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## Tracing the Source of the Elephant and Hippopotamus Ivory from the 14th Century B.C. Uluburun Shipwreck: The Archaeological, Historical, and Isotopic Evidence

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Tracing the Source of the Elephant and Hippopotamus Ivory from the 14<sup>th</sup> Century B.C.

Uluburun Shipwreck: The Archaeological, Historical, and Isotopic Evidence

by

Kathryn A. Lafrenz

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Arts  
Department of Anthropology  
College of Arts and Sciences  
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ABSTRACT

The aim of this study is to establish the provenance of the elephant and hippopotamus ivory recovered from the 14th century B.C. Uluburun shipwreck in order to reconstruct the trade mechanisms and associated social relationships (e.g. diplomacy) operating in the eastern Mediterranean during the Late Bronze Age (LBA). Elephant ivory came either from Northeastern Libya, Southeastern Sudan via Egypt or northwestern Syria during this period. Hippopotamus ivory likewise was obtained from Syria, Palestine, or Egypt.

The Uluburun's cargo is reconstructed by the excavator, George Bass, as "royal," and primarily originates from Cyprus and Syro-Palestine. Indeed, LBA trade is largely understood as gift-exchange between ruling elites, thereby reflecting a trade system organized by and for a centralized authority. With the transition to the Iron Age, an identifiable merchant class developed and decentralized trade (relative to the preceding era) under a system of *cabotage* shipping. If the ivory is shown to derive from several regions instead of a single location, a revision of LBA trade must be fashioned to include ruling elites acting as "merchants" to a larger degree than previously assumed, or the web of social relationships involved in "international" diplomacy as much more intricate.

Indeed, the *mechanisms* of the LBA trade must be established to provide a complete picture of trade, especially since the import and historical data is biased towards a simplistic, centralized trade system.

The  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{18}\text{O}$  reflect the climate and vegetation of the area in which a population dwells, so that areas with similar climate/vegetation will produce similar isotopic signatures, though these areas may be geographically separated. Nevertheless, examining  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios will distinguish between populations because  $^{87}\text{Sr}/^{86}\text{Sr}$  mirrors the isotopic signature of the underlying rock, and is sufficiently unique to each region to warrant differentiation.

Isotopic ratio analysis (carbon, nitrogen, oxygen, and/or strontium) was conducted on the collagen and apatite components of the ivory using mass spectrometry to differentiate between regions and therefore provide the provenance. Ultimately a source determination utilizing HR-ICP-MS for  $^{87}\text{Sr}/^{86}\text{Sr}$  was not successful. Future provenance research on ivory should employ TIMS, and consider triangulating  $^{87}\text{Sr}/^{86}\text{Sr}$  against lead and neodymium isotopes.

## **Chapter 1**

### **Introduction**

The Uluburun became anchored in the imagination of the public and specialists alike since it was first discovered off the southwest coast of Turkey in 1982. The shipwreck dates to 1300 B.C. (Late Bronze Age), as determined by dendrochronology (Pulak 1996), and is most well-known for its rich and cosmopolitan cargo, carrying artifacts from at least seven cultures: Mycenaean, Canaanite, Cypriot, Egyptian, Kassite (Babylonian), Assyrian, and Nubian. Given the unusually large cargo of metal (10 tons of copper and 1 ton of tin), the Uluburun has been interpreted by its excavators, George Bass (1987; 1997) and Cemal Pulak (1997; 1998; 2001), as a royal cargo. Part of this wealthy cargo was a primary section of a large elephant tusk (*cf.* Krzyszkowska 1993: 30), and even more surprising were six canines and seven incisors of hippopotamus ivory, which serve as the focal point for my investigation.

While the majority of the finds from the Uluburun shipwreck have been ascribed probable origins, the ivory recovered as raw material has thus far evaded assignment of provenance. The Uluburun ivory samples and three elephant bone samples from Maraş Fili (Turkey) were sent by Cemal Pulak to Robert Tykot for analysis, and thereupon handed over to me, which is how the present study was initiated. Several educated guesses for the provenance of ivory in the LBA Mediterranean, based on archaeological and historical data, have been offered. However, the lack of agreement among scholars, partly due to clear biases and inconsistencies within the archaeological and historical records, requires that another avenue of research be sought, that is, a source determination based on isotopic ratio analysis.

Unfortunately the source of ivory cannot be determined from the color or relative hardness of the ivory, and structural characteristics will only differentiate elephant ivory from hippopotamus ivory. There is furthermore no means for distinguishing ivory obtained from the Asian versus the African species of elephant, and the only diagnostic skeletal part to verify the presence of one of these species is the post-cranial material (Krzyszkowska 1990: 7-12; Karali-Yannacopoulos 1993: 58). As of yet there are no means for determining the provenance of ivory based on routine laboratory methods.

However, analyses conducted by van der Merwe *et al.* (1990) using  $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratios in the bone collagen of modern African elephants demonstrated the efficacy of isotopic analysis for provenancing elephant bone and ivory. Furthermore, recent research by White *et al.* (1998) utilized  $^{18}\text{O}/^{16}\text{O}$  to distinguish between human populations (see Chapter Six for a discussion of these studies). Isotope ratio analysis has furthermore been utilized in archaeological bone chemistry studies to reconstruct the diet and health of ancient populations, residence and mobility patterns, and palaeoclimate.

Stable isotopic ratio analysis of carbon and nitrogen isotopes was therefore conducted on the collagen of the Uluburun ivory samples, in addition to carbon and oxygen isotope analysis on the apatite component of the ivories.  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{18}\text{O}$  reflect the climate and vegetation of the area in which a population lives, and, as a result, areas with similar climate and vegetation will produce similar isotopic signatures, even though these areas may be geographically distant from one another. Consequently, strontium isotope ratio ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) analysis of the samples was also included in the research program in order to confidently distinguish between populations. The strontium

ratio mirrors the isotopic signature of the underlying rock, and is sufficiently unique to each source area to warrant differentiation. Three bone samples from Maraş Fili, Turkey, were also analyzed to compare the isotope ratio values of the ivory with those from a known region.

Ultimately a successful provenancing of the ivory will reveal much more than the mere source. Every last bit of information which will be culled from the cargo of the Uluburun shipwreck offers a rare chance to illuminate the *mechanisms* of Late Bronze Age trade, hitherto poorly understood except in broad assignments of “royal” versus “merchant” initiatives, and “Canaanite” versus “Mycenaean” agents. The reality is much more complicated, and research has been limited so far, not in effort but by the paucity of information, in reconstructions of Late Bronze Age trade in the eastern Mediterranean.

At the outset, however, I think it is important to stress that there are several things the present study is *not* trying to do. It is not trying to reconstruct with startling clarity the mechanisms of LBA maritime trade in the eastern Mediterranean on the basis of an admittedly small data set of ivory fragments. Nor is it advocating that external stimuli, such as trade, are the prime mover of cultural change, and as such should be paid a great deal of attention. Instead this investigation is trying to establish, in a pilot study, whether it is feasible or even possible to use isotope ratio analyses to provenance ivory from archaeological contexts. It is trying to give a wholly contextual investigation of the Uluburun ivories, and in doing so emphasizes the necessity of placing the archaeometric analysis of the ivories within the context of the archaeology itself. How does the sourcing of ivory contribute to the broader picture and say something about the culture history of the eastern Mediterranean? What theoretical questions are being asked about



LBA trade and how could an analysis of the Uluburun ivories possibly add to this discussion? Moreover, in the process of contextualizing archaeometric data, the symbolic and ideological concepts of ivory must be emphasized. What did ivory mean to people in the LBA, especially when they traded it? Just as the material itself lends the possibility of sophisticated scientific analyses on account of isotopes embedded within its composition, so also does the material argue for a unique perspective on LBA trade as it is embedded within an ideology of luxury, gift-exchange, internationalism and political entente.

Because the present investigation is, at its foundation, approached from a materials perspective, the morphological characteristics of ivory must be considered first, and will be covered in Chapter Two. The archaeological, historical, and osteological evidence for the sources of hippopotamus and elephant ivory in the eastern Mediterranean are then presented in Chapters Three and Four, respectively, so as to establish the geographical parameters of the isotopic ratio analyses. The results of these analyses will ultimately be incorporated into the larger picture of the mechanisms of Late Bronze Age trade. Since one of the principal stages in the ivory trade (and the hallmark of a palace economy) was the conversion of the raw material into even more valuable prestige objects, the ivory workshops within the eastern Mediterranean are the topic of Chapter Five. I will then switch gears into an explanation of the scientific analyses behind this study. A general overview of the principles of carbon, oxygen, nitrogen, and strontium isotopic analysis is given in Chapter Six, followed by a discussion of the ecological and dietary requirements of the hippopotamus and elephant (Chapters Seven and Eight), as knowledge of these are necessary for interpretation of the results. Further,

past isotopic research on modern populations of elephants and hippopotami are reviewed in Chapter Nine. The published geological literature for the source regions of ivory are likewise considered in Chapter Ten for strontium isotope ratio data of the underlying bedrock. The laboratory and analytical procedures (Chapter Eleven) including a brief description of the samples, and the results of the isotopic ratio analyses (Chapter Twelve) are presented before concluding with a discussion of the results (Chapter Thirteen) and suggestions for future research (Chapter Fourteen).

## **Historical Background**

The Late Bronze Age marked the height of political centralization the eastern Mediterranean region had yet seen, with several major political powers sharing common boundaries buffered by a number of city-states ruled by minor kings. Egypt had expelled the Hyksos by the middle of the 16<sup>th</sup> century B.C. and thereafter adopted an aggressive expansionist agenda to remove the threat of another such invasion, and probably also to atone for past injustices. A large portion of Palestine came under Egyptian control, with the result that Egypt shared a border for the first time with another major military power: the Mitanni in the 15<sup>th</sup> century B.C. and the Hittites in the 14<sup>th</sup>-13<sup>th</sup> centuries. Egypt formed an alliance with the Mitanni in an attempt to curtail the growing presence of the Hittites to the west, and a long period of peace followed under Amenophis III (ruled 1390-1352 B.C.; low chronology), whose reign also signaled the beginning of the Amarna period, late XVIIIth Dynasty. The period is named after the site of Tell el-Amarna, where the next pharaoh Akhenaten (1352-1336 B.C.) based his distinctive social and religious reforms. The period is famously documented by the Amarna letters (cited

as EA), clay tablets written primarily in Akkadian which recorded the royal correspondence with other rulers. After Akhenaten there followed a quick succession of pharaohs (including Tutankhamen), whose reigns were possibly cut short by the same plague that claimed several of the Hittite royalty. Horemheb then ruled from 1323-1295 B.C. and resumed Egyptian campaigning and tribute-collecting in Palestine (Kuhrt 1995: 185-202). The Uluburun thus sank towards the end of Horemheb's reign, circa 1300 B.C.

Palestine and North Syria were thus composed of many small city-states which jockeyed among themselves for power while also playing the larger powers off one another. Each minor king owed his throne to a "Great King," whether this was the Egyptian pharaoh, or the Mitannian or Hittite king, and the minor kings had to give public loyalty to the king through gifts/tribute. The Egyptians had administrative centers in the region at Sumur, Gaza, and Kumidi (Kamid-el-Loz), and Canaanite royalty were sometimes brought up at the Egyptian court (Kuhrt 1995: 324-328). Meanwhile, from 1500/1480-1350/1340 B.C., the Mitanni controlled an area stretching from northwest Iran, through north Iraq and the very north of Syria to the southeastern corner of Anatolia (the western boundary in the vicinity of Maraş, where the elephant bone samples hail from for this present thesis). This region included the city-states of Alalakh (Tell Atchana), Aleppo, Emar, Taide, Alshe, Ugarit (held briefly), and the regions of Assyria (north Iraq) and Arrapha (Kirkuk region) (Yener 2001; Kuhrt 1995: 283-296). Two city-states which shall figure prominently in the consideration of the ivory trade are Alalakh and Ugarit. Alalakh is located in the Amuq Plain (also known as the Plain of Antioch), a region which was home to elephants and hippopotami, and has yielded a number of ivory artifacts. Ugarit, on the other hand, was a major trading center with specialized craft

production in ivoryworking, metalworking, purple-dyed textiles, and furniture (often inlaid with ivory). The city's port at Minet el-Beida channeled North Syrian goods to Cyprus and farther west, and acted as a major supplier of grain to the Hittites through Cilicia (Kuhrt 1995: 300-303).

The Hittites were increasingly in conflict with the Mitanni until the Syrian conquests of Suppiluliuma I (1344-1322) and Mursili II (1321-1295) subjugated the Mitanni, essentially creating a buffer area between themselves and Assyria. By the time the Uluburun sank off their shores, the Hittites were in control of Aleppo, Alalakh, Nuhash-she, Amurru, Cilicia, and the Arzawa in western Anatolia. They had additionally signed a treaty with Ugarit whereby Ugarit recognized Hittite authority, although Ugarit retained much more autonomy than other city-states. The border between the Hittites and Egypt slowly moved farther south from the mouth of the Orontes to Byblos. Eventually the Hittites and Egypt signed a peace treaty under Hattusili III and Ramesses II in 1258 B.C., an agreement which was solidified by a royal marriage and led to a peaceful period in which members of the two royal families corresponded regularly with one another. Like at Amarna, a great amount of the Hittite royal archives are preserved at Hattusa, the capital of the Hittite kingdom. From these archives it is known that the Hittites also had trade or business dealings with Babylonia, Lycia, Cyprus, and the Ahhiyawa (Sherratt and Sherratt 1991: 371; Kuhrt 1995: 225-263).

To the west the mainland Mycenaean palace centers had gained prominence over Crete in the Aegean sphere, although Kommos still remained economically robust due to its location, effectively linking long-distance eastern Mediterranean trade with regional Aegean maritime circuits. Strangely enough there is a great dearth of Aegean and

Mycenaean material in central Anatolia, suggesting perhaps some sort of trade embargo was operating (Kuhrt 1995: 281; Sherratt and Sherratt 1991: 370-371). Cyprus on the other hand held a significant role in Late Bronze Age trade, due in large part to its role as primary supplier of copper to the eastern Mediterranean. The island witnessed major urbanization at centers such as Enkomi and Kition which linked the copper-rich interior with the ports.

Egypt's border was also extended southward into Nubia, and Hatshepsut sent a maritime expedition by the Red Sea to Punt, located roughly in the location of modern Eritrea. Very little is known about Punt as the archaeological evidence for it, other than historical references in Egypt, is severely lacking (Phillips 1997; Kitchen 1993; O'Connor 1993). In Nubia the situation is only slightly better. The archaeological record is more visible but with little diachronic differentiation. More is known about Upper Nubia than Lower Nubia, particularly because Upper Nubia had an environment more hospitable to permanent settlement and much of Lower Nubia is now submerged due to the construction of the Aswan High Dam. Prior to the Late Bronze Age the large site of Kerma probably prospered from monopolizing trade from the south going to Egypt. However, Kerma was destroyed and by the New Kingdom Egypt controlled Nubia as far upriver as the Fourth Cataract, most likely for closer access to trade with the south through middle agents such as the Irem of the Khartoum region. Nubian princes also were raised and educated in Egyptian courts, like Palestinian royal offspring (Shinnie 1984; O'Connor 1993: 583-584; Kuhrt 1995: 329-330; Luce 1998: 59). The material culture of Libya is also poorly understood. However, it is known that the region was home to pastoral nomads who exhibited aspects of political centralization and social

hierarchy by the LBA, and had established some cities in Cyrenaica, although these have not been located yet (O'Connor 1993: 576, 583; McBurney 1970).

## Chapter 2

### Morphological Characteristics of Ivory

#### Elephant Ivory

When one considers the word ‘ivory’ the tusk of the elephant is generally brought to mind. Yet it is just as appropriate to identify the incisors and canines of the hippopotamus as ivory tusks. Elephant and hippopotamus ivory are both primarily composed of dentine, and furthermore both represent permanent teeth of continuous growth (hence the designation ‘tusk’). In fact, dentine is found in all teeth and is a non-cellular structure with organic and inorganic components. Elephant ivory does not have enamel but is covered by a ridged cementum at the proximal end of the tusk.

Hippopotamus ivory, on the other hand, does have enamel on some areas of the tusk, and cementum elsewhere. It is possible to differentiate between elephant and hippopotamus ivory based on morphological characteristics and structural differences in dentine formation, and these features will be outlined below. Identifying anything beyond this, however, such as which species of elephant the ivory came from, or the environment or region from which the animal came, is not possible using morphological characteristics. Factors such as hardness, color, or size are not precise enough descriptors, nor are they consistent. Further, even if they were, they would be subject to observer bias. Some claim that ivory from the forest elephant (*Loxodonta africana cyclotis*) is harder than that from the bush elephant (*Loxodonta africana africana*). Similarly, hippopotamus ivory is more dense. In the end, though, and disregarding enamel and cementum, all ivory ranks between 1.5 to 2.5 on the Mohs scale (Krzyszkowska 1990: 8, 33; Raubenheimer *et al.* 1998: 641; Raubenheimer 1999: 57).

As mentioned above, the elephant tusk is a permanent tooth of continuous growth, and more specifically, tusks are the upper incisors (or “modified premaxillary lateral incisors”) of the elephant. Each tusk replaces a deciduous tooth called a ‘tush’ when the elephant is six months to one year old. The tusks increase in size with age, although sex, habitat, and the species will influence the size (Krzyszkowska 1990:33; Raubenheimer *et al.* 1995: 571; Raubenheimer 1999: 57). In general, males have longer tusks than females of the same age, and the circumference of the male tusk increases continuously, whereas for the female the tusk ceases to grow in circumference when she reaches an age of 30-35 years (Layser and Buss 1985: 408-410). One researcher in Zambia, Elder (1970), was able to identify correctly the sex of the elephant from 58 out of 60 tusks, based only on the shape of the tusk (cited in Layser and Buss 1985: 407). Another reason for differences in tusk size is that elephants are ‘right-tusked’ or ‘left-tusked,’ so that one tusk is a working tusk and consequently made shorter through greater use (Krzyszkowska 1990:51).

The tusk itself has a tapering pulp cavity in the third closest to the elephant’s head (the proximal end of the tusk). This end is also covered by ridged cementum. The tip (or distal end) is solid and has a smooth outer surface (Krzyszkowska 1990: 33-34; Raubenheimer 1999: 59; see Figure 1). Probably the most identifiable and diagnostic marker of elephant ivory is the “engine-turning” pattern (short for “engine-turned decussating appearance”) visible in transverse cross-sections of the tusk. This pattern is also called “lines of Retzius,” as distinguished from the “lines of Owen” which are the ovoid concentric rings spaced approximately 1 cm apart. Similar to tree rings, the lines



of Owen represent 6-8 years of tusk growth. The regular growth of the tusk is apparent in such “lamellae” or laminations, which are the layers of dentine formation (see Figure 2).

Figure 1: Morphology of the elephant tusk  
(adapted from Krzyszkowska 1990: 32, figure 12).

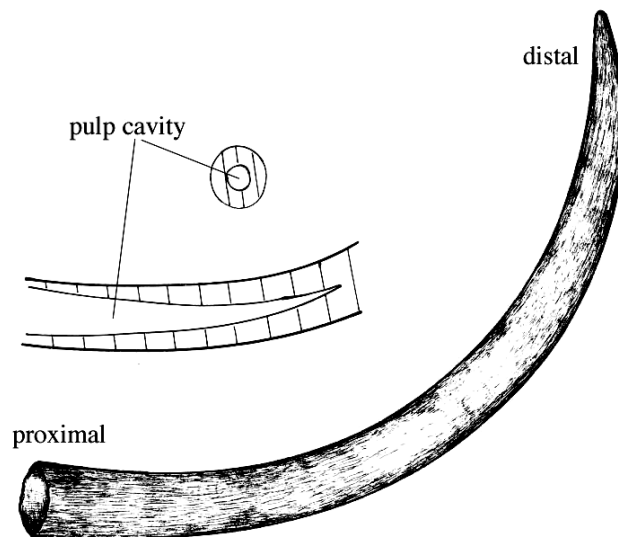
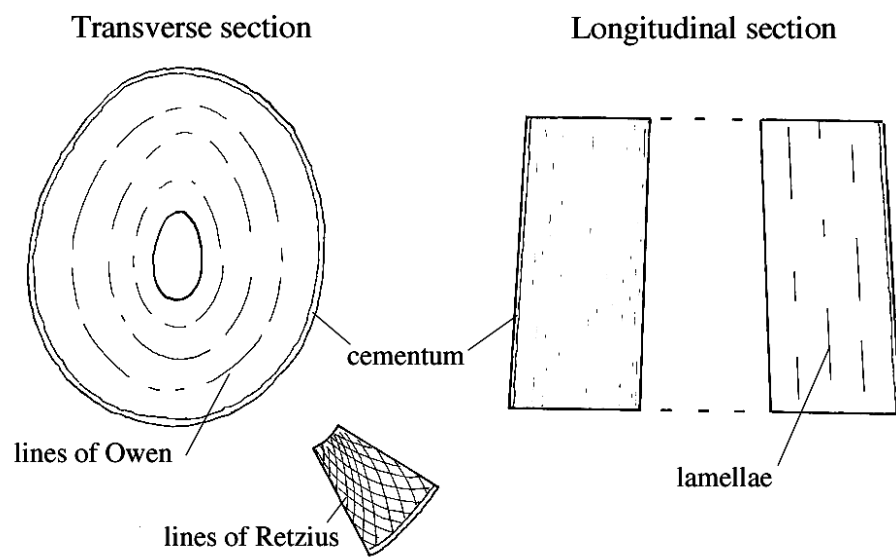


Figure 2: Structural characteristics of elephant ivory: transverse section depicting lines of Owen (left), longitudinal section showing pattern of lamellae (right), and a transverse section showing lines of Retzius (inset, below center)  
(adapted from Krzyszkowska 1990: 35; figure 13).



Dentine in elephant tusks is essentially a biological apatite deposited on an organic matrix of calcified connective tissue, and during its formation over 45 major and trace elements compete for incorporation (Krzyszkowska 1990: 34; Raubenheimer *et al.* 1998: 645; Raubenheimer 1999: 63). Nevertheless, it is not known whether these elements are structural substitutes within the hydroxyapatite crystal or absorbed onto the surface of the crystal (Raubenheimer *et al.* 1998: 645). This mineral (inorganic) composition is largely dependent on the diet of the elephant, although age, habitat, and metabolism of the animal also come into play (Sreekumar and Nirmalan 1989: 1562; Raubenheimer *et al.* 1998: 645; Raubenheimer 1999: 63). This composition is, moreover, stable after formation and not subject to turnover or remodeling, as in bones. A general survey of the range and average elemental composition of Indian and African elephant ivory was conducted by Sreekumar and Nirmalan (1989), and the results are listed in Table 1. The trace elements such as strontium are not reported.

Odontoblasts are the cells responsible for the formation of ivory (dentine). They come from the pulp and move centripetally (toward the axis of the tusk), depositing ivory along the way and essentially forming a cytoplasmic extension. The ivory mineralizes around this extension so that tubules are formed. The circumference of the pulp decreases towards the distal end of the tusk because of the centripetal movement of the odontoblasts. This in turn causes the odontoblasts to be more tightly packed and increases the intercellular pressure. Thus the odontoblastic tubules are crowded closer together (manifest in the dark bands of the ivory). The crowding is alleviated by the odontoblasts moving towards the proximal end, in addition to odontoblastic cell fusion

Table 1: Mineral composition of elephant tusks (mean  $\pm$  SE)  
(data from Sreekumar and Nirmalan 1989: 1561).

Element	African elephant	Asian (Indian) elephant
Sodium (mg %)	0.56 $\pm$ 0.22	0.56 $\pm$ 0.03
Potassium (mg %)	0.11 $\pm$ 0.29	0.19 $\pm$ 0.02
Calcium (mg %)	12.93 $\pm$ 0.29	12.72 $\pm$ 0.75
Magnesium (mg %)	1.58 $\pm$ 0.03	1.67 $\pm$ 0.09
Inorganic phosphate (mg %)	9.88 $\pm$ 0.03	9.53 $\pm$ 0.46
Manganese (ppm)	46.62 $\pm$ 3.53	45.03 $\pm$ 4.60
Zinc (ppm)	28.35 $\pm$ 2.59	34.64 $\pm$ 2.81
Iron (ppm)	167.13 $\pm$ 26.90	202.33 $\pm$ 26.52
Copper (ppm)	1.90 $\pm$ 0.57	12.51 $\pm$ 0.53

and cell death. Once this intercellular pressure is relieved (the light bands in ivory), the odontoblasts progress centripetally again. Morphologically this entire process appears as a regular sinusoidal course followed by odontoblasts (Raubenheimer 1999: 62).

Furthermore, the engine-turning pattern is caused by the intersection of dentinal tubules radiating in clockwise and anti-clockwise arcs from the center of the tusk (Krzyszkowska 1990:34), and visibly evident by the alternating light and dark lines mentioned above.

Fractures in ivory generally occur in the dark bands (Raubenheimer 1999: 59, 63).

Collagen is the principal organic component of elephant ivory, and elephant ivory has less organic content and collagen than bone (approximately 20% organic content in elephant ivory, 25% in bone; and 18% collagen in ivory, 25% in bone) (Krzyszkowska 1990: 50). The collagen molecule itself is composed of three intertwined helical chains of amino acid, particularly of glycine, proline and hydroxyproline. In dentine “the collagen fibrils are embedded in the organic matrix between the dentinal tubules and appear to be preferentially orientated parallel to the long axis of the tooth and

perpendicular to the tubules....[collagen is] found as a meshwork between the dentinal tubules” (Turner *et al.* 2000: 71).

Raubenheimer *et al.* (1998) conducted analyses of the inorganic and organic content of elephant ivory from seven park reserves in South Africa, Botswana, and Namibia. They were able to detect 20 elements in the inorganic fraction, and showed statistically significant differences in some of the elemental concentrations between different regions. Nevertheless, such analyses are not practical for the purposes of this thesis, as they require a very large dataset of elephant ivory from known and bounded geographical locations.

The researchers also found in their analyses of the organic fraction that the ivory from arid regions had significantly lower proline and hydroxyproline content and under-hydroxylation of lysine residues. Thus ivory from Kaokoveld and Etosha are more brittle and hydrolyzed more rapidly than the ivory from other regions (Raubenheimer *et al.* 1998: 641-643; Raubenheimer 1999: 62). Both the Kaokoveld and parts of Etosha have less than 200 mm rainfall per annum, and the elephants inhabiting these regions, known as “desert” elephants, will be discussed in Chapter Eight (see Viljoen 1988). The strength of collagen would be affected by malnutrition, and in particular a vitamin C deficiency. Kaokoveld and Etosha ivory also have high flouride contents, which effectively softens the mineral fraction and weakens the crystal (Raubenheimer *et al.* 1998: 645-646). All the same, hardness, and by extension ‘brittleness,’ is not acknowledged as an accurate criterion to consider in provenancing ivory, and at any rate, would be exceedingly difficult to demonstrate as feasible for ancient ivory due to differential preservation and diagenetic processes.

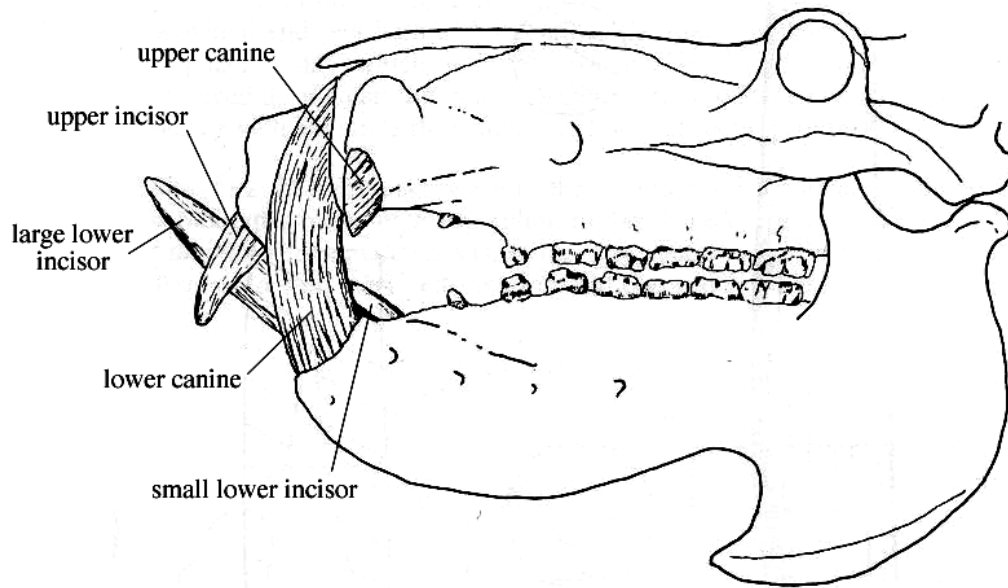
## **Hippopotamus Ivory**

As explained previously, hippopotamus ivory is also composed of permanent, continuous-growth dentine, but is formed differently from elephant ivory (Eltringham 1999: 14; Krzyszkowska 1990: 38, 47). Dentine in hippopotamus ivory is recognized as more dense and whiter than elephant ivory due to a tighter packing of smaller dentinal tubules, and is thus less predisposed to decay. Moreover, whereas the lamellae in elephant ivory are very regular and even, in the hippopotamus they are wavy and discontinuous. The tusk size of the hippopotamus also varies with age and sex.

The tusks of the hippo are depicted below in Figure 3. The large lower incisor and lower canine are, by far, the most frequently utilized hippopotamus ivory. These will therefore be discussed in further detail. The incisors and canines are not used by the hippo for feeding but rather for fighting, and can be quite formidable, especially since the lower canines can approach elephant tusks in size. This fact plus the whiter color and denser structure could have rendered hippopotamus ivory more valuable or sought after than elephant ivory in ancient times, if it were not for the shape of the tusks, which are harder to work with. For instance, the triangular cross-section and curving nature of the lower canine restricts the designs which may be fashioned from it (Eltringham 1999: 14). Inlays, discs, and lids are ultimately the favored uses of hippopotamus ivory (Krzyszkowska 1990: 46).

There are four canines (two larger lower ones and two shorter upper ones) all of which are ridged lengthwise. The upper and lower canines abut and keep each other sharp by grinding together. A large amount of sexual dimorphism affects the canines, so that the lower canines in males may weigh up to 1.5 kg and reach 30 cm in length, with a

Figure 3 : The incisors and canines of the hippopotamus  
(Krzyszkowska 1990: 39, figure 14).



potential upper limit of 70 cm due to a maximum 40 cm length root (Eltringham 1999: 14). Curving and with a triangular cross-section, the lower canine has three faces of different lengths (see Figure 4). The longest faces (A and B in Figure 4) are covered in a very hard (6-7 Mohs) ridged enamel and separated by a natural fracture (ii in Figure 4). The third side (C) faces towards the mouth and is protected only by cementum. The lower canine has a pulp cavity in the proximal end and visible wear on the distal end due to grinding against the upper canine (Krzyszkowska 1990: 42-43).

Other than the basic morphology, another means by which to identify the lower canine of the hippopotamus is through recognition of the lamellae patterns and several other extremely diagnostic features. The transverse cross-section exhibits wavy and discontinuous sub-triangular lamellae, in addition to a “commissure” in the center where the pulp cavity once was. Towards the proximal end of the lower canine, where the pulp cavity has yet to close up, the commissure looks like an angled crack. The pulp cavity, as

Figure 4: Characteristics and morphology of the hippopotamus lower canine.  
Left tusk depicted (adapted from Krzyszkowska 1990: 43).

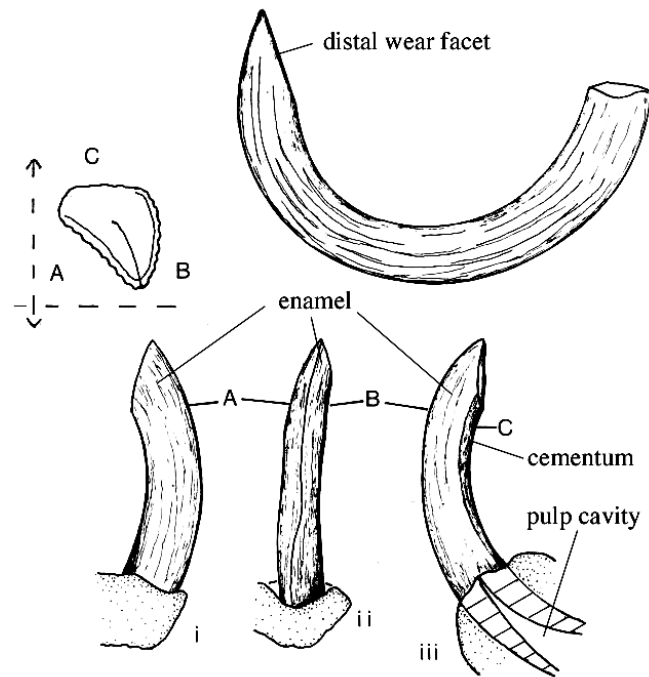
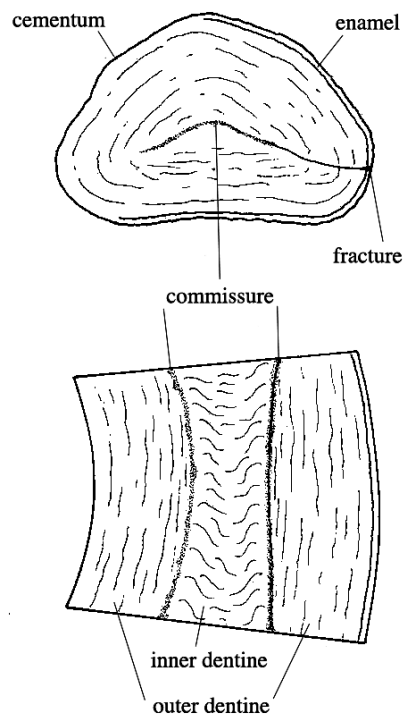


Figure 5: Left tusk of the hippopotamus lower canine in transverse section (above) and longitudinal section (below) (adapted from Krzyszkowska 1990: 45, figure 18).



for the elephant, is where the dentine is formed. Figure 5 gives an excellent illustration of the lamellae and commissure in the transverse of the hippopotamus lower canine. The center of the longitudinal section reveals the ‘inner dentine’ which is the most recently formed dentine. Compared to the outer dentine it often looks marbled and somewhat translucent, with a sometimes greenish color (Krzyszkowska 1990: 44).

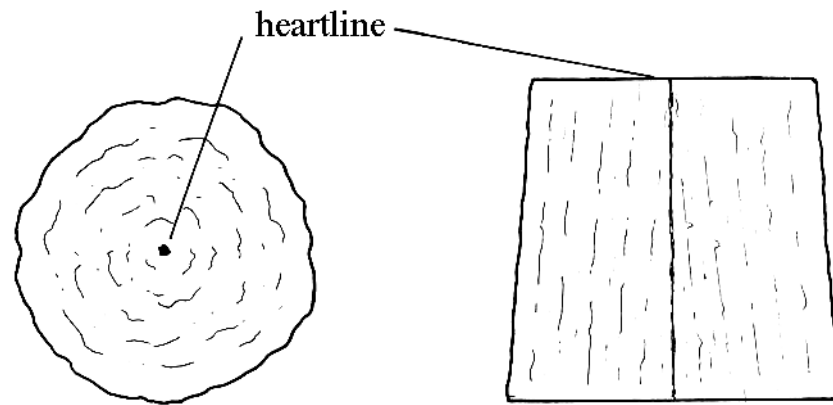
There are eight incisors of the hippopotamus, two of each type for a total of four types in each jaw (see Figure 3): a larger lower incisor, a smaller lower, a larger upper, and a smaller upper (not shown). The incisors are longer in the lower jaw and can reach 17 cm in length from the gum, and 6 cm in diameter. They project outwards and slightly upwards, with a tapering pulp cavity in the proximal end. The outer incisors in both jaws are furthermore larger than the inner incisors. They all possess blunt tips, but the small incisors have a more marked distal wear facet. Unlike the canines, the incisors are straight and have a sub-circular cross-section, where discontinuous and wavy concentric lamellae are visible as well as the “heartline” running through the center. However, the heartline is usually difficult to identify on artifacts made of hippo incisors (see Figure 6). The longitudinal section shows the lamellae running parallel with the surface and curving toward the distal end of the heartline (Eltringham 1999: 14; Krzyszkowska 1990: 39-42).

## **Conclusion**

In conclusion, there are obvious visual differences in elephant and hippopotamus ivory which may be used for identification purposes. There are, moreover, advantages and disadvantages to each type of ivory. Elephant ivory offers larger pieces for artisans to carve, and thus more flexibility in design. Hippopotamus ivory, on the other hand, is



Figure 6: Hippopotamus incisor showing patterns of lamellae in transverse section (left) and longitudinal section (right) (adapted from Krzyszkowska 1990: 41).



denser and whiter. The pulp cavity, or lack thereof, will also influence which final product is fashioned from the ivory. The specific artifacts often recovered of each type, in addition to a discussion of the workshop materials, will be discussed further in Chapter Five. Again, it is worth stressing that while the characteristics of hippopotamus and elephant ivory summarized above are useful for distinguishing between the two types, there are no reliable visual means for recognizing Asian elephant ivory versus African elephant ivory, nor for differentiating between ivory from different regions. The studies by Raubenheimer (1999, 1998, 1995) do not demonstrate basic elemental or amino acid identification as a dependable procedure for ivory from archaeological contexts.

### **Chapter 3**

#### **The Archaeological, Historical, and Osteological Evidence for the Provenance of Hippopotamus Ivory in the Late Bronze Age Eastern Mediterranean**

The hippopotamus (*Hippopotamus amphibius*) was utilized for ivory as much as the elephant, perhaps even more so in some times and places. Moreover, much of the ivory visually identified offhand as elephant could very well be hippopotamus ivory. The raw ivory cargo of the Uluburun ship supports this hypothesis, as the majority of the raw ivory is in fact hippopotamus ivory. Unfortunately not as much is known about the hippopotamus ivory trade as the elephant ivory trade, but the more specific diet and ecological requirements of the hippo narrows the geographical areas capable of supporting a trade in hippopotamus ivory. In Egypt the hippopotamus was the embodiment of one of the gods in the pantheon, and the word hippopotamus comes from the Greek for “river horse.” The average height and weight of the hippopotamus is 140-160 cm and 1100-2600 kg, respectively, and the animal has a life-span of approximately 40 years (Grubb 1993: 41; Eltringham 1999: 5).

#### **Present Distribution**

The hippopotamus once inhabited a much broader geographical area than it does today. Eltringham (1993; 1999) provides the two maps below which outline the approximate distribution of the hippopotamus today (Figure 7), and circa 1959 (Figure 8), the latter of which utilized data provided by J. Sidney (1965). Immediately apparent is the drastic reduction in the area where hippos dwell, and presumably a drastic reduction in their numbers. This is perhaps a modern phenomenon, but could be a process which has been going on since humans began to appropriate land for agriculture and

Figure 7: Current distribution of *Hippopotamus amphibius*  
(adapted from Eltringham 1993: 45).

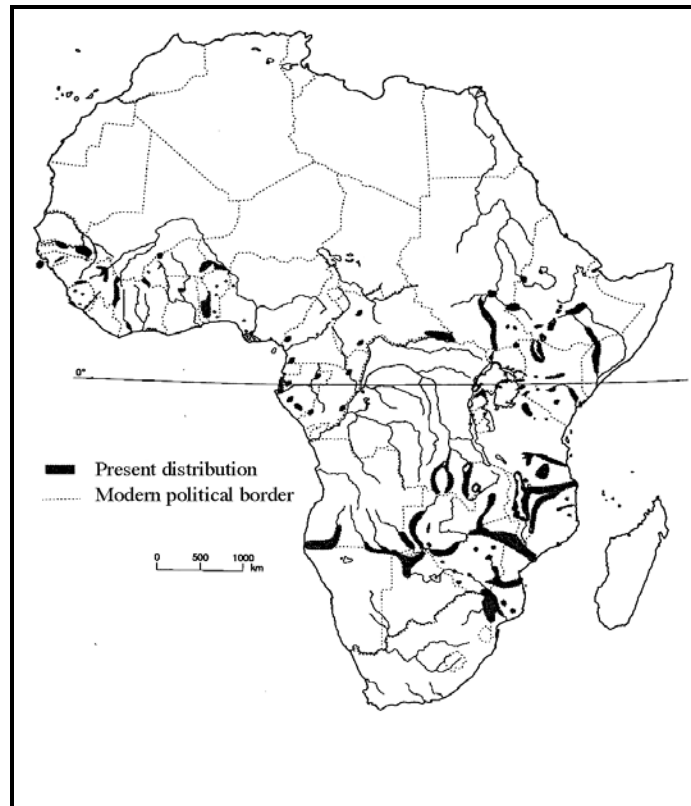
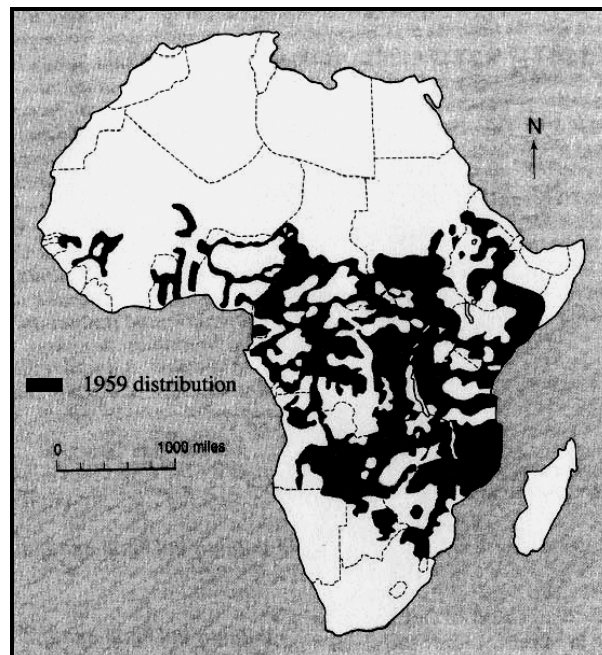


Figure 8: Distribution of *Hippopotamus amphibius* circa 1959  
(adapted from Eltringham 1999: 135).



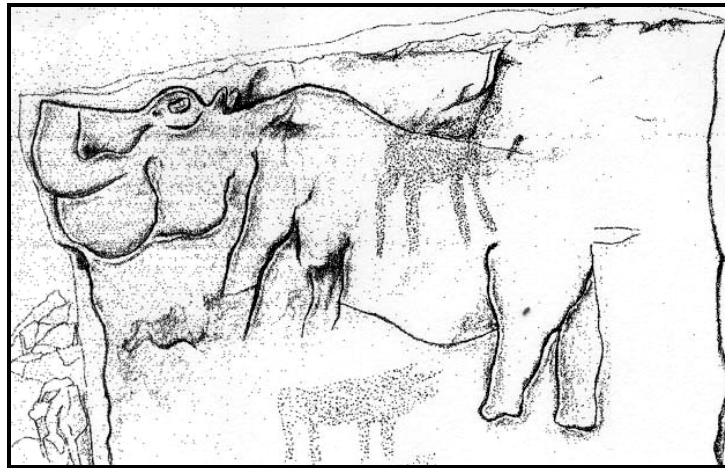
pastoralism. Today most of the hippos in Africa are found in the east along the White and Blue Niles, Sobat River and the Jur of southern Sudan, along other tributaries of the Nile, within several national parks in this area, as well as the Sudd. In the west of Africa the hippopotamus may be found in estuarine habitats, along rivers close to the coast, and in the sea in the Archipelago of Bijagos off the coast of Guinea Bissau (Eltringham 1993: 44-46). In the Late Bronze Age, however, the hippopotamus would have been present throughout sub-Saharan Africa in all areas where their ecological requirements were met.

### **Prehistoric Distribution**

Middle to Late Miocene fossils of hippopotamus recovered from East Africa support the view that the hippopotamus originated in Africa. The hippopotamus initially spread out of Africa in the late Miocene, and dispersed throughout Asia and Europe by the Pleistocene, with dwarf (*Phanourios minor*) and pygmy (*Phanourios minutus*) species colonizing Cyprus (Eltringham 1999: 40-41). *Phanourios minutus* persisted on Cyprus and was demonstrated to coexist with, and possibly be rendered extinct by, humans. The 8500 B.C. (uncalibrated) site of Akrotiri-Aetokremnos yielded over 200 disarticulated individuals in association with early or pre-Neolithic cultural remains (Simmons 1991, 1993; Reese 2001).

The modern species of *Hippopotamus amphibius* is featured in rock paintings and engravings in the high plains and mountains of the Sahara, suggesting that the Sahara was once watered. One example from Djanet in the Tassili n'Ajjer Mountains depicts a hippo hunt and dates from 2000 to 3000 BC, while the largest example comes from Tilemsin,

Figure 9: Rock engraving of a hippopotamus (adapted from Faleschini 1999: 142)



located near the western border of Libya in the Messak Mellet district (see Figure 9) (Faleschini 1999; Eltringham 1999).

### **Archaeological Evidence for the Hippopotamus in the Eastern Mediterranean**

The two most probable sources of hippopotamus ivory in the eastern Mediterranean during the Late Bronze Age are Syro-Palestine and Egypt. Osteological evidence suggests the hippopotamus dwelled in swampy areas in Syro-Palestine, including the Amuq plain and Orontes Valley, until at least the Early Iron Age (see Figures 10, 11, 12, and 13 for location of the Amuq and Orontes valleys) (Krzyszowska 1990: 20).

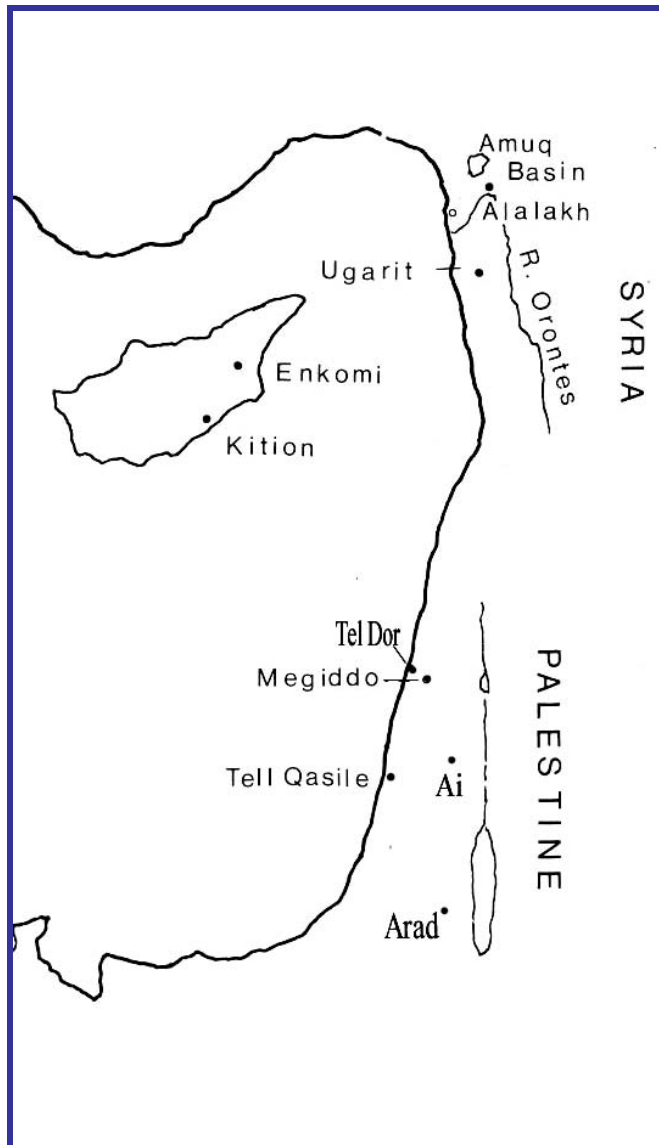
Osteological evidence offers substantial proof for the presence of the hippopotamus, specifically post-cranial remains. Crania or mandibles could have been brought from elsewhere, although it seems highly unlikely, and moreover such a phenomenon would expectedly result from short-distance exchanges (Karali-Yannacopoulos 1993: 58-59). With this in mind, the distribution of hippopotamus

remains in the Syro-Palestinian region and Egypt, minus the canines or incisors which could have been traded into the region, shall now be considered. Reese (1998) serves as the fundamental publication for the osteological evidence, due to his thoroughness and attention to detail, and many of the citations below are taken from this work. Further, workshops and worked hippopotamus ivory are covered together in Chapter Five, because often both hippopotamus ivory and elephant ivory are present in the same workshop, or the materials of artifacts are misidentified or elude identification. Worked material and workshops also represent separate stages in the exchange system.

### ***Syro-Palestine***

The only definitive Chalcolithic (4<sup>th</sup> millennium B.C.) osteological evidence has been recovered from Qatif on the Sinai coastal plain (a premolar and an astragalus) (Reese 1998: 140). The Early Bronze Age (3<sup>rd</sup> millennium B.C.) is represented by Tel Aphek on the Yarkon River, Tel Dalit, Tell Gath (Tel Erani), and Tell Sukas (northern Syria). However, the excavator of Tell Gath maintains that the humerus found there “must have been brought as an offering” (Yeivin 1959: 417). EBA finds in the ecological setting preferred by the hippopotamus include mandibles located near Nahal Hataninim/Kebara Swamp, and near Tell Qasile on the Yarkon River (northern Tel Aviv) (see Figure 10 for location of Tell Qasile). From the Middle Bronze Age came a single cuboid from Tel Nagila, in addition to several more remains reported from Orontes River sites in Syria from about 1500 B.C. (Bodenheimer 1960: 52). A jaw with teeth from Tel Dor dates to MBA or later, and additional finds from Tel Dor include a molar (11<sup>th</sup>-8<sup>th</sup> century B.C.) and an undated humerus (See Figure 10 for location). Tell Sukas also

Figure 10. Location of the Amuq Valley, Orontes River, and some major sites where hippopotamus faunal remains and ivory have been recovered (adapted from Krzyszkowska 1990: overleaf).



yielded a LBA or Early Iron Age (EIA) molar. A great deal of EIA hippopotamus bones and teeth came from Tell Qasile, including a metacarpal bearing a cut marks. Also EIA in date is a radius/ulna from Tell Garisa (Reese 1998: 141).

Hippopotamus teeth that could have been traded into the region include an unworked incisor (misidentified as an elephant tusk) from Chalcolithic Bir es-Safadi,

near Beersheba. An EB I lower right canine was found outside the sanctuary at Ai, and two EB II lower incisors hailed from Arad in the northern Negev (see Figure 10 for the location of Ai and Arad). The Late Bronze Age is well represented at Ras Shamra (Ugarit), whereas Minet el-Beida has just one canine. Iron Age cases come from Tell Jalul (one upper canine) and Zincirli (one canine tip) in the Syrian Amuq (now Turkish Hatay). Tell Qasile, in addition to the skeletal material discussed above, had one lower canine and an incisor from the Iron Age. Sidon contained two molars “probably Pleistocene or Holocene in date.” Other “probably Pleistocene or Holocene” material came from Tell Dan, Tell Gezer (tooth and fragment of a canine), Tell el-Hesi, Rabbah (molar), and Chekka (molar), located 10 km from Tripoli (Reese 1998: 140-141).

Thus the LBA is not well-represented by osteological evidence, but this seems to be a mere blip in the overall record, being preceded by and preceding ample evidence. Tusks, on the other hand, are most representative in LBA Ras Shamra (Ugarit), and directly linked to ivory workshops in this renowned entrepot. A significant proportion of the ivory recovered from the ivory workshops in Ugarit (dating to the fourteenth and thirteenth centuries) were from hippopotami rather than elephants (Krzyszkowska 1990: 20; Bass 1997: 161; Reese 1998: 141). Overall, the coastal plains and river valleys, including the Amuq region and the Orontes River, were the most probable sources of hippopotamus ivory in the Levant. See Figures 12, 13, and 14 for detailed maps of the Amuq and northern Orontes region, including the locations of Middle and Late Bronze Age sites in the area.



Figure 11: Location of the Amuq Plain (adapted from Yener 2001: figure 1)

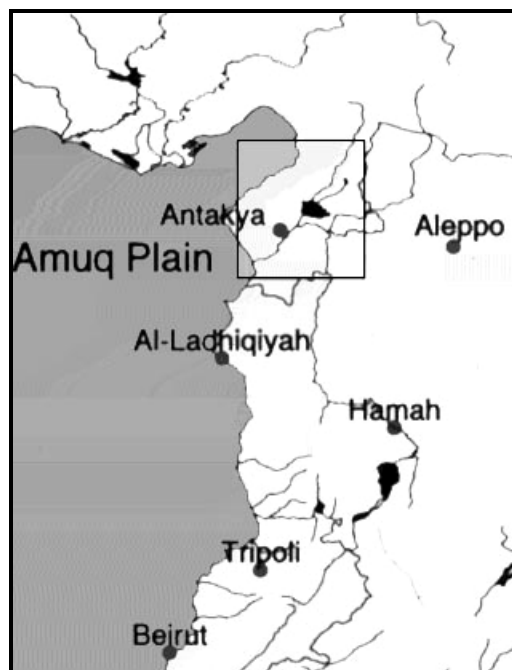


Figure 12: Geophysical map of the Amuq Valley, looking northeast from the Mediterranean coast. The geophysical characteristics of the region are well suited for elephants and hippopotami (adapted from <http://www-oi.uchicago.edu/OI/PROJ/AMU/Amuq.html>).

