The History of the Peoples of the Eastern Desert

edited by

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and

Kim Duistermaat

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The image on the cover is showing a dromedary race between riders of the Beja Khatmayah tribe as part of a religious festival (photograph by Lucy Skinner, Suakin Project, 2004). Such events are treasured celebrations of Bedouin life.

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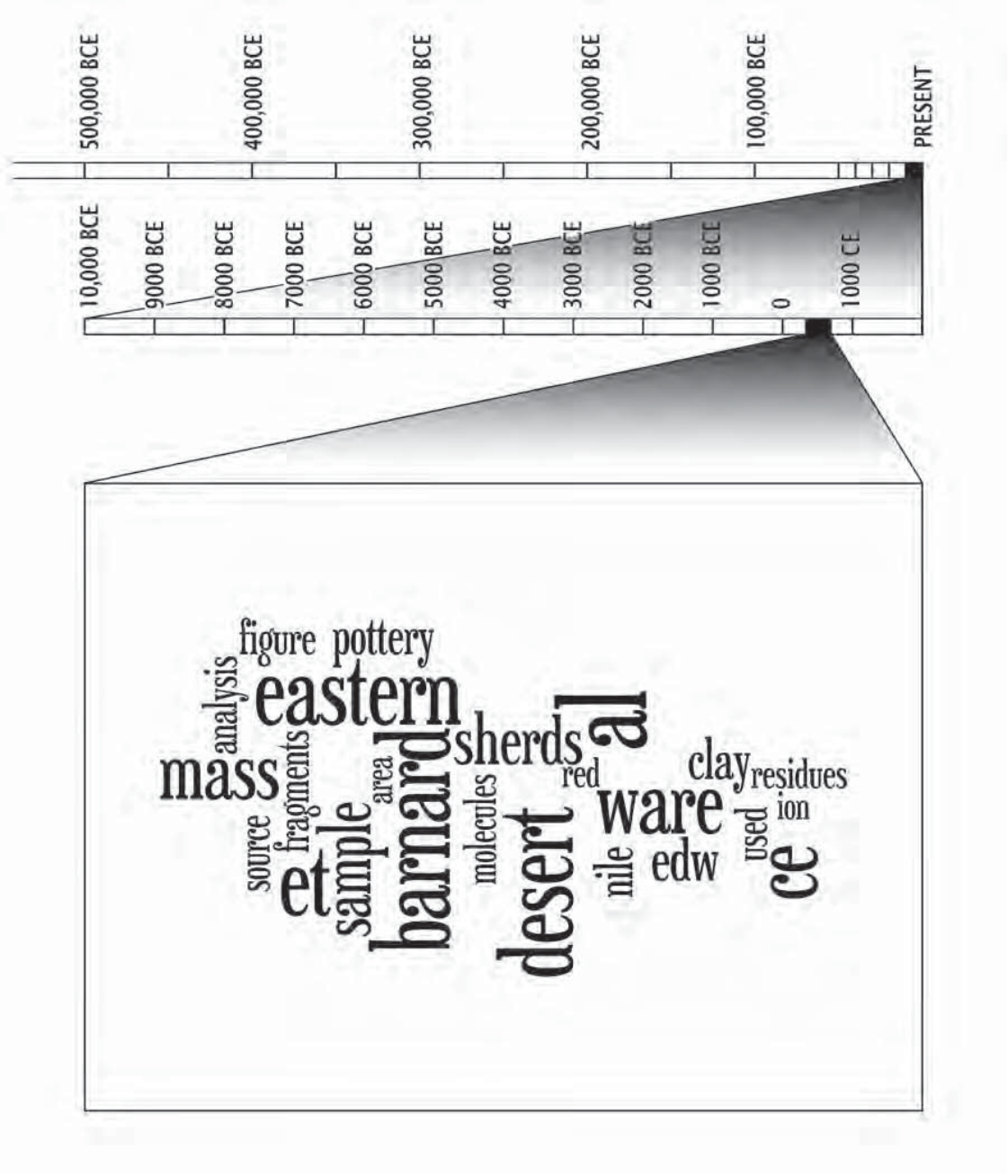

Time line and word cloud for Hans Barnard, *Results of Recent Mass Spectrometric Research of Eastern Desert Ware (4th–6th centuries CE)*. Word cloud by *www.wordle.net*, written by Jonathan Feinberg (IBM Research); the cloud shows the 25 words that occur most often in the text (typefont Sexsmith, all lower case), giving greater prominence to words that appear more frequently.

CHAPTER 19

Results of Recent Mass Spectrometric Research of Eastern Desert Ware (4th–6th centuries CE)

HANS BARNARD

Eastern Desert Ware (EDW) refers to a small corpus of handmade ceramic cups and bowls that are usually smoothed or burnished and frequently decorated with impressed or incised decorations (Figure 19.1). Their distinctive remains have been found in 4th–6th century CE contexts in the Nile Valley between the First and the Fifth Cataract, as well as in the Eastern Desert between there and the Red Sea coast (Table 19.1). Eastern Desert Ware invariably forms only a small percentage of the ceramic finds at these sites, among much greater numbers of Cream Ware and Red Ware sherds, associated with the Late Meroitic Nubia (Strouhal 1984; Barnard 2007, 2008a), or Egyptian Red Slip A and B sherds, associated with Late Roman Egypt (Tomber 1998, 1999; Barnard 2007, 2008a). The dates provided by these pottery finds have been confirmed by coins (Strouhal 1984; Sidebotham 2000), and by radiocarbon analysis (Magid 1998, 2004). Eastern Desert Ware has now been studied in some detail (Barnard 2002, 2006b, 2006a; Barnard and Rose 2007; Barnard 2008a), including chemical analysis of the ceramic matrix and the organic residues in the vessels (Barnard and Strouhal 2004; Barnard *et al.* 2005; Barnard and Magid 2006), as well as ethnographic and experimental archaeology (Barnard 2005-2006, 2008a, 2008b, 2009). It was concluded that Eastern Desert Ware was most likely made and used by one of the indigenous groups in the area at the time, which is concurrent with earlier assumptions based on more cursory studies of the material (Ricke 1967; Rose 1995; Sidebotham and Wendrich 1996, 2001; Luft *et al.* 2002). Despite the suggestions made in these earlier studies, however, the identification of this group remains enigmatic (Barnard 2005, 2007, 2009). In this chapter efforts to shed light on this matter by mass-spectrometric analysis of selected sherds of Eastern Desert Ware are discussed.

