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Eastern desert ware : traces of the inhabitants of the eastern desert in Egypt and Sudan during the 4th-6th centuries CE

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CHAPTER THREE

The Provenance of Eastern Desert Ware as Suggested by the Chemical Composition of the Fabric of the Vessels

Sherds of Eastern Desert Ware vessels have been found in places as different as the fertile Nile Valley and the arid Eastern Desert, and as far apart as Wadi Sikait in the north and Tabot in the south, a distance of about 650 km (Chapter 1). It is unclear where in this large and varied area the vessels were produced. They may have been produced locally, with most of the vessels discarded close to where they were made, or in one or more larger production areas, either related to known clay sources in the Nile Valley or elsewhere, from which the vessels were distributed over large distances. As ceramic vessels can be considered man-made geological materials the study of their fabric by geological methods will provide information on the origin of the raw materials and, by extrapolation, of the vessels themselves. About half of the 290 Eastern Desert Ware vessels in this study were available to be studied by a selection of these research techniques, specifically petrographic microscopy and geochemical analysis. These studies were impeded by the lack of information in the possible source, or sources, of the vessels. The only known provenance of the vessels is their archaeological provenance, the place where the vessels were found, and not where they were made. One of the features which set Eastern Desert Ware apart from other sherds found in the same context, however, was the fact that they were not made of any of the common Egyptian fabrics (Chapter 2). This observation could be confirmed by the geological study of the ceramic matrix of the vessels as will be discussed in more detail below.

No raw materials with a known geographical provenance were analyzed, partly for logistical reasons and partly because only one suggestion was ever made concerning the source of the raw materials used for the production of Eastern Desert Ware. This proposed the Quaternary redeposited *wadi* clays which are present in Berenike, and in many other places in the Eastern Desert, usually spread out as a thin layer on top of the sandy desert surface (Van As and Jabobse 1995). Combining the geochemical data with archaeological information suggests that a number of Eastern Desert Ware vessels were indeed made of such secondary clays. This assumption is based on the fact that the Eastern Desert Ware sherds found in the relatively small Mons Smaragdus area (about 10 x 10 km, Chapter 1) appear to have many geologically different origins. These could be associated with as many geographical source areas, or be interpreted as redeposited clay, which is naturally a mix of recently eroded materials with diverse geological backgrounds. Most of the Eastern Desert Ware sherds found in Berenike and Tabot, on the other hand,

appeared to have been made of geologically very similar raw materials. This could be interpreted as a primary clay source, possibly in the Eastern Desert, which may surface in several geographical places. The discussion, in this chapter, of the ways in which these tentative conclusions were reached is preceded by an outline of the geology of the area (Appendix 6) and of clay (Appendix 7), a description of the common fabrics of Egyptian pottery (the 'Vienna System') and a summary of the petrology of Eastern Desert Ware (Appendix 8).

Outline of the Geology of the Area

Egypt and northern Sudan, including the area in which Eastern Desert Ware has been found, are sitting on a Precambrian basement complex of hard igneous (such as diorite and granite) and metamorphic (such as gneiss and schist) rocks that are over 545 million years old (Appendix 6). In the east this basement complex dips into a rift which is part of a series of rift zones stretching from the Beqaa Valley (in Lebanon) in the north, under the Gulf of Aqaba and the Red Sea, to the Great Rift Valley and Lake Nyasa (at the border between Malawi and Mozambique) in the south. The basement complex is rich in precious metals, such as gold, and ornamental stone (Klemm and Klemm 1993; Klemm et al. 2001; Sidebotham et al. 2001). From the Upper Cretaceous to the Miocene, 100-35 million years ago (Ma), the region was covered by the warm and shallow Tethys Sea (Said 1990; Tawadros 2001). This sea deposited the top (marine) layer of the Nubia formation during the Upper Cretaceous (100-65 Ma), followed by layers of limestone and shale during the Palaeocene (65-56 Ma); limestone during the Eocene (56-37 Ma); sandstone during the Oligocene (37-24 Ma); and limestone and gypsum during the Miocene (24-5 Ma).

From the Oligocene onward, the area started to tilt, slowly driving the coastline of the Tethys Sea to the north and the west. New rivers coming into the sea from the east, of which Wadi Qena is a modern remnant, started to erode the relatively soft sedimentary layers off the Precambrian basement. During the Pliocene (5-1.8 Ma) the Tethys Sea again advanced into the area cutting a narrow bay that is now the delta of the River Nile. At the same time to the east, the basement complex was uplifted, to heights of 2000 m, forming the Red Sea Mountains. First this intensified the erosion, ultimately exposing large parts of the basement complex, later it changed the drainage system, ultimately resulting in the present-day River Nile and the Eastern Desert. Below the surface the movements allowed molten rock to

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intrude into the basement complex, forming numerous dolerite dikes. At the end of the Pleistocene (1,800,000-12,000 years ago), the modern Nile was formed when rivers from Ethiopia and East Africa joined the Egyptian drainage system after which the present floodplain and delta started to develop.

Potter's Clay

Clay is formed by the chemical or hydrothermal weathering of silicate minerals (especially feldspars, amphiboles and pyroxenes) in rocks. Clay consists of very small, less than 1-2 μm (0.001-0.002 mm, depending on the scientific context), layered particles made of sheets of silica tetrahedra and aluminium-oxide octahedra (Appendix 7). Clay minerals are reluctant to form large crystals and some have an affinity for water. Depending on their structure and chemical composition, four types of clay are recognized: kaolinite or halloysite clays, smectite or montmorillonite clays, illite or hydrous mica clays and chlorite clays (Appendix 7). In natural clay layers, the clay particles are mixed to varying degrees with silt (between 1-2 and 50-60 μm in size) and sand (50-60 μm -2 mm, again depending on the scientific context, Appendix 7). These grains are usually mostly quartz, with small amounts of other silicate minerals, such as feldspar or mica. Based on the proportion of these three components such mixtures are identified as, for instance, 'silty clay' or 'sandy clay'. Other erosional or biological products can also be included in the clay. Water is present in clay in three distinct ways: as integral part of the crystalline structure; attracted by the cations in the space between the layers; and free in the pores between the particles. The plasticity of the clay is directly dependent on the relative amounts of water; their controlled manipulation forms the basis of ceramic technology (Hertz and Garrison 1998; Nordström and Bourriau 1993; Rice 1987; Rye 1981).

In Egypt, four kinds of clay are traditionally used for pottery production (Appendix 6). Geologically the oldest is the so-called 'Aswan clay' (from a number of sources close to the First Cataract), an ancient soil (palaeosol) that was formed during or before the Cretaceous (140-65 Ma) by the weathering of the granitic basement complex. Aswan clay is kaolinite clay with abundant iron hydroxides and no calcium carbonate. It has been used for pottery production in southern Egypt and northern Sudan from at least 500 BCE. Marl clay was deposited in the Egyptian Nile Valley during the Tertiary (65-1.8 Ma) as a product of eroding shale and limestone. It contains abundant calcium carbonate, some iron-oxides and usually no organic matter. Marl clays have been used for pottery production in Egypt from Predynastic times onward. A third type of clay, which has been identified as 'plastic clay', was formed or deposited in the Nile Valley and the Western Desert during the Pliocene (5-1.8 Ma). This clay is characterized by relatively small

inclusions. It 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. Finally, large amounts of clay were deposited in the floodplain of the Nile Valley in Egypt and Sudan during the Quaternary (1.8 Ma-present). This clay, sometimes referred to as 'Nile silt' (غرين, Table 3-1) contains quartz and feldspar grains, organic matter (plant remains) and a variety of other non-plastic components such as mica, iron hydroxides and rock fragments. Nile clay has been used for the production of pottery from Predynastic times onward.

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

Table 3-1: Arabic and English vernacular terms for clay and silt.

Potter's clay is not a geological entity, but a man-made mix of one or more naturally occurring clays (blends of clay, silt and sand), water and a variety of additions (fillers or temper). In Egypt and other arid areas, clay is usually collected dry to almost stone-hard and has to be rehydrated to obtain sufficient plasticity. Larger impurities are removed by sieving or suspending the smaller particles (clay) in water allowing the larger particles (sand) to sink, a process referred to as 'levigation'. Usually some filler has to be added to prevent excessive shrinkage during the production process. A large variety of fillers can be used including volcanic ash, silt, sand, dung, chopped straw, crushed pottery (grog) or shells (Arnold et al. 1991; Bourriau et al. 2000; LeFree 1975; Rye 1981; Schiffer et al. 1994; Shepard 1976). Some clays are naturally levigated, as a result of slow deposition out of water (Nordström and Bourriau 1993), or naturally contain the right amount of non-plastic fillers to make them suitable for pottery production without the addition of mineral or organic fillers (Wisner 1999). The prepared substance intended to produce pottery is referred to as 'paste'. Sometimes different clays, from different geological sources, or different pastes are mixed to produce the required

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product. Another factor obscuring the geological sources of potter's clay is the vernacular terminology that in no way correlates with geological entities (Table 3-1).

The process of pottery production invariably entails stages in which the products are dried and fired. As the paste reaches a certain temperature it will change irreversibly and lose its capability to become plastic by taking up water. At ambient temperatures the free water in the pores between the clay particles, and some of the water attached to the crystal surfaces, will evaporate. This will cause the volume to decrease until the particles in the paste touch and only about 10% of the weight of the paste is water. The paste is now said to be 'leather-hard'. The decrease in volume until the leather-hard stage is reached may lead to catastrophic shrinkage of the product, causing it to crack or break. The presence of relatively large, non-plastic components in the paste, either naturally present or added as filler, will decrease shrinkage and breakage of the products. After reaching the leather-hard stage the adsorbed water will slowly evaporate until the paste is 'bone dry' and, apart from isolated pockets, the only water in the paste is part of the crystalline structure. Until this stage the process is completely reversible.

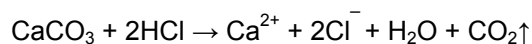
To irreversibly drive out the remaining water the paste needs to be heated to temperatures above 100°C. As the temperature rises the last free water will leave the paste, sometimes chipping off part of the surface (spalling). Montmorillonite clays may retain free water until a temperature of about 300°C is reached. Between 450-800°C the water in the clay crystals will also be driven out, destroying the structure of the crystals. As this happens the paste irreversibly loses its plastic properties and becomes a solid ceramic material, which could be interpreted as a man-made metamorphic rock. Kaolinite clays mature at 500-600°C, illite clays at 550-650°C and montmorillonite clays at 650-750°C. At higher temperatures, between 1000-1500°C, the paste will sinter and partly turn into glass (vitrification), a process resulting in faience or porcelain. Quartz and feldspar inclusions in the paste will change little below 1000°C; iron hydroxides will dehydrate between 300-400°C to form (red) ferric oxide (Fe₂O₃) in an oxidizing environment, or (black) ferrous ferric oxide (Fe₃O₄) in a reducing environment. Organic inclusions, either naturally present in the clay or added to the paste, will combust at 300-600°C and either fully oxidize or reduce to (black) carbon. Limestone fragments and silicates, such as chlorite and other micas or serpentine, will start to decompose at temperatures around 800°C.