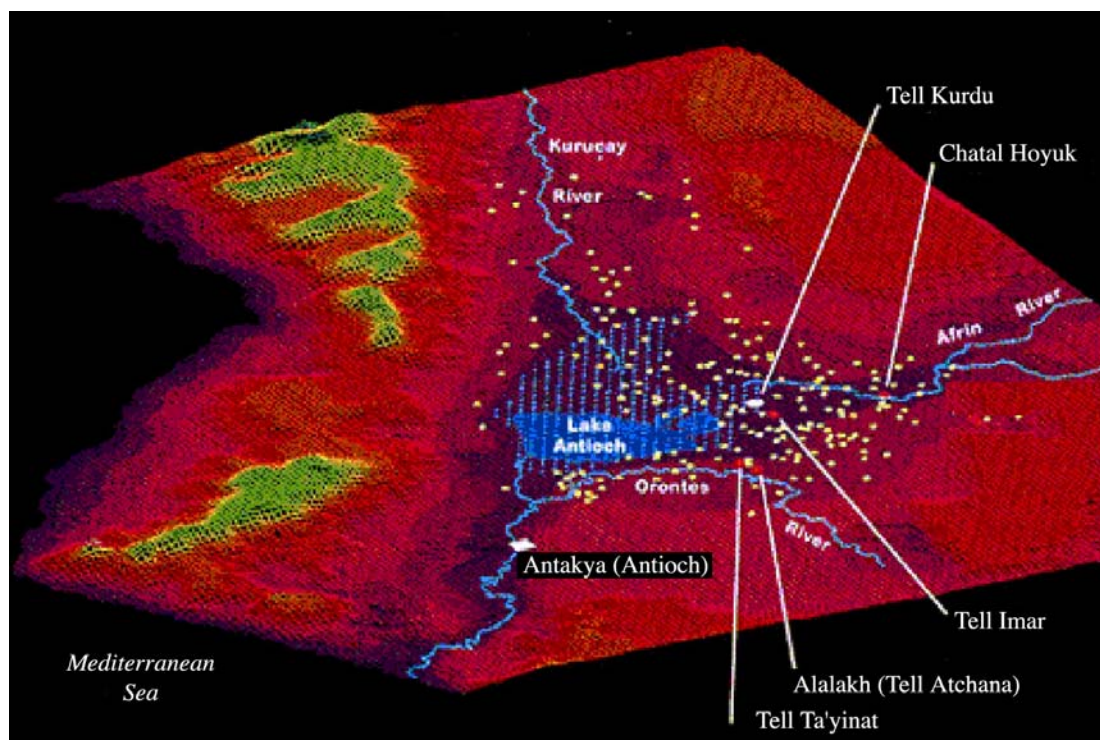
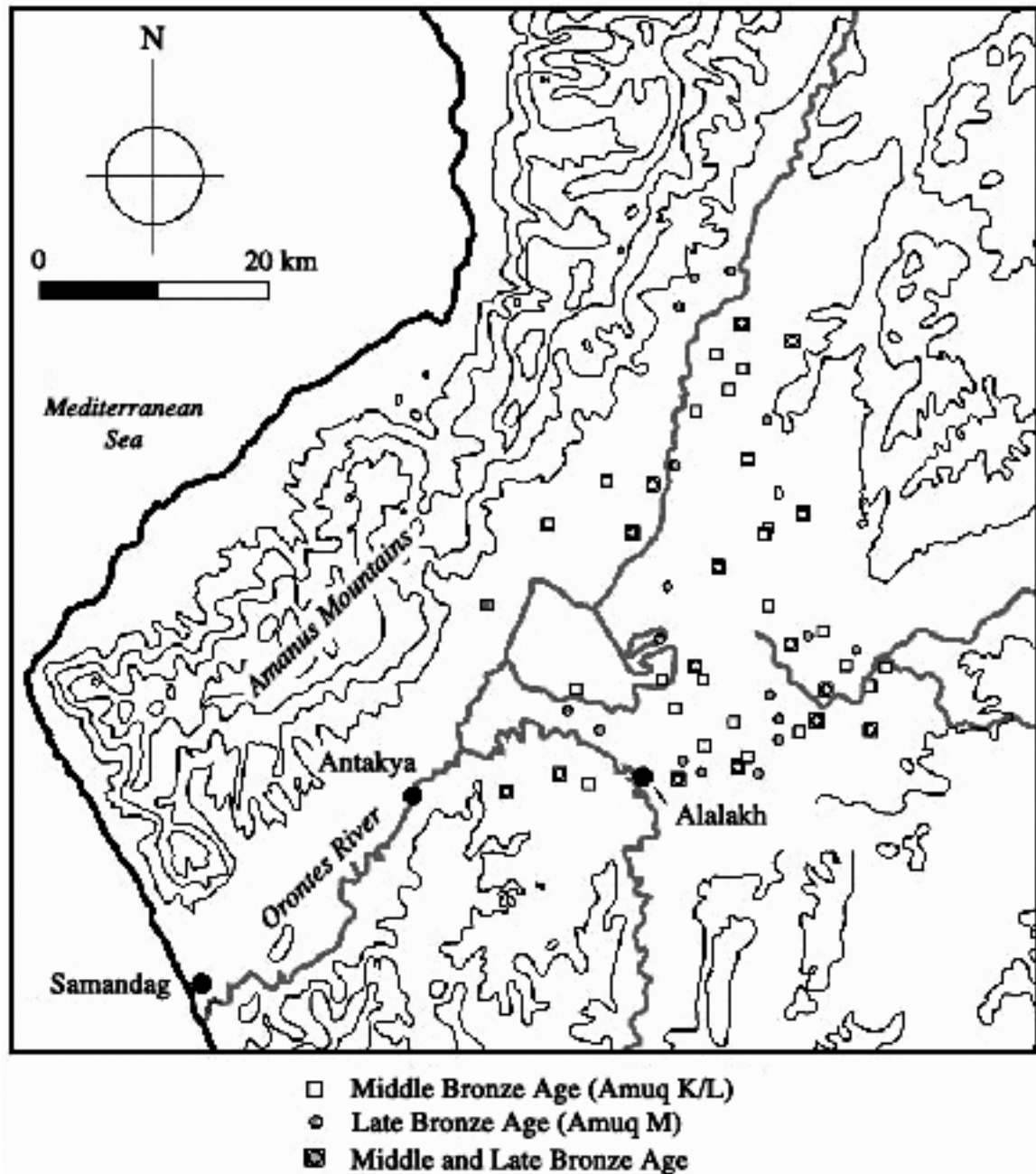


Figure 13: The distribution of Middle and Late Bronze Age sites in the Amuq Valley.  
Tell Atchana is ancient Alalakh (adapted from Yener 2001: figure 2).

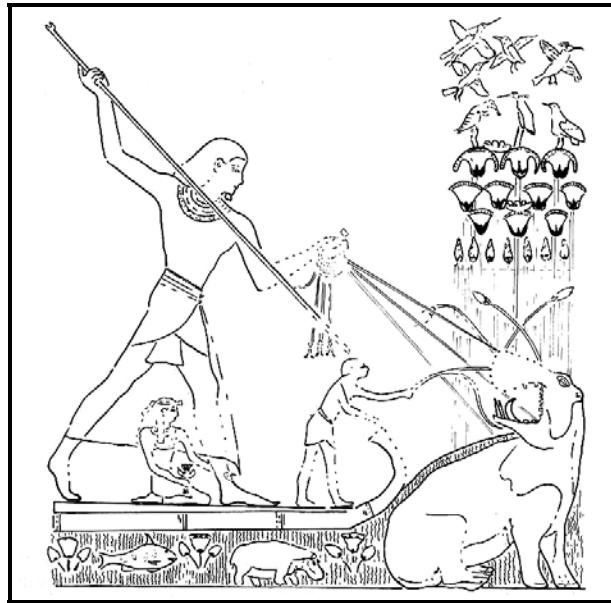


## *Egypt*

The hippopotamus was furthermore well-known in Egypt, as evidenced by tomb paintings (see Figure 14), and its ivory was widely used, especially prior to and during the Old Kingdom. The hippopotamus would have inhabited the Nile Delta in addition to those regions up-river. It went extinct in the delta in the seventeenth century A.D. and was last witnessed in Upper Egypt in the 20th century (Krzyszkowska 1990: 20).

Strangely enough, there is little in the way of unworked osteological evidence from Egypt, despite the fact that the hippopotamus is native to Egypt. In all there is one metacarpus from Late Predynastic (c. 2900 B.C.) Maadi near Cairo, a first phalanx from Gizeh dating Ist-IVth Dynasty (c. 3100-2494 B.C.) and six IIIrd to VIth Dynasty (c. 2686-2181 B.C.) samples from Elephantine. Approaching the time period of interest to this thesis are several examples from Tell el-Dab'a and North Karnak (Upper Egypt) circa 1600-1550 B.C., whereas contemporary with or later than the Uluburun wreck are numerous hippopotamus bones and teeth from XIXth Dynasty (c. 1306-1195 BC) Matmar and Qau in Middle Egypt (Reese 1998: 140). Moreover, in the southern Sudan the site of Debbat El Eheima (c. 1600-1000 B.C.), located on the western bank of the White Nile, produced a canine fragment, jugal tooth fragment, a carpal and two sesamoids in addition to several more fragments of hippopotamus bone (Gautier and Van Neer 1997: 55). The habitat of this area, a Nilotic riverine environmental zone which receives 500 mm annual rainfall, is undeniably hippopotamus territory, and the osteological evidence merely reaffirms this supposition. Truly Egypt, along with Syria, must be considered a chief candidate for the source of the hippopotamus ivory on the Uluburun.

Figure 14: 18<sup>th</sup> Dynasty Egyptian tomb relief from the reigns of Hatshepsut and Tuthmosis III (adapted from Krzyszkowska 1990: 21, figure 6).



As for worked ivory from Egypt, common artifacts carved explicitly from hippopotamus ivory include “wands” and “knives” of lower canines from the XI<sup>th</sup> to XVIII<sup>th</sup> Dynasties (c. 2133-1306 BC), and carved canines characterized by a hand or Hathor head terminal from c. 1900-1150 BC. Qau also has a large collection of XVIII<sup>th</sup> Dynasty worked hippopotamus ivory, but these may have been carved elsewhere, outside of Egypt (*cf.* Lilyquist 1998: 27, 30).

### *Cyprus*

As mentioned above, pygmy hippopotami were known on Cyprus, but in all likelihood died out shortly after the island was colonized by humans, which is too early for a consideration of the Late Bronze Age distribution of the hippopotamus (Krzyszkowska 1990: 12). All of the Bronze Age to Early Iron Age hippopotamus remains from Cyprus, save one molar, are incisors or canines. The molar was recovered from a Late Cypriot IIIA (c. 1190-1125) domestic context in Kition, and represented a

young individual, six to ten years old (Reese 1998: 140). Kition was a Phoenician settlement and major trade center, and the young hippo could very well have been brought over to Cyprus from Phoenicia, or on a Phoenician ship from Egypt or Syria. At any rate, Cyprus is unlikely to be a source of hippopotamus ivory in the Late Bronze Age. One molar is not enough to argue convincingly that hippos existed in Cyprus. The overwhelming majority of the hippopotamus material on Cyprus is in the form of ivory, including unworked and worked, and will be considered alongside the evidence for Cypriot ivory workshops in Chapter Five.

## **Conclusion**

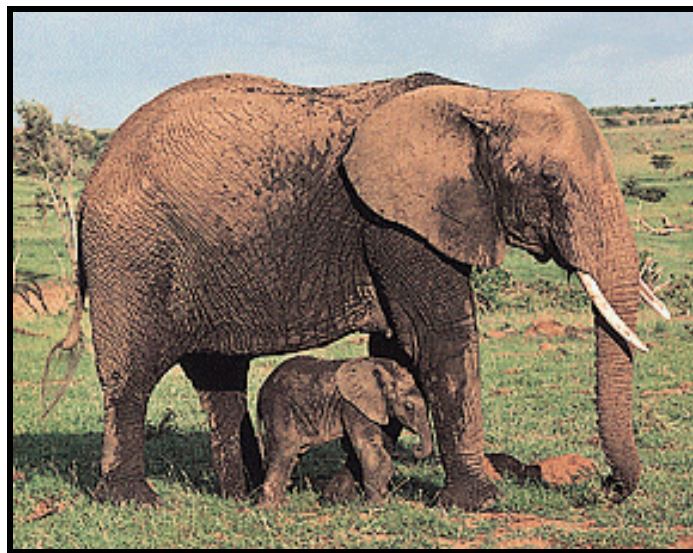
Thus if the osteological evidence is considered alone, Syro-Palestine would be the most likely source of hippopotamus ivory. The general dearth of osteological remains in Egypt is puzzling and it is quite possible that Egyptians did not use hippopotamus ivory, preferring instead to carve from elephant ivory. Perhaps hippopotamus populations were already dwindling rapidly by the New Kingdom, and were more likely to be found in regions of Upper Egypt than Lower Egypt. The tomb paintings in and of themselves do not argue for a specific location, and it could be that hippopotamus hunting was conducted primarily in Upper Egypt. The hippopotami certainly dwelled further up-river in the southern Sudan, and survive still in the tributaries of the Nile.

## Chapter 4

### The Archaeological, Historical, and Osteological Evidence for the Provenance of Elephant Ivory in the Late Bronze Age Eastern Mediterranean

Like the hippopotamus, there are two main areas from which the elephant ivory could have been obtained in the eastern Mediterranean in the Late Bronze Age: Egypt and Syria. However, the reconstruction of the trade in elephant ivory is complicated by the fact that Egypt acted as an intermediary, acquiring elephant ivory from the lands to the south (sub-Saharan Africa), and possibly to the west. Indeed elephant ivory from North Africa (with or without Egypt as an intermediary) is just as viable as an alternative provenance. Furthermore, instead of dealing with one species, as in the case of the hippopotamus, two species of elephant must be considered: the African elephant (*Loxodonta africana*, see Figure 15) and the Syrian elephant, the western version of the Asian elephant (*Elephas maximus*). There are also two sub-species of the African elephant: the Forest (*Loxodonta africana cyclotis*) and larger Bush (*Loxodonta africana africana*) elephant.

Figure 15: The African elephant (adapted from Macdonald 1984: 455)



## **Part I: The African elephant**

### ***Present Distribution and the Question of Sub-species***

The population of elephants has been greatly reduced in the past century due to habitat degradation, the trade in ivory, and other forms of human interference. Figure 16 depicts the current distribution for the African (*Loxodonta africana*) and Asian elephant (*Elephas maximus*). Elephants once inhabited all of Africa, but today are limited to small regions south of the Sahara (Scullard 1974: 24). The most northerly African elephant population is in Mauritania, West Africa (north of latitude 17°10' up to the heights of Tijelat) (Scullard 1974: 25; Krzyszkowska 1990: 29). This population may be the remnants of elephant populations spread throughout North Africa before the severe desertification of the Sahara, and attested in classical times north of the Atlas Mountains. What is more, Scullard (1974) believes the population in present-day Mauritania and the ancient North African population were Forest elephants (*Loxodonta africana cyclotis*), not Bush elephants (*Loxodonta africana africana*).

Indeed there is much discussion in the literature on whether the elephants utilized in ancient times for ivory were Forest or Bush elephants. Krzyszkowska (1990: 16-17) and Scullard (1974: 24-26) both conclude that of the African elephants only the Forest elephant was known to the eastern Mediterranean region in classical times, although the argument is based on negative evidence and from classical sources who only knew one type of African elephant. See Figure 17 for the present distribution of Forest and Bush elephants in Africa, and the regions exploited for ivory during classical times according to Scullard (although in the following discussion this region will be significantly expanded).



Figure 16: Present distribution of the African and Asian elephant (adapted from Macdonald 1984: 452).

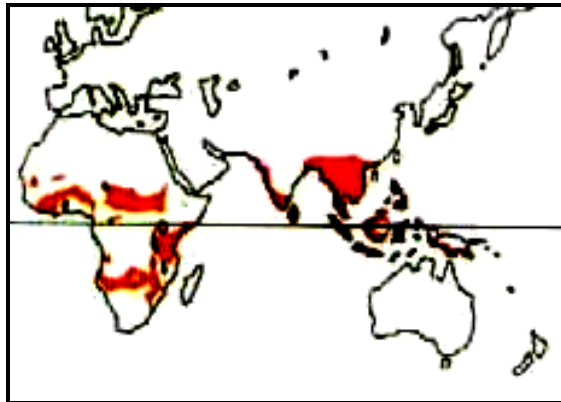
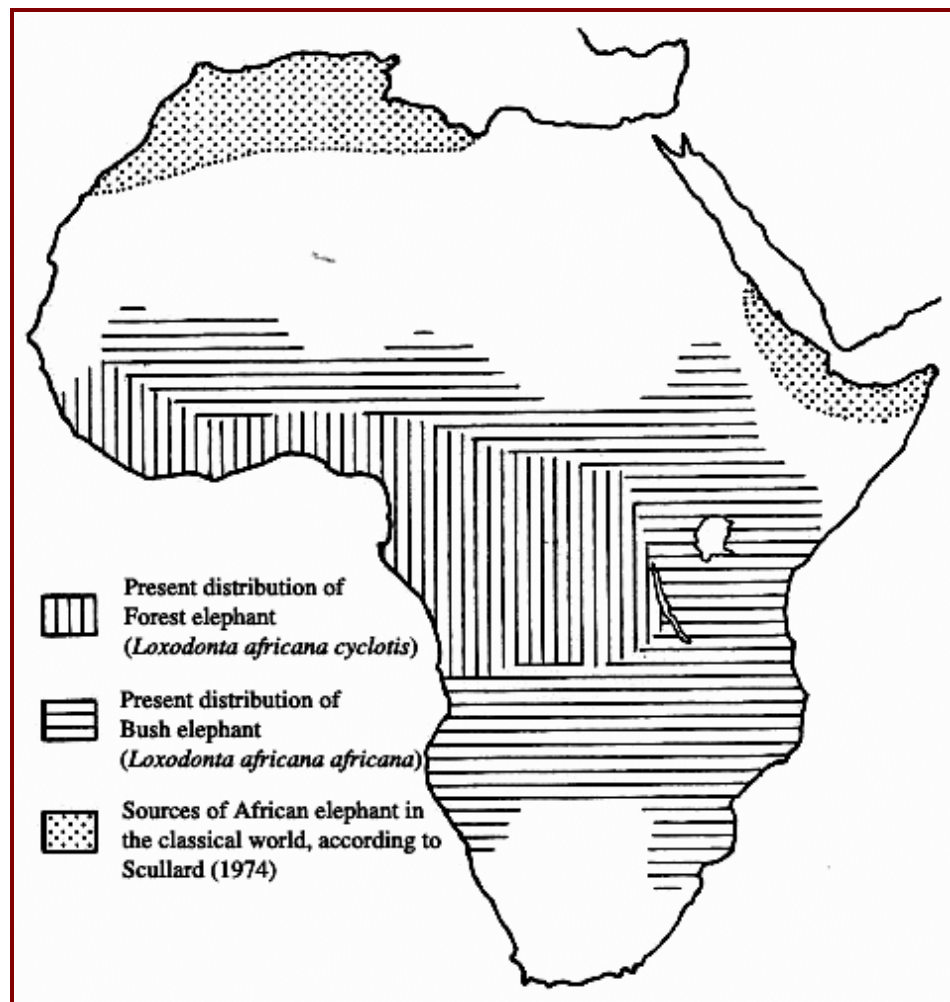


Figure 17: Distribution of Forest and Bush elephants in Africa, in addition to Scullard's reconstruction of the provenance of African ivory, particularly during the Hellenistic and Roman times (adapted from Scullard 1974: 25).



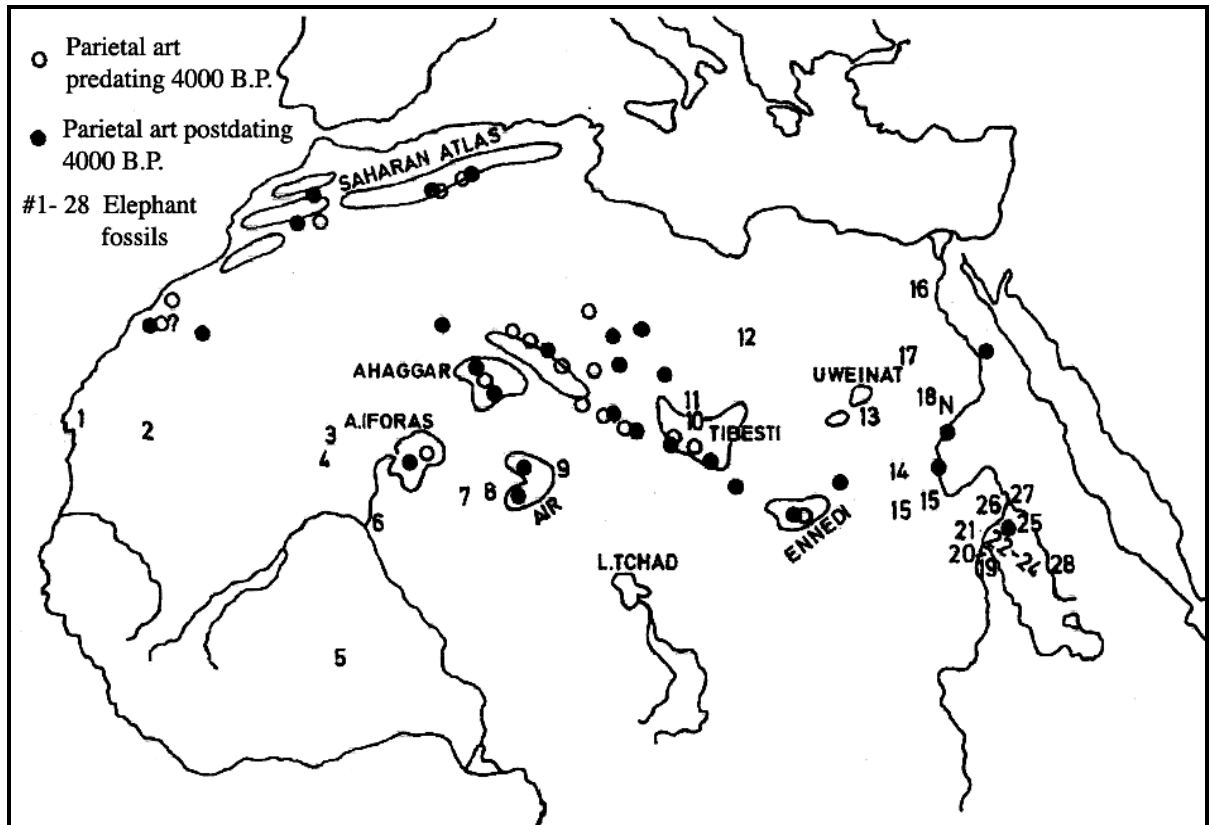


The only differences between the two elephants which concern the present study are in the tusks, which are larger and more curving in the Bush elephant, whereas in the Forest elephant the tusks are smaller and straighter (and some claim the ivory is harder) (Krzyszkowska 1990: 17). These differences have been noted in modern populations, and since smaller tusks can be the result of inbreeding, and furthermore since tusk size varies depending on the age, sex, and nutrition of the animal (Karali-Yannacopoulos 1993: 58), it cannot be assumed that these differences were applicable to the past. The discussion is, moreover, a moot one, since it is not possible to discern between the two species, or sub-species, from elephant ivory in the archaeological record (*cf.* Krzyszkowska 1990: 12), nor is the discussion relevant in the case of sub-species. Distinguishing between species and sub-species is more an academic exercise than a necessary one. Only *which* regions were exploited is pertinent to the present investigation.

### ***The African Elephant in Prehistoric North Africa***

The earliest evidence for elephants in the northern half of Africa is the subject of a comprehensive article by Gautier *et al.* (1994). The article was prompted by the discovery of an elephant skull in Nabta Playa, a drainage basin in the south of the Western Desert of Egypt, located approximately 100 km west of Abu Simbel. The individual was young when it died, about four to eight years old, and dates to “several tens of thousands” of years before present. The authors compiled an inventory of all Holocene elephant finds in the Sahara and adjacent Sudano-sahelian belt, excluding worked ivory (see Figure 18 for a map illustrating this inventory). Literature on the

Figure 18: Approximate location of the fossil and parietal art occurrences of *Loxodonta africana* in North Africa: N) Nabta, 1) Chami, 2) Oum Araouba, 3) Taoudenni basin, 4) Hassi-el Abiod, 5) Ntereso, 6) Karkarinchinkat, 7) Tamaya-Mellet, 8) Arlit, 9) Tin Ouaffadene, 10) Tibesti, Enneri Direnao, 11) Tibesti, Enneri Bardague, 12) Wadi Behar Belama, 13) Jebel Uweinat, 14) Wadi Shaw, 15) Wadi Howar, 16) Fayum, 17) Dakhleh Oasis, 18) Bir Kiseiba, 19) Shabona, 20) Khartoum Hospital, 21) Esh Shaheinab, 22) Kadero, 23) Saggai, 24) Geili, 25) Shaqadud, 26) El Kadada, 27) El Damar, Abu Darbein, Aneibis, 28) Ghasm-el-Girba (adapted from Gautier *et al.* 1994: 15, figure 10).



Maghreb was inaccessible or nonexistent, and the area is represented by few finds, but historical evidence from the Iron Age and later suggests elephants roamed the Maghreb into the first millennium A.D. These would have been the elephants Hannibal and the Carthaginians utilized in the Punic wars (Gautier *et al.* 1994: 13).

The authors conclude that the faunal and graphic art records agree well with one another. While the distribution may reflect the disproportionate levels of archaeological research or preservation in each region, generally it may be said from the number of finds

in Egypt and northern Sudan that the elephant was much more frequent in the Sudano-sahelian belt, with low population densities in the Sahara. Thus the elephant in North Africa not only lived in those areas bounding the Sahara, but in the Sahara as well, and what is more, was not restricted to only the mountainous regions of the Sahara.

Furthermore, elephants persisted in the Sahara until the second and maybe even the first millennium B.C., although the range was probably fragmented and gradually reduced to the point of extinction by increasing aridity, deterioration of the environment, and human activities (Gautier *et al.* 1994: 7, 16).

Another point expounded upon was that the occurrence of elephants in the Sahara should not be taken as evidence of “lush prehistoric landscapes” in the Sahara, because such a conclusion would be an “underestimation of the ecological tolerance of elephants” (Gautier *et al.* 1994: 8). Here the authors cite the studies by Viljoen (1989 and 1990, see also 1988) on elephants in very arid conditions to suggest that North African elephants adapted similarly to the Namib Desert elephants, and could survive in areas with limited or almost no rainfall and exploit the wadi system (Gautier *et al.* 1994: 16). The elephants of the Namib Desert are discussed further in Chapter Eight.

### ***Egypt and its Nubian Territories as a Potential Source of Ivory***

As for the Nile Valley in Nubia and Egypt, prehistoric elephant remains have not yet been recovered, although this could be ascribed to poor preservation from the annual flooding and dense human population (Gautier *et al.* 1994: 13). Krzyszkowska (1990: 17) agrees that the elephant was absent in Egypt, but reconstructs a range which includes parts of Mauritania and Libya in the west of Africa, and Ethiopia, Eritrea and Somalia in

the east. As argued above, this range was probably much more extensive, including the North African coast, Sudano-sahelian belt, and the Sahara. Thus Egypt would have imported ivory from elsewhere, and much of the evidence for ivory imports points to the south. The Tomb of Rekhmire (vizier of Thutmosis III) from the New Kingdom depicts four different peoples bringing tusks: Nubians, Syrians, men of Punt, and the Keftiu. The Nubians and men of Punt were both from the south where elephants were plentiful, and the “Keftiu” have been interpreted as people from Crete, who incidentally did not have local sources of ivory (Krzyszkowska 1990: 14,19; see part II of this chapter for a discussion of the Syrian tribute). The fourteenth century B.C. tombs of Meryra II and Huya also exhibit men from the south bringing elephant tusks, ostrich eggs, and ebony (Bass 1997: 160), all items recovered from the cargo of the Uluburun. Clearly the archaeological evidence from these tombs can only relate *some* of Egypt’s imports, and little is revealed about the mechanisms of trade or volume.

Turning to the historical evidence from Egypt only complicates the issue, as Egypt was importing *and* exporting ivory. The Annals of Tuthmosis III list eighteen elephant tusks among the tribute from Syria-Palestine c. 1439 BC (Hayward 1990: 103). More interesting, however, are the Amarna letters. This collection of clay tablets serves as an invaluable record of the fourteenth century reign of Akhenaton and his queen Nefertiti, and relates the royal correspondences between Akhenaton and other rulers or vassal kings. Alašia (EA 40) and Mittani (EA 22) are recorded as sending ivory or ivory objects to Egypt, probably as some sort of gift-exchange between rulers. Worked ivory is meanwhile recorded as sent to King Tarkhundaraba of Arzawa (EA 31:37) and to Kings Kadashman-Enlil I and Burnaburiash II of Babylon (EA 5:20; 14; col. III 75-77, col. IV

1-19, 60, 61), while there is additionally a letter from Burnaburiash asking for worked ivory (EA 11: Rev. 10-11) (Hayward 1990: 104; Bass 1997: 160). Hayward (1990: 104), however, points out that in the Amarna letters and other historical texts ivory was imported to Egypt, but only worked ivory was exported. Egypt's role as intermediary therefore requires more precise methods for ascertaining the source of ivory in the eastern Mediterranean.

### ***Nubia and Punt***

The land to the south of Egypt from which elephant ivory came was known as Punt and Meroe to the Egyptians and corresponds roughly to Somalia and eastern/southeastern Sudan, respectively (see Figure 19 for map of region south of Egypt). An expedition by Sesostri I (ruled c. 1971-1928) to Nubia is recorded to have brought back a live elephant, and the bones of a male elephant were recovered from a Ramsesside royal residence at Piramesse. Indeed, in the New Kingdom tusks were shipped down the Nile with increasing frequency and Queen Hatshepsut sent an expedition to Punt to procure tusks, among other goods, around 1500 B.C. (Scullard 1974: 27; Gautier *et al.* 1994: 13). Ivory was imported from the Sudan by way of the Nile Valley or the Red Sea during the 18th and 19th dynasties (c. 1550-1186 B.C.) since there were no elephants in Egypt *or* its Nubian territories by this time. An inscription from Qusr Ibrim in Lower Nubia, dating to the reign of Amenophis II (c. 1427-1400 BCE), mentions imports of approximately 500 tusks from the “southern countries” (Hayward 1990: 104). As mentioned above, the Tomb of Rekhmire depicted Nubians

(see Figure 20) and the men of Punt as bearing ivory to Egypt, with another six tusks piled at the head of the procession.

Figure 19: Map of Sudan and the Nile, including the location of the city of Meroe, which lent its name to the region and was later, beginning around the 8<sup>th</sup> century A.D., the center of the Meroitic civilization. Punt was located along the coast of the Red Sea southwards of the Second Cataract (adapted from [http://www-oi.uchicago.edu/OI/INFO/MAP/SITE/Sudan\\_Site\\_150dpi.html](http://www-oi.uchicago.edu/OI/INFO/MAP/SITE/Sudan_Site_150dpi.html)).

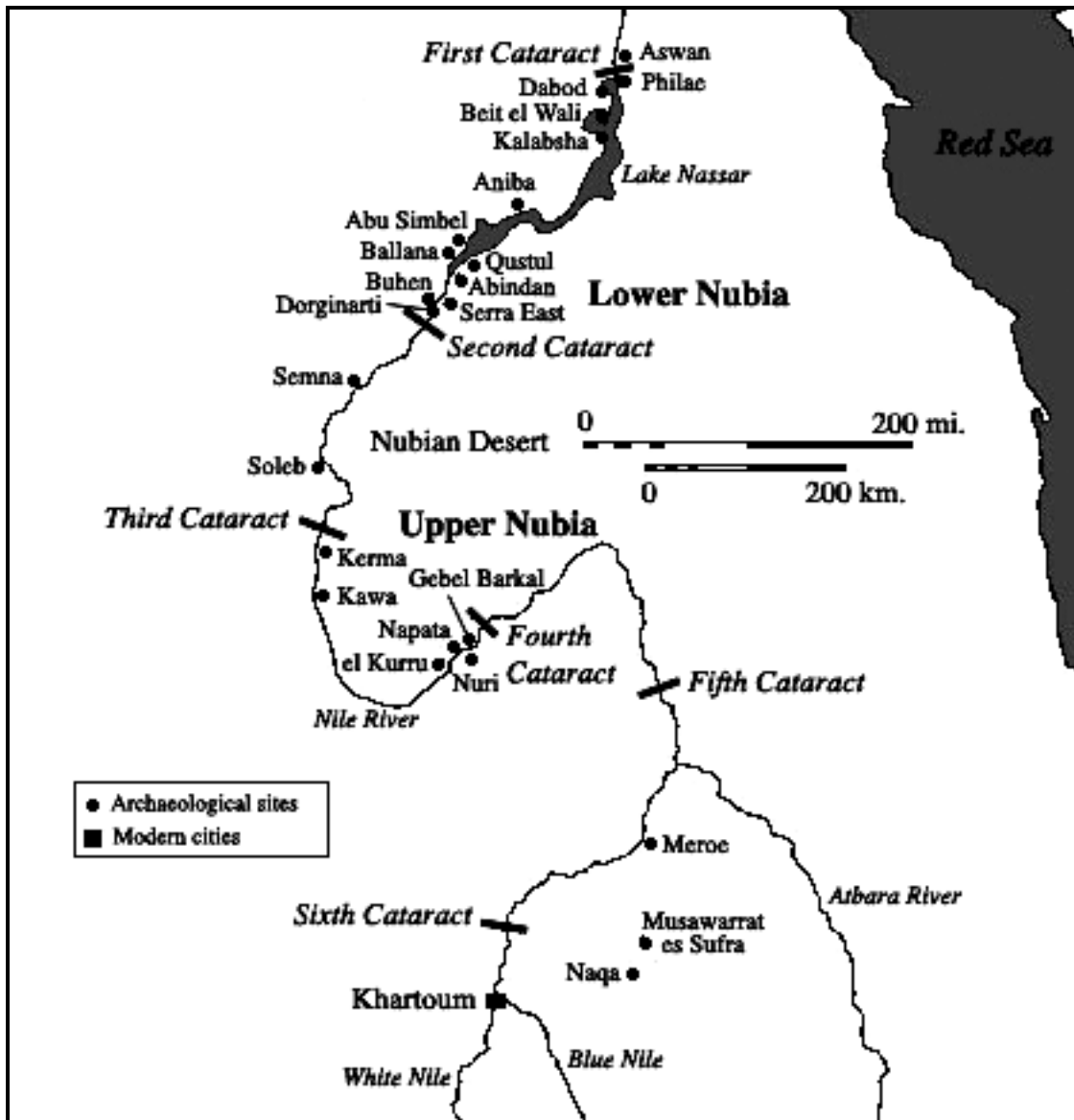
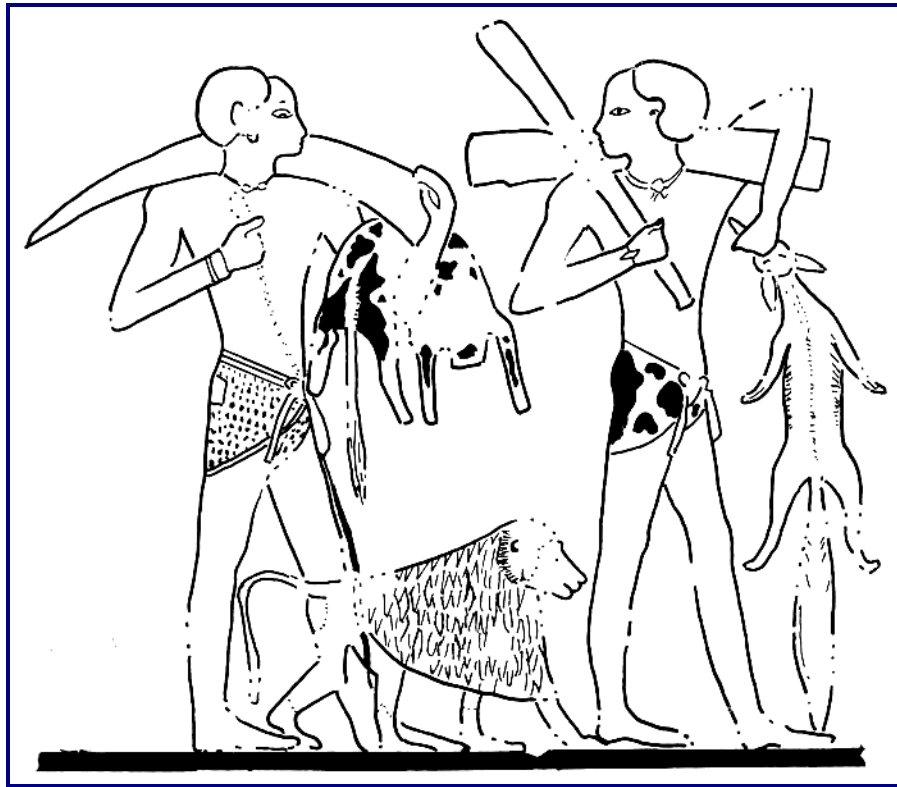


Figure 20: Nubians bearing tribute, from the Tomb of Rekhmire at Thebes (adapted from Krzyszkowska 1990: frontispiece).



### *North Africa*

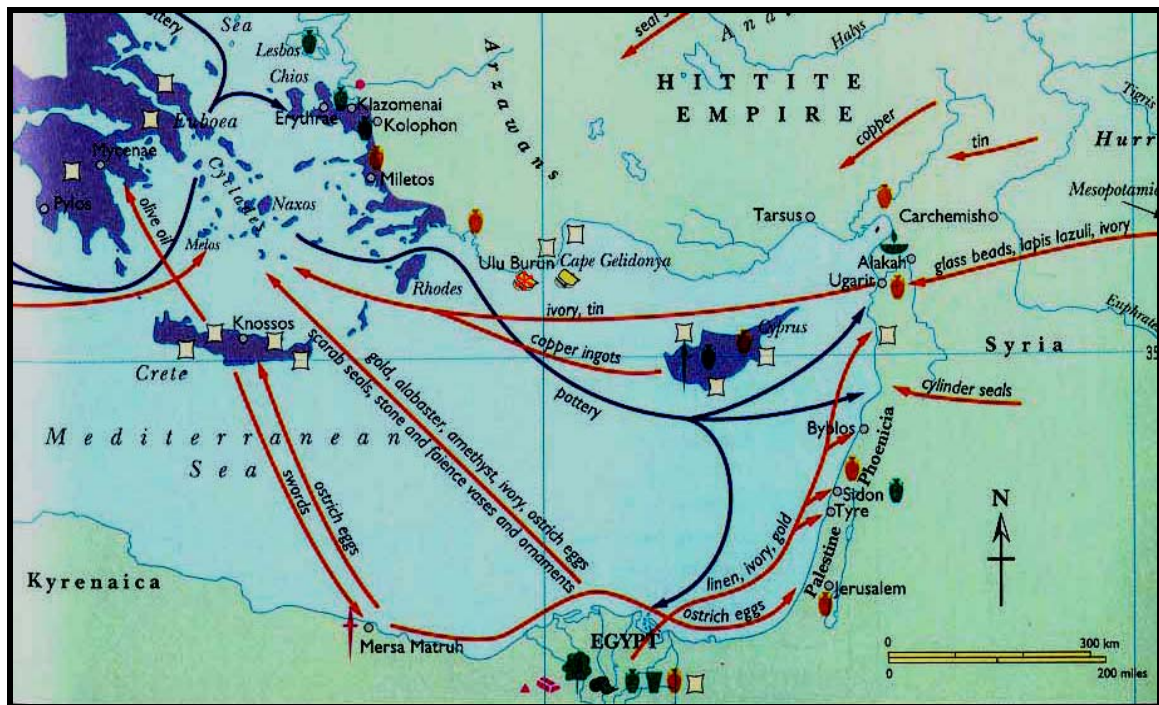
As advocated above, another source of elephant ivory in the Late Bronze Age may have been North Africa. Elephants almost certainly dwelled there, in forests which were later stripped by human activity, such as Julius Caesar's rebuilding his fleet from timber in the (then) heavily forested Sousse region in Tunisia. No trees grow naturally there today (Blondel and Aronson 1999: 203). Indeed, in the second half of the second millennium B.C. elephants are reconstructed as living between Morocco in the west to northwestern Libya in the east, through Northern Algeria and Tunisia, in addition to north and east of the Sudan (Hayward 1990: 104).

The degree of contact between the Late Bronze Age Aegean and North Africa (Libya) is a widely questioned and debated subject. While this area was not in direct contact with Egypt, ivory may have been traded through Minoan and Mycenaean contacts in the coastal regions of Northeastern Libya (ancient Cyrenaica). It must be emphasized that this hypothesis, advocated by L.G. Hayward (1990), is based on seemingly shaky evidence, according to Krzyszkowska (1990: 18, 29). Some Late Minoan artifacts have been recovered from Northeastern Libya, but not from Late Bronze Age contexts. Further support for this theory comes from representations of two Berber tribes with Aegean weapons in depictions of Ramesses III's two Libyan wars of his fifth and eleventh regnal years (c. 1180-1174 BCE) from his mortuary temple at Medinet Habu (Hayward 1990: 104-107). Krzyszkowska (1990) does not see North Africa as a source for ivory until the 8<sup>th</sup> century, at the earliest, although by the seventh century the area was utilized by Etrurian workshops, and by the fifth "Libyan" ivory was heavily depended on by Greece (Krzyszkowska 1990: 18). Gautier *et al.* (1994: 13) advocate the Mediterranean littoral of North Africa as capable of supporting a large number of elephants, ascribing the lack of finds to lack of research, and moreover support a much wider geographical range than just the coast.




















There is better evidence of trade contact in northwestern Egypt, where a considerable amount of imported Late Bronze Age Cypriot and Syro-Palestinian pottery and some Aegean sherds have come from a small island east of Marsa Matruh (ancient Paraetionium) (see Figure 21 for location of Marsa Matruh). Excavations at Marsa Matruh (see White 1986; 1989) have recovered Cypriot wares (White Slip II, Base Ring, Red Lustrous, and White Shaved), Levantine wares (a Canaanite jar and lamp), and a few



Figure 21: Late Bronze Age trade in the eastern Mediterranean. Note the location of Marsa Matruh on the north coast of Africa, as well as the counter-clockwise maritime trade route. The Uluburun is also marked (adapted from Morkot 1996: 28-29).



### Bronze age trade circa 1450 B.C.

 Mycenaean sphere of influence	<i>Goods from Crete:</i>	<i>Goods from the Aegean and the Cyclades:</i>
 Mycenaean exports	 Timber	 Spondylus shells (Aegean)
 Other trade routes	 Woven wools textiles	 Obsidian (Melos)
 Finds of copper ingots	 Daggers (before 1500 B.C.)	 Emery (Naxos)
 Shipwrecks	 Stone lamps and vessels	 Silver (Cyclades)
 Uluburun shipwreck	 Fine pottery (before 1450 B.C.)	 Swords and daggers
	 Metal vases (before 1450 B.C.)	<i>Goods from Greek mainland:</i>
		 Fine pottery (after 1500 B.C.)
		 Metal vases (after 1500 B.C.)

Minoan and Mycenaean sherds from the 14<sup>th</sup>/13<sup>th</sup> centuries in Late Bronze Age contexts. There is also evidence for copper smelting and trade in ostrich eggs (Vagnetti and Lo Schiavo 1989: 217; Luce 1998). The site has been reconstructed as a trade entropot inhabited during the 14<sup>th</sup>-12<sup>th</sup> centuries B.C., although Hayward (1990: 105) suggests the site “does not seem to have had any real connection with New Kingdom Egypt- until the time when a fortress was built at Zawiyat Umm ar Rakham, about 20 km to the west during the reign of Ramesses II (c. 1279-1213 BC).” Hayward further cites one of the obelisks erected by Hatshepsut at Karnak, which bears the inscription: “I brought the goods of Tjehenu (Eastern Libya/Western Egypt), consisting of 700 ivory tusks (which) were there...numerous panther skins (measuring) 5 cubits along the back (and) belonging to the southern panther, beside all the (other) goods of this country.” Hayward (1990: 107) then proceeds to suggest the tusks “must have originated further to the west, in North Western Libya... or, just possibly, south of the Sahara.” How the tusks *must have* originated to the west when the panther skins in the same inscription originated from the south seems questionable. Both the ivory and the panther skins could have been traded northward from south of the Sahara, as Hayward suggests, but then the inferred “other” in “other goods of this country” should be removed from her translation. Nevertheless, the inscription is a tantalizing and exceptional piece of evidence for Late Bronze Age trade of elephant ivory in Egypt.

### ***The Possibility, and Degree, of Contact Between the Aegean and North Africa***

Bass (1997) entertains the possibility of some of the Aegean ivory as coming from North Africa, noting that ships may have stopped at Marsa Matruh on a counter-

clockwise route around the eastern Mediterranean (see Figure 21). Other arguments for contact between the Aegean and North Africa rely on similarities between eastern Libyan and Minoan cultures, ancient Greek legends (i.e. Jason and the Argonauts), the Akrotiri frescoes, and later contact with the Sea Peoples (Hayward 1990: 105). The subject is addressed by Knapp (1981), who after reviewing the above points in favor of such a contact, flatly dismisses the hypothesis as unsupportable based on the available archaeological record in North Africa.

Thera, an island in the Cyclades, was destroyed by a volcano (circa 1700 B.C.) which fortunately preserved many frescoes. The frescoes were described by the excavator Marinatos (1974*a*, 1974*b*, cited by Knapp 1981: 249) as having “Libyan” or “African” elements. The fresco cited most often is the “Miniature Fresco”, which purportedly depicts tunics similar to those worn by North Africans, a desert replete with plants and animals (such as a cheetah, lion, and horned Berbery sheep) found in an African environment, and a type of shield similar to that used by a Libyan tribe, as described by Herodotus. The fresco is interpreted as depicting the arrival of Minoan ships at a settlement on the Libyan coast (Hayward 1990: 105), but Knapp (1981: 250-251) argues that all of the “Libyan” elements on the frescoes were either native to the Aegean or suggest sporadic and infrequent contact or exchange with the coast of North Africa west of Egypt. Furthermore, the handful of Bronze Age Aegean artifacts in Libya (Cyrenaica) have not been recovered from Bronze Age contexts. Yet Knapp (1981: 258) also states that the archaeological evidence for the third and second millennia B.C. is “lacking almost entirely in Libya.” So the problem is not so much that Aegean materials

are lacking in North Africa, but that almost any evidence for this time period is lacking, and certainly there were indigenous LBA cultures in North Africa.

The tribes inhabiting North Africa at this time included the Tehenu in the area west of the Nile Valley, the Libu who lived west of the Tehenu (eastern Cyrenaica), and the Meshwesh in western Cyrenaica (and perhaps further west). These tribes were known as pastoralists, as the *Odyssey* refers to “Libya of the numerous flocks,” and Libya was also mentioned as a destination for seafaring (IV.85-89 and XIV.295, cited by Knapp 1981: 267 and Luce 1998). An Aegean knowledge of the flocks and harbors of North Africa is entirely possible given the favorable sailing winds which blow from the Aegean to North Africa during the sailing season (May to October) (Casson 1995: 270-272; Knapp 1981: 257). Furthermore, the North African coast is a natural stopover on the way from the Aegean to Egypt, so it is very likely that ships coming from the Aegean stopped along North Africa and were in contact with the Meshwesh, Libu, and Tehenu. Even Knapp must admit to this probability: “It is conceivable that the ‘Ship’s procession’ in the ‘Miniature fresco’ may represent a generalized portrayal of an Aegean (Cycladic) trading mission to North Africa. If so, Cyrenaica may be regarded as having been part of a more extensive Bronze Age Aegean-Egyptian pattern of intercourse” (Knapp 1981: 269). Yet he then goes on to deny Cyrenaica any active role in this trade network operating in the eastern Mediterranean. Mostly he regards North Africa as devoid of anything that might be trade-worthy, and furthermore incapable of acting as a trade outlet for goods coming from the more resource-rich interior because “desert trade would have been difficult if not impossible without the camel” (Knapp 1981: 259), which was not introduced into the area until the 1<sup>st</sup> century A.D. But North Africans possibly did have trade resources; they

had perishable goods and ivory. I consider the idea that North Africa was not an active part of the eastern Mediterranean counter-clockwise trade route as patently absurd (and I am agreeing with Hayward on this point). As demonstrated by the research by Gautier *et al.* (1994) and Viljoen (1988; 1989; 1990) the elephant inhabited North Africa during the LBA; it did not go extinct until the 7<sup>th</sup> century A.D. (Krzyszkowska 1990: 18). The North African tribes could have exchanged ivory for perishable goods that have not survived to be part of the archaeological record (indeed, there is very little archaeologically visible in this region from the LBA). By the late 13<sup>th</sup> century the Meshwesh were moreover allied with the Sea Peoples against Egypt. From inscriptions at Karnak and a stela from Benha (ancient Athribis) in Lower Egypt it is known that the Libu, Meshwesh and Qeheq were in cohorts with the Ekwesh (generally identified as Eastern Mycenaeans), Teresh, Luka, Sherden and Shekelesh warriors in an invasion of Egypt circa 1209 B.C. (Hayward 1990: 105; Knapp 1981: 259). That only 100 years later people from the Aegean and from North Africa joined together to attempt a take-over of the political juggernaut of the day suggests that they must have had a close relationship prior to such a feat.

By the Iron Age and later the two regions were robust trade partners, as the fifth century B.C. Attic poet Hermippus (Athenaeus i.27.f) relates that “Libya supplies ivory in plenty for trade”- Libya meaning North Africa in general, west of Egypt (Gill 1993: 233; Scullard 1974: 32). Egypt also proved to be an important source for ivory to the classical and Hellenistic world, as receipts written on ostraka have been recovered as testimony to this trade (Gill 1993: 233). Taking all of this into account, North Africa must be a serious contender in the search for the provenance of the Uluburun ivory.

## Part II: The Syrian Elephant

Turning attention to the north, the Syrian population of elephants is just as promising a source for the elephant ivory on the Uluburun shipwreck. Some scholars (e.g. Miller 1986) believe the Syrian elephant may have been introduced into the region because there is a dearth of evidence for it before the 2<sup>nd</sup> millennium (in the form of, presumably, Mesopotamian historical references to an ivory trade from Syria), and due to the small size of the population described by the Egyptian and Assyrian historical sources (cf. Krzyszkowska 1990: 15; Miller 1986: 29-30; Winter 1973: 267-268; Hayward 1990: 103; Collon 1977). However, I see no reason for assuming that Syrian elephants did not exist in the region before the 2<sup>nd</sup> millennium. The elephants of Syria may not have been exploited for ivory, whether because Egyptian ivory was preferred (because it was coming from the larger-tusked Bush variety of the African elephant?), trade networks with Egypt were more established than those with Syria, or the inhabitants of Syria had not yet organized such a trade, for whatever reasons. Furthermore, the Syrian elephant is regarded to be of the same species as, or perhaps a sub-species of, the Asian elephant (*Elephas maximus*). Thus, like Asian elephants, only the male Syrian elephants would have had tusks (Krzyszkowska 1990: 15, 17, 27).

Suffice it to say for now that elephants are known to have inhabited Syria during the Late Bronze Age, based on osteological and historical evidence. Elephant bones, other than tusks, have been found at Ras Shamra (Ugarit), Alalakh, and several other Mesopotamian sites (Miller 1986: 30). The earliest osteological evidence for Syrian elephants are remains from Babylon (c. 1800 BC), although it is unclear whether these remains are in fact from the Syrian elephant and not the Asian elephant, traded in from

the east. Elephant molars have also been found at Ugarit and identified as coming from the Asian species (*Elephas maximus*) (Hooijer 1978: 187-188, cited by Krzyszkowska 1990: 27). Other early evidence for the Syrian elephant, albeit in the form of tusks, comes from Chagar Bazar in the Jezirah (c. 2000 B.C.), Megiddo, and the destruction level of the 18th century B.C. palace of Alalakh in northwest Syria (Scullard 1974: 30; Miller 1986: 30). Alalakh also yielded examples of worked ivory from the early 2<sup>nd</sup> millennium B.C., as did Ebla and Byblos. Pre-cut pieces of elephant ivory were interpreted as evidence for an active ivory workshop in Achemhöyük in Anatolia (Bourgeois 1993: 63).

Historical evidence from Egypt also advocates for a Syrian source of elephant ivory. Thutmose I recorded his endeavors of hunting elephants, as did his grandson Thutmose III. The Annals of Thutmose III include 18 elephant tusks as tribute from Syria-Palestine circa 1439 B.C. (Hayward 1990: 103). However, he also claims to have hunted and killed 120 elephants in Neya (or Niy), a region reconstructed as being located in the Ghab north of Hama, the Orontes Valley, or the Euphrates region near Aleppo, but nevertheless somewhere in Northwestern Syria (Miller 1986: 31; Krzyszkowska 1990: 15; Hayward 1990: 103-4; Kuhrt 1995: 323; see Figure 22 for location of Ghab and the Orontes Valley). In the Tomb of Rekhmire (the vizier to Thutmose II) Syrians are depicted as bringing an elephant as tribute (smaller than life-size- perhaps ascribable to artistic license; see Figure 23) (Krzyszkowska 1990: 14; Scullard 1974: 28). The fourteenth century B.C. tombs of Meryra II and Huyia also represent Syrians as bringing copper oxhide ingots and elephant tusks (Bass 1997: 160).

Figure 22: Location of Ghab Valley and the Orontes River, reconstructed as the region in which Tuthmosis III hunted Syrian elephants (adapted from Yasuda *et al.* 2000: 128).

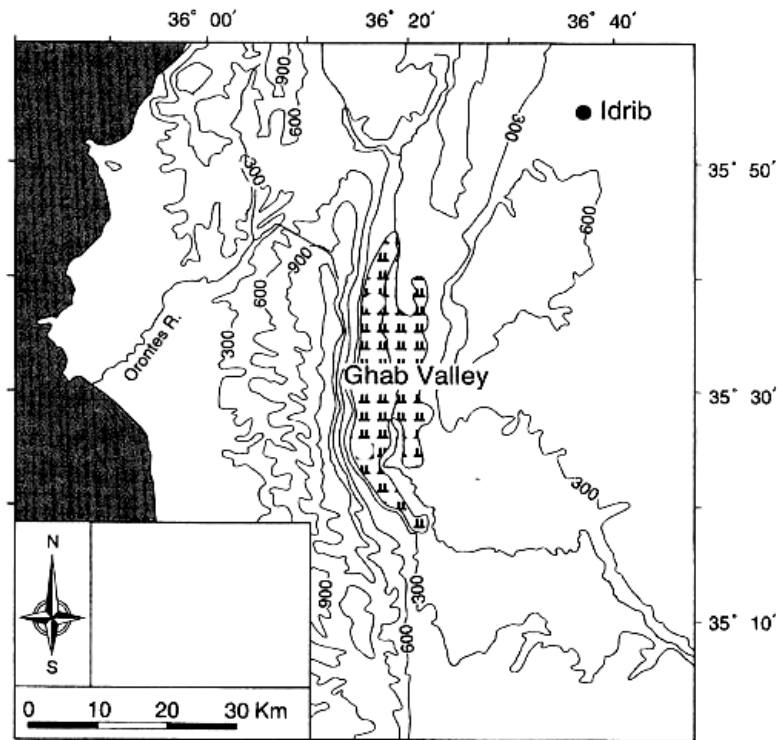
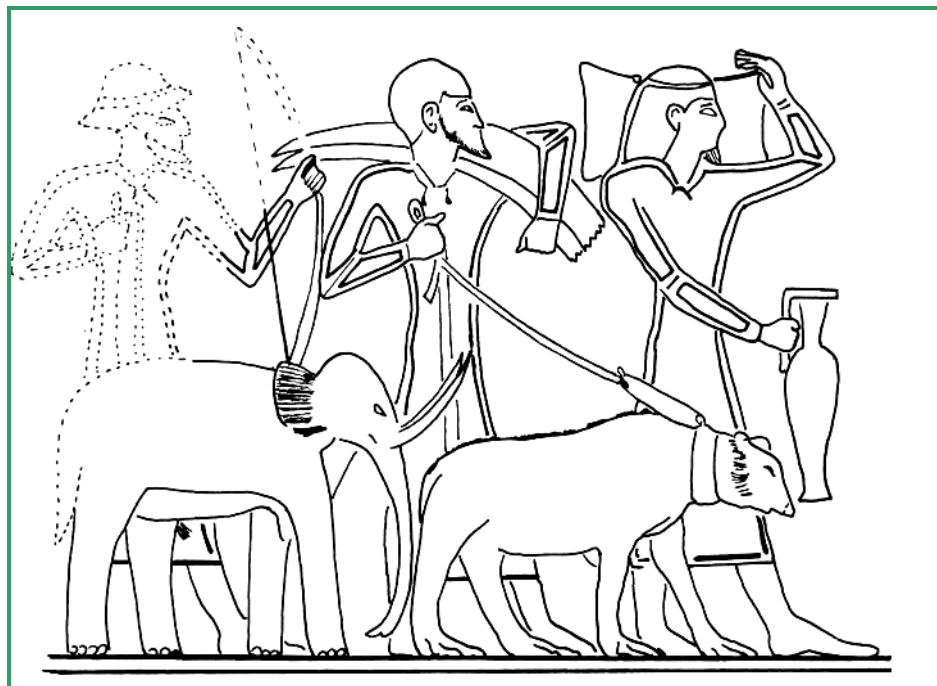


Figure 23: Relief from the Tomb of Rekhmire, depicting Syrian elephants brought as tribute (adapted from Krzyszkowska 1990: 14, figure 2).