Introduction to ICP-MS and GC/MS

Mass spectrometry refers to a variety of methods to accurately measure the mass, or rather the mass to charge ratio (m/z) of ions (charged molecules). All mass spectrometers consist of a sample inlet, an ion source (where molecules in the sample are ionized), the actual mass analyzer (where ions are separated according to their m/z) and an ion detector (Figure 19.2). The sample inlet transforms part of the sample into a form and quantity fit to be analyzed by the instrument. Mass analyzers separate ions with a different m/z by applying electromagnetic forces, requiring the molecules in the sample to be ionized (charged) so that they will respond to such forces. How an ion is recorded by the detector at the end of the instrument depends on its m/z, not its mass. Ions that carry a double charge will appear to have half their actual mass, while molecules that do not accept the 'correct' ionization, either positive or

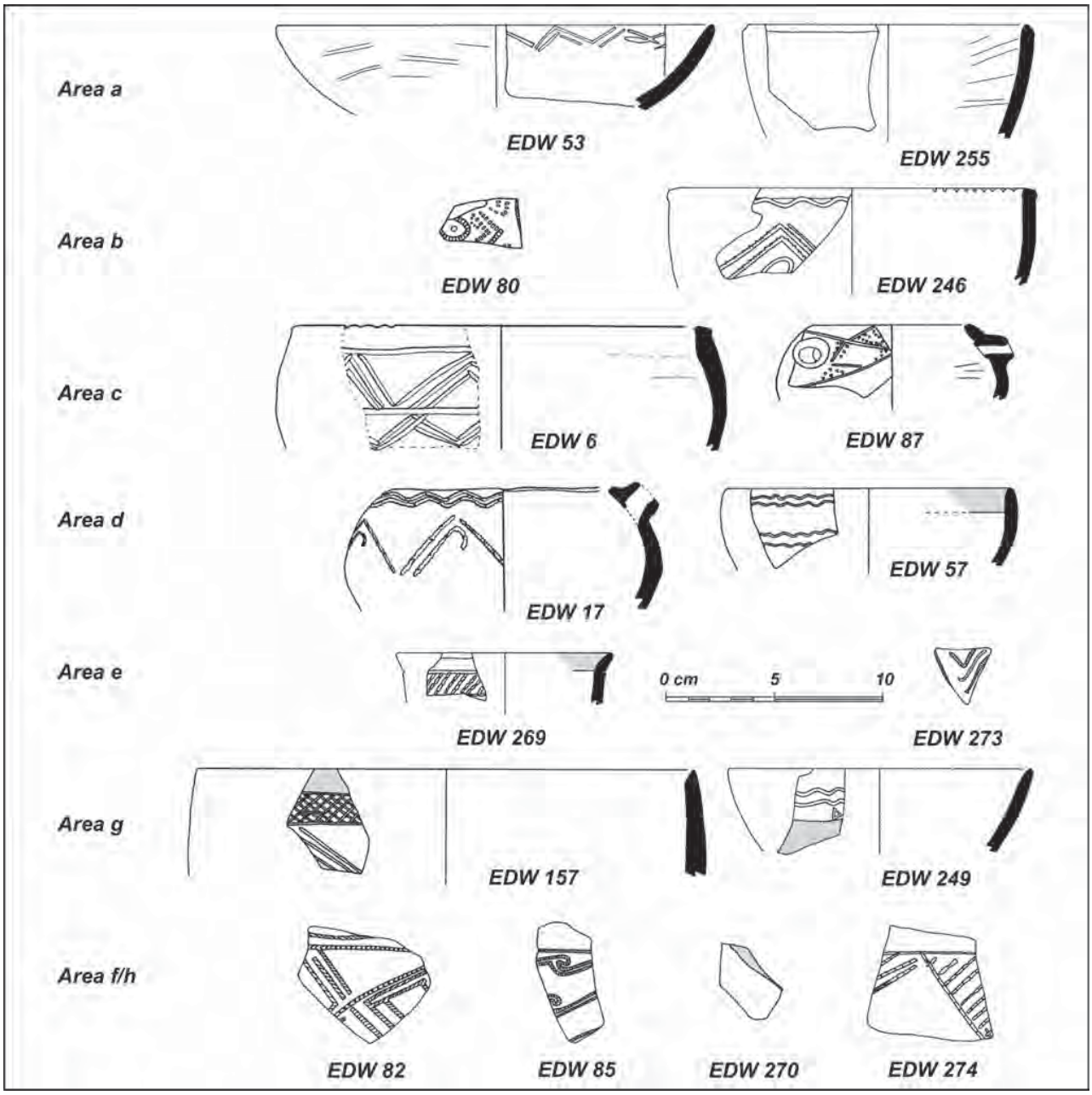

Figure 19.1. Examples of Eastern Desert Ware (EDW) apparently from different production areas ("a" through "f/h") as inferred from the chemical composition of the clay matrix established by ICP/MS. Adapted from Barnard 2008a: 61-62.

negative depending on the setting of the instrument, will escape analysis.

In laser ablation, inductively coupled plasma mass spectrometry (LA-ICP-MS), as used in this study, the sample inlet is a powerful laser that evaporates part of the sample. The resulting vapors are transported into an argon torch, which comprises argon plasma at a temperature of around 7000 °C, trapped in and powered by a magnetic field. Such an argon torch is an aggressive ion source that breaks up most of the molecules in the sample into positively charged elemental ions. After ionization, ions of different m/z can be separated in time or space using the differences in their response to the electromagnetic forces inside a mass analyzer. A time-of-flight mass analyzer (ToF) consists of a metal tube at high vacuum with an ion accelerator at its beginning and an ion detector at its end. Upon entering the analyzer, the ions are accelerated by an

Table 19.1. Approximate date, location and function of the sites where Eastern Desert Ware has been found. *Bayt* (بيت) = house, tent; *wali* (ولي) = governor, saint; *bir* (بئر) = well, spring; *gebel* (جبل) = mountain, hill; *hitan* (حيطان) = walls, ruins; *marsa* (مرسى) = anchorage, beach; *qadim* (قديم) = old, ancient; *qaria* (قرية) = village, hamlet; *qasr* (قصر) = castle, palace; *wadi* (وادي) = valley, river bed. Adapted from Barnard 2008a: 4.