Pottery Fabrics

The fired paste of which ceramic objects are made is referred to as their fabric. Apart from the mineral inclusions, the identification of the fabric of a ceramic

object is based on all relevant archaeological data, such as the geographical and chronological context, as well as the technology, shape or decoration of the object. Even though the fabric is a man-made mix of clay, water and fillers that has been thermally altered in a specific way, it is often possible to relate a certain fabric to a specific geological area or a geographical place. Especially since different clay sources or typical pastes, as defined by the treatment of the raw materials, are often used in a specific region for a limited period of time and can in that way be diagnostic for a certain ceramic tradition.

Fifteen different 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' (Nordström and Bourriau 1993). The Vienna System divides the fabrics into two main groups: 'Nile clay' and 'marl'. These are each subdivided into five large subsections (designated A-E) and several smaller ones, resulting in the fabric types Nile A, B1, B2, C, D and E; and Marl A1, A2, A3 A4, B, C1, C2, D and E. The identification of these fabrics is made macroscopically or at low magnification (<30x) 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 (Bourriau and Nicholson 1992; Bourriau et al. 2000; Nordström and Bourriau 1993). Characteristics of the fabric include the colour of the surfaces and the matrix (compared to the standard colours of the Munsell Color Chart), the hardness of the fabric (on Moh's scale) and the reaction to HCl, which shows the presence of calcium carbonate in marl clays by the release of carbon dioxide:



In several cases the identifications have been supported by petrographic thin-sections (Hope et al. 1981, Porat et al. 1991, Bourriau et al. 2000) or elemental analysis (Hancock et al. 1986, Porat et al. 1991, Mallory-Greenough et al. 1998).

Around 90% of the Eastern Desert Ware vessels in this study appeared to have been made of an orange to rusty-red fabric with many, poorly sorted white inclusions (Chapter 2). One typical arrangement was identified as fabric EDW-1, while a very similar fabric with a reduced and therefore very dark to black interior was labelled EDW-2. Other vessels had additional small, well sorted, sparkling flakes, better visible on the surface of the vessel rather than in the break. The fabric of these was labelled EDW-3. Two vessels, EDW 196 from Wadi Qitna and EDW 269 from Qasr Ibrim (both in the Nile Valley), preserved small fragments of unmixed clay in their fabric. This rare fabric was labelled EDW-4. Fabrics that could not readily be assigned one of these categories, but were obviously of a similar fabric type

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were identified as 'unclassified EDW' (Chapter 2, Appendix 5). None of these fabrics readily fall within the categories of the Vienna System, which is among the

reasons that even small Eastern Desert Ware sherds have been recognized and collected separately at different sites (Chapters 1 and 2).

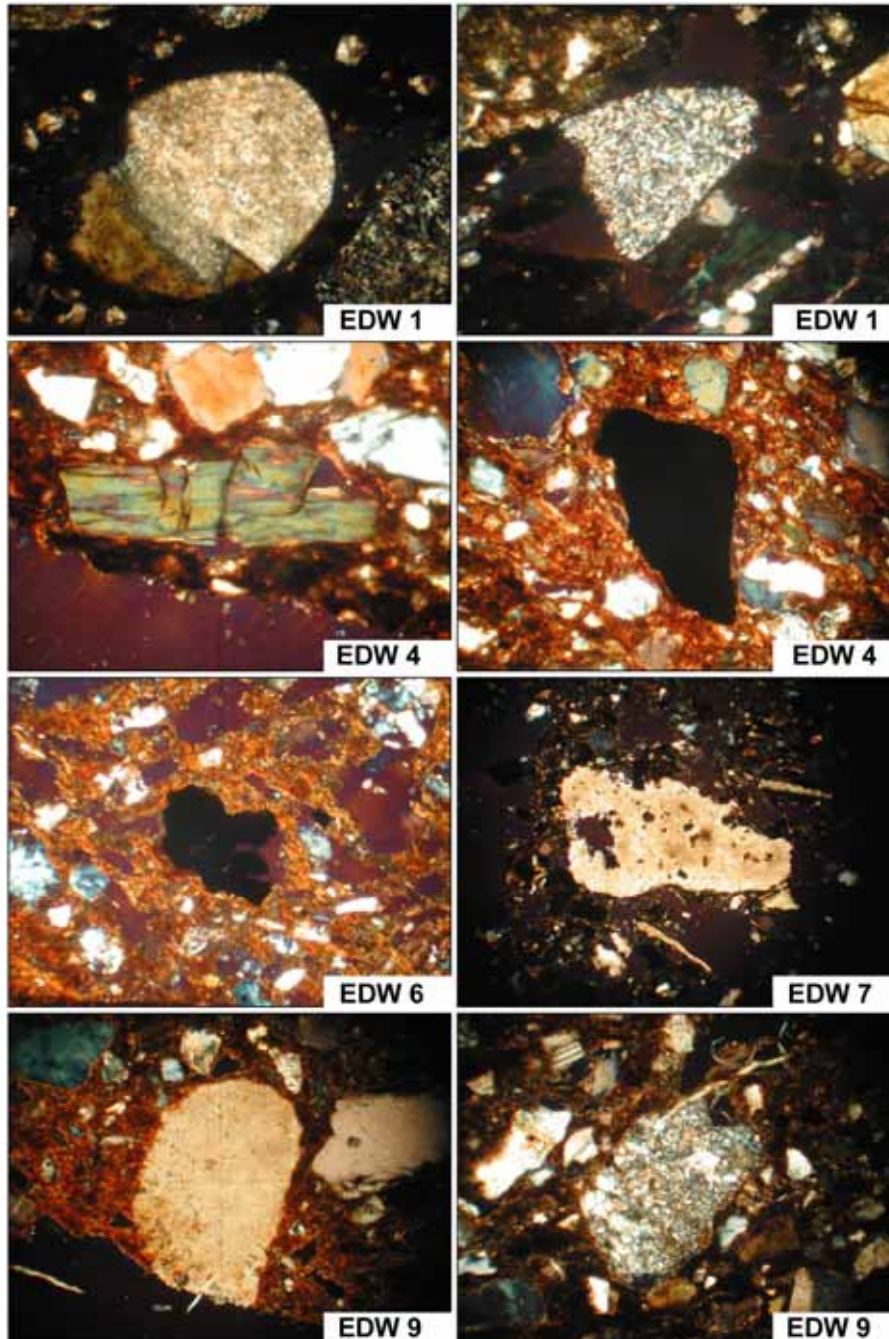


Figure 3-1: Some of the inclusions in Eastern Desert Ware from Berenike (Egypt) between crossed nicols (XPL) at 100x magnification. In EDW 1: a metamorphic rock fragment (left) and a fragment of sandstone (right); in EDW 4: an amphibole (left) and a metal-oxide fragment (right); in EDW 6: a metal-oxide fragment; in EDW 7: a fragment of limestone; in EDW 9: a fragment of limestone (left) and a fragment of sandstone (right).

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Microscopy of Eastern Desert Ware

Macroscopically the typical fabrics of Eastern Desert Ware vessels (predominantly red with relatively large, poorly sorted mineral inclusions and little organic remains) are reminiscent of Nile clay, especially type Nile A of the Vienna System. This fabric type is mostly found to be associated with late Predynastic and early Dynastic vessels (around 3000-2500 BCE), predating Eastern Desert Ware by 3500 years. In combination with the technology and decoration of Eastern Desert Ware, which resemble the vessels of the C-Horizon (2300-1500 BCE, Chapter 2), this result in a 'prehistoric' appearance of the vessels.

In petrographic thin-section the clay matrix of most Eastern Desert Ware vessels was brown to red, with many mineral inclusions and holes. Some holes are without doubt the result of 'plucking', the inadvertent removal of mineral grains from the fabric during the production of the thin-section; others are likely native to the paste. In thin-sections for which Crystalbond™ 509 was used to attach both the pottery and the cover-slip to the slide (Appendix 8), clay and minerals were spread out, exaggerating the number and the size of the holes. Most of the mineral inclusions appeared to be relatively angular, poorly sorted quartz and feldspar grains. Most sherds preserved small numbers of a variety of other mineral inclusions (Figures 3-1 and 3-2), including amphiboles and microcline. These minerals are common in igneous and metamorphic rocks that are abundant in the Red Sea Mountains where many of the vessels were found. Rock fragments were present in the fabric of most Eastern Desert Ware sherds. These included varying amounts of limestone, sandstone and granitic rock fragments, sometimes all present in the same sherd. Metal oxide fragments were also seen, mostly likely iron-oxide, but possible oxides of other metals as well.

The results of the study of the thin-sections confirmed the macroscopic observations that the fabric of Eastern Desert Ware falls outside the Vienna System. Limestone fragments are usually absent in Nile clays, except Nile D in which they are present in conspicuous abundance. Nile clays also preserve varying amounts of organic remains, either naturally present in the clay or added as filler. These are absent in the fabric of most Eastern Desert Ware sherds. Some of the marl fabrics fire grey to light pink or olive green, very different from the rusty red of Eastern Desert Ware; others, which fire brown to red, are very dense or preserve the remains of abundant organic temper (chaff). Marl clays typically preserve many limestone fragments, but usually no sandstone or granitic rock fragments (Nordström and Bourriau 1993).

The presence of a variety of mineral inclusions from different geological sources in the same vessel, as

observed in Eastern Desert Ware, can be explained by an origin of the clay from redeposited layers, in which clay is mixed with other erosional products (Butzer 1974). This would be consistent with the assumption that Quaternary *wadi* clays (Appendix 6), deposited in the desert after being eroded from elsewhere together with other materials, was the primary raw material for the production of Eastern Desert Ware (Van As and Jacobs 1995). Another possibility is that Quaternary sand (mostly angular quartz and feldspar grains with occasional rock fragments) from the Eastern Desert was added as filler to clay or clays from other sources (Tertiary or Cretaceous).

The mineralogy is presented here in some detail as a first record of the microscopic aspect of Eastern Desert Ware and to substantiate the differences between the Eastern Desert Ware fabrics and the common pottery fabrics in ancient Egypt as described in the Vienna System. Next to these differences, another observation was the variety in microscopic aspect of Eastern Desert Ware, not only between the different macroscopically defined fabric groups (EDW-1, EDW-2, EDW-3 and EDW-4), but also within each of these groups. No obvious correlation was found between these macroscopic groups and the aspect of the fabric in thin-section. A more detailed study of the thin-sections of Eastern Desert Ware, preferably including samples of possible clay sources, may more securely locate the sources of the raw materials of which Eastern Desert Ware was produced (Boggs 1992; Bourriau et al. 2000). This, however, is outside the scope of this study which concentrated on the elemental composition of Eastern Desert Ware fabrics as established by mass spectrometry.

LA-ICP Mass Spectrometry

One method to study the provenance of geological materials, and also ceramic vessels, is by comparing their chemical (elemental) composition (Glowacki and Neff 2002; Hancock et al. 1986; Jenner et al. 1990; Longerich et al. 1990; Mallory-Greenough et al. 1998; Porat et al. 1991). This can be established by breaking a small fraction part of the vessel down into it composing elements, for instance with hydrofluoric acid (HF) or laser ablation, and measuring the abundance of a selection of the composing elements by mass spectrometry.

