained from extracts from ceramics from Salūt-ST1 are characteristic of degraded animal fats, some with evidence of the input of plant products, which is discussed in Section 5.2. The molecular evidence suggests that the source of most of the animal fats was from ruminants (indicated by the presence of branched-chain fatty acids in 47/69, 68% of the samples). The fatty acid-isotopic results also indicate the presence of ruminant adipose fats (6/19, 32%) and dairy products (4/19, 21%), with the use of domestic ST1-Sandy Ware jars and suspension vessels appearing to be more frequently used as containers for ruminant adipose fats, although the analysis of more vessels is necessary to support this. Evidence of dairy products was detected in different vessel types, such as a FR-OM suspension vessel, ST1-SW pot and indeterminate vessel form, as well as an Indus BSJ (Figure 6). These data represent the first direct evidence of dairy products in EBA vessels in the Oman Peninsula. It is worth noting that the presence of animal products was also reported in Umm an-Nar vessels from Hili 8 and Hili North Tomb A (Suryanarayan et al., 2022).

The significant presence of animal fats in the Salūt-ST1 pottery serves as a reminder of the importance of animal resources, specifically of pastoral lifeways and products during the Umm an-Nar period, which is easy to overlook due to the generally poor preservation of animal bones in archaeological contexts from the Oman peninsula and limited state of research on Bronze Age inland sites. At other inland Umm an-Nar 'tower' settlements, domestic cattle, sheep and goats constituted the striking majority of faunal remains, with wild fauna being only a very small percentage of the assemblage (Uerpmann & Uerpmann, 2008). At Hili 8, the small sample studied from the Umm an-Nar period indicated that in terms of bone weight, an indicator of the amount of meat per taxon, cattle contributed around 60% of the bone weight of domestic taxa, while sheep and goats constituted the rest, with goat slightly outnumbering sheep (Uerpmann & Uerpmann, 2008, pp. 468–469).

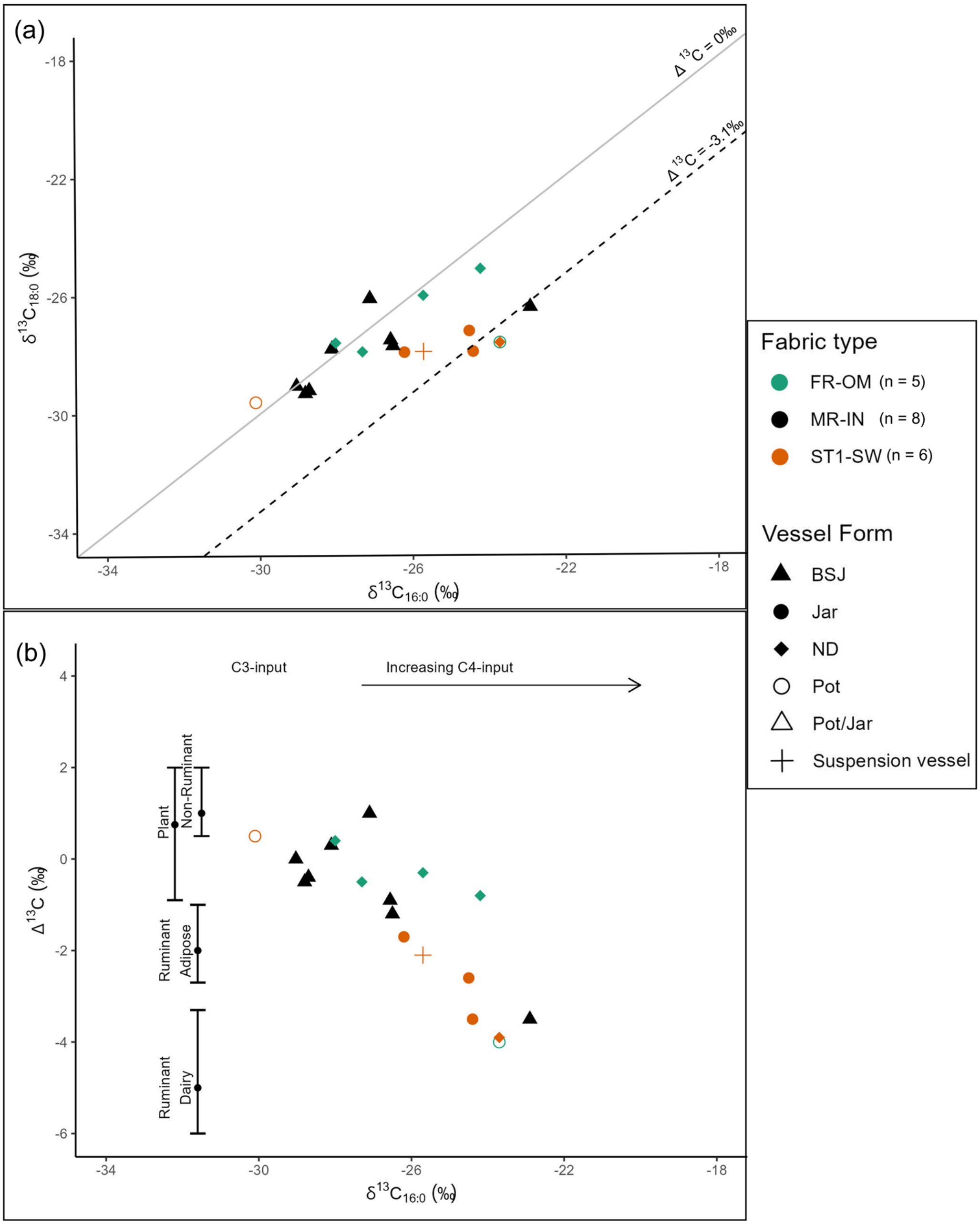

FIGURE 6 Scatter plots showing the δ^{13}C values of (a) $C_{18:0}$ and $C_{16:0}$ fatty acids and (b) Δ^{13}C ($C_{18:0}$–$C_{16:0}$) and $C_{16:0}$ fatty acid values, measured from lipid extracts of potsherds from Salūt-ST1. In (a), the dashed line at –3.3‰ indicates the limit of Δ^{13}C values for reference dairy fats and the grey line indicates 0‰. In (b), ranges depicted represent the mean ± 1 s.d. of Δ^{13}C values of modern reference terrestrial fats from Africa and Asia and C_3 plant oil references published elsewhere (Craig et al., 2005; Dunne et al., 2012; Lucquin et al., 2016; Outram et al., 2009; Steele et al., 2010). Modern references from the study region are not yet available. Instrumental error is less than ±0.5‰. BSJ, Black Slipped Jar; FR-OM, Fine Red Omani Ware; ND, vessel form not determined; ST1-SW, ST1 Sandy Ware.

