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DINING IN THE DAKHLEH OASIS, EGYPT:

DETERMINATION OF DIET USING

DOCUMENTS AND STABLE

ISOTOPE ANALYSIS

By

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Abstract

This study involves the reconstruction of diet for three cemetery populations (ca. 800 BC to AD 350) from the Dakhleh Oasis, Egypt, using stable carbon and nitrogen isotope analysis in conjunction with documentary and archaeological evidence. Very few isotopic paleodietary studies have been conducted on samples from extremely arid conditions, nor have they had the luxury of including documentary and archaeological evidence of diet. Results indicate a shift in diet from the early cemeteries ('ein Tirghi and Kellis 1 cemeteries) where inhabitants consumed a diet composed mainly of C_3 foods, to a diet that included millet (a C_4 plant) by the early Roman period (Kellis 2 cemetery). Comparisons within cemetery populations, particularly Kellis 2, reveal sex and age differences in diet. Adult males were found to be enriched in ^{13}C over females, indicating a heavier reliance on either millet or the flesh of cows and/or goat (which were found to be significantly enriched in ^{13}C in comparison to the other animals). Infants' $\delta^{13}C$ and $\delta^{15}N$ values were also found to be significantly elevated in comparison to adults. The enrichment in ^{13}C suggests that supplementary foods of cow's and/or goat's milk was introduced at a very young age (before 6 months). Comparisons of $\delta^{13}C$ values between archaeological and modern botanical remains suggest that towards the end of the occupation of the Roman period site of Kellis the agricultural fields were becoming increasingly laden with salt. This may have contributed to the ultimate demise and abandonment of this site during the 4th century AD. These findings suggest that by the Roman period the inhabitants of the Oasis had changed their dietary regime through the introduction of millet, reflecting changes in the economic and social structure of greater Egypt during this time period.

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Chapter 1

Introduction

1.1 Introduction

This dissertation focuses on the dietary reconstruction of individuals from three temporally distinct cemetery populations from the Dakhleh Oasis, Egypt using stable isotope analysis, documentary and archaeological evidence. The use of stable isotope analysis has long been recognized as a plausible method to investigate diet in prehistoric and historic populations (Lee-Thorp and Sealy 1986; Schwarcz and Schoeninger 1991). Since its establishment stable isotope analysis has been used to document diets in temperate, arctic, and tropical ecological zones; however, very little work has been conducted on very arid regions where individuals have limited access to water for drinking and farming. Recent excavations in the Dakhleh Oasis, Egypt, have revealed several skeletal samples on which such an analysis can be performed. A unique aspect of the research presented here involves the reconstruction of diet based on two different sources: stable isotopes and historical documents, particularly the Kellis Agricultural Account Book. Dietary studies involving isotopic analysis rarely, if ever, are conducted

in conjunction with documentary evidence of this caliber. The historical documentation is used in conjunction with the isotope data and also serves as an independent criterion for dietary reconstruction.

The reconstruction of diet in past populations is an essential part of anthropology. The importance of food in almost every aspect of anthropological study has been evident for decades, and there has been an increasing emphasis put upon nutritional concerns in explaining variability in human biology, behaviour and culture (Johnston 1987). Information regarding an individual's diet or a population's subsistence base can reveal a substantial amount of information about that person and their society. Dietary components are a vital part of health, disease, reproduction and migration, and as such diet plays an important role in the demographics of any given population (Adair 1987). As food is the sustenance of life, how a society organizes itself is largely dependent on how food is obtained. Subsistence in many cultures is intimately connected to religion, social organization, the division of labour and hierarchy.

Considering that diet affects several human variables, defining a population's diet can reveal vital information about the biology, economy and culture of a given society. Dietary studies can reveal information about fertility, mortality, food procurement, population movement, social and political organization, and population dynamics. Any knowledge regarding diet can be used to develop a deeper understanding of the society being studied.

Approaches used to reconstruct diet are very diverse. Empirical approaches

include studies of faunal and botanical remains, subsistence technology, skeletal pathology, trace element analysis and stable isotope analysis (Keegan 1989). The incomplete nature of the archaeological record necessitates that an integrated approach be taken when reconstructing subsistence patterns. This involves the use of two approaches.

The first approach involves the use of the archaeological record. This record provides indirect evidence of diet in many forms, including animal and plant remains, food production and processing implements, skeletal pathological characteristics reflective of dietary causes, and documentary evidence. Botanical and faunal remains provide evidence about the types of food that may have been available for consumption. The nature of archaeological sites in most cases, however, causes preservational biases, which makes it difficult to create a complete menu of foods, or difficult to make comments as to food quantities or the importance of certain food items in the diet. To overcome such biases a second approach can be pursued. This approach involves the integration of data from the direct measurement of long or short term consumption. This can be accomplished using the methodology of stable isotope analysis.

The situation in the Dakhleh Oasis is unique in respect to potential dietary reconstruction. The extremely arid environment has allowed for excellent preservation of skeletal and soft tissue material in three cemetery sites. This environment has also allowed for the exceptional preservation of archaeological botanical and faunal remains, and written documentation that specifically refers to food resources. In this case it is possible to integrate the information from the archaeological evidence and the data from

stable isotope analysis.

1.2 Hypotheses to be Tested

The main thrust of this thesis involves the reconstruction of diet in the Dakhleh Oasis during three distinct economic and political time periods. The populations analyzed consist of individuals from the 'ein Tirghi cemetery (supposed to be from Third Intermediate, ca. 800 BC), the Kellis 1 cemetery (Ptolemaic Period, ca. 200 BC) and the Kellis 2 cemetery (Romano-Christian Period, ca. AD 1-400). Archaeological botanical and faunal remains were excavated from the ancient village of Kellis (directly associated with the Kellis 1 and 2 cemeteries). Historical documentation, especially the Kellis Agricultural Account Book (ca. AD 350), was also discovered in the village of Kellis. One of the unique aspects of this dissertation is the reconstruction of diet of the inhabitants of the Dakhleh Oasis using three independent sources of information: stable isotope analysis, faunal and floral remains, and historical documentation. Although these data sources are discrete, it is possible to integrate them in such a way as to gain a broader understanding of the lives of the inhabitants of the Dakhleh Oasis.

Dietary reconstruction of the individuals from the Dakhleh Oasis allows for the testing of several hypotheses. Given the nature of these data it is possible to test for differences between the three cemetery populations. The primary questions asked are: 1) what, if any, changes in subsistence practice occurred during these specific time periods? and, 2) how do variations in diet through time and space in the Dakhleh Oasis re-

flect similar variations recorded in the Kellis Agricultural Account Book or in the archaeological faunal and botanical remains? It is hypothesized that there are inherent differences in diet between these populations because they represent three distinct political and economic time periods.

Within the populations themselves, it is also possible to discuss several social issues. Using stable isotope analysis it is possible to detect differences between component groups in a population (i.e., sex or age groups). The primary question asked in this thesis is, to what extent is it possible to recognize homogeneities in the consumption of food amongst residents of each site, and how do these homogeneities relate to social organization? To answer this question, differences in diet between males and females, and also between adults and sub-adults are examined. In addition, dietary change during the life cycle of infants is also examined. The determination of the age at which infants are no longer consuming their mother's milk may provide information regarding birth spacing, fertility and population control in a given society (Katzenberg and Pfeiffer 1995). It is hypothesized that there are detectable variations in diet between males and females in the populations and also between adults and children because of the possibility of differential access and use of food/resources.

1.3 Structure of the Dissertation

An introduction to the Dakhleh Oasis project, and the geography and ecology of the Dakhleh Oasis is presented in Chapter 2. In addition, an introduction to the

Kellis Agricultural Account Book occurs in this chapter. This information is essential to understanding the harsh geographic and climatic conditions that would have affected the individuals living in the Oasis during the time periods considered in this dissertation.

To understand diet and any potential changes in diet over time or between subgroups in the Dakhleh Oasis, it is important to examine the cultural setting for each cemetery. One fruitful avenue involves examining the political, economic and social environment at the time in which each of the cemeteries was in use. Chapter 3 presents this for the Third Intermediate, Ptolemaic and Romano-Christian periods which are the periods under study in this research.

Before it is possible to interpret the results of the stable isotope analyses, it is necessary to construct a menu of foods that would have been available for consumption by the inhabitants of the Dakhleh Oasis. This reconstruction requires an amalgamation of all the evidence of food items, including iconographic, documentary and archaeological evidence. It is also vital, particularly for a reconstruction of a menu for the Third Intermediate period, to examine evidence from not only the Dakhleh Oasis, but from the whole of Egypt. A discussion of food in the Dakhleh Oasis and Egypt is presented in Chapter 4.

In addition to creating a menu of foods to aid in the understanding of the stable isotope results, it is also necessary to discuss the science of stable isotope analysis in detail. An understanding of the principles of stable isotope analysis is essential to the interpretation of the human, animal and plant data. Chapter 5 presents a detailed litera-

ture review of stable isotope analysis.

The cemetery sites and the samples used for the stable isotope analysis and the methodology used are discussed in Chapter 6. Results of the stable isotope analysis are presented in Chapter 7. A discussion of the stable isotope results, in addition to an integration of the documentary, archaeological and stable isotope results are presented in Chapter 8.

Taken together, the evidence presented in this dissertation stresses the dietary importance of trade to the lives of the individuals in the Dakhleh Oasis. Although the Egyptian Oases have previously been portrayed as insular communities (i.e., Dzierzykray-Rogalski 1978; 1989), this was not the case in the Dakhleh Oasis. Trade was essential for survival in the Oasis environment, and changes in the political and economic structure of Egypt over time directly affected the goods available for consumption. Of particular importance in dietary reconstruction is the introduction of millet into the Oasis during the Romano-Christian period. The detection of the presence and consumption of millet in the Oasis has dramatically influenced the interpretation of dietary change through time; has helped to identify differences in diet between males and females, and for the first time, its presence helps to documents changes in infant feeding practices in association with increasing Roman influence at Dakhleh.

Chapter 2:
The Dakhleh Oasis

2.1 Introduction

The purpose of this chapter is to introduce the reader to the general mandates of the Dakhleh Oasis Project and to the geographical and ecological context of the Dakhleh Oasis. The climate, location and water supplies of the Dakhleh Oasis are some of the factors that make the Oasis such a unique environment in which to conduct human biological research. The last section presents the Kellis Agricultural Account Book, an integral source for this dissertation.

2.2 The Dakhleh Oasis Project

The Dakhleh Oasis Project (DOP) began in 1978 under the auspices of the Royal Ontario Museum and the Society for the Study of Egyptian Antiquities. The project has been under the direction of Anthony Mills since its inception. The DOP is an international, multidisciplinary project whose mandate is the study of human biocultural adaptation to the Saharan ecozone from the beginning of the Neolithic period to

present day (Mills 1984). The project's research is based on both the archaeological study of human activity in the Oasis and the environmental history of the Oasis. The first four years of research conducted by the DOP consisted of an archaeological survey of the entire Oasis. At this time more than 400 archaeological sites were recorded. Since that time many of these sites have been excavated and several more have been located.

The multidisciplinary nature of the DOP and the help of many project members has made this thesis project possible: Anthony Mills (Project Director) and Dr. Rufus Churcher (University of Toronto) analysed and identified the faunal remains from the village of Kellis. Dr. Ursula Thanheiser (Vienna University) analysed and identified the botanical remains from the village of Kellis. Dr. Klaas Worp (University of Amsterdam) provided translations of several papyri. Dr. Roger Bagnall (Columbia University) gave me preliminary drafts of the translation of the Kellis Agricultural Account Book. Dr. Manfred Woidich (University of Amsterdam) provided insights on modern agricultural practices. On-site advice and assistance with sample collection was given by Peter Sheldrick, M.D. and Dr. El Molto (Lakehead University).