Site	Approximate date	Location				Function						
		Nile Valley	Mons Smaragdus	Red Sea coast	Eastern Desert	Mine / quarry	Fort / way-station	Rest house	Harbor	Cemetery	Other	Unclear
Bayt al-Wali	350–400 CE	×								×		
Berenike	250 BCE–550 CE			×					×			
Bir Abraq?	50 BCE–50 CE				×		×					
Bir Minih	250–650 CE				×							×
Bir al-Murayr	250–550 CE				×						×	
Bir Umm Fawakhir	450–550 CE				×	×						
Gabati?	150 BCE–550 CE	×								×		
Gebel Zabara	450–550 CE		×			×						
Gelli (Wadi Gamal South)	250–550 CE		×								×	
Hitan Rayan	450–650 CE				×							×
Kab Marfu'a (Wadi Gamal orth)	50–450 CE		×								×	
Kalabsha North	300–400 CE	×								×	×	
Kalabsha South	250–550 CE	×								×		
Kurgus	1500 BCE–1000 CE	×					×					
Marsa Nakari (Nechesia?)	50–350 CE			×					×			
Nubt	650–1000 CE				×					×		
Qaria Mustafa 'Amr	450–550 CE				×							×
Qasr Ibrim (Primis)	650 BCE–1850 CE	×									×	
Quseir al-Qadim (Myos Hormos)	250 BCE–550 CE			×					×			
Sayala (near Hiera Sycaminos)	50–350 CE	×						×		×		
(Wadi) Sikait	450–550 CE		×			×						
Tabot	250–350 CE				×		×					
(Hitan) Shenshef	450–550 CE				×							×
Umm Heiran	450–550 CE		×									×
Wadi Abu Qreiya	250–550 CE				×						×	
Wadi Alaqi	650–750 CE				×					×		
Wadi al-Arab	250–550 CE	×						×				
Wadi Qitna	250–550 CE	×								×		
Wadi al-Tareif	350–550 CE	×								×		

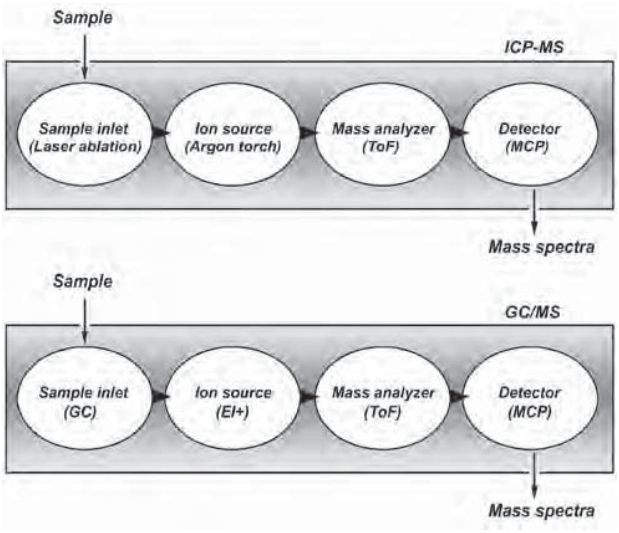

Figure 19.2. Schematic representation of an ICP-MS instrument (top) and a GC/MS instrument (bottom). Both consist of a sample inlet (left), where the samples are transformed into a state that facilitates analysis; an ion source, in which some of the molecules from the sample are ionized (charged); a mass analyzer, where the ions from the sample are separated by mass (using electromagnetic forces); and a detector (right), where the abundance of ions with a specific mass is measured. ToF: time-of-flight mass analyzer; MCP: multichannel plate ion detector; GC: gas chromatograph; EI+: electron impact ion source. Adapted from Barnard 2008a: 47, 68.

electromagnetic pulse, after which they are allowed to drift toward the detector. Typically it takes 10–100 μsec for ions to travel the distance of around 2 m between the accelerator and the detector. The speed of each ion, and consequently the time it needs to complete this journey, depends on its mass and charge state (m/z). Different ions reach the detector at different times from which the m/z of each ion can be extrapolated. As the atomic mass of all elements is very accurately known, these data represent the elemental composition (fingerprint) of the (ceramic) sample.

Interpretation of the results of ICP-MS analysis to provide information on the provenance of materials has been used extensively in geology (Jenner *et al.* 1990; Longerich *et al.* 1990) and archaeology (Porat *et al.* 1991; Mallory-Greenough *et al.* 1998; Glowacki and Neff 2002). As the size of a sample produced by laser ablation is relatively small and the fabric of pottery is a heterogeneous mix of clay, mineral inclusions and fillers, the data on the chemical composition as produced by LA-ICP-MS will vary with every analysis of a single sherd. Therefore, multiple samples of each sherd need to be analyzed, not only to provide an average abundance of the selected elements within the sherd, but initially also to show the validity of the method for the corpus as whole. The resulting large amount of data is usually evaluated with statistical methods, most frequently principal component analysis (Glowacki and Neff 2002). Ideally, raw clay materials from the various source areas of the pottery should also be analyzed in order to compare results with the results of the actual pottery. As such source areas and materials are often unknown, however, elemental fingerprinting is generally limited to arranging the sherds into groups, most likely from the same, unknown source.

The sample inlet of a combined gas chromatography/mass spectrometry (GC/MS) instrument consists of a gas chromatograph at the center of which is a long and narrow glass column through which a flow of carrier gas is maintained. This column is coated on the inside with a thin layer to which some of the molecules in the sample will be attracted. The column is in an oven of which the temperature can be carefully controlled. The end of the column is connected to the ion source of a mass spectrometer. Once the sample is on the column, the mobile phase (the carrier gas) and the stationary phase (the coating inside the column) compete for the molecules in the sample. For each molecule the outcome of this competition depends on the temperature inside the column. As this temperature is slowly raised, the various components of the sample leave the stationary phase one by one and travel with the carrier gas to the end of the column and into the ion source of the mass spectrometer. Even ionization methods more gentle than the argon torch described above will not just change the charge status (m/z) of the original molecule, but will usually also cause some of them to fracture. Analysis of the resulting fragments and their abundance provides additional information that is helpful in identifying the original molecule. This is especially the case when molecules are ionized by a beam of high-energy electrons, in an electron impact ion source (EI+), in which the fragments and their relative abundance appear to be highly reproducible. This allows the comparison of the mass spectra generated by an unknown compound with known spectra in large digital libraries. Thus, the output of a GC/MS instrument is a combination of a single chromatogram and a large number of mass spectra. Each peak in the chromatogram represents a molecule in the sample and a mass spectrum can be created for each of these peaks. With specialized software, mass spectra of the unknown compounds in the sample can

be electronically compared with the spectra of known compounds in a digital library. This usually leads to the identification, with a reasonable amount of certainty, of many of the components in most of the samples (Barnard *et al.* 2007b).