At Maysar, domestic animals are also predominant with cattle bones constituting between 50% and 60% of the bone weight of domestic ruminants (Uerpmann & Uerpmann, 2008, pp. 470–472). Preliminary results from the zooarchaeological study of selected contexts from Salūt-ST1 indicate a similar pattern, with the assemblage dominated by domestic ruminants (Strolin, 2018). Looking at the relative proportions of bone weights of domestic ruminants, sheep and goats together constitute 64% of the weight (Minimum Number of Individuals [MNI] of 31) with a predominance of goats, and cattle constitute the rest (MNI of 3). All these taxa thus contributed in terms of meat including adipose fat. Taking into account their bone frequency and the presence of adults and females, zooarchaeological data are consistent with the exploitation of meat and secondary products such as milk. Considering other ruminants, the fatty meat of camel, likely wild, could also be exploited despite low bone count.

The same may apply to gazelle adipose fat: gazelle bones are so far absent from Salūt-ST1's studied assemblage, but are documented at other sites in the area (Uerpmann & Uerpmann, 2008, pp. 468–472). As such, the present analyses match with previous zooarchaeological results.

The $\delta^{13}C_{16:0}$ values from fatty acids also provide an indication of the plant isoscapes that constituted the foraging environments of the animals (e.g., Dunne et al., 2022). Previously reported carbon isotopic values from faunal enamel from EBA contexts in the Oman Peninsula suggest that ruminants were foddering on both C_3 and C_4 plants (Gregoricka, 2013), which is confirmed by the present analysis. Slightly more negative $\delta^{13}C_{16:0}$ values for ruminant dairy products indicate that the domestic ruminants exploited for dairy likely consumed more C_4 plants, confirming previous observations (Gregoricka, 2013). Evidence for dairying, although minimal, is consistent with herding practices also aiming at obtaining useful secondary products, as suggested by zooarchaeological evidence.

5.2 | Extent of plant input and other aspects of vessel-use

The presence of plant products was suggested in some extracts from Salūt-ST1. This was indicated by high abundances of $C_{14:0}$ relative to other fatty acids, possibly indicating seed oils (Dunne et al., 2016) which were observed in four Indus BSJ fragments (SLT01: BSJ 1, SLT02: no vessel ID, SLT74: BSJ 2 and SLT79: BSJ 5); the presence of α,ω-dicarboxylic acids ranging from C_5–C_{12}, derived from unsaturated acids that may have originated from plant products (Regert et al., 1998) in two fragments (SLT35: Red Sandy Ware vessel, and SLT09: Indus BSJ 2); and finally high abundances of long-chain fatty acids (LCFAs) relative to other fatty acids in two FR-OM vessels (SLT53 and SLT54, Figure 5). LCFAs originate in leaf or stem epicuticular waxes, and likely denote the processing of leafy plants in these vessels (Dunne et al., 2022; Kolattukudy et al., 1976; Tulloch, 1976). The evidence suggests that both animal and plant products played a role in daily domestic practices at Salūt-ST1. However, the importance of plants may be underestimated as the presence of both meat and plants in the same vessel would 'swamp' the plant signal, as animal products contain several orders of magnitude higher lipid content than plant products (Charters et al., 1997; Dunne et al., 2022; Evershed, 2008; Hammann & Cramp, 2018). It is worth noting, however, that the presence of plant oils was also detected in a small minority of vessels from Hili 8 and Hili North Tomb A, including two Fine Red Omani necked pots from Hili North Tomb A, and one Fine Red Omani necked pot and two Indus Black-Slipped Jars from Hili 8 (Suryanarayan et al., 2022).

As mentioned in Section 4.4, the interpretation of the $\delta^{13}C$ values of fatty acids that fall outside the established ranges of ruminant adipose fats and ruminant dairy fats is more challenging. In the current data set, a number of extracts have fatty acid $\delta^{13}C$ values that fall above ranges of ruminant adipose fats; some within ranges reported for non-ruminants (Lucquin et al., 2016; Outram et al., 2009), mixtures of non-ruminant and ruminant carcass fats (Mukherjee et al., 2008) or those of C_3 oilseed plants (Steele et al., 2010). Non-ruminant animals are rarely reported in faunal assemblages from the Oman Peninsula (Uerpmann & Uerpmann, 2008), and so their contribution to food in vessels is unlikely. Similarly, non-ruminant animal remains are scarcely attested at Salūt-ST1. Only three equid bones were recorded and there is no direct evidence related to meat consumption (Strolin, 2018). However, the inclusion of equids or other local or traded-in non-ruminants in the diet cannot be completely ruled out.

For interpreting the values falling within references of non-ruminant fats, multiple elements must be considered. First, the lipid content of pottery represents mixtures derived from multiple use events; in addition, as mentioned above, the representation of commodities is biased toward fat-rich foodstuffs. At the same time, fatty acids which are derived from plants are likely to contribute carbon more depleted in ^{13}C, altering the $\delta^{13}C$ values of the $C_{16:0}$ and $C_{18:0}$ fatty acids (Hendy et al., 2018; Suryanarayan et al., 2022; Whelton et al., 2021), and plant oils have a wide range of fatty acid $\delta^{13}C$ values (Steele et al., 2010). The mixing of plant oils and animal products, or other wild resources, can create equifinal isotopic values, making it challenging to determine the source(s) of the lipids in archaeological vessels (e.g., Whelton et al., 2021). The absence of reference fats from the region creates further complexity in interpretation.

No evidence for ketones or other heat markers was detected in any of the extracts, making inferences about cooking practices limited. Similarly, no patterns emerged when investigating the relationship between vessel form and contents, however, regionally produced Fine Red Omani vessels from Salūt-ST1 had relatively higher lipid yields compared to other fabric types (Figure 3). Moreover, in addition to lipid profiles indicative of degraded animal fats (comparable to other vessels), the results from two Fine Red Omani fragments (SLT53: body and SLT54: base; undetermined vessel form) suggest the use of leafy plants in the vessels. In contrast, locally produced Sandy Wares had narrower ranges of lipid yields, despite being microporous (Méry, 2000, p. 102), which is a factor known to facilitate lipid absorption (Drieu et al., 2019). Lipid profiles from Sandy Wares were typical of degraded animal fats, with fatty acid isotopic values falling within ranges of ruminant fats, with one exception (SLT13) (Figures 3 and 6). This pattern could suggest that vessels from these two fabric types, one, a finer variety produced and distributed regionally around the Oman Peninsula (FR-OM), and the other, a more domestic ware (ST1-Sandy Ware),

TABLE 4 Details of fragments of Indus BSJs analysed from Salūt-ST1, grouped by unique vessels identified.