2.3 Geography and Ecology of the Dakhleh Oasis

2.3.1 Location

The Dakhleh Oasis is located in the Western Desert of Egypt (Figure 2.1). The Dakhleh Oasis is located 660 Km SSW of Cairo, between latitudes 25°28'N and

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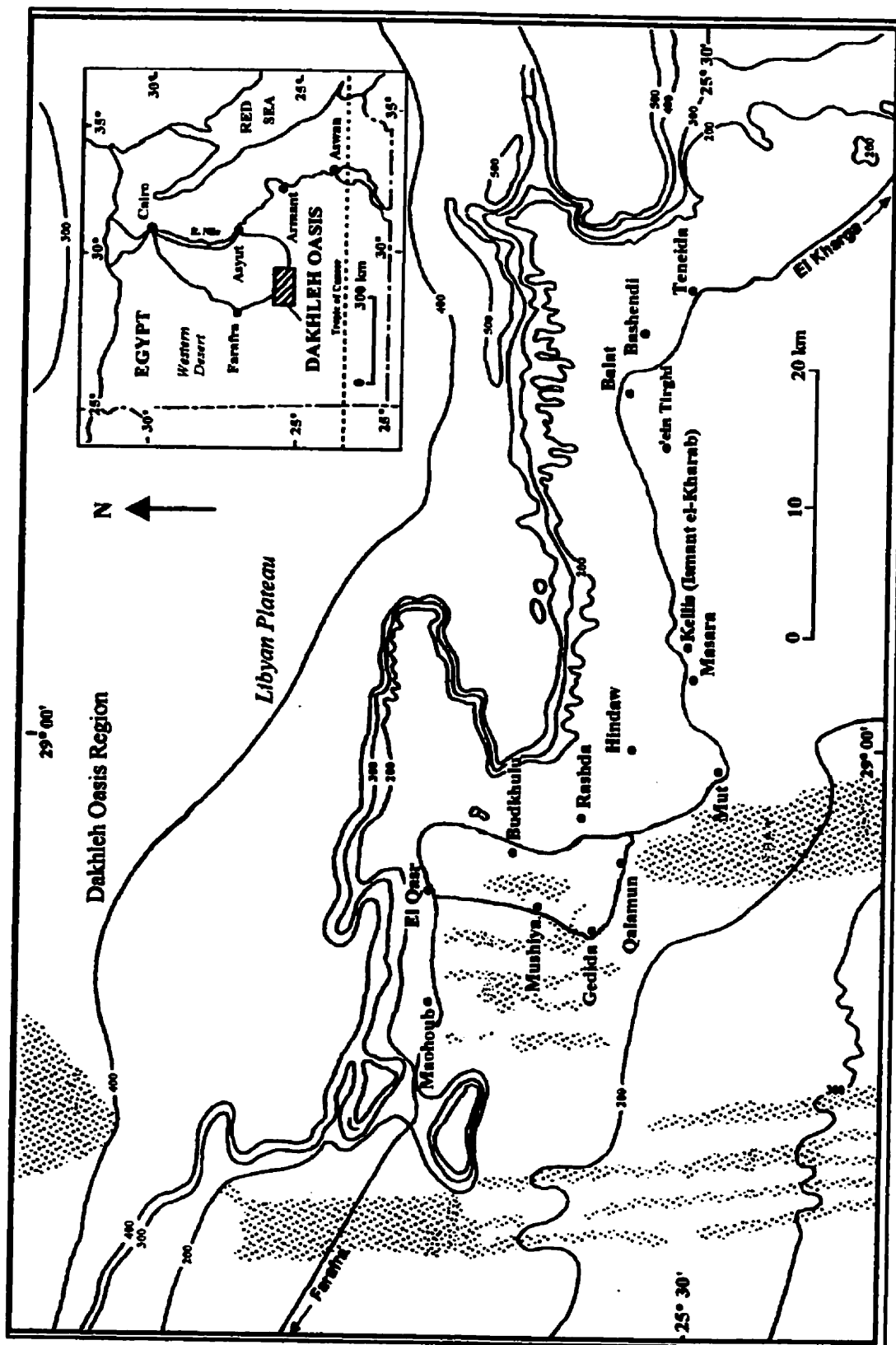
Figure 2.1. Location of the Dakhleh Oasis within Egypt, showing the locations of the sites of Kellis and 'ein Tirghi.

25°44'N and between longitudes 28°48'E and 29°21'E (Cook et al. 1988; Giddy 1987).

It extends approximately 100 km from East to West, and approximately 25 km from North to South and is oriented in a west-north-west to east-south-east direction. The northern portion of the oasis is bordered by a large escarpment, while the southern border is ill-defined. The depression that makes up the Oasis is approximately 100 meters below the general level of the Libyan Plateau.

There are three possible means of communication by land between the Dakhleh Oasis and the Nile Valley – directly across the Libyan Plateau, or via the Kharga Oasis or Farafra Oasis (Figure 2.2). Giddy (1987) provides extensive commentary regarding routes and water holes from Dakhleh to the Nile Valley. Both Kharga and Dakhleh occupy the same large depression but they are separated by a large ridge. From the eastern edge of the Dakhleh Oasis, the distance to Kharga is approximately 140 kms. This distance would have taken approximately 2 days by camel, although Winlock in 1908 reported the round trip between Dakhleh and Kharga to take 3 days by camel (Giddy 1987). There are several routes reported between Kharga and the Nile Valley, all approximating 150 km in length. A camel trek from the Dakhleh Oasis to the Nile using this route would take between 4 and 5 days.

Several natural passes in the escarpment allow for access to the Libyan Plateau and a more direct route to the Nile Valley. The distance between the escarpment and the Nile Valley is reported as being approximately 250 km. Until early this century, this route was still in use by date caravans and took roughly six and a half days of travel
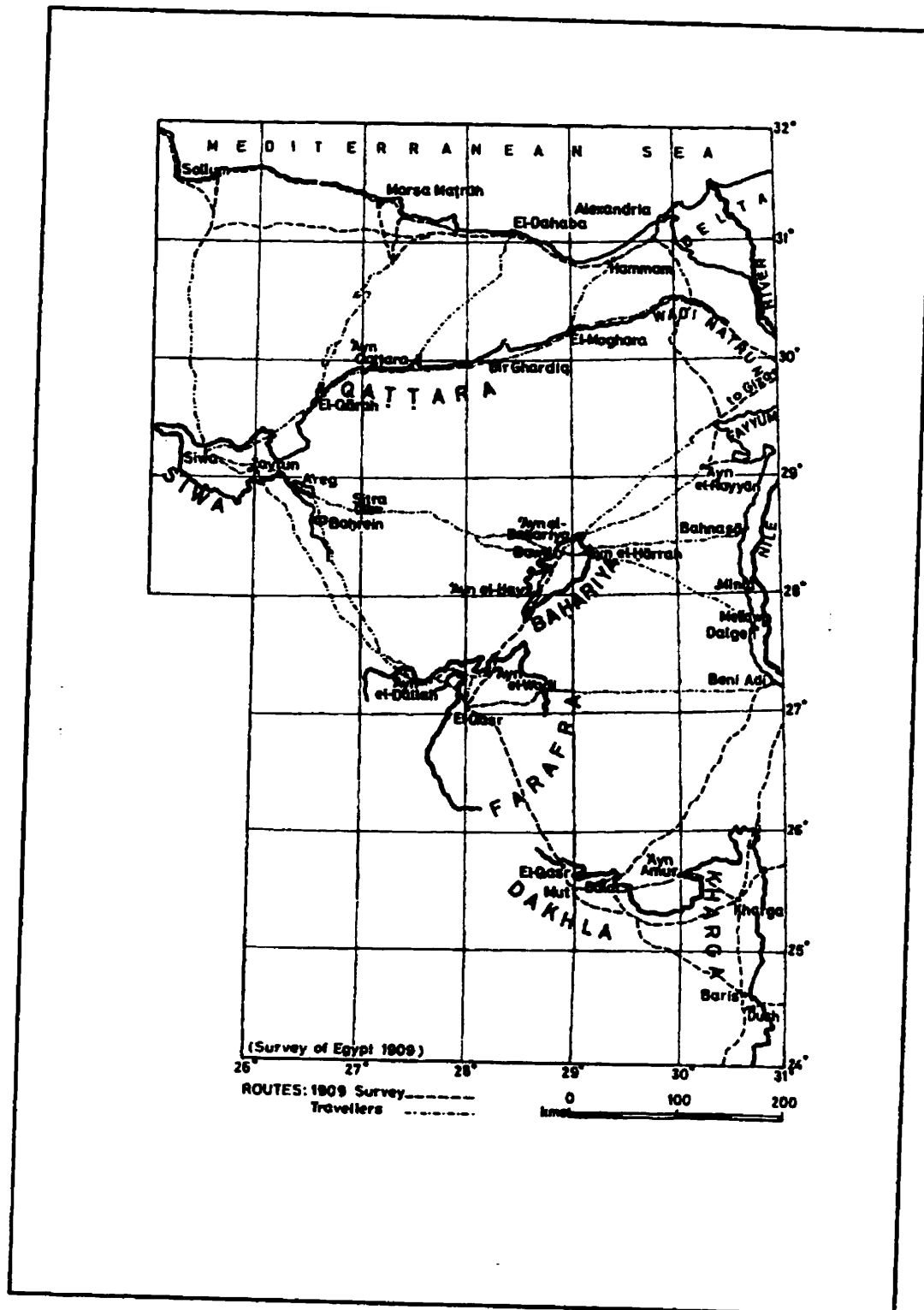
Figure 2.2. Location of the Dakhleh Oasis in relation to the Nile Valley and other Oases. Communication routes are marked. Adapted from Giddy (1987).

on camel. Giddy (1987) reports that Moritz, in 1900, made the crossing in only four days, keeping a grueling pace of 60 km/day and travelling with lightly loaded camels.

The last route that may have been used to access the Nile Valley from the Dakhleh Oasis was via the Farafra Oasis. The distance between Dakhleh and Farafra is approximately 200 km and the caravan route takes approximately 4 days. The terrain between Farafra and the Nile Valley is described as being extremely harsh and inhospitable, hence the routes from Farafra to the Nile Valley passed through neighboring oases (i.e., Dakhleh or Bahariya). The distance between Farafara and Bahariya is approximately 185 km, and would take approximately 4 days by camel. From this Oasis there are several routes to the Nile Valley, the shortest of which is approximately 190 km, or 4 days by camel. Accessing the Nile Valley via Farafara and Bahariya would take approximately 12 days via camel caravan.

2.3.2 Climate and Ecology

The Dakhleh Oasis is noted for seasonal extremes in temperature. Winter temperatures range from 0 to 2°C before sunrise with a midday range from 20 to 25°C (Giddy 1987). Hot summer days range from 40 to 50°C (Blume et al. 1984), and the mean annual daily temperature is 24°C. Precipitation is rare in the Oasis. The mean annual rainfall in Dakhleh is 0.3 mm/year (Blume et al. 1984). The Dakhleh Oasis is thus extremely arid with very low humidity. From March to September the humidity ranges from 23 to 30% with a rise to 33 to 50% from October to February (Doering and Gericke, 1984). The evapotranspiration rate is very high in both oases. Doering and

Gericke (1984) report evaporation rates of 24 mm/day when measured in the bare soil, and rates of 15 mm/day when measured in an area surrounded by irrigated crops. Blume et al. (1984) note that the potential annual evaporation is greater than 2000 mm.

Wind poses one of the most rigorous climatic challenges for humans in the Dakhleh Oasis. Regardless of season there is a constant wind laden with sand that blows from north to south. The wind can reach speeds greater than 20 m/second and can easily do irrevocable damage to crops. During the months of April and May violent winds called the *Khamasins* cause extensive damage to crops, especially those in sensitive conditions such as citrus blooms, ripening tomatoes and other vegetables (Doering and Gericke 1984). The sand accumulates in dunes and covers anything in its path. The inhabitants of the Dakhleh Oasis plant either bushes or tamarisks as protective barriers for crops, or construct walls of mud brick to protect wells, homes and fields (Giddy 1987). These walls must receive constant maintenance as they are always besieged by abrasive wind-blown sand.