Fatty acids, steroids and terpenoids preserved in the ceramic matrix of unglazed archaeological vessels are relatively well studied because of their propensity to survive archaeologically and their amenable behavior in laboratory conditions (Condamin *et al.* 1976; Hill *et al.* 1985; Patrick *et al.* 1985; Mills and White 1989; Gerhardt *et al.* 1990; Oudemans and Boon 1991; Evershed 1993; Charters *et al.* 1995; Shimoyama *et al.* 1995; Regert *et al.* 1998; Malainey *et al.* 1999; Mottram *et al.* 1999; Stern *et al.* 2000; Eerkens 2002). Interpretation of the results of these studies to arrive at the origin of such residues, by finding biomarker molecules or establishing the ratio in abundance of selected compounds, is often still problematic (Barnard *et al.* 2007a). Usually, only general remarks can be made on the original use or contents of the pottery under investigation. Combined with archaeological and historical information, however, these remarks can help create important insights into the former function of archaeological pottery (Skibo and Deal 1995; Barnard *et al.* 2007a; Barnard and Eerkens 2007).

Fingerprints of Eastern Desert Ware

In Egypt, four types of clay are most commonly used for pottery production. Geologically the oldest is so-called 'Aswan clay,' from a number of sources near the First Cataract, which has been used for pottery production in southern Egypt and northern Sudan since at least 500 BCE. Tertiary marl clays and Quaternary Nile alluvium have been used for pottery production in Egypt from Predynastic times onward. A fourth type of clay used by Egyptian potters occurs in isolated patches in the Nile Valley between Cairo and Esna, and also in Kharga Oasis (in the Western Desert). The exact relation between this clay and pottery production in antiquity is unclear. 'Potter's clay,' however, is not a geological entity, but rather a man-made mix of one or more naturally occurring clays (natural blends of clay, silt and sand), water and a variety of additions, fillers or temper, added to the mix to prevent excessive shrinkage during the production process. A large variety of fillers can be used, including volcanic ash, silt, sand, dung, crushed pottery (grog) or shells, or chopped straw (Shepard 1976; Rye 1981; Skibo *et al.* 1989; Arnold *et al.* 1991; Arnold and Bourriau 1993; Bell 1994; Schiffer *et al.* 1994; Bourriau *et al.* 2000a, 2000b; Stark 2003). Another factor obscuring the geological sources of potter's clay is the vernacular terminology that in no way correlates with geological entities, in English nor in Arabic (Table 19.2). The prepared substance intended to produce pottery is referred to as 'paste,' and the final fired material constituting the ceramic vessel as its 'fabric.'

Table 19.2. Arabic vernacular terms for clay. Adapted from Barnard 2008a: 42.

Arabic		Translation
عربي	*transcription*	
صاصال	*sasal*	(dry) clay, argillaceous clay, marl
طفلة	*taflah*	(potter's) clay, marl, argil
طين	*teen*	(potter's) clay, argil, mud, alluvium
غرين	*ghareen*	(Nile) clay, alluvium
وحل	*wahal*	mud (also proverbial), silt

Fifteen different pottery fabrics were identified for ancient Egyptian pottery during a meeting of experts in Vienna in 1980 and are therefore referred to as the 'Vienna System' (Arnold and Bourriau 1993). The Vienna System divides the fabrics into two main groups: Nile clay and marl, which are each subdivided into five large subsections (designated A–E) and several smaller ones. The identification of these fabrics is made macroscopically or at low magnification (10–20x) on fresh breaks and combines characteristics of the fabric itself, the inclusions in the paste (non-plastic and organic), as well as the ceramic technology of the vessel, especially the firing conditions (Arnold and Bourriau 1993; Bourriau *et al.* 2000b). Macroscopically the typical fabric of Eastern Desert Ware is a rusty red with relatively large, poorly sorted mineral inclusions and little organic remains. This is reminiscent of fabric type Nile A of the Vienna System, which is mostly associated with late Predynastic and early Dynastic vessels predating Eastern Desert Ware by 3500 years. The technology and decorations of Eastern Desert Ware resemble those of the C-Horizon, 2300–1500 BCE, adding to the 'prehistoric' appearance of the vessels. In petrologic thin-section, most of the mineral inclusions appeared to be angular, poorly sorted quartz and feldspar grains. Many sherds also contained small numbers of amphiboles and microclines (Figure 19.3). Limestone,