Sample ID	Fragment type	Individual BSJ#	Lipid concentration (μg g^{-1})	Mean lipid yield of individual vessel (μg g^{-1})	Molecular composition	$\delta^{13}C_{16:0}$ (‰)	$\delta^{13}C_{18:0}$ (‰)	$\Delta^{13}C$ (‰)	Molecular interpretation	Isotopic interpretation
SLT01	Rim	BSJ 1	85.2		FAs ($C_{14:0}$, $C_{16:0}$, $C_{18:0}$; **$C_{14:0}$ abundant**)	−27.1	−26.1	1.0	Degraded animal fats + plant oil?	Plant/non-ruminant/mixture
SLT03	Between body and funnel	BSJ 2	6.6	21	FAs($C_{14:0}$–$C_{20:0}$), UFAs ($C_{18:1}$), Diacids (C_8, C_9), Sulphur				Degraded animal fats	
SLT04	Body-top	BSJ 2	18.3		FAs($C_{12:0}$–$C_{20:0}$), UFAs ($C_{18:1}$), Diacids (C_8, C_9), Sulphur				Degraded animal fats	
SLT05	Body	BSJ 2	20		FAs($C_{12:0}$–$C_{24:0}$), BrFAs (C_{17}), UFAs ($C_{18:1}$, $C_{22:1}$), Diacids (C_8, C_9), Sulphur				Degraded animal fats	
SLT08	Body	BSJ 2	35.9		FAs($C_{16:0}$, $C_{18:0}$), UFAs ($C_{18:1}$, $C_{22:1}$)				Degraded animal fats	
SLT09	Body	BSJ 2	18.4		FAs ($C_{14:0}$–$C_{26:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{16:1}$, $C_{18:1}$, $C_{22:1}$), Diacids (C_5, C_6, C_7, C_8, C_9, C_{10})	−28.7	−29.2	−0.4	Degraded animal fats + plant product?	Plant/non-ruminant/mixture
SLT62	Body	BSJ 2	25.9		FAs ($C_{14:0}$–$C_{18:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{18:1}$)	−28.1	−27.8	0.3	Degraded animal fats	Plant/non-ruminant
SLT74	Rim	BSJ 2	21.9		FAs ($C_{12:0}$–$C_{20:0}$; **$C_{14:0}$ abundant**)), BrFAs (C_{15}, C_{17}), UFAs ($C_{18:1}$, $C_{22:1}$), Diacid(C_9)	−29.03	−29.05	0.0	Degraded animal fats + plant oil?	Plant/non-ruminant/mixture
SLT38	Body	BSJ 3	30.9	42	FAs ($C_{12:0}$–$C_{20:0}$), UFAs($C_{16:1}$, $C_{18:1}$), Diacids (C_9)				Degraded animal fats	
SLT60	Body	BSJ 3	35.5		FAs ($C_{12:0}$–$C_{24:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{16:1}$, $C_{18:1}$), Diacids (C_9)				Degraded animal fats	
SLT63	Body	BSJ 3	59.5		FAs ($C_{12:0}$–$C_{22:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{18:1}$), Diacids (C_9)	−22.9	−26.4	−3.5	Degraded animal fats	Dairy
SLT73	Body	BSJ 4	20.1		FAs ($C_{12:0}$–$C_{22:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{18:1}$), Diacids (C_9), *n*-alkanes (C_{25}, C_{27}, C_{29})	−26.5	−27.7	−1.2	Degraded animal fats + plant wax?	Ruminant adipose
SLT78	Funnel	BSJ 5	65.4	57.7	FAs ($C_{14:0}$, $C_{16:0}$, $C_{18:0}$)				Degraded animal fats	
SLT79	Base	BSJ 5	50		FAs ($C_{14:0}$, $C_{16:0}$, $C_{18:0}$; **$C_{14:0}$ abundant**); BrFAs (C_{15}, C_{17})	−26.56	−27.5	−0.9	Degraded animal fats + plant oil?	Ruminant adipose

TABLE 4 (Continued)

Sample ID	Fragment type	Individual BSJ#	Lipid concentration (µg g^{-1})	Mean lipid yield of individual vessel (µg g^{-1})	Molecular composition	$\delta^{13}C_{16:0}$ (‰)	$\delta^{13}C_{18:0}$ (‰)	$\Delta^{13}C$ (‰)	Molecular interpretation	Isotopic interpretation
SLT02	Between body and funnel	No vessel ID	22.9		FAs ($C_{14:0}$, $C_{16:0}$, $C_{18:0}$; **$C_{14:0}$ abundant**)	−28.8	−29.3	−0.5	Degraded animal fats + plant oil?	Plant/non-ruminant/mixture
SLT10	Body	No vessel ID	5.7		FAs ($C_{16:0}$, $C_{18:0}$)				Uninterpretable	
SLT59	Between body and funnel	No vessel ID	50.8		FAs ($C_{14:0}$–$C_{24:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{16:1}$, $C_{18:1}$), Diacids (C_9)				Degraded animal fats	
SLT70	Body	No vessel ID	57.1		FAs ($C_{12:0}$–$C_{22:0}$), BrFAs (C_{15}, C_{17}), UFAs ($C_{18:1}$), Diacids (C_9)				Degraded animal fats	

Note: Lipid concentrations, lipid composition and when available, fatty acid $\delta^{13}C$ values and interpretations for every fragment are provided. For discussion of isotopic interpretation, see Section 5.1.

produced in the area of Salūt-ST1, had different uses. A similar observation based on lipid concentrations and the presence of plant oils in some Fine Red Omani vessels was found at Hili 8 (Suryanarayan et al., 2022). Further analyses with a larger data set of vessels from other sites may enable this pattern to be more clearly discernible.

5.3 | The uses of Indus Black-Slipped Jars

An abundance of Indus material culture as well as Indus-style pottery was discovered at Salūt-ST1. This study focused on the analysis of Indus BSJs from two stratigraphical contexts. Although the fragments were not analysed chemically, visual examination suggested that they were produced in the lower Indus Valley like other BSJs (Méry & Blackman, 1999, 2004), and transported via boats to the Oman Peninsula, possibly carrying foodstuffs or other commodities (Méry & Blackman, 2004). However, given Salūt-ST1's location within central Oman, it is likely that the vessels were emptied, refilled and reused for other commodities upon their arrival in the Oman Peninsula.

Among the BSJ fragments studied from Salūt-ST1, some could be assigned to the same vessel either if they were attached to each other, or if they had a similar state of vessel preservation; as well as the colour of the interior and exterior slip (Section 3.1). Five individual BSJs were identified in the studied assemblage. Table 4 provides an overview of all the Indus BSJ fragments analysed from Salūt-ST1, with lipid concentrations, lipid composition and fatty acid isotopic results (when available), to determine the possible contents and uses of this unique vessel form at the site.