Another contributor to aridity is the persistent high atmospheric pressure in the Sahara (Walton 1969). As a result of the influence of the earth's rotation, a high pressure air mass moves with the westerly winds along the parallels of latitude. As the air mass moves higher it becomes cooler as heat is lost through radiation. The cool, dry air then subsides to produce large areas of high atmospheric pressure (Walton 1969). The high atmospheric pressure, in combination with absence of precipitation, high temperatures and high winds, affects the capacity of meteorological conditions to supply

moisture to the Oasis (Heathcote 1983).

2.3.3 Water and Irrigation

The promise of a steady water supply has allowed for the continuous occupation of the oases for over 2000 years (Giddy 1987). The source of this water is the Nubian Sandstone Series. The Nubian Sandstone Series includes a water bearing stratum which underlies the entire Western Desert (Doering and Gericke 1984). The water, however, is only accessible in the floors of wind-eroded depressions in the desert. The areas surrounding the depressions are much too thick for drilling and too high to allow the water to flow naturally to the surface. The sandstone of this series is porous and is effective in carrying water. It is a confined aquifer enclosed with layers of shale which prevent the water from escaping (Price 1985). The hydraulic gradient trends south to north, causing the water to flow from Sudan into Egypt and eventually into the Mediterranean. The thickness of the sandstone aquifer is by no means uniform. At the Kharga Oasis this layer is only 500m thick, while at Dakhleh it is 1,500 m and in Farafra it is 2,500 m thick. The thickest layer, near the Libyan border, is 4000 m thick (Doering and Gericke 1984).

Oasis dwellers have been accessing the waters of the aquifer for at least 2000 years. Inhabitants have gained access to this water by boring deep artesian wells. It is not known when the first well appeared; however, in the fifth century AD, Olympiodorus noted that the inhabitants of the oases had the reputation of being expert well drillers (Wagner 1987). The ancient wells of Dakhleh are known today as the Roman

wells and their depth varies from 150 to 300 meters. The drilling of these wells was a collective effort and their use in ancient times was regimented; hence, the water flow was restricted and irrigation was controlled by the collective group (Wagner 1987).

Although there was a steady supply of water available for irrigation during the Roman period, the irrigation efficiency was probably less than 50% due to the high rates of evaporation (Doering and Gericke 1984). Another potential problem could have been the uncontrolled output of artesian wells, in addition to blockage of irrigation canals by silt or wind blown sand. These two problems would have caused water to collect in shallow ponds and ultimately resulted in a high degree of saturation of salt in the soil which would have eventually rendered the land unusable for agriculture. In order to avoid this problem the Romans constructed large cisterns to cover the wells. These brick structures helped to collect water and the arched masonry roofs functioned as protection against excessive evaporation (Fakhry 1974; Walton 1969). These protective measures helped to assure that there would be enough water for crop irrigation and the maintenance of livestock.

2.4 The Kellis Agricultural Account Book

The study of past food production at the Dakhleh Oasis is made even more significant by the discovery of the Kellis Agricultural Account Book (KAB). As Bagnall notes, "This codex of wooden tablets contains the most extensive and well-preserved set of accounts for an agricultural entity to survive from the fourth century.
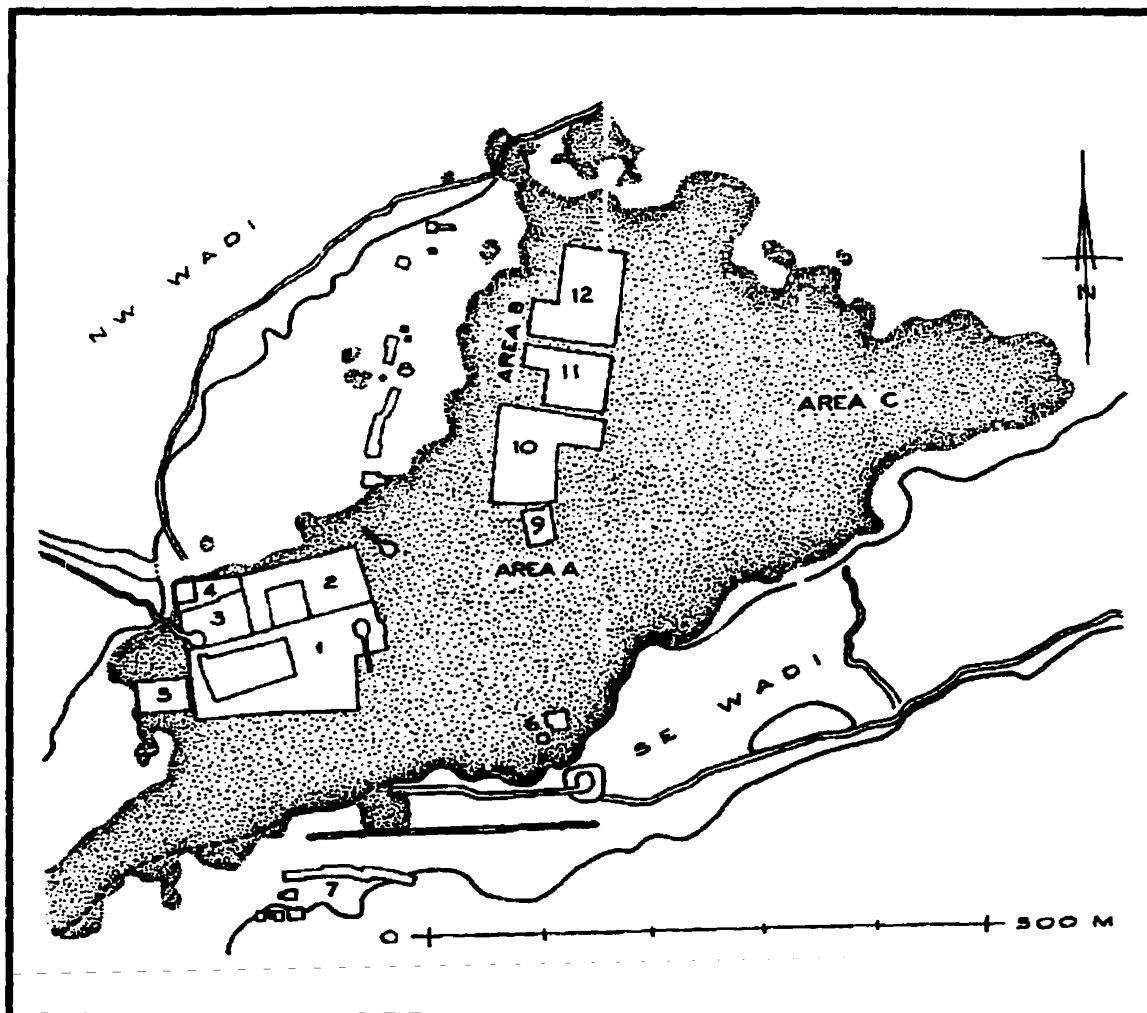
Figure 2.3. Site map of the village of Kellis, adapted from Hope (1987). This map only gives the main areas, and does not show excavations up to date. 1 – Main Temple and Enclosure 1; 2-4 – Enclosures 2-4; 5 – West Temple; 6 – East Churches; 7 – South Tomb group; 8 – North Tomb group; 9 – Area A, Houses 1-2 and Structure 4; 10-12 – Area B, Structures 1-3.

Indeed it is exceptional even for the entirety of the thousand years from which we have

Greek papyrological texts from Egypt" (1997:v). The information in the KAB, in addi-

tion to the archaeological faunal and floral remains, constitutes the bulk of the data used

to create a list of possible food items in the Dakhleh Oasis.

The KAB, dated to approximately AD 350, was excavated from House 2 in

Area A in the ancient village of Kellis (Hope 1987; 1988). See Figure 2.3 for a site map of the village of Kellis. It is composed of 8 wooden leaves, written in ancient Greek (Sharpe 1987). It contains an accounting of all income and expenditures, including agricultural and animal goods, that were coming in and out of an estate in the village of Kellis. It should be emphasized that this document contains the accounts from only one estate, and because of this it should be noted that other estates may have had different foods and that there may have been variability from one estate to another. The majority of the text contains sections which deal with, "income in particular commodities and with expenditures in some – but not all – of the same commodities. In addition, there are accounts for particular storehouses, for the writer's payables and receivables, and a few [accounts] for individual tenants or other specific needs" (Bagnall 1997:25). Information from this text therefore also proved useful in formulating ideas as to the importance or status of certain food items (see Chapter 4).

Chapter 3:
Economic Management, Politics and Foreign Trade in Ancient Egypt: Impact on Food Availability

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"Nothing is so admirable in politics as a short memory"
- John Kenneth Galbraith

3.1 Introduction

Food availability, economics and politics are intimately connected. The title of this chapter suggests that it is only politics and economics that affects food availability and the food choices that are made by individuals. In fact, the title could just as easily be changed to "Food Availability in Ancient Egypt: Its Impact on Politics and Economic Management". Food surplus or food shortages can have a drastic impact on the shaping of a country's political and economic system. On the other hand, a country's political and economic system can create situations that have a direct impact on the types of food that are available for consumption (e.g., trade). It is difficult, however, to comment on the impact that food may have had on politics and economics in ancient

Egypt, as the historical documents rarely make such links. It is possible, however, to reconstruct the history of the changing political and economic systems in ancient Egypt and comment on the situations that were created that would have had a direct impact on the availability of food sources.

One of the foci of this thesis is the comparison of diet between three different cemetery populations from the Dakhleh Oasis, all from different time periods. The earliest cemetery, 'ein Tirghi, dates to circa 800 BC and falls during the Third Intermediate period. The next cemetery, Kellis 1, dates to the Ptolemaic period (circa 250 BC) while the latest cemetery, Kellis 2, dates to the Romano-Christian period (circa AD 250-450) (refer to Chapter 6 for a discussion of the dating of all three cemeteries). One of the most striking differences between each of these time periods is the structure of the political and economic system in Egypt. If there are any detectable differences in diet between the individuals from the three cemeteries, they are most likely linked to changes in the political and economic system in greater Egypt. Because little is known about trade and the Dakhleh Oasis during the Third Intermediate and Ptolemaic periods a brief examination of each time period is warranted to understand the potential influence that the changing political and economic structure may have had on the availability of food in the Dakhleh Oasis.

3.2 The Influence of Ancient Egyptian Politics, Economic Management and Foreign Trade on the Dakhleh Oasis

Sources suggest that the Dakhleh Oasis was relatively isolated until recent times (e.g., Dzierzoykray-Rogalski 1978; 1989). When considering all lines of evidence, however, it is quite evident that populations in the Oasis were in constant contact with the Nile Valley and surrounding areas, particularly during the Roman occupation of Egypt. Prior to the Roman period, contact with the surrounding area may have been restricted because the camel had yet to be introduced into the area (Bulliet 1975).

At present no habitation site is known to be associated with the 'ein Tirghi cemetery at Dakhleh. As a result it is difficult to make any commentary regarding the influence that politics, economics and trade may have had on the individuals who lived in the Dakhleh Oasis circa 800 BC. In addition, sources discussing the politics and economics of Egypt during this time rarely make mention of the Oases beyond the Fayum. Evidence from other Ptolemaic and Roman period sites in the Dakhleh Oasis, however, indicates that trade was a vital part of life in the Oasis (Kaper 1997; Mills 1984;1990). In fact, life in the Oasis would have been nearly impossible without trade and contact with other locations.

The Dakhleh Oasis also produced valuable commodities, especially dates, that were sought after in the Nile Valley, and in the Mediterranean world, and olives during the Roman period (Bagnall 1997; Wagner 1987). It is hard to imagine that the government of Egypt during the Third Intermediate, Ptolemaic and Roman periods

would not have tried to control the flow of these commodities. It has been suggested (A. Mills, pers. comm.) that during the Roman period the government introduced several agricultural policies in order to encourage migrant farmers to settle permanently in the Oases. This was the period of most active construction of temples, villages, wells, and irrigation systems throughout the Dakhleh Oasis. In response, the population of the Oasis increased to its highest level ever, and such high population levels have not been reached since (Shabaan 1988).