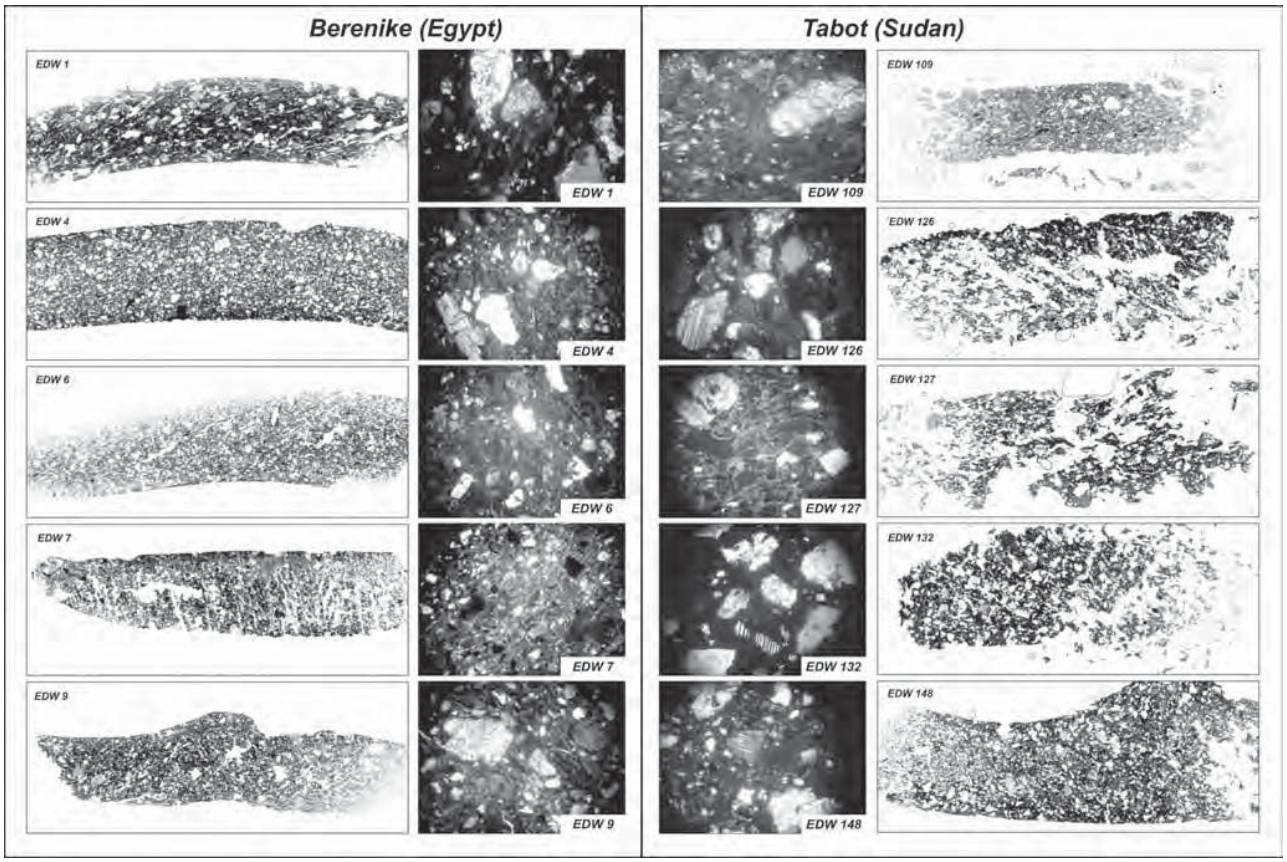

Figure 19.3. Petrologic thin sections of selected Eastern Desert Ware sherds, at low magnification as well as high magnification in cross-polarized light. Next to abundant quartz and feldspar fragments, these reveal sandstone and metamorphic rock fragments (EDW 1), amphiboles and metal-oxide fragments (EDW 4), metal-oxide fragments (EDW 6), limestone fragments (EDW 7), limestone and sandstone fragments (EDW 9), sandstone fragments (EDW 109), microclines, limestone and sandstone fragments ((top), sandstone fragments (EDW 126), granitic rock fragments (EDW 127), metal-oxide and granitic rock fragments (EDW 132), and sandstone fragments (EDW 148). Adapted from Barnard 2008a: 201.

sandstone and granitic rock fragments were often seen, sometimes all in the same sherd. This combination of minerals is outside the Vienna system, but concurrent with the igneous and metamorphic rocks that form the Red Sea Mountains (Butzer 1974; Arnold and Bourriau 1993; Barnard 2008a).

To investigate the provenance of Eastern Desert Ware, the abundance of 44 selected elements in 141 sherds was established with a GBC OptiMass Orthogonal ToF ICP-MS, with attached New Wave 213 LUV Laser Ablation System, owned by the Institute for Integrated Research in Materials, Environments, and Society (IIRMES) at California State University, Long Beach (Table 19.3; Figure 19.4). The sherds were from Tabot (59), the Mons Smaragdus area (45), Berenike (26), Qasr Ibrim (7), Marsa Nakari (3) and Quseir al-Qadim (1). To minimize contamination the analysis was performed on a fresh break and the first pass of the laser was always discarded. After each 5–10 samples, four standard materials were analyzed to monitor for instrument drift, partly caused by fluctuations in the argon torch, and allow for correction of the data. The newly acquired data were compared with the published data on 20 wheel-thrown Egyptian vessels (Mallory-Greenough *et al.* 1998; see also Barnard and Strouhal 2004), 16 made of Nile clay and 4 of marl during the New Kingdom (Table 19.4).

Two methods were employed to reduce the data and select elements that are specific for each of the hypothetical production areas. Both methods are based on simple statistical techniques and were used to produce graphs allowing visual inspection and interpretation of the data. Principal component analysis (PCA) was used to find elements best representing the differences among the sherds (Neff 2002; Glascock *et al.* 2004). This is a

Table 19.3. Average abundance (in parts/million) of 44 elements in 141 Eastern Desert Ware sherds (189 measurements) as established by LA-ICP-MS. Adapted from Barnard and Strouhal 2004; Barnard 2008a: 48-51.

Element	Atomic number	Average mass (Da)	Average abundance (ppm)	Element	Atomic number	Average mass (Da)	Average abundance (ppm)
Na	11	22.99	25118.426	**Sb**	51	121.76	0.8365079
Mg	12	24.31	6986.6599	**Cs**	55	132.91	0.9898942
Al	13	26.98	113654.65	**Ba**	56	137.33	426.59534
Si	14	28.09	258278.37	**La**	57	138.91	22.370265
K	19	39.10	19942.010	**Ce**	58	140.12	50.815397
Ca	20	40.08	38538.118	**Pr**	59	140.91	24.006720
Sc	21	44.96	22.113652	**Nd**	60	144.24	21.878413
Ti	22	47.87	6620.1073	**Sm**	62	150.36	7.5183069
V	23	50.94	82.573175	**Eu**	63	151.96	1.7918519
Cr	24	52.00	79.754709	**Gd**	64	157.25	8.7307407
Mn	25	54.94	575.23439	**Tb**	65	158.93	1.8182540
Fe	26	55.85	54753.365	**Dy**	66	162.50	8.0115344
Ni	28	58.69	186.18720	**Ho**	67	164.93	4.1966667
Co	27	58.93	30.796349	**Er**	68	167.26	5.4266667
Cu	29	63.55	66.051482	**Tm**	69	168.93	4.1114286
Zn	30	65.41	178.07714	**Yb**	70	173.04	5.0989947
As	33	74.92	5.2461905	**Lu**	71	174.97	1.9967196
Rb	37	85.47	40.689153	**Hf**	72	178.49	5.8931217
Sr	38	87.62	306.88757	**Ta**	73	180.95	3.6616402
Y	39	88.91	16.907937	**Pb**	82	207.21	79.435926
Zr	40	91.22	148.01598	**Th**	90	232.04	3.6496825
Sn	50	118.71	13.220582	**U**	92	238.03	1.2523280

standard statistical technique in which a complex set of data, containing a large number of variables per element, is transformed into a smaller set of variables that still represent the variance of the original data set. Another way in which elements were selected for investigation was by calculating the signal/noise ratio for each element from three separate measurements of the composition of eight sherds. Table 19.4 shows the average values of the five selected elements (Co, Ce, Sm, Eu and Tm) for four archaeological regions where Eastern Desert Ware has been found (the Mons Smaragdus area, the Red Sea coast, Sudan and the Nile Valley) as well as the seven hypothetical production areas (a–e, g and f/h). These are compared with the published data on Nile clay and marl from the Egyptian Nile Valley (Mallory-Greenough *et al.* 1998).