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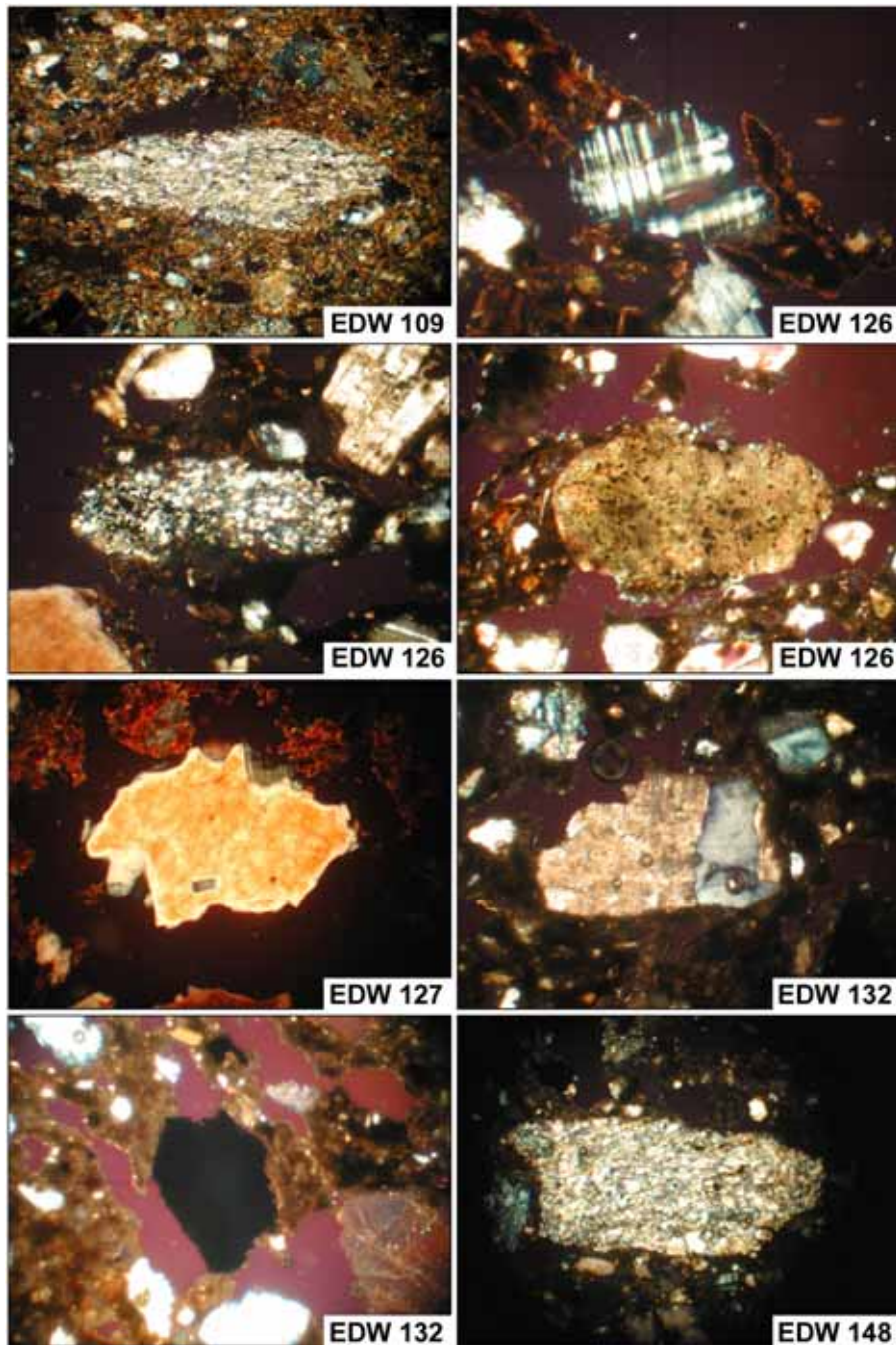


Figure 3-2: Some of the inclusions in Eastern Desert Ware from Tabot (Sudan) between crossed nicols (XPL) at 100x magnification. In EDW 109: a fragment of sandstone; in EDW 126: a microcline (top), a fragment of sandstone (bottom left) and a fragment of limestone (bottom right); in EDW 127: a granitic rock fragment; in EDW 132: a granitic rock fragment (top right) and a metal-oxide fragment (bottom left); in EDW 148: a fragment of sandstone.

Elemental Composition

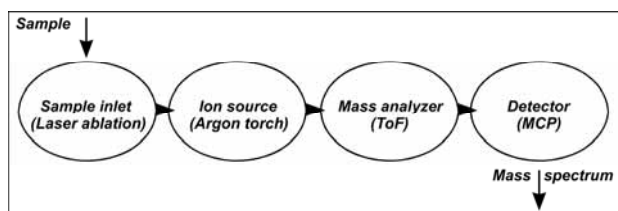


Figure 3-3: Diagram of a LA-ICP-MS instrument, consisting of a laser, an argon torch, a time-of-flight mass analyzer (ToF) and a multi channel plate ion detector (MCP), producing mass spectra (on the right) of the elemental composition of the inserted sample (on the left), cf. Figure 4-1.

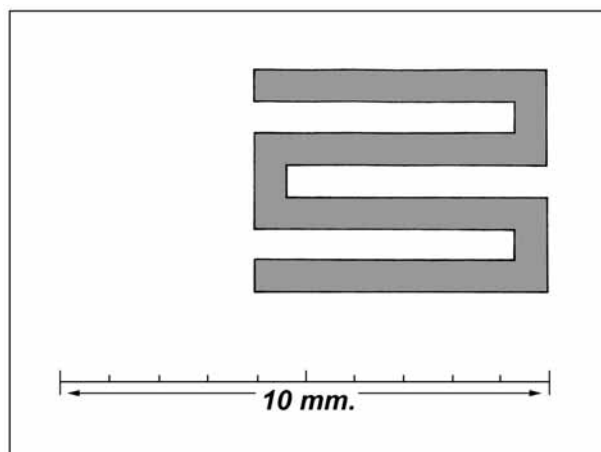


Figure 3-4: Path of the laser beam (approximately 6.0 x 4.5 mm) ablating part of the ceramic matrix for analysis by inductively coupled plasma mass spectrometry (ICP-MS).

Mass spectrometry refers to a variety of methods to accurately measure the mass, or rather the mass to charge ratio (m/z , definitions of the terminology used here and in Chapter 4 can be found in Appendix 10), of ions (charged molecules). All mass spectrometers consist of a sample inlet, an ion source (where the molecules in the sample are ionized), the actual mass analyzer (where ions are separated according to their m/z) and an ion detector (Figure 3-3). Mass analyzers separate ions with a different m/z by applying electro-magnetic forces, requiring the molecules in the sample to be ionized (charged) so that they will respond to such forces. The sample inlet transforms part of the sample into a form and quantity fit to be analyzed by the instrument. 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 along a fixed path (Figure 3-4). The resulting vapours are transported into the ion source by a flow of argon gas (Ar, atomic number 18, average mass 39.95 Da).

The ion source of an IPC-MS instrument is an argon 'torch', which comprises a hot plasma consisting of argon gas and argon ions (Ar^+), trapped in a magnetic field fed by a radio frequency signal (about 10^6 Hz). The first argon ions are generated by an electric spark after which ions and free electrons are accelerated by the radio frequency signal. As they collide with argon atoms more ions are created. This quickly results in a stable plasma with a temperature of around 7000°C. Such an argon torch is an aggressive ion source that breaks up most of the molecules in the sample into positively charged ions (mostly M^+ , but also small quantities of MAr^+ , M_2^+ and M^{2+} , in which 'M' stands for the ionized molecule of interest).

After ionization, ions of different m/z can be separated using the differences in their response to the electro-magnetic forces inside the mass analyzer. All mass analyzers need to be at a high vacuum, below 10^{-3} Pa (which equals about 10^{-8} atm or 10^{-5} mmHg), to avoid collision of the sample ions with other molecules. With the steady influx from the ion source this vacuum needs to be constantly maintained. A time-of-flight mass analyzer (ToF) is basically an empty metal tube with an ion accelerator at its beginning and an ion detector at its end. Upon entering the analyzer the ions are accelerated by an electro-magnetic pulse, after which they are allowed to drift towards the detector (a distance of about 2 m). 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 will reach the detector, where their arrival is recorded, at different times (usually in the 10-100 μs range). The m/z of each ion can be extrapolated from its time of flight. All ion detectors are designed to amplify the impact of a single ion and turn this into a measurable electric current. The intensity of this current is a measure for the relative abundance of each ion. As the atomic mass of all elements is very accurately known, this data directly represents the elemental composition (fingerprint) of the (ceramic) sample (Jenner et al. 1990; Longerich et al. 1990; Mallory-Greenough et al. 1998; Porat et al. 1991).

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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), but also in archaeology (Glowacki and Neff 2002; Mallory-Greenough et al. 1998; Porat et al. 1991). Given the very small sample size, the method works better on homogeneous materials, such as obsidian (Gratuze 1999; Negash and Shackley 2006). As the fabric of pottery is by definition a heterogeneous mix of clay, mineral inclusions and fillers, some of which are geological materials, the data on the chemical composition as produced by LA-ICP-MS will vary with the place where the sample was taken (Appendix 8). Multiple samples of the same sherd need to be analyzed to show the validity of the method and to provide an average abundance of the selected elements within one sherd.

Suggestions for the geographical provenance of ceramic materials can only be made after raw materials from the prospective source areas have been analyzed by the same method. Where possible sources of raw materials are unknown, as is the case with Eastern Desert Ware, however, the chemical analysis of pottery fabrics can

serve to separate the sherds into groups that probably originated in the same, or a similar, geological area. These hypothetical areas can be different clay sources a great distance apart, but also layers with different geological origins within a single clay layer.

Materials and Method

The elemental composition of 141 Eastern Desert Ware vessels (Appendix 5) was established with the 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 with the help of Dr. Hector Neff. The sherds were from sites on the Red Sea coast (26 from Berenike, 3 from Marsa Nakari and one from Quseir al-Qadim), in the Eastern Desert (45 from the Mons Smaragdus area and 59 from Tabot) and in the Nile Valley (7 from Qasr Ibrim). A number of vessels were analyzed more than once (Appendix 9), leading to a total of 189 data sets. Each of these consists of the abundance of 44 selected elements (Table 3-2) in parts/million (ppm).