Further historical references to the Syrian elephant come from the twelfth century Assyrian king Tiglath-pileser I (ruled 1114-1076 B.C.), who in his fifth campaign drove the Ahlami (Aramaeans) to Carchemish and “in the region of Haran and of the river Habur I slaughtered ten mighty male elephants and took four alive. Their hides and tusks, together with the live elephants, I brought to my city of Assur” (quoted in Scullard 1974: 29).

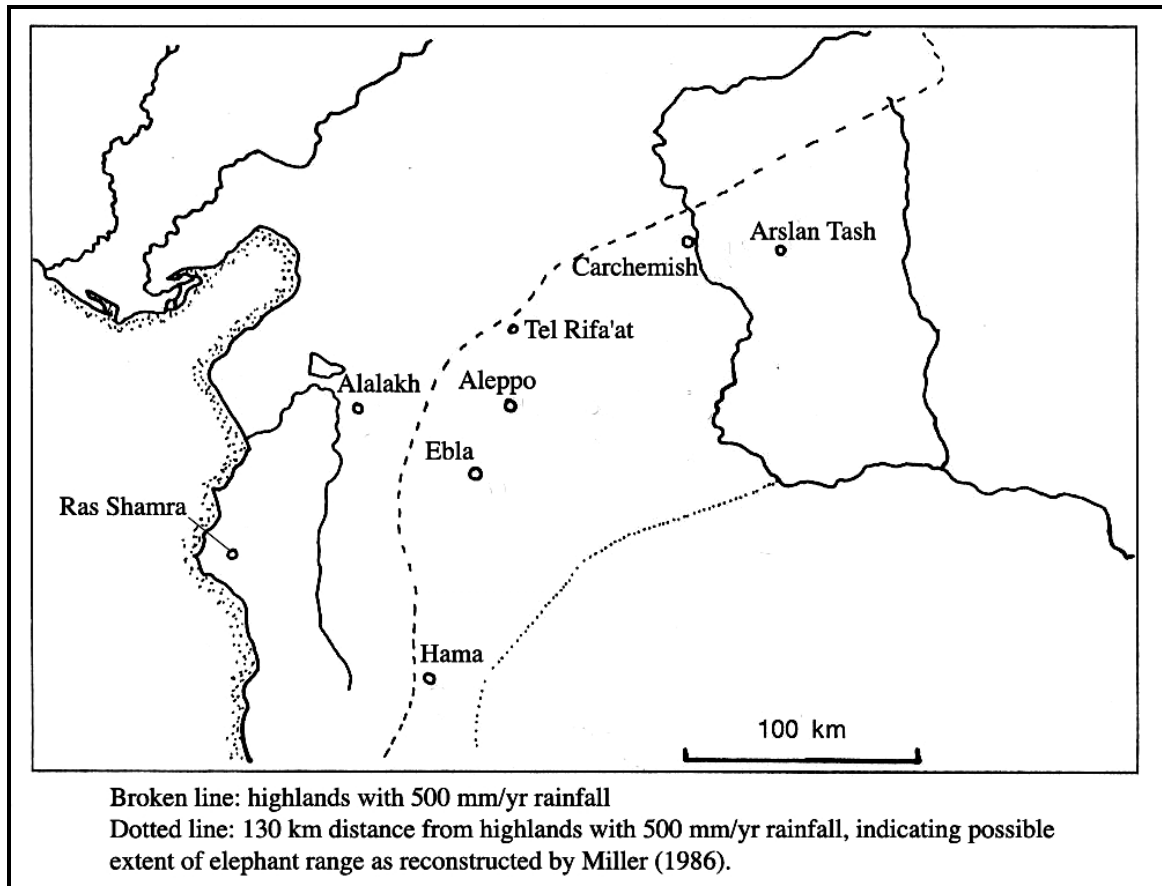
Given that the number of Syrian elephant osteological remains is small, most reconstructions of the elephant distribution in western Asia rely on the known environmental needs of the animal and the biogeography of the region in antiquity (Krzyszkowska 1990: 28; Miller 1986). Krzyszkowska (1990) reconstructs a rather large range of northern and western Syria, including the Amuq plain, across to the foothills of the Zagros mountains, and southwards through the Assyrian plain to southern Mesopotamia (Krzyszkowska 1990: 15). Similarly, Miller (1986: 29) examined the biogeographical needs of elephants and concluded that two key interrelated factors operated in the consideration of the range of the Syrian elephant: the development of a woody savanna habitat in conjunction with a period of low settlement density. He considers work by Cloudsley-Thompson (1977) and Wing and Buss (1970) on the ecological requirements of elephants, but overestimates the browse requirements of the elephant and underestimates their resourcefulness and flexibility in adapting to conditions hitherto considered inadequate for elephants. He notes that elephants are generalist feeders, and given abundant food resources may exploit a range of 16-52 km<sup>2</sup>, although these ranges may be extended considerably. Elephants moreover require an optimum mix of grasses, bark, and tender branches in their diet, but Miller proffers that Asian

elephants show a lower preference for grasses compared to the African elephant (see Miller 1986: 32-33, and Sukumar *et al.* 1987:11). He correctly states that a mixture of woodland and grassland is the optimum environment for elephants, and that habitat change (from forest to savanna) promotes a decline in elephant populations (Miller 1986: 32). While I agree that the environment influences the size of elephant populations, and that less than optimum conditions may explain the theoretically small size of the Syrian elephant population, he may nevertheless be placing too much emphasis on environmental determinism, particularly in his focus on optimization. Elephants, unlike hippopotami, are able to exploit a great variety of environments, as shown in Chapter Eight and particularly by the findings of Viljoen (1988).

In the end, Miller reconstructs the geographic range of the Syrian elephant as including the mountainous forested areas of northwest Syria and southern Turkey (which has the optimal 500 mm annual rainfall). Here the Syrian elephant could have seasonally exploited the high quality (high protein) browse available in the arid steppe between the Orontes and the Euphrates, as well as the area of Lake Jabbul, and the Hama steppe stretching across to below the bend of the Euphrates southeast of Aleppo (Miller 1986: 30, see Figure 24 below).

Miller then ties all of this up beautifully by establishing an inverse relationship between the elephant populations and human population density; a relationship which is furthermore exacerbated by human induced deforestation (see also Yasuda *et al.* 2000). During this time the advances in metal-working required more fuel, and population increases lent the way for more pasture and agricultural zones to be established. All of Miller's argument makes perfect sense but I presume that the situation for the Syrian

Figure 24: A reconstruction of the Syrian elephants' range, primarily based on rainfall per annum (adapted from Miller 1986: 31, figure 1).



elephants' demise was not so clear cut, and that other factors (such as, possibly, over-hunting for ivory) were at work. Moreover, the elephants' ecological requirements are not so dependent on forest resources. The fact that studies on Asian elephants, such as Sukumar *et al.* (1987), showed a preference for browse does not mean that Asian elephants cannot exist in other habitats. We do not know how Asian elephants would react to desert or savanna environments, such as those in the Namib Desert or East Africa, but considering that Asian and African elephants are extraordinarily similar overall, it may be surmised that Asian (and Syrian) elephants are able to dwell in habitats

similar to those of the African elephant. Miller's conclusions are also based on the assumption that abandonment of large sites (such as Aleppo following destruction by the Hittites) equates to low settlement density. The population could very well have dispersed out of the urban centers, but not necessarily declined significantly.

Eventually deforestation *and* overhunting (for sport or ivory) did annihilate the Syrian elephant population in the Early Iron Age, with the last references to Syrian elephants coming from the ninth century B.C. (Scullard 1974: 30; Francis and Vickers 1983: 251; Miller 1986: 32; Krzyszkowska 1990: 15). Francis and Vickers (1983: 249-251) and Gill (1993: 233) propose the misidentification of the Al Mina elephant tusks (later identified as a horn core of water buffalo and domesticated cattle) as evidence against an exportation of Syrian elephant ivory. The Al Mina 'tusks' (Al Mina was an Iron Age Greek emporium) are from the 8<sup>th</sup> century B.C., and therefore serve better as an argument for the extinction of the Syrian elephant before this time than as a refutation for the utilization of Syrian elephants for ivory.

While the population was probably never very large, at least compared to the populations in Africa, it is nonetheless a viable source for the ivory of the Uluburun shipwreck, and even Hayward (1990: 103) notes that the Uluburun shipwreck "would tend to indicate that the Aegean did indeed receive raw elephant ivory from Syria during the Late Bronze Age." Further, an increase in the incorporation of ivory into luxury craftwork during the late 2<sup>nd</sup> millennium could very well be tied to accessibility of Syrian elephant ivory (Miller 1986: 31).

## Conclusion

Thus there are two general derivations of elephant ivory in the eastern Mediterranean during the Late Bronze Age: Syria or Africa. Egypt would have acted as an intermediary between trade from Nubia and the Sudan, but nothing in the historical records indicate that Egypt ever exported raw ivory. As a result, any sort of discussion on Egypt as a source for raw ivory is pure conjecture at this point. North Africa, however, could very well be a supplier of elephant ivory as a raw material, even though this region also lacks supporting evidence for such a claim. The difference between advocating for either of the two regions is that there is a great deal of archaeological and historical evidence in Egypt, whereas the rest of North Africa suffers from the vagueries of archaeological invisibility. One would be hard-pressed to argue that differential preservation of the archaeological record was at work in Egypt, and then turn around and cite negative evidence in Libya as grounds for its dismissal as a source of ivory. Moreover, Egypt also carried off tusks from North Africa, as mentioned in the Qusr Ibrim inscription. The ivory traded from North Africa could have originated from the south or the coastal regions of North Africa, and if from the south (Nubia/Sudan) the middle agent(s) (Egyptian or Libyan) may be difficult to discern. Syria, on the other hand, is known to have exported ivory, typically depicted as tribute in Egyptian historical sources, and the Mitanni in northern Syria sent ivory as gift-exchange to the Egyptian pharaoh. Raw ivory and osteological remains are furthermore found in a number of Syria's major trade centers, where workshops transformed the elephant ivory into prestige objects. How the trade in raw ivory articulates with the distribution of ivory workshops and ivory carving styles is the topic of the next chapter.

## Chapter 5

### Ivory Workshops in the Late Bronze Age Mediterranean

In my consideration of the provenance of ivory in the Late Bronze Age Mediterranean, I have thus far concentrated on the “supply” end of the trade and will now focus on the “demand” or acquisition end (although I am not using these terms to imply a modern economic system in the LBA). Both ends of trade nevertheless represent “consumption” if we take Gosden’s broad yet applicable definition of “using things in social acts” (1999: 163; cited in Jones 2002: 96). It is to this end that the next stage in the use-life of ivory must be considered. As discussed earlier, there could be any number of intermediaries in the trade, from the example of Egypt and the phenomenon of *cabotage* trade, before the ivory reached the next stage in the process: the workshop (either associated with a royal palace or not). The workshop transformed the ivory into a product with even higher value and/or prestige, and consequently the workshop represents a transformative stage in the trade, technically and socially, and the luxury items could be shipped elsewhere or retained close at hand.

The archaeological evidence from the Aegean has not been considered until now because the Aegean had no local sources of ivory and therefore had to procure the precious material through maritime trade. The archaeological evidence from the Aegean is, moreover, abundant and includes remarkable examples of workshops. Cyprus, Syria, Anatolia, and Palestine additionally possessed workshops. Overall the eastern Mediterranean in the Late Bronze Age saw the “resurgence and apogee of ivory working” as a widespread and decidedly international phenomenon, embodied by the 14<sup>th</sup> to 13<sup>th</sup> century Ras Shamra and 13<sup>th</sup> century Tell Fakhariyah ivories in Syria, the 14<sup>th</sup> to 13<sup>th</sup>

century Middle Assyrian ivories in northern Mesopotamia, and the Aegean, Egyptian, and Palestine workshops (Liebowitz 1987: 20). In any discussion of workshops stylistic considerations are sometimes brought to the fore in order to demonstrate distinct workshop traditions, but such methods are fraught with difficulty due to the international character of the LBA, as will be seen from an examination of “Egyptianizing” versus local innovations in style.

### **The Signature of an Ivory Workshop in the Archaeological Record**

All of this of course begs the question of how one recognizes a workshop in the archaeological record, and Krzyszkowska (1993) addresses this question in her investigation of LBA Aegean workshops. Workshop material includes every stage of the manufacturing process: from raw material in the form of whole or partial tusks, to prepared blocks and blanks, roughouts, waste pieces (such as large offcuts to chips and trimmings), rejects, mistakes, salvaged material for secondary working, unfinished pieces, as well as the finished pieces (1993: 25-27). Elephant tusks are the preferred form of ivory as larger solid flat blanks may be cut from prepared blocks. These blocks were cut lengthwise from the tusk, not transversely, whereupon the outer “bark” (cementum and enamel) was removed. The final product to be carved from the blanks may be deduced from the shape and size of the blanks, in addition to possible guidelines on the blank. The proximal end with the tapering pulp and the distal tip were more difficult to carve and were utilized for pyxis (squat container) manufacturing. Small chips, such as those recovered from Knossos, are “good indicators of a working area proper, as opposed to a storeroom for a workshop” (1993: 27). The shape of the waste

pieces may also intimate what sort of objects were carved in the workshop. Thin and relatively regular trimmings would suggest the manufacture of inlays, whereas carving in the round or high relief would leave irregular flakes or chips in the working area. Some of the waste pieces may be reused for secondary manufacture, as for pegs, dowels, or other types of joins.

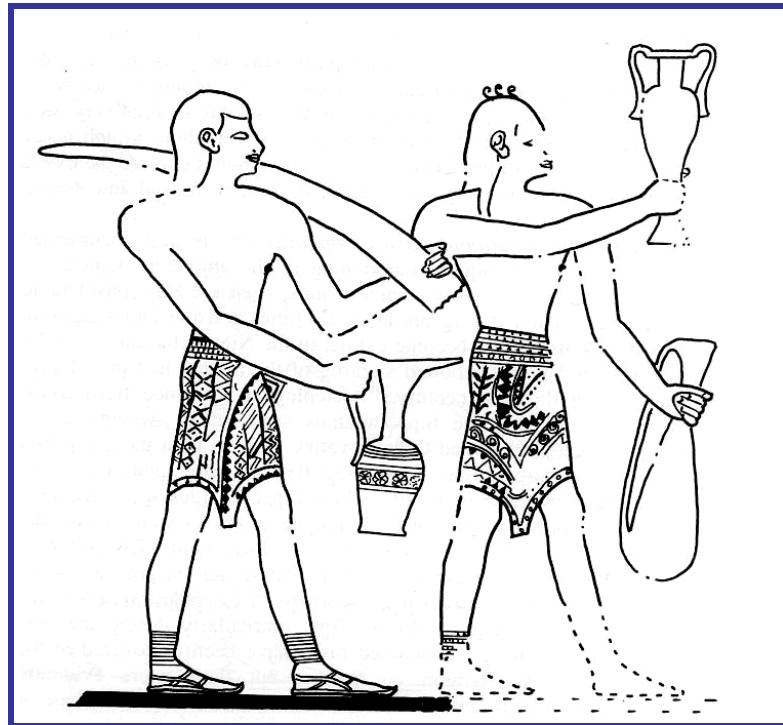
Krzyszkowska (1993: 28) further warns “no single site has yielded a complete range of workshop material from unworked tusk to finished product, by way of blanks and unfinished pieces and with a full complement of workers’ waste. Nor do I expect such a site to be found... I suspect that our rather offhand use of the term ‘ivory workshop’ may have seduced us into seeing ivory production as a much more centralized activity than it actually was.” By ‘centralized’ Krzyszkowska means the idea that all stages of manufacture occur in a single, central, workshop, not that the ivory workshops were free of centralized control. For example, the ivory may have been stored in one location, carved in another, and assembled in yet another area. Thus in the archaeological record working areas may be distinct from assembly areas and storerooms. There may additionally be separate storerooms for separate stages of the manufacturing process (i.e. raw materials, blanks, reusable offcuts, interim stages of manufacture, and finished pieces). Of course each site is unique and these stages may be collapsed into one area or extended further, and may not offer such a nice and clean-cut picture: at Knossos, for example, there is “debris of ivory-working in fairly close proximity to an assembly area for finished inlays. But where the inlays were made is a mystery, since they are hippopotamus ivory and the chips and offcuts are elephant ivory” (Krzyszkowska 1993: 28).



## Ivory Workshops in the Aegean

The now familiar Tomb of Rekhmire, in addition to depicting Nubians and Syrians as bearing elephant tusks, also depicts the Keftiu (generally agreed to be Cretans) as bringing a tusk in tribute (see Figure 25). But Crete had no sources of ivory of their own, and after importing it they may have traded the material further or presented the ivory as a gift-exchange among ruling elites (Krzyszkowska 1990: 19).

Figure 25: Keftiu bearing ivory to Egypt, from the Tomb of Rekhmire (adapted from Krzyszkowska 1990: Fig. 5).



In Homer (and the later authors Hesiod and Pindar) the word *elephas* (ελέφας) meant ivory, not the elephant (Scullard 1974: 32), as they presumably had no familiarity with the animals from which ivory came. References to ivory in Homer include likening Menelaus' white skin to the ivory of bridal ornaments after he is injured (*Iliad* IV.141), the ivory of Menelaus' palace (*Odyssey* IV.73), the couch of Penelope as inlaid with

ivory and silver (*Odyssey* XIX.55) and a bed that Odysseus built and inlaid with gold, ivory, and silver (*Odyssey* XXIII.200) (Dodge 1955: 18). There is moreover the speech by Penelope: “‘Ah my friend,’ seasoned Penelope dissented, ‘dreams are hard to unravel, wayward, drifting things- not all we glimpse in them will come to pass... Two gates are there for our evanescent dreams, one is made of ivory, the other made of horn. Those that pass through the ivory cleanly carved are will-o’-the-wisps, their message bears no fruit. The dreams that pass through the gates of polished horn are fraught with truth, for the dreamer who can see them’” (*Odyssey* XIX.630, translated by Fagles 1996). Clearly ivory is a luxury item in all the above Homeric references, and could be inferred to be available to the Aegean only in restricted quantities.

Aegean ivory is generally found in workshop contexts located in prestigious places such as palaces (Zakro and Knossos in Crete, Mycenae and Pylos in mainland Greece), or within sanctuaries, or as grave-goods (Karali-Yannacopoulos 1993: 58). The most common products of Aegean workshops were combs, plaques and inlays, with elephant ivory the preferred medium (Krzyszkowska 1993: 26). The earliest (worked) pieces come from the pre-palatial period (2500-2000 B.C), but do not definitively argue for workshops in Crete. Ivory seals were found in the communal burials of the period, and a worked hippopotamus lower canine was excavated from the fill below the West Court at Knossos (Reese 1998: 142). Hippopotamus ivory has additionally been discovered in the pre-palatial workshops of Crete, which Krzyszkowska suggests may be of Egyptian origin (1990: 20).

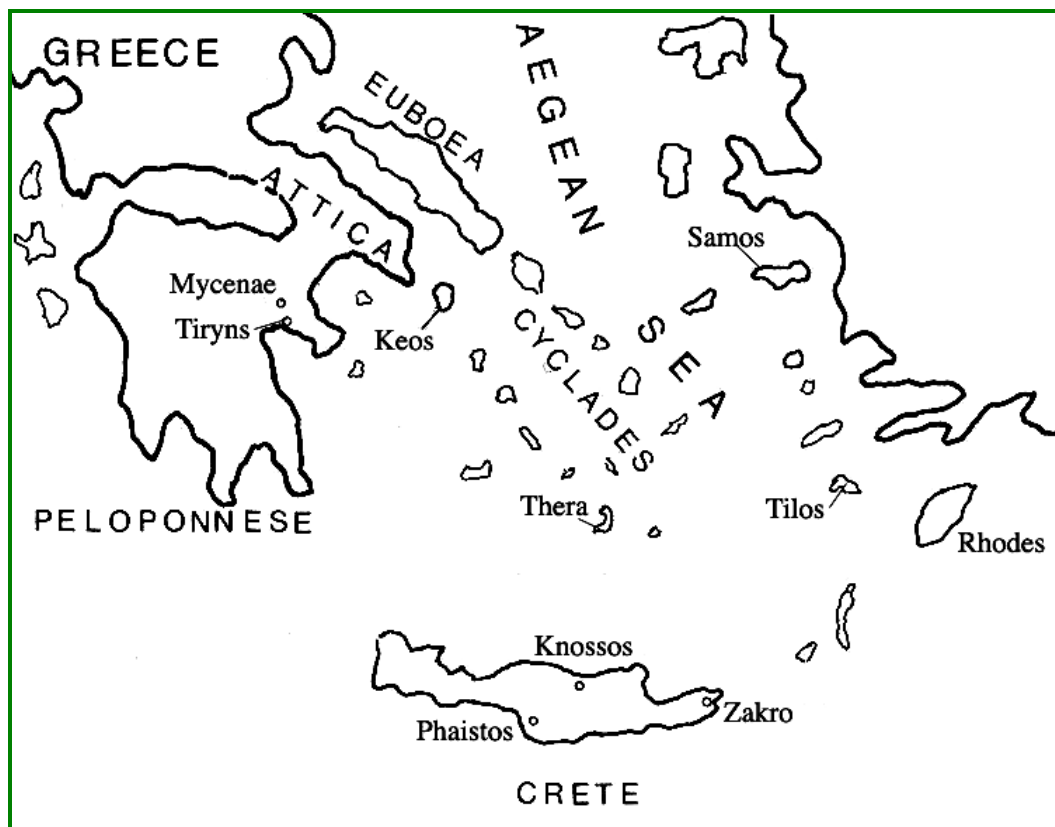
By the Late Bronze Age the amount and geographical range of Aegean workshop material dramatically increases, and represent two phases: early 16<sup>th</sup> century-early 14<sup>th</sup>

century and the LH IIIB2 period on the mainland (ca. 1250-1200 BC). Many of the ivory objects from the LBA are hippopotamus lower canines and incisors rather than elephant tusks (Reese 1998: 142; Krzyszkowska 1990), with a higher percentage of hippopotamus ivory in the first phase of Aegean ivory-carving, and by the second phase (represented primarily in mainland Greece) the majority of the material is elephant. Ivory production on Crete, meanwhile, is limited to the first period (LM IA-LM IIIA1) (Hayward 1990: 103), and represented by finds in Knossos, Zakro, Archanes, Kommos and Palaikastro. At the Royal Road excavations in Knossos a working area for a workshop (including over one kg of small chips, and evidence of secondary manufacture), fragments of large ivory statuettes, and many small inlays were recovered (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 27, 30-31; Scullard 1974: 260). The inlays were primarily fashioned from hippopotamus ivory, but are in close association with the chips and offcuts which are elephant ivory (Krzyszkowska 1990: 112; 1993: 28). Four elephant tusks from the Zakro palace are dated to the LM IB destruction, circa 1450 B.C. (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 30; Krzyszkowska 1990: 112; Scullard 1974: 260) (see Figure 26 for location of Knossos and Zakro). Two pieces of tusk sections from Archanes, and the center of a tusk and unfinished pieces from Palaikastro have been recovered as evidence of ivory working (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 30). Additionally LM III Kommos yielded two small elephant tusk segments, as well as partly worked ivory and leftover waste ivory (Reese and Krzyszkowska 1996: 324; Krzyszkowska 1993: 30).

The finds from the mainland are much less than those from Crete during this period. Ivories on the mainland were manufactured from the early 16<sup>th</sup> to the late 13<sup>th</sup>

century B.C. (LH I-LH IIIB), but the vast majority date to the 14<sup>th</sup> and 13<sup>th</sup> centuries B.C. and are of elephant ivory (Hayward 1990: 103). The earliest examples come from the Shaft Graves from Mycenae (see Figure 26 for location of Mycenae), some of which (Shaft Graves IV and V) include tusk tips that may be considered trophies (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 31; 1990: 112).

Figure 26. Locations of ivory workshop material from the Aegean (adapted from Krzyszkowska 1990: overleaf).



The LHIIIA and IIIB witnessed the climax in a systematic long-distance trade within the central Mediterranean, articulating farther west with peninsular Italy, Sardinia, and Sicily (Vagnetti 1999; which also serves as the citation source for all proceeding references in this paragraph). A fragment of an ivory Mycenaean warrior head was recovered in southern Sardinia (Ferrarese Ceruti *et al.* 1987), and the site of Frattesina in peninsular Italy yielded a local ivory workshop in the form of waste material and finished objects, primarily combs (Bietti Sestieri 1981; 1997). The “Frattesina type” of comb was also fashioned from bone and horn, and is found at other sites in Italy, with one example in elephant ivory from Torre Mordillo. A waste piece was also found at Torre Mordillo, offering further intimations of potential ivory workshops in peninsular Italy (Arancio *et al.* 1995). Interestingly, another Frattesina type comb was recovered at Enkomi in Cyprus (Vagnetti 1986), suggesting reciprocity in manufactured ivory goods between east and west.

Returning to Greece, while ivory carving was known in the mainland from the 16<sup>th</sup> century B.C., the art form did not reach its zenith until the 13<sup>th</sup> century, that is, the LH IIIB2 period (circa 1250-1200 BC), in what may be described as the final phase of Aegean ivory working (Krzyszkowska 1990: 112; Liebowitz 1987: 20). Elephant ivory, instead of hippopotamus ivory, was utilized far more than in the previous period and makes up a great majority of the recovered ivory (Karali-Yannacopoulos 1993: 57; Krzyszkowska 1993: 30). Common items were pyxides, combs, plaques, and the appliques and inlays for furniture. A great deal of workshop material comes from Mycenae, from the aforementioned Shaft Graves, Schliemann’s excavations on the acropolis, the Citadel House and the Artisans’ Quarter. The House of the Shields and the

House of the Sphinxes include storerooms for workshop material (Krzyszkowska 1993: 30). A small cube from Schliemann's excavations, and a larger cube from the Citadel house represent partly worked ivory (Reese and Krzyszkowska 1996: 325). The Citadel House reveals hardly any evidence of the act of ivory working, but it possesses workshop material in many storerooms. Surprisingly enough the bulk of this workshop material is not primary raw material (tusks or sections of tusks), nor finished pieces, but rather works in progress, off-cuts and waste (awaiting secondary manufacture). Krzyszkowska (1993: 28) concludes that there was an obvious control of the raw materials by the workshop, so that "fixed amounts could have been issued for piecework, with any waste or salvage being returned on completion of the task." A noteworthy find, because it is hippopotamus ivory, includes a burnt unworked piece of a lower canine from the Citadel House (Reese 1998: 142). From Tiryns (see Figure 26) came a partly worked piece of elephant ivory, in addition to a number of other pieces, including evidence for secondary manufacture (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 27, 30). Nichoria also had a large partly worked offcut of elephant ivory, while Pylos produced some unworked fragments in a mixed context from the Lower Town. There is a bit of partly worked ivory from a burnt deposit in Thebes (Reese and Krzyszkowska 1996: 325; Krzyszkowska 1993: 30).

So much for the Mycenaean workshop material. Much of the ivory in the Cyclades probably arrived already worked and the volume was not great (Krzyszkowska 1990: 112-113). However, a small rectangular piece of ivory, possibly a blank, was recovered at Ayios Irini, Kea (Krzyszkowska 1993: 32). Much later in the seventh

century B.C. unworked hippopotamus ivory tusks were left as offerings at the Heraion on Samos (Reese 1998: 142; Krzyszkowska 1990: 20).

### **Ivory Workshops in Anatolia**

The ivory carving tradition is also separated into two phases, that of the Assyrian Colony period (19<sup>th</sup>-18<sup>th</sup> centuries B.C.), and the Hittite empire period (14<sup>th</sup>-13<sup>th</sup> centuries B.C.). The Assyrian Colony period is represented by finds from Kültepe, Acemhöyük, and Eskiyaşur, whereas the Hittite empire ivory derives from Bogazköy and Beycesultan. Bourgeois (1993) addresses the material from the first period, and while this lies a bit before the period with which the present investigation is concerned, some details are in order. In a complex near the palace at Acemhöyük (which was destroyed circa 1750 B.C.) was a completely mineralized tusk of *Elephas maximus*, in addition to numerous fragments of elephant ivory and a variety of pre-cut pieces suggesting active ivory production (Bourgeois 1993: 61-63; Krzyszkowska 1990: 50). Manufactured objects such as pyxides were also made of elephant ivory. For hippopotamus ivory, however, only finished objects were recovered, and these were fashioned from lower incisors and canines. Caubet considers the hippopotamus ivory goods as imported from Syria (personal communication cited in Bourgeois 1993: 64), a sentiment shared by Potts (1987: 69). He considers the ivories from Anatolia as indirect evidence of Syrian workshops “since this is the closest possible source of raw material. The Syrians are unlikely not to have exploited a resource desired by others. The relative scarcity of ivories in MB Syria-Lebanon probably reflects more the extent of reuse and the ill fortune of discovery than a genuine dearth.” The second phase of Anatolian ivory-

working may be illustrated by an example from Palestine. A small plaque from Megiddo dates stylistically to the 13<sup>th</sup> century Hittite empire, but represents one Anatolian ivory in a hoard of three hundred ivories, and was moreover possibly transported to Megiddo after the fall of the Hittite empire (Alexander 1991: 182). The second-phase Anatolian ivory workshops would have acquired their ivory from the Syrian elephant herds in southeast Turkey/North Syria, or imported hippopotamus and elephant ivory from Syria. These workshops were outshadowed, however, by the Syrian workshops.

### **Ivory Workshops in Syria**

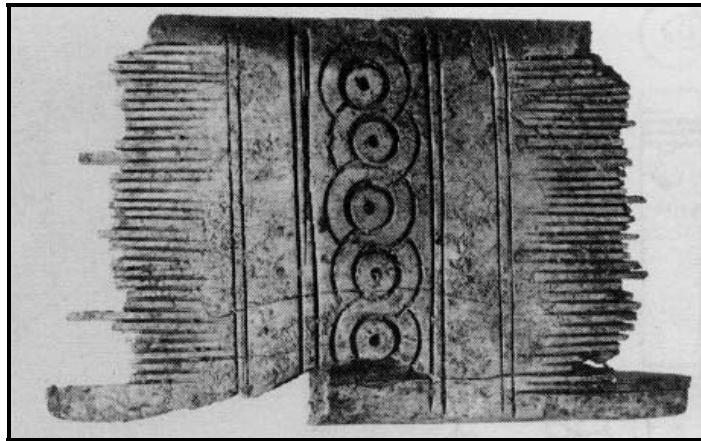
The Amarna letters of the 18<sup>th</sup> Dynasty record the Mittani of Syria as sending ivory or ivory objects to Egypt (EA 22), probably as some sort of gift-exchange between rulers (Hayward 1990: 104; Bass 1997: 160). As described in Chapter Four, Syria had hippopotami and elephants living in the region, and two elephant tusks were recovered from the destruction level of the 18th century B.C. palace of Alalakh (Scullard 1974: 30; Miller 1986: 30; Krzyszkowska 1990: 50). There was also the mistaken identity business of the 8<sup>th</sup> century B.C. Al Mina ‘tusks’ later shown to be horn cores (Krzyszkowska 1990: 50; Francis and Vickers 1983: 249-251).

Tell Fakhariyah has only yielded examples of worked ivory (Liebowitz 1987: 19). However, by far the most spectacular example of ivory-working in LBA Syria comes from Ugarit (Ras Shamra), a LBA trade center with its bustling port of Minet el Beida. Caubet and Poplin (1993) have shown that more than three-quarters of the ivory objects from Ugarit (Ras Shamra) are made from hippopotamus canines and incisors. The LBA palace at Ugarit exhibits two destruction episodes: the first circa 1370/1350 B.C. and the



second around 1180, thus placing almost all the luxury items from the site in the 140 year period of 1320-1180 B.C. (Lilyquist 1998: 27, citing a personal communication with Caubet). All in all there are approximately 350 ivory objects, most of which have not been published (Gachet 1993: 67-70). These objects include items from daily life such as combs (see Figure 27), duck-shaped boxes (to be discussed in more detail below), circular boxes, pyxides, discs/lids, and spindles and rods.

Figure 27: Ivory comb from Ugarit (Ras Shamra). Poplin has examined one of the combs and determined it was made of elephant ivory (adapted from Gachet 1993: 68, figure 2b).



The distribution of the daily life objects and more uncommon objects, such as figurines and furniture inlays, suggests that ivory was indeed a luxury item. In Ugarit the king owned the ivories with the greatest prestige, “but a range of stereotyped shapes is present everywhere, as the property of individuals during life and death; their function or their significance is considered to be important for they are present also in the sanctuaries (as ritual furniture? or offerings?). Moreover, the objects are so standardized that no variants of the shapes themselves exist: the social hierarchy is reflected only in the more frequent use of ivory for whole objects and of elephant ivory for larger pyxides” (Gachet

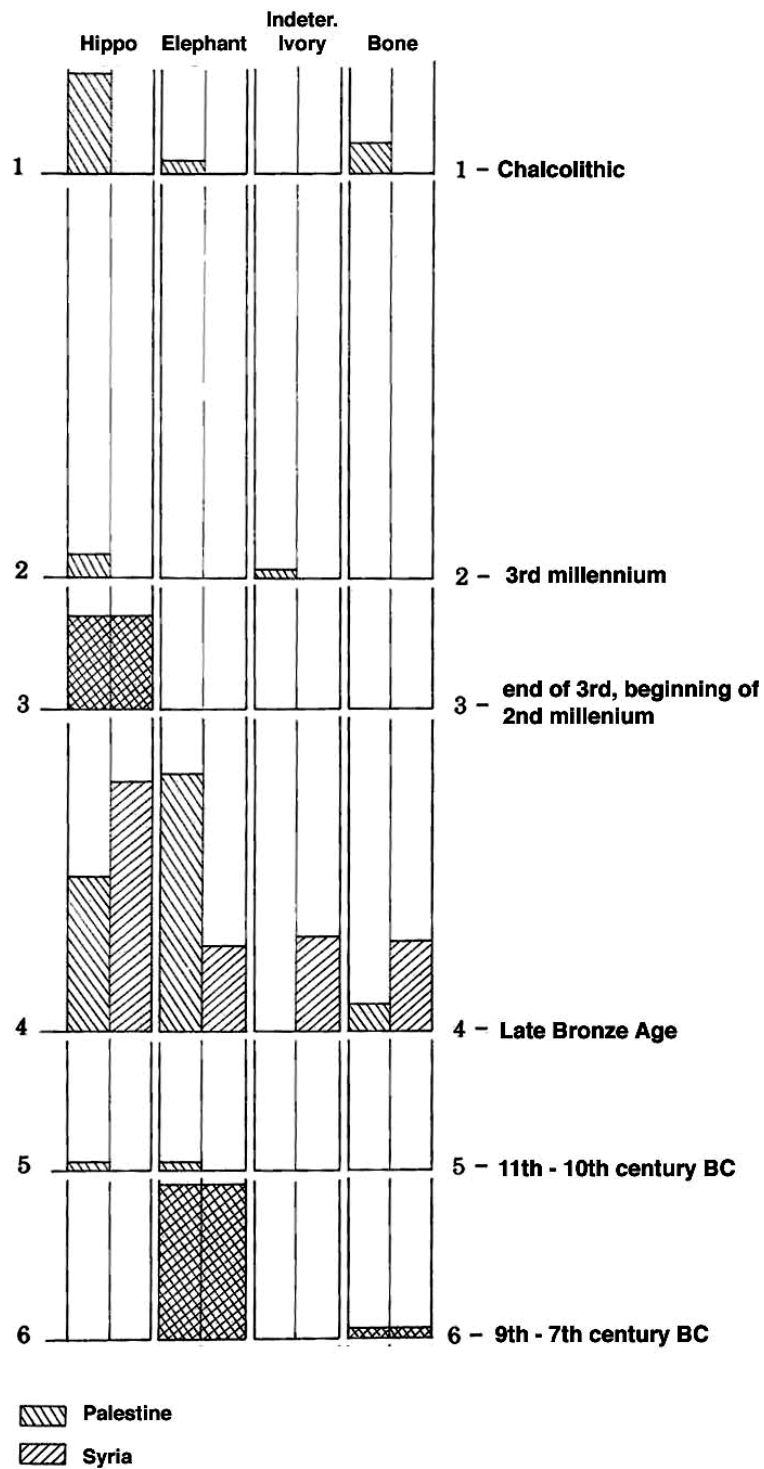
1993: 75). The standardization of shapes in my opinion argues for an established and centralized ivory-working tradition.

Hippopotamus ivory was far more frequently utilized than elephant ivory, yet also remains a luxury item, which raises more questions about why the traders of Ugarit relied so heavily on hippopotamus ivory when elephant ivory was available. A number of possibilities include: either the Syrian elephant population was difficult to utilize as a source of ivory, the herds were too small or scattered, the Ugaritic traders (whether independent or acting under royal initiative) preferred to export the more valuable ivory, or the ivory-carvers were skilled enough to work around the difficulties in working hippo ivory. The only ivory in the process of being carved was excavated from the priest's neighborhood near the temples, suggesting that ivory-workers did not require their own workshop but could take their work with them to the person commissioning the work (Gachet 1993: 74-75). There were additionally a "magic wand" and a clapper with Hathoric head recovered which are possibly Egyptian imports, found in a tomb and the seer's house respectively.

### **Ivory Workshops in Palestine**

The Palestinian ivory-carving tradition thrived in the Late Bronze Age in spite of continuous subjugation of the city-states to the Egyptians, Mitanni, and Hittites. The small kingdoms were able to maintain their importance and wealth by playing one great power against another and by establishing their usefulness as international emporia. While Canaanite art may have its stylistic origins in Egyptian carving styles, by the 14<sup>th</sup> and 13<sup>th</sup> centuries the region had developed a unique style of its own, albeit still retaining

Figure 28: Comparison of utilization of hippopotamus versus elephant ivory in Syria and Palestine (adapted from Caubet and Poplin 1993: 100). Hippopotamus ivory is more prevalent in Syria during the LBA, while elephant ivory is preferred in Palestine. Syria does possess more unidentified material, however, and also utilizes more bone.



some “Egyptianizing” influences (Kantor 1956: 160). Most of the ivories from Palestine are from the second half of the LBA, as carved ivory more or less replaces bone in LB II as a luxury item (Liebowitz 1987: 3-4). There is, however, no concrete evidence for Palestinian ivory workshops, in that no evidence for workshops in the archaeological record of Palestine exists. Only the finished products were recovered. Megiddo has yielded the most notable examples of LBA ivories in Palestine, and other sites possessing worked ivory include Lachish (Fosse Temple III), Tel Far‘ah, Ebla, Pella, Kamid el-Loz, Lachish, Nahal Sorek (el-Jisr), Ekron, Tell el-‘Ajul (Gaza), Shiqmona, and Beth Shan (Liebowitz 1980 and 1987; Lilyquist 1998: 26-28; Potts 1987: 59-71; Reese 1998: 141-142). Of these, worked hippopotamus lower canines were recovered from LB I Tell el-‘Ajul (fragment of a clapper/wand), Shiqmona (a 14<sup>th</sup> century LB II hand and Hathor-headed clapper/wand), another Hathor-headed clapper/wand from Beth Shan at the Great Court of the Temple of Amenophis III (1411-1314 BC), and Megiddo (a LB I wand) (Reese 1998: 141-142). In fact at least ten of the worked ivories from Megiddo were fashioned from hippopotamus canines or incisors.

Much of the discussion about Palestinian workshops centers around the extent and meaning of the Egyptianizing stylistic influences. Once believed to be Egyptian imports, many scholars now agree that most of the Egyptianizing ivories in the Levant are of Levantine manufacture (Lilyquist 1998: 29; Liebowitz 1987; Potts 1987), and of these Liebowitz (1987: 3-4, 16-19) believes the majority are Palestinian and not Syrian. There are differing opinions, however, on what exactly these Egyptianizing stylistic influences mean. Potts (1987) claims that the Lion Box from Pella (from the first half of the Late Bronze Age when the number of Palestinian ivories is markedly less) is evidence for a

strong Egyptian presence in Canaan. Lilyquist (1998) on the other hand regards linking artistic style to political situations as injudicious. She asserts “the new ivories from Ebla display as pure an Egyptian iconography as anything in Late Bronze Palestine... Does this mean that Ebla was under Egyptian political control? In my view, no; almost all objects from there... are Syro-Canaanite” (Lilyquist 1998: 28). Thus local Palestinian artisans appropriated Egyptian motifs and styles, but these are often used without understanding and formed part of a larger “quasi-international” style with influences from Assyria and Cyprus as well (Lilyquist 1998: 29; Liebowitz 1987: 4; Potts 1987: 68-69). This international style was perhaps more prevalent in the trade entrepôts of the Levant than farther inland (after Potts 1987: 69). With all of this in mind, I shall now turn to the evidence for ivory-working in Egypt.

### **Ivory Workshops in Egypt**

Ivory carving was healthy during the early part of the 18<sup>th</sup> Dynasty (around the time that saw Hatshepsut and Tuthmosis importing tusks) but saw its apogee during the reigns of Amenophis III and Tutankhamen until the end of the 18<sup>th</sup> Dynasty (Liebowitz 1987: 20). Common items are curving wands or knives made from hippopotamus lower canines (c. 2133-1306 B.C.), often found in tombs, as well as hippo canine clappers with hands or Hathor heads at the terminus (c. 1900-1150 B.C.) (Reese 1998: 140). Nevertheless, Egypt’s refined style, royal workshops, comparably better preservation of material culture, and well-established chronology, does not mean that the ideas for all items made in Egypt originated there (Lilyquist 1998: 27-28). Worked ivory was, moreover, imported *and* exported, as recorded by the Amarna letters and discussed in

Chapter Four. Lilyquist does not consider the Qau ivories (large deposits of hippopotamus ivories in Middle Egypt) to be 18<sup>th</sup> Dynasty Egyptian due to the “foreign overtones, as exhibited by Aegeanlike animal scenes and Near Eastern criss-cross hatching and decorative drill work, as well as by animal scenes with Cypriot or eastern Mediterranean style” (1998: 27, 30). Plus, ivory-decorated furniture was brought from the Levant during the time of Tuthmosis and his successors (Potts 1987: 69).

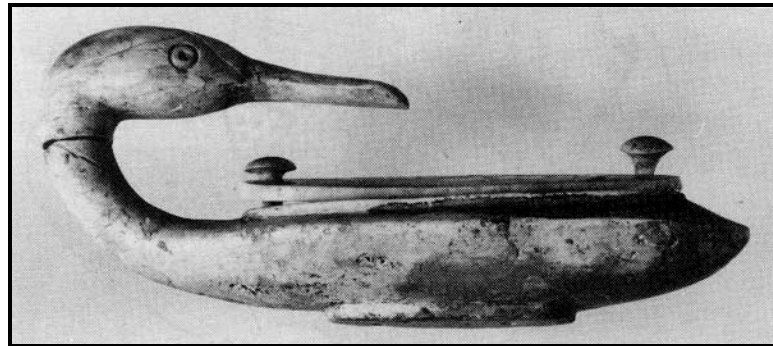
### **Duck-shaped Containers**

The duck containers alluded to in the discussion of the Ras Shamra ivories are an interesting phenomenon, and especially germane to the discussion since one was recovered from the Uluburun and is included in the stable isotope ratio analyses for this thesis (KW 2534; see Figure 29). Duck-shaped containers were popular in the Levant and have been recovered from Ras Shamra, Alalakh, Kamid el-Loz, Lachish, Megiddo, Tel Dan, Shechem, Lachish, Meskene-Emar, Tell el Far‘ah, Akko, Sidon, and Gezer (Lilyquist 1998: 27; Gachet 1993: 77; Karali-Yannacopoulos 1993; Liebowitz 1987: 14). They have also been found at Knossos and Mycenae, in addition to some other sites (see below) and most definitely represent imports (Gachet 1993: 77; Krzyszkowska 1990: plate 17b). The containers date from 1400-1200 B.C., although a tighter chronology of 13<sup>th</sup> to 12<sup>th</sup> century may be the case at Ras Shamra, Kamid el-Loz, Lachish, and Megiddo (Lilyquist 1998: 27, citing a personal communication with Caubet; Liebowitz 1987: 14). The example from Tomb 24 at Megiddo is not MB II, but was out of context and is LB II instead (Liebowitz 1987: 14), although Gachet (1993) does mention some Iron Age examples from Tell Qasile and Gezer (Gachet 1993: 77). Duck pyxides are always

Figure 29: Duck-shaped container from Uluburun (KW 2534).



Figure 30: A back-turned head duck container from Ugarit (Ras Shamra) (adapted from Gachet 1993: 84).



carved from hippopotamus ivory, generally from lower canines for the body (Gachet 1993: 68; Krzyszkowska 1990: 78).

Two types are represented at Ugarit (Ras Shamra): duck containers with a back-turned head and an oval lid (17 examples, see Figure 30) and containers with a forward looking head, two-part wing-shaped lid, and a separate tail joined to the body (five examples). These two types are extremely standardized shapes, as with most ivory objects at Ras Shamra, and were painted. The majority of the containers were recovered

from funerary contexts, while some fragments such as heads, necks, lids or bases (never bodies) derive from the houses, suggesting composite pieces made of ivory and wood (Gachet 1993: 68).

The back-turned head shape is considered to have originated in New Kingdom Egypt, but is well represented and standardized in Syria and Palestine at such sites as Alalakh, Kamid el Loz, Megiddo, Akko, Sidon, Lachish, and Gezer. They have also been found in Cyprus at Enkomi and Kalavassos-Ayios Dhimitrios as well as in the Aegean at Ialysos, Asine, and possibly at Zafar Papoura and Mycenae. The forward looking head type has a similar origin and distribution, but occurs less frequently. This type has been recovered from Alalakh, Meskene-Emar, Byblos, Kamid el Loz, Megiddo, and Tell Dan, in addition to Cypriot examples from Enkomi and Kition (Gachet 1993: 77). However, while some scholars consider the back-turned head type as blatant copies of Egyptian types, possibly constructed of wood (Bryan 1996: 49), Lilyquist (1998: 27) argues that for both of the types “nothing in Egypt can be dated earlier than examples in the eastern Mediterranean, and those in Egypt are objectively later. The “turned back” examples are certainly more plentiful outside Egypt, and their vibrant style is more at home in the Levant,” thus declaring the two types as Canaanite. The tomb of Kenamun (Dynasty 18, from the time of Amenhotep II) depicts a back-turned head duck container, but this should be interpreted as a Syrian import or Egyptian-made in a Syrian style, possibly by a Canaanite ivory-worker (Lilyquist 1998: 27, 30). Liebowitz (1987: 14) agrees, saying “the type does not appear to have been typical of Egypt” and are not present before the 18<sup>th</sup> Dynasty.



## **Ivory Workshops in Cyprus**

Cyprus enjoyed a thriving ivory-working tradition, as discussed in Chapters Three and Four with the discussion of hippopotamus and elephant faunal material. But Cyprus was home to neither of these animals, and consequently had to import the ivory, and sometimes subsequently export it as well. Alashiya, commonly regarded as Cyprus, is recorded as sending ivory or ivory objects to Egypt (EA 40), probably as some sort of gift-exchange between rulers. (Hayward 1990: 104; Bass 1997: 160; Krzyszkowska 1990: 19, 29).

Much of the ivory from Cyprus is hippopotamus and dates to Late Cypriot II-III (c. 1450-1050 B.C.) and common objects in the LC III include boxes, handles, and mirrors (Reese 1998: 140,142; Karageorghis *et al.* 2000). Like the Aegean, and unlike Palestine, there is much evidence for ivory carving on the island, principally at Hala Sultan Tekke, Kition, Palaepaphos (Kouklia), and Enkomi (Reese 1998: 142; Åström 1993: 101). Excavations at Hala Sultan Tekke have uncovered approximately thirty ivory artifacts, with half coming from the tombs and the other half from the LC III (early 12<sup>th</sup> century) settlement (Åström 1993: 101). Two sawn and two partly worked pieces of elephant ivory were from the settlement, suggesting an ivory workshop (Reese and Krzyszkowska 1996: 325-326). Åström (1993) proposes that the ivory workshop at Hala Sultan Tekke also produced works in stone, as at Enkomi where Dikaios (1969: 99-100) proposed a joint stoneworking/ivorycarving workshop based on the findings of unworked stone cylinders in association with waste from ivory carving (Åström 1993: 102). The artisans responsible for carving ivory may also have worked on stone since ivory was expensive and probably not always readily available.

As mentioned previously, a molar was present at Kition from a Late Cypriot IIIA-B context, but it is extremely unlikely this elephant was originally from Cyprus (Reese 1998: 140; Reese and Krzyszkowska 1996: 325). From Well 1 of Temple 1 in Kition was the tip of an incisor dating from 1300-1000 B.C. (Reese 1998: 140). Palaepaphos-*Teratsoudhkia* yielded a number of LC I-III ivories carved from hippopotamus incisors, including a waste piece, whereas abundant debris from ivory working was present at Kouklia-*Evreti* from Late Cypriot III period (Reese 1998: 140; Reese and Krzyszkowska 1996: 326). Plus two upper canines from Episkopi-Bamboula recently turned up in 2001, one of which had saw marks on it. The Kition incisor associated with the temple and a 13<sup>th</sup> century unmodified upper canine from a tomb at Enkomi may be votive offerings, similar to other unmodified hippopotamus teeth associated with temples at Ai and Samos, as well as at the Minet el-Beidha (Ras Shamra) tombs (Reese 1998: 142).

### **The End of Ivory-working in the LBA Eastern Mediterranean**

The ivory-carving tradition across the eastern Mediterranean suffered the same fate as much else c. 1200-900 B.C.: it disappeared, and was not seen again until the ninth century when the renowned North Syrian and Phoenician schools of ivory-working arose (see Winter 1973, 1976; 1981; Kantor 1956; Krzyszkowska 1990: 112-113). These schools had their roots in the LBA ivory tradition, as evidenced by some common motifs which transcend the intervening “dark” period. These schools saw an eventual end in the eighth century, which some scholars link to the depletion or extinction of Syrian elephants (Miller 1986: 32; Scullard 1974: 30; Barnett 1939: 18), but this argument ignores the fact that hippopotamus ivory (or even bone) could have been substituted.

## Chapter 6

### Principles of Stable Isotope Ratio Analysis

After a review of the pertinent archaeological and historical evidence, it becomes evident that a detailed program of source discrimination using isotope ratio analyses is in order, so as to trace the source of the raw material of ivory. Analyses conducted by van der Merwe *et al.* (1990) using  $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratios in the bone collagen of modern African elephants demonstrated the efficacy of this method for provenancing elephant bone and ivory. Furthermore, recent research by White *et al.* (1998) testified to the utilization of  $^{18}\text{O}/^{16}\text{O}$  to distinguish between populations. Thus a detailed analysis of the elephant and hippopotamus ivory from the Uluburun shipwreck was carried out by determining the isotope ratios of  $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ ,  $^{18}\text{O}/^{16}\text{O}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$ .  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  will be measured from the collagen component of the ivory and bone samples, if preserved, whereas  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  was measured from the apatite (inorganic component of ivory and bone). An ashed sample will be used to analyze the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio. All measurements were made with a Finnigan MAT Delta plus XL mass spectrometer or by ICP-MS (Inductively Coupled Plasma Mass Spectrometry). The ivory samples may be provenanced by comparing the strontium isotope ratio values obtained with published geological data on the regions under study (namely, Syria, Palestine, Egypt, Sudan, and Libya). The carbon, nitrogen, and oxygen isotope ratios are useful in reconstructing the environment of the animal, and therefore help to narrow down the possibilities.

Isotope ratio analysis has been utilized in archaeological bone chemistry studies to reconstruct the diet and health of ancient populations, palaeoclimate, as well as to

study residence and mobility. Katzenberg and Harrison (1997) offer a comprehensive review of the state of archaeological bone chemistry studies. The various isotopes of a given element differ in the number of neutrons, while sharing the same number of protons and electrons. Mass spectrometry is used to determine the amount of a given isotope present in the sample. Stable isotopes do not change over time, and the isotope ratios are used to characterize bone and ivory samples. The isotope ratios are expressed using the delta ( $\delta$ ) notation in parts per thousand (per mil: ‰), and are derived from the equation below, where R is the ratio of the heavier isotope to the lighter isotope:

$$\delta(\text{‰}) = [(R_{\text{sample}}/R_{\text{standard}})-1] \times 1000$$

### **Stable Carbon Isotope Ratios**

The two stable carbon isotopes are  $^{12}\text{C}$  and  $^{13}\text{C}$ .  $^{12}\text{C}$  accounts for 98.89% of naturally occurring carbon, whereas  $^{13}\text{C}$  accounts for 1.11%. The international standard is derived from the *Belemnitella americana* marine fossil limestone from the Peedee geological formation in South Carolina (PDB). Because limestone has more  $^{13}\text{C}$  than organic matter, the  $\delta^{13}\text{C}$  values from analyses of organic tissues are negative. The variation in  $\delta^{13}\text{C}$  in plants reflects the different photosynthetic processes of  $\text{C}_3$ ,  $\text{C}_4$ , and CAM (crassulacean acid metabolism) plants, which all obtain their carbon from atmospheric  $\text{CO}_2$ .  $\text{C}_3$  plants generally grow in temperate climates and include trees, shrubs, tubers, and temperate grasses, while  $\text{C}_4$  plants are subtropical grasses capable of growing in hot and dry climates. Fractionation occurs in biological systems because  $^{12}\text{C}$  reacts first since it is lighter and leaves behind the heavier  $^{13}\text{C}$ , so that plants end up with far less  $^{13}\text{C}$  than is present in the atmosphere. The  $\delta^{13}\text{C}$  values of  $\text{C}_3$  plants range from

-22‰ to -38‰ (average -26‰). Compared to C<sub>3</sub> plants, C<sub>4</sub> plants have a reduced discrimination against <sup>13</sup>C isotopes, and consequently have values that range from -9‰ to -21‰ (average -12.5‰) (Tykot and Staller 2002; Larsen 1997: 271; Sukumar and Ramesh 1992).