To understand how political and economic changes may have affected the Dakhleh Oasis during each of the relevant time periods, it is important to understand how the inhabitants of the Dakhleh Oasis needed trade in order to survive in the specialized environment of the Oasis.

3.2.1 Trade as a Means of Survival in the Oases

In a homogeneous self sufficient environment there is really no reason for inhabitants to become involved in trade beyond the level of the village, nor is there much reason for specialization. However, when two different types of environments are located beside one another, the incentive to become specialized and to trade is increased. According to Curtin one of the most important divisions between ecological zones, "... in any part of the world is the desert edge, the *sahel*, separating land where agriculture can be practiced from the arid steppe and desert where only pastoral nomadism is possible" (1984:16). In Africa, for example, the forest dwellers have different food products compared to people who live in the savanna. This is also true for the

semi-nomadic pastoralists who have a surplus of cattle to trade for wheat, fiber and other agricultural products produced by the sedentary farmers. Curtin comments that, "Oasis dwellers were even more likely to trade because they controlled a small island of ecological specialization in a much larger arid region. It is hardly surprising then that they were active traders from an early date" (1983:372). The individuals who pioneered the trans-Saharan trade are thought to have all been oasis dwellers by origin.

Another important incentive to trade was the fact that many resources were un-evenly distributed throughout Africa. One such resource was salt, which is a nutrient especially necessary for human survival in the aridity of the desert. Although salt was readily available in the coastal areas of Africa, it was also available in large quantities in some of the Saharan oases. Several oases, although not Dakhleh in particular, used salt as an important bargaining tool in trade. One of the most important Saharan oases for salt production was the Bilma Oasis (Jaffre and Derou 1978). Vischer, who was trek-king across the Sahara in 1910, described the process of salt preparation in the Bilma Oasis:

> In places where the salt deposits are the richest, large holes are dug in the ground, four to five feet deep, and of varying diameter. The water then fills the hollow and in doing so dissolves the salt; after a few days a crust of salt crystals covers the surface like a thin sheet of ice; this is broken up and the bits sink to the bottom; a new crust forms and is treated likewise, and thus the water-hole gradually fills up with the crystals, which are taken out and spread in the sun to dry. The salt is pressed into large cones called *Kantu*, each weighing about 40 pounds, or into flat cakes, locally known as *Kunkuru* (tortoise), which are much smaller (263).

This same process is also discussed in detail by Jaffre and Derou (1978).

McDougall (1985) also expressed the importance of the salt trade in the Sudanese oases. In this region the salt trade, not the date trade, was probably the most lucrative and trade and exchange routes from the Sudan were far-reaching. During the 13th to 15th centuries, the route tied into the trans-Saharan route and extended as far as the Atlantic through the Portuguese trade routes, and trade in gold and slaves reached into the Sudan via the Niger River (McDougall 1985). Vikor (1985) also discussed the importance of the salt trade to the inhabitants of the Kewar Oasis, located in present day Niger. The salt was produced in substantial quantities and traded with neighbors in Sudan, Bornu and Zinder in exchange for millet. The millet, along with dates, made up their staple diet. Vikor comments that, "... there is no doubt that it would have been impossible to maintain the population level of Kewar without the millet introduced through the salt trade" (1985:701). This underlines the importance of trade in oasis life.

One of the most significant aspects of the origin of trans-Saharan trade is that the originators came from oases which grew the date palm. In addition to salt, the other special resource that was only readily cultivated in the oases was the date palm. Areas of high humidity and substantial rainfall do not produce good quality dates, and as such the specialized environment of the oasis was the only place that could produce high quality dates. Dates are a great source of several vitamins and sugar, but they do not make an adequate staple diet (Curtin 1983). For this reason alone the date producers in the oases are very much like the cattle nomads or the people who catch fish on the coasts - they all have very valuable commodities but the real value can only be realized

through trade. For those individuals living in the Dakhleh Oasis this meant trade with the Fayum and the Nile Valley, or with the other surrounding oases which may have traded with other areas.

Although the oases had valuable commodities to trade, it was vital for the oasis dwellers to have access to an efficient and cheap mode of transportation for their goods. The areas surrounding the oases were much too dry to attempt raising large herds of cattle or other pasture reliant animals that would be good for transportation. The oasis dwellers solved this problem by relying on the camel which was introduced into the Sahara from Arabia during the first or second century AD (Bulliet 1975). Oasis dwellers were able to use camels as efficient transport animals because of their ability to travel long distances without needing to consume water. The use of camels meant that the Sahara desert was no longer an impassable barrier and it then became uniquely possible for the oasis dwellers to grow dates almost exclusively and trade them with people in the more arable lands for products such as grain and other food supplies (Curtin 1983). In other words, oasis dwellers were able to face the problem of living in a very specialized environment by growing a specialized food crop and realizing its full potential through extensive trade. Curtin (1984) refers to the interaction between the oasis, the date palm and the camel as the date-camel-trade complex.

The geographical position of the Dakhleh Oasis made it accessible from only the Nile Valley or from the Farafra or Kharga oases. If the Oasis dwellers wished to purchase any items from other regions in Africa this could only be accomplished

through relay trade, with the commodity in question moving from one trade network to another. For example, if the inhabitants of the Dakhleh Oasis were in need of salt it would have been transferred from the Bilma Oasis to Fezzan where it then would have made the journey to the Siwa Oasis, then to Farafra and finally on to the Dakhleh Oasis (Refer to Figure 3.1).

The direction of trade remained the same from the time of the Assyrian conquest of Egypt in 671 BC into the Roman period. Merchandise from Sudan and inner Africa was directed to the caravan routes via the Egyptian oases. From there it would continue into the Mediterranean where it was shipped to Greece, Rome and other European destinations (Fakhry 1973). This direction of travel assured that the Oases had access to several goods from other regions of Africa. It must be noted, however, that the volume of trade was probably quite minimal before the introduction of the camel which facilitated caravan trade.

The routes between the Dakhleh Oasis and the Nile Valley and those between the other oases have changed over the centuries in accordance with ecological conditions. The use of a certain route depended on the location and existence of water holes, pastures and passages through hills (Thomas 1957). It is most likely, however, that the established routes from the Dakhleh Oasis have remained relatively stable for centuries. Two routes were used by the Dakhleh inhabitants to reach the Nile Valley. One of the routes was direct, while the other passed through the Kharga Oasis and then on to the Nile Valley. The Dakhleh Oasis was also linked to the Farafra Oasis by means of an ancient

Figure 3.1. The location of the Dakhleh Oasis in relation to other Oases and trade locations.

caravan route still in use today (Giddy 1987). Unfortunately, not all of the routes used during the Third Intermediate, Ptolemaic and Roman periods are known today, and we can only suggest what routes may have been used in earlier times. Even with little knowledge of exactly which routes were used for trade, it is evident that trade was successful as habitation in the Oasis continued for hundreds of years.

3.3 The Third Intermediate Period (1069-702 BC)

The beginning of the Third Intermediate period marked the end of the Ramesside period in Egypt and the start of a poorly documented and confused era in Egyptian history. The majority of studies written about the Third Intermediate deal specifically with the leadership of Egypt during this time period (i.e., Grimal 1992; Kitchen 1986). In addition, when describing the political, economic or social conditions in 'ancient' Egypt, most authors tend to discuss the entire Pharaonic period as though there were no significant changes during approximately 2500 years of history. Bagnall (1993) notes that this is a characteristic of Egyptian history, as there is a definite historical continuity in aspects of both social and economic facets in Egyptian life. What was true during the Pharaonic period may have continued during the Roman period. As a result, the writers of most of the sources cited for this section have lumped together several thousands of years of social and economic history. What is known for certain about the Third Intermediate period in Egypt is that the population was essentially local. There were very few foreigners who came to settle in Egypt during this time.

3.3.1 Political Structure in Egypt with Respect to Economic Management during the Third Intermediate Period

At the beginning of the Third Intermediate Period Egypt was a sovereign state. The King was the absolute ruler and he had many titles, including religious, political, military and economic ones. To aid in the smooth running of the country the King also appointed individuals (usually his sons or relatives) to look after important social and religious posts (Kemp 1989).

It was also necessary for the King to appoint an individual to the position of vizier. This individual was extremely important in the economic administration of the royal state (separated from the religious state). Among other things, his duties included the general management of the economic affairs of Egypt as a whole, and of each of the regions of Egypt. He was also responsible for the allotment of land, irrigation and canals, agriculture, the cutting down of trees, and taxes (Petrie 1924). The King therefore controlled the economic structure of Egypt, and, consequently, food production.

3.3.2 Economics, Foreign Trade and Food during the Third Intermediate Period

During the Third Intermediate Period in Egypt there was a distinct change in the economy, and particularly foreign trade. At the beginning of this period, foreign trade was limited and considered to have been completely under the King's control. Towards the end of the Third Intermediate period, foreign trade was still limited, but had begun to open up slightly. Sir Flinders Petrie (1924) notes that foreign trade was con-

ducted with four regions – Nubia, Punt[1] and the Red Sea, Syria, and the West. Trade

with the West was not opened up until after the XXVIth dynasty (ca. 672-525 BC).

The main products imported from Nubia were gold, slaves, frankincense,

gums, oxen, wheat, ivory, ebony and panther skins. Although it is not clear what prod-

ucts were imported from Punt, they purportedly arrived in Egypt via the Red Sea.

Foreign trade with Syria was important. There is evidence to suggest that

trade in glassware had commenced before the Pharaonic period and that Syrian orna-

ments, musical instruments, some food items (not specified), wine and beer were just

some of the products that were imported into Egypt. Pine and cedar were imported to

build furniture, and Syrian linens were used as Egyptian sails. Food does not appear to

have constituted a large part of foreign trade during this time period, possibly because

Egypt was agriculturally self-sufficient.

3.4 The Ptolemaic Period (332-30 BC)

With the exception of very brief periods of independence, Egypt had been

dominated by foreign powers for approximately 600 years before Alexander the Great

invaded in 332 BC (Ellis 1994). The Libyans, Ethiopians and Assyrians had ruled the

country in turn. The Persians took control of Egypt in 525 BC, but relinquished this

control by 410 BC. The Persians made several attempts to regain control of Egypt, but

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[1] The present day location of Punt is a hotly debated topic. Some authors theorize that Punt was located in the Eastern Delta of Egypt, while others postulate that it was located to the south of Egypt around Nubia. See Nibbi (1981) for a description of all the evidence concerning the geographical location of Punt, and the current debate surrounding this issue.

were unable to do so until 343 BC. In the years preceding the arrival of Alexander, internal struggle against Persian rule had weakened the country. In 332 BC, when Alexander arrived in Egypt, there was no resistance, and in fact the Egyptians hailed him as their liberator (Bevan 1968).

During the Ptolemaic dynasty Egypt underwent social, political and economic change. Instead of the rather homogeneous native population structure that had existed during the Third Intermediate period, a two-tiered population structure arose (Bevan 1968). The upper stratum of the population consisted of the ruling class made up mostly of Greeks and Macedonians, while the lower class was composed of native Egyptians. Thus, the political system changed to reflect the ideology of the Macedonians, who had in turn adopted their political ideology from the Greeks.

Ptolemy I, a Macedonian, realized that even with all the riches that Egypt could bring him, Egypt did not have sufficient man-power to form an effective army. To solve this problem he recruited thousands of Macedonian and Greek farmers, to be spread out all over Egypt. During times of peace these men and their families could grow wheat and raise cattle on their plots of land along the Nile, but could also be called upon either to form an offensive or defensive army. This concept of a military force composed of 'colonists' was a characteristic feature of the Ptolemaic period (Bevan 1968).