Closer inspection of the data revealed that most of the Eastern Desert Ware sherds found in northern Sudan and on the Red Sea coast, but not necessarily produced there, were probably made of raw materials from a single geological source, which is not necessarily in a single geographical location. This is most obvious in the relative concentrations of europium (Eu) and thulium (Tm). The average concentration of these elements is almost the same in Eastern Desert Ware sherds found in northern Sudan and on the Red Sea coast (Figure 19.5), but quite different in sherds found in the Mons Smaragdus area or the Nile Valley. The chemical fingerprints of Eastern Desert Ware are also quite different from New Kingdoms sherds produced and found in the Nile Valley (Table 19.4; Figure 19.5). As these analyses were made on different instruments, with different sensitivities and settings, the differences may be partly caused by instrument bias. The fingerprints of Eastern Desert Ware found in the Nile Valley, however,

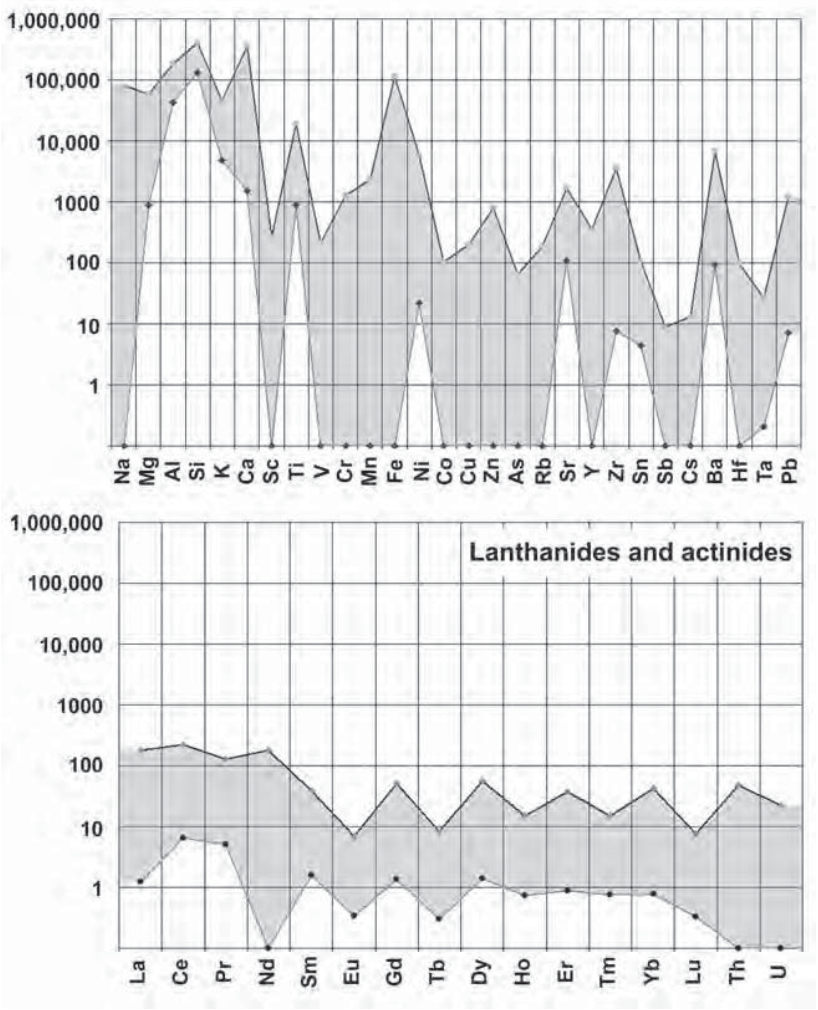

Figure 19.4. Maximum and minimum abundance of 44 elements in 141 Eastern Desert Ware sherds (189 measurements) on a logarithmic scale. The concentration of lanthanides and actinides are presented separately to facilitate inspection of the data. Adapted from Barnard 2008a: 51.

Table 19.4. Average abundance (in parts/million) of cobalt (Co), cerium (Ce), samarium (Sm), europium (Eu) and thulium (Tm) in Eastern Desert Ware found in four regions in the Eastern Desert (ED, top) and produced in seven hypothetical production areas (af/h), compared to the hypothetical source of the vessels found on the Red Sea coast and in Sudan (the Red Sea Mountains) and to 20 wheel-thrown vessels produced in the Nile Valley during the Egyptian New Kingdom (NV, bottom). Selection of the elements is based on the signal/noise ratio (deduced from repeated measurements on selected sherds), as well as on statistical analysis of the data (by principal component analysis). Adapted from Mallory-Greenough *et al.* 1998; Barnard 2008a: 60.

		Co 27 (58.93 Da)	**Ce** 58 (140.12 Da)	**Sm** 62 (150.36 Da)	**Eu** 63 (151.96 Da)	**Tm** 69 (168.93 Da)
ED	Mons Smaragdus	28.24	65.59	9.19	1.90	5.08
	Red Sea coast	32.53	49.12	7.00	1.77	3.25
	Sudan	33.94	35.09	5.91	1.53	3.59
	Nile Valley	25.08	81.82	10.20	2.97	4.30
Hypothetical	area a	25.07	135.69	27.53	6.70	4.87
	area b	25.95	87.60	20.15	1.79	9.20
	area c	33.48	103.79	16.23	2.70	13.33
	area d	26.98	52.55	5.49	1.83	2.09
	area e	18.83	111.28	13.36	3.68	4.28
	area g	36.80	36.66	6.18	1.63	4.68
	area f/h	22.70	93.10	9.26	2.23	4.79
	Red Sea Mountains	33.55	38.08	6.08	1.54	3.52
NV	marl	—	55.78	5.19	1.32	0.28
	Nile clay	—	66.56	7.00	1.95	0.42