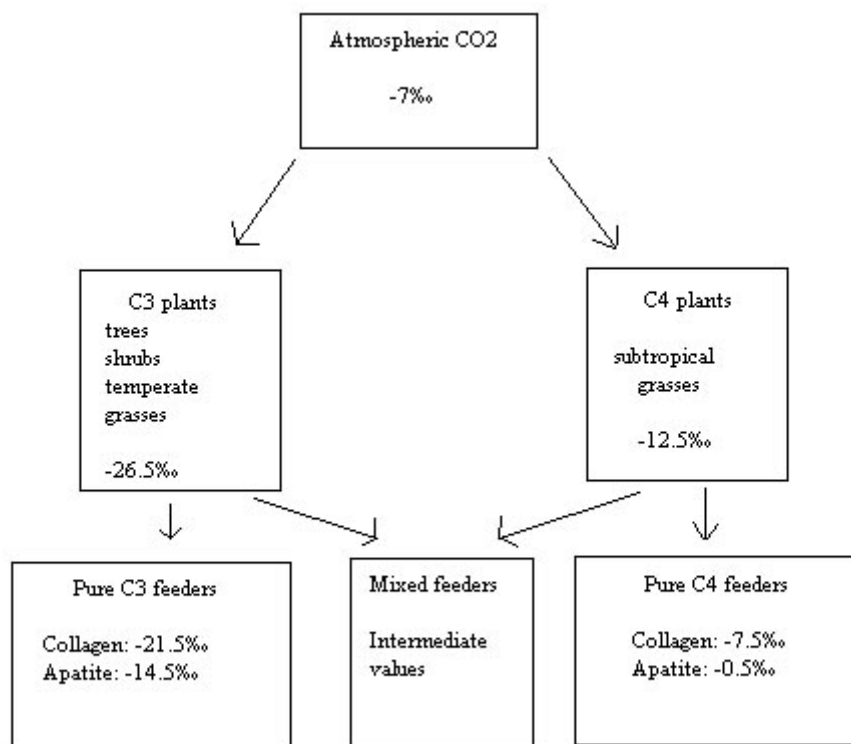
Notice these values do not overlap, thereupon making it possible to differentiate between animal diets based solely on either type of plant. C<sub>4</sub> plants have  $\delta^{13}\text{C}$  values that are on average about 14‰ less negative than C<sub>3</sub> plants. Different carbon isotope ratios may occur between plants of the same species due to differences in 1) atmospheric CO<sub>2</sub> in forested and high altitude areas, and 2) latitude, which will affect the amount of sunlight and therefore the efficiency of photosynthesis. Moreover, carbon isotope ratios will differ within the plant from one part to another. Considering that most animals eat a variety of plants, these intra-species and intra-plant differences in carbon isotope ratios are of little concern when reconstructing diets since the analysis is aimed at a larger scale, that is, the relative contribution of C<sub>3</sub> versus C<sub>4</sub> plants to the diet (Larsen 1997: 271).

An additional consideration, however, is the CAM photosynthetic pathway. This pathway is designed in such a way as to allow the plant to switch between a C<sub>3</sub> or C<sub>4</sub> pathway depending on the environmental conditions, and CAM plants (cacti and other succulents) have  $\delta^{13}\text{C}$  values intermediate between and overlapping those of C<sub>3</sub> and C<sub>4</sub> plants. Marine plants also have  $\delta^{13}\text{C}$  values between and overlapping those of C<sub>3</sub> and C<sub>4</sub> plants (Larsen 1997: 272; Tykot and Staller 2002).

The isotopic signature of the plants are passed on to herbivores, after a trophic shift due to fractionation by metabolic processes (van der Merwe *et al.* 1988: 165). Generally the trophic level shift is around 5‰ from plant to the collagen of the animal

feeding on the plant (Sukumar and Ramesh 1992: 536; Sukumar and Ramesh 1995: 369; Tieszen *et al.* 1989; DeNiro and Epstein 1978). Collagen moreover largely reflects the  $\delta^{13}\text{C}$  values of the protein component of the animal's diet, since collagen is formed from amino acids. Conversely, the apatite represents the whole diet (carbohydrates, fats, and protein), and is therefore more useful for characterizing the entire diet, and in particular the carbohydrate portion of the diet, since to a large extent it is not represented in collagen (Larsen 1997: 272), as determined by controlled feeding laboratory experiments (*cf.* Ambrose and Norr 1993; Tieszen and Fagre 1993). See Figure 31 for a summary of the carbon isotope fractionation through the foodchain and the difference in  $\delta^{13}\text{C}$  values between collagen and apatite.

Figure 31: Carbon isotope fractionation in terrestrial foodchains



The  $\delta^{13}\text{C}$  values in elephant bone collagen reflect a mixture of  $\text{C}_3$  foliage or  $\text{C}_4$  grasses in the diet, and are directly proportional to the density of  $\text{C}_3$  browse, in addition to having a simple linear relationship to tree density (van der Merwe *et al.* 1988: 163; 1990: 744). Of particular note is the possibility that Forest elephants may be identified isotopically by their more negative  $\delta^{13}\text{C}$  values due to what is known as the “canopy effect,” whereby the denser the forest, the more negative the  $\delta^{13}\text{C}$  value due to the recycling of isotopically light  $\text{CO}_2$  under the forest canopy (van der Merwe *et al.* 1988: 171; 1990: 745).

### **Stable Nitrogen Isotope Ratios**

Nitrogen isotope ratio analysis has focused mainly on differentiating between terrestrial and marine food resources, as well as weaning practices (Katzenberg and Harrison 1997). The stable nitrogen isotopes are  $^{14}\text{N}$  (99.95% of all nitrogen) and  $^{15}\text{N}$  (0.05%). The international standard is atmospheric nitrogen (cleverly referred to as Ambient Inhalable Reservoir, or AIR). Stable nitrogen isotope ratios are most useful for differentiating between marine and terrestrial food sources, because nitrogen-fixing plants (and bacteria) convert nitrogen directly from the air into plant material, whereas other plants obtain nitrogen through bacteria on their roots. Nitrogen-fixing plants have  $\delta^{15}\text{N}$  values close to zero since their values are similar to air, whereas non-fixing plants have values approximately 2‰ higher than nitrogen-fixers because the nitrates in the soil, derived from the decomposition of organic matter, have relatively more  $^{15}\text{N}$  than  $^{14}\text{N}$  compared to the atmosphere. Terrestrial plants have  $\delta^{15}\text{N}$  values which are on average

4‰ lower than those of marine plants, and terrestrial plants have a wide spread of  $\delta^{15}\text{N}$  values. For terrestrial foodchains in general, there is a 2-3‰ trophic level shift higher from plants to herbivores, as well as a 2-3‰ trophic level shift from herbivores to carnivores, which is due to the preferential excretion of  $^{14}\text{N}$ , leaving behind  $^{15}\text{N}$  in the animal. Marine ecosystems also have trophic levels shifts, but more of them, so that “ $\delta^{15}\text{N}$  values in marine organisms and those in other aquatic settings (e.g., rivers and lakes) are higher than in terrestrial ones (up to 20‰)” (Larsen 1997: 283).

The  $\delta^{15}\text{N}$  values are furthermore influenced by climate, so that “cool forest soils have low  $\delta^{15}\text{N}$  values, owing to higher nitrogen fixation and mineralization rates, and hot savannah or desert soils have higher  $\delta^{15}\text{N}$  values. Other contexts producing generally high  $\delta^{15}\text{N}$  soils include areas with a history of evaporation (e.g., saline soils) and those enriched in organic matter” (Larsen 1997: 283). Indeed, the nitrogen isotope ratios ( $^{15}\text{N}/^{14}\text{N}$ ) in bone collagen of African mammals has been shown to be related to rainfall or water stress, and these values are caused by differential fractionation of nitrogen during fixation or absorption in plant groups (Tykot and Staller 2002; van der Merwe *et al.* 1990: 744). The  $\delta^{15}\text{N}$  values in bone collagen of elephants and hippopotami is higher in more arid habitats, which is due to the higher  $^{15}\text{N}$  levels of the local vegetation, as well as the effect of drought stress on the protein metabolism of the animals, which is expected in areas with an annual rainfall of <400 mm (Vogel *et al.* 1990: 747; van der Merwe *et al.* 1990: 745). In areas with <500 mm the  $\delta^{15}\text{N}$  of elephants will be higher than 10‰ (Heaton *et al.* 1986). In fact, these effects are such that terrestrial animals living in arid environments will have higher  $\delta^{15}\text{N}$  values than marine animals, and water-dependent herbivores have lower nitrogen isotope ratios (2-4‰) than drought-tolerant



ones (i.e. ones with physiological adaptations for water conservation) in the same habitat (Ambrose 1986: 707, 721; Ambrose 1989: 293; Larsen 1997: 284).

### **Stable oxygen isotope ratios**

Oxygen isotope ratio studies have mainly been utilized in climate studies “on the principle that  $\delta^{18}\text{O}$  of bone has a positive linear relationship to the isotopic composition of ingested water, which is indicative of climate” (Katzenberg and Harrison 1997: 275). The stable isotopes of oxygen are  $^{16}\text{O}$  (99.759% of all oxygen),  $^{17}\text{O}$  (0.037%), and  $^{18}\text{O}$  (0.204%), but only  $^{16}\text{O}$  and  $^{18}\text{O}$  are used for isotope ratio analysis. Studies have also been conducted using oxygen isotope ratio analysis on human bone phosphate to differentiate between geographically separated populations, and to attempt to ascertain their point of origin (*cf.* White *et al.* 1998). The isotopic composition of water consumed by mammals is chiefly controlled by the composition of local meteoric precipitation, which is determined by geography and climate. The  $\delta^{18}\text{O}$  is hypothesized to decrease with distance from the sea, with elevation, and with falling temperature. Humidity can also have an effect on  $\delta^{18}\text{O}$  values (White *et al.* 1998: 645; Larsen 1997: 289; Katzenberg and Harrison 1997: 275).

However, the range of variation in oxygen isotope ratio measurements makes interpretation difficult, and “part of this variation is due to problems with the identification of specific water sources (the primary source of  $^{18}\text{O}/^{16}\text{O}$ ) for the deceased individuals, [and with] problems with turnover in bone” (Price *et al.* 2000: 911), in addition to geographical movement and dietary heterogeneity (White *et al.* 1998:645).

Studies which have focused on evaluating this variation within a population have ranged from finding very low variation (i.e. 1‰) to statistically significant variation (White *et al.* 1998:645). Furthermore, diagenesis of oxygen can occur from equilibrium with groundwater, which may be exacerbated by invasive biological organisms (White *et al.* 1998:647-48; Ayliffe *et al.* 1992).

### **Strontium Isotope Ratios**

The  $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ , and  $^{18}\text{O}/^{16}\text{O}$  isotope ratios provide three avenues of investigation in order to ascertain the provenance of the ivory samples from the Uluburun shipwreck, and may be compared against one another to discover if any isotopic ratio signatures exist within the sample set. However, because these isotope ratios are based on climate and vegetation, animals from geographically separated regions could exhibit the same isotopic ratios if the environments are similar enough. As a result, a fourth isotope ratio, that of  $^{87}\text{Sr}/^{86}\text{Sr}$ , is evaluated in the Uluburun ivories. Strontium isotopes have proved particularly useful in other studies in identifying geographically distinct populations and immigrants (*cf.* Price *et al.* 1994a, 1994b, 1998, 2000, 2001; Sillen *et al.* 1998; Cox and Sealy 1997; Ezzo *et al.* 1997; Grupe *et al.* 1997; Sillen and Sealy 1995; Sealy *et al.* 1991; van der Merwe *et al.* 1990; Vogel *et al.* 1990; Ericson 1989) due to their ability to produce a sufficiently unique signature mirroring the local geology of the region (van der Merwe *et al.* 1990: 744; Price *et al.* 2000: 903).  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios derived from ivory or bone reflect the average Rb/Sr ratios of the parent rocks in a particular area, which in turn is based on the age (because  $^{87}\text{Sr}$  is produced by the slow radioactive decay of  $^{87}\text{Rb}$ , which has a half-life of approximately  $4.7 \times 10^{10}$  years) and the initial Rb/Sr

composition of the rock. Thus geologists use Sr ratios to date geological formations by the proportion of  $^{87}\text{Rb}$  that has decayed. The higher the initial Rb/Sr ratios and the older the rock, the higher the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio (van der Merwe *et al.* 1990: 746; Price *et al.* 1998: 407; 2000: 906; 2002: 118; Vogel *et al.* 1990: 747; Koch *et al.* 1995: 1340-3). This ratio value will be virtually similar in the rock, groundwater, soil, plants and animals of the region, due to the fact that the relative mass differences between  $^{87}\text{Sr}$  and  $^{86}\text{Sr}$  are small and therefore no isotopic fractionation takes place (some exceptions are discussed below). The strontium in the soil is absorbed by the water and then up into the food chain, where it is then deposited in the hard tissues (such as bone and ivory) in animals (Ericson 1985: 503; Koch *et al.* 1995: 1340-3; Price *et al.* 1998: 407; 2000: 906; 2002: 118, 121).  $^{86}\text{Sr}$ , on the other hand, is a stable isotope (Koch *et al.* 1995: 1340-3).  $^{88}\text{Sr}$  is the most abundant strontium isotope in nature (c. 82.53%) whereas  $^{87}\text{Sr}$  makes up 7.04%,  $^{86}\text{Sr}$  9.87%, and  $^{84}\text{Sr}$  0.56% of all strontium. As a result, the total global ratio of  $^{87}\text{Sr}/^{86}\text{Sr}$  is approximately 0.71327 (7.04/9.87) (Price *et al.* 1998; 2000; 2002).

Research on strontium levels across the globe have already discovered some generalizations regarding strontium levels. Sr ratios usually range between 0.700 to 0.750 across the globe. Overall, animals in areas with old granitic crust have high Sr isotope ratios ( $>0.715$ ), whereas in areas with young volcanic, basaltic, or marine sediments the animals will have low values (Koch *et al.* 1995: 1340-3; van der Merwe *et al.* 1990: 746). Young volcanic soils, such as those found in the Rift Valley, have ratios similar to the value of ocean water: 0.70906. In fact the strontium budget of the ocean remains remarkably homogeneous due to the long residence of Sr in a rapidly mixing environment (Stein *et al.* 2000: 2039). In a study by Price *et al.* (1998: 407) the granitic

sediments in one area had isotopic ratios greater than 0.710, but even ranging to 0.750 and higher, whereas the glacial origin loess and marine carbonates (glacially redeposited chalk sediments) had strontium isotope ratios ranging between 0.708 and 0.710. The difference in these values enabled him to track migration in the Bell Beaker culture.

Geologically young rocks (<1-10 million years) with low Rb/Sr ratios (i.e. Late Cenozoic volcanic fields in the highlands of Mesoamerica) have  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of less than 0.706. Basalt, which has a very low initial Rb/Sr composition, can have  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of less than 0.704, compared to clay-rich rocks with high Rb/Sr ratios (e.g. shales and granites) with values up to 0.730 (Price *et al.* 2000: 906; 2002: 118). However, granites may vary widely from 0.700 to 0.737, whereas those of ocean basalts remains relatively invariant at about  $0.7037 \pm 0.0001$  (Ericson 1985: 505-506). Considering that modern thermal ionization mass spectrometers (TIMS) have a measurement error between  $\pm 0.00003$  and  $\pm 0.0001$  for strontium isotope ratios, generally very slight variations are easily detectable. Even areas with similar geology will have different strontium ratios, which is the value of such an analysis in the first place. Another interesting consideration is that “because the strontium values for continental granites are linearly correlated with geological age... one can estimate the expected isotopic ratio for the granite if its geological age is known” (Ericson 1985: 505). This could prove particularly useful for approximating the  $^{87}\text{Sr}/^{86}\text{Sr}$  values for regions where the strontium isotope ratios are unknown or have not been published. Similarly, once a  $^{87}\text{Sr}/^{86}\text{Sr}$  value is obtained for the ivory samples, and working under the premise that the underlying rock may be granite, one could reconstruct the age of the rock and therefore potentially the provenance.

Nevertheless, some caution must be used in interpreting strontium isotope data, since, depending on the area, the strontium isotope values may vary locally between the bedrock, sediment, and water, and Sr ratios of skeletal components (bone, dentine, enamel) may vary as well (Price *et al.* 2002: 119). Moreover, “biologically available strontium”, that is, strontium circulating in the natural environment, may be different from geological strontium due to atmospheric sources of strontium (aeolian and precipitation) and differential mineral weathering of rocks (Price *et al.* 2002: 119-120; citing Chadwick *et al.* 1999; Miller *et al.* 1993; Graustein and Armstrong 1983). Price *et al.* 2002: 119) resolves these problems by offering that “the impacts of such atmospheric contributions are probably minimal in most areas, and particularly in much of prehistory.”

More insights into specifics of strontium in the environment include the following: a) alluvial sediments generally have  $^{87}\text{Sr}/^{86}\text{Sr}$  values that are averaged from the geological sources; b) plants growing close to rivers will have Sr values close to the value of the river water, while those not close to rivers will have Sr values of the soil, and the same goes for the animals eating these plants; c) the Sr value of plants is distinct from bedrock values; and d) surface water may have a lower Sr ratio than the surrounding plants and soils (Price *et al.* 2002: 120-121, citing Sillen *et al.* 1998). Thus the one to one relationship of strontium values between bedrock geology, sediments, plants, and water has been dismissed, which shifts the emphasis to a “biologically available strontium” approach when employing strontium isotopes. Luckily animal skeletal tissues serve as an averaging mechanism for the potentially heterogeneous strontium values available in the

local environment, and thus answer the question of how to measure biologically available strontium isotope levels (Price *et al.* 2002: 122; see also Sillen *et al.* 1998).

Diagenesis (addition, loss, or replacement) of strontium in skeletal tissues is another very important consideration however. Initially the problem was considered dealt with if the samples were properly cleaned, as with acetic acid (Ericson 1985: 508), or repeatedly washed in acetic acid/sodium acetate buffer solution (Sealy *et al.* 1991: 399). Other techniques for removing contamination are discussed in Price *et al.* (1992), Sillen and Sealy (1995), Koch *et al.* (1997), and Nielsen-Marsh and Hedges (2000; cited by Price *et al.* 2002: 127). Sealy *et al.* (1991, 1995) addressed problems of diagenesis of strontium in bone, and concluded that while diagenesis definitely affects the elemental abundance (Sr concentration), it does not seem to affect the isotopic ratio to any considerable degree. However, more recent studies by Budd *et al.* (2000) and Chiaradia *et al.* (2003) refute this. Moreover, treatments involving weak acids to remove diagenetic material assume that the diagenetic Sr is additive and not exchanged (Budd *et al.* 2000: 668). Horn and Müller-Sohnius (1999) recently criticized Grupe *et al.* (1997) for not recognizing signs of diagenesis in their data (increases in Sr content and changes in Sr isotope ratio between enamel and bone) (discussed in Budd *et al.* 2000: 668; see also Grupe's reply: Grupe *et al.* 1999).

Budd *et al.* (2000) compared the Sr concentration and isotope ratios in enamel and dentine from prehistoric, Romano-British and medieval individuals in Britain with soil samples taken from each of the sites. They found that the Sr isotope ratios from the enamel and soil samples were significantly different. The dentine Sr ratios were also different from the soil, but closer in value. These results are not surprising if the

individuals had migrated in their lifetime, since the Sr isotope ratio of the enamel will reflect in utero conditions (the diet of the mother) or the first few years of an individual's life, when the enamel was formed. It is the difference between the dentine and enamel which is worrisome, as both tissues are formed at the same time. "Secondary dentine" can be incorporated into the dentine as the individual ages, but the researchers sidestepped this problem by removing the tooth crowns and tissues adjacent to pulp cavity to obtain samples of "predominantly" primary dentine (Budd *et al.* 2000: 688-689).

Another indication of diagenesis is an increase of the Sr concentration (ppm). The researchers demonstrate the presence of diagenesis in Figure 32 where the Sr concentration is plotted against the parameter standard measure of difference in  $^{87}\text{Sr}/^{86}\text{Sr}$  values between the samples and the 'bulk earth' (expressed as  $\Delta\epsilon^{87}\text{Sr}$ ). The same data are reproduced in Price *et al.* (2002) as Figure 33. These graphs show that Sr concentration in dentine is constantly higher than in enamel, in addition to showing the different strontium isotope ratios between the enamel and dentine, as discussed above. Since the strontium ratios of the dentine are closer to the soil values (dotted line), they have lower  $\Delta\epsilon^{87}\text{Sr}$ , presumably as a result of diagenesis. However, the diagenesis *appears* to be primarily additive, as the strontium concentrations are also higher in dentine than enamel, and the enamel strontium concentrations are similar to modern samples not affected by diagenesis. The researchers then demonstrate, after some elaborate calculations, that most of the samples were affected by partial replacement (leaching and deposition) of the sample (biogenic) strontium with strontium from the soil (Budd *et al.* 2000: 691-693). They conclude that enamel, as a more resistant tissue to diagenesis, serves as a reliable test subject for research utilizing strontium isotope ratios, whereas dentine is believed

Figure 32: Sr concentrations plotted against  $\Delta\epsilon^{87}\text{Sr}$  for enamel (open symbols) and dentine (filled symbols) samples. The dashed line represents aqueous soil leaches from the four sites (adapted from Budd *et al.* 2000: 690)

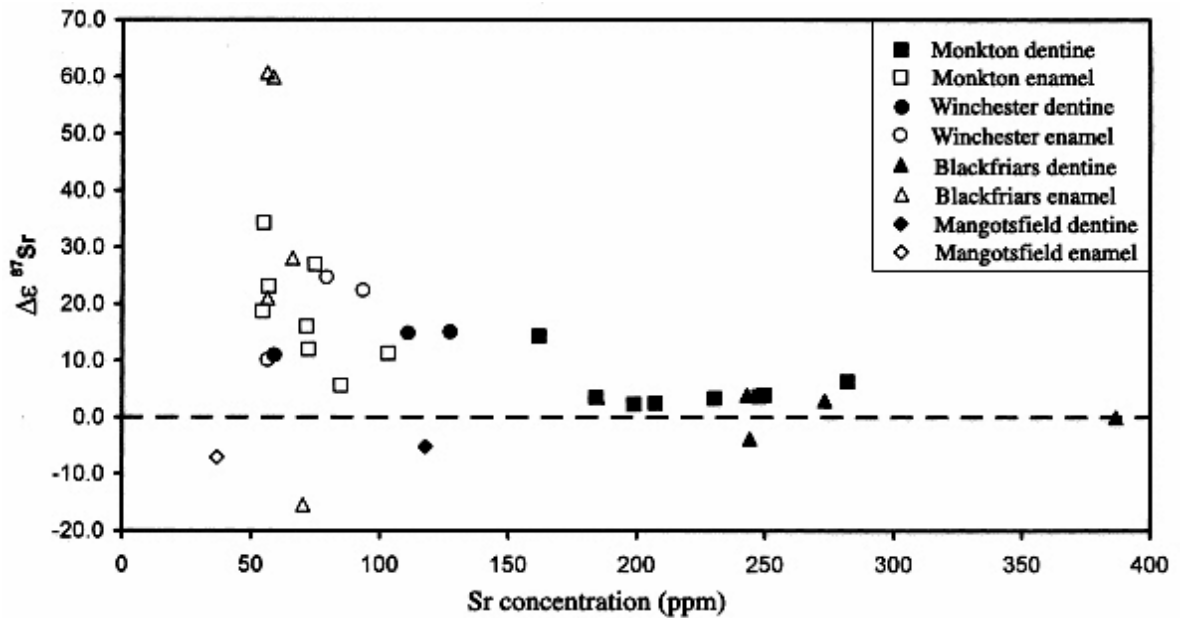
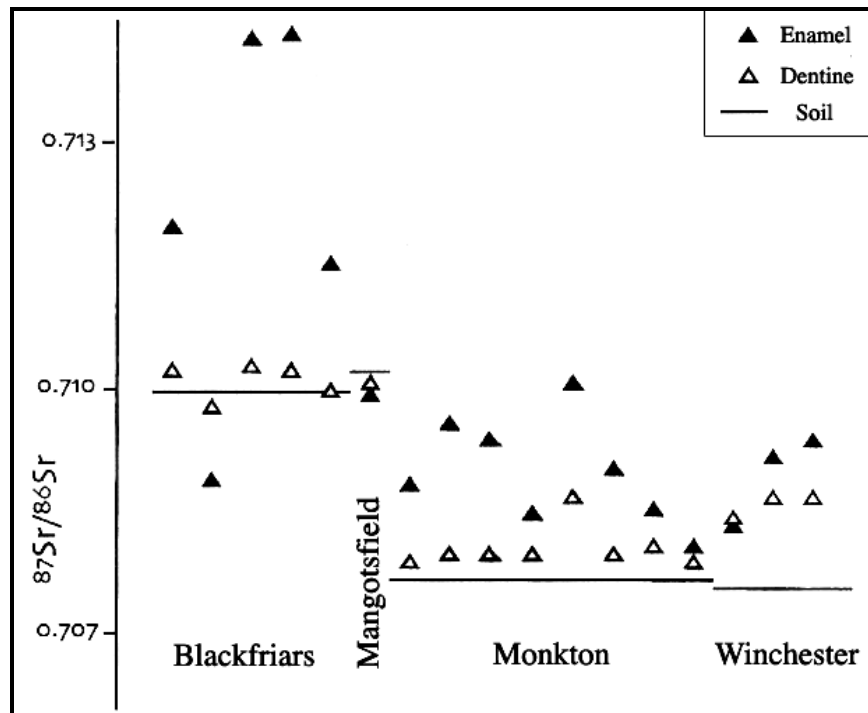


Figure 33: Available soil (line), enamel (solid triangle), and dentine (open triangle)  $^{87}\text{Sr}/^{86}\text{Sr}$  values from four sites in England (figure adapted from Price *et al.* 2002: 126; data from Budd *et al.* 2000).



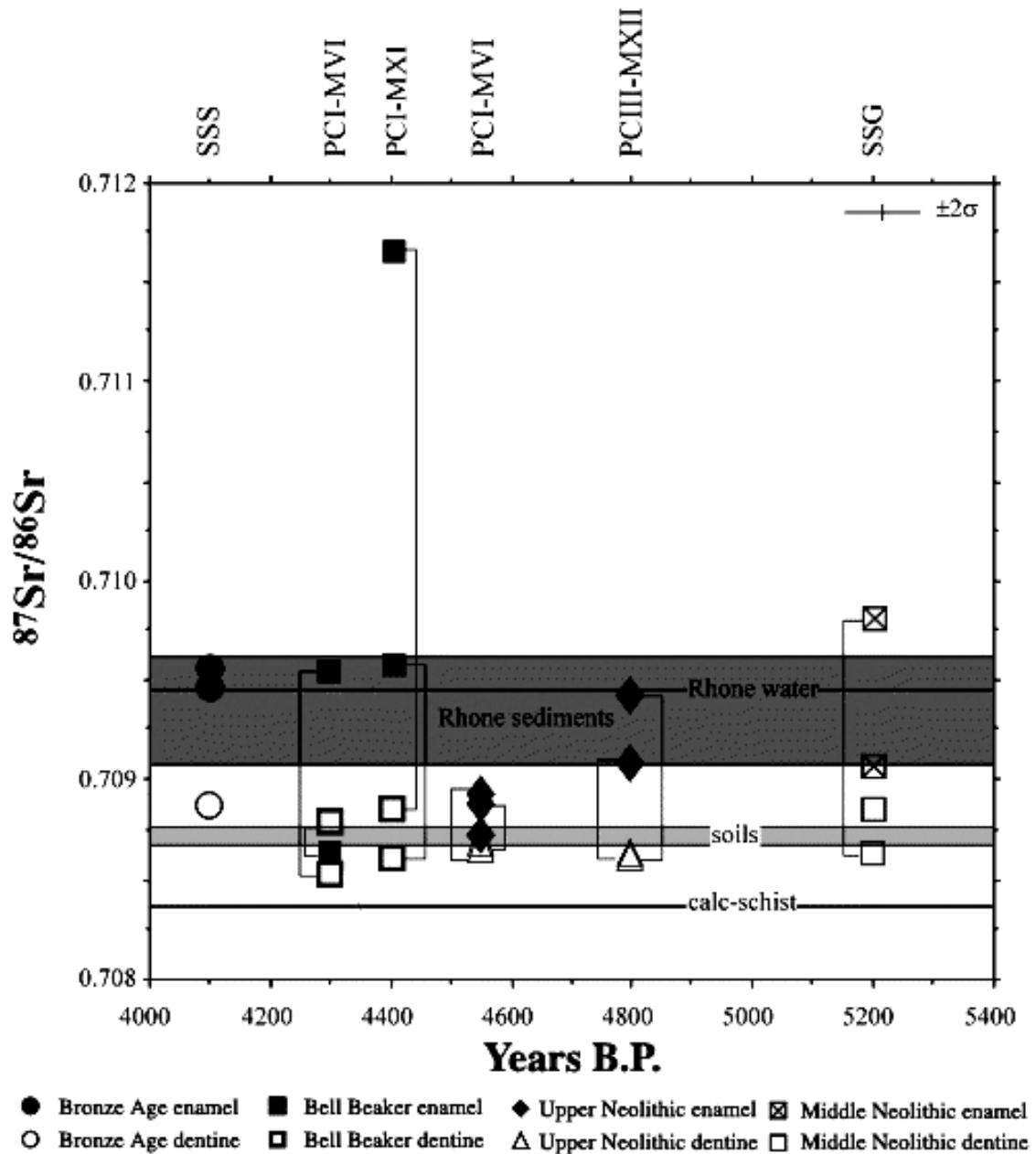


unreliable. However, dentine could be used as a proxy for determining how effective pretreatments were in removing contamination. If similar strontium ratios for enamel and dentine were obtained, then the treatment would be considered successful and could be used on bone, which would have a different strontium ratio anyway if the individual migrated since bone is subjected to turnover (and therefore could not be compared with enamel or dentine).

Chiaradia *et al.* (2003) came to similar conclusions after analyzing the dentine and enamel of individuals from the necropolis of Sion (Switzerland) for strontium as well as lead isotopes. Their research showed consistently higher Sr concentrations in the dentine relative to the enamel, as well as differences in their isotopic ratios (Figure 34). Two teeth from the same individual, moreover, had different Sr and Pb isotopic ratios for the enamel, suggesting diagenesis of enamel as well.

Taking all of this into account, Price *et al.* (2002: 131-132) offer some suggestions. Obviously enamel is preferable to dentine or bone, when available, as it is less susceptible to diagenesis. It is moreover a good idea to establish what the biologically available strontium is for a region, and the best way to do this is to analyze the local faunal assemblage, especially enamel or shells. The enamel of the faunal assemblage could be compared to modern enamel from the same species (and same area) to get an idea of the level of diagenesis. Thus while Budd *et al.* (2000), Price *et al.* (2002), and Chiaradia *et al.* (2003) have brought valid concerns to the attention of researchers, there are ways to work around the problems of diagenesis and the potential heterogeneity of strontium in a given locale. Unfortunately with ivory only dentine is available, since a) it is only found on two faces of the hippopotamus lower canine, b)

Figure 34:  $^{87}\text{Sr}/^{86}\text{Sr}$  vs. age of the ancient teeth from Sion, Switzerland. The square brackets join isotopic compositions of dentine-enamel pairs of the same tooth. Also reported are the isotopic compositions of soil and calc-schists leaches as well as of Rhone sediments and water. PCI, PCIII, SSG, SSS are the burial sites (adapted from Chiaradia *et al.* 2003: 364).



would be carved away as one of the first steps, in the primary sectioning of the tusk, and c) is often worn away through use on the distal end of the tusk. As a result, the dearth or complete lack of enamel on ivory indicates that diagenesis problems are more difficult to demonstrate and/or control for ivory. Another important consideration is that while the high precision of TIMS may detect even very slight variations in strontium isotope ratios and is most amenable to comparing with the geological literature, the work for this thesis had to utilize ICP-MS because of the small sample sizes available and lower cost. Interpretation of the strontium isotope values received must therefore take into account the lower precision of ICP-MS.

## Chapter 7

### Ecological and Dietary Requirements of Hippopotami

Additional lines of evidence for the geographical distribution of the hippopotamus in the Late Bronze Age may be found by examining the ecological and dietary requirements of the animal. As shown in Chapter Six, these factors also prove indispensable for interpreting the carbon, oxygen, and nitrogen stable isotope ratio analyses. In all there are two genera of hippopotami: *Hexaprotodon* and *Hippopotamus*. Only one modern species is recognized in either genus, and these are the West African pygmy hippopotamus (*Hexaprotodon liberiensis*) and the more commonly known *Hippopotamus amphibius* (Eltringham 1993: 41).

First, unlike the pygmy hippopotamus, *Hippopotamus amphibius* cannot live in forest or thick brush. The hippo instead resides in all types of water: rivers, lakes, muddy wallows, and even off the sea shore. The skin of the hippopotamus is very sensitive and cracks if exposed to direct sunlight for too long. The animal therefore requires a source of permanent moisture, whether it be water or its much-loved wallowing medium of mud (Eltringham 1999: 4). Hippos may leave the water source during the day but will return if they become overheated. The body of water hippos inhabit must also be suitably vast to accommodate the male hippos in their territorial requirements. Indeed, the male hippos are only territorial in water and each lords over a strip of shoreline and associated bank. Klingel (1991) documented the sizes of these linear territories in Uganda as varying from 250-500 m on the lake shore, although in rivers they were considerably shorter (50 to 100 m in length) Females, on the other hand, are not territorial and furthermore not tied to any one male territory. After grazing most females return to the

same territory, although some utilize several areas (Klingel 1991: 73-75; Eltringham 1993: 51; 1999: 49-51).

Areas for grazing are just as ecologically important. While the hippo spends the day in the water, during the night the hippo grazes as an individual, except for mothers and their young who feed together. The hippo requires open grassland within traveling distance from the wallows and water. The distance traveled at night may vary from a few hundred meters to several kilometers or more. Studies have shown an average distance of 2.2 to 3.5 kilometers roundtrip, or about 1.0 to 1.3 kilometers from water, with large seasonal differences. The hippopotamus must travel farther during the dry season to find adequate graze, but during the wet season is capable of enlarging its range by resting during the day in temporary wallows. In Uganda, feeding ranges were extended through temporary wallows by as much as 7 kilometers, that is, 10 kilometers from the permanent water source. Such wallows are generally utilized only by non-territorial males (Clemens and Maloiy 1982: 151; Eltringham 1993: 51; 1999: 43, 51-53).

The hippopotamus is a strict grazer of short grasses and follows regular paths to reach the grazing areas, so that after a while there are noticeable trails. The grazing areas are known in the literature as “hippo lawns” because the grazing activities of the hippos keep the grass clipped rather short. The animal plucks the grass with its lips while swinging its head from side to side (Mugangu and Hunter 1992: 346; Eltringham 1993: 51; 1999: 53, 77-78). As a result, certain types of grass are either “selected” or “preferred,” and in fact there is some disagreement among scholars as to which it is. Van Hoven (1983: 47) argues that the hippo is an unselective grazer, because the plucking and swinging of the head “rules out any degree of feed selection.” Indeed, the flat snout and

wide, straight lips of the hippo enable it to graze so close to the soil surfaces that, as Clemens and Maloiy (1982: 151) point out, considerable amounts of soil is inadvertently consumed, thereby strengthening the argument for unselective feeding. Nevertheless, Eltringham (1999: 78, 80-81) suggests that, despite the unselective physiology and feeding behavior, the hippopotamus does exhibit preferences since the types of plants ingested are not in proportion to their occurrence in the natural environment. The hippo may not select for grass species, per se, but rather selects the patches of grass sward in which to feed. Swards are usually composed of only a handful of grass species and the grazing activity of hippos creates an environment which favors the growth of short and creeping grasses. The lips of the hippopotamus are adept at breaking off the short and creeping grasses from the ground, whereas coarse tussock-forming grasses are difficult to break off as they slip between the lips. Fortunately the short and creeping variety are what the hippo favors and they tend to grow aggressively, effectively pushing out other species less agreeable to the hippopotamus.

Several studies have investigated the specific species of grasses in the diet of the hippopotamus. Field (1970, 1972; cited in Eltringham 1999: 79-81) analyzed the stomach contents of the hippos in Queen Elizabeth National Park (Uganda) owing to culling operations, and determined that some species were selected while others were avoided. Such distinctions were made by comparing the percentage of the plant species within the hippos' stomachs with the percentage of the plant species in the natural environment. If the percentage within the stomach is significantly more than within the grassland then the species is said to be selected or preferred, whereas if the percentage within the stomach is less, then the species is avoided. There were, furthermore, seasonal

differences in the frequency of species. Another culling study by van Hoven (1983) in Kruger National Park (South Africa) concluded that hippos largely ate grass in proportion to the availability of the grass, which according to the author agrees with an earlier study in Kruger National Park conducted by Young (1966). Field's studies, nevertheless, are more likely accurate, and thus his conclusions more likely correct, since van Hoven only identified plant species and not their percentages. However, only differentiating between browse and graze is necessary for the purposes of this research, and the hippo is decidedly a grazer, overwhelmingly consuming grasses, some of which are likely to be C<sub>4</sub> grasses.

Even so, hippos are known to consume other types of food, particularly in times of environmental stress such as drought or high grazing animal density, which would limit the availability of grass. These other types of food include elephant dung (Dudley 1996: 488; Dudley 1998: 58), fruit (i.e. *Acacia albida*. Eltringham 1999: 79; Dunham 1990), aquatic plants (van Hoven 1983: 48; Field 1970; Mugangu and Hunter 1992; Eltringham 1999: 79), and even other animals (Dudley 1996: 486-487, 1998: 58-59; Eltringham 1999: 82-84).

While it is generally agreed that aquatic plants are not a significant part of the hippo's diet, small amounts are consumed. Young (1966) in his Kruger NP study found traces of reeds (*Phragmites communis*) in the stomachs of the hippos (as reported by van Hoven 1983: 48). Eltringham (1993, 1999) also reports from Field's research (1970) that hippos were seen eating a floating plant, the Nile cabbage (*Pistia stratiotes*), and having witnessed the same behavior himself, Eltringham is of the opinion that the hippos "appeared to be merely toying with the plants in a rather bored, desultory way and it is

unlikely that many were actually eaten” (1999: 79). However, Mugangu and Hunter (1992) observed hippos foraging on aquatic vegetation in Lake Rutanzige in Virunga National Park, Zaire, during the dry season of 1989. They found that the grasses, other than *Panicum repens*, did not produce adequate levels of crude protein to adequately nourish the hippos, and therefore aquatic plant consumption was likely a response to food shortage (Mugangu and Hunter 1992: 345). Measuring the percentage of crude protein in the diet of animals is means of determining food quality. The specific aquatic species consumed included Nile salad (*Pistia stratiotes*, approx. 70% coverage in Lake Rutanzige), a grass (*Leersia hexandra*) and a sedge (*Cyperus* sp.) (approx. 10% coverage each). However, the hippo foraged more on the sedge and grass than the Nile salad (Mugangu and Hunter 1992: 346, *contra* Field 1970). The hippos were also seen eating a creeping vine (*Ipomoea cairica*) and two herbs (*Justicia flava* and *J. cynorensis*) along the river bank.

Carnivory in hippos, on the other hand, is an even rarer occurrence. Dudley (1996: 486-487) reported instances of carnivory in Hwange National Park, located in the Zambezi of southern Africa, during the 1995 winter dry season. Drought conditions had been instigated by low rainfall and high grazing animal density. Dudley (1998) later detailed further incidents reported to him or personally witnessed in the years following his first publication. Eltringham (1999: 82-84) even gives an account of an episode of cannibalism! Nevertheless, carnivory (and most decidedly cannibalism) are likely the consequence of scavenging due to severe nutritional stress and not predation. As such, the hippopotamus will not be treated as a carnivore in the interpretation of the stable



isotope ratio results, although Dudley (1998: 58) does argue convincingly that hippos have a much broader feeding niche than previously recognized.

Thus, from the diet and ecological requirements of the hippopotamus described above, a more informed interpretation of the results from the stable isotope ratio analyses is discussed in Chapter Thirteen. However, several points may briefly be inferred:

- (a) The hippopotamus is regarded as a strict grazer consuming a diet composed primarily of grasses, including C<sub>4</sub> grasses, and this should become evident in the analysis of the stable carbon isotope ratio results;
- (b) Due to their aquatic ecosystem, the stable oxygen and nitrogen isotope ratio values should reflect their proximity to water, yet exhibiting a reliance on terrestrial plants. The oxygen isotopes may even mirror the signature of the water in which the hippo resides;
- (c) Based on their ecological and dietary requirements, in addition to the archaeological and historical evidence, those geographical areas in which they most likely dwelled during the Late Bronze Age in the eastern Mediterranean may be deduced. As such, this informs which geological strontium values to consider when interpreting the strontium isotope ratio results.

The territorial tendency of some males may also have important implications for understanding the stable isotope ratio analyses. Since the females are not tied to one territory, they are thus able to exploit a wider geographical area for food, and in times of environmental stress would have access to more and better resources. The female and non-territorial male diet could potentially reflect more of an average of the local vegetation than the territorial males, who would have access to only a limited number of “hippo lawns.” However, the carbon stable isotope ratio would only indicate the

proportion of  $C_3$  to  $C_4$  vegetation in the diet. Thus the female and non-territorial male hippo may have a higher proportion of  $C_4$  than the male, since grass is their preferred foodstuff, and in times of environmental stress the territorial male, behaviorally restrained to his territory and those lawns within distance of this territory, would necessarily be forced to utilize a broader feeding niche.

## Chapter 8

### Ecological and Dietary Requirements of Elephants

As the archaeological and historical evidence indicate, elephant ivory in the Late Bronze Age was most likely not obtained from the Asian elephant but rather the African elephant. While the two species are not entirely different in their diets and physiology, their diet is largely influenced by the available vegetation (Ayliffe *et al.* 1992: 180), and therefore the diet and ecological requirements of only the African elephant will be considered here.

Unlike the strict graze diet of the hippopotamus, the African elephant may be best described as an opportunistic or mixed feeder, consuming both browse ( $C_3$  plants, including some grasses) and graze (including  $C_4$  grasses). Their diets can include more than 100 species, including grasses, stems, the leaves, barks and small twigs of trees and shrubs, forbes, palms, and fruit. The trunk limits their ability to be selective when grazing, so that only tall grasses are generally consumed. Mature elephants, moreover, ingest approximately 100-200 kg of food each day depending on the individual's body size. Water is also a vital part of the diet, and during most of the night and in the middle of day elephants occupy the local drinking holes (Clemens and Maloiy 1982: 151; van Hoven 1983: 47; Ayliffe *et al.* 1992: 180).

The African elephant is furthermore capable of residing in extremely diverse habitats, from open savannah-grasslands, and bush or woodlands, to dense forests, and even deserts. Moreover, studies on the feeding preferences of elephants vary widely from one region to another (Dhakal and Ojha 1995: 29). Yet while the African elephant shows remarkable variation in habitat and diet, the two are correlated, and as such the

diet as interpreted from the stable carbon and nitrogen isotope ratios will typify the habitat from which the elephant derived. For example, increasing habitat change is correlated with an increasing proportion of grass in the diet (Laws 1970, cited by van Hoven 1983: 47). The habitat also influences the degree of seasonal change in diet, in addition to the size of the elephant's home range, and both of these factors will in turn affect the stable oxygen and strontium isotope signatures. Therefore, due to the geographical differences in the habitats of Africa, each region of Africa (East, West, and South) will be examined separately in terms of diet and feeding and ranging behavior. The main geographical focus, as determined in Chapter Four, is North and East Africa. As no elephants currently inhabit North Africa, the environment and diet of elephants that once lived there in the Late Bronze Age will have to be reconstructed. Furthermore, while South and West Africa are not considered as likely sources for Late Bronze Age ivory in the eastern Mediterranean, the studies from South and West Africa will illustrate the diet and behavior associated with those types of habitat which may have existed in North or East Africa during the Late Bronze Age.

### **East Africa**

Studies by Kabigumila (1993) and Barnes (1983) examined the diet and feeding behavior of African elephants in the national parks of Tanzania, while a more general study by Eltringham (1980) looked at range usage by large mammals in Uganda. In general, the vegetation of East Africa includes both C<sub>3</sub> (browse) and C<sub>4</sub> (graze) plants, with the grasses almost exclusively C<sub>4</sub> (Tieszen and Imbamba 1980: 237), but as mentioned previously, seasonal variation in diet will affect the ratio of browse to graze.

In the Ngorongoro Crater of northern Tanzania, Kabigumila (1993) considered this seasonal variation in the diet of African elephants. The Ngorongoro Crater is grassland, with some areas of swamp and closed canopy Acacia forest. He found that the elephants' diet in this area consisted of at least 36 different plant species, with an emphasis on high-quality vegetation such as forbs and grasses during the wet season, and sedges and tree-browse during the dry season. Moreover, the shoots, leaves, and inflorescences of the most important plant species, the sedge *Cyperus immensus*, were targeted in the wet season while the bark, wood, and twigs were ingested in the dry season, showing seasonal preferences for plant parts within a species. Sedges such as *C. immensus* are generally considered to be a low quality vegetation, with a 5.8-7.0% crude protein content.

Indeed, with the advent of the dry season and subsequent drying out of the grasses and forbs in the grasslands, elephants concentrated their feeding on twigs of trees and sedges from the Lerai forest. Thus the proportion of browse in the diet was higher during the dry season. Field (1971, cited by Kabigumila 1993: 162) suggested that elephants browse more during the dry season because a) browse has a higher crude protein content than grass, and b) grasses are less palatable because they become more fibrous and accumulate tannins. Kabigumila also found that there was a significant increase during the wet season in the number of elephants using the Crater.

Ranging behavior was the focus of the studies by Barnes (1983) in Ruaha National Park, located in south-central Tanzania, and Leuthold (1977) in Tsavo National Park in Kenya. Leuthold (1977) established that range size is dependent on the quality of the environment. In Tsavo East, an area with comparatively poorer habitat, the elephants

had larger ranges than those elephants dwelling in the more favorable habitat of Tsavo West. Barnes (1983) reports further that there is a difference between males and females in ranging behavior, especially during the mid-dry season when bulls traveled only short distances each day while females and their young journeyed long distances in search of higher quality food. Males traveled the most in the mid-winter and early dry seasons when they were sexually active.

Eltringham's (1980) study on the Mweya Peninsula, Rwenzori National Park, (Uganda) found that elephant numbers decreased significantly when there was an increase of other animals in the same area. There was a deterioration in the grassland due to an increase in the hippopotamus population, which in turn led the elephants to avoid the Peninsula. As a result, reconstructions of the past environment in the Late Bronze Age must take into account other animals- in particular the hippopotamus, which is known to cause deterioration in the environment due to over-grazing, or at least render the grasslands unusable to other animals who are unable to feed on the closely cropped grass of the 'hippo lawns.' The implication is that hippopotamus ivory is not as likely to come from the same geographic localities as elephant ivory.

### **West and Central Africa**

In the Acacia woodlands of Central Africa elephants prefer browse in the hot dry season, but grasses in the wet season. Again, these season-dependent food preferences seem to be correlated to the protein content of the available food.

West Africa, unlike the dry grasslands of East Africa, is covered by much forest. Short (1981) and Tchamba and Seme (1993) examined elephant diet and feeding

behavior in the tropical closed canopy forests of two national parks in West and Central Africa. Here the diet is heavily browse with little reliance on grass. Bia National Park is located in the forest belt of western Ghana, receives 1500 mm rain per annum, and is described by Short (1981) as lowland tropical rainforest with characteristics of evergreen and semi-deciduous forest. Browse (mainly woody leaves and stems) constituted the bulk of elephants' diet in Bia, in addition to some fruit. Grass, on the other hand, is almost completely absent from Bia NP and thus does not contribute to the diet of these elephants. Although closed canopy forests dominate the landscape, the elephants preferred to browse in open forest and old forest gaps. The only feeding activities that took place in closed forest were barking and gathering of fruits. Accordingly, vegetation cover type is not utilized in proportion to its occurrence, and elephants' avoidance of closed forest and preference for open canopy with dense ground vegetation is also supported by Wing and Buss (1970) and Laws *et al* (1975) (cited by Short 1981: 184).

Another interesting finding by Short was that elephants in different habitats prefer different types of trees, depending on the total vegetation assemblage. Two species, *Pipideniastrum africanum* and *Parinari excelsa*, heavily barked in other studies (see Wing and Buss 1970 and Laws *et al* 1975), were not barked at all in Bia NP. Also, the elephants are highly selective, preferring to bark from a small number of species. Short offers several explanations for this phenomenon:

- (i) elephants with a greater range of choice in forest, select alternative species;
- (ii) palatability or calcium content may differ for these species between areas;
- (iii) elephants' need for a particular mineral may vary between areas;
- (iv) learned preferences may differ between areas (Short 1981: 184).

Tchamba and Seme (1993) likewise reported on the feeding behavior and diet of the ‘forest’ elephant in the Santchou Reserve in western Cameroon. The habitat of the reserve is also a tropical closed canopy forest with 1750 mm rainfall a year and 700-800 m altitude. Here, unlike Bia National Park, the main component of the elephants’ diet was grass, particularly *Pennisetum purpureum*, and the woody material (leaves and stems) only made up a small fraction of the diet. Fruit was also very important to the diet, with 22 varieties being represented. Also contrasting with Short’s study, Tchamba and Seme found that the elephants exploited the habitat types (closed forest, swamp forest, savanna, farmland) in direct proportion to their occurrence. Taking these factors into consideration, the authors propose that the Santchou elephants’ diet and feeding behavior are more similar to the results from East African studies (i.e. Wing and Buss 1970 and Field 1971) than West African ones (i.e. Short 1981).

Thus, while sufficient browse is available in East Africa, grass generally accounts for 80-90% of the bulk diet for elephants of this region. The diet of the Santchou elephants agrees with eastern Africa findings, but the diet of the Bia elephants agrees with southern Africa research, such as that of Williamson (1975; cited by Short 1981: 181). Consequently, research conducted in South Africa is the next region to be considered.

### **South Africa**

Williamson (1975) found that browse constituted the bulk of the diet for South African elephants, except during the wet season (Short 1981: 181). Steyn and Stalmans (2001) found in the Songimvelo Game Reserve in the Barberton Mountains, South



Africa, that the forest, thickets and woodlands were preferred. The shrublands and grasslands, however, were barely utilized. The Songimvelo Game Reserve receives from 800 to 1400 mm rainfall per annum and the vegetation (particularly in the winter) is considered low-quality for grazing. van Hoven (1983: 47), however, suggests that the majority of woodland plant species in Southern Africa are consumed in proportion to their occurrence, with only a few species preferred or avoided.

Particularly fascinating are the “desert” elephants of the western Kaokoveld, located in the northern Namib Desert (Southwest Africa), a region which receives less than 150 mm per year in rainfall and is characterized by dry savanah and shrub. Research conducted by Viljoen (see 1988; 1989; and Viljoen and du P. Boethma 1990) has brought this hitherto ignored and unique population of elephants to the forefront in discussions of the ecological requirements of elephants. These elephants are, furthermore, not a recent introduction to the area as there is evidence for them since before 1793. Not only do the elephants that live in this region survive droughts that kill off other “desert” mammals, but the populations also have shown no history of migrating eastward out of this supposedly inhospitable terrain to more favorable regions. In fact, their home ranges are rarely modified, even after multiple human attempts to chase them out of the region. They are capable of traveling up to 70 km per day in search of water or food, and moreover are able to go without water for up to four days in the dry season. Viljoen estimates that they may utilize food resources up to 80 km away from the nearest water. Water can also be obtained by digging in the sandy river beds. Nevertheless, their detailed knowledge of the distribution of resources is probably the most important factor in their adaptation to the desert (Viljoen 1988: 111-113). It seems that the elephant is in

fact adapted to the desert, and this has crucial implications for the reconstruction of the African elephant range in North and East Africa during the Late Bronze Age.

In conclusion, the diet of the African elephant does vary from region to region, but some generalizations may be drawn. When open forest *and* grasslands are available, the elephants prefer more browse than graze during the dry season and more graze (grass) than browse during the wet. Their stable carbon isotope signatures will therefore range in the middle of the spectrum of carbon isotope values, reflecting a mixed C<sub>3</sub> and C<sub>4</sub> diet.

In areas where grassland is rare, elephants will rely almost wholly on open forest and somewhat on closed forest (as seen in West Africa). These elephants will exhibit a pure C<sub>3</sub> diet (with some exceptions, as explained in Chapter Six). Regions such as East Africa characterized by grassland with limited open forest will host elephants with strong C<sub>4</sub> grass diets, as they consume browse only during the dry season when the grass dries out and reduces in nutritional value. “Desert” elephants’ carbon signatures would be more difficult to decipher since research has not been conducted specifically on their diet, but their nitrogen and oxygen isotope values would reflect an arid environment.

Furthermore, while elephants are known to be capable of large ranges, they do exhibit range-specific behavior, thus narrowing the geographical scope for interpreting the strontium isotope ratios.

## Chapter 9

### **A Review of Stable Isotope Ratio Studies for Modern Populations of Elephants and Hippopotami**

Having considered the mechanics of isotope analysis in Chapter Six, and the diet and ecological requirements of hippopotami and elephants (Chapters Seven and Eight) to better interpret these analyses, I now turn to take a brief look at previous isotopic research on elephants (there is virtually none on hippopotamusi) to consider past successes.

Research on elephants has focused primarily on diet, utilizing stable carbon and nitrogen isotopes (Tieszen and Imbamba 1980; Sukumar *et al.* 1987; van der Merwe *et al.* 1988; Sukumar and Ramesh 1992, 1995; Koch *et al.* 1995; Ishibashi *et al.* 1999). More germane to the present investigation are several studies using additional isotopes such as strontium and lead to illustrate the potentiality for sourcing illegally poached ivory (van der Merwe *et al.* 1990; Vogel *et al.* 1990).

Tieszen and Imbamba (1980) were one of the first to apply isotopic analysis to elephants (*cf.* Heaton *et al.* 1986 for another seminal article), and were the only researchers to investigate hippopotami isotopically. They measured  $\delta^{13}\text{C}$  values from fecal samples of a number of East African herbivores. In the lowlands of East Africa all the grasses are  $\text{C}_4$ , so they were able to estimate the percentage of browse ( $\text{C}_3$ ) to graze ( $\text{C}_4$ ) for the animals. As expected, elephants exhibited a generalized feeding pattern, utilizing  $\text{C}_3$  and  $\text{C}_4$  with high individual variability in percentages of each (Table 2). Hippopotami have a high  $\text{C}_4$  component as well, but not as high as anticipated. In one

Table 2:  $\delta^{13}\text{C}$  values and %  $\text{C}_4$  from fresh fecal samples of elephants and hippopotami in Kenya, East Africa. Coefficient of variation (CV) is expressed as a percentage of the  $\delta^{13}\text{C}$  (data from Tieszen and Imbamba 1980: 240).