3.4.1 Political Structure in Ptolemaic Egypt with Regard to Economic Management

The era of the Ptolemies is considered to be the last period in Egypt's history in which it could be considered a sovereign state. The general system of government during the Ptolemaic period was firmly in place by the death of Ptolemy II in 247 BC (Bevan 1968). When Alexander the Great arrived in Egypt there was little left of the governing system that was dominant during the reign of the Pharaohs. Years of foreign rule by the Persians, and the chaotic internal strife that plagued Egypt during the intervening years, had left Egypt's governing system in tatters. Agriculture had suffered because of years of neglect of the banks and canals along the Nile. Its commerce was almost completely in the hands of foreigners, particularly the Greeks and the Phoenicians. Egypt's industry was in the hands of the temples and priests, and thus religion and the clergy played a dominant role in Egypt's political, social and economic structure.

The Ptolemies looked to the Greeks to design a governing system that would return Egypt to the status of a profitable nation. The system they designed was so successful that it lasted into the Roman period, and certain remnants even survived into the Mohammedan era. The Ptolemaic king was ultimate leader of Egypt. The analogy put forth by Bevan (1968:133) describes the governing system in Egypt under the Ptolemies:

> The Ptolemaic king has to be thought of as a landowner and farmer
> on a huge scale, one whose estate was the whole land of Egypt. All
> of the officials were his personal servants, the army an instrument of
> his will, raised from the men who held plots of land assigned to them
> out of his territory on the condition of rendering him military service,

or recruited as mercenaries, from Greece or the Balkans or Asia, and attached to him personally as their employer.

Since one of the most important mandates of the Ptolemaic dynasty was to create a profitable nation, economics was of utmost importance. The individual who was responsible for the management of the economic affairs of the kingdom was called the *dioketes*. Also associated with the post of *dioketes* was the *eklogistes* (a direct subordinate to the *dioketes*), whose responsibility was the management of accounts for the kingdom. The *dioketes* and *eklogistes* also held the responsibility of governing all of the individuals who were responsible for the economic affairs of each territory in Egypt.

3.4.2 Economic Management, Foreign Trade and Food in Ptolemaic Egypt

It was during the Ptolemaic period that trade between Egypt and other nations began to open up. During the Third Intermediate period there had been very little sea-borne commerce between Egypt and the rest of the Mediterranean, and little trade with surrounding neighbors. The geographer Strabo comments that during the Pharaonic period, the kings of Egypt were content with the goods and food produced in Egypt, and they were opposed to foreigners and imported goods (Bevan 1968).

One of the primary concerns of the Ptolemaic government was to improve its internal resources and encourage foreign trade (Charlesworth 1926). At this time Egypt gained access to the foreign trade routes that had been established by Alexander during his conquests. Several small port cities sprang up on the Mediterranean coast of

Egypt, in particular Alexandria, which facilitated sea-borne trade. In addition, the introduction and establishment of a monetary system took place early in the Ptolemaic period (Bowman 1986). This allowed for a greater increase in foreign trade in the Mediterranean and in the East.

The economy of Egypt flourished. This was accomplished by a steady stream of commodities and food items imported from and exported to the Mediterranean, the South and the East. The chief exports of Egypt to these areas included wheat, paper, glass and linen. The main goods imported to Egypt from the Mediterranean consisted of timber, copper, purple dye, marble and wine. From the South, Egypt received elephants for the military, and ivory. Expensive spices and gums were brought in from the East (Charlesworth 1926).

Egypt was also an important stopover for goods that were coming from India and South Arabia, en route to the Mediterranean. The main goods that came from India and South Arabia consisted mainly of spices and aromatics, and once they reached Egypt they were transformed into perfumes and unguents before continuing their journey to the Mediterranean. In exchange for these goods, Egypt exported textiles, oils, metal goods such as armory, glass and Mediterranean wine to South Arabia.

Imported food items are discussed in one of the papyri, dated to 259 BC, from the archive of Zeno. The documented food items include grape syrup, Greek wines from Chios and Thasos, fresh figs, honey from Attica, Rhodes, and Lycia, nuts, wild boar, venison, and goat (Bowman 1986). The importation of these items indicates

that they were most likely either not present or unavailable in sufficient quantities in Egypt to meet demand. Significantly, staple foods, such as grain, were not being imported. The majority of imported food items can be considered 'luxury' items most likely brought in to satisfy the tastes of the Greeks and Macedonians.

3.5 The Roman Period (27 BC – AD 395)

The Ptolemaic dynasty ended in 30 BC when Octavian invaded Egypt which became a Roman province in 27 BC under the Emperor Augustus. The province of Egypt was considered to be the prize possession of the Roman Empire and, as such, it was governed differently than other Roman provinces. In fact, the internal politics of Egypt operated much as they had under the Ptolemies. Even the building of temples, dedicated to local gods not worshiped by the Romans, continued. The names of Roman emperors are found in hieroglyphics on these temples. Evidence of this continuing trend is noted in the Dakhleh Oasis (Kaper 1997).

3.5.1 Political Structure in Egypt during the Roman Period

Augustus recognized the special value of Egypt and as such he designated a ruling administration that had to answer directly to him. The other provinces in the empire were governed by Roman officials who had risen to the rank of proconsul. Egypt, on the other hand, was governed by a prefect (*praefectus Aegypti*) who only held the rank of an equestrian (had to possess a minimum of 400,000 sestertii) (Bowman 1986). He lived and worked in Alexandria, but each year he would travel for four to five

months to different towns to hear grievances and scrutinize the accounts and perform-ances of the local administrators.

As the overall responsibilities of governing Egypt were vast, there were sev-eral individual positions under the prefect which helped to divide the work load. These individuals were also of equestrian rank and were appointed by the emperor. These ad-ministrators included the *Iuridicus* (shared the burden of civil jurisdiction), the Chief Priest, the *Dioketes* (finance minister), the *Idios Logos* (administration of the special ac-count; patrimonial procurator), the procurators (administration of imperial property and revenues), and the military commanders (*dux*, or head of the provincial garrisons) (Lewis and Reinhold 1990; Wells 1992). These positions were not mutually exclusive, and each would depend on the other to run the daily administration of the province.

Also answering directly to the prefect were the *epistrategoi*. The province of Egypt was divided into four administrative regions known as the Thebaid, the Hepta-nomia, and the East and West Delta (Bagnall 1993). Dakhleh Oasis was considered to be part of the Thebaid region. Each region was governed by an *epistrategos*, who was also an official of equestrian rank and was appointed by the emperor. Each of the four regions were divided further into smaller geographical units called nomes. In all there were 30 or so nomes in Egypt (the number of nomes fluctuated through time), and each nome was governed by a *strategos* (Bagnall 1993). Refer to Appendix B for a list of nomes and their geographical area. The *strategoi* were usually officials of Greco-Egyptian heritage and were appointed by the provincial administration. They reported

directly to the *epistrategos* of the region in which the nome was situated. The *strategos* was responsible for the administration of the nome, and this included controlling the administration of villages. Each village had a town council (*boule*) and also the liturgists who ran the daily business of the village and answered to the *strategos*. Those individuals serving at the level of the village were elected or co-opted, while those serving as liturgists were appointed to compulsory public services (Bagnall 1993). Liability for the position of liturgist was based on property or income – individuals of little means were not required to serve compulsory public positions.

The military was commanded by the *dux* who reported indirectly to the emperor by means of the prefect. As the individuals appointed by the emperor to govern Egypt would not have had much contact with the commoners, it becomes apparent that the military would have been the most visible symbol of Roman rule in the eyes of the civilians. The number of soldiers, as well as the structure and location of the garrison in Egypt, would have been directly controlled by the emperor. It is these factors that would have had an effect on the lives of the civilians.

3.5.2 Economic Management, Foreign Trade and Food in Roman Egypt

During the Roman period, foreign trade was a very important part of the economic structure of Egypt. The geographical extent and quantity of products that were exported from and imported into Egypt far surpassed that experienced during the Third Intermediate and Ptolemaic periods. One of the primary reasons that foreign

trade flourished during the Roman period is that two very important resources were exploited to the fullest. Of utmost importance for foreign trade were the Nile River and the port city of Alexandria. Goods were shipped from sub-Saharan Africa on the Nile, and its connection via road and artificial channel to the Red Sea brought in goods from Arabia and India (Heaton 1928). Its tributaries to Alexandria connected it to the rest of the Mediterranean and Roman Empire.

Alexandria was considered to be the most important commercial city in Egypt. It was home to two large coastal harbours which welcomed ships from all over the Mediterranean. A third harbour was located inland and received goods from the South, India and Arabia. Raw materials from the South, Arabia and India were transformed into products for export to the rest of the Mediterranean world, such as linen, rough cloth, bricks, papyrus, glass ware, perfumes, cosmetics, and beer (Charlesworth 1926). The city also boasted a very diverse population during the Roman period. Native Egyptians lived side-by-side with Greeks, Syrians, Arabs, Italian merchants, Romans, Indians and Jews. This eclectic melange of nationalities allowed for the development of a very strong economy in Alexandria.

Because Egypt was a possession of the Roman Empire, most of its agricultural products were exported directly to Rome. Egypt produced a large surplus of wheat and provided approximately 1/3 of the annual grain supply to the city of Rome (Bagnall 1993). Other major agricultural exports included barley, dates, and olive oil. Non-agricultural exports included minerals, porphyry marble, textiles, glassware and papyrus

(Bagnall 1993; Bowman 1986).

Bowman (1986) notes that Egypt was able to maintain a healthy economy during this period because exports always exceeded imports. Part of the reason for this is that the rulers of Egypt restricted the types of items that could be imported into Egypt to ensure secure revenue. For example, the growing of papyrus was strictly regulated so that prices could be maintained at high levels.

Some of the taxed imported goods included olives, dates, cucumbers, marrows, vegetables, spices, beans and green fodder (Bowman 1986). There is also evidence to suggest that Rhodian wine was still imported during the Roman period. Non-agricultural goods included silks and cottons from India, ivory from sub-saharan Africa and gums and spices from Arabia (including cinnamon, myrrh, pepper and ginger) (Charlesworth 1926). Gold and iron were imported from Meroe (present day Ethiopia), while copper and iron were brought in from Syene (present day Aswan). Amber and tin were brought in from the North-west. Asian, Greek and Italian wines were also imported. Drugs, Indian incense, precious stones, ivory and tortoise-shell, Indian steel, cotton and rough cloth flowed in from the East (Casson 1984; Charlesworth 1926).

3.6 Summary

In the brief examination of the influence of politics and economics on food availability in greater Egypt during the Third Intermediate, Ptolemaic and Roman periods, one thing becomes increasingly clear. This is the fact that foreign trade increases

from one period to the next, as a result of changing political and economic policies. During the Third Intermediate period, Egypt is still relying heavily on internal resources and very little on foreign goods. The King had complete control over items that came into or left the country. The political and economic systems of Egypt went through up-heaval and chaos during the intervening years between the Third Intermediate period and the Ptolemaic dynasty. When Alexander the Great took over Egypt, he introduced a new governing system based on Greek ideology. This change in political and economic structure opened up foreign trade to a greater extent than ever before; however, the King still exercised great control over the products that were imported. Foreign trade in-creased even more during the Roman period. Not only was there an increase in the number of products that were traded, but the geographical extent within which trade took place also increased. The port city of Alexandria and the Nile River were used to their fullest to promote foreign trade. The number of countries that Egypt traded with, or was able to receive goods from via relay-trade, increased dramatically.

Successful and sustained existence in the Dakhleh Oasis meant that trade had to be a priority. Because the Dakhleh Oasis was part of Egypt, we may assume that the Oasis was not isolated from greater Egypt and the political and economic structure that was in place during each of the discussed time periods. It is hard to speculate, how-ever, on the extent to which these policies had a direct effect on the lives of the inhabi-tants. What can be said though is that as foreign trade opened up in greater Egypt, and as camels were added to the caravan, the inhabitants of the Dakhleh Oasis would have

had greater access to different food items and non-agricultural products. In this way, the changing political and economic circumstances of greater Egypt had an indirect effect on the lives of the inhabitants.

The next chapter examines the evidence for sources and types of food in Egypt during these time periods, and sheds more light on the impact that trade had on the lives of the inhabitants of the Dakhleh Oasis.