Lipid yields of all the analysed BSJ fragments were relatively low (ranging from 5.7 to 65.4 µg g^{-1}). It has been suggested that the dense paste and presence of a black slip on both the inner and outer surfaces of the vessels limits the permeability of contents into the fabric of the vessels; and was probably deliberately applied to protect the content of vessels from the outside (Méry & Blackman, 2004, p. 232). Most of the individual BSJ fragments that corresponded to the same vessel had comparable lipid profiles indicative of degraded animal fats. BSJ 2, from which seven fragments were analysed, had higher lipid yields from body fragments than the rim and base. This may be indicative of upper or mid-body filling of the vessel, as lipids are less dense than water and so concentrate at the surface (Charters et al., 1997; Drieu et al., 2022). Lipid compositions for five of the seven fragments from BSJ 2 were suggestive of degraded animal fats, but one fragment (SLT 74: the rim) had a high abundance of $C_{14:0}$ relative to other fatty acids, a profile indicative of seed oils, and another fragment (SLT09: body) had the minor presence of short-chain diacids, also suggestive of plant products. A comparison of the available fatty acid $\delta^{13}C$ values from three fragments of

BSJ 2 reveals that they fall within a similar reference range, that is, within that of non-ruminant fats, plant oils, non-ruminant and ruminant adipose mixtures or mixtures of animal fats and plant products (Figure 7). As discussed in Section 5.1, the use and re-use of vessels for different products could create mixed lipid signatures, and the equifinality of isotopic values of these resources complicates interpretation. The combined lipid and isotopic evidence for fragments of BSJ 2 demonstrate the challenge in ascertaining a specific use of a vessel through lipid residue analysis if it had a complex use history.

Three body fragments of BSJ 3 had relatively higher lipid concentrations than most fragments from BSJ 2, with lipid profiles typical of degraded animal fats, and fatty acid $\delta^{13}C$ values of one fragment (SLT63) indicating the presence of dairy products in the vessel. One fragment from BSJ 4 (SLT73) had a lipid profile typical of degraded animal fats and low abundances of odd-chain *n*-alkanes, which are found in higher plants and indicative of the processing of leafy products. The fatty acid $\delta^{13}C$ values of this extract indicated that the source of the animal fat was ruminant carcass fats. Finally, the

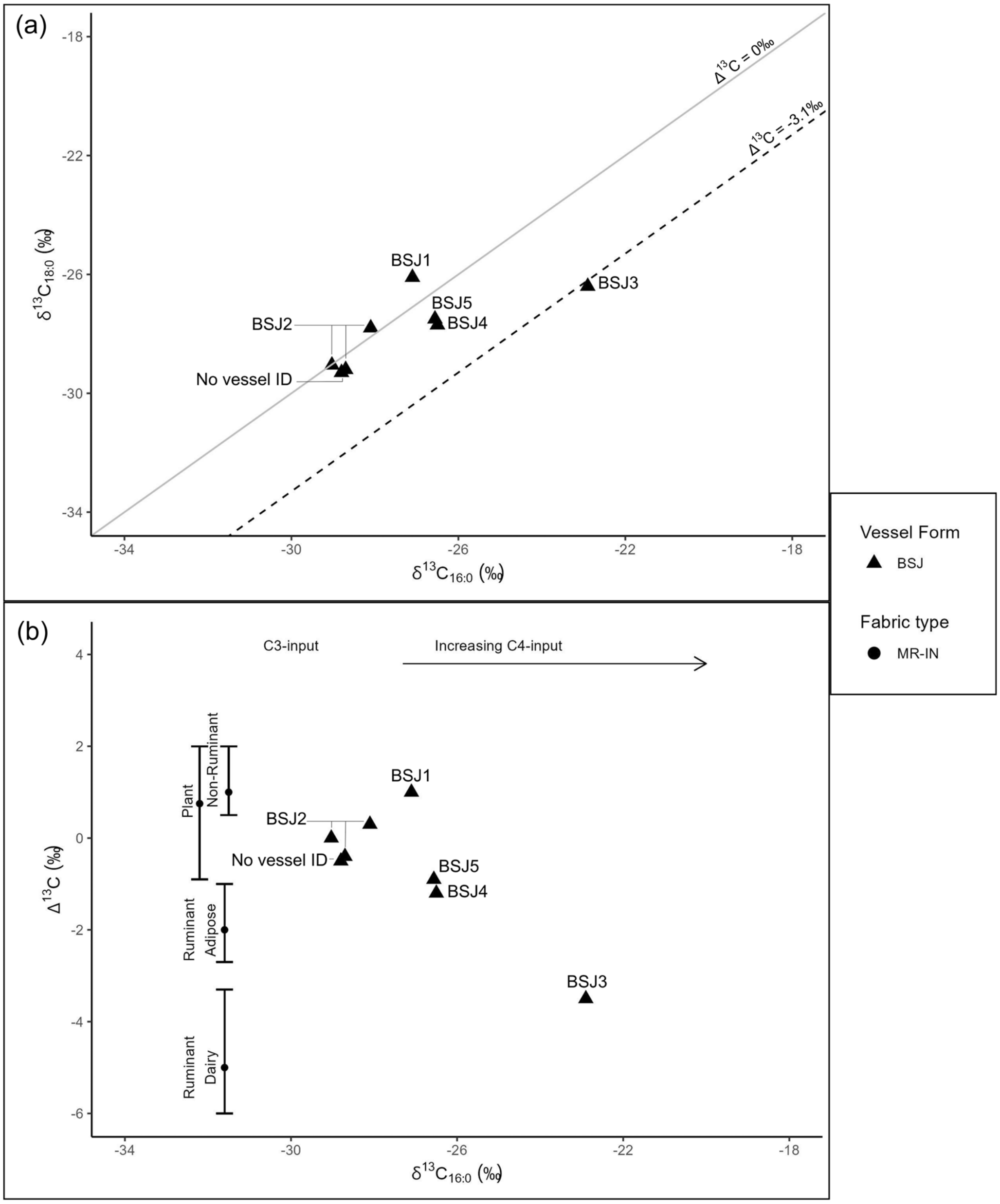

FIGURE 7 Scatter plots showing the $\delta^{13}C$ values of (a) $C_{18:0}$ and $C_{16:0}$ fatty acids and (b) $\Delta^{13}C$ ($C_{18:0}$–$C_{16:0}$) and $C_{16:0}$ fatty acid values, measured from lipid extracts of individual Indus BSJ fragments and corresponding vessel IDs from Salūt-ST1. In (a), the dashed line at −3.3‰ indicates the limit of $\Delta^{13}C$ values for reference dairy fats and the grey line indicates 0‰. In (b), ranges depicted represent the mean ±1 s.d. of $\Delta^{13}C$ values of modern reference terrestrial fats from Africa and Asia and C_3 plant oil references published elsewhere (Craig et al., 2005; Dunne et al., 2012; Lucquin et al., 2016; Outram et al., 2009; Steele et al., 2010). Modern references from the study region are not yet available. Instrumental error is less than ±0.5‰. BSJ, Black-Slipped Jar; MR-IN, Micaceous Red Indus.

funnel (SLT78) and base (SLT79) fragments of BSJ 5 had relatively higher lipid concentrations than most other analysed BSJ fragments; however, with lipid profiles different to one another, with the latter suggestive of the input of plant oil due to a high relative abundance of $C_{14:0}$ (Table 4). The fatty acid $\delta^{13}C$ values of this extract also indicated that ruminant carcass fats were contained in this vessel.