Amboseli National Park /Samburu Game Reserve/ Aberdares National Park									
	Mean	CV (%)	% $\text{C}_4$	Mean	CV (%)	% $\text{C}_4$	Mean	CV (%)	% $\text{C}_4$
Elephant	-17.1	14.1	70	-16.4	12.5	75	-26.5	1.7	10
Hippo	-18.4		62						

forested area, Aberdares National Park, the elephants exhibited a heavy reliance on  $\text{C}_3$  plants. The authors caution that sampling feces may overestimate the  $\text{C}_4$  as these plants do not break down as well in the digestive tract.

In a study with a broader geographical scope, van der Merwe *et al.* (1988) analyzed the bone collagen of elephants from twelve wildlife refuges in East and South which spanned many types of habitats: primary rain forest, savanna woodland, and desert. The results are given in Figures 38 and 39. A linear relationship was found between tree density and the  $\delta^{13}\text{C}$  values. This is due to factors such as the availability of browse in savanna woodland and forest, the dominance of  $\text{C}_4$  grasses in grassland habitats verses  $\text{C}_3$  grasses in forests, and the “canopy effect” whereby the  $\delta^{13}\text{C}$  values in forests are more negative than  $\text{C}_3$  plants in open woodlands (van der Merwe *et al.* 1988: 164-169). The variation among elephants within each refuge is very small, probably due to the artificial boundaries of the refuges, as well as the clan-based social organization. However, the  $\text{C}_4$  component is probably under-represented in collagen, since field studies of the parks suggest elephants eat a greater amount of  $\text{C}_4$  grasses.

Another study published around this time was that of Sukumar *et al.* (1987), who tested the bone collagen of Asian elephants for carbon isotopes and reported wide individual variability (-11.1 to -20.8). The researchers related the variability to age, as

Table 3:  $\delta^{13}\text{C}$  values of bone collagen from African elephants  
(data from van der Merwe *et al.* 1988: 166-167).

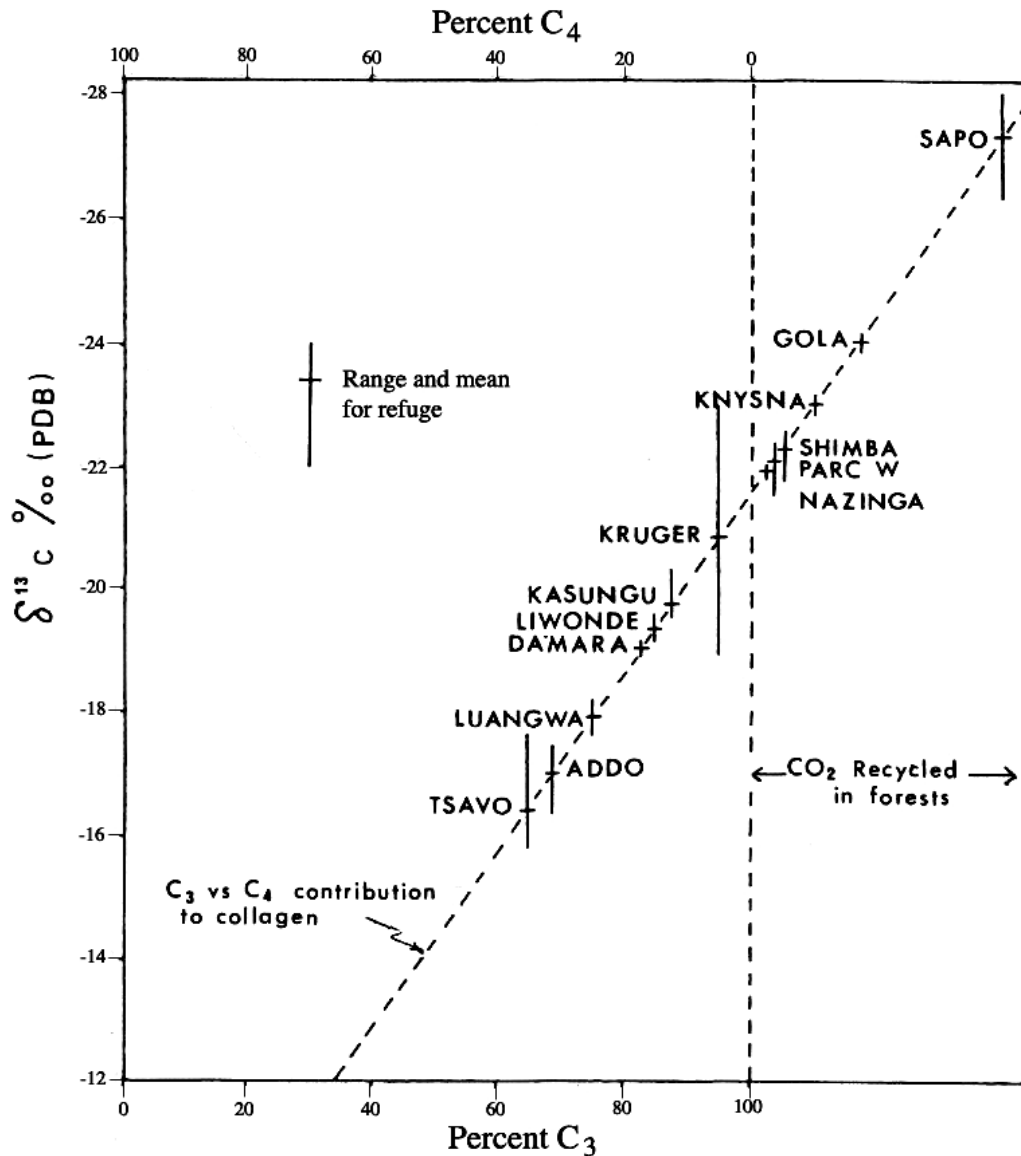
Park, Country	Vegetation	Lab number	$\delta^{13}\text{C}$ (‰)
Sapo, Liberia	Primary rainforest	1646	-26.3
		1647	-26.9
		1648	-27.6
		1649	-27.5
		1650	-27.1
		1651	-27.3
		1652	-28.1
		1653	-27.4
Gola, Sierra Leone	Primary and secondary rainforest	1645	-24.0
Knysna, South Africa	Coastal forest	1668	-23.2
Shimba Hills, Kenya	Forest-woodland mosaic	913	-21.7
		914	-22.1
		915	-22.2
		916	-22.6
		1457	-21.0
		1458	-20.8
		1459	-20.1
		1460	-21.4
		1461	-19.6
		1462	-21.7
		1463	-19.9
		1464	-20.5
		1465	-21.8
		1466	-19.4
		1436	-21.8
		1437	-20.0
		1438	-21.8
		1439	-22.7
		1440	-21.0
		1441	-19.8
		1442	-21.1
		1447	-19.3
		1448	-23.0
		1449	-21.0
		1450	-19.9
		1443	-20.6
		1444	-20.3
		1445	-21.0
		1446	-22.1
		1454	-20.9

(Table 3 continued on next page)

Table 3:  $\delta^{13}\text{C}$  values of bone collagen from African elephants (continued).

Park, Country	Vegetation	Lab number	$\delta^{13}\text{C}$ (‰)
Shimba Hills, Kenya (cont.)	Forest-woodland mosaic	1455	-20.1
		1456	-20.9
		1433	-21.3
		1434	-22.0
		1435	-18.9
Parc W, Niger	Northern guinea savanna	1657	-22.1
		1658	-21.5
		1659	-21.8
		1660	-22.0
		1661	-22.4
Nazinga, Burkina Faso	Northern guinea savanna	1655	-21.9
		1656	-21.9
Kasungu, Malawi	<i>Brachystegia</i> woodland	909	-20.3
		910	-19.6
		911	-19.6
		912	-19.5
Kruger, South Africa	Bushveld savanna	1451	-20.9
		1452	-20.1
		1453	-19.9
Liwonde, Malawi	Mopane woodland with marsh	1643	-19.1
		1644	-19.7
		1654	-19.1
Luangwa, Zambia	Mixed woodland with mopane	905	-18.1
		906	-17.9
		907	-17.7
		908	-18.0
Damaraland, Namibia	Semi-desert	1490	-19.0
Addo, South Africa	<i>Portulacaria</i> thicket	1696	-17.2
		1697	-17.0
		1698	-17.4
		1699	-16.3
		1700	-17.2
East Tsavo, Kenya	Elephant-induced grassland	917	-17.6
		918	-16.1
		919	-15.8
		920	-16.0

Figure 35: Average  $\delta^{13}\text{C}$  values of elephant bone collagen from twelve African wildlife refuges. The diagonal dotted line (from 100%  $\text{C}_3 = -21.5\text{‰}$  to 100%  $\text{C}_4 = -7.0\text{‰}$ ) equals the relative contribution of  $\text{C}_3$  and  $\text{C}_4$  plants to the diet (adapted from van der Merwe *et al.* 1988: 165).



the results suggested young elephants preferred graze while adults consumed more browse (Figure 36; see also Sukumar and Ramesh 1992: 537). These findings are elaborated upon by Sukumar and Ramesh (1992; 1995), and the problem of under-representation of  $\text{C}_4$  is also considered. The results are compared to data from African

elephants (Tieszen *et al.* 1989) and presented in Table 4. The variance in sub-adults (<25 years) is greater than in adults, suggesting that the usual seasonal alternation between C<sub>4</sub> plants in the wet season and C<sub>3</sub> in the dry season is made more visible in growing animals due to a high collagen turnover rate (Sukumar and Ramesh 1992: 536-538; 1995: 372). The researchers, like van der Merwe *et al.* (1988), also noticed that more of the carbon in collagen was incorporated from C<sub>3</sub> plants, thus under-representing the C<sub>4</sub> component. This may be explained by higher protein contribution of C<sub>3</sub> to the diet (per unit of quantity consumed), so that C<sub>3</sub> plants are more important to the diet of elephants for growth. The carbon from C<sub>4</sub> grasses may be more important for other metabolic functions however (Sukumar and Ramesh 1992: 536; 1995: 368-373).

Figure 36: Percentage of time spent in feeding on C<sub>3</sub> (browse) plants on average during different seasons by adult elephants (solid circles, upper line) and sub-adult elephants (open circles, bottom line). The dry season is from December to April and the wet season is May to November (adapted from Sukumar and Ramesh 1992: 538).

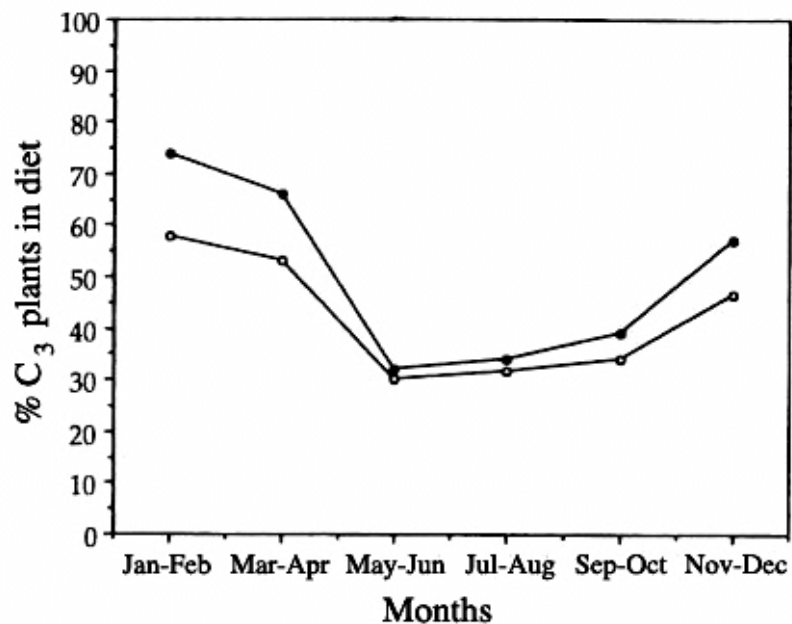




Table 4: Percentage of C<sub>3</sub> plants in diet as inferred from stable carbon isotope ratios of bone collagen in African elephant population. Data from Sukumar and Ramesh (1995: 370) and Tieszen *et al.* (1989).

Region/Country	Vegetation type	$\delta^{13}\text{C}$ per mil $\pm$ SD	% C <sub>3</sub> plants in diet
Nilgiris-E.Ghats, India	Moist & dry deciduous forest	-18.6 $\pm$ 1.36 (n=16, adults)	71
		-16.4 $\pm$ 3.61 (n=65, all ages)	57
Tsavo, Kenya	Grasslands & dense woodland	-18.4 $\pm$ 0.18 (n=65)	75
East Tsavo, Kenya	Grassland	-16.4 $\pm$ 0.7 (n=4)	65
Addo, South Africa	Portulacaria thicket	-17.0 $\pm$ 0.4 (n=5)	68
Damaraland, Namibia	Semi desert	-19.0 (n=1)	82
Luangwa, Zambia	Mixed woodland with mopane	-17.9 $\pm$ 0.2 (n=4)	75
Liwonde, Malawi	Mopane woodland with marsh	-19.3 $\pm$ 0.3 (n=3)	85
Kruger, South Africa	Bushveld savanna	-20.8 $\pm$ 1.0 (n=34)	97
Kasungu, Malawi	Brachystegia woodland	-19.8 $\pm$ 0.3 (n=4)	88
Nazinga, Burkino Faso	Northern guinea savanna	-21.9 (n=2)	100
Parc W., Niger	Northern guinea savanna	-22.0 $\pm$ 0.3 (n=5)	100
Shimba Hills, Kenya	Forest-woodland mosaic	-22.2 $\pm$ 0.3 (n=4)	100
Knysna, South Africa	Coastal forest	-23.2 (n=1)	100
Gola, Sierra Leone	Rain forest	-24.0 (n=1)	100
Sapo, Liberia	Primary rain forest	-27.3 $\pm$ 0.5 (n=8)	100

Koch *et al.* (1995) reported on several isotopes (carbon, nitrogen, and strontium) from elephants in Amboseli National Park, Kenya, to track dietary and habitat changes. Time series were gathered by microsampling sequential growth laminations in molar roots (because tooth dentine grows by accretion in elephants). The results are presented in Table 5. There were no coherent temporal trends for the nitrogen isotopes, but the  $\delta^{15}\text{N}$  values were as expected for elephants living in a semi-arid environment. The carbon isotopes did change with time, showing a switch in the diet from browse to grass. A negative correlation was observed between carbon and strontium isotope values (Figure 37) as a result of two isotopically distinct regions within the park: the  $\text{C}_3$  rich bushlands on Precambrian soils (low  $\delta^{13}\text{C}$ , high  $^{87}\text{Sr}/^{86}\text{Sr}$ ) and the  $\text{C}_4$  rich grassland on Plio-Pleistocene volcanic and lakebed soils (medium to high  $\delta^{13}\text{C}$ , low  $^{87}\text{Sr}/^{86}\text{Sr}$ ). The soils overlying the Proterozoic gneiss had Sr ratios of approximately 0.7067, whereas the soils on the Plio-Pleistocene volcanic rocks were approximately 0.7048. At 0.70518 the mean elephant Sr value is closer to the Plio-Pleistocene volcanic rocks, suggesting a greater residence time in this region (see Figure 38 for map of study area).

The researchers also warn that ivory may be more isotopically variable than bone, as illustrated by the carbon isotope data. They suggest that “in the face of such high within-tusk variability, it may be difficult to characterize a tusk or ivory artifact on the basis of a single, small (for example, 20 mg) isotopic sample. Isotopic discrimination between populations could probably be obtained if multiple samples of different geologically controlled isotopes (Sr, Nd, and Pb) were examined for each artifact” (Koch *et al.* 1995: 1343). While this may hold true for elephants (particularly with carbon isotopes) because of their seasonal diet and large home-range, hippopotami are much less

Table 5: Isotope values for Amboseli elephant collagen listed by year of death (YD)  
(data from Koch *et al.* 1995: 1341).

Name	Age	YD	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$^{87}\text{Sr}/^{86}\text{Sr}$
<i>Females</i>					
Annabelle	44	74	-18.3	12.0	0.70597
C75-17	Ad	75	-18.2	11.3	
Vera	22	76	-17.1	10.7	0.70556
Gabriella	17	78	-13.2	10.3	0.70460
Daphne	18	79	-12.3	10.2	0.70449
Tamar	12	83	-13.9	10.3	0.70490
Ruth	23	83	-19.4	11.4	0.70695
Zoe	30	84	-13.3	10.8	
Tia	34	84	-15.3	10.1	0.70462
Priscilla	41	84	-13.4	10.1	
Teresia	62	84	-17.3	9.7	0.70532
Sara	39	85	-15.5	11.6	0.70486
Calandra	22	86	-12.6	9.1	0.70456
Big T	53	86	-14.3	10.1	
Ophelia	20	87	-15.5	10.4	
Harriet	49	87	-15.5	10.2	0.70521
Gardenia	8	88	-12.0	8.6	0.70452
Emily	41	89	-14.2	9.8	
<i>Males</i>					
SPC 33	35	70	-18.8	10.2	0.70533
SPC 39	50	70	-16.8	11.3	0.70539
C75-27	Ad	72	-17.9	11.3	
C75-6	Ad	72	-18.2	9.5	
M33	39	76	-17.7	12.4	0.70573
Rex	5	84	-13.3	10.4	
Noah	5	85	-14.1	11.2	
M252	15	85	-13.7	11.9	
M185	16	85	-13.2	10.7	
M153	28	85	-15.1	10.7	0.70474
M144	29	85	-15.3	10.3	0.70464
Daniel	9	86	-11.9	10.4	
Zeppo	9	86	-13.9	11.4	0.70475
SPC 23	21	86	-14.7	10.7	
Zach	24	87	-18.4	10.8	0.70737
Ali 83	5	88	-11.9	10.7	0.70458
M178	28	90	-15.0	11.9	0.70469
SPC 31	28	90	-15.6	12.0	

Figure 37: Plot showing relation between  $\delta^{13}\text{C}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  in elephant bones (adapted from Koch *et al.* 1995: 1342).

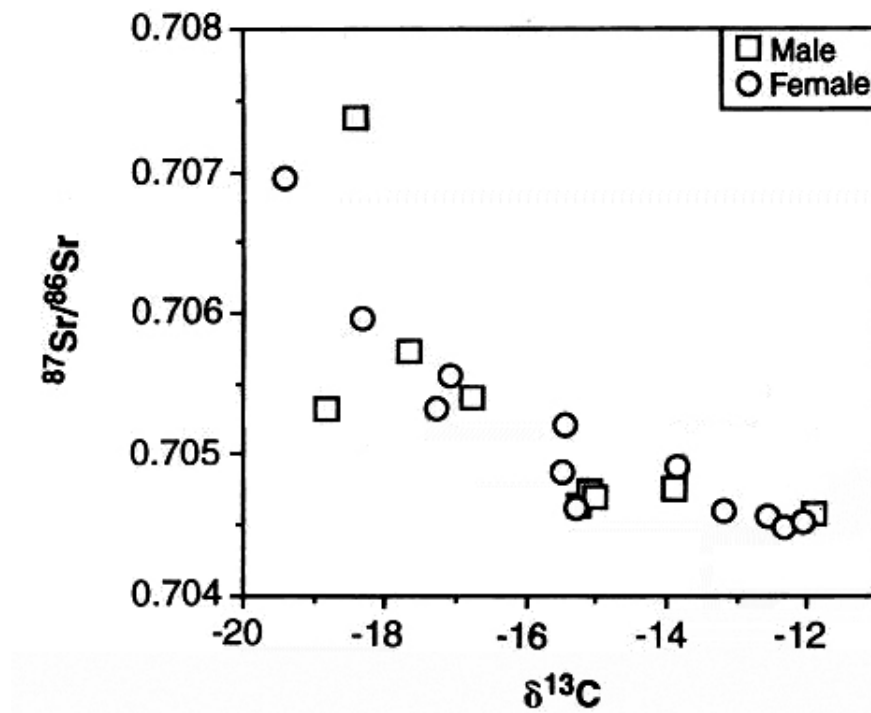


Figure 38: Map of the Amboseli Basin, Kenya (adapted from Koch *et al.* 1995: 1341).

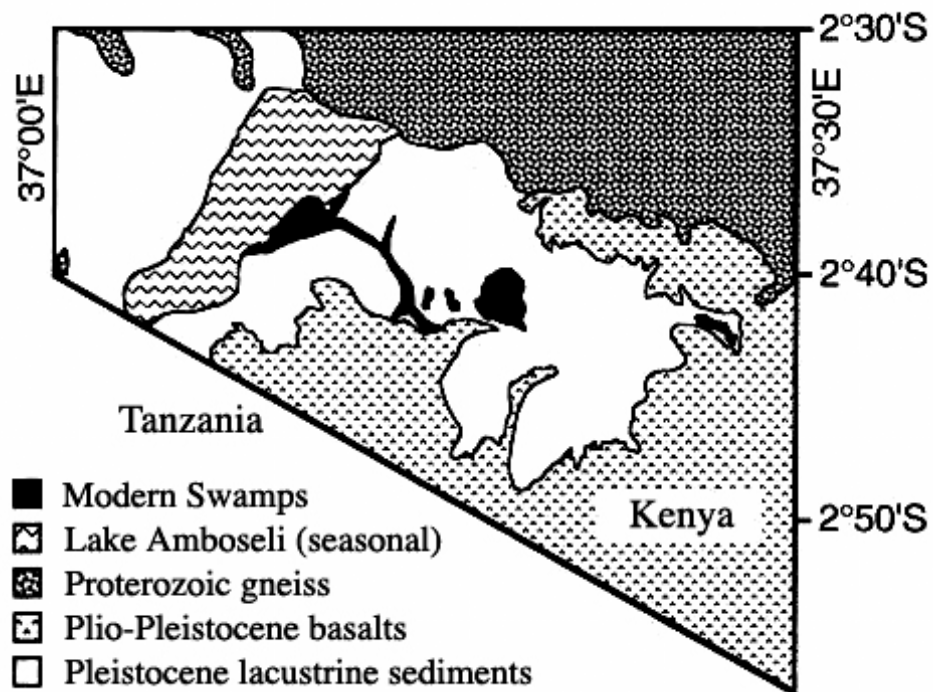
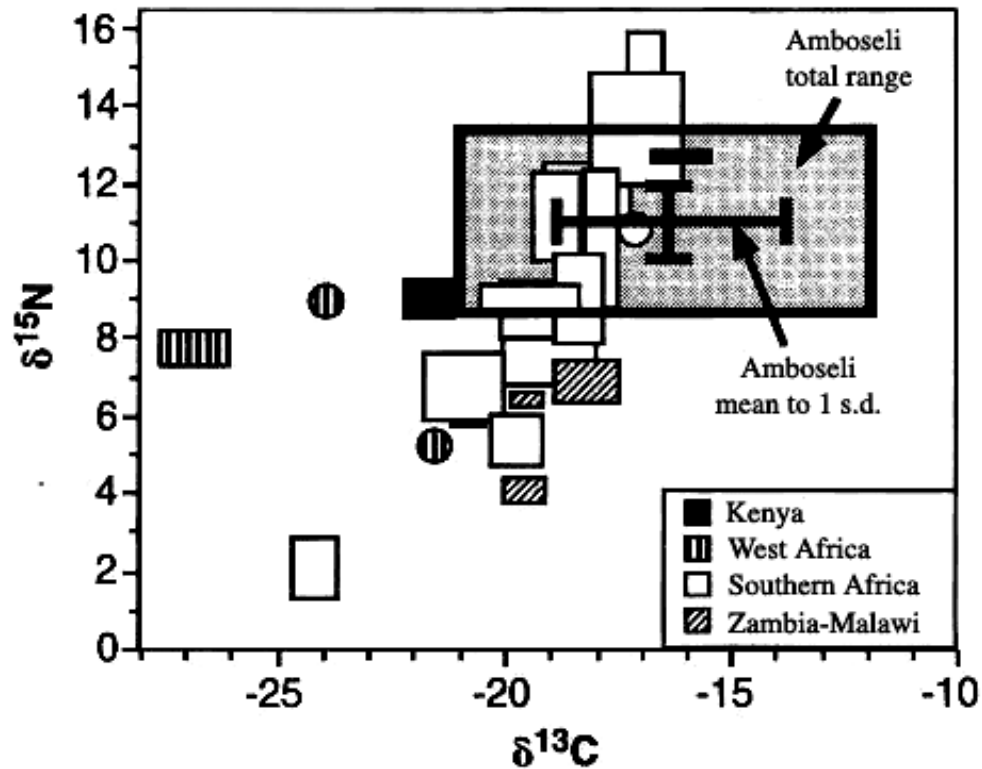


Figure 39: Carbon versus nitrogen isotope ratios for African elephant populations. Boxes indicate mean  $\pm 1$  SD for each population, whereas circles refer to single specimens. Note the significant overlap between the Amboseli population and several other populations, especially for the Amboseli total range. Data from van der Merwe *et al.* (1990), Vogel *et al.* (1990), and Koch *et al.* (1995), and figure adapted from Koch *et al.* (1995: 1342).



likely to exhibit intra-tusk variability. Moreover, because carbon and nitrogen isotope values may be the same in geographically separated populations (see Figure 39 for illustration of this problem), sourcing ivory should rely heavily on those geological isotopes (Sr, Nd, and Pb) as suggested above.

Ishibashi *et al.* (1999) conducted one of the largest research programs on elephants utilizing isotopic analysis: eighty-one samples (collagen) from eleven countries, including some countries previously included in isotopic studies (Sudan, Djibouti, and Ethiopia). The results of their research are listed in Table 6 by country.

Interestingly, the two samples from Sudan have  $\delta^{13}\text{C}$  values indicating a diet rich in  $\text{C}_3$ , and  $\delta^{15}\text{N}$  values corresponding to an environment with much rainfall. The sample from Ethiopia, however, suggests a  $\text{C}_4$  rich diet and arid environment. Similar arid  $\delta^{15}\text{N}$  values were found in the desert areas of Damaraland and the Kaokoveld in Namibia. Their data are plotted for each region in Figures 40-43.

Table 6: Isotopic analysis results for ivory samples from Ishibashi *et al.* (1999: 2-3).

Country	Lab number	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	Average $\delta^{15}\text{N}$	Average $\delta^{13}\text{C}$
Botswana	93EL26	8.2	-21.0	$8.9 \pm 3.7$	$-21.7 \pm 1.9$
	93EL27	5.6	-23.9		
	93EL28	12.8	-20.3		
Congo	92EL01	9.8	-25.8	$10.2 \pm 2.3$	$-25.3 \pm 1.4$
	92EL02	9.6	-26.1		
	92EL03	--	-24.2		
	92EL04	6.9	-24.8		
	92EL05	13.2	-27.0		
	93EL06	8.9	-27.3		
	93EL07	7.8	-23.9		
	93EL08	9.7	-26.1		
	93EL09	10.2	-26.2		
	93EL10	9.3	-25.7		
	93EL11	11.6	-25.3		
	93EL12	11.8	-25.4		
	93EL13	7.6	-21.6		
	93EL14	7.6	-23.2		
	93EL15	8.3	-27.4		
	93EL16	5.7	-27.5		
	94EL01	12.5	-26.0		
	94EL02	9.7	-24.8		
	94EL03	14.0	-24.4		
	94EL04	13.9	-25.0		
	94EL05	11.8	-24.4		
	94EL06	11.9	-24.3		
	94EL07	12.4	-25.6		
Djibouti	94EL08	7.0	-18.8	N/A	N/A

(Table 6 continued on next page)

Table 6: Isotopic analysis results for ivory samples from Ishibashi *et al.* (1999)  
(continued).

Country	Sample number	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	Average $\delta^{15}\text{N}$	Average $\delta^{13}\text{C}$
Ethiopia	94EL09	12.4	-17.5	N/A	N/A
Gabon	92EL06	11.4	-29.4	$10.1 \pm 1.3$	$-27.2 \pm 1.5$
	92EL07	10.3	-28.9		
	92EL08	8.7	-27.7		
	93EL01	10.1	-26.1		
	93EL02	9.2	-28.2		
	93EL03	11.6	-27.3		
	93EL04	9.3	-28.9		
	93EL05	8.9	-27.1		
	94EL10	11.8	-26.1		
	94EL11	11.8	-25.4		
	94EL12	8.5	-24.6		
Mozambique	92EL09	9.9	-28.4	$10.5 \pm 0.4$	$-25.3 \pm 3.4$
	93EL33	10.8	-26.6		
	94EL13	10.5	-26.0		
	94EL14	10.8	-20.4		
South Africa	92EL12	10.3	-17.6	$9.9 \pm 1.5$	$-19.4 \pm 2.3$
	92EL13	9.1	-20.9		
	92EL14	10.6	-19.4		
	92EL16	8.2	-20.0		
	92EL17	9.7	-18.4		
	93EL29	11.7	-15.3		
	93EL30	12.5	-20.4		
	93EL31	8.4	-23.2		
	93EL32	8.4	-21.5		
	94EL15	10.4	-17.4		
Sudan	92EL10	5.9	-29.9	N/A	N/A
	92EL11	--	-28.3		
Zaire	92EL20	--	-25.4	$10.0 \pm 2.1$	$-26.7 \pm 1.2$
	92EL21	11.8	-24.9		
	92EL22	10.1	-28.5		
	92EL23	--	-27.4		
	92EL24	13.8	-28.7		
	93EL17	6.4	-24.9		

(Table 6 continued on next page)

Table 6: Isotopic analysis results for ivory samples from Ishibashi *et al.* (1999)  
(continued).

Country	Sample number	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	Average $\delta^{15}\text{N}$	Average $\delta^{13}\text{C}$
Zaire (cont.)	93EL18	8.6	-27.2	$10.0 \pm 2.1$	$-26.7 \pm 1.2$
	93EL19	6.8	-25.5		
	93EL20	9.4	-27.2		
	93EL21	9.3	-27.6		
	93EL22	9.5	-27.5		
	93EL23	11.2	-27.3		
	94EL17	9.4	-25.8		
	94EL18	11.9	-25.9		
	94EL19	11.9	-26.2		
Zambia	92EL18	7.5	-21.6	$7.1 \pm 0.7$	$-21.0 \pm 0.9$
	92EL19	--	-21.6		
	93EL24	6.5	-20.2		
	93EL25	7.9	-19.9		
	94EL16	6.4	-21.9		
Zimbabwe	92EL25	11.9	-22.1	$10.1 \pm 2.3$	$-22.6 \pm 3.3$
	92EL26	--	-19.5		
	92EL27	12.0	-22.0		
	92EL28	9.4	-21.2		
	92EL29	7.1	-28.2		
Unknown	92EL30	5.9	-31.0	N/A	N/A
	92EL31	12.9	-26.6		
	92EL32	--	-25.1		
	92EL33	--	-32.5		
	92EL34	--	-30.5		
	92EL35	--	-29.0		
	92EL36	--	-28.0		
	92EL37	5.6	-23.3		
	92EL38	7.9	-21.1		



Figure 40:  $\delta^{13}\text{C}$  versus  $\delta^{15}\text{N}$  for South African countries (adapted from Ishibashi *et al.* 1999:5).

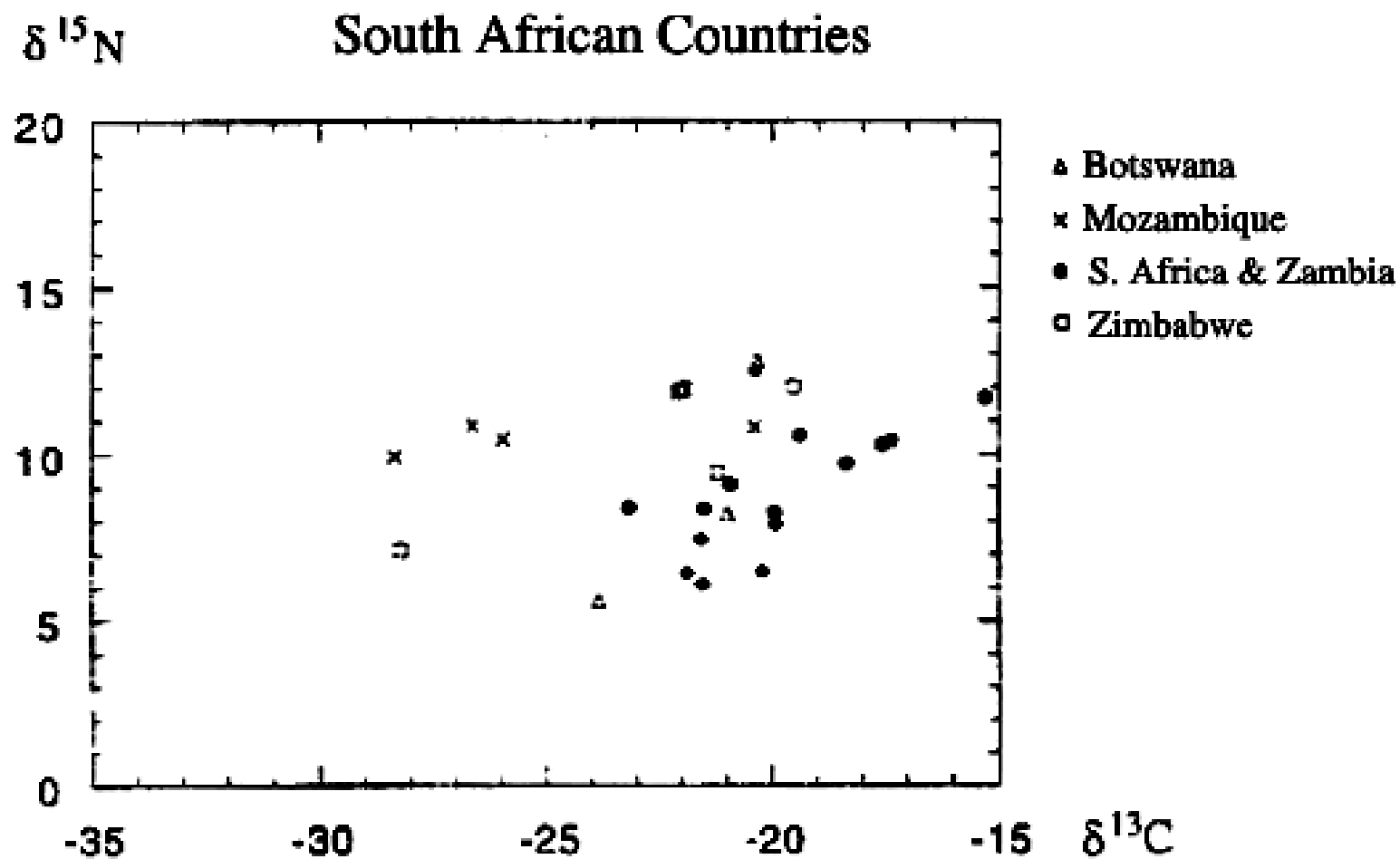


Figure 41:  $\delta^{13}\text{C}$  versus  $\delta^{15}\text{N}$  for East African countries (adapted from Ishibashi *et al.* 1999: 6).

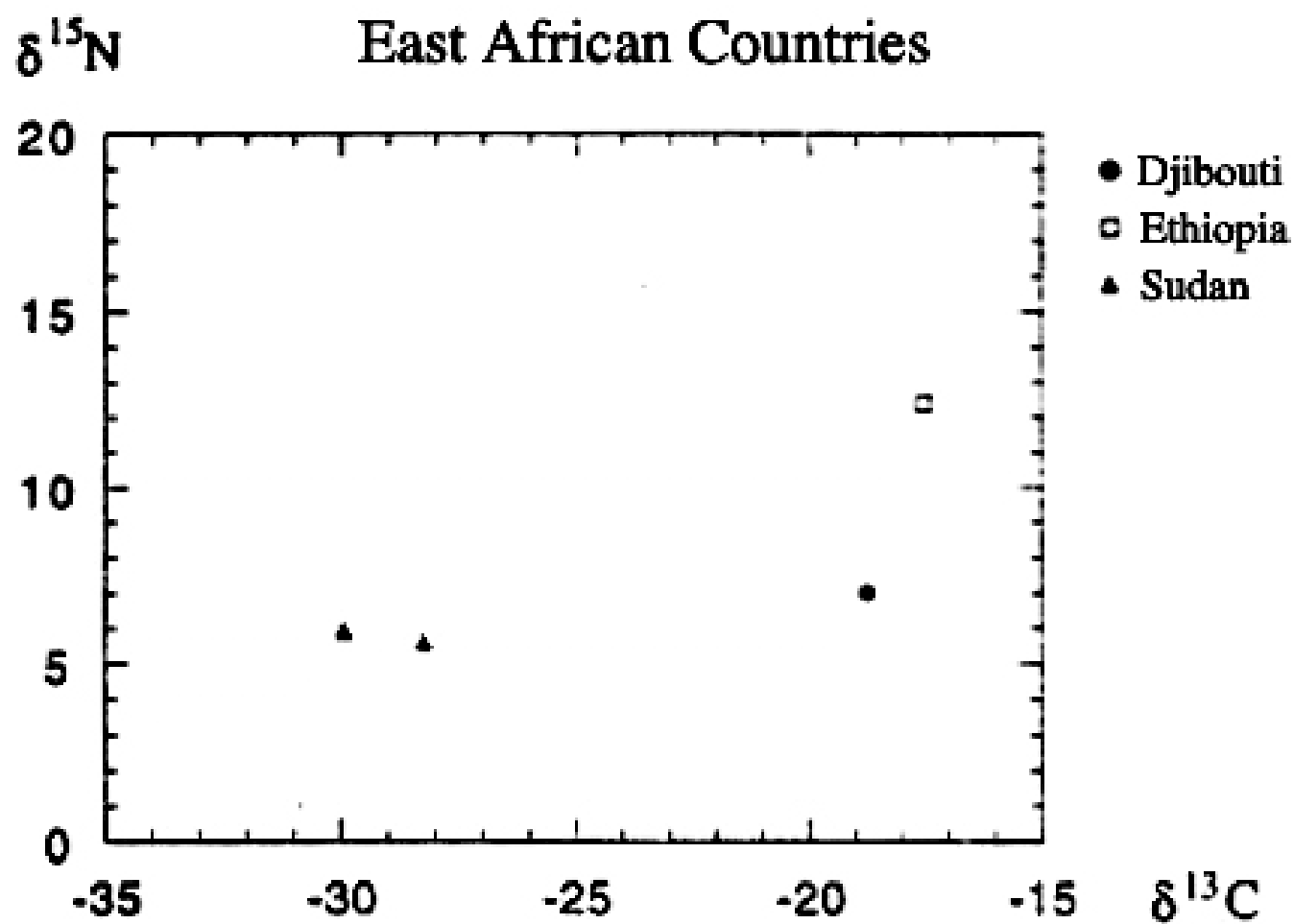


Figure 42:  $\delta^{13}\text{C}$  versus  $\delta^{15}\text{N}$  for Middle African countries (adapted from Ishibashi *et al.* 1999: 6).

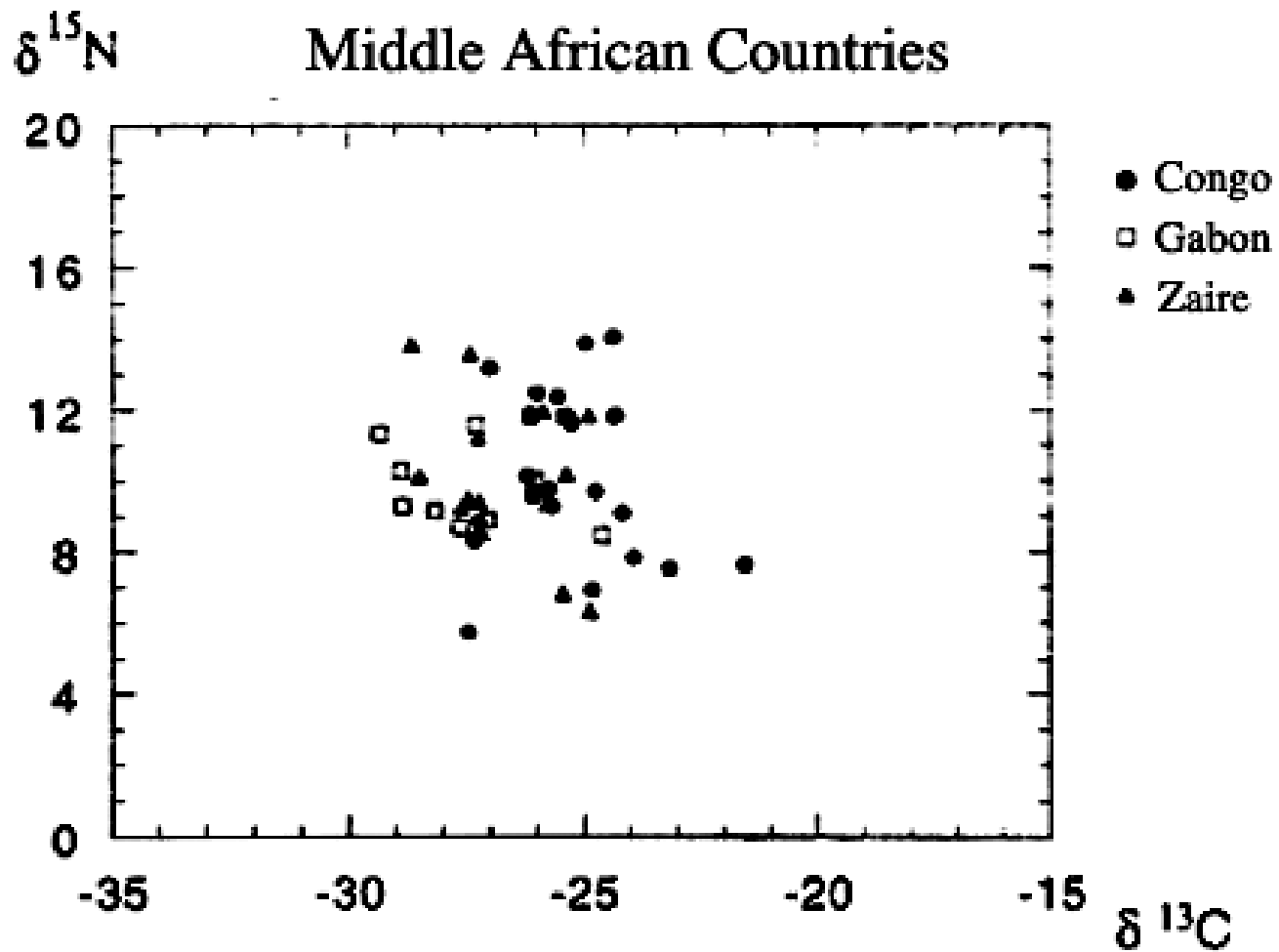
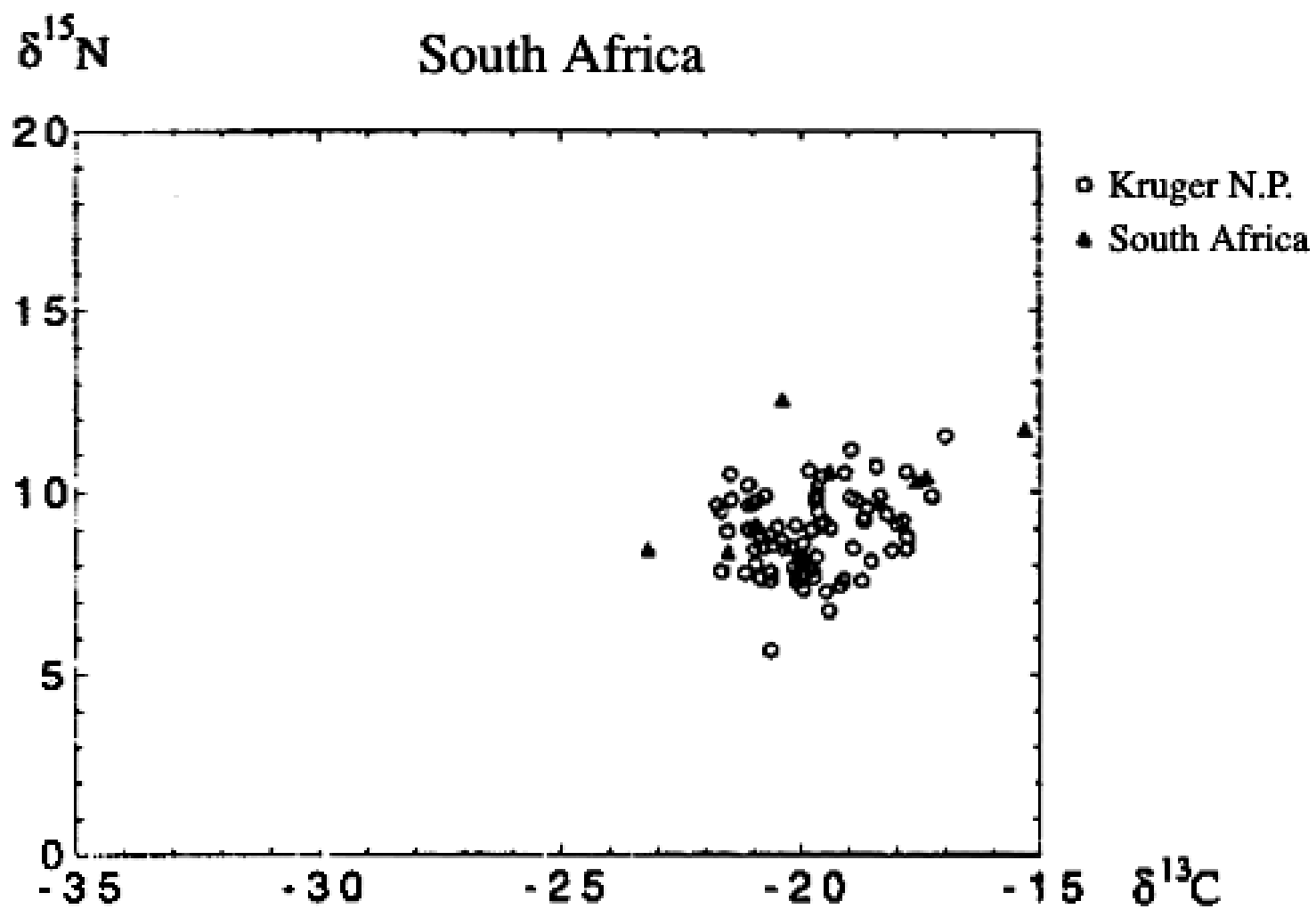
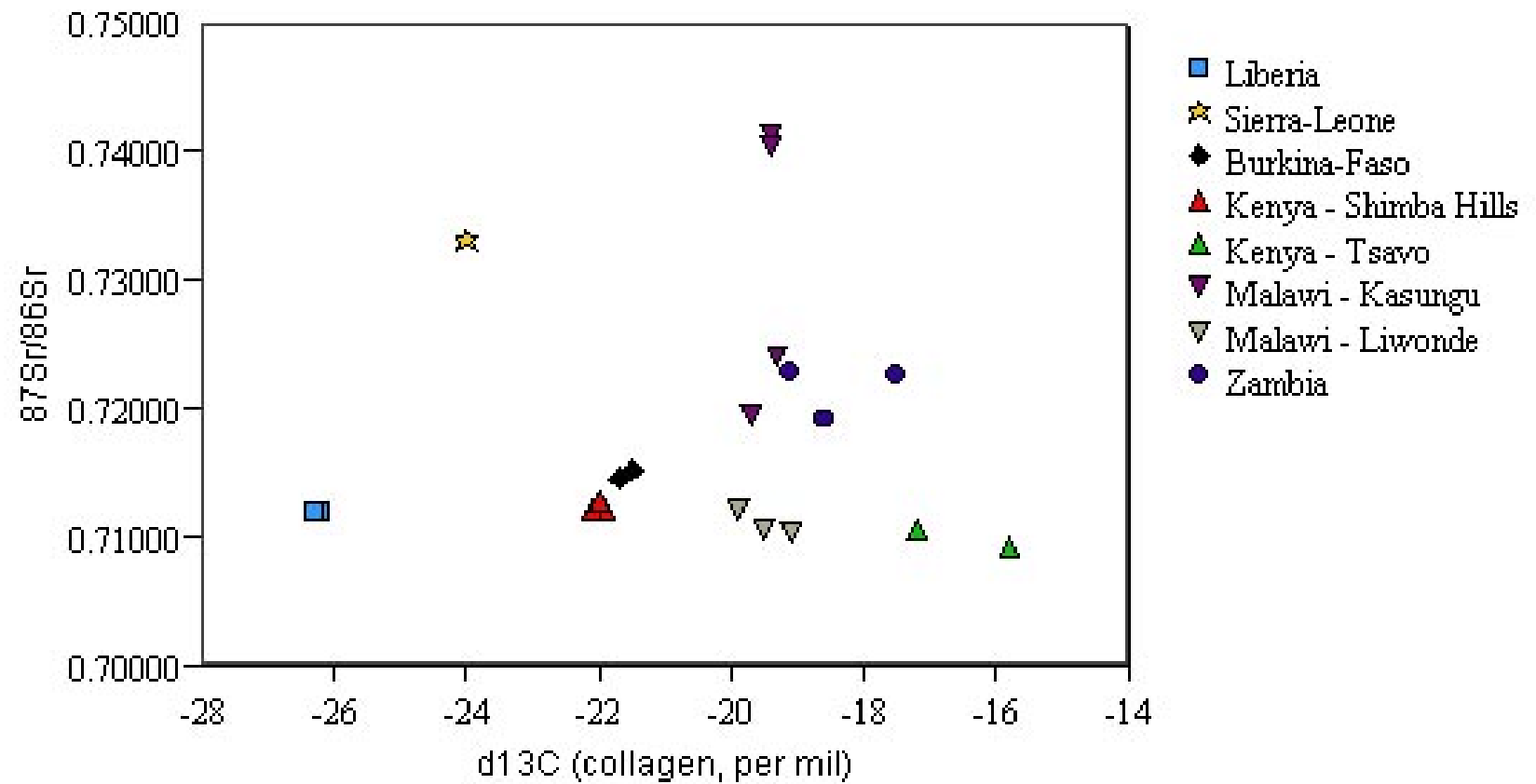


Figure 43:  $\delta^{13}\text{C}$  versus  $\delta^{15}\text{N}$  for South Africa (adapted from Ishibashi *et al.* 1999: 6).

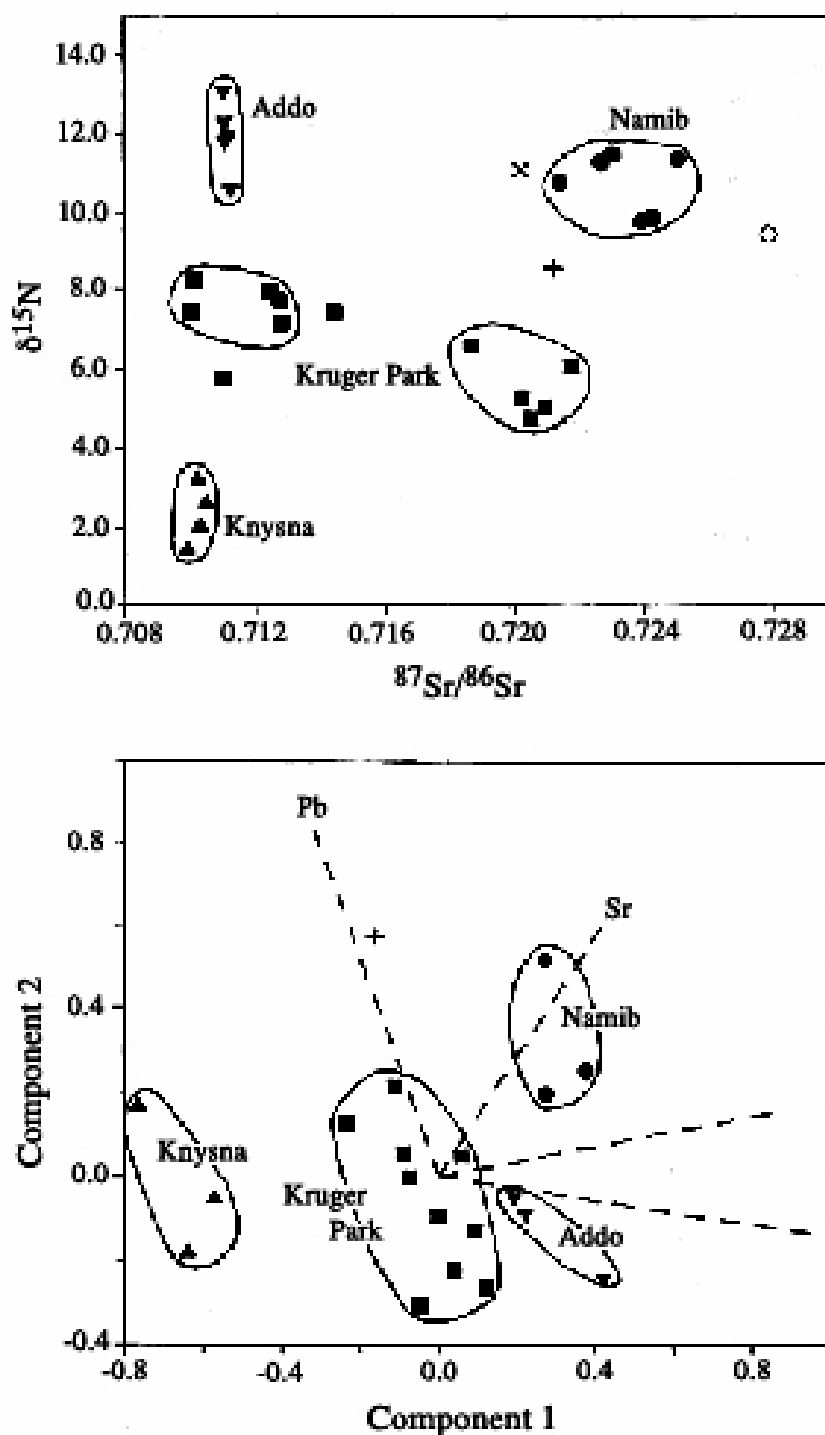


The two hallmark articles illustrating the success of using isotopes to source ivory are van der Merwe *et al.* (1990) and Vogel *et al.* (1990). As Price *et al.* (2002: 122) pointed out, the homogeneity of the isotopic signatures (with a very low standard deviation and coefficient of variation) despite potentially heterogeneous geological sources and seasonal variation in diet is encouraging for sourcing ivory. Van der Merwe *et al.* (1990) sampled bone and ivory from 100 elephants in 20 game refuges in 10 African countries and found seasonal variation in diet and seasonal migration most pronounced in desert regions (i.e. Northern Namibia). Elephant populations from areas situated on old granitic rocks (shield areas) have ratios  $>0.715$ , while populations from basaltic regions have  $<0.715$ . Some of the data is presented below as Figure 44, where definite grouping of areas is evident. Vogel *et al.* (1990) also tested African game refuges ( $n = 7$ ) but looked at lead isotopes in addition to carbon, nitrogen, and strontium. The researchers obtained similar results to those of van der Merwe *et al.* (1990), but found that the lead isotopes were not useful in distinguishing populations. However, they employed multivariate statistics to characterize populations, using “combined R- and Q-mode component analysis, based on a correlation similarity matrix. Ninety-eight percent of the total variance in the data set is explained by three components which are essentially dominated by the isotope ratios of C and N (component 1), Pb and Sr (component 2), and Sr (component 3). Distinction of the four populations is quite clear on a plot of component 1 against component 2” (Vogel *et al.* 1990: 748; see Figure 45b). Vogel *et al.* (1990) furthermore tested ivory and bone from three individuals to see how the values of the different tissues compared, and found that the ivory values were in the same grouping (Figure 45a) as those for the bone for each individual.