Chapter 4

The 'Menu': Evidence of Food Items in Ancient Egypt

"Man is the only animal that can remain on friendly terms
with the victims he intends to eat until he eats them"
                                                    - Samuel Butler

4.1 Introduction

One of the limitations of stable isotope analysis is its inability to identify individual food items in the diet (see Chapter 5). Stable isotope analysis can only be used to distinguish certain food groups and create a consumption profile (Keegan 1989). A complete dietary analysis requires information from other sources to provide context for the isotopic results. Thus, it becomes important to examine archaeological, iconographic, and documentary evidence to create a list of individual food items that would have been available to the inhabitants of Egypt, and more specifically, the Dakhleh Oasis. The purpose of this chapter is to create a 'menu' of food items that would have been available to the inhabitants of the Dakhleh Oasis.

Food was not only considered to be an important source of nutrients in ancient[1] Egypt, but it was very intimately associated with the 'bodily' elements of water, air, earth and fire. In effect, eating was a means by which to replenish the body with the forces or essences of which it had run out (Darby et al. 1977). Food made an impact on art, religion and Egyptian culture, and as a result there exists a rich archaeological record of food in Egypt. Archaeological evidence for food in ancient Egypt comes in many forms. Food items and the human manipulation of food are depicted in iconographic forms on tomb and temple walls. Various food items are also documented in tomb and temple inscriptions, and also on papyrus and ostraca[2]. Lastly, due to the superb level of preservation in Egypt, various food items have been preserved from as early as the Predynastic epipalaeolithic period.

This chapter presents and evaluates the archaeological and documentary evidence pertaining to food in the Dakhleh Oasis. It is limited in time and space. The majority of the evidence comes from the village of Kellis and is limited to the 2nd to 4th centuries AD. Because of this, it is necessary to examine evidence of food in greater Egypt to formulate a list of all possible food items that may have been eaten by the individuals interred at 'ein Tirghi (ca. 800 BC and later). The presence of food items found at Kellis and those listed in various papyri and the KAB may have been influenced by the political and economic changes that occurred in Egypt during the Ptolemaic and Ro-

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[1] Throughout this dissertation the term 'ancient' will be used to describe Egypt from the Pharaonic period until the end of the Romano-Christian period.

[2] Ostraca (s. ostracon) are broken pieces of pottery with inscriptions written on them. Ostraca were easy to obtain and a cheap alternative to papyrus for writing (Bagnall 1995).

man periods and therefore may not accurately reflect the diet of those buried in 'ein Tirghi. It is possible to reconstruct a 'menu' by examining the evidence for foods that were available in Egypt during this time period, and excluding those that were introduced during the Ptolemaic and Roman periods. Information pertaining to the faunal remains from the Dakhleh Oasis was provided by Rufus Churcher (University of Toronto). Information regarding the botanical remains from Kellis is based on analysis by Ursula Thanheiser (Vienna University) of circa 70,000 plant remains from various locations in Kellis, including habitation areas, the temple, churches, and cemeteries. Before examining the foods that may have made up the menu that adults and possibly juveniles had to choose from, infant feeding practices will be considered. This is important for understanding the stable isotope data for infants and young children. In the context of this research the individuals discussed in 'infant feeding practices' section include children from the start of breast feeding (birth) to the cessation of the weaning process (approximately 3 years of age). The use of 'infant' in this manner does not take into consideration the demographic definition of infant (children under 1 year of age), but includes all children that potentially could have experienced the breast feeding and weaning process.

4.2 Infant Diet in Ancient Egypt

4.2.1 Infant Feeding Practices in the Dakhleh Oasis

At present there have been no documents or pictorial evidence recovered from the Dakhleh Oasis which shed light on the question of infant feeding during the

three time periods being studied. In Chapter 3 it was suggested that the reigning political and economic ideology would have had a direct impact on the inhabitants of the Dakhleh Oasis. It is also possible that the beliefs and customs concerning infant feeding and weaning would have been adopted by the inhabitants of the Oasis, particularly during the Roman period. With foreign trade opening up, the addition of the camel to the trade caravan, and the presence of the Roman army in the Oasis, the inhabitants would have been exposed to these customs and beliefs.

Stable isotope analysis (Chapter 7 and 8) is used to create a consumption profile for the infants from the cemeteries in question. A sample of 51 infants and children from the Kellis 2 cemetery (Roman period) allows for the testing of the ideologies set forth during the Roman period, particularly those propounded by the physicians Soranus and Galen. Because there is no information from the Dakhleh Oasis pertaining to infant feeding practices, evidence from greater Egypt and the Mediterranean world will be considered from each time period to establish an idea of what may have been occurring in the Dakhleh Oasis.

4.2.2 Pharaonic Egypt

During the Pharaonic period in Egypt, documentary sources indicate that infants were breastfed for up to three years (Donadoni 1997; Fildes 1986; Robins 1993). The majority of women most likely breastfed their own infants, but there is evidence to support the use of wet nurses by the royalty and nobility of Egypt (Fildes 1988), and in some cases by the lower classes (Robins 1993). It is not known if wet nurses were em-

ployed when the mother's own milk supply had dried up, or if they were employed when the mother had died. There is also evidence to suggest that the use of wet nurses may have been a status symbol (Fildes 1986).

The weaning process was gradual in this society, and other foods were introduced into the diet when the child was several months old (an exact age can not be clarified from the documentary evidence). The primary foods given to infants at an early stage were eggs (not specified as to bird) and animal milk, particularly that of camels, goats, sheep and cows (Fildes 1986). If a mother could not feed her own infant, and a wet nurse was not used, infants were fed milk from either sheep, goats or cows. Iconographic evidence depicts children and infants suckling directly from cows, however these images are considered to be purely symbolic, representing a god (i.e., a cow) nourishing other gods or royalty. Although these are considered to be symbolic images, it must also be considered that humans would try to emulate the gods. The Egyptians may therefore have considered cow's milk to be very important in feeding infants and children. Another possibility is that in these images gods were portrayed as doing what humans did. Vessels showing women holding breastfeeding infants or holding horns were thought to be used as feeding vessels for infants. It has been suggested that these vessels were used for holding and administrating animal milk to infants (Fildes 1986).

4.2.3 Greco-Roman Egypt

After the Pharaonic period, Egyptians were exposed to the ideology of the Greeks during the Ptolemaic period, and then to that of the Romans after 30 BC. This

included attitudes and ideas about pregnancy, childbirth and infant feeding practices. Because of this it is necessary to look beyond Egypt and examine both Greek and Roman ideology concerning infant feeding.

The exact length of time that infants were breastfed during the Ptolemaic period is uncertain. Wet nurses were still used, and one nursing contract from Egypt mentions breastfeeding for 6 months and then giving cow's milk for the following 18 months (Fildes 1986). Large numbers of feeding vessels have been found in the graves of infants all over Greece and Italy. This may indicate that infants were weaned relatively early (Fildes 1986). There are virtually no references to supplementary foods given to infants during the Ptolemaic period. Fildes (1986) suggests that infants were probably given milk and cereal dishes. After the cessation of breastfeeding infants are believed to have been fed on milk and honey until they were old enough to eat other foods.

During the Roman period there are two important documentary sources which shed light on Roman ideology concerning infant feeding practices. The first source is the *Gynecology* (ca. AD 98-117) written by the Greek physician Soranus of Ephesus. The other important source is Galen (AD 130-200), a Roman physician, who wrote extensively about infant and child care in his *De sanitate tuenda* (*'Hygiene'*).

Soranus recommended that the first food to be given to infants should consist of either boiled honey or honey and goat's milk. After 20 days the infant should begin to be fed breast milk by either the mother or a wet nurse; Soranus then advises

mothers to feed their infants exclusively on breast milk for 6 months. There is some indication, however, that this was not the general practice. Soranus himself writes that "Those women are too hasty who, after only 40 days, try to give cereal food (as do those for the most part who find nursing a burden)" (cf Fildes 1986:34). Both Soranus and Galen recommend the introduction of other foods at around 6 months of age, or when the first teeth appeared. It was thought that the infant should be weaned completely by the age of 3 years, or when the infant had enough teeth to readily chew more solid foods. The weaning process was described by both Galen and Soranus as a gradual process, with other foods being increased gradually and breast milk being decreased slowly at the same time. Both Galen and Soranus recommend bread as being the first solid food, but each recommends different preparation. Soranus advises that the bread be crumbled up and softened with milk, hydromel (a mixture of honey and water), sweet wine or honey wine. A mixture of eggs and porridge was recommended for slightly older infants (Fildes 1986). Galen, on the other hand, disproved of giving infants wine, and suggests that infants should first be given bread, then later pre-masticated vegetables, meat and other foods.

4.2.4 Summary

This section has outlined the scant information that is available concerning infant feeding practices in ancient Egypt. The shift in politics and economics from the Pharaonic period to the Roman period most likely influenced the general beliefs and practices concerning infant feeding in the Dakhleh Oasis. In all cases, it appears as

though the weaning process was gradual, with infants being breastfed up until they were 3 years of age. Documentary evidence from the Roman period indicates that supplementary foods were introduced into the diet at around 6 months of age. Animal milk, primarily cow's milk during the Pharaonic period, and goat milk during the Ptolemaic and Roman period, were a very important supplementary food.

The diet of infants is a very important consideration. How and what infants are fed can have a large impact on their survival, and as such, may dramatically influence the size of the population. The remainder of this chapter discusses the possible diet of juveniles and adults.

4.3 Sources of Protein in the Diet: Livestock, Wild Animals, Birds, and Fish

A list of the possible sources of protein in the diet of the ancient Egyptians is presented in Table 4.1. All but sheep were present in Kellis by virtue of documentary evidence or faunal remains and are discussed in detail in the following sections.

4.3.1 Bovines

During the Roman period, several sources list cattle among the primary sources of protein for Roman soldiers in Egypt (Bowman 1986; Davies 1989; Lewis 1983). In addition, cow's milk and cheese may have provided further protein in the diet. Many Roman military bases have revealed the remains of cheese-squeezers, indicating that soldiers were making their own cheese (Davies 1989). Evidence from the Dakhleh Oa-

Table 4.1. Protein sources consumed in ancient Egypt. Animals highlighted in bold represent those that were consumed in Kellis. Adapted from Darby et al. (1977); Churcher (1993; in prep), Ikram (1995) and Bagnall (1997).

Animal	Earliest Appearance	Type of Evidence	Present in Kellis	Type of Evidence
Cow	Predynastic	Iconographic/archaeological	Yes	Literary/faunal
Pig	Predynastic	Archaeological	Yes	Literary/faunal
Sheep	Middle Kingdom	Iconographic/archaeological	No	
Goats	Unknown	Iconographic/archaeological	Yes	Faunal
Camel	Old Kingdom	Iconographic	Yes	Literary/faunal
Donkey	Old Kingdom	Literary/Archaeological	Yes	Literary/faunal
Gazelle	Predynastic	Archaeological	Yes	Faunal
Hartebeest	Predynastic	Archaeological	Yes	Faunal
Hare	Old Kingdom	Iconographic	Yes	Faunal
Chicken	Hellenistic	Archaeological	Yes	Literary/faunal
Pigeon	Predynastic	Archaeological/Iconographic	Yes	Faunal
Duck	Predynastic	Archaeological/Iconographic	Yes	Faunal
Geese	Predynastic	Archaeological/Iconographic	Yes	Faunal
Ostrich	Predynastic	Iconographic/Archaeological	Yes	Iconographic/faunal
Fish	Predynastic	Iconographic/Archaeological	Yes	Literary/faunal

sis also indicates that cattle were present during the Romano-Christian period. Specifically, the papyrus P.Kellis inv. P.17.S+AA+BB, discusses the sale of a half part of a heifer (Worp 1995). It should be noted, however, that this papyrus identifies the seller and buyer as living in areas other than Kellis at the time the papyrus was written. Another papyrus (P.Kellis inv. P.97), an official document dated to the 4th century AD, mentions the production/presentation of cows (Worp 1995). The existence of skeletal evidence and this type of documentary evidence is indicative that cows were present in

the Dakhleh Oasis, and more specifically at Kellis.