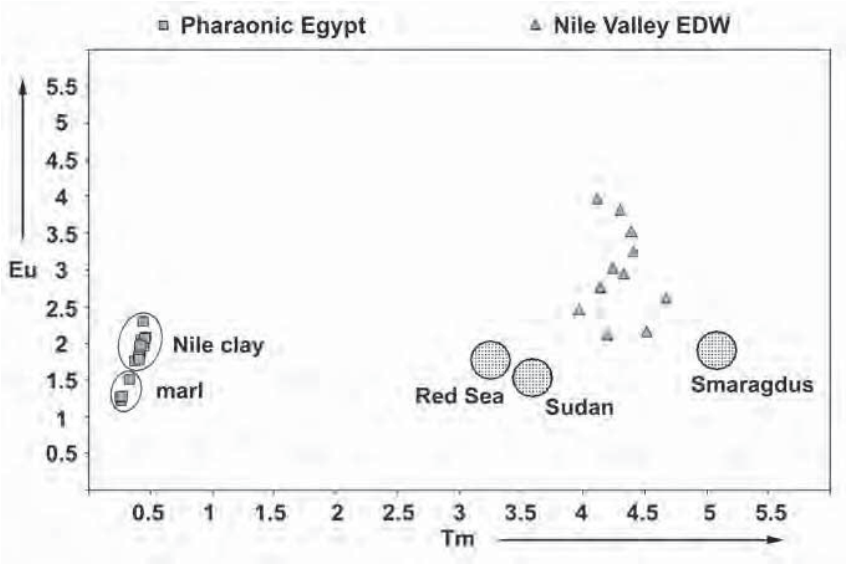

Figure 19.5. Scatter plot indicating the relation between the abundance of Tm (thulium, on the x-axis) and Eu (europium, on the y-axis) for Middle Kingdom sherds and Eastern Desert Ware found in the Nile Valley. The average for all analyzed Eastern Desert Ware sherds found on the Red Sea coast, in northern Sudan and in the Mons Smaragdus area are indicated as large circles (the size of this circle has no statistical significance). Adapted from Barnard 2008a: 57.

are also distinctly different from Eastern Desert Ware found in the Eastern Desert. It seems therefore safe to assume that the raw material for most Eastern Desert Ware did not originate from the usual Egyptian sources. Until alternative source areas have been identified and raw materials with a known provenance have been analyzed, the location or locations of this source will remain unknown. The suggestion that this source, or these sources, is associated with the Red Sea Mountains can thus only remain tentative, although in combination with the provenance of many sherds and the observations on the petrologic thin-sections, this is now quite likely.

Organic Residues in Eastern Desert Ware

Fragments of 51 Eastern Desert Ware sherds (31 from Berenike and 20 from the Mons Smaragdus area) were available for organic residue analysis (Figure 19.6). The surfaces of these samples were removed with an aluminum-oxide grinding stone to minimize post-depositional contamination of the sample. The remaining core of the sherd was crushed using an aluminum-oxide mortar and pestle. Of the resulting pottery powder 400 mg was transferred into a clean glass test tube to which 2 ml of a 2:1 chloroform-methanol mix was added. Powder and solvent were thoroughly mixed and sonicated for 30 min at room temperature. After centrifuging at 2000xg for 15 min, the supernatant was transferred into a second test tube. Fresh solvent was added to the sediment, which was again mixed, sonicated, centrifuged and decanted. After three such extractions the depleted pottery powder was discarded. The solvents in the second test tube were evaporated, after which the dry residue was derivatized

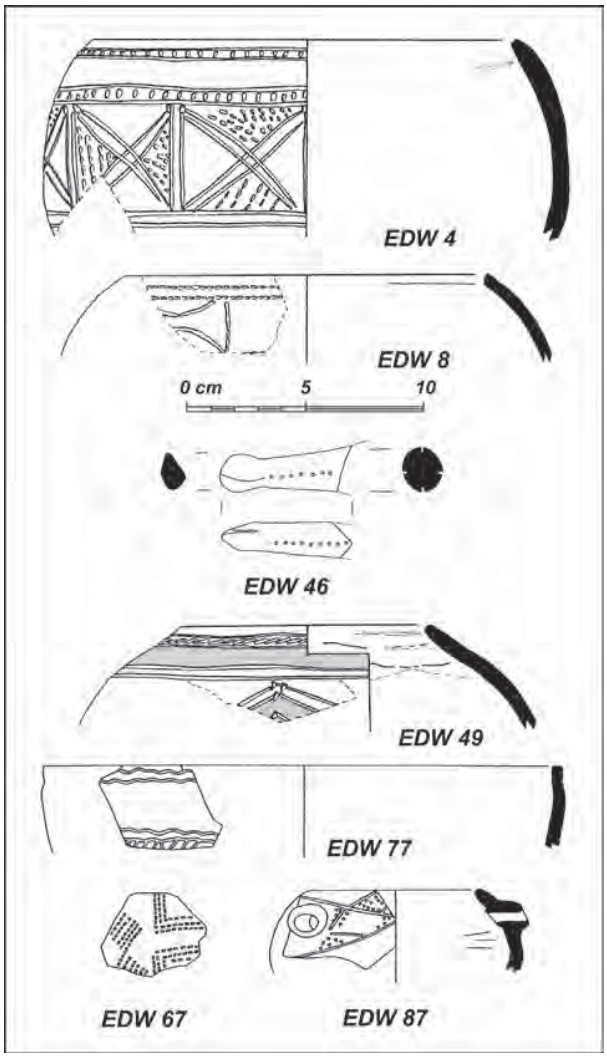

Figure 19.6. The seven Eastern Desert Ware sherds for which the organic residues are discussed in this chapter. Adapted from Barnard 2008a: 78.

(Barnard *et al.* 2005, 2007b; Barnard 2008a). To prevent contamination the sample preparation was completed using gloves from which the talcum powder was removed. Residual pottery powder was removed from gloves and tools with three rinses of water, formic acid and acetone, respectively. To monitor the procedure, empty sample vials were included as well as vials with the powder of new ceramic vessels or of modern vessels in which known foodstuffs had been prepared.

The instrument used to analyze the samples was a gas chromatograph (GC) feeding into a time-of-flight mass spectrometer (MS), built by Waters/Micromass, owned by the Pasarow Mass Spectrometry Laboratory at the University of California, Los Angeles (Figure 19.2). The injector vials were loaded in the automated injector set to inject 1 µl of each sample into the injector port heated to 250 ºC. The vapors released from the samples were carried through the CG column by a 1.2 ml/min flow of helium. The column used was an HP 5MS fused silica capillary, stationary phase 5% methyl silicone, 50 m long, 0.32 mm internal diameter, 0.25 micron film thickness, made by Agilent Technologies. The resulting chromatograms and mass spectra were stored and studied off-line using MassLynx 4.0 software and the 2002 version of the NIST/EPA/NIH Mass Spectral Library enabling comparison of the spectra of the samples with those of almost 150,000 known molecules.