Element					PC 1	PC 2
Group	Abb.	Name	No.	Mass		
I	Na	Sodium	11	23.0	-0.244	-0.142
II	Mg	Magnesium	12	24.3	-0.449	-0.087
III	Al	Aluminium	13	27.0	0.189	0.024
IV	Si	Silicon	14	28.0	0.321	-0.121
I	K	Potassium	19	39.1	0.043	-0.059
II	Ca	Calcium	20	40.1	0.113	0.032
TM	Sc	Scandium	21	45.0	-0.508	0.157
	Ti	Titanium	22	47.9	-0.340	0.275
	V	Vanadium	23	50.9	-0.772	0.198
	Cr	Chromium	24	52.0	-0.698	0.090
	Mn	Manganese	25	54.9	-0.683	0.242
	Fe	Iron	26	55.8	-0.762	0.262
	Co	Cobalt	27	58.9	-0.803	0.075
	Ni	Nickel	28	58.7	-0.483	-0.047
	Cu	Copper	29	63.5	-0.644	0.045
	Zn	Zinc	30	65.4	-0.530	0.573
V	As	Arsenic	33	74.9	-0.625	0.191
I	Rb	Rubidium	37	85.5	-0.181	0.566
II	Sr	Strontium	38	87.6	0.252	0.148

Elemental Composition

Element					PC 1	PC 2
Group	Abb.	Name	No.	Mass		
TM	Y	Yttrium	39	88.9	-0.022	0.550
	Zr	Zirconium	40	91.2	0.194	0.287
	Sn	Tin	50	118.7	0.053	0.371
	Sb	Antimony	51	121.8	-0.268	-0.012
I	Cs	Caesium	55	132.9	-0.139	0.461
II	Ba	Barium	56	137.3	0.098	0.153
La.	La	Lanthanum	57	138.9	0.078	0.786
	Ce	Cerium	58	140.1	0.131	0.742
	Pr	Praseodymium	59	140.9	0.171	0.741
	Nd	Neodymium	60	144.2	0.120	0.783
	Sm	Samarium	62	150.4	0.086	0.914
	Eu	Europium	63	152.0	0.076	0.640
	Gd	Gadolinium	64	157.3	0.197	0.803
	Tb	Terbium	65	158.9	0.105	0.939
	Dy	Dysprosium	66	162.5	0.045	0.919
	Ho	Holmium	67	164.9	0.134	0.904
	Er	Erbium	68	167.3	0.046	0.913
	Tm	Thulium	69	168.9	0.142	0.761
	Yb	Ytterbium	70	173.0	0.062	0.873
	Lu	Lutetium	71	175.0	0.142	0.826
TM	Hf	Hafnium	72	178.5	0.190	0.285
	Ta	Tantalum	73	180.9	0.062	0.656
	Pb	Lead	82	207.2	-0.220	0.078
Ac.	Th	Thorium	90	232.0	0.042	0.540
	U	Uranium	92	238.0	-0.174	0.557

Table 3-2 (on this and the previous page): Properties of the 44 elements measured in 141 Eastern Desert Ware vessels. Group: TM = transition metals, Ac. = actinide series, La. = lanthanide series; Abb.: scientific abbreviation; Name: trivial name; No.: atomic number = number of protons; Mass: average mass in Daltons. PC 1 = loading of principal component 1 and PC 2 = loading of principal component 2 after Principal Component Analysis of the raw data of 189 analyses (including duplicates). Elements selected for the further interpretation are in bold.

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 sherds of 5 vessels from India, which were found in Berenike in contexts similar to those in which Eastern Desert Ware was found, were also analyzed. The newly acquired data was 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 four of marl during the New Kingdom (1570-1070 BCE).

Results

The raw data were collected into a Microsoft Excel spreadsheet and corrected for instrument drift (by Dr. Hector Neff of the IIRMES). The average abundance (ppm) of each of the selected elements, after 189 measurements (141 different Eastern Desert Ware vessels) and correction, is presented in Figure 3-5. To facilitate inspection of the data, the elements have been divided into 'lanthanides and actinides' (right, Table 3-2) and 'other elements' (left), while the vertical axes are logarithmic. As expected, silica is the most abundant element (Si = 258,278 ppm), followed by aluminium (Al = 113,655 ppm), iron (Fe = 54,753 ppm), calcium (Ca =

Eastern Desert Ware

38,538 ppm) and sodium (Na = 25,118 ppm). Antimony is the least abundant element (Sb = 0.83651 ppm), followed by caesium (Cs = 0.98989 ppm), uranium (U = 1.25233 ppm), europium (Eu = 1.79182 ppm) and terbium (Tb = 1.81821 ppm). The minimum and maximum readings for each element are presented in Figure 3-5 (bottom), which shows the large variance in the abundance of some elements, most notably iron (Fe: 0-113,727 ppm), sodium (Na: 0-82,054 ppm), manganese (Mn: 0-2362.0 ppm) and chromium (Cr: 0-1263.8 ppm). The maximum and average standard deviation for each of the elements is presented in Figure

3-6. To facilitate comparison between the different elements, with abundances varying between 0-398,406 ppm (Si) and 0-6.02281 (Sb), the standard deviation of each element is divided by the maximum value of the same element. The raw data on eight sherds of which the elemental composition was measured three times (EDW 119, 123, 127, 129, 143, 150, found at Tabot, EDW 157, found at Nubt, and EDW 158, found at Qasr Ibrim) are presented in Appendix 9 together with the signal/noise ratio that was inferred from these measurements (as discussed below).

Elemental Composition

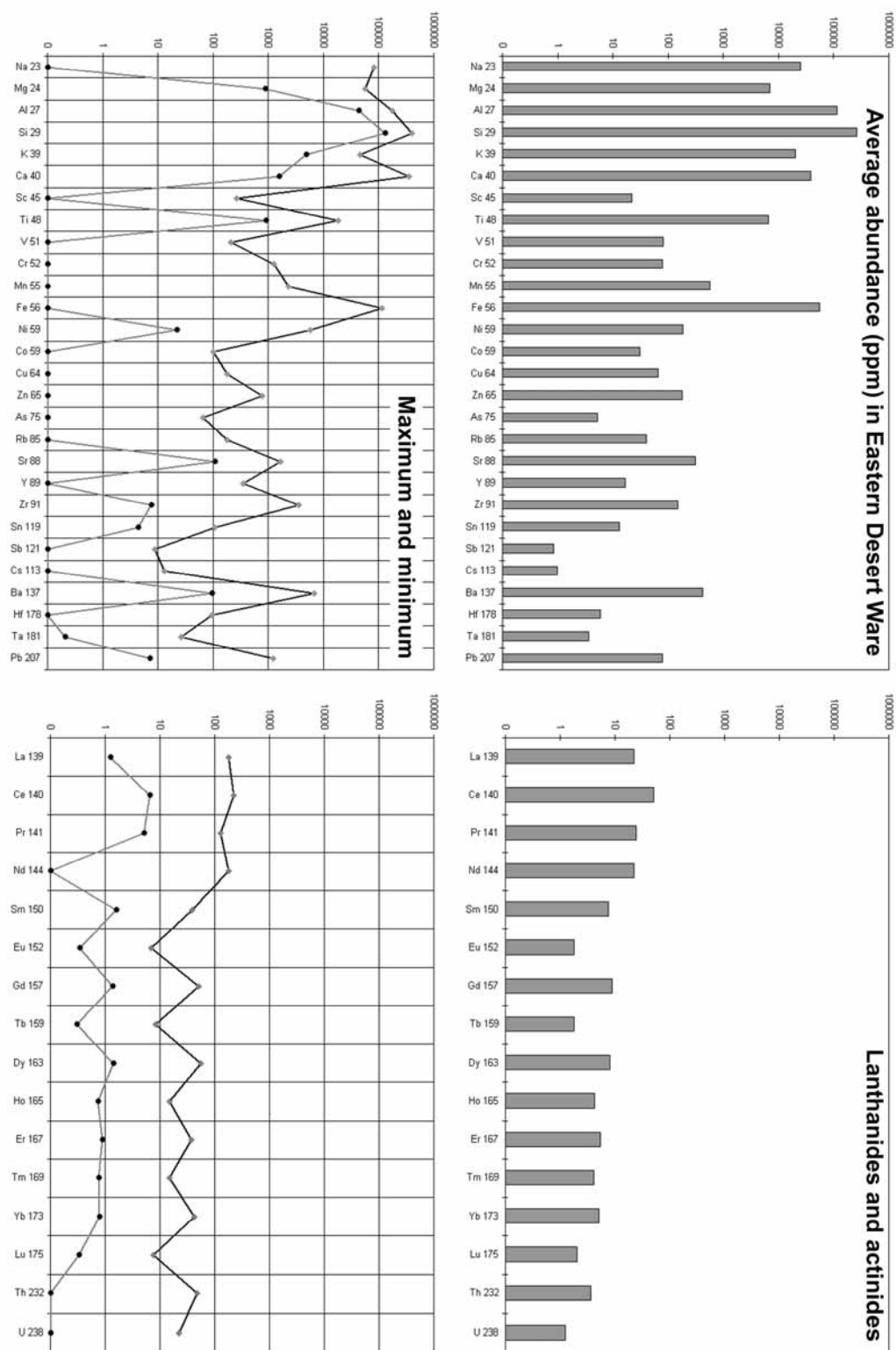


Figure 3-5: Overview of the results of the elemental composition analysis by LA-ICP-MS of 141 Eastern Desert Ware sherds (a total of 189 measurements). The bar graphs on top present the average value of each element on a logarithmic scale, the graphs at the bottom present the maximum and minimum value for the same elements. The elements have been divided into 'lanthanides and actinides' and 'other elements' to facilitate inspection of the data.

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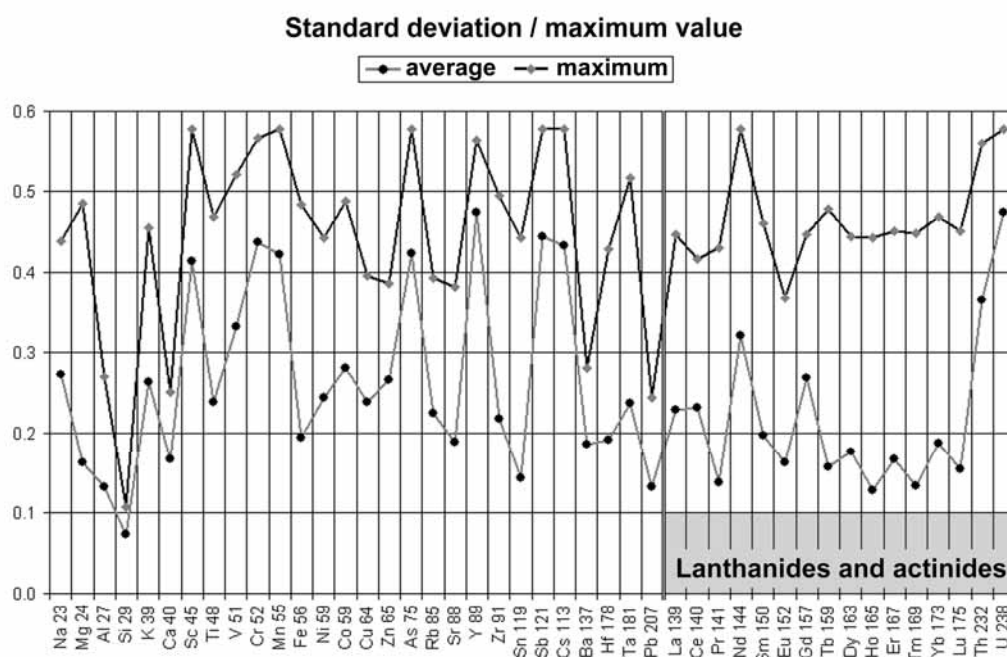


Figure 3-6: Average and maximum standard deviation (divided by maximum value to facilitate comparison) of 189 measurements, using LA-ICP-MS, of the elemental composition of 141 Eastern Desert Ware sherds. The elements have been divided into 'lanthanides and actinides' and 'other elements' to facilitate inspection of the data.