This idea is corroborated by entries made in the Kellis Agricultural Account Book. Although cows are not specifically documented there are five entries that mention the purchase of 'meat'. In addition, cheese, and possibly butter, is documented in the text. Unfortunately, it is not known whether these two products were made from cow or goat milk (Bagnall 1997). Lewis (1983) comments that the Greeks considered cow's milk to be inferior to that of goat for making cheese. The Romans, however, considered cheese made from cow's milk to be more nutritious, so the cheese represented in the KAB may well have been made from cow's milk.

Several lines of evidence substantiate the presence of cows in the Dakhleh Oasis. Bones and preserved fecal matter from several cows have been identified from and around several of the houses in Kellis (Churcher 1993). Cattle are well represented in the faunal assemblage from Kellis because their bones are robust and preserve well. Churcher (1993) comments that because of the cow's large size, the remains of one cow can provide many fragments, therefore skewing the faunal results and over-representing the true number of cows. That cows were in the Oasis is not disputed, however, they were probably not numerous and would not have been the primary source of protein for the inhabitants of Kellis. This differs from the faunal assemblages of the Nile Valley, where cattle are considered to be one of the most important animals.

Although some bovid species have been identified as having inhabited Egypt before the arrival of humans, it was not until the unification of Egypt (ca. 3200 BC) that

cow and bull worship spread throughout Egypt. It was at this time that a 'cattle indus-

try' developed in central and southern Egypt (Darby et al. 1977). Iconographic evidence

throughout Egypt depicts both bulls and cows being bred, calving, as beasts of burden in

agriculture, being milked, fed, fattened, butchered, branded, sacrificed, and eaten. The

Middle Kingdom tomb of the noble Meketre[3] contained three models that depict the

care and handling of cattle. Gilbert comments that these three models appear to "form a

continuous narrative describing the process whereby animals are chosen for slaughter,

fattened, and finally killed and butchered" (1988:71). The animals in the scene appear

to represent common domestic cattle, and have been identified as *Bos taurus*.

Several authors comment that cows were most likely consumed in larger quanti-

ties by the more affluent part of Egyptian society (i.e., large land holders, priests and

royalty) and rarely by the lower classes. This restriction was probably a function of eco-

nomics more than anything else (Darby et al. 1977; Ikram 1995). Cows were expensive

to purchase and were considered to be very valuable both as beasts of burden and for

their ability to supply milk; hence, the butchering of a cow by a lower class citizen was

most likely restricted to the occasional special feast. Towards the end of the Ptolemaic

period and the beginning of the Roman period, however, certain parts of the cow such

as tripe, stomach, tongue, kidneys and ears were sold at meat shops and may have been

more widely available to a greater range of the population than previously (Ikram 1995).

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[3] Meketre was an important figure during the reign of Pharaoh Nebhepetre Mentuhotep II (2040-2009 BC), and is thought to have died and been interred during the reign of the next Pharoah, S'ankhkara Mentuhotep III (circa 2000 BC) (Gilbert 1988). His tomb is located in the Valley of the Nobles in present day Luxor.

In rebuttal to the idea that cows were consumed by the elite of the Egyptian society, two classical sources note that beef was avoided or considered to be taboo in Egypt. Herodotus[4] comments on the inhabitants of Libya,

> The coast of Libya, then, between Egypt and Lake Tritonis is occupied by nomads living on meat and milk - though they do not breed pigs, and abstain from cow's meat for the same reason as the Egyptians. Even at Cyrene women think it is wrong to eat heifers' meat, out of respect for the Egyptian Isis, whose honour they celebrate both fasts and festivals. At Barca the women avoid eating pig's flesh as well as cows' (IV, 186).

Later, in the 3rd century AD, Porphyry[5] notes in On Abstinence from Animal Food, "... with the Egyptians, therefore, and Phoenicians, anyone would sooner taste human flesh than the flesh of a cow..." (2, 1). Early 19th and 20th century writers of Egyptian history have propagated these ideas in their writings -

> Beef and goose constituted the principal part of the animal food throughout Egypt; and by a prudent foresight, in a country possessing neither extensive pasture lands, nor great abundance of cattle, the cow was held sacred, and consequently forbidden to be eaten (Wilkinson 1854:166).

Darby et al. (1977) comment, however, that early writers simply repeated arguments that were previously stated in antiquity. In the third century BC, Philochorus of Athens wrote, "...at one time, also when there was a dearth of cows, a law was passed, on account of the scarcity, that they should abstain from these animals since they wished to amass them and fill up their numbers by not slaughtering them" (according to Athenaeus 9, 375c, cf. Darby et al. 1977:142). Wilkinson's statement appears to be very

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[4] Herodotus from Halicarnissus (484 to circa 415 BC) wrote The Histories, and traveled extensively in Egypt.
[5] Porphyry of Tyre lived from AD 232-306.

closely related to this passage.

Can we conclude that beef was avoided in ancient Egypt? Darby et al. (1977) argue that this is not the case. If there were such taboos they were most likely restricted to the priests and nobility. Herodotus' primary Egyptian informants were thought to be priests and upper class citizens; therefore his information was bound to be biased by the attitudes, beliefs and customs of this particular section of society. Herodotus' views on this subject were also reflected in the writings of ancient historians that followed after him. The iconographic and archaeological evidence pertaining to the eating of beef indicates that if there were such a taboo it was limited in time and only to a small section of the population. If such a taboo existed it was probably influenced by changes in politics and economy throughout Egypt's long and varied history.

Little is known about how beef may have been prepared for consumption. Several tomb illustrations depict beef being hung to dry by butchers, and there is some evidence that it may have been boiled. The evidence for roasting beef is rare - only one example from the tomb of Ukh-hotp (a noble during the Middle Kingdom) has been recorded (Darby et al. 1977).

Cow parts were consumed for medicinal purposes. Several papyri, particularly the Ebers papyrus (circa 1550 BC) (Ebbell 1937, cf. Darby et al. 1977), call for specific parts of the cow to be used in medicinal formulae. Cow-grease was consumed with a mixture of honey, yeast-water, roast ami, and the gum of the acacia to expel coughs. Grease was also mixed with ingredients and applied externally to relieve burns. Cow

organs and blood were also used for medicine. Of special note is the use of the cow liver to combat night blindness. The high concentration of vitamin A, although certainly unknown to the ancient Egyptians, would have been very effective for this purpose. Fresh meat was applied to flesh wounds, and in particular, to animal bites. Cow's milk was also a treatment for ailments of the stomach and ulcers on the tongue and mouth.

4.3.2 Swine

A great deal of evidence exists for the presence and consumption of pork in the Dakhleh Oasis. Papyri from the village of Kellis specifically mention pigs (Worp 1995). In a private letter dated circa AD 330, P. Kellis inv. A/2/83, Pausanias writes to Gena sending instructions for him to buy two pigs in exchange for a quantity of grain. A second, and very interesting papyrus, P. Kellis inv. P. 78 G+J+K, dated to AD 353, describes a petition that was made by a resident of Kellis to Flavius Faustinus, the local *Praeses*[6] of Thebaid. In this papyrus the individual lodges a public complaint against a fellow resident, explaining that while being engaged in a fight he was robbed of his wine and pigs by said resident. It is obvious from this petition that the stolen goods were considered to be valuable commodities. The KAB does not make any specific reference to pork; however Bagnall (1997) comments that the five mentions of unspecified 'meat' are probably in reference to pork.

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[6] The *Praeses* was a 'civil governor' who governed over a specific province in Egypt (in this case the Thebaid province).

Churcher (1993) reports that fragmentary pig (*Sus sus*) skeletal remains are the most abundant animal remains in Kellis. The majority of the remains are from immature or suckling pigs. From the frequency of the remains and the age at death of the pigs, Churcher (1993) suggests that pig meat was the dominant source of protein in the Kellis inhabitants' diet.

Pork is thought to have been a major component of the diet in Pre-dynastic Egypt (pre 3200 BC), particularly of the inhabitants in the northern part of Egypt. As the skeletal remains of wild pigs are indistinguishable from domesticates, it is difficult to determine whether or not the Egyptians were raising pigs or hunting them at this time. After 3200 BC, however, the archaeological evidence for pork consumption all but disappears. Although there is no evidence that pork consumption was completely abolished, this lack of archaeological evidence may be construed to mean that pork had become a tabooed food item.

Ikram (1995) argues that there are many misconceptions surrounding the consumption of pork in ancient Egypt. Until very recently both ancient and modern historians considered pigs to be a taboo food item abhorrent to the Egyptians. Once again, Herodotus popularized this view. He claimed that, "Pigs are considered unclean. If anyone touches a pig accidentally in passing, he will at once plunge into the river, clothes and all, to wash himself..." (section II, line 47). If the Egyptians could not touch pigs, one might assume that they would not have eaten them either. This view of pigs may have been further perpetuated by the fact that pigs were commonly associated

with the Egyptian god Seth, who was the god of chaos and evil. Several New Kingdom (1552-1069 BC) tombs display images depicting the god Seth as a pig (Darby et al. 1977). One scene in particular shows Thot, the god of knowledge and secret science, beating Seth (shown as a pig) in front of Osiris. To further promote his idea of pig taboos, Herodotus states that swineherders were the lowest class of people and were restricted in their social interactions with other Egyptians. "... and swineherds, though of pure Egyptian blood, are the only people in the country who never enter a temple, nor is there any intermarriage between them and the rest of the community, swineherds marrying their daughters and taking their wives only from amongst themselves" (II, 47). The only time that Herodotus mentions pigs in a positive manner is when he refers to their use in agriculture, "... turns pigs into it [fields] to tread in the seed, and then waits for the harvest. Pigs are used also for threshing, after which the grain is put into storage" (II, 14).

Unfortunately almost all of the early Egyptologists relied heavily on the writings of the Greeks, and more specifically Herodotus, when forming their opinions and hypotheses about ancient Egyptian diet and taboos. Consequently, most of the history written about Egyptian food taboos directly reflects the ideas and writings of Herodotus. This idea may have also been reinforced by the fact that modern Muslims in Egypt, and previous Jewish residents of nearby Palestine, both consider pork to be taboo. Archaeological evidence, however, does not support this view.

Although "absence of proof is not proof of absence" (Sagan 1977), Egyptologists

have also suggested that the lack of iconographic evidence of pigs (in comparison to other animals) in Egypt is further proof that pigs were considered taboo in Egypt (Darby et al. 1977). Pigs are nevertheless depicted in several tombs throughout Egypt (although there are fewer Old Kingdom representations), and clay models of pigs have been found at several sites from the Pre-dynastic period onward (Ikram 1995).

The breeding of pigs may also have had several advantages in ancient Egypt. Digestively, pigs and humans are very similar, hence pigs are able to scavenge and eat any waste or leftovers that humans produce, making them an "edible sanitation service" (Miller 1990). In ancient Egypt the preservation of food, particularly foods that spoil quickly and are hosts for harmful bacteria, was nearly impossible, and pigs would have been very useful in the disposal of such food items. In addition, pigs have a very flexible diet and are able to digest and hydrolyze large amounts of fat. Their demands for carbohydrates and protein are very low compared to other domesticated animals. Pigs also grow very quickly and the "... potential returns for the investment of energy and other nutrients ... can be three - to fivefold greater than with other domestic animals" (Miller 1990:129). Pig excreta also provides a valuable supply of fertilizer.

On the negative side, however, pigs are poorly adapted to climates like that found in Egypt. They lack the ability to regulate their body temperature through vasodilation (sweating) and require shade and water. Both of these commodities are at a premium in Egypt and, as such, pigs may not have been the preferred animal to raise. In addition to requiring shade, pigs often wallow in mud to protect their skin from burning,

aiding in thermoregulation. If mud is not available, a common situation in Egypt, then pigs will roll in their own excreta. This unattractive habit may have been the basis for pig avoidance by some members of Egyptian society (Ikram 1995). Pig meat also spoils very quickly and can be responsible for transmitting trichinosis, a parasitic worm, that can cause diarrhea, stiffness, pain, swelling, sweating, and insomnia. These factors may have contributed to a pig taboo in ancient Egypt; however, textual and archaeological skeletal evidence suggest that if there were a taboo, it was restricted to a very small section of society.