All 51 sherds that were investigated appeared to have preserved an organic residue, arguing against a production of Eastern Desert Ware as receptacles for water or to be used specifically as grave goods, unless they were filled with food for the deceased or used for a funeral feast before being interred in the grave. No biochemical technique is capable of identifying all organic molecules in a complex sample, such as an ancient pottery vessel, and the methodology described above is designed to find traces of lipids, such as fatty acids, acylglycerols and cholesterol (Barnard *et al.* 2007a; Barnard and Eerkens 2007). Different avenues have been developed to interpret the combination of molecules that results from biochemical analysis of ancient residues in order to hypothesize on their source (Evershed 1993; Skibo and Deal 1995; Malainey *et al.* 1999; Eerkens 2005; Barnard *et al.* 2007a). These include the search for marker molecules, more or less specific for a group of foodstuffs, and calculating the ratios of certain fatty acids, such as mono-unsaturated fatty acids C16:1/C18:1 and odd-chain fatty acids (C15:0+C17:0)/C18:0 (Figure 19.7),[1] and then comparing these with the marker molecules or ratios found in the residues of known foodstuffs (Barnard *et al.* 2005; Eerkens 2005).

Sherd EDW 4 (Figures 19.6 and 19.7) preserved many saturated fatty acids, both even-chained and odd-chained, as well as mono-unsaturated oleic acid (C18:1). The azelaic and oxysebacic acid in the residue are probably the oxidation products of longer mono-unsaturated fatty acids. Odd-chained and mono-unsaturated fatty acids are more common in food of vegetable origin and thus concurrent with a residue of seeds and berries (cereals). The plant hormones germanicol and β-sitosterol were also present, but could have originated from micro-organisms living off the residue after the vessels was discarded. Phytanic acid and cholestanyl are probably of animal origin, suggesting a residue of mixed origin. The vessel may have been used for fish, which is relatively high in both odd-chained and mono-unsaturated fatty acids, as well as phytanic acid and cholestanyl. This would be concurrent with the provenance of the vessel (Berenike) and its shape. Sherds EDW 8 and EDW 49 preserved rich and quite similar organic residues. The residue in sherd EDW 8 was interpreted as originating from a meat stew, the residue in sherd EDW 49 as originating from a vegetable stew (Barnard *et al.* 2005). Sherd EDW 46 preserved palmitic (C16:0) and stearic (C18:0) acid in almost equal amounts, as well as low amounts of oleic (C18:1) and erucic (C22:1) acid. This is concurrent with a residue from seeds and berries (cereals). Sherd EDW 67 preserved many saturated and mono-unsaturated fatty acids, but little else. This is concurrent with an origin from greens, probably mixed with vegetable oil given the relative abundance of lipids. Sherd EDW 77 preserved low amounts of palmitic (C16:0) and stearic (C18:0) acid, as well as even smaller amounts of palmitoleic (C16:1) and oleic (C18:1) acid, and most likely originated from vegetable foodstuffs naturally low in lipids. Sherd EDW 87 preserved palmitic (C16:0), palmitoleic (C16:1), stearic (C18:0) and oleic (C18:1) acid in almost equal amounts, most likely from vegetable oil. This is concurrent with the shape of the vessel (spouted bowl).

[1] C15:0 = pentadecanoic acid (with 15 C atoms and no double bonds); C16:1 = hexadecenoic or palmitoleic acid (with 16 C atoms and one double bond); C17:0 = heptadecanoic or margaric acid; C18:0 = octadecanoic or stearic acid; and C18:1 = octadecenoic or oleic acid.

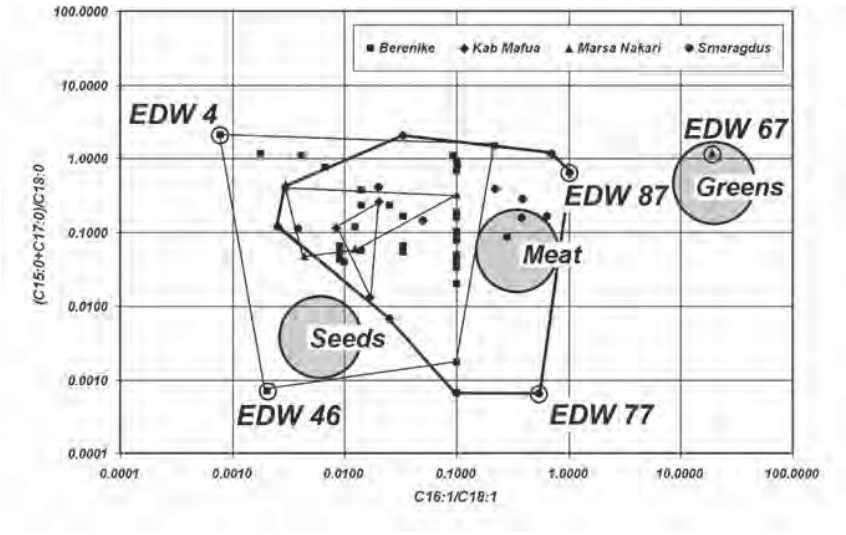

Figure 19.7. Selected fatty acid ratios, on logarithmic axes, of the 51 Eastern Desert Ware sherds analyzed in this study. The gray circles show the approximate position of the same ratios in the residues of known foodstuffs. Adapt from Eerkens 2005; Barnard 2008a: 77.

The small number of vessels in this study does not allow for a statistical correlation of organic residues with vessel form or decoration. The fact that a small tubular-spouted bowl (EDW 87) was apparently used to hold vegetable oil, however, suggests that such a correlation most likely does exist. Most organic residues in Eastern Desert Ware seem to originate from cereals (seeds; Figure 19.7). Residues probably associated with meat or fish were more often encountered in bowls, compared to residues with vegetal origins that were more often seen in cups. Residues in vessels from the Mons Smaragdus area were likely to be from food sources richer in animal products, and possibly associated with a wealthier lifestyle, than residues from Berenike. It is noteworthy that although the modern inhabitants of the Eastern Desert do not produce pottery, they often use it, while their staple diet consists of porridge and bread made of wheat or sorghum. Even though lipid residues are not very specifically associated with foodstuffs, their analysis can provide valuable information, especially when combined with information from experimental, historical and (ethno-)archaeological sources (Barnard *et al.* 2007a; Eerkens and Barnard 2007).

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