Interpretation of the Results

The elemental composition of Eastern Desert Ware sherds can only serve to sort the sherds into groups with a similar geological origin by comparing the abundances of two or more selected elements. As no possible production areas are known as yet, these hypothetical sources cannot be correlated with reference materials with a known provenance. Initially the sherds were grouped according to their archaeological provenance: 'Red Sea' (sherds from Berenike, Marsa Nakari and Quseir al-Qadim), 'Sudan' (sherds from Nubt and Tabot), 'Smaragdus' (sherds from Gebel Zabara, Wadi Gamal North, Umm Heiran, Wadi Gamal South and Wadi Sikait), 'Nile Valley' (sherds from Qasr Ibrim) and 'India' (sherds from Indian vessels found in Berenike). As vessels may be transported over considerable distances, as is obvious for the last group, the place where a sherd is found may be far from the place where the vessel was produced and, consequently, sherds found together in the same area may be produced in as many different places. Therefore, there may be no correlation between the archaeological provenance and the elemental composition of the sherds. The interpretation of the results of the ICP-MS measurements should therefore include a search for hypothetical source areas independent of the archaeological provenance of the sherds.

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 the visual inspection and interpretation of the data. First, as suggested by Neff (2002) and Glascock et al. (2004), Principal Component Analysis (PCA) was used to find elements best representing the differences between the sherds. PCA is a 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. Analysis was performed using Statistix 1.4 software which appends to Microsoft Excel. The results are presented in Table 3-2 and Figures 3-7 and 3-8.

Figure 3-7 shows the relation between all elements with a high loading (> 0.6) on either component 1 or component 2 and a low loading (< 0.5) on the other component (the selected elements are listed in the caption, Table 3-2). For each measurement a data point was calculated with the sum of the natural logarithms of the abundances of all elements with a high loading for component 1 (but not component 2) as x-coordinate and the sum of the natural logarithms of the abundances of all elements with a high loading for

Elemental Composition

component 2 (but not component 1) as the y-coordinate. Figure 3-7 (top-left) shows these data points for all sherds except for the Indian sherds found in Berenike; these are shown in grey in Figure 3-7 (top-right) together with the data points for the Eastern Desert Ware sherds from the Mons Smaragdus area and from the Nile Valley. In Figure 3-7 three possible outliers can be identified: EDW 103 (found in Tabot) and EDW 252 (found in Wadi Gamal South) have very low concentrations of the elements in the $PC2 > 0.6$ group (y-axis), while EDW 129 (found in Tabot) has low concentrations of the elements in the $PC1 > 0.6$ group (x-axis). EDW 6 (found in Berenike), EDW 87 and 246 (found in Wadi Sikait) and EDW 255 (found in Wadi Gamal South) have relatively high concentrations of the elements in both groups. Presented in this way the data points do not appear to separate into recognizable groups. The average values for all data points for finds from the five archaeological areas are shown in Figure 3-7 (bottom-right).

Plotting the relation between single elements with a high loading did lead to the partial separation of the data points into groups, most clearly in the case of cobalt (Co, atomic number 27, average mass 58.9 Da) versus samarium (Sm, atomic number 62, average mass 150.4 Da). Figure 3-8 (top) shows that the fabrics of the vessels found in the Mons Smaragdus area contain more cobalt than the fabrics of the vessels found elsewhere. Eastern Desert Ware vessels found in the Nile Valley appear to contain less cobalt than Eastern Desert Ware vessels found in the Mons Smaragdus area and more samarium than Eastern Desert Ware vessels found in Sudan. Eastern Desert Ware vessels found in Sudan and on the Red Sea coast appear to have very similar concentrations of cobalt and samarium. The Indian sherds found in Berenike appear to contain less cobalt than most Eastern Desert Ware vessels and similar concentrations of samarium (Figure 3-8, bottom).

Eastern Desert Ware

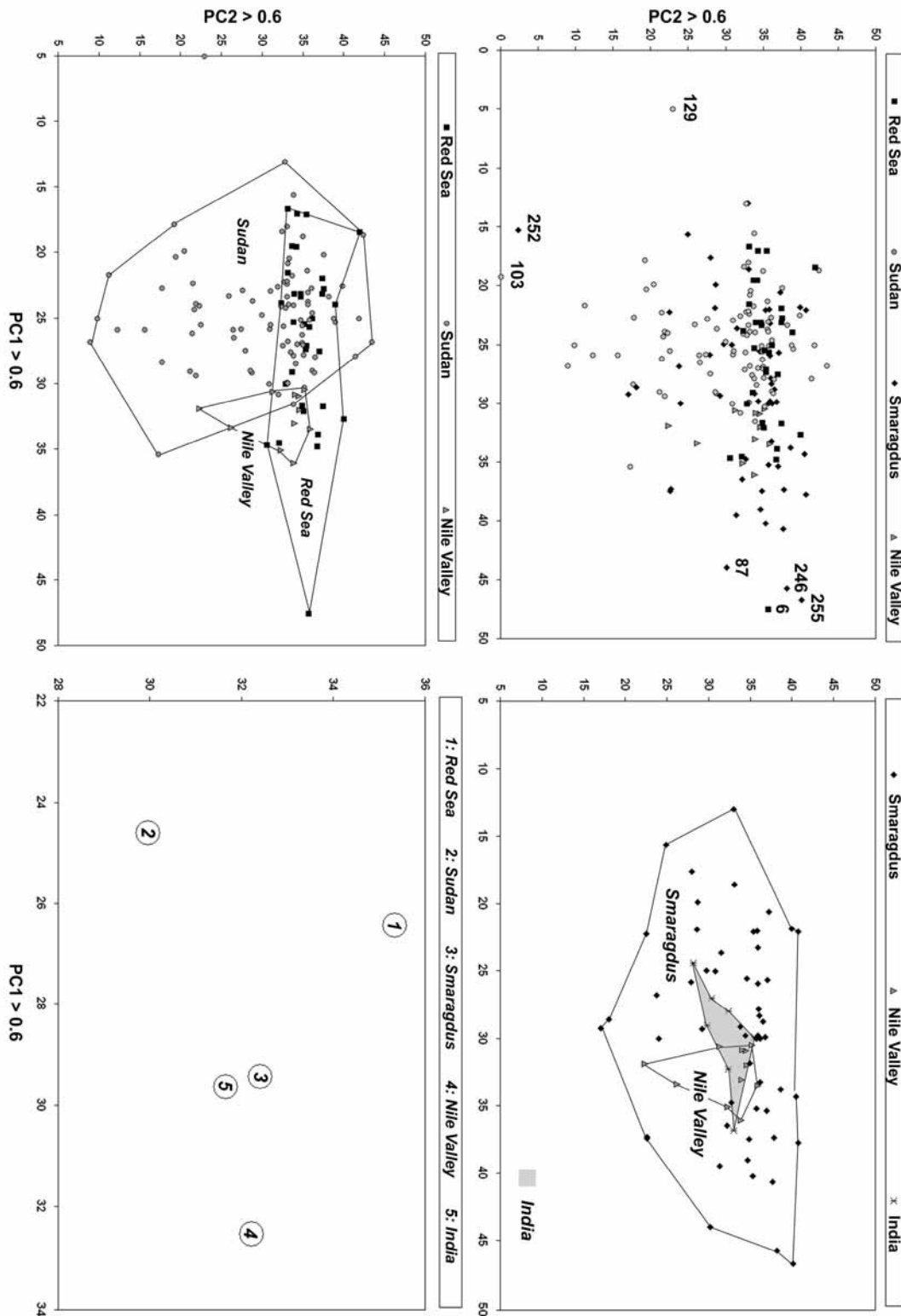


Figure 3-7: Graphs showing, on the x-axis, the sum of the natural logarithms of all elements with $PC1 > 0.6$ and $PC2 < 0.5$ (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Ta) versus, on the y-axis, the sum of the natural logarithms of all elements with $PC2 > 0.6$ and $PC1 < 0.5$ (V, Cr, Mn, Fe, Co, Cu and As). 1-4: average values of the sherds found in different archaeological regions; 5: average values of five Indian sherds excavated in Berenike (on the Red Sea coast). The lines serve to encircle data points from sherds with the same provenance and have no statistical significance.

Elemental Composition

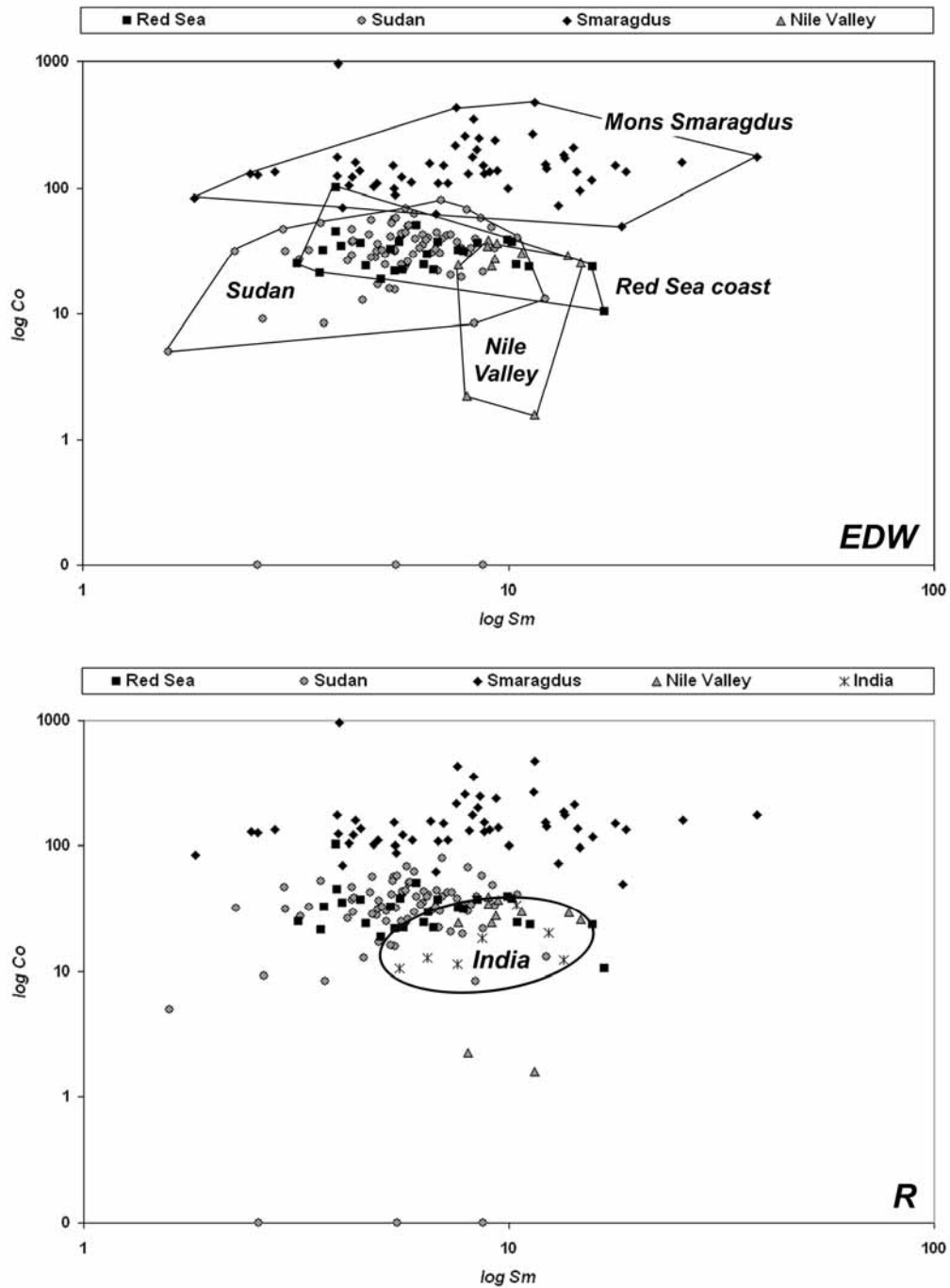


Figure 3-8: Abundance of the elements samarium (Sm, atomic number 62, average mass 150.4 Da), on the x-axis, and cobalt (Co, atomic number 27, average mass 58.9 Da), on the y-axis, in the fabric of 141 Eastern Desert Ware vessels (189 data points). In the graph at the bottom 7 data points on 5 Indian sherds excavated in Berenike are shown for comparison. The lines do not have a statistical meaning, but rather encompass data points from sherds found in the same region (with the exclusion of some outliers).