Together, the results suggest the multifunctionality of BSJs at Salūt-ST1, perhaps indicative of the use of BSJs for the transport and storage of different products once they arrived in the Oman Peninsula. The results mirror those from BSJs at Hili 8, which have both evidence of plant oils and degraded animal fats (Suryanarayan et al., 2022). Scholars have provided long tentative lists of Indus products that may have been exported to the Oman Peninsula, such as clarified butter, pickled vegetables, fruit, honey, wine, indigo, or even grain (Gouin, 1990; Kenoyer, 1998, p. 97). Unfortunately, at present, evidence of specific imported products from afar in Indus BSJs at Salūt-ST1 cannot be determined, but the re-use of BSJs as storage vessels in domestic contexts can be suggested.

6 | CONCLUSION

Approaches to studying domestic lifeways and settlements within Arabian archaeology have been limited, with previous research focusing on the monumental or mortuary aspects of the Umm an-Nar period. This paper provides new insights into the types of resources that were used in daily domestic practice during the Umm an-Nar period at Salūt-ST1 through the analysis of lipid residues in local and imported vessels. The presence of animal products in most of the pottery fragments, such as ruminant carcass fats and dairy products, highlights the role of pastoralism in Umm an-Nar society, an aspect often rendered invisible due to the poor preservation of, and limited studies on, animal bones from archaeological sites. At Salūt-ST1, the lipid residue results are in good agreement with zooarchaeological studies on faunal remains, and the first direct detection of dairy products in different vessels confirms the existence of a dairy economy during the Umm an-Nar period. The presence of plant products is also detected in some vessels.

The analysis of Indus Black Slipped Jars from Salūt-ST1 reveals that the vessels had complex use-life histories; with vessels used for the storage of different types of animal products and possibly plant products. Fine Red Omani wares, which were made of finer pastes and probably produced at a regional scale, have relatively higher lipid concentrations and may have had different uses compared to Sandy Ware pottery, although this is currently speculative. Even though the present results were unable to provide clear evidence for the presence of specific products in imported or regionally produced vessels, they highlight the multifunctionality of vessels in the past and the pitfalls associated with determining a single use or function of a specific vessel type from archaeological contexts. Finally, the present results are comparable to preliminary results published from EBA contexts from Hili 8, and thus encourage further research to investigate possible common practices in inland sites in south-east Arabia.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Supporting Information of this article.

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REFERENCES

al-Jahwari, N. S. (2009). The agricultural basis of Umm an-nar society in the northern Oman peninsula (2500–2000 BC). *Arabian Archaeology and Epigraphy 20*, 122–133. https://doi.org/10.1111/j.1600-0471.2009.00315.x al-Jahwari, N. S., Douglas, K., Al-Belushi, M., & Williams, K. D. (2018). Umm an-Nar settlement at Dahwa (DH1), Oman: Preliminary results of the archaeological investigation, 2014–2016. In S. Döpper (Ed.), *Beyond tombs and towers: Domestic architecture of the Umm an-Nar Period in Eastern Arabia* (pp. 29–50). Harrassowitz Verlag. https://doi.org/10.2307/j.ctvcm4ffm

al-Jahwari, N. S., & Kennet, D. (2010). Umm an-Nar settlement in the Wadi Andam (Sultanate of Oman). *Proceedings of the Seminar for Arabian Studies*, *40*, 201–212.

Azzarà, V. M. (2018). Exploring cultural, social and economic complexification: Settlement life through the Umm an-Nar period at Ras al-Jinz RJ-2. In S. Döpper (Ed.), *Beyond tombs and towers: Domestic architecture of the Umm an-Nar period in Eastern Arabia* (pp. 97–120). Harrassowitz Verlag. https://doi.org/10.2307/j.ctvcm4ffm

van Bergen, P. F., Bull, I. D., Poulton, P. R. & Evershed, R. P. (1997). Organic geochemical studies of soils from the Rothamsted Classical Experiments—I. Total lipid extracts, solvent insoluble residues and humic acids from Broadbalk Wilderness. *Organic Geochemistry*, *26*, 117–135. https://doi.org/10.1016/S0146-6380(98)00188-0

Blackman M. J., Méry S. & Wright R. P. (1989). Production and exchange of ceramics on the Oman peninsula from the perspective of Hili. *Journal of Field Archaeology*, *16*/*1*, 61–77. https://doi.org/10.2307/529881

Bouquillon, A., Méry, S., Schneider, G., & Quivron, G. (1996). Third millennium BC pottery at Nausharo, Pakistan: First results of a mineralogical and chemical program. In S. Demerci, A. M. Ozer, & G. D. Summers (Eds.), *Archaeometry 94, Proceedings of the 29th International Symposium on Archaeometry* (pp. 151–168). Tubitak.

Blau S. (2007). Skeletal and dental health and subsistence change in the United Arab Emirates. In M. Cohen & G. Crane-Kramer (Eds.), *Ancient health: Skeletal indicators of agricultural and economic intensification* (pp. 190–206). University Press of Florida.

Cable, C. M., & Thornton, C. P. (2013). Monumentality and the third millennium 'towers' of the Oman Peninsula. In S. A. Abraham, P. Gullapalli, T. P. Raczek, & U. Z. Rizvi (Eds.), *Connections and complexity: New approaches to the Archaeology of South Asia* (pp. 375–399). Left Coast Press. https://doi.org/10.4324/9781315431857

de Cardi, B., Collier, S., & Doe, D. B. (1976). Excavations and survey in Oman, 1974-1975. *Journal of Oman Studies*, *2*, 101–187.

Charbonnier J. (2008). L'agriculture en Arabie du Sud avant l'Islam. *Chroniques Yéménites*, *15*, 1–28. https://doi.org/10.4000/cy.1627

Charbonnier, J., Purdue, L., Calastrenc, C., Régagnon, V., Sagory, T., & Benoist, A. (2017). Ancient agricultural landscapes in Southeast Arabia: Approach and first results of an archaeological, geo-archaeological, and spatial study of the Masāfī Palm Groove, Emirate of Fujairah, In W. Y. al-Tikriti & P. Yule (Eds.), *Proceedings of Water and Life in Arabia Conference*, 14-16 December 2014, Abu Dhabi Tourism and Culture Authority, 45–65.

Charters, S., Evershed, R. P., Goad, L. J., Leyden, A., Blinkhorn, P. W., & Denham, V. (1993). Quantification and distribution of lipid in archaeological ceramics: Implications for sampling potsherds for organic residue analysis and classification of vessel use. *Archaeometry*, *35*/*2*, 211–223. https://doi.org/10.1111/j.1475-4754.1993.tb01036.x

Charters, S., Evershed, R. P., Quye, A., Blinkhorn, P. W., & Reeves, V. (1997). Simulation experiments for determining the use of ancient pottery vessels: The behaviour of epicuticular leaf wax during boiling of a leafy vegetable. *Journal of Archaeological Science*, *24*/*1*, 1–7. https://doi.org/10.1006/jasc.1995.0091

Cleuziou, S. (1989). Excavations at hili 8: A preliminary report on the 4th to 7th campaigns. *Archaeology in the United Arab Emirates*, *5*, 61–87.