**Figure 44:**  $\delta^{13}\text{C}$  versus  $^{87}\text{Sr}/^{86}\text{Sr}$  for elephants in African game refuges (data from van der Merwe *et al.* 1990).



**Figure 45:** Above:  $^{87}\text{Sr}/^{86}\text{Sr}$  versus  $\delta^{15}\text{N}$  for elephant bone, indicating the complete separation of the different elephant populations from Knysna, Addo, Kruger Park and the Northern Namib Desert. The specimens belonging to specific populations are circled. Below: plot of the first two principal components of the multivariate statistical analysis (adapted from Vogel *et al.* 1990: 747).



In conclusion, isotopic analysis has generally been utilized to study the diet of elephants and sometimes the climate in which they lived. However, the possibility of using isotopic analysis to source ivory is demonstrated by van der Merwe *et al.* (1990) and Vogel *et al.* (1990), and the advice of Koch *et al.* (1995) to look into neodymium and lead isotopes for sourcing offers future avenues of research worth investigating. Because neodymium and lead isotopes are tied to local geology, like strontium, and often reported alongside strontium in the geological literature, triangulating these three isotopes against one another would offer a more unique and descriptive fingerprint for sources. However, since the scope of this study is restricted to strontium, I shall now turn to a review of the strontium isotope ratio values reported in the geological literature for the eastern Mediterranean and northeast Africa.



## **Chapter 10**

### **A Review of the Published Strontium Isotope Ratio Values for the Eastern Mediterranean and Northeast Africa**

The results of the ICP-MS analysis for strontium isotope ratios of the Uluburun ivory and Maraş Fili samples must be compared against the strontium isotope ratios available in the geological literature for the areas in question: Northwest Syria/Southeast Turkey, the Levantine coast, Egypt (Nile River Valley), Northeastern Libya, and Southeastern Sudan. Unfortunately there are several obstacles to making sound comparisons between any strontium isotope values obtained for the Uluburun/Maraş Fili samples and the geological strontium isotope values, some of which have been already discussed in Chapter Six.

Not only is there a paucity, or a complete lack, of information for some of the areas under consideration, but often the research questions of interest to geologists are of very particular and geographically limited areas. Therefore the strontium isotope values published are not representative for the region. Nevertheless, some general trends were discerned, and are discussed below.

#### **Syria and Southeastern Turkey**

The region defined as northern and western Syria and southeastern Turkey is plagued by insufficient strontium isotope data, which is extremely unfortunate considering this region was almost certainly the source of quite a bit of ivory in the Late Bronze Age trade and home to one of the most important trade centers of the era

(Ugarit/Ras Shamra). Only two studies address the geology of the region: Alici *et al.* (2001) and Gale *et al.* (1981).

The Karasu Valley in Hatay, southeastern Turkey, was the area of investigation for Alici *et al.* (2001). The area is bounded by two major fault lines, namely the Dead Sea transform fault and the East Anatolian fault (see Figure 46 for location of study area and faults). Karasu Valley is considered the northern segment of the Dead Sea transform

Figure 46: Map of the Karasu Valley region in Southeast Turkey. Inset: DSF = Dead Sea fault; EAF = East Anatolian fault (adapted from Alici *et al.* 2001: 122).

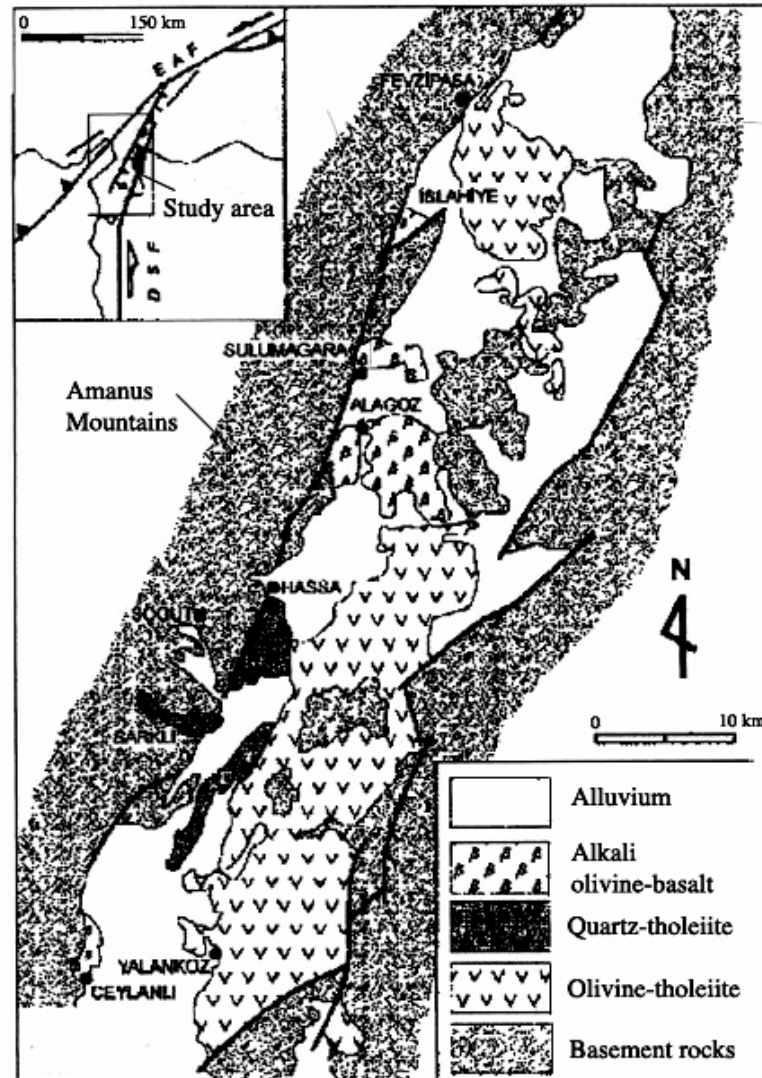
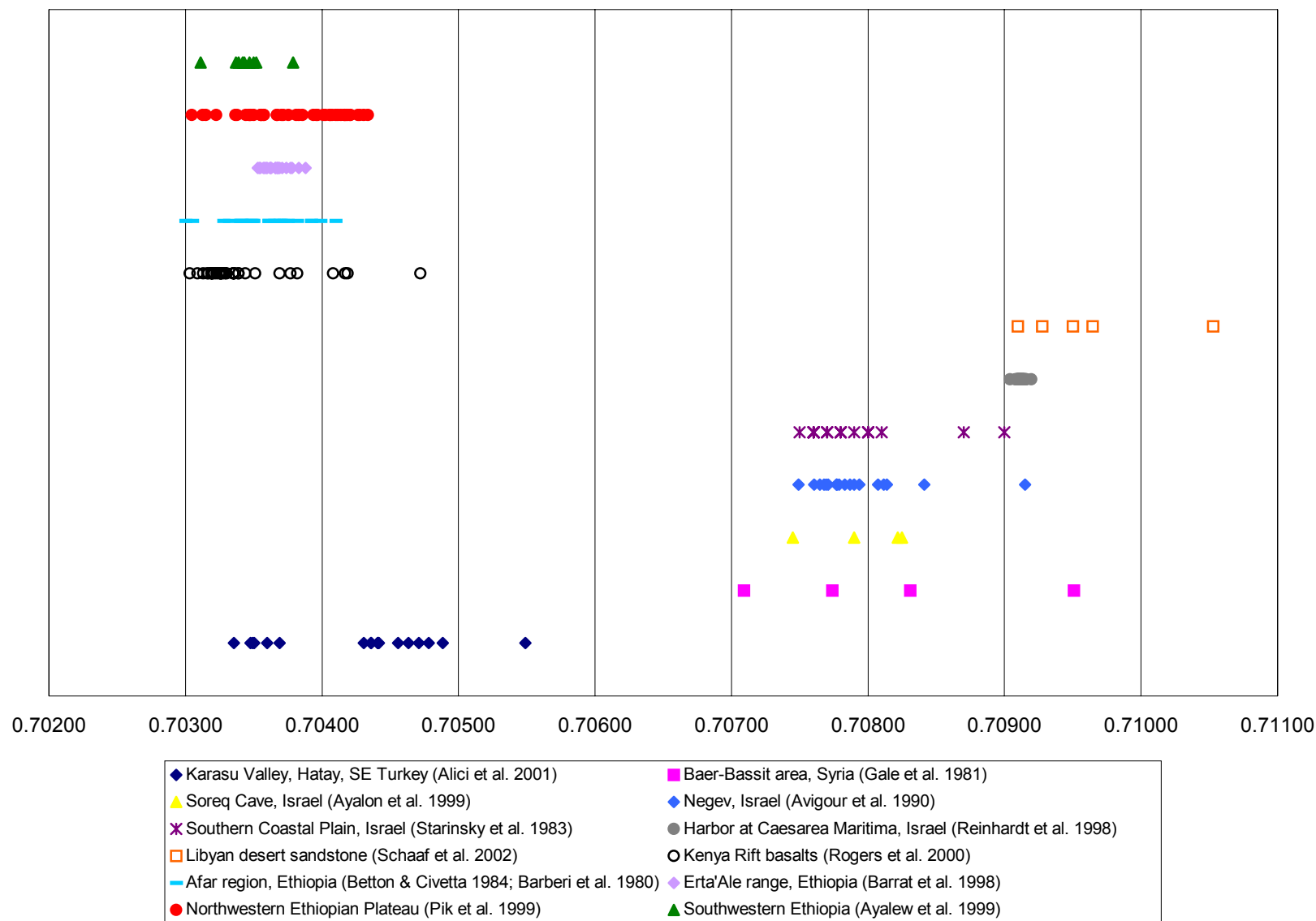


Figure 47: Published strontium isotope ratios for the eastern Mediterranean and Northeast Africa



fault and is filled with flood-basalt type volcanics of Quaternary age. This valley is, understandably, an active fault zone that is known as the "Karasu fault," and extends in a NE-SW direction. The authors collected eighteen samples for strontium isotope analysis from alkali basalts, quartz tholeiites, and olivine tholeiites, the results of which are reproduced in Figure 47 (solid dark-blue diamond). The  $^{87}\text{Sr}/^{86}\text{Sr}$  values for the basalts range from 0.703353 to 0.704410, whereas the quartz-tholeiites are from 0.704410 to 0.705490, and the olivine tholeiites from 0.703490 to 0.704780. The latter two types have higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values due to contamination of magmas by crustal materials (Alici *et al.* 2001: 124, 129). The second study, by Gale *et al.* (1981), hails from the Baër-Bassit area of Syria which lies north of Ugarit/Ras Shamra along the Levantine coast. The study is a more specific investigation concentrating primarily on the metalliferous sediments associated with Upper Cretaceous ophiolites. Only four samples were collected, and their locations are depicted in Figure 48. See also Figure 49 for a larger geologic map of the region. The results are reproduced in Figure 47 (solid pink squares).

It is readily apparent that the values from southeastern Turkey and northwestern Syria range on opposite ends of the spectrum of typical  $^{87}\text{Sr}/^{86}\text{Sr}$  values. The Karasu Valley has  $^{87}\text{Sr}/^{86}\text{Sr}$  values typical of the basalt geology of the area, whereas the Baër-Bassit values derive from the strontium isotope signature of the Campanian-Maestrichtian sea, when the sediments were formed (Gale *et al.* 1981: 1299). These two studies only highlight the difficulties inherent in trying to characterize a geologically complex area by a narrow range of  $^{87}\text{Sr}/^{86}\text{Sr}$  values. The complicated nature of the geology requires a large number of site-specific studies in order for a strontium isotope profile of the region to be developed, and unfortunately such studies are not available at this time.

Figure 48: Locations of the metalliferous sediment samples associated with the ophiolitic rocks of the Baër-Bassit area, northwestern Syria. 1 = upper Maestrichtian-Pliocene shallow-water marine carbonates; 2 = deformed Triassic-Upper Cretaceous volcano-sedimentary association tectonically underlying the ophiolitic rocks; 3 = ophiolitic rocks;; (adapted from Gale et al 1981: 1295, figure 3).

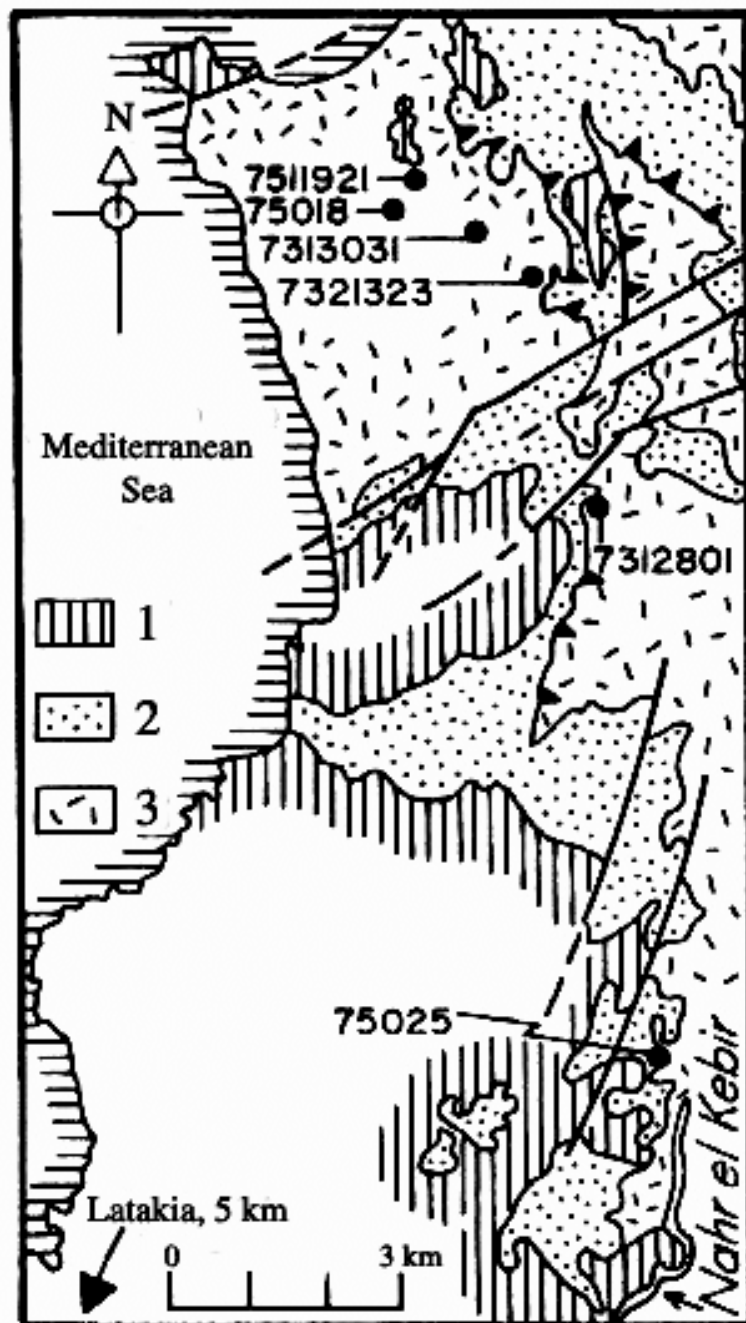
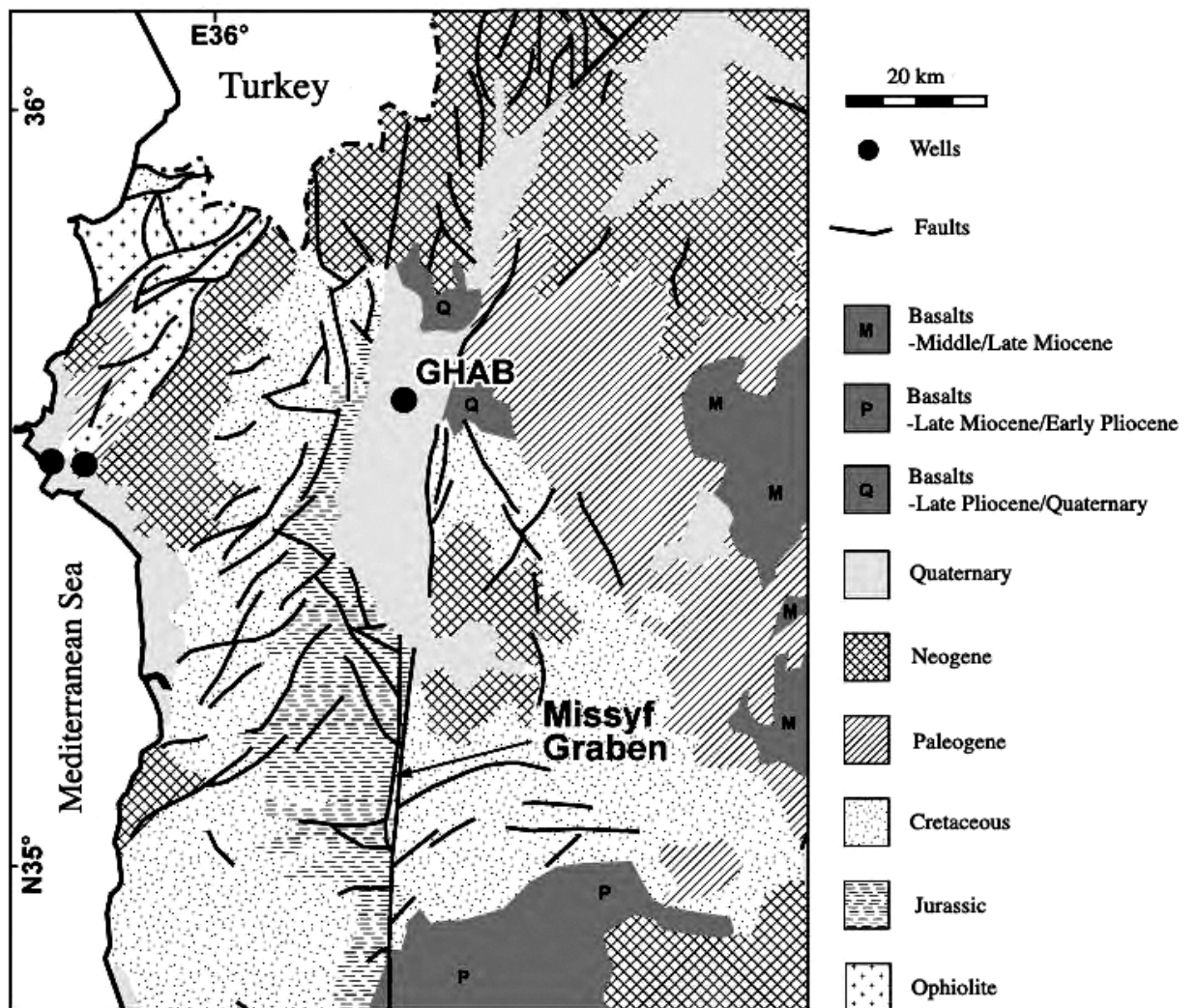


Figure 49: Geologic and fault map of Northwestern Syria  
(adapted from Brew 2001, figure 4.3).



## Israel

Published strontium isotope data from Israel are available, but the geological coverage is less than ideal. The coastal areas are of primary interest for Israel, since these regions are where hippopotami would have once dwelled. However, the rest of Israel will be considered as well.

Ayalon *et al.* (1999) sought to reconstruct the palaeoclimate of the eastern Mediterranean region based on  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  variations in speleothems from Soreq Cave in Israel, about 40 km inland from the coast. They noticed an increase in isotopic ratios during colder and drier periods, and established that strontium isotopes, like oxygen isotopes, can be influenced by climatic factors (Ayalon *et al.* 1999: 715, 719). More important for the purposes of this thesis, however, they found the local dolomite host rock to have a  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.70745, and the Holocene values from the speleothems to range from 0.7079 to 0.70825, with the majority around 0.70822. These values are reproduced in Figure 47 (solid yellow triangles). The disparity between the dolomite host rock and the speleothems is attributed to exogenic sources to the speleothem such as sea spray and aeolian dust (Ayalon *et al.* 1999: 720). Another article by the same group of researchers sees the strontium isotope ratios as influenced by “major changes in the temperature, the mean annual rainfall and its isotopic composition, the isotopic composition of the Mediterranean vapor source, the soil moisture conditions, and in the mixing proportions of sources with different  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (sea spray, dust particles and dolomitic host rock)” (Bar-Matthews *et al.* 1999: 85). However, a correlation between strontium isotope ratios and climate may only be encountered in special geological situations like that of speleothems.

The Negev Desert in Southern Israel was the focus of the next study by Avigour *et al.* (1990). The purpose of the study was to compare the strontium isotope compositions of secondary calcites to those of their marine carbonate host rocks. The host rocks, which are of the most use for the present investigation, ranged from 0.707251 to 0.70755. The results of both the host rock and the secondary calcites are depicted in Figure 47 (solid blue diamonds). The sample locations are furthermore portrayed in Figure 50.

Also from this general area, but along the coastal plain of southern Israel (see Figure 51 for location), come more  $^{87}\text{Sr}/^{86}\text{Sr}$  values from Starinsky *et al.* (1983). These values span from 0.7075 to 0.7090, with an average value of 0.7081 (see Figure 47 for values, depicted as purple stars).

In an innovative use of strontium isotope values for reconstructing the history of the ancient harbor at Caesarea Maritima, Reinhardt *et al.* (1998) also provided strontium isotope ratios for the coastal region. The researchers took 42 samples from fossils for  $^{87}\text{Sr}/^{86}\text{Sr}$  measurements to investigate temporal paleosalinities that may be related to the shape of the harbor, and the results are listed in Figure 47 (solid gray circles). By recognizing that “environments in close proximity to the fluvial input of strontium to the world’s oceans may have  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios that deviate from that of the global value for normal seawater” (Reinhardt *et al.* 1998: 3), they were able to draw some conclusions about the form and function of the harbor by taking the known value of groundwater in Israel (0.7080) and calculating mixing averages with the seawater in the eastern Mediterranean (0.709072). Using this same principle, the strontium isotope budget of the eastern Mediterranean will now be considered.



Figure 50: The main faults and folds of the Negev and the sampling sites, as marked by numbers (adapted from Avigour *et al.* 1990: 70).

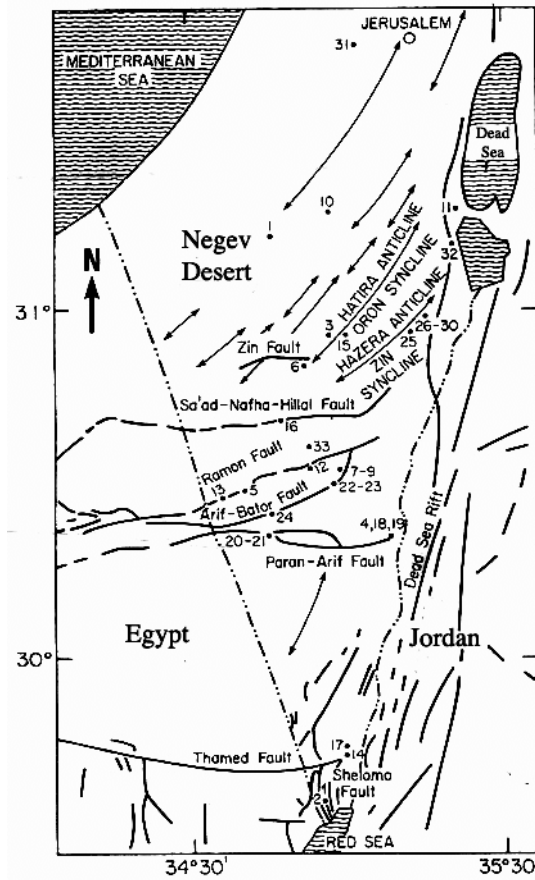
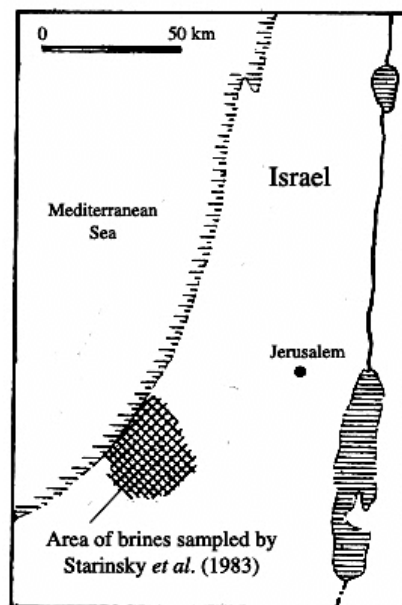


Figure 51: Location of the studied area in Starinsky *et al.* (1983). Figure adapted from Starinsky *et al.* (1983: 688).



## The Eastern Mediterranean and the Nile

The seawater of the eastern Mediterranean, especially along the Levantine coast, has a  $^{87}\text{Sr}/^{86}\text{Sr}$  value directly affected by the fluvial strontium input from the Nile, which is mirrored by the surface sediments as well. Stable oxygen and carbon isotopes from two cores off the coast of southern Israel (see Figure 52 for location) were evaluated by Schilman *et al.* (2001) to illustrate this process, and in particular the effects of climatic and environmental changes in the southeast Mediterranean during the Late Holocene (3.6 ka BP). The factors contributing to the  $\delta^{18}\text{O}$  value of the seawater and sediment of the Southeast Mediterranean are outlined in Figure 53. These factors include water coming from the Atlantic Ocean through the Strait of Gibraltar, sediment from Saharan dust (composed primarily of Precambrian rocks), water from rainfall over the Mediterranean,

Figure 52: Location of two cores, indicated by a star (adapted from Schilman *et al.* 2001: 159).

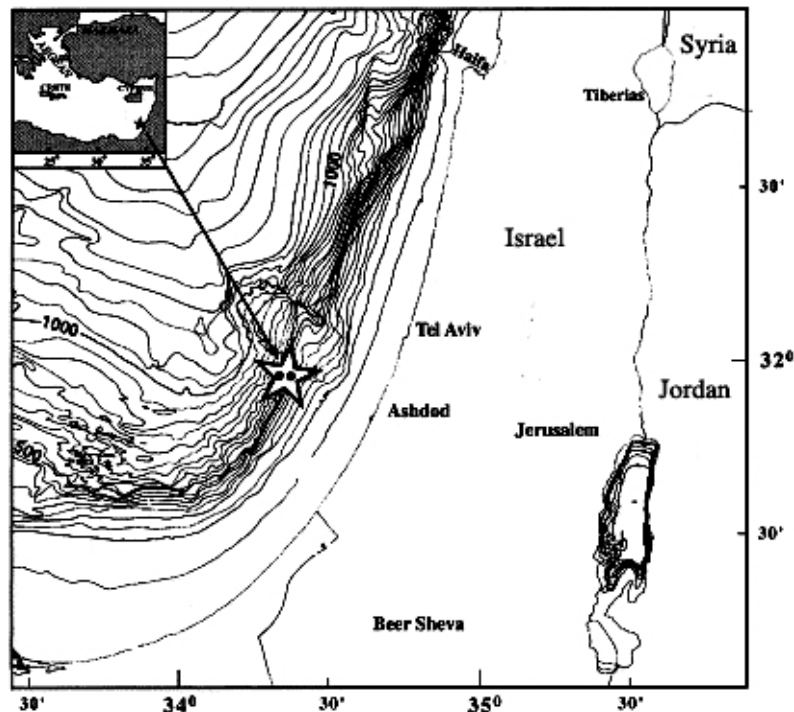
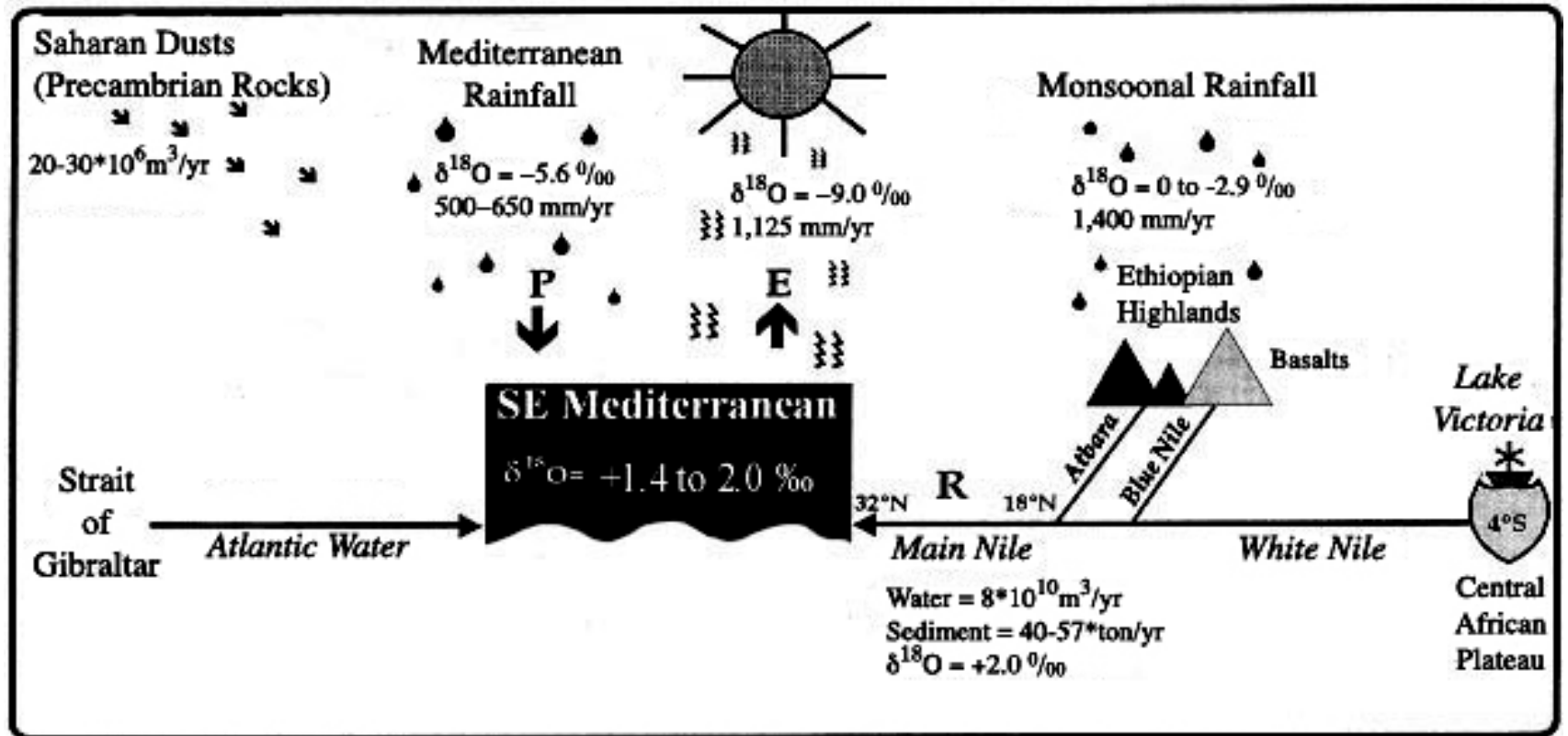


Figure 53: Schematic diagram showing the main inputs of water and sediment to the SE Mediterranean surface waters. The  $\delta^{18}\text{O}$  and the  $\delta^{13}\text{C}$  of the freshwaters and their annual amounts are also shown. The precipitation (P), runoff (R), and evaporation (E) affecting the sea-surface layer, together with the present-day contribution of the Saharan dust and the Nile particulate matter are included (adapted from Schilman *et al.* 2001: 168, figure 5).



and water and sediment from the Nile. The four main sources of the Nile include the Atbara, Sobat, and the Blue Nile, all of which hail from monsoonal rainfall over the Ethiopian highlands, and the White Nile which originates from Lake Victoria in the Central African Plateau.

At present the Blue Nile and Atbara contribute 97% of the sediment load of the Nile, and these sediments derive from the weathering of Tertiary basalts in the Ethiopian Highlands. The White Nile on the other hand only contributes 3% of the sediment load. Aeolian Saharan dust from Paleozoic Nubian sandstones and Cretaceous rocks of the North Africa desert belt mixes with the sediment load of the Nile to form the surface sediments of the eastern Mediterranean (Schilman *et al.* 2001: 171).

The researchers found that the relative contribution of aeolian dust and Nile sediments changed with time, reflecting an aridification trend in the eastern Mediterranean. This aridification process included the reduction of vegetation cover in East Africa, which in turn “led to an increased erratic flood-related sediment flux via the Nile River... This is reflected by the general change in the local sediment composition. At 3.6 ka, the Saharan eolian input reached 65% whereas at about 0.3 ka 70% of the SE Mediterranean sediment was composed of Nile particulate matter” (Schilman *et al.* 2001: 157; see also Abell and Williams 1989). Thus, from Figure 54, the surface sediment composition circa 1300 B.C. may be roughly extrapolated as 40% Nile sediments and 60% Aeolian dust. The modern predominance of Nile sediment in the surface sediments of the eastern Mediterranean was also discussed by Waldeab *et al.* (2002). They found the surface sediments of the eastern Mediterranean to exhibit the lowest  $^{87}\text{Sr}/^{86}\text{Sr}$  values (average 0.709541) of the entire Mediterranean, which reflected the input of the Nile

sediment. As may be seen in Figure 55, the low strontium values follow the natural current counter-clockwise up the Levantine coast. The same researchers quote the average value of Nile river sediments as 0.707043 and the average value of Saharan dust as 0.721788 (Waldeab *et al.* 2002: 142; citing Goldstein *et al.* 1984; Grousset *et al.* 1998, Krom *et al.* 1999). If these values are used and the extrapolated inputs circa 1300 B.C. from Schilman *et al.* (2001) are considered, then an estimate may be deduced for the average strontium input to the eastern Mediterranean c. 1300 B.C.:

$$^{87}\text{Sr}/^{86}\text{Sr}_{\text{NS}} (\text{percent input}) + ^{87}\text{Sr}/^{86}\text{Sr}_{\text{SD}} (\text{percent input}) =$$

$$\text{Average } ^{87}\text{Sr}/^{86}\text{Sr} \text{ input to EM}$$

$$0.707043 (0.40) + 0.721788 (0.60) = 0.71589$$

where NS = Nile Sediment, SD = Saharan dust, and EM = eastern Mediterranean.

Figure 54: Ti/Al ratios plotted against calendar ages (ka), showing higher Saharan dust contribution at past times (65%) compared with the Nile particulate matter contribution (70%), which is higher towards the present (adapted from Schilman *et al.* 2001: 171).

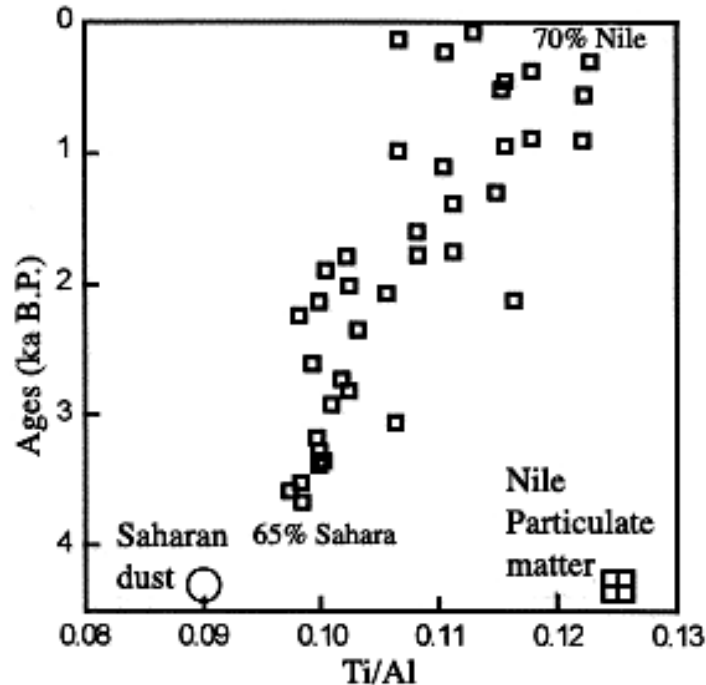
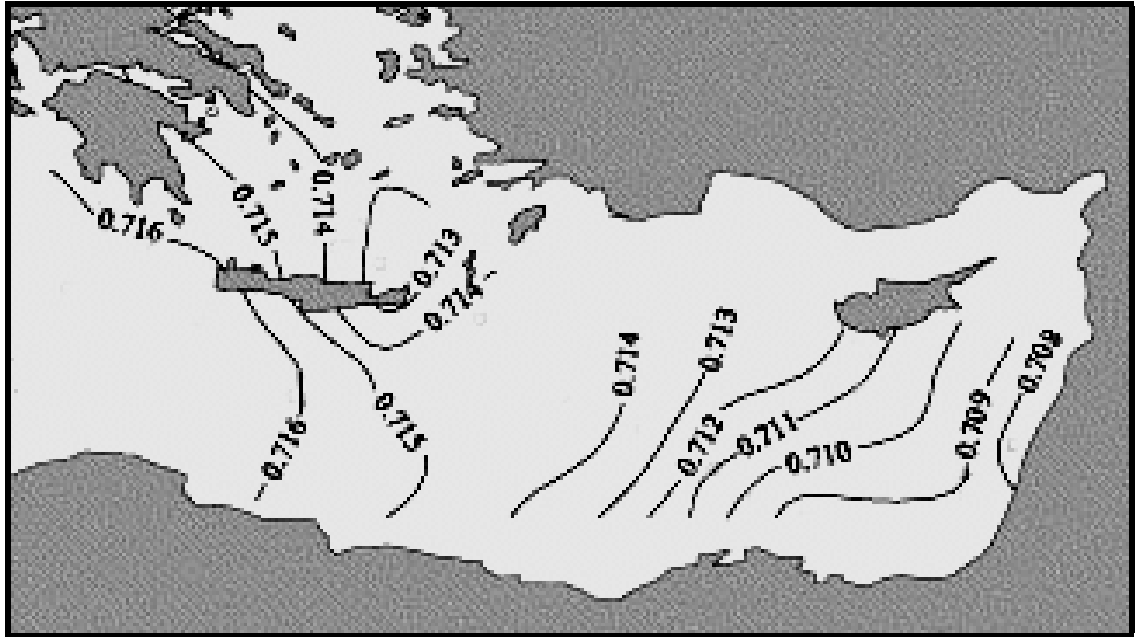


Figure 55: Contour diagrams for the isotopic composition of lithogenic surface sediments in the eastern Mediterranean. Contours are drawn at intervals of 0.001 (adapted from Weldeab *et al.* 2002: 145, figure 4b).



Thus the average input to the eastern Mediterranean circa 1300 B.C. was approximately 0.71589. This is only an estimate because modern values for Nile sediment and Saharan dust were used, and moreover Pe-Piper and Piper (2001) cite slightly higher modern Nile sediment values of 0.7075 to 0.7078.

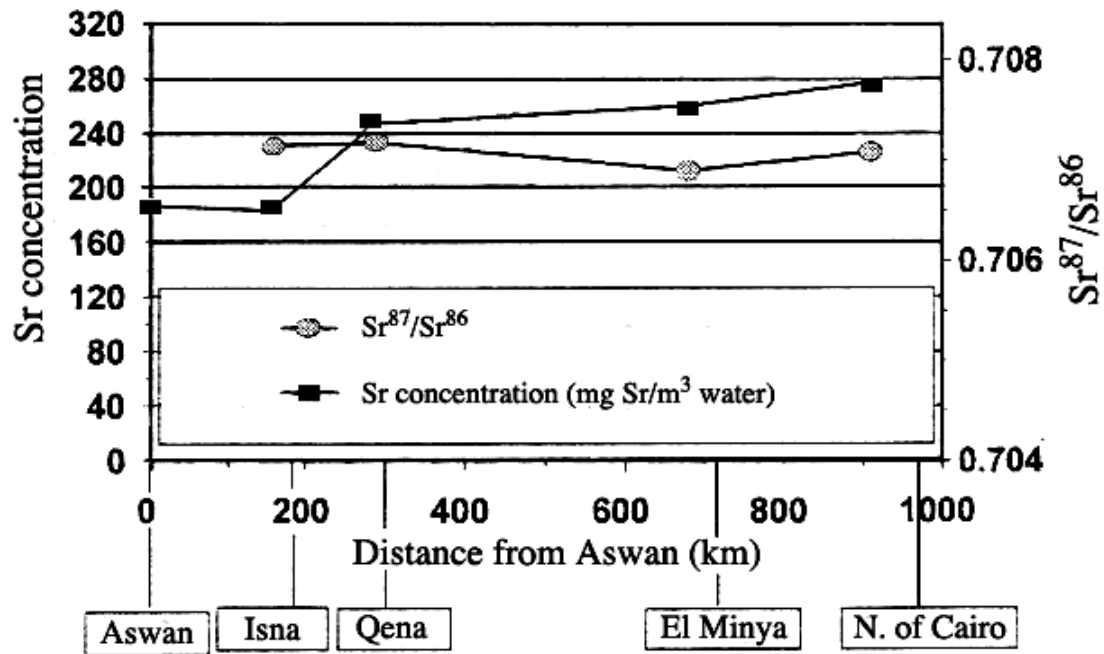
Gerstenberger *et al.* (1997) address the origin of strontium in the Nile, tracing the major fluvial inputs, their sources, and the sources of change to the strontium signature during the course of the rivers. As mentioned previously, the Blue Nile, Atbara, and Sobat drain from the Ethiopian highlands which are geologically characterized by oceanic crustal rocks. As a result, the strontium content of these rivers bears an old oceanic crustal signature of relatively higher  $^{87}\text{Sr}/^{86}\text{Sr}$  values. The White Nile drains

from a large area of supracrustal metamorphic rocks with even higher strontium isotope ratios, including the Lake Victoria plateau and Bahr el Ghazal region. However, it is also fed by the Sobat. The Nile is constrained to these sources, as north of the Atbara there is no inflow. However, the relative contributions of these sources varies: “whereas the flow rate of the White Nile is well regulated by lakes and swamps, resulting in a relatively constant proportion (16%) of the average discharge of the Nile, the Blue Nile and the Atbara discharge rates differ extremely as a result of the seasonal rainfall pattern” (Gerstenberger *et al.* 1997: 349-350).

The strontium isotope ratio of the White Nile is 0.7114, a high value typical of silicate weathering of cratonic rocks including the Sabaloka granulites, migmatites and granites. The Blue Nile flows a shorter distance in a floodplain than the White Nile-across metasedimentary gneiss, oceanic volcanosediments and ophiolitic rocks. As to be expected from this type of the geology, the  $^{87}\text{Sr}/^{86}\text{Sr}$  of the Blue Nile is a relatively low 0.7056. The Aswan High Dam reservoir represents a major modern alteration to the river, but for the purposes of this thesis has only slight consequences as it serves to level out the seasonal fluctuations of the strontium isotope values caused by the variable discharge rates of the Blue Nile. The effective outflow from the Aswan Dam is 0.7062 (Gerstenberger *et al.* 1997: 352-353). As Figure 56 demonstrates, the  $^{87}\text{Sr}/^{86}\text{Sr}$  values remain fairly constant with distance downstream from Aswan, although at a slightly higher strontium isotope ratio of approximately 0.7070, probably due to evaporation along the course of the river.

Taking another look at the principal lakes and rivers of the Upper Nile, Talbot *et al.* (2000: 343-345) note a Sr ratio of 0.7113 for Lake Victoria and 0.7073 for Lake

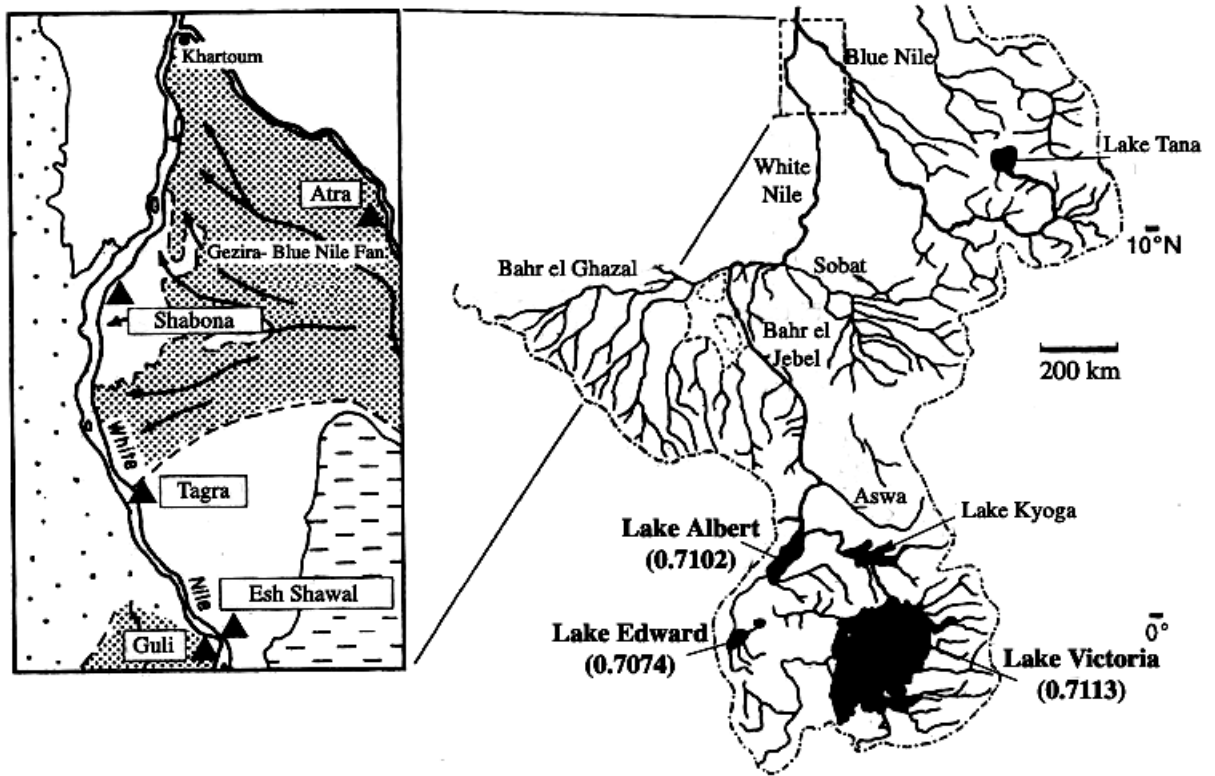
Figure 56: The Sr isotope ratios in the water of the Nile from Aswan to North of Cairo (gray ovals) (adapted from Gerstenberger *et al.* 1997: 354, figure 2).



Edward, whereas Lake Albert, which receives water from both lakes, has an intermediate value of 0.7102. The Bahr el Jebel river downstream from the lakes has a higher Sr ratio of 0.7117 at Bor. Farther downstream, the Sobat empties into the White Nile, effecting lower Sr ratios at Esh Shawal, Guli and Tagra of 0.7093 to 0.7109 (determined from fossil mollusks and faunal remains). The Sobat probably has values similar to the Gezira region of the Blue Nile (0.7062), as the both empty from the volcanic geology that is the Ethiopian highlands. See Figure 57 for a map of this region and locations of sampled fossils, and Figure 58 for a schematic diagram of strontium ratio values during the course of the White Nile.



Figure 57: White and Blue Nile drainage networks with detailed map of area between Esh Shawal and Khartoum. Numbers in parentheses = modern Sr isotope ratios; solid triangles = fossil localities (adapted from Talbot *et al.* 2000: 343).



## Ethiopia

Having considered the hydrology of the Nile, and in particular its catchment areas, I shall now turn to the geology of Ethiopia. Fortunately there is a great deal of literature for this region because of researchers' interest in the unique geology of the Kenya and Ethiopian rift valleys.

Rogers *et al.* (2000) investigated the geology of the Kenya rift system which has a basement composed of three zones: the Archaean Tanzanian craton (TC), the late Proterozoic Pan-african Mozambique mobile belt (MB) and a zone of craton margin reactivated (remobilized) during the Pan-african orogeny (RCM) (see Figure 59 for map

Figure 58: Schematic diagram along Upper Nile-White Nile from headwater lakes to Khartoum, summarizing Sr isotope composition of main components of drainage system. Water analyses are open stars, numbers are sample ages in  $^{14}\text{C}$  ka BP, long arrows are main water courses. End member values are for two principal types of catchment geology: Precambrian-lower Paleozoic crystalline basement and Cenozoic-Holocene volcanic rocks (adapted from Talbot *et al.* 2000: 344, figure 2).

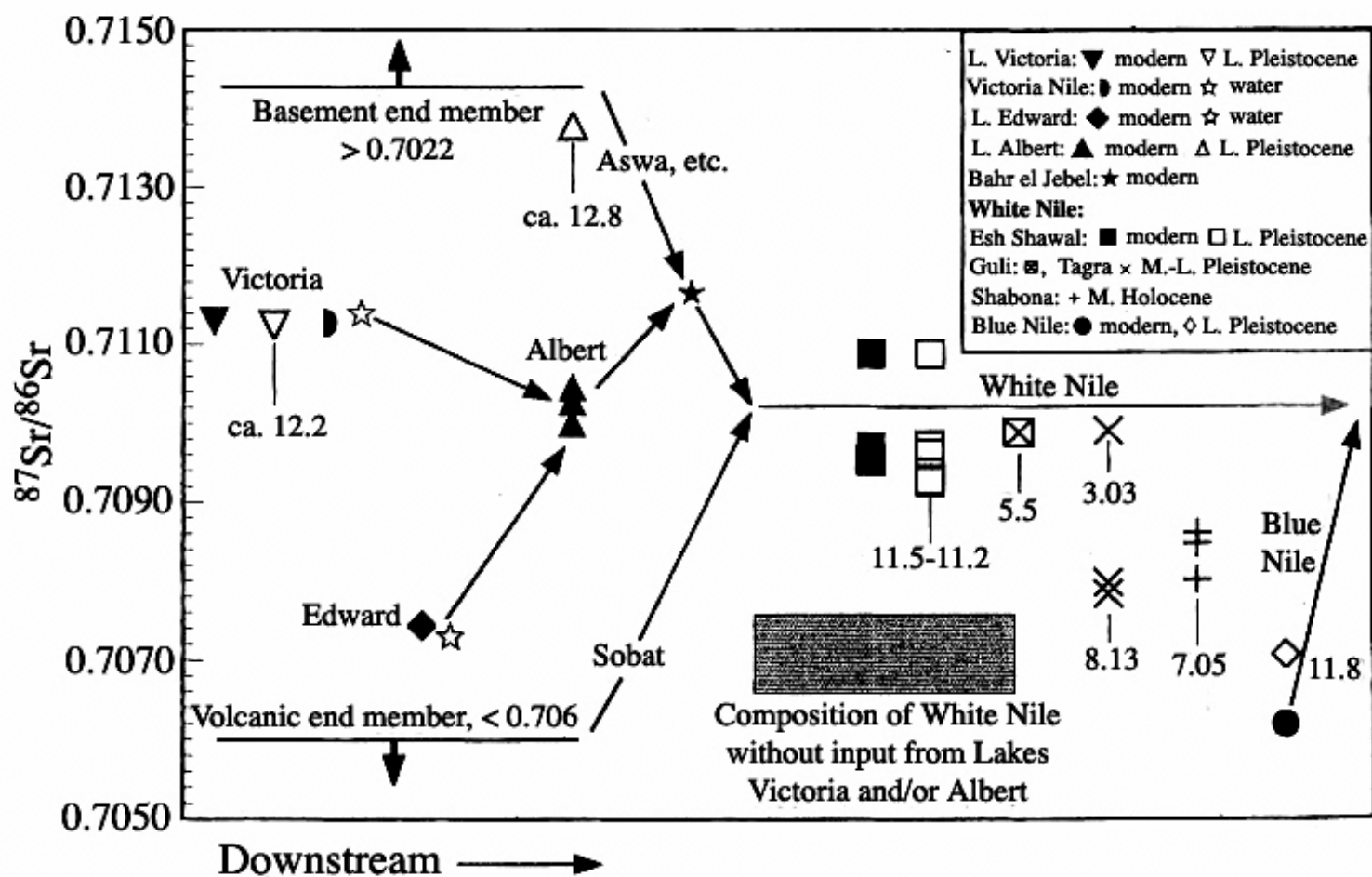
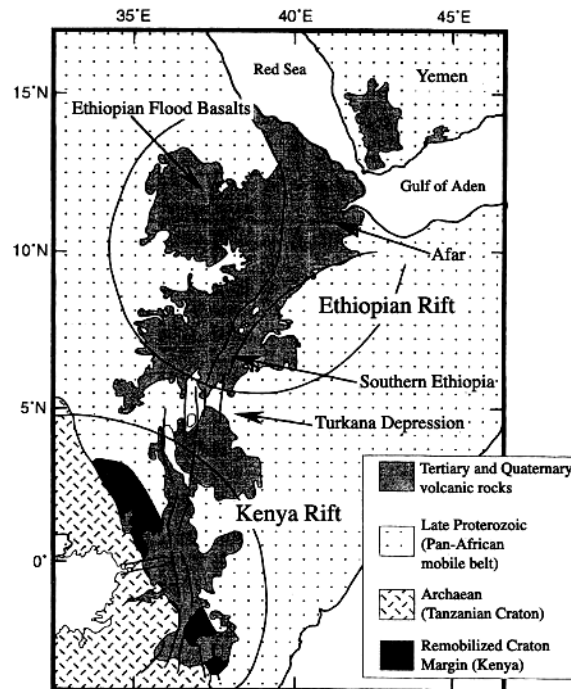


Figure 59: Map of the Kenya and Ethiopia rifts, showing the distribution of Tertiary-Recent volcanism, and the MB, TC, and RCM. The curved solid lines denote the extent of the Ethiopian and east African plateaus (adapted from Rogers *et al.* 2000: 389).



of these zones). These basalts located along the axial regions of the Kenya Rift have Sr ratios of 0.7030 to 0.7055. Specifically, the TC and RCM have values ranging from 0.7035-0.7056 (or  $> 0.7035$ ), and the MB yields ratios from 0.7030-0.7035 (or  $< 0.7035$ ) (389). All of these values agree with the volcanic end member of  $< 0.706$  suggested by Talbot *et al.* (2000) in Figure 58 above. Specific Sr ratios from geological samples were only given for the MB and RCM, and these are depicted in Figure 47 as unfilled black circles.

Strontium isotope ratios for the Afar region (see Figure 59 above for location) are given by Betton and Civetta (1984). These values, ranging from 0.70328 to 0.70410, are represented in Figure 47 as light-blue filled rectangles and represent the entire range of geological compositions in Afar (from low-K tholeiites and alkali basalts) (Betton and

Civetta 1984: 61; Barberi *et al.* 1980). Slightly north of Afar is the Danakil Depression where one of the most important axial volcanic chains of the Afar region, the Erta' Ale range is located (see Figure 60 for location). Strontium ratios from this range have a fairly limited spread of 0.7035-0.7038 (Barrat *et al.* 1998: 85), which fit well with the strontium data from Betton and Civetta (1984). The Erta' Ale data is depicted in Figure 47 as light-purple solid triangles. Surrounding the Afar region are basalt highlands, which in Northern Ethiopia and Yemen were formed by volcanism starting in the Oligocene (Pik *et al.* 1999: 2264). The Blue Nile also hails from this region.