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The second 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 selected sherds (Appendix 9). For this method, 'signal' was defined as the variance in the eight average readings for each element and 'noise' as the average variance of three measurements of the same element in the same sherd. A high signal/noise ratio signifies more informative measurements. Fourteen elements (As, Ca, Ce, Eu, Hf, La, Nd, Pb, Sc, Sn, Sr, Th, Tm and Zr) appeared to have a signal/noise ratio > 2 and the combination cerium (Ce, atomic number 58, average mass 140.1 Da), europium (Eu, atomic number 63, average mass 152.0 Da) and thulium (Tm, atomic number 69, average mass 168.9 Da) appeared to produce the best graphical separation of the data points (Figures 3-9 and 3-10).

Figure 3-10 shows the abundances of europium (y-axis) and thulium (x-axis) of most Eastern Desert Ware sherds (with abundances of the elements between 0-6 ppm), as well as the Indian sherds found in Berenike and the 20 wheel-thrown Egyptian vessels made of Nile clay and marl (Mallory-Greenough et al. 1998). The data points

associated with the reference vessels from Egypt and India as well as with the Eastern Desert Ware vessels found in the Nile Valley appear to fall into distinctive clusters (Figure 3-10, top-left). The data points associated with other Eastern Desert Ware vessels (found on the Red Sea coast, in the Mons Smaragdus area and in Sudan) fail to separate into recognizable groups. For reasons of clarity the data points associated with the vessels from the Red Sea coast, the Mons Smaragdus area and Sudan are presented separately, the average values for the finds from each of these archaeological areas are shown in Figure 3-10 (top-left).

Figure 3-11 (top) presents the europium (y-axis) and thulium (x-axis) abundance of all Eastern Desert Ware vessels. Figure 3-11 (bottom) shows the same cluster of data points as Figure 3-10 (abundances < 6 ppm) with the abundance of cerium added as the third dimension (z-axis) resulting in a series of contour lines. In these figures the data points are not marked for archaeological provenance, but with their EDW-number in an attempt to identify geological provenances independent of the archaeological provenance of individual sherds.

Elemental Composition

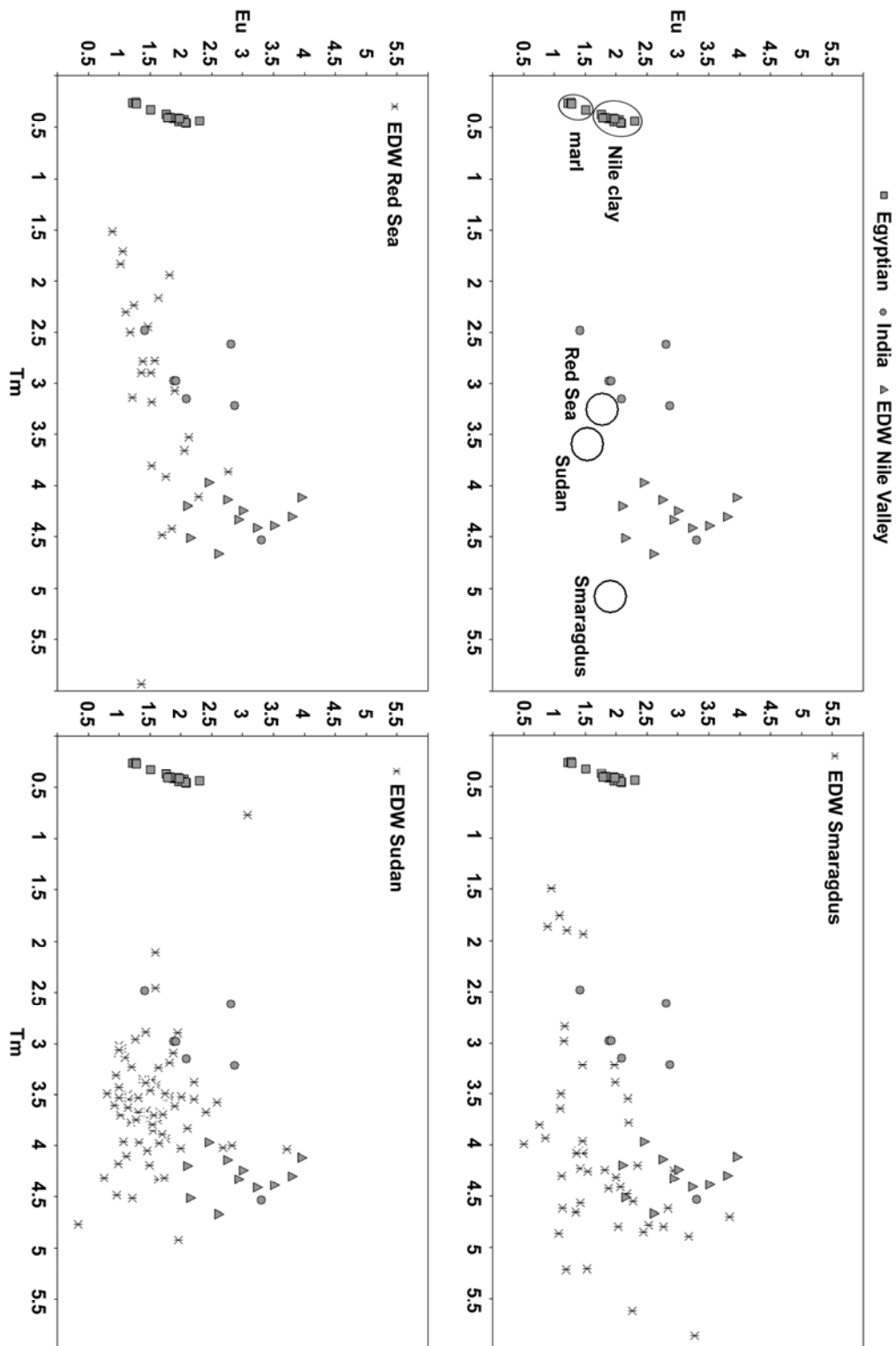


Figure 3-9: Graph showing the abundance of thulium (Tm, atomic number 69, average mass 168.9 Da), on the x-axis, and europium (Eu, atomic number 63, average mass 152.0 Da), on the y-axis, of Eastern Desert Ware sherds from the Nile Valley (top-left), the Red Sea coast (bottom-left), the Mons Smaragdus area (top-right) and the Sudanese Eastern Desert (bottom-right). The average values and the data points from two reference areas (Egypt and India) are also shown (top-left). The lines are drawn to indicate selected data points and have no statistical significance.

Eastern Desert Ware

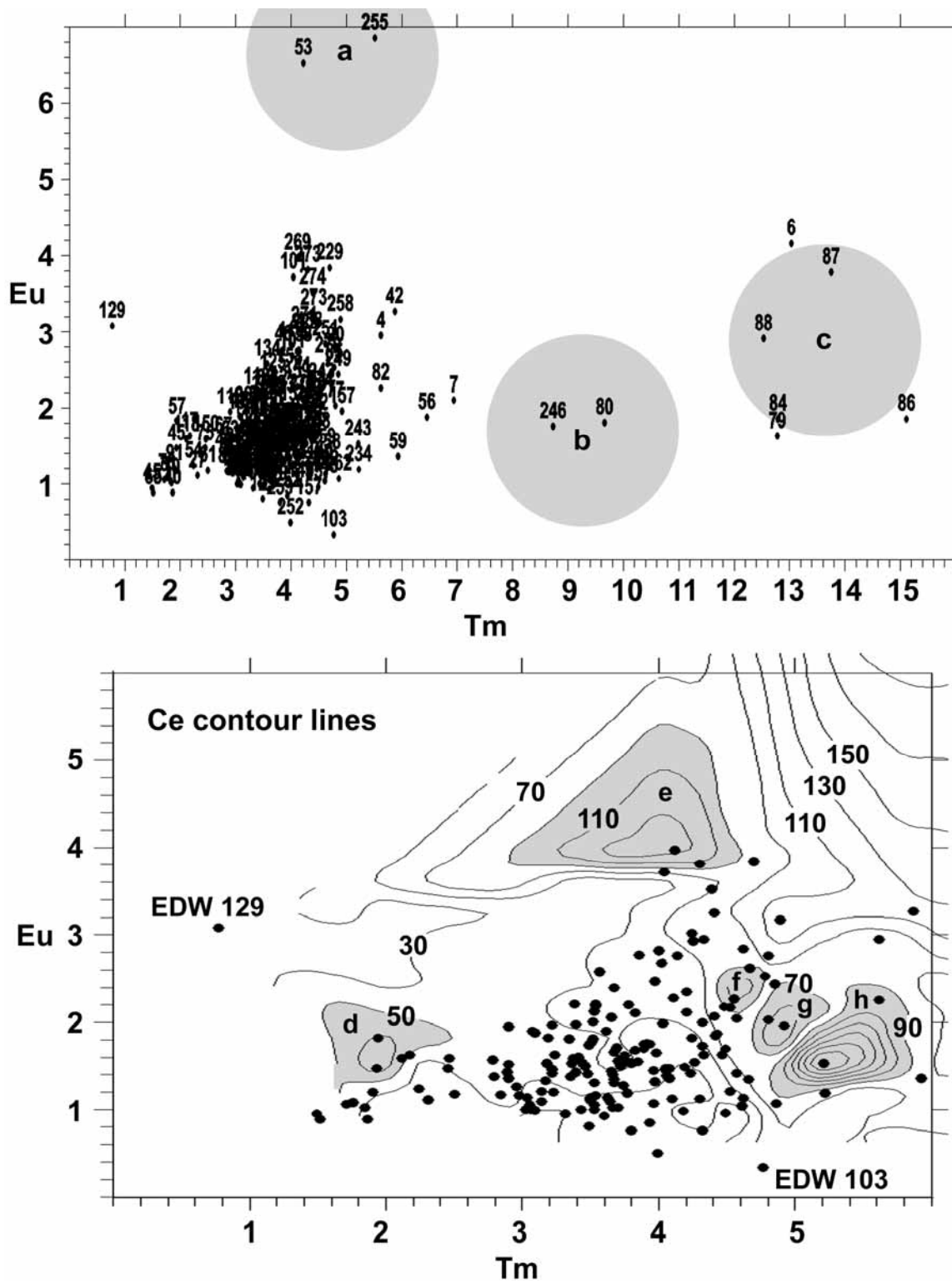


Figure 3-10: Graph showing the abundance of thulium (Tm, atomic number 69, average mass 168.9 Da), on the x-axis, and europium (Eu, atomic number 63, average mass 152.0 Da), on the y-axis, of all 141 Eastern Desert Ware vessels (top); the abundance of cerium (Ce, atomic number 58, average mass 140.1 Da) is added as the third dimension to the largest cluster of data points (below). The grey areas indicate seven hypothetical production areas (a, b, c, d, e, g and f/h).