Cleuziou, S., & Méry, S. (2002). In-between the great powers: The Bronze Age Oman Peninsula. In S. Cleuziou, M. Tosi, & J. Zarins (Eds.), *Essays on the late prehistory of the Arabian Peninsula* (pp. 273–316). Istituto italiano per l'Africa e l'Oriente.

Cleuziou, S., & Tosi, M. (2007). *In the shadow of the ancestors: The prehistoric foundations of the early Arabian civilisation in Oman* (p. 334). Ministry of Heritage & Culture, Sultanate of Oman.

Cleuziou S., & Tosi, M. (2020). D. Frenez, & R. Garba (Eds.), *In the shadow of the ancestors: The Prehistoric Foundations of the Early Arabian Civilization in Oman: Second Expanded Edition*. Archaeopress. https://doi.org/10.2307/j.ctv1dwq0rp

Copley, M. S., Berstan, R., Dudd, S. N., Docherty, G., Mukherjee, J., Straker, V., Payne, S., & Evershed, R. P. (2003). Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences of the United States of America*, *100*/*4*, 1524–1529. https://doi.org/10.1073/pnas.0335955100

Copley, M. S., Bland, H. A., Rose, P., Horton, M., & Evershed, R. P. (2005). Gas chromatographic, mass spectrometric and stable carbon isotopic investigations of organic residues of plant oils and animal fats employed as illuminants in archaeological lamps from Egypt. *Analyst*, *130*, 860–871. https://doi.org/10.1039/b500403a

Correa-Ascencio, M., & Evershed, R. P. (2014). High throughput screening of organic residues in archaeological potsherds using direct acidified methanol extraction. *Analytical Methods*, *6*, 1330–1340. https://doi.org/10.1039/c3ay41678

Craig, O. E., Chapman, J., Heron, C. P., Willis, L. H., Bartosiewicz, L., Taylor, G., Whittle, A., & Collins, M. J. (2005). Did the first farmers of Central and Eastern Europe produce dairy foods? *Antiquity*, *79*/*306*, 882–894. https://doi.org/10.1017/S0003598X00115017

Craig, O. E., Saul, H., Lucquin, A., Nishida, Y., Taché, K., Clarke, L., Thompson, A., Altoft, D. T., Uchiyama, J., Ajimoto, M., Gibbs, K., Isaksson, S., Heron, C. P., & Jordan, P. (2013). Earliest evidence for the use of pottery. *Nature*, *496*, 351–354. https://doi.org/10.1038/nature12109

Cramp L. J. E., & Evershed R. P. (2014). Reconstructing aquatic resource exploitation in human prehistory using lipid biomarkers and stable isotopes. In Holland H. D., & Turekian K. K. (Eds.), *Treatise on geochemistry*, 2nd ed., 14 (pp. 219–339). Elsevier.

David, H. (1996). Styles and evolution: Soft stone vessels during the Bronze Age in the Oman Peninsula. *Proceedings of the Seminar for Arabian Studies*, *26*, 31–46.

Deckers, K., Döpper, S., & Schmidt, C. (2019). Vegetation, land, and wood use at the sites of Bat and Al-Khashbah in Oman (fourth–third millennium BC). *Arabian Archaeology and Epigraphy*, *30*, 1–14. https://doi.org/10.1111/aae.12123

Degli Esposti, M. (2011). The excavation of an Early Bronze Age tower near Salut (Bisyah, Sultanate of Oman): The Iron Age levels. *Egitto e Vicino Oriente*, *XXXIV*, 189–224.

Degli Esposti, M. (2014). Iron Age Seals from ST1 and Salut, Central Oman. *Egitto e Vicino Oriente*, *XXXVII*, 133–147.

Degli Esposti, M. (2016). Excavations at the Early Bronze Age site "ST1" near Bisya (Sultanate of Oman): Notes on the architecture and material culture. In R. A. Stucky, O. Kaelin, & H.-P. Mathys (Eds.), *Proceedings of the 9th International Congress on the Archaeology of the Ancient Near East* (pp. 665–678). Harrassowitz Verlag.

Döpper, S. (2018). *Beyond tombs and towers: Domestic architecture of the Umm an-Nar Period in Eastern Arabia*. Harrassowitz Verlag.

Drieu, L. Horgnies, M., Binder, D., Pétrequin, P., Pétrequin, A.-M., Peche-Quilichini, K, T. Lachenal, T., & Regert, M. (2019). Influence of porosity on lipid preservation the wall of archaeological pottery. *Archaeometry*, *61*/*5*, 1081–1096. https://doi.org/10.1111/arcm.12479

Drieu, L., Regert, M., Mazuy A., Vieugué, J., Bocoum, H., & Mayor, A. (2022). Relationships between lipid profiles and use of ethnographic pottery: An exploratory study. *Journal of Archaeological Method and Theory*, *29*, 1294–1322. https://doi.org/10.1007/s10816-021-09547-1

Dudd S. N. (1999). *Molecular and isotopic characterisation of animal fats in archaeological pottery*. University of Bristol.

Dudd S. N. & Evershed R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science*, *282*, 1478–1481. https://doi.org/10.1126/science.282.5393.1478

Dunne, J., Evershed, R. P., Salque, M., Cramp, L., Bruni, S., Ryan, K., Biagetti, S., & di Lernia, S. (2012). First dairying in green Saharan Africa in the fifth millennium BC. *Nature*, *486*/*7403*, 390–394. https://doi.org/10.1038/nature11186

Dunne, J., Mercuri, A. M., Evershed, R. P., Bruni, S., & Di Lernia, S. (2016). Earliest direct evidence of plant processing in prehistoric Saharan pottery. *Nature Plants*, *3*, 1–6. https://doi.org/10.1038/nplants.2016.194

Dunne, J., di Lernia, S., Chłodnicki, M., Kherbouche, F. & Evershed, R. P. (2018). Timing and pace of dairying inception and animal husbandry practices across Holocene North Africa. *Quaternary International*, *471*, 147–159. https://doi.org/10.1016/j.quaint.2017.06.062

Dunne, J., Salvatori, S., Maritan, L. Manning, K., Linseele, V., Gillard, T., Breeze, P. Drake, N, Evershed, R. P., & Usai, D. (2022). Wild food: Plants, fish and small animals on the menu for early holocene populations at al-Khiday, Central Sudan. *African Archaeological Review*, *39*, 255–281. https://doi.org/10.1007/s10437-022-09490-w

Evershed R. P. (2008). Organic residue analysis in archaeology: The archaeological biomarker revolution. *Archaeometry*, *50*/*6*, 895–924. https://doi.org/10.1111/j.1475-4754.2008.00446.x

Evershed, R. P., Heron, C., & Goad, L. J. (1990). Analysis of organic residues of archaeological origin by high-temperature gas chromatography and gas chromatography-mass spectrometry. *Analyst*, *115*, 1339–1342. https://doi.org/10.1039/AN9901501339

Evershed, R. P., Payne, S., Sherratt, A. G., Copley, M. S., Coolidge, J., Urem-Kotsu, D., Kotsakis, K., Özdoğan, M., Özdoğan, A., Nieuwenhuyse, O., Akkermans, P. M. M. G., Bailey, D., Andeescu, R.-R., Campbell, S., Farid, S., Hodder, I., Yalman, N., Özbaşaran, M., Bicakci, E., Garfinkel, Y., Levy, T., & Burton, M. M. (2008). Earliest date for milk use in the Near East and Southeastern Europe linked to cattle herding. *Nature*, *455*/*7212*, 528–531. https://doi.org/10.1038/nature07180

Frenez, D., Degli Esposti, M., Méry, S., & Kenoyer, J. M. (2016). Bronze age salut (ST1) and the Indus civilization: Recent discoveries and new insights on regional interaction. *Proceedings of the Seminar for Arabian Studies*, *46*, 107–124. https://www.jstor.org/stable/45163421

Frifelt, K. (1969). Archaeological investigations in the Oman Peninsula. *Kuml*, *1968*, 170–175.