Figure 60: Geological map of the Danakil Depression (adapted from Barrat *et al.* 1998: 86).

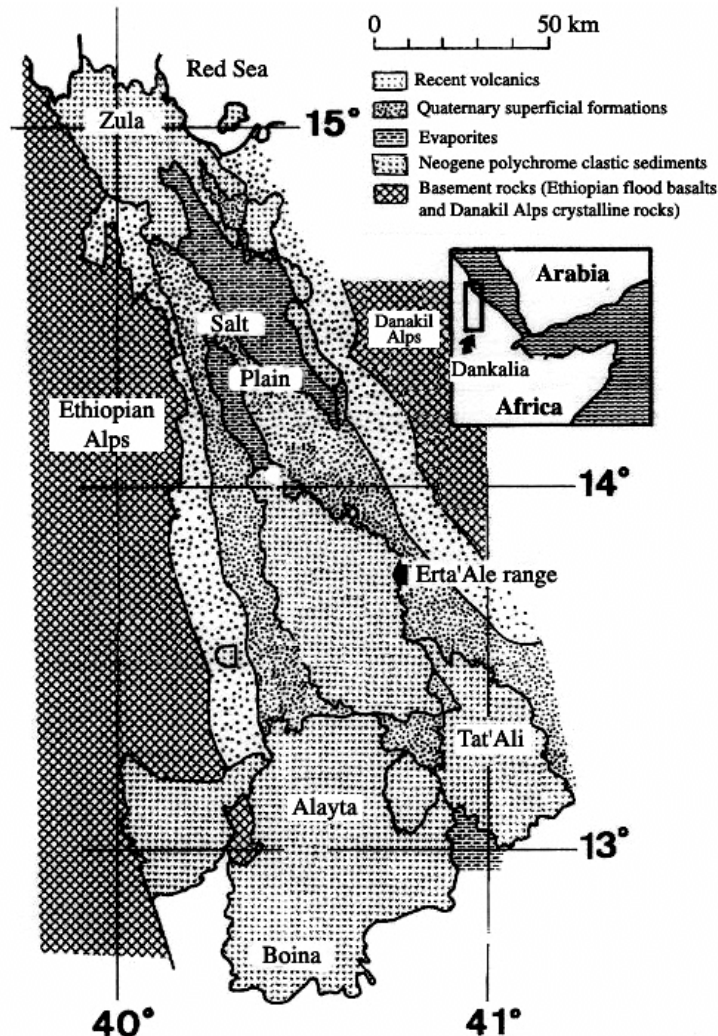
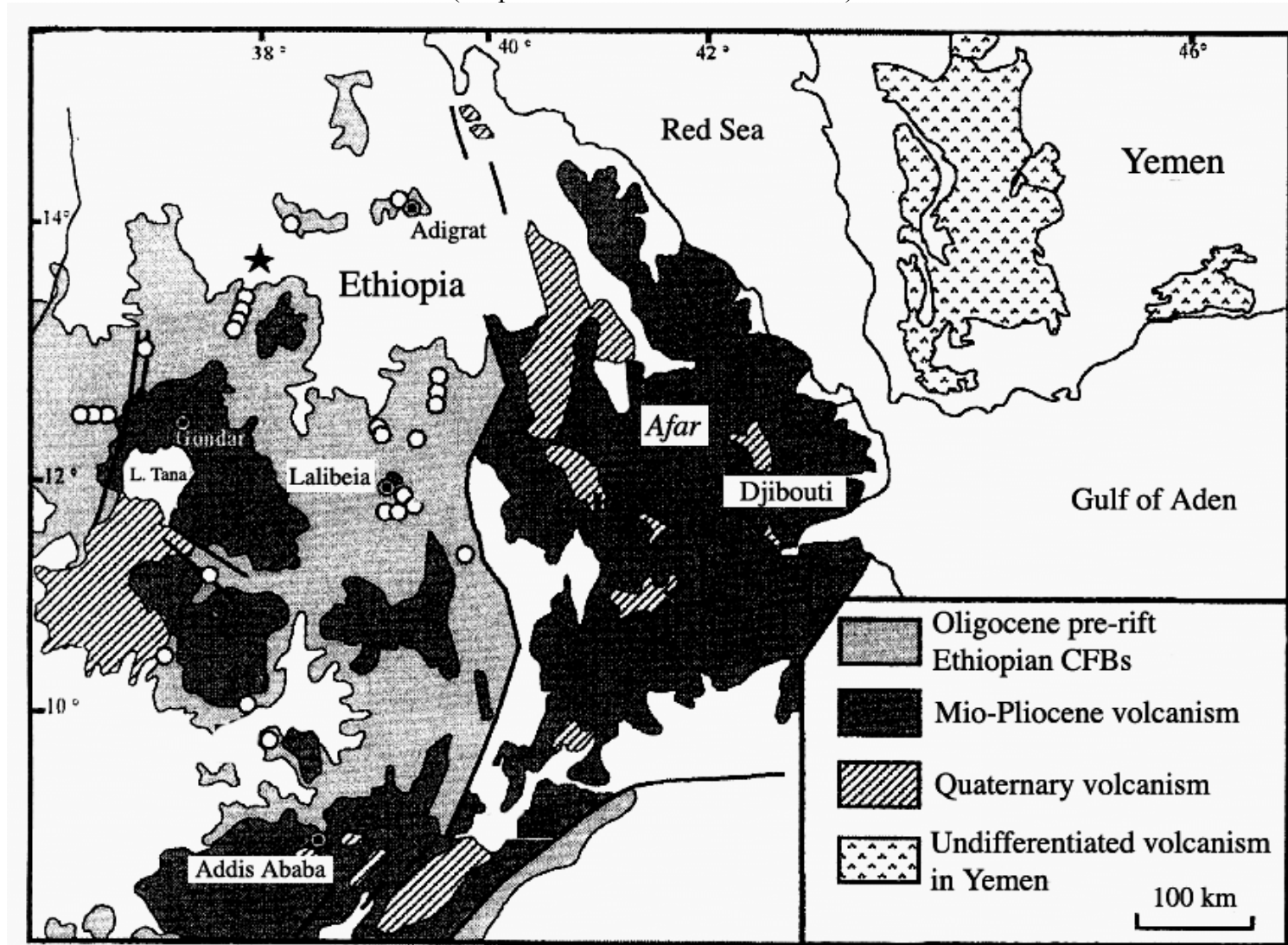


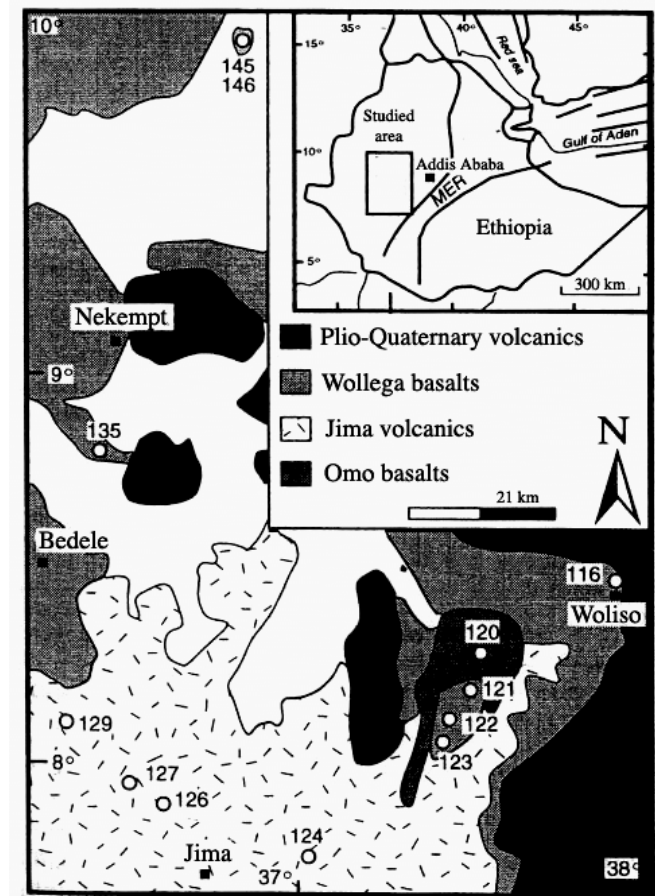
Figure 61: Location map of the northwestern volcanic province and Afar triple junction, showing the main tectonic features and phases of volcanism. Open circles represent sample locations on the northwestern Ethiopian plateau (adapted from Pik *et al.* 1999: 2265).



These flood basalts have  $^{87}\text{Sr}/^{86}\text{Sr}$  values of 0.70304-0.70429 in the northwestern Ethiopian highlands (data represented in Figure 47 by solid red circles; see Figure 61 for geological map of the region and locations of samples tested).

Basalts from Southwestern Ethiopia were analyzed for strontium isotopes by Ayalew *et al.* (1999), again demonstrating a small range of 0.7031-0.7039 (Figure 47, represented by solid green triangles). Figure 62 illustrates the location of these samples. Moreover, Barbieri *et al.* (1976) have similar values at an average of  $0.7035 \pm 0.0004$  ( $n = 6$ ) for Late Tertiary-Quaternary basalts from the Harar Plateau, 50 km northeast of Gara Badda (Kennan *et al.* 1990: 41).

Figure 62: Map of southwestern Ethiopia showing the main volcanic geology and sample locations (white circles) (adapted from Ayalew *et al.* 1999: 383, figure 1).



## North Africa

Now moving north another dearth of published strontium isotope values is seen. Whatever strontium values are available as outlined below have been culled from research either not directly discussing the region, or concerned primarily with very specific geological formations. From the Great Sand Sea in western Egypt the  $^{87}\text{Sr}/^{86}\text{Sr}$  values for the local sandstone range from 0.70910 to 0.71053 ( $n = 5$ ; plotted in Figure 47 as open orange squares) (Schaaf *et al.* 2002: 570). The local sandstone was sampled from the area where the arrow in Figure 63 indicates “LDG strewn field.” Nevertheless, these values are only useful if ‘desert’ elephants should be represented in the Uluburun samples. However, the local sandstone (marked “LDG field”) was plotted, in Figure 64, against sandstone samples from the BP and Oasis craters (data from Abate *et al.* 1999) and Precambrian granitic rocks from northeast Africa west of the Nile (data from Pegram *et al.* 1976; Schandelmeier and Darbyshire *et al.* 1984; Harms *et al.* 1990). From this graph a value of 0.70625 to greater than 0.7140 is estimated for the Precambrian granitic rocks.

Küster and Liégeois (2001) sampled many types of geology along the Nile in the Bayuda Desert, located north of Khartoum (see Figure 65 for location). Unfortunately the strontium isotope values (Table 7) have an extremely large range and as a result prove virtually useless.

Returning full circle to the topic of the strontium budget of the eastern Mediterranean, the strontium isotope signature for Saharan dust is discussed by Grousset *et al.* (1998), but in the context of the Atlantic off the coast of northwest Africa. It seems that  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios increase with decreasing grain size in carbonate-free sediments

Figure 63: Map of the Libyan Desert (hatched). Location of sampled sandstones indicated by arrow. Notice also the location of the BP and Oasis craters (adapted from Schaaf *et al.* 2002: 566).

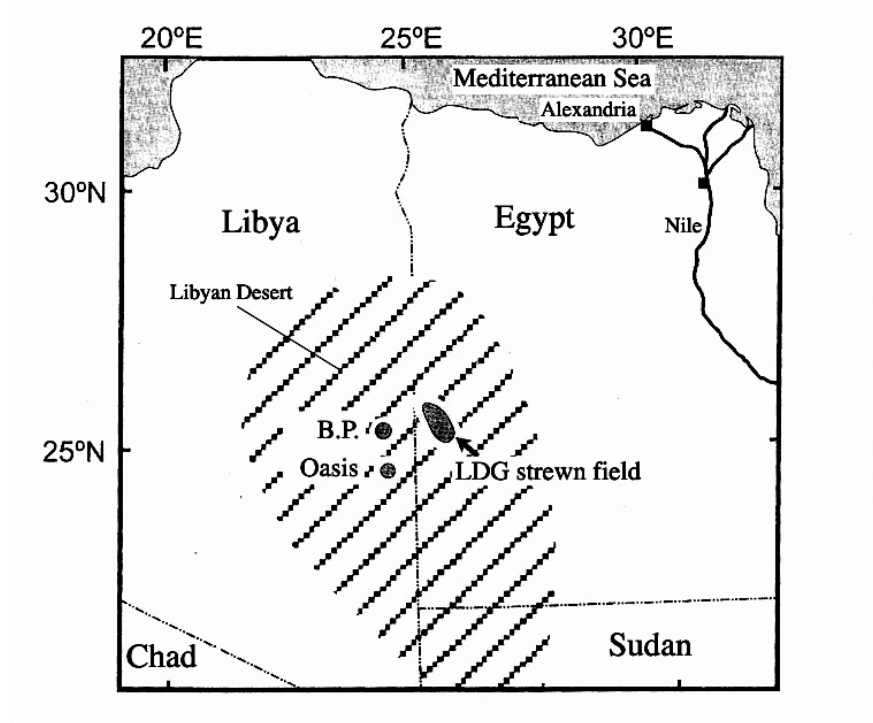


Figure 64: Strontium isotope ratios of sandstone samples from BP and Oasis craters (Libya) and 5 sandstone samples from the LDG strewn field compared to Precambrian granitic rocks from northeast Africa west of the Nile (shaded area) (adapted from Schaaf *et al.* 2002: 573, figure 7).

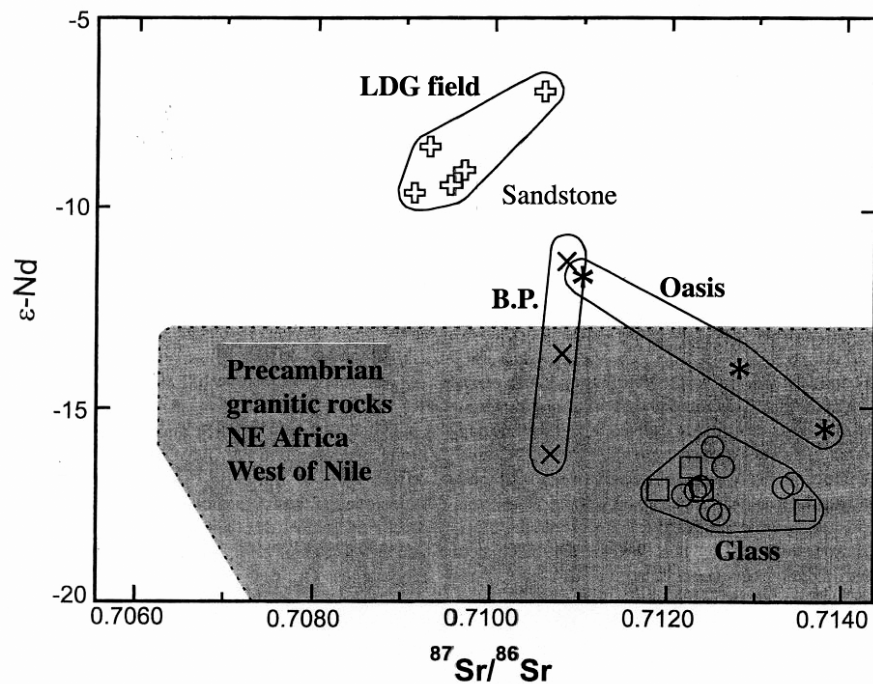




Figure 65: Geological map of the Bayuda Desert and surrounding areas. The boxed areas represent sampling zones (adapted from Küster and Liégeois 2001: 4).

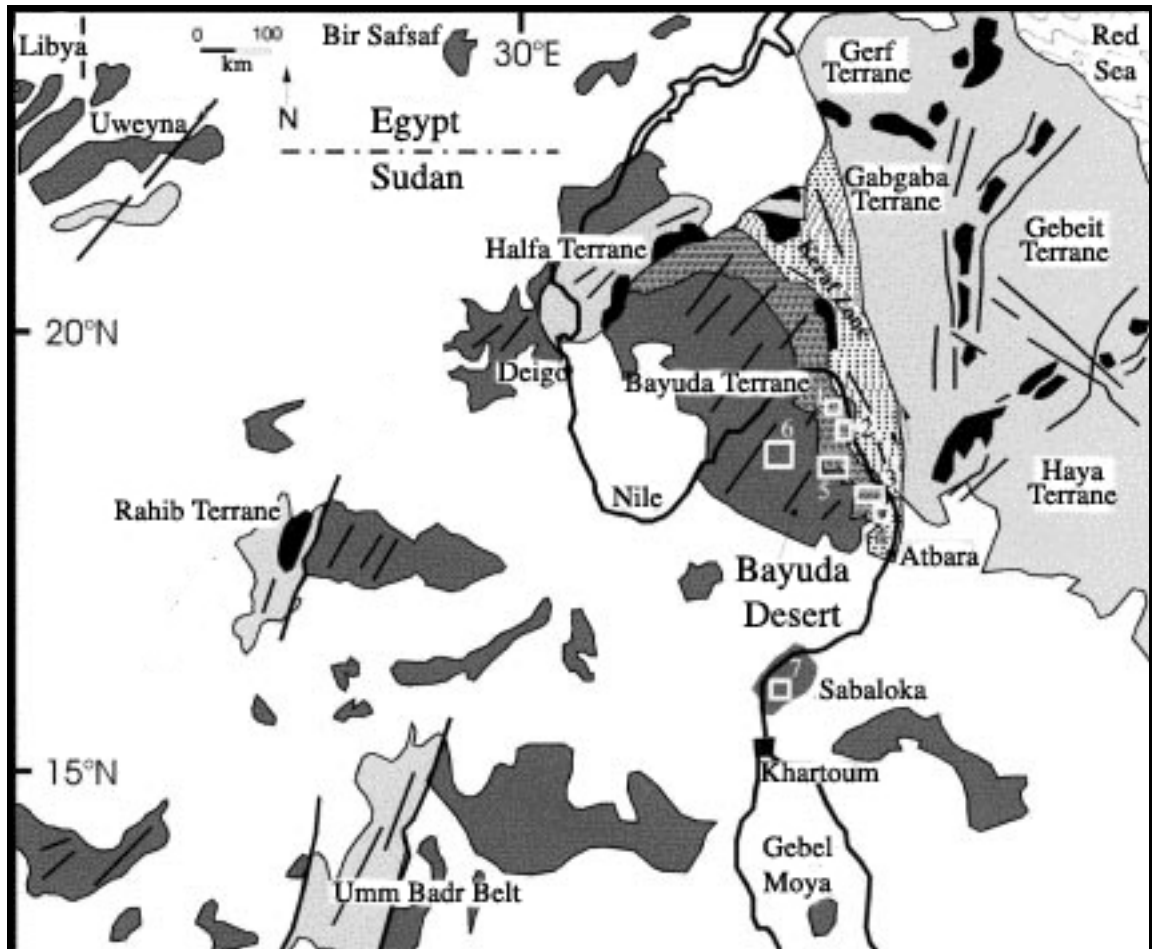


Table 7: Isotopic data of high-grade metamorphic rocks from the Bayuda Desert  
(data from Küster and Liégeois 2001: 10).

Sample no.	Rb	Sr	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	$2\sigma$
<i>Amphibolites</i>					
12-4a	2.05	151	0.0393	0.708912	0.000010
12-6	1.04	139	0.0217	0.708514	0.000009
6-2a	0.14	471	0.0008	0.703929	0.000008
10-5a	2.06	130	0.0458	0.704332	0.000013
10-1a	1.05	64	0.0475	0.705476	0.000013
9-5	1.08	64	0.0488	0.704281	0.000008
9-2a	0.52	241	0.0062	0.703127	0.000010
11-1	24.2	777	0.0901	0.704259	0.000008
<i>Epidote-biotite gneisses</i>					
9-1	9.41	493	0.0552	0.703456	0.000008
11-2a	27.2	564	0.1395	0.704277	0.000008
6-3	89.0	300	0.8588	0.711177	0.000009
<i>Muscovite-biotite gneisses</i>					
12-3	259	51	14.9580	0.888458	0.000011
12-2	253	49	15.2366	0.891699	0.000011
12-5b	242	73	9.6957	0.816103	0.000013
14-9	211	73	8.4328	0.790800	0.000009
<i>Meta-sedimentary rocks</i>					
11-2b	26.0	48	1.5689	0.717021	0.000009
6-5	0.67	155	0.0125	0.703914	0.000011
6-8b	80.0	16	14.6403	0.827762	0.000015
7-1	47.3	314	0.4362	0.708155	0.000010
14-11	141	92	4.4576	0.764279	0.000014
17-6b	128	63.9	5.8405	0.784470	0.000022

(Dasch 1969), thus explaining one of the reasons for the rather high Sr value for Saharan dust (Grousset *et al.* 1998: 399-400). For the Atlantic off the coast of northwestern Africa the smallest fraction of surface sediments and aerosols range from 0.7135 to 0.7253. This research is worth mentioning because it reports some Sr values for samples taken in Algeria (n = 4), Morocco (n = 4), and Mauritania (n = 7). All of the values given

are extremely high: Algeria = 0.726253, 0.720515, 0.724395, 0.713; Morocco = 0.716593, 0.726932, 0.728197, 0.734041; Mauritania = 0.735679, 0.727284, 0.737645, 0.737535, 0.731493, 0.728389, 0.720021.

## **Conclusion**

Thus from the above review of the available literature, the difficulties involved in sourcing by strontium isotope ratios from such a large geographical area with such spotty publishing are readily evident. The largest misfortune is that those areas which could potentially have been the source of elephant ivory but have been ignored or disregarded by scholars are those same areas with a complete dearth of literature, namely Syria and the north coast of Africa. On a fortunate note, the regions with the most available strontium isotope data correlate well with the areas in which hippopotami resided, namely the Levantine coast and the Nile. Hippopotamus ivory luckily represents the largest number of samples in the present investigation as well. The separation between the Levant and the Nile plus associated tributaries is particularly encouraging, as the Levant has  $^{87}\text{Sr}/^{86}\text{Sr}$  values  $>0.707$  and the Nile and its tributaries are  $<0.707$ . Obviously the downfalls are the great lacunae in geographical strontium values which will limit the ability to provenance with absolute certainty, as well as the danger of diagenesis with the seawater of the Mediterranean, which would tend to pull either endmember (the Levant versus the Nile) toward the middle (although slightly more to the Levant side).

## Chapter 11

### **Analytical Procedures, Sample Preparation, and Description of the Uluburun and Maraş Fili Samples**

Researchers have concluded that there is no difference between using bone and ivory (other than that ivory grows by accretion and represents growth over lifetime, whereas bone has a turn-over rate) and that their isotope ratio values can be compared within the same set (Vogel *et al.* 1990: 748; van der Merwe *et al.* 1990: 745; Koch *et al.* 1995: 1340-3). Ivory sample sizes required for analysis are generally 2-3 mg, although a mass spectrometer can measure samples less than a milligram (Tykot and Staller 2002). The samples were processed for collagen and apatite and analyzed using mass spectrometry at the University of South Florida. Samples were sent to MURR (Missouri University Research Reactor) for analysis of strontium isotope ratios by HR-ICP-MS. For descriptive details on the specific samples analyzed see Table 8.

Four ivory samples (KW 744, KW 1182, KW 1192, and KW 3843) and 3 bone samples (MTA 2142, MTA 2711, and MTA X) were selected for collagen (see Table 9). The ivory and bone collagen samples for carbon and nitrogen stable isotope ratio analysis were prepared according to the laboratory protocol of the Laboratory of Archaeological Science at the University of South Florida. The samples were ultrasonically cleaned in acetone, the solution poured off, and the samples dried in a drying oven at 60°C for 24 hours. Approximately 200 mg of whole ivory or bone were then weighed out from each sample and 50 mls of 2% HCl acid was added to remove the bone mineral (apatite) portion of the sample. After 24 hours the ivory and bone samples were cut into smaller pieces so as to increase the surface area and thereby ensure the reaction followed to

Table 8: Description of Uluburun ivory and Maraş Fili bone samples

Sample number	Material	Sample Description	Site	Initial weight (g)	Apatite USF#	Collagen USF#
KW 744	Ivory	Hippopotamus canine. Fragmentary, white with brown surface.	Uluburun	0.60	5862	5876
KW 1182	Ivory	Hippopotamus tusk fragment. Fragmentary, green with dark green/black surface.	Uluburun	1.70	5863	5877
KW 1192	Ivory	Hippopotamus canine. Fragmentary, light green and white with light brown surface.	Uluburun	7.05	5864	5878
KW 1523	Ivory	Hippopotamus canine. White with light brown surface.	Uluburun	0.30	5865	N/A
KW 2557	Ivory	Hippopotamus tusk fragment. Fragmentary, light green/light brown.	Uluburun	0.32	5866	N/A
KW 2877	Ivory	Hippopotamus incisor. Fragmentary, light green with some dark green.	Uluburun	0.24	5867	N/A
KW 3614	Ivory	Hippopotamus incisor. Very fragmentary, light brown with some medium brown.	Uluburun	0.10	5868	N/A
KW 162	Ivory	Elephant tusk. Very fragmentary, light green with some dark brown. Noticeably treated with consolidates.	Uluburun	0.11	5869	N/A
KW 3843	Ivory	Hippopotamus incisor. Fragmentary, white with some gray.	Uluburun	1.06	5870	5879
KW 2534	Ivory	Artifact (Duck-shaped cosmetic container). Extremely fragmentary, light green with some medium green.	Uluburun	0.03	5871	N/A
KW 1723	Ivory	Artifact (scepter). Extremely fragmentary, off-white. Analyzed only for strontium isotopes.	Uluburun	< 0.01	N/A	N/A
MTA 2142	Bone	<i>Elephas maximus</i> molar. Last pre-erupted molar from left jaw cavity.	Maraş Fili.	54.65	5873	5880
MTA 2711	Bone	Rib of <i>Elephas maximus</i> . Flakes from left anterior rib (rib 3, 4, or 5).	Maraş Fili.	0.72	5874	5881
MTA X	Bone	Rib of <i>Elephas maximus</i> .	Maraş Fili.	140.00	5875	5882

Table 9: Collagen samples for analysis of carbon and nitrogen isotope ratios

USF #	Museum Catalog #	Site	Country	Material	Sample Description	Initial weight (mg)
5876	KW 744	Uluburun	Turkey	Ivory	Hippopotamus canine	245.58
5877	KW 1182	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	209.79
5878	KW 1192	Uluburun	Turkey	Ivory	Hippopotamus canine	223.59
5879	KW 3843	Uluburun	Turkey	Ivory	Hippopotamus incisor	243.84
5880	MTA 2142	Maraş Fili	Turkey	Molar	<i>Elephas Maximus</i> molar. Last pre-erupted molar from left jaw cavity	362.31
5881	MTA 2711	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i> . Flakes from left anterior rib (rib 3, 4, or 5)	568.08
5882	MTA X	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximas</i>	361.57

completion. Sample USF 5879 (KW 3843) was lost after this first 24 hour period, indicating the sample was poorly preserved and had retained no viable collagen. The HCl solution was poured off and replaced with fresh HCl solution, and allowed to sit for another 24 hours. After 24 hours the remaining ivory samples (USF 5876, 5877, and 5878) exhibited a clear solution (that is, was not colored yellow) and no bubbles, so the samples were removed from solution and dried in the oven at 60°C for 24 hours. The HCl solutions of the remaining bone samples (USF 5880, 5881, and 5882) were replaced and the samples allowed to sit another 24 hours. This was again repeated the next day, and samples USF 5881 (MTA 2711) and USF 5882 (MTA X) were lost during this stage.

Ten ivory samples (KW 744, KW 1182, KW 1192, KW 1523, KW 2557, KW 2877, KW 3614, KW 162, KW 3843, and KW 2534) and 3 bone samples (MTA 2142, MTA 2711, and MTA X) were selected for apatite (see Table 10). The ivory and bone apatite samples for carbon and oxygen stable isotope ratio analysis were also prepared according to the laboratory protocol of the Laboratory of Archaeological Science at the University of South Florida. The samples were ultrasonically cleaned in acetone, the solution poured off, and the samples were dried in the drying oven at 60°C for 24 hours. Approximately 20 mg of each sample was weighed out and pulverized using a mortar and pestle. The samples were treated with 1 ml of 1M acetic acid/sodium acetate buffer solution for 24 hours, after which the samples were centrifuged and the solution was poured off. The samples were then rinsed with distilled water and centrifuged again, and this process of rinsing with distilled water and centrifuging was repeated four times. The samples were dried in the oven at 60°C for 24 hours, and the resulting ivory or bone powder of each sample was weighed. The collagen and apatite samples were analyzed by

Table 10: Apatite samples for analysis of carbon and oxygen isotope ratios

USF #	Museum Catalog #	Site	Country	Material	Sample Description	Initial weight (mg)	Final weight (mg)	Sample weight for MS (µg)
5862	KW 744	Uluburun	Turkey	Ivory	Hippopotamus canine	27.98	22.63	1210
5863	KW 1182	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	23.20	19.74	925
5864	KW 1192	Uluburun	Turkey	Ivory	Hippopotamus canine	27.35	23.88	1175
5865	KW 1523	Uluburun	Turkey	Ivory	Hippopotamus canine	25.40	21.80	1202
5866	KW 2557	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	24.89	21.51	1190
5867	KW 2877	Uluburun	Turkey	Ivory	Hippopotamus incisor	20.82	17.52	1091
5868	KW 3614	Uluburun	Turkey	Ivory	Hippopotamus incisor	25.34	21.01	1088
5869	KW 162	Uluburun	Turkey	Ivory	Elephant tusk	33.24	28.59	1227
5870	KW 3843	Uluburun	Turkey	Ivory	Hippopotamus incisor	31.63	25.91	1184
5871	KW 2534	Uluburun	Turkey	Ivory	Artifact (Duck-shaped cosmetic container)	25.25	6.67	1123
5873	MTA 2142	Maraş Fili	Turkey	Molar	<i>Elephas Maximus</i> molar. Last pre-erupted molar from left jaw cavity	31.46	25.60	998
5874	MTA 2711	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i> . Flakes from left anterior rib (rib 3, 4, or 5)	37.08	28.21	1019
5875	MTA X	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i>	31.07	22.00	1092



a Finnigan MAT Delta plus XL mass spectrometer at the University of South Florida, and 800-1200 µg of each sample was weighed out for analysis.

Approximately 2-3 mg is required for strontium isotope ratio analysis by ICP-MS, utilizing a Thermo Elemental Axiom high resolution magnetic sector ICP. A standard sample preparation for strontium isotope ratio analysis is described in Sealy *et al.* (1991). The strontium samples were prepared by MURR and placed in aqueous solution for analysis by HR-ICP-MS.

Samples were chosen for analysis of apatite, collagen, and strontium isotopes based on the available amount of the sample sent by Cemal Pulak, the excavator of the Uluburun. As may be seen from Table I, some samples were quite large and all three analyses could be performed for these. Six samples did not have enough for analysis of collagen, and the sample from a carved ivory scepter (KW 1723) only had enough for strontium isotope analysis (< 0.01 g).

Photographs of the larger samples are presented as Figures 66 through 72: the Uluburun ivory samples are Figures 74 to 78 and the Maraş Fili elephant bone samples are given in Figures 79 and 80. A slight greenish color may be discerned in Figures 66-69, which is due to the in situ proximity of the ivory to the copper ingots.

Figure 66: KW 1182 (Hippopotamus tusk fragment).



Figure 67: KW 1192 (Hippopotamus canine).



Figure 68: KW 1523 (*Hippopotamus* canine).



Figure 69: KW 2557 (*Hippopotamus* tusk fragment).



Figure 70: KW 3843 (*Hippopotamus* incisor).



Figure 71: MTA 2142 (*Elephas maximus* molar. Last pre-erupted molar from left jaw cavity).



Figure 72: MTA X (*Elephas maximus* rib).



## **Chapter 12**

### **Results and Discussion**

#### **Results of the Isotope Ratio Analyses for Carbon, Oxygen, Nitrogen, and Strontium**

The results of the carbon and oxygen isotope ratios from apatite for the ten Uluburun ivory samples and three Maraş Fili bone samples are listed in Table 11. These results are moreover presented graphically as a simple X-Y plot in Figure 73. The carbon and nitrogen isotope ratios from collagen for four ivory samples and three bone samples are given in Table 12.

Unfortunately the results from the ICP-MS measurement of strontium isotope ratios are difficult, if not impossible, to interpret. The samples were analyzed several times and different numbers were given for many of the samples, suggesting the particular type of ICP-MS employed lacked the necessary precision. Interpretation of the carbon, oxygen, and nitrogen isotopes, as well as a discussion regarding the lack of reliable strontium measurements follows in the next section.

#### **Interpretation of the Stable Carbon, Oxygen, and Nitrogen Isotope Ratio Analyses of Apatite and Collagen**

From Figure 73 it is evident almost immediately that there are distinct groupings from the Uluburun and Maraş Fili samples. Foremost of these is the expected grouping according to animal, as the discussion from Chapters Seven and Eight on the diet and ecological requirements of hippopotami and elephants demonstrated that elephants tend to have a higher reliance on C<sub>3</sub> browse, since elephants are generalist mixed feeders

Table 11: Results of mass spectrometry analysis of carbon and oxygen isotope ratios in apatite

USF #	Museum Catalog #	Site	Country	Material	Sample Description	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$
5862	KW 744	Uluburun	Turkey	Ivory	Hippopotamus canine	-2.7	2.3
5863	KW 1182	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	-3.2	1.0
5864	KW 1192	Uluburun	Turkey	Ivory	Hippopotamus canine	-2.1	0.3
5865	KW 1523	Uluburun	Turkey	Ivory	Hippopotamus canine	-3.7	2.7
5866	KW 2557	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	-4.3	2.1
5867	KW 2877	Uluburun	Turkey	Ivory	Hippopotamus incisor	-2.3	2.3
5868	KW 3614	Uluburun	Turkey	Ivory	Hippopotamus incisor	0.4	1.0
5869	KW 162	Uluburun	Turkey	Ivory	Elephant tusk	-9.6	0.2
5870	KW 3843	Uluburun	Turkey	Ivory	Hippopotamus incisor	-5.3	1.2
5871	KW 2534	Uluburun	Turkey	Ivory	Artifact (Duck-shaped cosmetic container)	-3.0	1.1
5873	MTA 2142	Maraş Fili	Turkey	Molar	<i>Elephas Maximus</i> molar. Last pre-erupted molar from left jaw cavity	-7.3	-1.7
5874	MTA 2711	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i> . Flakes from left anterior rib (rib 3, 4, or 5)	-7.0	-1.1
5875	MTA X	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i>	-5.1	0.8

Figure 73:  $\delta^{13}\text{C}$  versus  $\delta^{18}\text{O}$  for Uluburun ivory and Maraş Fili bone samples.

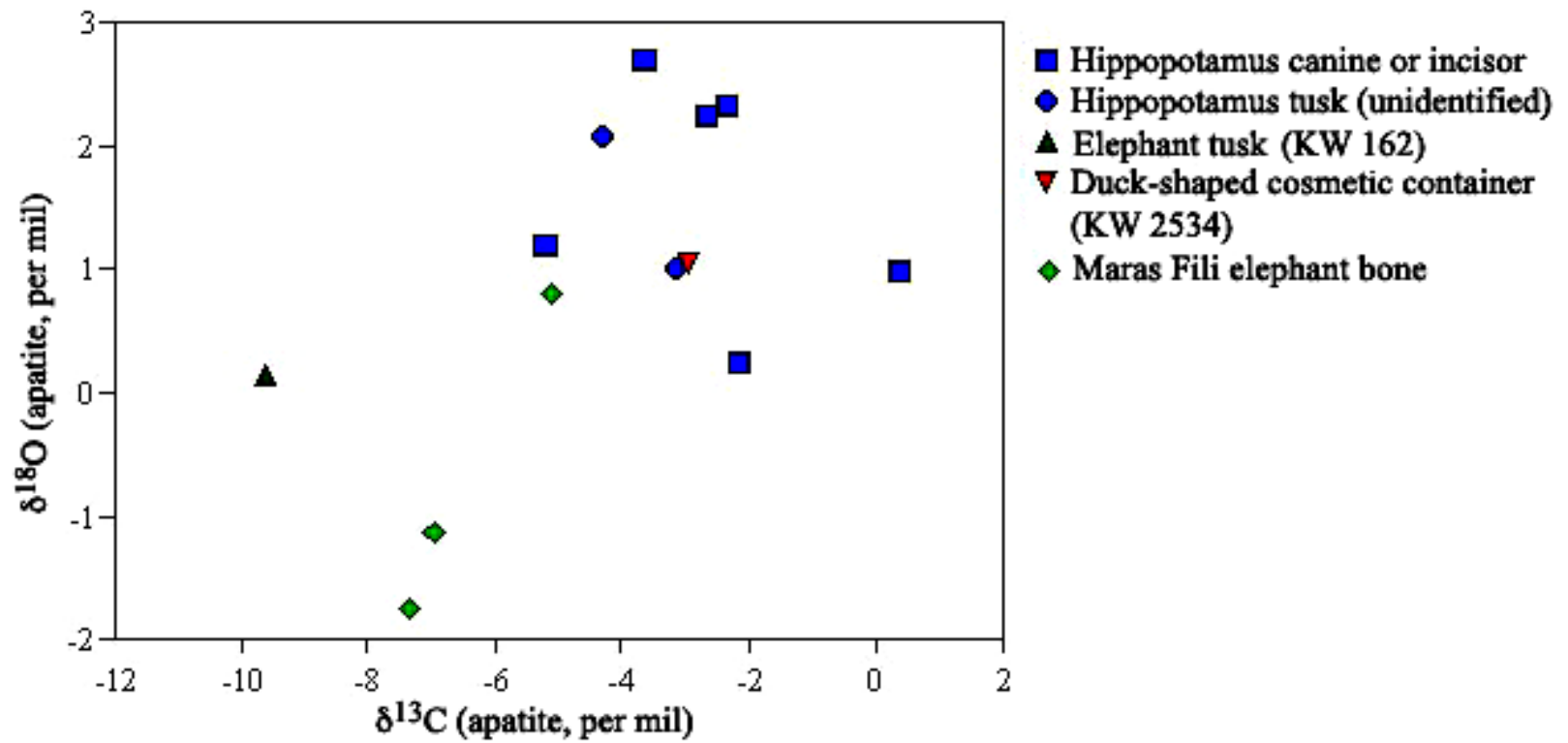




Table 12: Results of mass spectrometry analysis of carbon and nitrogen isotope ratios in collagen  
 (\* = not accepted as accurate because collagen not preserved, as indicated by absence of N<sub>2</sub> to measure)

USF #	Museum Catalog #	Site	Country	Material	Sample Description	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C:N Ratio
5876	KW 744	Uluburun	Turkey	Ivory	Hippopotamus canine	-19.0	5.0	4.6
5877	KW 1182	Uluburun	Turkey	Ivory	Hippopotamus tusk fragment	-30.2*	N <sub>2</sub> below detection	N/A
5878	KW 1192	Uluburun	Turkey	Ivory	Hippopotamus canine	-30.6*	N <sub>2</sub> below detection	N/A
5879	KW 3843	Uluburun	Turkey	Ivory	Hippopotamus incisor	N/A	N/A	N/A
5880	MTA 2142	Maraş Fili	Turkey	Molar	<i>Elephas Maximus</i> molar. Last pre-erupted molar from left jaw cavity	-19.1	10.2	3.4
5881	MTA 2711	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i> . Flakes from left anterior rib (rib 3, 4, or 5)	N/A	N/A	N/A
5882	MTA X	Maraş Fili	Turkey	Bone	Rib of <i>Elephas Maximus</i>	N/A	N/A	N/A

and hippopotami are grazers. To compare the carbon isotope ratios from apatite with those from collagen 7 per mil must be subtracted from the apatite values (since there is a +5 fractionation from the diet of the animal to their collagen and a +12 fractionation from diet to bone apatite). Past isotopic research considered in Chapter Nine was overwhelmingly concerned with elephant diet and generally used collagen, as the researchers were using modern samples not affected by the preservation issues which plague archaeological samples. Unfortunately most of the samples for this thesis are hippopotamus, and all but one of the elephant samples are from a known region: southeastern Turkey. These factors restrict comparisons between the carbon and oxygen isotope ratios of the Uluburun samples with past isotopic research.

In general, however, the hippopotamus ivory is closely clustered in Figure 73, and the duck-shaped cosmetic container (KW 2534) is very likely fashioned from hippopotamus ivory. The elephant tusk (KW 162) holds the most negative carbon isotope ratio (-9.6‰), and compared to elephant collagen data from Chapter Nine (after subtracting 7 per mil), a value of -16.6‰ would cluster close to those arid regions where elephants must rely on C<sub>4</sub> the most, compared to other elephants. These regions include East Tsavo, Kenya (average  $\delta^{13}\text{C} = -16.4\text{‰}$ ), Addo in South Africa (average -17.0‰), and the famous “desert” elephants of Namibia (-19.0‰) (see Table 3 from van der Merwe *et al.* 1988: 166-167, Table 4 with data from Tieszen *et al.* (1989) and Figure 44 from van der Merwe *et al.* 1990). However, the sample sizes for all these regions are small ( $n \leq 5$ ). The large study conducted by Ishibashi *et al.* (1999) also shows similarities between the Uluburun elephant tusk (KW 162) and elephants from arid regions, such as Ethiopia (-17.5‰) and South Africa (see Figure 43). Other research

summarized in Chapter Nine is not useful for comparison, as the  $\delta^{13}\text{C}$  values have too wide a spread for Amboseli National Park, Kenya (Koch *et al.* 1995, see Figure 39), and Tieszen and Imbamba (1980) were analyzing feces of the hippos and elephants, not collagen or apatite. In Figure 73 the elephant sample does group near to the Maraş Fili samples as well, but the Maraş Fili samples are some of the most positive  $\delta^{13}\text{C}$  encountered in any isotopic study of elephants. Either the Uluburun's elephant ivory came from a region where elephants had an extremely heavy reliance on  $\text{C}_4$  grasses, such as very arid grasslands, or there is a problem of preservation. Calcite carbonates from the ocean water may be incorporated with time or semi-fossilization may occur, and the presence of this contaminating carbon may be detected by using X-ray diffraction (XRD).

The oxygen isotope values from the Uluburun and Maraş Fili samples fit well with the  $\delta^{18}\text{O}$  values of the eastern Mediterranean, as depicted in Figure 53 (Schilman *et al.* 2001: 168). The ocean water of the southeast Mediterranean has  $\delta^{18}\text{O}$  ranging from +1.4 to 2‰, the Nile is +2‰, the monsoonal rainfall from the Ethiopian highlands ranges from 0 to -2.9‰, and Mediterranean rainfall averages at -5.6‰. The extent of diagenetic effects on stable oxygen isotope ratios and the multitude of factors controlling  $\delta^{18}\text{O}$  values in animal bone are still poorly understood, so I hesitate to draw conclusions on the oxygen isotope data. Nevertheless, the  $\delta^{18}\text{O}$  values do fit well with the eastern Mediterranean, and diagenesis from the ocean water would have acted to pull the Uluburun hippopotamus  $\delta^{18}\text{O}$  values further towards the negative or zero, as most of these values are greater than +2‰. Also, I suspect hippopotami will pick up the oxygen isotope signature of the water source which they inhabit during the day, so that the Nile valley as a potential source of most of the hippopotamus tusks would not be so far-

etched (with the Nile  $\approx +2\%$ ). The Maraş Fili samples overall have more negative  $\delta^{18}\text{O}$  values, which also accords well with an environment (whether the elephant's or the burial conditions) more influenced by Mediterranean rainfall.

Overall, though, the carbon and oxygen isotope data are essentially inconclusive, especially since it is uncertain how affected the samples were by diagenesis. Apatite tends to be less susceptible to preservation issues than collagen, in that it may still be retrievable in the laboratory, which is why this investigation has utilized apatite for isotopic analysis. As the processing of the collagen samples clearly verified, retrieval of the collagen component of the ivory and bone proved much more difficult. Three samples (KW 3843, MTA 2711, and MTA X) were lost during processing, as there were no more viable collagen remaining in these samples, and in two of the samples (KW 1182 and KW 1192) the collagen was not preserved, so that the nitrogen (in the form of  $\text{N}_2$  gas) was not detectable. The  $\delta^{13}\text{C}$  results for these two samples were not accepted as reliable, and therefore discarded, since the collagen was not preserved. Another standard indicator of deterioration of the original isotopic signal is the ratio of %C to %N, and acceptable values range from 2.9 to 3.7. From the two samples (KW 744 and MTA 2142) which retained detectable nitrogen, only MTA 2142 has an acceptable C/N value at 3.4 (see Table 12). Only samples which show this sort of preservation should be considered as an accurate description of the original isotopic ratios, so MTA 2142 is the only collagen sample suitable for interpretation, and this thesis is not attempting to source MTA 2142 as its provenance is already known. The  $\delta^{13}\text{C}$  value of the collagen was -19.1‰, while the carbon from the apatite for the same sample was -7.3‰. This is a difference of greater than 7 per mil, suggesting the apatite was contaminated by

carbonates in the groundwater of the depositional environment. Collagen is not subject to such contamination. The nitrogen isotope ratio of +10.2‰ is standard for semi-arid environments, as the  $\delta^{15}\text{N}$  of elephants will be higher than 10‰ in areas with <500 mm rainfall per annum (Heaton *et al.* 1986).

### **Interpretation of the Strontium Isotope Ratio Analysis by HR-ICP-MS**

The results of the strontium isotope analysis by ICP-MS are disappointing, but the data serve a purpose in highlighting the problems involved in isotopic analysis. The entire sample set was analyzed several times with different numbers returned for each run. Some of the samples were run through the mass spectrometer as many as four times without obtaining similar enough measurements. Thus the primary challenge is precision of measurement. There are several types of ICP mass spectrometers, the differences lying primarily in how the particular isotopes or elements are measured or collected. Quadrupoles are the most common ICP-MS, although a newer version is the high resolution (HR-ICP-MS) magnetic sector instruments with single or multiple collectors. Our investigation used HR-ICP-MS, which has showed isotopic discrimination between sources for some studies, although not yet for strontium isotope ratio analysis. Previous strontium isotope studies (*cf.* Price *et al.* 1994a, 1994b, 1998, 2000, 2001; Vogel *et al.* 1990; Koch *et al.* 1997; Grupe *et al.* 1997) either had favorably large distinction between regional strontium values or utilized a TIMS (Thermal Ionization Mass Spectrometer). While ICP-MS scans the whole mass spectrum and is most suited to measuring elemental concentrations, TIMS has the ability to focus on specific mass ranges, which is much more appropriate for isotopic applications and gives better measurement precision,

especially multiple measurements such as ratios. Analysis of the Uluburun and Maraş Fili samples by TIMS was prohibitively expensive, and requires 5-10 mg of sample as opposed to the 2-3 mg required for ICP-MS. As forewarned in Chapter One, this investigation was a pilot study in determining the efficacy of source discrimination of archaeological ivory. Ivory is a unique material because the science behind sourcing it has been established for modern samples, and for materially comparable bone samples from archaeological contexts, but only very small sample sizes are available for study since it is a valuable material, and made more valuable with time. Moreover, as this thesis is a pilot study, a beneficial and fitting conclusion is to end with suggestions for future provenancing research on ivory. Another aim of this study, however, was to investigate the mechanisms of the ivory trade, and to situate the archaeometric data within the cultural context and larger research questions of the Late Bronze Age in the eastern Mediterranean. Indeed it is to this end that it must be established whether a successful source discrimination of ivory by isotopic analysis is worth further time and money (*cf.* Cherry and Knapp 1991).

### **Mechanisms of Late Bronze Age trade in the Eastern Mediterranean and Theoretical Considerations**

Shipping was indirect, involving different outbound and inbound routes, often hugging the coast and articulating with smaller regional shipping cycles at trade entrepôts such as Ugarit, Enkomi, Kommos, and Marsa Matruh. The ivory trade probably followed the metals trade, and most of the copper in circulation hailed from Cyprus, whereas most of the gold was Egyptian. Bigger ships were required for the metal-heavy cargoes and

longer distances, and ivory would have served as an excellent “space-filler” or ballast item (Gill 1993: 235). The Uluburun data support such a view of an important but usually archaeologically invisible trade in raw materials (often including vast amounts of metal), and serves as a calibration for the archaeological record (Bass 1991; Sherratt and Sherratt 1991: 373). The Uluburun is, moreover, confidently interpreted as a royal, or ruling-elite, shipment which was following a tramping counter-clockwise course to the Aegean when it sank (Bass 1991: 76). However, this tramping *cabotage* trade should be characterized as more decentralized than implied by our current notions of what a “royal” shipment means, in particular when taking the quotidian and heterogeneous nature of the Cypriot pottery into account (Hirschfeld 2004).

The archaeological and historical context of ivory is characteristically elite-centered, being socially embedded in dialogues of power, conspicuous consumption, and royal gift-exchange. Recognition of the archaeological correlates of social stratification has been one of the first steps in the interpretation of the material record, followed by a focus on the rich and powerful and what was seen as the historically important major political actors. The acknowledgment of the significance of other social classes and every-day events to the overall reconstruction of culture history was a just counter-balance to the previous emphasis on the rich, powerful, and “history-worthy.” It forced archaeologists to unleash cultures from bounded homogenous units and refract the result into a spectrum of heterogeneity where population-oriented rather than typology-oriented thinking was required.

Thus I argue that while the ruling class and elites have been the subject of much (some would say too much) archaeological research, it is worth considering their role

again in light of an unbounded, population-focused, concept of culture (see also Schortman 2001: 372). So in the analysis of LBA trade the “culture of the elite,” “the culture of merchants,” and the “culture of craft specialists” must be considered. The ruling elite and their merchants, who served as ambassadors of sorts in trading ventures which were essentially diplomacy via gift-exchange, were operating in an increasingly international environment. The LBA is known for its cosmopolitan and internationalizing character, and artisans in their workshops were carving in an Internationalizing style which reflected the times. In this setting the ivory trade represents these lateral relationships throughout the eastern Mediterranean.

Previous discussions on Late Bronze Age trade centered around Levantine versus Aegean agency were not useful. This discourse had quite a bit of momentum in the literature (e.g. Liverani 1987: 68) and the Uluburun shipwreck was unwittingly pulled into these discussions (see Bass 1991; Knapp 1993: 335). As Knapp (1993) and Sherratt and Sherratt (1991: 337) argued, looking for specific agents of trade within nationalities (Syrian/Canaanite/Semitic versus Minoan/Mycenaean) is misleading, for reasons discussed above and also because no monopoly on trade or thalassocracy existed at this time. So many were trading that there were no serious inequalities in trade in the region.

More useful are those discussions taking centralized royal trade initiatives versus decentralized *cabotage* merchant trade as their starting point. These debates have focused on economic theory and the role of merchants in attempting to illuminate the mechanisms of LBA trade. The “primitivist” or “substantivist” (per Karl Polanyi) schools of economic thought considered the economy as driven by reciprocity (including royal gift-exchange) and redistribution. The large storage facilities of the palace



economies of the Aegean and Near East were taken as evidence of redistributive economies focused on the internal procurement of resources, and thus import-led trade. Most important, ancient economies could not be interpreted in modern economic frameworks (because they were not market economies), and the ancient economy was socially embedded. Short distance redistributive trade was viewed as more important than long-distance trade (Sherratt and Sherratt 1991: 352-353; Melas 1991; Snodgrass 1991; Finley 1965, 1981; Ratnagar 2001: 353; citing Polanyi 1946: 51-53). Sherratt and Sherratt (1991: 353) contend that while this debate has been beneficial “in exorcising anachronistic modernism, it has too often resulted instead in replacing it with an equally anachronistic primitivism.” They argue, along with Knapp (1993), for an export-led, consumption-oriented perspective of economy which “looks at the incentive to trade: the desire, on the part of a minority, to acquire goods which have... social significance. The goods themselves acquire such significance as parts of social practices” (Sherratt and Sherratt 1991: 354) which include social strategies of recruitment and exclusion. The desire for valuable goods (metal as well as luxury goods such as worked ivory) on the part of elites motivated the intensification of local production and the extraction of surplus. Moreover, any sort of dichotomy between reciprocal gift-exchange and bulk trade in raw materials obscures understanding of LBA trade mechanisms (Peltenberg 1991: 170), and indeed, the cargo of the Uluburun contained luxury items alongside a huge cargo of metal ingots.

Entrepreneurship and the degree of autonomy maintained by merchants are closely tied in reconstructions of LBA economy. Gift-exchange between elites, as documented most clearly in the Amarna letters, occurred under the agency of envoys

between rulers, who were involved in diplomatic relations but frequently traveled with merchants. The merchants, likewise, operated within this framework of international relations and benefited from it, but were semi-independent and commercially-oriented (Peltenberg 1991: 169; Sherratt and Sherratt 1991: 365; Warren 1991: 295). That is, non-palatial markets existed alongside palace-centered gift-exchange, particularly in a shared interest in the procurement of raw materials. Merchants were never completely autonomous because they were subject to taxation and agreements between rulers. The *tamkars* of Ugarit are the best example of the commercial merchant in the LBA. The title is mentioned in Ugaritic lists of professions, sometimes as an office appointed by the king (Kuhrt 1995: 302-303; Warren 1991: 295; Snodgrass 1991: 17). In one instance a merchant, Sinaranu, was freed from taxation, possibly on account of his connection with the Aegean:

Declaration of Ammistamru, King of Ugarit (RS/PRU III, 16.238:1-11)

From this day, Ammištamru, son of Niqmepa, king of Ugarit, has ‘freed’ (from import duty) Sinaranu, son of Sigina. As the Sun (the Hittite king) is free, he is free. His grain, his beer, his oil need not enter into the palace (for accounting).

His boat is free (from duties), if his boat comes from Crete (Kabturi) (quoted in

Knapp 1991: 68, see also Peltenberg 1991: 169).

In a similar document a *tamkar* is exempted from serving in a diplomatic office (PRU III, 105; cited by Peltenberg 1991: 167). In return for services these state merchants received land and rations from the palace. Foreigners also operated in Ugarit as merchants, including merchants from Cyprus (Alashia) and the merchants of Ura, from a town located in Cilicia, who managed the grain shipments to Hatti on behalf of the Hittites

(Kuhrt 1995: 302-303; Peltenberg 1991: 167; Zaccagnini 1977). Apparently the Hittite king was irritated with the economic independence of his merchants in Ugarit, and in an edict of Hattusili III (ruled 1275-1245/1264-1239 B.C.) curtailed the transactions of the Ura merchants by forbidding them to invest money or buy property in Ugarit. Nor could they accept Ugaritic property as collateral in loans, claim property from past debtors, or live in Ugarit during the summer (Kuhrt 1995: 309-310). Similar royal interventions in the commercial activity of merchants include a Hittite-Egyptian agreement regarding Hittite merchants in Egyptian territory (southern Beqa valley) acquired after the Mitannian-Egyptian alliance (Kuhrt 1995: 324-328), and a 13<sup>th</sup> century treaty by Sausgamuwa, which banned Ahhiyawan merchants from access to Assyria through the Syrian ports of Amurru (Peltenberg 1991: 168). In one of the Amarna letters (EA 39: 10-16) the diplomatic envoys sent by ruling elite to the Egyptian court is described as a merchant (Luce 1998: 60). International trade and diplomacy were inextricably linked.