Elemental Composition

Hypothetical Production Areas

Based on Figure 3-10 seven hypothetical production areas for Eastern Desert Ware can be proposed independent of the archaeological provenance of the sherds. Areas a, b and c (Figure 3-10, top) are distinct from the large cluster of data points, in the lower-left of the figure, with high concentrations of europium (area a) and thulium (areas b and c). Within the large cluster of data points (Figure 3-10, bottom) five additional areas can be identified based on differences in the abundance of cerium (Ce, atomic number 58, average mass 140.1 Da), which was added as a third dimension and is represented by a series of contour lines. The sherds in areas d and g have relatively low concentrations of cerium (around 50 ppm), while those in areas e, f and h have relatively high concentrations of cerium (around 100 ppm). EDW 243 (found in Wadi Sikait) is represented with data points resulting from different measurements in both area f and area h. These two areas should therefore be considered connected above the plane of the figure, with area g situated below that plane and area f/h. The seven resulting areas could represent geologically different production areas, characterized by distinct concentrations of certain elements, although the geographical relation of these areas remains uncertain. Clays with various geological origins may be present in the same clay layers, especially in redeposited layers such as the Quaternary *wadi* clays in the Eastern Desert (Appendix 6). Until raw materials with a known provenance have been studied using the same methodology it will be impossible to determine the actual source areas of Eastern Desert Ware.

Some details on the 27 Eastern Desert Ware vessels from each of the seven hypothetical production areas are given in Table 3-3 and Figures 3-12 through 3-14 (Appendix 5). Although the numbers are too small to allow for statistical analysis, there seems to be no relation between the production areas and the macroscopic fabric, the form or the decoration of the vessels. On the other hand, there appears to be a correlation between the hypothetical sources of the vessels and their archaeological provenance (for instance areas b, e and h) which may indicate that most vessels were used, and discarded, close to where they were produced (Chapter 6). It is also remarkable that vessels found in the Mons Smaragdus area seem overrepresented in the list of hypothetical production areas, which means that they show greater variability in the abundance of selected elements than the group of Eastern Desert Ware vessels as a whole. This is concurrent with Figures 3-7 and 3-8 where the vessels found in Sudan and on the Red Sea coast appear similar in chemical composition, while the vessels from the Mons Smaragdus area form a distinctly different and rather diffuse group.

Area	Number	Site	Diameter	Thickness	Fabric	Form	Lay-out
a	53	Be	19	7.2	3	H9	D2
	255	Ge	13	5.3	1	H2b	D0
b	80	WS	?	5.6	uc	H0	D0
	246	WS	17	4.8	2	H2a	D7
c	6	Be	17	5.6	1	H2b	D3
	79	WS	?	7.1	1	H0	D0
	84	WS	?	7.3	uc	H0	D0
	86	WS	21	6.8	uc	H2c	D3
	87	WS	7	6.5	uc	H7	D8
	88	WS	?	6.3	uc	H0	D0
d	17	Be	11	5.0	uc	H7	D3
	45	KM	?	5.3	uc	H0	D0
	57	Be	13	5.0	uc	H2b	D3
	118	Ta	14	5.5	uc	H2b	D3
e	269	QI	10	5.3	4	H1	D3
	273	QI	?	4.9	uc	H0	D0
g	77	WS	18	6.9	uc	H2b	D3
	157	Nu	21	8.8	uc	H3	D6
	249	WS	14	6.2	3	H2b	D3
f	44	KM	?	4.8	NS	H0	D8
	85	WS	?	4.2	at	H0	D0
	243	WS	12	5.5	uc	H1c	D8
	270	QI	?	5.8	uc	H0	D0
	274	QI	?	7.4	1	H2	D7
h	82	WS	?	6.8	1	H0	D0
	234	WS	11	5.9	uc	H2c	D3
	243	WS	12	5.5	uc	H1c	D8

Table 3-3: Properties of 27 Eastern Desert Ware sherds associated with seven hypothetical production areas (Figures 3-10 and 3-12 through 3-14; Appendices 4 and 5). Area = Hypothetical production area (Figure 3-10); Number = EDW number; Site = Be: Berenike; Ge: Gelli (Wadi Gamal South); KM: Kab Marfu'a (Wadi Gamal North); Nu: Nubt; QI: Qasr Ibrim; Ta: Tabot or WS: Wadi Sikait; Diameter = reconstructed rim diameter (cm.); Thickness = average thickness (mm.); Fabric: 1 = EDW-1; 2 = EDW-2; 3 = EDW-3; 4 = EDW-4; uc = unclassified Eastern Desert Ware fabric; NS = fabric resembling 'Nile silt' or at = atypical; Form and lay-out = classification according to Strouhal 1984, modified by Barnard and Strouhal 2004 (Appendix 4).

Eastern Desert Ware

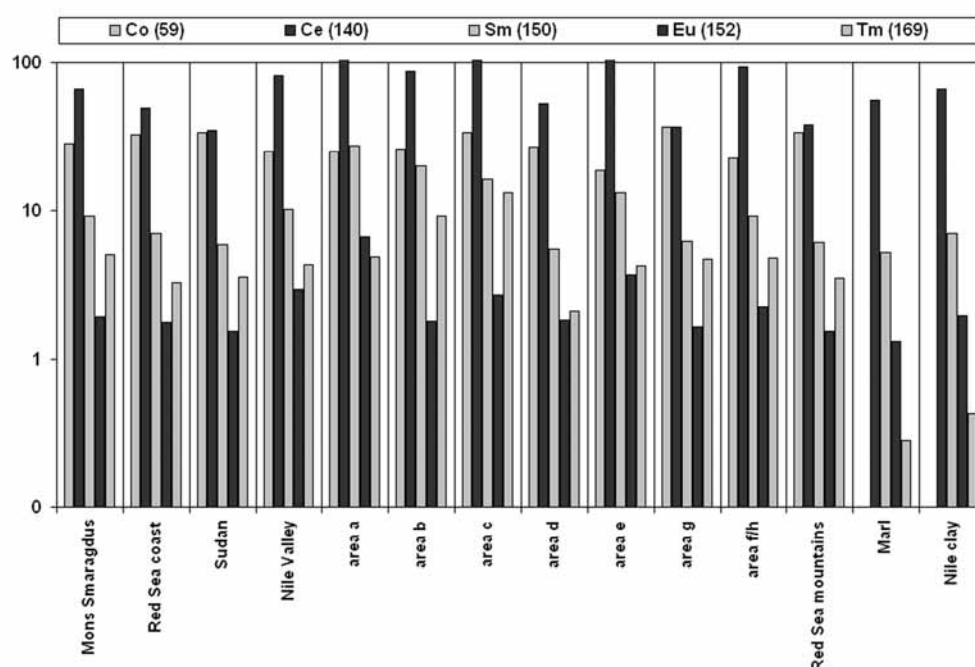


Figure 3-11 (cf. Table 3-4): Average relative abundance of selected elements in Eastern Desert Ware found in four regions in the Eastern Desert (left) and from seven hypothetical production areas (a - f/h), compared to the hypothetical source of the vessels found on the Red Sea coast and in Sudan (the 'Red Sea Mountains') and 20 wheel-thrown vessels produced in the Nile Valley during the Egyptian New Kingdom (right).

		Co (59)	Ce (140)	Sm (150)	Eu (152)	Tm (169)
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

Table 3-4 (cf. Figure 3-11): Average abundance (in parts/million) of selected elements in Eastern Desert Ware found in four regions in the Eastern Desert (ED, top) and from seven hypothetical production areas (a - f/h), compared to the hypothetical source of the vessels found on the Red Sea coast and in Sudan (the 'Red Sea Mountains') and 20 wheel-thrown vessels produced in the Nile Valley during the Egyptian New Kingdom (NV, bottom).

Elemental Composition

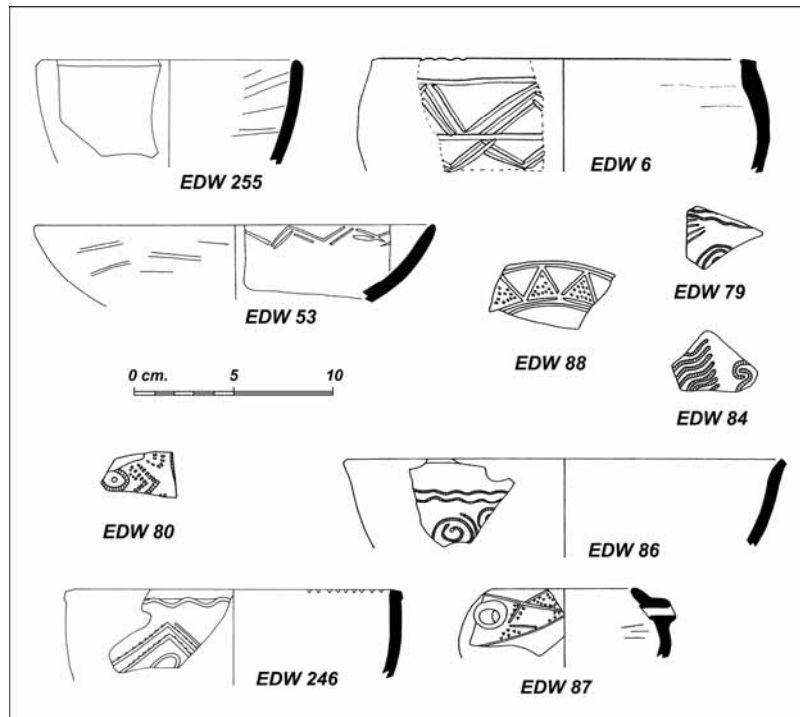


Figure 3-12 (cf. Table 3-3 and Appendix 5): Eastern Desert Ware vessels associated with hypothetical production areas 'a' (EDW 53 and 255, found in Berenike and Wadi Gamal South respectively), 'b' (EDW 80 and 246, both found in Wadi Sikait) and 'c' (EDW 6, found in Berenike and EDW 79, 84, 86, 87 and 88, found in Wadi Sikait).