Frifelt, K. (1976). Evidence of a third millennium BC town in Oman. *Journal of Oman Studies*, *2*, 57–73.

Frifelt, K. (1985). Further evidence of the third millennium BC town at Bat in Oman. *Journal of Oman Studies*, *7*, 89–104.

Frifelt, K. (1995). *The island of Umm an-Nar: The third millennium settlement*. Jysk Arkæologisk Selskab.

Gregoricka, L. (2013). Geographic origins and dietary transitions during the Bronze Age in the Oman Peninsula. *American Journal of Physical Anthropology*, *152*/*3*, 353–369. https://doi.org/10.1002/ajpa.22360

Gouin, P. (1990). Rapes, jarres et faisselles: La production et l'exportation des produits laitiers dans l'Indus du 3e millénaire. *Paleorient*, *16*/*2*, 37–54. https://doi.org/10.3406/paleo.1990.4531

Hammann, S., & Cramp, L. J. E. (2018). Towards the detection of dietary cereal processing through absorbed lipid biomarkers in archaeological pottery. *Journal of Archaeological Science*, *93*, 74–81. https://doi.org/10.1016/j.jas.2018.02.017

Hendy, J., Colonese, A. C., Franz, I., Fernandes, R., Fischer, R., Orton, D., Lucquin, A., Spindler, L., Anvari, J., Stroud, E., Biehl, P. F., Speller, C., Boivin, N., Mackie, M., Jersie-Christensen, R. R., Olsen, J. V., Collins, M. J., Craig, O. E., & Rosenstock, E. (2018). Ancient proteins from ceramic vessels at Catalhoyuk West reveal the hidden cuisine of early farmers. *Nature Communications*, *9*, 4064. https://doi.org/10.1038/s41467-018-06335-6

Humphries, J. H. (1974). Harvard archaeological survey in Oman: II—Some late prehistoric sites in the Sultanate of Oman. *Proceedings of the Seminar for Arabian Studies*, *4*, 49–77.

Kenoyer, J. M. (1998). *Ancient cities of the Indus Valley civilization*. Oxford University Press.

Kolattukudy P. (1970). Plant waxes. *Lipids 5*/*2*, 9–275.

Kolattukudy, P. E., Croteau, R., & Buckner, R. S. (1976). Biochemistry of plant waxes. In P. E. Kolattukudy (Ed.), *Chemistry and biochemistry of natural waxes* (pp. 289–347). Elsevier.

Littleton, J., & Frohlich, B. (1993). Fish-eaters and farmers: Dental pathology in the Arabian Gulf. *American Journal of Physical Anthropology*, *92*(4), 427–447. https://doi.org/10.1002/ajpa.1330920403

Lucquin, A., Gibbs, K., Uchiyama, J., Saul, H., Ajimoto, M., Eley, Y., Radini, A., Heron, C. P., Shoda, S., Nishida, Y., Lundy, J., Jordan, P., Isaksson, S., & Craig, O. E. (2016). Ancient lipids document continuity in the use of early hunter–gatherer pottery through 9,000 years of Japanese prehistory. *Proceedings of the National Academy of Sciences United States of America*, *113*/*15*, 3991–3996. https://doi.org/10.1073/pnas.1522908113

Méry S. (2000). *Les céramiques d'Oman et l'Asie moyenne: Une archéologie des échanges à l'Age du Bronze*. CNRS.

Méry S. (2013). The first oases in Eastern Arabia: Society and craft technology, in the 3rd millennium BC at Hili, United Arab Emirates. *Revue d'ethnoécologie*, *4*, 2–17. https://doi.org/10.4000/ethnoecologie.1631

Méry S., & Blackman M. J. (1999). Harappa et Mohenjo-Daro: Deux zones de production de jarres à engobe noir au Pakistan à la période Indus. *Paléorient*, *25*/*2*, 167–177. https://doi.org/10.3406/paleo.1999.4694

Méry S., & Blackman M. J. (2004). Socio-economical patterns of a ceramic container: The Harappan Black-Slipped Jar. In C. Jarrige & V. Lefèvre (Eds.), *South Asian Archaeology 2001. i. Prehistory* (pp. 226–235). Éditions Recherche sur les Civilisations.

Méry, S., Degli Esposti, M., Frenez, D., & Kenoyer, J. M. (2017). Indus potters in central Oman in the second half of the third millennium BC. First results of a technological and archaeometric study. *Proceedings of the Seminar for Arabian Studies*, *47*, 163–183. http://www.jstor.org/stable/45163458

Mukherjee, A. J., Gibson, A. M., & Evershed, R. P. (2008). Trends in pig product processing at British Neolithic Grooved Ware sites traced through organic residues in potsherds. *Journal of Archaeological Science*, *35*/*7*, 2059–2073. https://doi.org/10.1016/j.jas.2008.01.010

Munoz, O. (2017). Transition to agriculture in South-Eastern Arabia: Insights from oral conditions. *American Journal of Physical Anthropology*, *164*(33), 702–719. https://doi.org/10.1002/ajpa.2330

Orchard, J. J., & Orchard, J. C. (2007). The third millennium BC oasis settlements of Oman and the first evidence of their irrigation by aflaj from Bahla. In J. C. Orchard & J. J. Orchard (Eds.), *Archaeology of the Arabian Peninsula through the ages: Proceedings of the international symposium (7th–9th May 2006)* (pp. 143–172). Ministry of Heritage and Culture.

Outram, A. K., Stear, N. A., Bendrey, R., Olsen, S., Kasparov, A., Zaibert, V., Thorpe, N., & Evershed, R. P. (2009). The earliest horse harnessing and milking. *Science*, *32*/*5919*, 1332–1335. https://doi.org/10.1126/science.1168594

Potts, D. T. (1990). *The Arabian Gulf in Antiquity Volume I: From prehistory to the fall of the Achaemenid empire*. Clarendon Press.