Gift-exchange amongst the ruling elite also involved the exchange of specialists such as physicians, scribes, cooks, seers, chariot-makers and sculptors, which were sent from one palace to another (Zaccagnini 1983: 248-251). Thus craft specialists, such as those that carved and worked ivory, were also bound up in international relations, and this is reflected in the Internationalizing style of pottery decoration, sculpture (wood, stone, and ivory), architecture (domestic and funeral), and bronze working. This was a common stylistic eastern Mediterranean *koine* of the LBA (Melas 1991: 391). The mechanisms of LBA trade also show a separation of production from the source, as a trade in the raw material of ivory must be distinguished from the trade in prestige goods fashioned from ivory. In fact, those huge storerooms of the major palace centers, which

the substantivists and primitivists cite as evidence that the palace economy was essentially a redistributive system, should be replaced with an emphasis on the workshops and manufacturing areas. In this light the palace economy was essentially exploitative and collected products (agricultural or luxury items) in the large storerooms to increase demand and therefore value, rather than to provide subjects with the benefits of redistribution (Sherratt and Sherratt 1991: 366). In fact the recipients of redistribution were other ruling elites (Ratnagar 2001: 355), and the raw material of ivory tusks was “stored” in a sense and converted to luxury items in workshops, so that “additional labor inputs had a direct effect on value; and it is the central concentration of production in an attempt to monopolize this added value” which characterizes the palace economy (Sherratt and Sherratt 1991: 359). As discussed in Chapter Five, workshops may have tightly controlled ivory in the Aegean, as Linear B texts record ivoryworkers as receiving ivory from the royal storerooms and then returning the finished object back to storage (Warren 1991: 295; Peltenberg 1991: 166, 169, 172). The most common ivory-carving style in the eastern Mediterranean has been called Egyptianizing or Orientalizing (recall Chapter Five) but is more accurately titled Internationalizing, as it was a conglomeration of styles from all the major palace centers. The Internationalizing style replaced an indigenous Aegean style in the Late Bronze Age (Sherratt and Sherratt 1991: 370; Peltenberg 1991: 166). As the Aegean had no local sources of ivory, the Internationalizing style was likely transported along with the material and the material’s name from Syria-Palestine, ivory in Linear B (e-re-pa) is derived from a Semitic language (Cline and Cline 1991: 52; Astour 1964; 1973).

Across the eastern Mediterranean the Internationalizing style in ivory carving may be regarded as a common symbolic language, laterally tying together in aesthetic fashion the ruling elites. Because the style was so common, and subject to mass production (as in Ugarit), elite demand would have encouraged competition between palace centers. Some form of economic competition may have operated at this time, as the King of Cyprus offers an Egyptian pharaoh a better deal than he can get elsewhere (EA 35:50-53; cited by Peltenberg 1991: 170), and the Cypriots were also producing cheaper imitations of Mycenaean pottery, especially drinking sets, for import to the Levant (Sherratt and Sherratt 1991; see also Gittlen 1981, and for the Early Iron Age see Winter 1976: 21-22). Interestingly, in the Aegean two palace centers within three kilometers of one another, Mycenae and Tiryns, have very different eastern imports. Mycenae has predominantly Egyptian imports with very little Cypriot material, while Tiryns has the opposite case (Cline and Cline 1991: 54). A similar case has been uncovered at Laish/Dan and Akko in Palestine, where the Mycenaean ceramic imports recovered in Laish/Dan came exclusively from the Mycenae/Barbati region and the Akko imports came from Nichorie in Messenia (Gunneweg and Michel 1999). There is also an almost complete absence of trade between Hittite Anatolia and the Aegean, suggesting an embargo of some sort (Cline and Cline 1991: 52; Sherratt and Sherratt 1991: 370). Late Bronze Age trade then was not a monolithic entity but composed of a great deal of circuits of various sizes, some articulating with one another. These routes were governed by international relations which relied on good will between the ruling elite as expressed through gift-exchange of luxury items such as ivory. Those luxury items carved from ivory or

incorporating ivory likewise manifested this international diplomacy symbolically in the Internationalizing style.

Thus, in the final analysis, exchange should be viewed as a form of diplomacy rather than “economic” as defined by the modern western understanding of economics (see also Bradley and Edmonds 1993; Jones 2002). The trade in ivory in the eastern Mediterranean during the Late Bronze Age must ultimately be seen as the exchange of symbols, expressed as the exchange of their material correlates, which legitimated social relations and could be manipulated, particularly in the act of emulation, competition, or the pursuit of reputation (Bourdieu 1977; Hodder 1982: 209; Melas 1991: 393-395; Knapp 2000). Speaking more generally, consumption should be viewed as “using things in social acts” (Gosden 1999: 163). As emphasized in the introduction, this investigation has at its foundation a materials perspective, both from a scientific archaeometric angle and from the recognition of the symbolic nature of material culture, in particular the symbolic significance of ivory. Moreover, one of the advantages of material culture, of artifacts, in shaping social relations is via the *mobility* of the object, so that social influence may be extended geographically and temporally (Jones 2002). Luxury items fashioned from ivory, or even simply the raw material, held a value beyond their relative scarcity, which was to express the importance of being related to a certain person (or group, polity, or idea) (Sherratt and Sherratt 1991: 354-356). In gift-exchange between the ruling elite the relationship was embedded within international diplomacy and could express political affiliation, royal approval, obligation, favor seeking, or even simply the desire to locate other humans similar to oneself. The Hittite and Egyptian royal families exchanged letters on a regular basis, royal children writing to other royal children, wives

to other wives. There was a practicality to international relations in the LBA, as the great powers of the Egyptians, Mitanni, and Hittites shared common borders and were forced into a “conditioned coexistence” (a term coined by Liverani 1987: 68). Expansion was not possible by land, and the minor kingdoms within Syria, Palestine, and Nubia acted as merchants to the great powers. Cyprus led the way with commercial exchange, answering to none for its political legitimation and controlling most of the copper resources. The international relationships could be viewed cynically as masking purely commercial intentions, but this is probably not the case.

From the letters exchanged between the ruling elite and other historical sources, the fundamental ideas “expressed with obsessive insistence” (Liverani 1987: 67) were reciprocity and brotherhood. Other ideas included “generosity and disinterest (even in the specific form of an augmented restitution), the contrast between self-sufficiency and exchange, the personalization of the gifts... The ideological complex was quite coherent” (Liverani 1987: 67; Sherratt and Sherratt 1991: 371). Gift-exchange could also be presented as tribute to one’s subjects. But equality was emphasized perhaps because the ruling elite were matched well in the specific political configuration of power, but also as an inversion of (or reaction to) the growing inequality within societies, inequalities which would eventually come to a head at the end of the LBA with the mass destruction and population movements throughout the eastern Mediterranean. The growing inequalities and social problems could be ignored if one operated within a “culture of the elite” in which peers mutually reinforced one another in their justification of power.

A successful isotopic provenancing of ivory would have therefore said something about the circulation of these symbols amongst the upper crust of society in the eastern

Mediterranean. The degree to which the objects were passed from one ruler to another in a “prestige chain network” (Peltenberg 1991: 168) would be evident, but more important, the other trade cycles operating alongside and perhaps outside of royal trade initiatives would be finally documented if the ivory samples from the Uluburun shipwreck were shown to come from a variety of sources. This merchant, commercially-oriented, trade is widely suspected to have existed, but could be rendered particularly archaeologically visible if it were shown to operate even in the realm of a material assumed to be primarily controlled by the palace centers. The Uluburun ship may be a royal exchange venture, but the extent of trade in ivory before it was loaded onto the boat could be ascertained.



## **Chapter 13**

### **Conclusion and Suggestions for Future Research**

To sum up the endeavors of this exploration into the ivory trade of the eastern Mediterranean in the Late Bronze Age via recent advances in archaeometric analyses, the results must be said to be inconclusive. The most successful isotopes, in terms of retrieval of values to work with, were the carbon and oxygen isotopes from the apatite component of the ivory and bone. However, the carbon and oxygen isotope data must remain essentially inconclusive, as it is uncertain to what extent the samples were affected by diagenesis. Possibly these samples could be analyzed by X-ray diffraction (XRD) in the future to detect the presence of contaminating carbonates. However, the inquiry itself is not inconclusive as knowledge has been gained in how to approach the research program in the next round. The HR-ICP-MS instrument did not have the precision required, but TIMS or other new types of mass spectrometers could be utilized in the future.

Overall, several suggestions for further strontium isotope research on ivory are in order. First of all, as recommended by Price et al. (2002), faunal samples from the specific regions considered as sources of ivory should be analyzed to determine the “biologically-available” strontium. However, the biologically-available strontium, while more accurate than the strontium values available in the geological literature database, will differ from ivory samples. Bone acts as an averaging mechanism for the strontium circulating in the environment, whereas ivory grows by accretion. An average could be taken from the ivory sample by taking several micro-samples of each sample, or by physically mixing the powdered sample. At any rate, the variation in ivory would be

more significant in elephants, as their diet varies seasonally and the home range of the elephant may cover geologically heterogeneous regions. Hippopotamus ivory would likely not show significant variation. Water and soil samples from the regions would be beneficial as well. Enamel should also be compared with dentine from the same sample to determine the extent of contamination and diagenesis in the depositional environment, when available. The probability of finding enamel on archaeological ivory samples is very small though. The enamel is either not present (in the case of elephant ivory and most of the teeth of the hippopotamus, excluding the lower canine), or was removed by humans (possibly before shipping even), or by nature, as the enamel tends to wear off with use.

The availability of strontium isotope data in the geological literature for some regions leaves something to be desired. The next step would be to search out unpublished data by contacting mining companies and governmental geological surveys. In general the geological literature is biased, understandably, towards answering research questions of interest to geologists. These tend to concern unusual formations or processes. But the geological literature should not be solely depended on anyway, because of the potential differences between biologically-available strontium and geological strontium.

The stable carbon, oxygen, and nitrogen isotopes did not provide isotopic signatures like those reported by van der Merwe *et al.* (1990) and Vogel *et al.* (1990), primarily because the oxygen and nitrogen isotopes were not retrievable or potentially contaminated by diagenetic processes. These isotopes were not expected to differentiate source areas, since they are based on diet and environmental factors, and therefore

populations from geographically separated regions could have the same isotopic signature. XRD should also be conducted on apatite samples to determine to what degree the burial environment has affected the integrity of the isotopic signal.

Strontium isotope ratios, because they are based on the geology of the region, are therefore the best suited for provenance studies. Other isotopes, such as lead (Pb) and neodymium (Nd), are also incorporated into bone and ivory of animals from the environment based on the underlying bedrock geology. In the future strontium isotopes should be analyzed alongside lead and neodymium, as the more isotopes available to compare, the more unique the regional isotopic fingerprints will be, and sophisticated statistical analyses may also be performed to better interpret the data (as in, for example, Koch *et al.* 1995). Lead and neodymium isotopes are furthermore widely available in the geological literature, perhaps more so than strontium isotopes. Lead isotopes have been successfully utilized in archaeological research application (Aufderheide *et al.* 1981, 1988; Molleson *et al.* 1986; Gale 1989; Reedy and Reedy 1991; Carlson 1996). To my knowledge neodymium isotopes have not been exploited yet for archaeological purposes.

Naturally a larger sample size is required, and the most practical solution would be to establish a database so that any isotopic research on ivory, or even any research utilizing strontium isotopes, could be compared quickly and efficiently. The problem, as usual, is time and money, as TIMS would be essential for adequate precision. Also, a database of a single material type is unnecessarily restrictive, as eventually all categories of exchange items should be incorporated to give a broader picture of Late Bronze Age trade. Certainly, the contribution to archaeological research in general of studying trade patterns and exchange mechanisms (“the trade perspective” as I call it) is that it offers the

“wide” perspective in giving larger scales of analysis, just as “settlement” or “landscape” archaeology opened up the focus from site analysis to regional analysis. As was demonstrated here, the trade perspective is capable of encompassing large geographical areas and recognizing lateral social relationships, expressed via international relations for the ruling elite. If culture is to be regarded as unbounded and population-based, a move must be made to larger scales of analysis. Moreover, archaeology as a discipline does well to elucidate the relationship between “people” and “material things.” If objects are utilized to initiate, shape, maintain, and manipulate social relations, and if one of the primary advantages of a given object is its mobility, then studies of long-distance trade are especially important for articulating the relationship between small-scale social practice and large-scale pan-Mediterranean frameworks.

## References Cited

- Abate, B., Koeberl, C., Kruger, J.F., and Underwood, J.R. Jr. 1999. BP and Oasis impact structures, Libya, and their relation to Libyan Desert Glass. In (B.O. Dressler and V.L. Sharpton, Eds.) *Large Meteorite Impacts and Planetary Evolution II*, pp. 177-192. Geological Society of America Special Paper 339.
- Abell, P.I., and Williams, M.A.J. 1989. Oxygen and carbon isotope ratios in gastropod shells as indicators of paleoenvironments in the Afar region of Ethiopia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 74: 265-278.
- Alexander, R.L. 1991. Šaušga and the Hittite ivory from Megiddo. *Journal of Near Eastern Studies* 50: 161-182.
- Alici, P., Gundogdu, M.N., Temel, A., Gourgaud, A., and Vidal P. 2001. Quaternary tholeiitic to alkaline volcanism in the Karasu Valley, Dead Sea rift zone, Southeast Turkey: Sr-Nd-Pb-O isotopic and trace-element approaches to crust-mantle interaction. *International Geology Review* 43: 120-138.
- Ambrose, S.H. 1986. Stable carbon and nitrogen isotope analysis of human and animal diet in Africa. *Journal of Human Evolution* 15: 707-731.
- Ambrose, S. H. 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* 18: 293-317.
- Ambrose, S. H., and Norr, L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In (J.B. Lambert and G. Grupe, Eds.) *Prehistoric Human Bone: Archaeology at the Molecular Level*, pp. 1-37. New York: Springer-Verlag.
- Arancio, M.L., Buffa, V., Damiani, I., Tagliacozzo, A., Trucco, F., and Vagnetti, L. 1995. L'abitato di Torre Mordillo nel quadro dello sviluppo dell'insediamento protostorico nell'alto Ionio. In (N. Christie, Ed.) *Settlement and economy in Italy 1500 BC to AD 1500*, pp. 227-239. Oxford: Oxford University Press.
- Astour, M.C. 1964. Greek names in the Semitic world and Semitic names in the Greek world. *Journal of Near Eastern Studies* 23: 193-201.
- Astour, M.C. 1973. Ugarit and the Aegean. In (H.A. Hoffner, Jr., Ed.) *Orient and Occident*, pp. 17-27. Neukirchener: Verlag Butzon and Bercker Kevelaer.

- Åström, P. 1993. Ivories from Hala Sultan Tekke. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 101-103.
- Aufderheide, A.C., Neiman, F.D., Wittmers, L.E., and Rapp Jr., G. 1981. Lead in Bone II: Skeletal-Lead Content as an Indicator of Lifetime Lead Ingestion and Social Correlates in an Archaeological Population. *American Journal of Physical Anthropology* 55: 285-291.
- Aufderheide, A.C., Wittmers, L.E., Rapp Jr., G., and Wallgren, J. 1988. Anthropological applications of skeletal lead analysis. *American Anthropologist* 90: 931-936.
- Avigour, A., Magaritz, M., Issar, A., and Dodson, M.H. 1990. Sr isotope study of vein and cave calcites from southern Israel. *Chemical Geology* 82: 69-81.
- Ayalew, D., Yirgu, G., and Pik, R. 1999. Geochemical and isotopic (Sr, Nd and Pb) characteristics of volcanic rocks from southwestern Ethiopia. *Journal of African Earth Sciences* 29: 381-391.
- Ayalon, A., Bar-Matthews, M., and Kaufman, A. 1999. Petrography, strontium, barium and uranium concentrations, and strontium and uranium isotope ratios in speleothems as palaeoclimatic proxies: Soreq Cave, Israel. *Holocene* 9: 715-722.
- Bar-Matthews, M., Ayalon, A., Kaufman, A., and Wasserburg, G.J. 1999. The Eastern Mediterranean paleoclimate as a reflection of regional events: Soreq cave, Israel. *Earth and Planetary Science Letters* 166: 85-95.
- Barberi, F., Civetta, L., and Varet, J. 1980. Sr isotopic composition of Afar volcanics and its implication for mantle evolution. *Earth and Planetary Science Letters* 50: 247-259.
- Barbieri, M., Brotzu, P., Morbidelli, L., Penta, A., Piccirillo, E.M., and Traversa, G. 1976. Trace elements and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the basic stratoid volcanism in the southeastern Ethiopian plateau. *Periodico di Mineralogia* 45: 129-145.
- Barnes, R.F.W. 1983. Elephant behavior in a semi-arid environment. *African Journal of Ecology* 21: 185-196.
- Barnett, R.D. 1939. Phoenician and Syrian ivory carving. *Palestine Exploration Quarterly* 71: 4-19.
- Barnett, R.D. 1982. Ancient ivories in the Middle East and adjacent countries. *Qedem* 14. Jerusalem: Institute of Archaeology, Hebrew University.

Barrat, J.A., Fourcade, S., Jahn, B.M., Cheminee, J.L., and Capdevila, R. 1998. Isotope (Sr, Nd, Pb, O) and trace-element geochemistry of volcanics from the Erta'Ale range (Ethiopia). *Journal of Volcanology and Geothermal Research* 80: 85-100.

Bass, G.F. 1987. Oldest known shipwreck reveals splendors of the Bronze Age. *National Geographic* 172: 693-733.

Bass, G.F. 1991. Evidence of trade from Bronze Age shipwrecks. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 69-82. *Studies in Mediterranean Archaeology* 90. Göteborg: Paul Åströms Förlag.

Bass, G.F. 1997. Prolegomena to a study of maritime traffic in raw materials to the Aegean during the fourteenth and thirteenth centuries B.C. In (R. Laffineur and P.P. Betancourt, Eds.) *TEXNH. Craftsmen, Craftswomen and Craftsmanship in the Aegean Bronze Age*, pp. 153-170. *Aegaeum* 16.

Betton, P.J., and Civetta, L. 1984. Strontium and neodymium isotopic evidence for the heterogeneous nature and development of the mantle beneath Afar (Ethiopia). *Earth and Planetary Science Letters* 71: 59-70.

Bietti Sestieri, A.M. 1981. Economy and society in Italy between the Late Bronze Age and the Early Iron Age. In (G. Barker and R. Hodges, Eds.) *Archaeology and Italian society, Papers in Italian Archaeology II*. BAR International Series 102: 135-155. Oxford: Oxford University Press.

Bietti Sestieri, A.M. 1997. Il territorio padano dopo le terramare. In (M. Bernabo Brea, A. Cardarelli, and M. Cremaschi, Eds.) *Catalogue of the Exhibition "La terramare: La piu antica civiltà padana"*, pp. 757-770. Milan.

Blondel, J., and Aronson, J. 1999. *Biology and Wildlife of the Mediterranean Region*. Great Britain.

Bourdieu, P. 1977. *Outline of a Theory of Practice*. Cambridge: Cambridge University Press.

Bourgeois, B. 1993. An approach to Anatolian techniques of ivory carving during the second millennium BC. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 61-66.

Bradley, R., and Edmonds, M. 1993. *Interpreting the axe trade*. Cambridge: Cambridge University Press.

- Brew, G. 2001. *Tectonic evolution of Syria interpreted from integrated geophysical and geological analysis*. Ph.D. dissertation, Cornell. Online at <http://atlas.geo.cornell.edu/people/brew/gbthesisintro.html>.
- Budd, P., Montgomery, J., Barreiro, B. and Thomas, R.G. 2000. Differential diagenesis of Sr in archeological human dental tissues. *Applied Geochemistry* 15: 687–694.
- Casson, L. 1995. *Ships and Seamanship in the Ancient World*. Baltimore: Johns Hopkins University Press.
- Carlson, A.K. 1996. Lead isotope analysis of human bone for addressing cultural affinity: a case study from Rocky Mountain House, Alberta. *Journal of Archaeological Science* 23: 557-567.
- Catling, H.W. 1991. Bronze Age trade in the Mediterranean: a view. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 1-13. Studies in Mediterranean Archaeology 90. Göteborg: Paul Åströms Förlag.
- Caubet, A., and Poplin, F. 1993. La place des ivoires d'Ougarit dans la production du proche orient ancien. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 91-100.
- Cherry, J.F., and Knapp, A.B. 1991. Quantitative provenance studies and Bronze Age trade in the Mediterranean: some preliminary reflections. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 92-120. Studies in Mediterranean Archaeology 90. Göteborg: Paul Åströms Förlag.
- Chadwick, O.A., Derry, L.A., Vitousek, P.M., Huebert, B.J., and Hedin, L.O. 1999. Changing sources of nutrients during the four million years of ecosystem development. *Nature* 397: 491-497.
- Chiaradia, M., Gallay, A., and Todt, W. 2003. Different contamination styles of prehistoric teeth at a Swiss necropolis (Sion, Valais) inferred from lead and strontium isotopes. *Applied Geochemistry* 18: 353-370.
- Clemens, E.T., and Maloiy, G.M.O. 1982. The digestive physiology of three East African herbivores: the elephant, rhinoceros and hippopotamus. *Journal of Zoology, London* 198: 141-156.
- Cline, E.H., and Cline, M.J. 1991. "Of shoes and ships and sealing wax": international trade and the Late Bronze Age Aegean. *Expedition* 33: 46-54.
- Cloudsley-Thompson, J.L. 1973. Developments in the Sudan Parks. *Oryx* 12: 49-52.



- Cloudsley-Thompson, J.L. 1977. *Man and the Biology of Arid Zones*. London: Arnold.
- Cox, G., and Sealy, J. 1997. Investigating identity and life histories: isotopic analysis and historical documentation of slave skeletons found on the Cape Town foreshore, South Africa. *International Journal of Historical Archaeology* 1: 207-224.
- Dasch, E.J. 1969. Strontium isotopes in weathering profiles, deep-sea sediments and sedimentary rocks. *Geochimica et Cosmochimica Acta* 33: 1521-1552.
- DeNiro, M., and Epstein, S. 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42: 495-506.
- Dhakal, G., and Ojha, N.P. 1995. Studies on diet preferences of the elephant (*Elephas maximus*) in Royal Chitwan National Park. *Tigerpaper* 22: 29-31.
- Dikaio, P. 1969. *Enkomi. Excavations 1948-1958 I*. Mainz.
- Dodge, B. 1955. Elephants in the Bible Lands. *Biblical Archaeologist* 18: 17-20.
- Dudley, J.P. 1996. Record of carnivory, scavenging and predation for *Hippopotamus amphibius* in Hwange National Park, Zimbabwe. *Mammalia* 60: 486-488.
- Dudley, J.P. 1998. Reports of carnivory by the common hippo *Hippopotamus Amphibius*. *South African Journal of Wildlife Research* 28(2): 58-59.
- Dunham, K.M. 1990. Fruit production by *Acacia albida* trees in Zambezi riverine woodlands. *Journal of Tropical Ecology* 6: 445-457.
- Eltringham, S.K. 1980. A quantitative assessment of range usage by large African animals with particular reference to the effects of elephants on trees. *African Journal of Ecology* 18: 53-71.
- Eltringham, S.K. 1993. The Common Hippopotamus (*Hippopotamus amphibius*). In (W.L.R. Oliver, Ed.) *Pigs, Peccaries, and Hippos*, pp. 43-55. Switzerland: IUCN.
- Eltringham, S.K. 1999. *The hippos: Natural history and conservation*. London: T & A.D. Poyser.
- Ericson, J.E. 1985. Strontium isotope characterization in the study of prehistoric human ecology. *Journal of Human Evolution* 14: 503-514.
- Ericson, J.E. 1989. Some problems and potentials of strontium isotope analysis for human and animal ecology. In (P.W. Rundel, J.R. Ehleringer and K.A. Nagy, Eds.) *Stable Isotopes in Ecological Research*. Ecological Studies 68: 252-259.

- Ezzo, J.A., Johnson, C.M., and Price, T.D. 1997. Analytical perspectives on prehistoric migration: a case study from east-central Arizona. *Journal of Archaeological Science* 24: 447-466.
- Fagles, R. 1996. *The Odyssey*. New York: Penguin.
- Faleschini, G. 1999. La “stele” dell’ippopotamo nel Messak Mellet (Fezzan, Libia). *Sahara* 11: 141-142.
- Ferrarese Ceruti, M.L., Vagnetti, L., and Lo Schiavo, F. 1987. Minoici, Micenei e Ciprioti in Sardegna alla luce delle più recenti scoperte. In (M. Balmuth, Ed.) *Studies in Sardinian Archaeology, III. Nuragic Sardinia and the International World*. BAR International Series 387: 7-37. Oxford: Oxford University Press.
- Field, C.R. 1970. A study of the feeding habits of the hippopotamus (*Hippopotamus amphibius* Linn.) in the Queen Elizabeth National Park, Uganda, with some management implications. *Zoologica Africana* 5: 71-86.
- Field, C.R. 1971. Elephant ecology in the Queen Elizabeth National Park, Uganda. *East African Wildlife Journal* 9: 99-123.
- Finley, M.I. 1965. Classical Greece. *Trade and Politics in the Ancient World: Deuxieme conference internationale d’histoire economique* 1: 11-35.
- Finley, M.I. 1981. Mycenaean palace archives and economic history. In (B.D. Shaw and R.P. Saller, Eds.) *Economy and Society in Ancient Greece*, pp. 199-212. London.
- Fischer, P.M., and Herrmann, G. 1995. A carved bone object from tell al-Kharaz in Jordan: A Palestinian workshop for bone and ivory? *Levant* 27: 145-163.
- Francis, G.D., and Vickers, M. 1983. ‘Ivory tusks’ from Al Mina. *Oxford Journal of Archaeology* 2: 249-251.
- Gachet, J. 1993. Ugarit Ivories: Typology and distribution. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 67-83.
- Gale, N.H. 1989. Lead isotope analyses to provenance studies – a brief review. In (Y. Maniatis, Ed.) *Archaeometry*, pp. 469-503. Amsterdam: Elsevier.
- Gautier, A., Schild, R., Wendorf, F., and Stafford, T.W. 1994. One elephant doesn’t make a savanna. Palaeoecological significance of *Loxodonta africana* in the Holocene Sahara. *Sahara* 6: 7-20.

- Gautier, A., and Van Neer, W. 1997. Animal remains from Debbat El Eheima and Debbat Bangdit (1600-1000 B.C./400-1000 A.D.; southern Sudan). *Archaeozoologia* 9: 49-72.
- Gerstenberger, H., Haase, G. and El Nour, F.A. 1997. The origin of strontium and the strontium isotope budget of the river Nile. *Isotopes in Environmental and Health Studies* 33: 349-356.
- Gill, D.W.J. 1993. The ivory trade. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 233-237.
- Gittlen, B.M. 1981. The cultural and chronological implications of the Cypro-Palestinian trade during the Late Bronze Age. *Bulletin of the American Schools of Oriental Research* 241: 49-59.
- Goldstein, S.L., O’Nions, R.K., and Hamilton, P.J. 1984. A Sm-Nd isotopic study of atmospheric dusts and particulates from major river systems. *Earth and Planetary Science Letters* 70: 221-236.
- Gosden, C. 1999. *Anthropology and archaeology: a changing relationship*. London: Routledge.
- Grammenos, A. 1993. The ivories from Spata, Attica. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 45-56.
- Graustein, W.C., and Armstrong, R. 1983. The use of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios to measure atmospheric transport into forested watersheds. *Science* 219: 289-292.
- Grousset, F.E., Parra, M., Bory, A., Martinez, P., Bertrand, P., Shiemmiel, G., Ellam, R.M. 1998. Saharan wind regimes traced by the Sr-Nd isotopic composition of subtropical Atlantic sediments: Last Glacial maximum vs. today. *Quaternary Science Reviews* 17: 395-409.
- Grubb, P. 1993. The Afrotropical Hippopotamuses: *Hippopotamus* and *Hexaprotodon*. In (W.L.R. Oliver, Ed.) *Pigs, Peccaries, and Hippos*. Switzerland: IUCN, pp. 41-43.
- Grupe, G., Price, T.D., Schörter, P., Söllner, F., Johnson, C., and Beard, B. 1997. Mobility of Bell Beaker people revealed by stable strontium isotope ratios of teeth and bones. A study of southern Bavarian skeletal remains. *Applied Geochemistry* 12: 517-525.

- Grupe, G., Price, T.D., Schröter, P., and Söllner, F., 1999. Mobility of Bell Beaker people revealed by Sr isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains: A reply to the comments by Peter Horn and Dieter Müller-Sohnius. *Applied Geochemistry* 14: 271–275.
- Gunneweg, J., and Michel, H.V. 1999. Does the different layout of the Late Bronze Age tombs at Laish/Dan and Akko in northern Canaan reflect different trade relations? An instrumental neutron activation study on Mycenaean pottery. *Journal of Archaeological Science* 26: 989-995.
- Harms, U., Schandelmeier, H., and Darbyshire, D.P.F. 1990. Pan-African reworked early/middle Proterozoic crust in NE Africa west of the Nile: Sr and Nd isotopic evidence. *Journal of the Geological Society, London* 147: 859-872.
- Hayward, L.G. 1990. The origin of the raw elephant ivory used in Greece and the Aegean during the Late Bronze Age. *Antiquity* 64: 103-109.
- Heaton, T.H.E., Vogel, J.C., von la Chevallerie, G., and Collett, G. 1986. Climatic influence on the isotopic composition of bone nitrogen. *Nature* 322: 822-823.
- Hirschfeld, N. 2004. Presentation at the annual conference of the Archaeological Institute of America, San Francisco, January 2004.
- Hodder, I. 1982. Toward a contextual approach to Prehistoric exchange. In (J.E. Ericson and T.K. Earle, Eds.) *Contexts for Prehistoric exchange*, pp. 199-211. New York: Academic Press.
- Hooijer, D.A. 1978. The Indian elephant at Bronze Age Ras Shamra, Ugarit. *Ugaritica* 7: 187-188.
- Horn, P., and Müller-Sohnius, D., 1999. Comment on "Mobility of Bell Beaker people revealed by Sr isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains" by Gisela Grupe, T. Douglas Price, Peter Schröter, Frank Söllner, Clark M. Johnson and Brian L. Beard. *Applied Geochemistry* 14: 263–269.
- Ishibashi, H., Takeuchi, T., Whyte, I., and Koike, H. 1999.  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  measurements from the African elephant, *Loxodonta africana*, used for ivory sourcing. *Bulletin of the Graduate School of Social and Cultural Studies, Kyushu University* 5: 1-8.
- Jones, A. 2002. *Archaeological theory and scientific practice*. Cambridge: Cambridge University Press.
- Kabigumila, J. 1993. Feeding habits of elephants in Ngorongoro Crater, Tanzania. *African Journal of Ecology* 31: 156-164.

- Kantor, H.J. 1956. Syro-Palestinian ivories. *Journal of Near Eastern Studies* 15: 153-174.
- Karageorghis, V., Mertens, J.R., and Rose, M.E. 2000. *Ancient art from Cyprus: The Cesnola collection in the Metropolitan Museum of Art*. New York: The Metropolitan Museum of Art.
- Karali-Yannacopoulos, L. 1993. Sources of ivory in the Aegean Bronze Age: An environmental approach. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 57-59.
- Katzenberg, M.A., and Harrison, R.G. 1997. What's in a bone? Recent advances in archaeological bone chemistry. *Journal of Archaeological Research* 5: 265-293.
- Kennan, P.S., Mitchell, J.G., and Mohr, P. 1990. The Sagatu Ridge dyke swarm, Ethiopian rift margin: revised age and new Sr-isotopic data. *Journal of African Earth Sciences* 11: 39-42.
- Kitchen, K.A. 1993. The land of Punt. In (T. Shaw, P. Sinclair, B. Andah, A. Okpoko, Eds.) *The Archaeology of Africa: food, metals and towns*, pp. 587-608. One World Archaeology 20.
- Klingel, H. 1991. The social organization and behavior of *Hippopotamus amphibius*. In *African Wildlife Research and Management*, (F.I.B. Kayanja and E.L. Edroma), pp. 73-75. International Council of Scientific Unions.
- Knapp, B.A. 1981. The Thera frescoes and the question of Aegean contact with Libya during the Late Bronze Age. *Journal of Mediterranean Anthropology and Archaeology* 1: 249-279.
- Knapp, A.B. 1991. Spice, drugs, grain and grog: Organic goods in Bronze Age East Mediterranean trade. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 21-68. Studies in Mediterranean Archaeology 90. Göteborg: Paul Åströms Förlag.
- Knapp, A.B. 1993. Thalassocracies in Bronze Age Eastern Mediterranean trade: making and breaking a myth. *World Archaeology* 24: 332-347.
- Knapp, A.B. 2000. Archaeology, science-based archaeology and the Mediterranean Bronze Age metals trade. *European Journal of Archaeology* 3: 31-57.
- Koch, P. L., Heisinger, J., Moss, C., Carlson, R.W., Fogel, M.L. and Behrensmeyer, A.K. 1995. Isotopic tracking of change in diet and habitat use in African elephants. *Science* 267: 1340-1343.

- Koch, P.L., Tuross, N., and Fogel, M.L. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. *Journal of Archaeological Science* 24: 417-429.
- Krom, M.D., Cliff, R.A., Eijssink, L.M., Herut, B., and Chester, R. 1999. The characterization of Saharan dusts and Nile particulate matter in surface sediments from the Levantine basin using Sr isotopes. *Maritime Geology* 155: 319-330.
- Krzyszowska, O.H. 1990. Ivory and Related Materials: An Illustrated Guide. *Classical Handbook 3; Institute of Classical Studies, Bulletin Supplement 59*. London.
- Krzyszowska, O.H. 1993. Aegean ivory carving: Towards an evaluation of Late Bronze Age workshop material. In (J. Lesley Fitton, Ed.) *Ivory in Greece and the Mediterranean from the Bronze Age to the Hellenistic Period*. British Museum Occasional Papers 85: 25-35.
- Kuhrt, A. 1995. *The Ancient Near East. Volumes I and II*. New York: Routledge.
- Küster, D., and Liégeois, J.-P. 2001. Sr, Nd isotopes and geochemistry of the Bayuda Desert high-grade metamorphic basement (Sudan): An early Pan-African oceanic convergent margin, not the edge of the East Saharan ghost craton? *Precambrian Research* 109: 1-23.
- Larsen, C.S. 1997. *Bioarchaeology: Interpreting Behavior from the Human Skeleton*. Cambridge: Cambridge University Press.
- Laws, R., Parker, I.S.C., and Johnstone, R.C.B. 1975. *Elephants and Their Habitats*. Oxford: Clarendon.
- Layser, T.R., and Buss, I.O. 1985. Observations on morphological characteristics of elephant tusks. *Mammalia* 49: 407-414.
- Liebowitz, H. 1980. Military and feast scenes on Late Bronze Palestinian ivories. *Israel Exploration Journal* 30: 162-169.
- Liebowitz, H. 1987. Late Bronze II ivory work in Palestine: Evidence of a cultural highpoint. *Bulletin of the American Schools of Oriental Research* 265: 3-24.
- Lilyquist, C. 1998. The use of ivories as interpreters of political history. *Bulletin of the Schools of Oriental Research* 310: 25-33.
- Liverani, M. 1987. The collapse of the Near Eastern regional system at the end of the Bronze Age: the case of Syria. In (M. Rowlands, M. Larsen, and K. Kristiansen, Eds.) *Centre and periphery in the ancient world*, pp. 66-73. Cambridge: Cambridge University Press.

- Luce, J.V. 1998. Late Bronze Age trade and the Homeric tradition. *Report of the Department of Antiquities, Cyprus, 1998*. Nicosia: Department of Antiquities, Cyprus
- Macdonald, D. 1984. *The encyclopedia of mammals*. New York: Facts on File Publications.
- McBurney, C.B.M. 1970. Libya before the Greeks. *Libyan Studies, Annual Report of the Society for Libyan Studies* 2: 19-25.
- Meiggs, R. 1982. *Trees and Timber in the Ancient Mediterranean World*. Oxford: Oxford Press.
- Melas, M. 1991. Mediterranean trade in the Bronze Age: a theoretical perspective. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 387-398. *Studies in Mediterranean Archaeology* 90. Göteborg: Paul Åströms Förlag.
- Miller, E.K., Blum, J.A., Friedland, A.J. 1993. Determination of soil exchangeable-cation loss and weathering rates using Sr isotopes. *Nature* 362: 438-441.
- Miller, R. 1986. Elephants, ivory, and charcoal: an ecological perspective. *Bulletin of the American Schools of Oriental Research* 264: 29-43.
- Misra, M.K., and Rodgers, W.A. 1990. Elephant feeding and forest impact in Rajaji National Park. *Journal of Tropical Forestry* 6: 77-85.
- Molleson, T.I., Eldridge, D., and Gale, N. 1986. Identification of lead sources by stable isotope ratios in bones and lead from Poundbury Camp, Dorset. *Oxford Journal of Archaeology* 5: 249-253.
- Morkot, R. 1996. *The Penguin historical atlas of Ancient Greece*. New York: Penguin Books.
- Mugangu, T.E., and Hunter, M.L. Jr. 1992. Aquatic foraging by *Hippopotamus* in Zaire: Response to a food shortage? *Mammalia* 56: 345-349.
- Nielsen-Marsh, C.M., and Hedges, R.E.M. 2000. Patterns of diagenesis in bone II: effects of acetic acid treatment and the removal of diagenetic CO<sub>3</sub>. *Journal of Archaeological Science* 27: 1151-1159.
- O'Connor, D. 1993. Urbanism in Bronze Age Egypt and northeast Africa. In (T. Shaw, P. Sinclair, B. Andah, and A. Okpoko, Eds.) *The Archaeology of Africa: food, metals and towns*, pp. 570-585. *One World Archaeology* 20.

Pe-Piper, G., and Piper, D.J.W. 2001. Late Cenozoic, posts-collisional Aegean igneous rocks: Nd, Pb and Sr isotopic constraints on petrogenetic and tectonic models. *Geological Magazine* 138: 653-668.

Pegram, W.J., Register, J.K. Jr., Fullagar, P.D., Ghuma, M.A., and Rogers, J.J.W. 1976. Pan-African ages from a Tibesti massif batholith, southern Libya. *Earth and Planetary Science Letters* 30: 123-128.

Peltenberg, E. 1991. Greeting gifts and luxury faience: a context for Orientalising trends in Late Mycenaean Greece. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 162-179. *Studies in Mediterranean Archaeology* 90. Göteborg: Paul Åströms Förlag.

Phillips, J. 1997. Punt and Aksum: Egypt and the horn of Africa. *Journal of African History* 38: 423-457.

Pik, R., Deniel, C., Coulon, C., Yirgu, G., and Marty B. 1999. Isotopic and trace element signatures of Ethiopian flood basalts: Evidence for plume-lithosphere interactions. *Geochimica et Cosmochimica Acta* 63: 2263-2279.

Polanyi, K. 1946. *Origins of our Time: The Great Transformation*. London: Victor Gollancz.

Potts, T.F. 1987. Bronze Age ivory-decorated box from Pella (Pahel) and its foreign relations. *Studies in the History and Archaeology of Jordan* 3: 59-71.

Price, T.D., Blitz, J., Burton, J., and Ezzo, J.A. 1992. Diagenesis in prehistoric bone: problems and solutions. *Journal of Archaeological Science* 19: 513-529.

Price, T.D., Grupe, G., and Schroter, P. 1994a. Reconstruction of migration patterns in the Bell Beaker period by stable strontium isotope analysis. *Applied Geochemistry* 9: 413-417.

Price, T.D., Johnson, C.M., Ezzo, J.A., Ericson, J., and Burton, J.H. 1994b. Residential mobility in the prehistoric southwest United States: A preliminary study using strontium isotope analysis. *Journal of Archaeological Science* 21: 315-330.

Price, T.D., Grupe, G., and Schröter, P. 1998. Migration in the Bell Beaker period in central Europe. *Antiquity* 72: 405-411.

Price, T.D., Manzanilla, L., and Middleton, W.D. 2000. Immigration and the ancient city of Teotihuacan in Mexico: a study using strontium isotope ratios in human bone and teeth. *Journal of Archaeological Science* 27: 903-913.

Price, T.D., Bentley, R.A., Lüning, J., Gronenborn, D., and Wahl, J. 2001. Prehistoric human migration in the Linearbandkeramik of Central Europe. *Antiquity* 75: 593-603.



- Price, T.D., Burton, J.H., and R.A. Bentley. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44: 117-135.
- Pulak, C. 1996. Dendrochronological dating of the Uluburun ship. *The INA Quarterly* 23(1): 12-13.
- Pulak, C. 1997. The Uluburun shipwreck. In (S. Swiny, R.L. Hohlfelder, and H.W. Swiny, Eds.) *Res Maritimae: Cyprus and the Eastern Mediterranean from Prehistory to Late Antiquity*, pp. 233-262. ASOR Archaeological Reports 4.
- Pulak, C. 1998. The Uluburun shipwreck: an overview. *The International Journal of Nautical Archaeology* 27: 188-224.
- Pulak, C. 2001. The cargo of the Uluburun shipwreck and evidence for trade with the Aegean and beyond. In (L. Bonfante and V. Karageorghis, Eds.) *Italy and Cyprus in Antiquity 1500-450 BC*, pp. 13-60. Nicosia: The Costakis and Leto Severis Foundation.
- Ratnagar, S. 2001. The Bronze Age: unique instance of a pre-industrial world system? *Current Anthropology* 42: 351-379.
- Raubenheimer, E.J., van Heerden, W.F.P., van Niekerk, P.J., de Vos, V., and Turner, M.J. 1995. Morphology of the deciduous tusk (tush) of the African elephant (*Loxodonta africana*). *Archives of Oral Biology* 40: 571-576.
- Raubenheimer, E.J., Brown, J.M.M., Rama, D.B.K., Dreyer, M.J., Smith, P.D., and Dauth, J. 1998. Geographic variations in the composition of ivory of the african elephant (*Loxodonta africana*). *Archives of Oral Biology* 43: 641-647.
- Raubenheimer, E.J. 1999. Morphological aspects and composition of African elephant (*Loxodonta africana*) ivory. *Koedoe* 42(2): 57-64.
- Reedy, T.J., and Reedy, C.L. 1991. Statistical analysis of lead isotope data in provenance studies. *Materials Research Society Symposium Proceedings* 185: 39-47.
- Reese, D.S., and Krzyszkowska, O.H. 1996. Elephant ivory at Minoan Kommos. In (J.W. Shaw and M.C. Shaw, Eds.) *Kommos I/2: The Kommos Region and Houses of the Minoan Town*, pp. 324-328. Princeton: Princeton University Press.
- Reese, D.S. 1998. Appendix III: A hippopotamus tooth from Hala Sultan Tekke. In (P. Åström, Ed.) *The Wells. Hala Sultan Tekke* 10. *Studies in Mediterranean Archaeology* XLV: 140-145. Jonsered: Paul Åströms Förlag.

- Reese, D.S. 2001. Some comments on the Akrotiri *Aetokremnos* fauna. In (S. Swiny, Ed.), *The Earliest Prehistory of Cyprus: From Colonization to Exploitation*, pp. 19-36. *American Schools of Oriental Research Reports* 5. Cyprus American Archaeological Research Institute Monograph Series 2. Boston: American Schools of Oriental Research.
- Reinhardt, E.G., Patterson, R.T., Blenkinsop, J., and Raban, A. 1998. Paleoenvironmental evolution of the inner basin of the ancient harbor at Caesarea Maritima, Israel; foraminiferal and Sr isotopic evidence. *Revue de Paleobiologie* 17: 1-21.
- Rogers, N., Macdonald, R., Fitton, J.G., George, R., Smith, M., and Barreiro, B. 2000. Two mantle plumes beneath the East African rift system: Sr, Nd and Pb isotope evidence from Kenya Rift basalts. *Earth and Planetary Science Letters* 176: 387-400.
- Schaaf, P., and Müller-Sohnius, D. 2002. Strontium and neodymium isotopic study of Libyan Desert Glass: Inherited Pan-African age signatures and new evidence for target material. *Meteoritics and Planetary Science* 37: 565-576.
- Schandelmeier, H., and Darbyshire, D.P.F. 1984. Metamorphic and magmatic events in Uweinat-Bir Safsaf uplift (Western Desert, Egypt). *Geologische Rundschau* 73: 819-831.
- Schilman, B., Bar-Matthews, M., Almogi-Labin, A., and Luz, B. 2001. Global climate instability reflected by Eastern Mediterranean marine records during the late Holocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 176: 157-176.
- Schortman, E. 2001. CA response to "The Bronze Age: unique instance of a pre-industrial world system?" by S. Ratnagar. *Current Anthropology* 42: 371-372.
- Scullard, H.H. 1974. *The Elephant in the Greek and Roman World*. Cambridge: Thames & Hudson
- Sealy, J.C., Armstrong, R., and Schrire, C. 1995. Beyond lifetime averages: Tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* 69: 290-300.
- Sherratt, A., and Sherratt, S. 1991. From luxuries to commodities: the nature of Mediterranean Bronze Age trading systems. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 351-386. *Studies in Mediterranean Archaeology* 90. Göteborg: Paul Åströms Förlag.
- Shinnie, P.L. 1984. The mainlines of socio-economic development in the Sudan in Post-Neolithic times. In (L. Krzyzaniak and M. Kobusiewicz, Eds.) *Origin and early development of food-producing cultures in North-eastern Africa*, pp. 109-115. Poznan: Polish Academy of Sciences.

- Short, J. 1981. Diet and feeding behavior of the forest elephant. *Mammalia* 45: 177-185.
- Sidney, J. 1965. The past and present distribution of some African ungulates. *Transactions of the Zoological Society of London* 30: 1-399.
- Sillen, A., and Sealy, J.C. 1995. Diagenesis of strontium in fossil bone: a reconsideration of Nelson *et al.*, 1986. *Journal of Archaeological Science* 22: 313-320.
- Sillen, A., Hall, G., and Armstrong, R. 1998.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios in modern and fossil food-webs of the Sterkfontein Valley: implications for early hominid habitat preference. *Geochimica et Cosmochimica Acta* 62: 2463-2478.
- Simmons, A.H. 1991. Humans, island colonization and Pleistocene extinctions in the Mediterranean: the view from Akrotiri Aetokremnos, Cyprus. *Antiquity* 65: 857-869.
- Simmons, A.H. 1993. Early Cypriots and extinct pygmy hippopotami. *Research and Exploration* 9: 123-125.
- Snodgrass, A.M. 1991. Bronze Age exchange: a minimalist view. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 15-20. Studies in Mediterranean Archaeology 90. Göteborg: Paul Åströms Förlag.
- Sreekumar, K.P., and Nirmalan, G. 1989. Mineral composition of elephant tusk. *Indian Journal of Animal Sciences* 59: 1561-1562.
- Starinsky, A., Bielski, M., Lazar, B., Steinitz, G., and Raab, M. 1983. Strontium isotope evidence on the history of oilfield brines, Mediterranean coastal plain, Israel. *Geochimica et Cosmochimica Acta* 47: 687-695.
- Stein, M., Starinsky, A., Agnon, A., Katz, A., Raab, M., Spiro, B., and Zak, I. 2000. The impact of brine-rock interaction during marine evaporite formation on the isotopic Sr record in the oceans: Evidence from Mt. Sedom, Israel. *Geochimica et Cosmochimica Acta* 64: 2039-2053.
- Steyn, A., and Stalmans, M. 2001. Selective habitat utilisation and impact by African elephant within a heterogeneous landscape. *Koedoe* 44(1): 95-103.
- Sukumar, R., Bhattacharya, S.K., and Krishnamurthy, R.V. (1987). Carbon isotopic evidence for different feeding patterns in an Asian elephant population. *Current Science* 56, 11-14.
- Sukumar, R., and Ramesh, R. 1992. Stable carbon isotope ratios in Asian elephant collagen: implications for dietary studies. *Oecologia* 91: 536-539.

- Sukumar, R., and Ramesh, R. 1995. Elephant foraging: Is browse or grass more important? In (J.C. Daniel and H.S. Datye, Eds.) *A week with elephants: proceedings of the International Seminar of the Conservation of Elephant, June 1993*, pp. 368-374. Oxford: Oxford University Press.
- Talbot, M.R., Williams, M.A.J., and Adamson, D.A. 2000. Strontium isotope evidence for late Pleistocene reestablishment of an integrated Nile drainage network. *Geology* 28: 343-346.
- Tchamba, M.N., and Seme, P.M. 1993. Diet and feeding behavior of the forest elephant in the Santchou Reserve, Cameroon. *African Journal of Ecology* 31: 165-171.
- Tieszen, L.L., and Imbamba, S.K. 1980. Photosynthetic systems, carbon isotope discrimination and herbivore selectivity in Kenya. *African Journal of Ecology* 18: 237-242.
- Tieszen, L.L., Boutton, T.W., Ottichilo, W.K., Nelson, D.E., and Brandt, D.H. 1989. An assessment of long-term food habits of Tsavo elephants based on stable carbon and nitrogen isotope ratios of bone collagen. *African Journal of Ecology* 27: 219-226.
- Tieszen, L.L., and Fagre, T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO<sub>2</sub>, bone collagen, bioapatite, and soft tissues. In (J. B. Lambert and G. Grupe, Eds.) *Prehistoric Human Bone: Archaeology at the Molecular Level*, pp. 121-155. New York: Springer-Verlag.
- Turner, M.L., Baker, C., and du Toit, D. 2000. The spatial arrangement of collagen in African elephant (*Loxodonta africana*) ivory. *Microscopy Society of Southern Africa Proceedings* 30: 71.
- Tykot, R.H., and Staller, J.E. 2002. The importance of early maize agriculture in Coastal Ecuador: New data from La Emerenciana. *Current Anthropology* 43: 666-677.
- Vagnetti, L. 1986. Cypriot elements beyond the Aegean in the Bronze Age. In ( V. Karageorghis, Ed.) *Cyprus between the Orient and the Occident*, pp. 201-214. Nicosia.
- Vagnetti, L. 1999. Mycenaeans and Cypriots in the central Mediterranean before and after 1200 B.C. In (W. Phelps, Y. Lolos, and Y. Vichos, Eds.) *The Point Iria wreck: Interconnections in the Mediterranean ca. 1200 B.C.* Proceedings of the International Conference, Island of Spetses, September 1998. Athens.
- Vagnetti, L., and Lo Schiavo, F. 1989. Late Bronze Age long distance trade in the Mediterranean: the role of the Cypriots. In (E. Peltenberg, Ed.) *Early society in Cyprus*, pp. 217-243. Edinburgh: Edinburgh University Press.

van der Merwe, N. J., Lee-Thorp, J.A., and Bell, R.H.V. 1988. Carbon isotopes as indicators of elephant diets and African environments. *African Journal of Ecology* 26: 163-172.

van der Merwe, N.J., Lee-Thorp, J.A., Thackeray, J.F., Hall-Martin, A., Kruger, F.J., Coetzee, H., Bell, R.H.V., and Lindeque, M. 1990. Source-area determination of elephant ivory by isotopic analysis. *Nature* 346, 744-746.

van Hoven, W. 1983. African elephant and hippopotamus: the results of nutritional research. *Proceedings of the Annual Dr Scholl Conference on the Nutrition of Captive Wild Animals* 2: 47-62.

Viljoen, P.J. 1988. The desert-dwelling elephant. Hardy survivor. *African Wildlife* 42(2): 111, 113-115.

Viljoen, P.J. 1989. Spatial distribution and movements of elephants (*Loxodonta africana*) in the northern Namib Desert region of the Kaokoveld, Namibia. *Journal of Zoology, London* 219: 1-19.

Viljoen, P.J., and du P. Bothma, J. 1990. Daily movements of desert-dwelling elephants in the northern Namib Desert. *South African Journal of Wildlife Research* 20: 69-72.

Vogel, J.C., Eglington, B. and Auret, J.M. 1990. Isotope fingerprints in elephant bone and ivory. *Nature* 346: 747-749.

Warren, P.M. 1991. A merchant class in Bronze Age Crete? The evidence of Egyptian stone vases from the city of Knossos. In (N.H. Gale, Ed.) *Bronze Age trade in the Mediterranean: Papers presented at the conference held at Rewley House, Oxford, in December 1989*, pp. 295-302. Studies in Mediterranean Archaeology 90. Göteborg: Paul Åströms Förlag.

Weldeab, S., Siebel, W., Emeis, K.C., and Hemleben, C. 2002. Provenance of lithogenic surface sediments and pathways of riverine suspended matter in the Eastern Mediterranean Sea: Evidence from  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios. *Chemical Geology* 186: 139-149.

White, C.D., Spence, M.W., Stuart-Williams, H.L.Q., and Schwarcz, H.P. 1998. Oxygen isotopes and the identification of geographical origins: The Valley of Oaxaca versus the Valley of Mexico. *Journal of Archaeological Science* 25: 643-655.

White, D. 1986. 1985 excavations on Bates's Island, Marsa Matruh. *Journal of the American Research Center in Egypt* 23: 51-84.

Williamson, B.R. 1975. The condition and nutrition of elephants in Wankie National Park. *Arnoldia* 7(12): 1-20.

- Wing, L.D., and Buss, I.O. 1970. Elephants and forest. *Wildlife Monographs* 19: 1-92.
- Winter, I. 1973. *North Syria in the early first millennium BC, with special reference to ivory carving*. Doctoral dissertation, Columbia University. Ann Arbor: University Microfilms.
- Winter, I.J. 1976. Phoenician and North Syrian ivory carving in historical context: Questions of style and distribution. *Iraq* 38: 1-22.
- Winter, I.J. 1981. Is there a South Syrian style of ivory carving in the early first millennium B.C.? *Iraq* 43: 101-130.
- Yeivin, S. 1959. Gath. *Revue Biblique* 65: 417-418
- Yener, K.A. 2001. Alalakh: A Late Bronze Age capital in the Amuq Valley, southern Turkey. *The Oriental Institute News and Notes* 169.  
Online at [http://www-oi.uchicago.edu/OI/PROJ/AMU/NN\\_SPR01/NN\\_Spr01.html](http://www-oi.uchicago.edu/OI/PROJ/AMU/NN_SPR01/NN_Spr01.html).
- Young, E. 1966. Nutrition of the hippopotamus (*Hippopotamus amphibius*). *African Wildlife* 20: 165-167.
- Zaccagnini, C. 1977. The Merchant at Nuzi. *Iraq* 29: 171-190.
- Zaccagnini, C. 1983. Patterns of mobility among ancient Near Eastern craftsmen. *Journal of Near Eastern Studies* 42: 245-264.