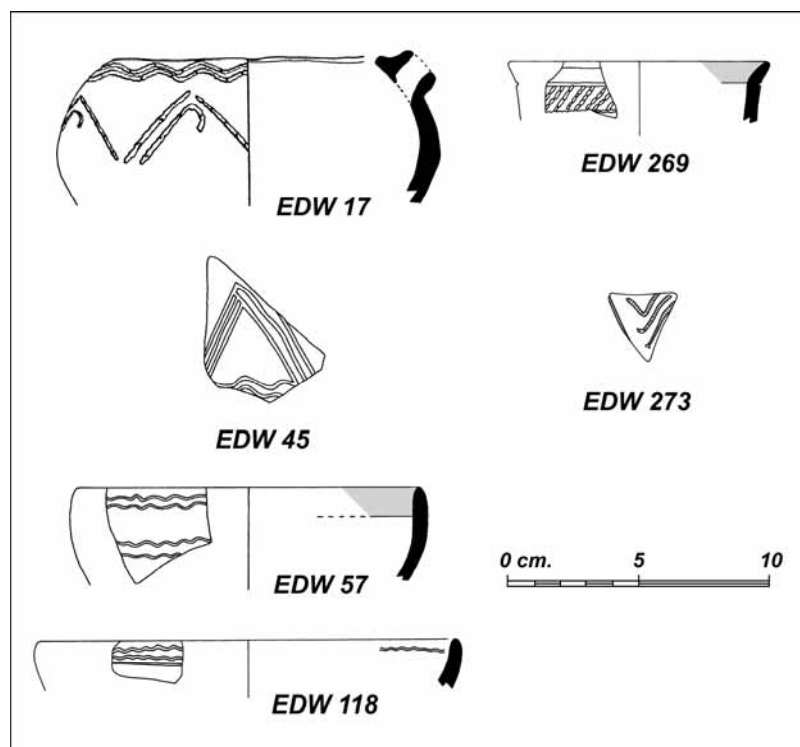


Figure 3-13 (cf. Table 3-3 and Appendix 5): Eastern Desert Ware vessels from hypothetical production areas 'd' (EDW 17 and 57, found in Berenike, EDW 45, found in Wadi Gamal North, and EDW 118, found in Tabot) and 'e' (EDW 269 and 273, both found in Qasr Ibrim).

Eastern Desert Ware

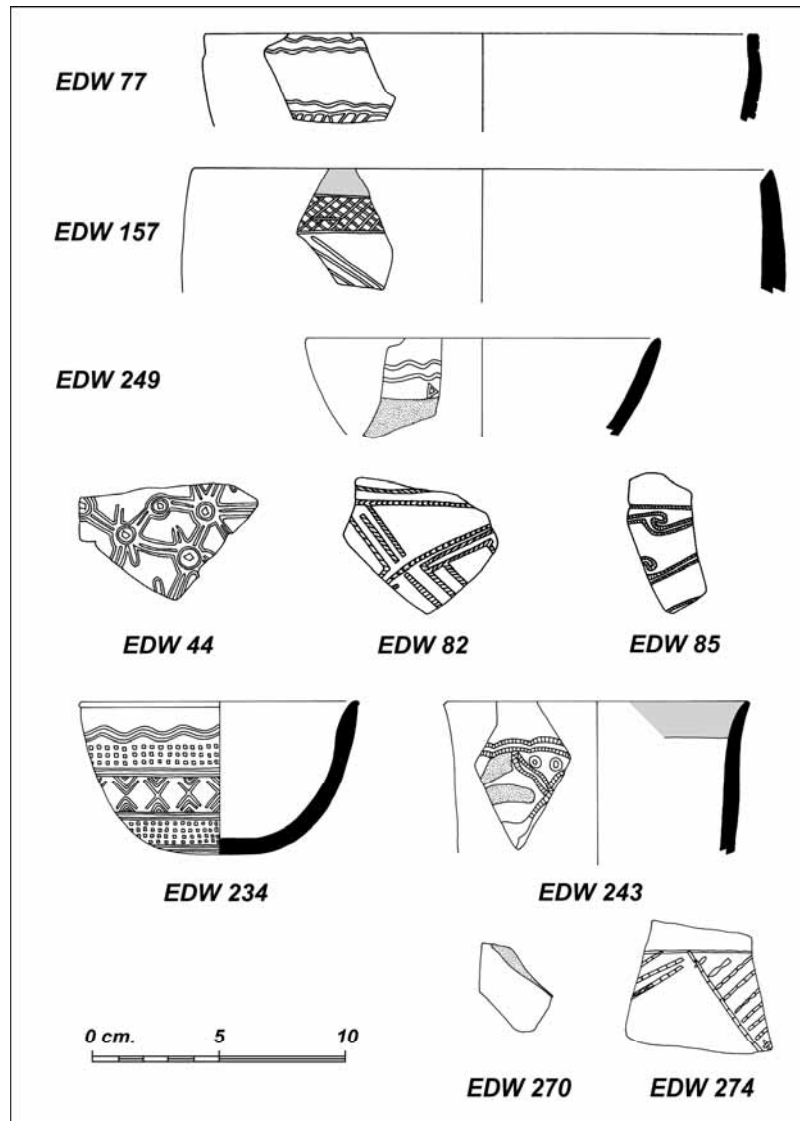


Figure 3-14 (cf. Table 3-3 and Appendix 5): Eastern Desert Ware vessels from hypothetical production areas 'g' (EDW 77 and 249, found in Wadi Sikait, and EDW 157, found in Nubt) and 'f/h' (EDW 44, found in Wadi Gamal North, EDW 82, 85, 234 and 243, found in Wadi Sikait, and EDW 270 and 274, found in Qasr Ibrim).

Figure 3-11 and Table 3-4 show 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). Most of the vessels found in Sudan and on the Red Sea coast appear to have been made of raw materials from the same geological source, characterized by the central clusters in Figures 3-8 and 3-10, with the following chemical 'fingerprint': Co: 33.55 ppm; Ce: 38.08 ppm; Sm: 6.08 ppm; Eu: 1.54 ppm; Tm: 3.52 ppm (the hypothetical 'Red Sea Mountains' in Table 3-4). This source need not be in a single geographical place

and until possible 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 it is associated with the Red Sea Mountains, although likely, can therefore only be tentative.

Discussion

Potter's clay and ceramic vessels are basically man-made geological materials and can therefore be studied with geological methods, such as petrographic microscopy and ICP-MS elemental analysis. Ideally, such studies can confirm or even identify the provenance of the raw materials that were used to produce the pottery. However, no possible source areas for the raw materials of Eastern Desert Ware have yet been identified. Quaternary Nile clay and Tertiary marl clay, harvested close to the Nile Valley, are the most common clay sources for Egyptian wheel-thrown pottery. Macroscopic and microscopic investigation of most of the 290 Eastern Desert Ware vessels in this study indicated that these were not made of the usual raw materials, but rather of clay and mineral inclusions or temper from one or more unknown sources. Until additional clay sources have been identified and studied the geographical place of these sources will remain unknown, but some tentative observation can be made.

Although the vessels from Tabot (in the Sudanese Eastern Desert) and from Berenike (on the Egyptian Red Sea coast) seem different in general appearance (Chapter 2) and have a rather variable microscopic aspect (Appendix 8), their chemical composition appears quite similar (Figures 3-7, 3-8 and 3-10). This means that they were most likely made of clay from the same geological source, which could extend over a large geographical area. Given the distribution of the finds and the fact that the vessels were not made in the Nile Valley, it is possible that this clay source is located in the Red Sea Mountains. In one or more places, one of the layers that constitute these mountains (Appendix 6) is weathering into clay and the potters that produced the vessels later found in Berenike and Tabot used this clay as the raw material for their pottery. As the same geological layer may surface and weather into clay in many places, Eastern Desert Ware sherds made as far apart as they are found can still have the same geochemical fingerprint. It remains unknown whether clay or finished vessels were transported to Berenike and Tabot, but the latter seems more likely as the supply of water and fuel, necessary to produce pottery, will have been limited in these desert settlements (Chapter 1). The observed macroscopic differences in the fabric of the vessels can be explained by local differences in the clay formation process and the ways in which the different potters treated their raw materials; the differences in the style of the vessels and their decorations can be fully attributed to the latter. This supports the suggestion of local production, or at least the production in several different localities rather than the production in one central area from which the vessels were distributed over the different sites where they were ultimately discarded and found.

The Eastern Desert Ware vessels from the Mons Smaragdus area, a number of settlement sites located around the Graeco-Roman beryl mines in the Egyptian Eastern Desert, appear to have been made of clay from various geological sources, mostly different from the source of Eastern Desert Ware from Berenike and Tabot (Figure 3-8). It is remarkable that while most Eastern Desert Ware vessels from Berenike and Tabot appear to originate from a single geological source, there seem to have been many different geological sources for the raw materials of the Eastern Desert Ware vessels found in the Mons Smaragdus area (Table 3-3). Possible explanations are that the inhabitants of the settlements in the Mons Smaragdus area imported their clay or vessels from many different regions, or from a region with clays of different geological origins. More likely is that the Eastern Desert Ware vessels found in the Mons Smaragdus area were made of Quaternary redeposited *wadi* clays. These are clay deposits consisting of clays that have been eroded by the action of wind or water from where they were originally formed, and other erosional debris. Such deposits obviously contain materials with very different geological origins, either entirely mixed or in subtle but discrete layers. Using such clay for the production of pottery (Van As and Jacobs 1995) will lead to vessels with very different geological fingerprints (Butzer 1974), even though their geographical places of origin may be very similar. The appearance of the Eastern Desert Ware vessels found in the Mons Smaragdus area suggests that they were made by different potters, probably over a period longer than the life of a single potter, but also that these potters were in contact with each other as well as with the potters that produced the Eastern Desert Ware found elsewhere.

The Eastern Desert Ware vessels found in Qasr Ibrim, in the Nile Valley, appear to have been made of raw materials from a single geological source, which is different from the usual sources for vessels found in the Nile Valley (Nile clay or marl) and also different from the source of the Eastern Desert Ware vessel found in Sudan and on the Red Sea coast (Figures 3-7, 3-8 and 3-9). Vessels from Qasr Ibrim are represented in hypothetical production areas e and f (Table 3-3). The latter has been tentatively identified as Quaternary *wadi* clay, which could well be the origin of the vessels found in Qasr Ibrim. Alternatively, the vessels from hypothetical production areas e and f/h were made of clay from the same geological source and were distributed, either as raw material or finished vessels, over the different sites where they were ultimately discarded and found.

Eastern Desert Ware

The reasons why the potters that produced the Eastern Desert Ware vessels found in Berenike and Tabot used other clay sources than the potters that produced the vessel in the Mons Smaragdus area and Qasr Ibrim can only be addressed after raw materials from possible source areas have been investigated. It could be that the primary clay layers of the Red Sea Mountains were less easily accessible in the Mons Smaragdus area, or that the secondary *wadi* clay was more plentiful there than it was elsewhere. It could also be that the inhabitants of the settlements in the Mons Smaragdus area could or did not need to travel to the clay sources in the Red Sea Mountains, while the inhabitants of Tabot and Berenike preferred or were forced to use the primary clay sources in the Red Sea Mountains over the locally available secondary *wadi* clays. Next to material from possible clay sources, more Eastern Desert Ware from sites in the Nile Valley also needs to be analyzed. The minimally invasive technique of LA-ICP-MS would be an ideal way to finish the research started by J. Čejka, E. Kaprálová and Z. Urbanec (Strouhal 1984: 195-200; see also Strouhal and Barnard 2004). This should be combined with the results of the further study of the petrology of the mineral inclusions, of which only an outline could be presented here.