Potts, D. T. (1993). The late prehistoric, protohistoric, and early historic periods in eastern Arabia (ca 5000–1200 BC). *Journal of World Prehistory*, *7*, 163–212. https://doi.org/10.1007/BF00975450

Rageot, M., Mötsch, A., Schorer, B., Bardel, D., Winkler, A., Sacchetti, F., Chaume, B., Della Casa, P., Buckley, S., Cafisso, S., Fries-Knoblach, J., Krausse, D., Hoppe, T., Stockhammer, P., & Spiteri, C. (2019). New insights into Early Celtic consumption practices: Organic residue analyses of local and imported pottery from Vix-Mont Lassois. *PLoS One*, *14*/*6*, e0218001. https://doi.org/10.1371/journal.pone.0218001

Regert, M., Bland, H. A., Dudd, S. N., van Bergen, P. F., & Evershed, R. P. (1998). Free and bound fatty acid oxidation products in archaeological ceramic vessels. *Proceedings: Biological Sciences*, *265*/*1409*, 2027–2032. https://doi.org/10.1098/rspb.1998.0536

Roffet-Salque, M., Dunne, J., Altoft, D. T., Casanova, E., Cramp, L. J. E., Smyth, J., Whelton, H., & Evershed, R. P. (2017). From the inside out: Upscaling organic residue analyses of archaeological ceramics. *Journal of Archaeological Science: Reports*, *16*, 627–640. https://doi.org/10.1016/j.jasrep.2016.04.005

Roffet-Salque M., Regert M., Evershed R. P., Outram A. K., Cramp L. J. E., Decavallas O., Dunne J., Gerbault P., Mileto S., Mirabaud S., Pääkkönen M., Smyth J., Šoberl L., Whelton H. L., Alday-Ruiz A., Asplund H., Bartkowiak M., Bayer-Niemeier E., Belhouchet L., Bernardini F., Budja M., Cooney G., Cubas M., Danaher E. M., Diniz M., Domboróczki L., Fabbri C., González-Urquijo J. E., Guilaine J., Hachi S., Hartwell B. N., Hofmann D., Hohle I., Ibáñez J. J., Karul N., Kherbouche F., Kiely J., Kotsakis K., Lueth F., Mallory J. P., Manen C., Marciniak A., Maurice-Chabard B., Mc Gonigle M. A., Mulazzani S., Özdogan M., Peric O. S., Peric, S. R., Petrasch J., Pétrequin A.-M., Pétrequin P., Poensgen U., Joshua Pollard C., Poplin F., Radi G., Stadler P., Stäuble H., Tasic, N., Urem-Kotsou D., Vukovic J. B., Walsh F., Whittle A., Wolfram S., Zapata-Peña L., & Zoughlami, J. (2015). Widespread exploitation of the honeybee by early Neolithic farmers. *Nature*, *527*/*7577*: 226–230. https://doi.org/10.1038/nature15757

Schmidt, C., & Döpper, S. (2017). The development of complexity at third-millennium BC al-Khashbah, Sultanate of Oman: Results of the first two seasons, 2015 and 2016. *Proceedings of the Seminar for Arabian Studies*, *47*, 215–226.

Strolin, L. (2018). *Archaeozoological campaign: preliminary report of activities (16th of February—29th of March 2018)*. Internal Report.

Steele, V.-J., Stern, B., & Stott, A. W., (2010). Olive oil or lard?: Distinguishing plant oils from animal fats in the archaeological record of the eastern Mediterranean using gas chromatography/combustion/isotope ratio mass spectrometry. *Rapid Communications in Mass Spectrometry*, *24*/*23*, 3478–3484. https://doi.org/10.1002/rcm.4790

Suryanarayan, A., Méry, S., Mazuy, A., & Regert, M. (2022). Foodstuffs and organic products in ancient SE Arabia: Preliminary results of ceramic lipid residue analysis of vessels from Hili 8 and Hili North Tomb A, al Ain, United Arab Emirates. *Proceedings of the Seminar of Arabian Studies*, *54*, 379–401.

Swerida, J. (2022). Revisiting 'settlement': A case study of terminology and Early Bronze Age southeast Arabia. *Journal of Anthropological Archaeology*, *65*, 101382. https://doi.org/10.1016/j.jaa.2021.101382

Swerida, J., & Thornton, C. P. (2019). al-Khafaji reinterpreted: New insights on Umm an- Nar monuments and settlement from Bat, Oman. *Arabian Archaeology and Epigraphy*, *30*, 1–16. https://doi.org/10.1111/aae.12131

Tengberg M. (2012). Beginnings and early history of date palm garden cultivation in the Middle East. *Journal of Arid Environments*, *86*, 139–147. https://doi.org/10.1016/j.jaridenv.2011.11.022

Thornton, C. P., Cable, C. M., & Possehl, G. L. (2016). *The Bronze Age Tower at Bat, Sultanate of Oman: Research by the Bat archaeological project 2007–12*. University of Pennsylvania Museum of Archaeology and Anthropology.

Thornton C. P., & Ghazal R. O. (2016). Typological and chronological consideration of the ceramics at Bat, Oman. In C. P Thornton, C. M. Cable, & G. L. Possehl (Eds.), *The Bronze Age towers at Bat, Sultanate of Oman: Research by the Bat Archaeological Project 2007–12*. (pp. 179–216) University of Pennsylvania Museum of Archaeology and Anthropology.

Tulloch, A. P. (1976). Chemistry of waxes of higher plants. In P. E. Kolattukudy (Ed.), *Chemistry and biochemistry of natural waxes* (pp. 235–287). Elsevier.

Uerpmann M., & Uerpmann H-P. (2008). Animal economy during the Early Bronze Age in south-east Arabia. In E. Vila, L. Gourichon, A. M. Choyke, & H. Buitenhuis (Eds.), *Archaeozoology of the Near East VIII. Actes des huitièmes rencontres internationales d'archéozoologie de l'Asie du Sud-Ouest et des régions adjacentes* (pp. 465–485). Maison de l'Orient et de la Méditerranée Jean Pouilloux.

Weeks, L. (2022). *Early metallurgy of the Persian Gulf: Technology, trade, and the Bronze Age world)*. Brill.

Whelton, H. L., Hammann, S., Cramp, L. J. E., Dunne, J., Roffet-Salque, M., & Evershed, R. P. (2021). A call for caution in the analysis of lipids and other small biomoleculars from archaeological contexts. *Journal of Archaeological Science*, *132*, 105397. https://doi.org/10.1016/j.jas.2021.105397

Whelton, H. L., Roffet-Salque, M., Kotsakis, K., Urem-Kotsou, D., & Evershed, R. P. (2018). Strong bias towards carcass product processing at Neolithic settlements in northern Greece revealed through absorbed lipid residues of archaeological pottery. *Quaternary International*, *496*, 127–139. https://doi.org/10.1016/j.quaint.2017.12.018

Willcox, G., & Tengberg, M. (1995). Preliminary report on the archaeobotanical investigations at Tell Abraq with special attention to chaff impressions in mud brick. *Arabian Archaeology and Epigraphy*, *6*, 129–138. https://doi.org/10.1111/aae.1995.6.2.129

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