Even though pigs are discussed in unfavorable terms in the Book of the Dead and are associated with Seth, pigs were not excluded from lists of offerings left by pharaohs for the gods. Pigs are mentioned in list 45 of Ramesses III's temple at Medinet Habu as offerings for a feast of Nefertum (Nelson 1934). Morkot (1990) reports that Amenophis III offered 1000 pigs and 1000 piglets at the temple of Ptah at Memphis. Epstein (1971) notes that according to the Nauri decree, pigs were bred in Seti I's Abydos temple domains. Pigs must have been plentiful in order that the title of "Overseer of Swine" existed during the time of Senwoset I (Newberry 1928). In addition, pigs are also mentioned in the Ebers Papyrus for their medical uses. Pig's teeth were used to cure coughs and colds; pig's eyes were used to cure blindness; their blood for curing "hair in the eye" (an unknown disease); pig's grease was used to ease stiff joints and encourage blood flow; and pig's intestines were used to cure worms (Ebbell 1937, cf. Darby et al. 1977).

The most definitive evidence that pigs were consumed in Egypt comes from the discovery of archaeological faunal remains. Pig bones have been found in substantial quantities spanning several time periods and geographical areas throughout Egypt. According to Boessenek and von den Driesch (1988) pigs were much more abundant than either cows or sheep/goats, particularly in the delta region during the Early Dynastic Period. Pig bones have been found in Maadi, Merimde Beni Salame, Buto, Helwan, and other Lower Egyptian sites. In upper Egypt pig bones have been excavated from sites in Armant, Toukh, and Abydos (Darby et al. 1977). Pig bones have also been recovered from sites representing later time periods, including Malkata, Amarna, where pig-sties have been identified, Elephantine, Deir el-Medina, and Tell el-Daba (Kemp 1984). One important distinction to make is that all of these sites that are associated with pig bones are settlement and not funerary sites. One possible reason for this is that very little analysis has been done on faunal remains from funerary sites; another reason is that pigs were considered to be a low status and cheap food, particularly if a higher status food could not be afforded (Ikram 1995).

Both the Greeks and the Romans favored pigs as a food item, and this may have influenced the amount of pork consumed during the Ptolemaic and Roman periods in Egypt. Lewis (1983) comments that during the Roman period pork was favored so much that in AD 215, when Caracalla issued an expulsion order for all non-resident Egyptians to leave Alexandria, he deliberately excluded pig merchants from the list. In fact, during the Roman period, adult Egyptian males were required to pay an additional

two drachmas on their poll tax for the pig tax. Lewis (1983) suggests that this tax may have been used to supply Greek and Roman temples with sacrificial animals, thereby acting as an incentive for Egyptian farmers to raise an animal that they might not have raised otherwise. By the 3rd and 4th centuries AD it is apparent that pork is an important part of the diet, particularly for the Roman army in Egypt. Davies (1989) notes that pork was one of the basic staples of the Egyptian Roman army's daily diet during times of peace. Specific evidence from Egypt, dated to AD 199, lists pigs as one of the food items eaten on a regular basis (Vitelli 1912, cf. Davies 1989). In addition, excavations at Karanis, an occupation site of the Roman army, revealed the remains of several pig bones (Boak 1933).

4.3.3 Ovicaprids

Sheep and goats are grouped together in the category of ovicaprids because their close biological/zoological relationship makes it very difficult to distinguish between their bones (Churcher 1993; Ikram 1995). Although it is not known exactly when sheep (ovids) and goat (capra) were domesticated in ancient Egypt, several rock art sites along the Nile dating to the Mesolithic and Neolithic period depict sheep. Several rock art sites in the Dakhleh Oasis also show ovid type animals being kept by human figures. The recovery of domesticated ovid bones in several Egyptian sites suggests that these animals were domesticated before the Maadian period. In the Nile valley, these animals appear to be second in importance only to cattle, and they would have provided milk, meat, dairy products, wool and skins.

4.3.3.1 Sheep

Although there is no mention of sheep in the KAB, one papyrus from Kellis does mention fleece and wool (Worp 1995). In this private letter, P.Kellis inv. P.85.B#1, dated to mid 4th century AD, Pekysis writes to Pamouris asking why he has not yet sent a fleece. He goes on to ask Pamouris to send a small quantity of coloured wool.

Archaeological excavations in the town of Kellis have revealed large quantities of ovicaprid bones and horns (Churcher 1993). Unlike faunal assemblages found in the Nile valley, it appears that sheep are not represented in the faunal assemblage. This is based on the lack of "oval and compressed" remains of horns, which are typical of ovids. Churcher (1993), however, does note that ovid bones are less robust than, for example, goat bones, and therefore may be underrepresented. There is no conclusive evidence yet to warrant the inclusion of sheep on the list of possible food sources in Kellis.

Two species of sheep have been documented in ancient Egypt. The first, *Ovis longipes paleoaegyptiaca*, was a poor wool producer and appears to have disappeared from Egypt by the end of the Middle Kingdom. From the Middle Kingdom on *Ovis platya aegyptiaca* appears in both iconographic and archaeological deposits. The ram of this species was worshiped in many Egyptian nomes[7] for its virility and aggressiveness, and it was a symbol of power and fertility. Because of their status as a worshipped animal it is thought that sheep were not consumed by the priest class and the nobility. Sheep were bred by the common Egyptian for their ability to produce wool, butter,

[7] From the Ptolemaic period, Egypt had been organized in geographical units referred to as *nomoi* in Greek, and *nomes* in English. Refer to Appendix B for a list of Egyptian nomes as they appeared in the 4th century AD.

cheese and milk. Herodotus makes the observation that the nobility and priest class would only dress in linen, and the 'common man' was observed to have worn wool (II: 37, 81), indicating that the sheep and their by-products may have been considered to be of lower status.

4.3.3.2 Goats

Although goats are not mentioned in either the KAB or in papyri from Kellis, there is abundant skeletal material to support the idea that the Oasis dwellers raised and ate goats. Churcher (1993; in prep) reports that goat bones (*Capra hircus*) are almost as abundant as pig bones. The possibility exists that goat may have been as important in the diet as pigs, but because goat bones do not survive well in the archaeological record, they may be underrepresented. They are easily consumed by canine scavengers and may even be consumed by humans if they are boiled for a sufficient period of time. In addition to meat, goat byproducts, such as milk and cheese, were probably consumed.

Although the date of introduction of goats into ancient Egypt is unknown, several species have been identified from both skeletal and iconographic evidence. Specifically, screw-horned goats, such as *Capra hircus girgentana* have been identified. Other species identified include a dwarf goat, *Hircus reversus*, the Syrian or Mamber goat, *C. hircus mambricus*, and the Theban goat, *C. hircus thebaicus* (Ikram 1995). Evidence for goats is found in the Pre-dynastic period and onward. Documentary evidence and tomb paintings depict goats in various life activities, and record sacrificial offerings of goats to the Egyptian deities.

4.3.4 Camels

Camels were clearly present in the Dakhleh Oasis. Several papyri from Kellis mention camels (P.Kellis inv. P.97; P.Kellis inv. P.52.B+C+D+H), camel sheds (P. Kellis inv.P.52.F), camels as transportation (P.Kellis inv.P.7.A), and camel drivers (P. Kellis inv.P.7.A; P.Kellis inv.P.35.B) (Worp 1995). Skeletal evidence and preserved fecal matter also place camels in the Oasis. In the discussion of food in Egypt, camels are rarely mentioned as a dominant food source; however, there is some evidence from Kellis to suggest that camels were occasionally consumed. Churcher (1993; in prep) describes the remains of camel vertebrae that show classic signs of butchering with an axe to provide specific cuts of meat. Although there is evidence for the consumption of camel meat in the Oasis, it is safe to assume that because of their value as a beast of burden, camels would not have been consumed on a regular basis, and if consumed would have been eaten only by the privileged members of Dakhleh society.

Next to water, camels were the most important possession of the Oasis dweller, and it is safe to say that life in the oasis would have been more difficult until the introduction of the camel. The Saharan camel was, and remains, the one humped dromedary Arabian camel (*Camelus dromedarius*) that has been used in Egypt since the first or second century AD (Bulliet 1975). In addition to being a source of meat and milk, the camel was used extensively as transportation for goods and humans, and also for working in the fields (Bulliet 1975). Most importantly, camels were used constantly for transporting goods and merchandise between the oases, the Fayum, and the Nile Valley.

Camels could navigate the difficult terrain and travel the long routes without water (Curtin 1984). It has been estimated that the dromedary camel can endure between 10 to 15 days without drinking.

4.3.5 Donkeys

The presence of the donkey is well documented in the Dakhleh Oasis, and particularly at Kellis. In a private letter, dated circa AD 330, P.Kellis inv. A/2/109, Gena writes to Pausanias asking him to make inquiries about purchasing a donkey for him. Another papyrus contains a petition written by Pamouris, a villager in Kellis. In this petition to the Praeses of Thebaid, dated circa AD 300-320 (P.Kellis inv. P.61.V+X+P.63. A), Pamouris complains about the theft of his donkey by an influential inhabitant of the city of Mothis. A receipt for the transportation of goods (P.Kellis inv.P.35.B), circa AD 320, describes the delivery of a donkey load of olives (Worp 1995).

Skeletal remains of donkeys also substantiate their existence in the Oasis. Churcher (1993; in prep), however, notes that donkey remains (*Equus asinus*) make up a very small portion of the total faunal assemblage. Most of these remains bear cut marks, so it can be suggested that donkey was consumed, but very infrequently.

Donkeys are known to have been in Egypt by the first dynasty (circa 3150 BC). Although Darby et al. (1977) report that there is no evidence that donkeys were eaten in

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[8] Refer to Appendix C for a list of measures and weights and their modern equivalents.

the dynastic period, they were, and still are, important beasts of burden. The donkey was used in much the same manner as the camel; however, the donkey could only transport two or three *artabes* while the camel could carry six to ten *artabes* (Wagner 1987) and must drink water at regular intervals. Donkeys, however, were much cheaper to purchase and their daily upkeep was also substantially less than that of the camel. For the inhabitants of the oasis who did not have much money, the donkey offered a cheaper alternative to the more costly camel, and it allowed them to remain active competitors in trans-Saharan trading.

4.3.6. Hunted Animals

Although hunting would have provided the primary source of meat in the diet before the advent of domestication, hunting remained a common way to supplement meat in the diet from the dynastic to the Byzantine period. Evidence from the Roman period demonstrates that hunting was still a very popular way to supplement the diet. This is demonstrated in a letter written by an auxillary soldier stationed at Wâdi Fawâk-hir in Egypt:

> Antonius Proculus to Valerianus. Write the note to say that from the month of Agrippina until now we have been hunting species of wild animals and birds for a year under the orders of the prefect (Guéraud 1942, cf. Davies 1989).

The list of ancient Egyptian fauna is very extensive and it is nearly impossible to make an exhaustive list of all the wild animals that may have been consumed (Ikram 1995). Instead the focus in this discussion is on those wild animals that appear fre-

quently in the archaeological record of the Dakhleh Oasis. Overall, domesticate remains represent the majority of the faunal assemblage in the site of Kellis, while the remains of hunted animals are much less frequent, and would have made up only a very small portion of the diet.

4.3.6.1 Cervids and Other Perissodactyls

At the site of Kellis the only archaeological examples of antelope found have been the gazelle (*Gazella dorcas*) and the hartebeest (Churcher 1993). These remains are quite rare, and as such the importance to the diet is minimal.

Ikram (1995) states that antelope were the largest class of hunted animal in Egypt. Antelope are commonly pictured in tomb scenes, showing them being slaughtered as offerings. Antelope were thought to be plentiful and as such would have been easy to hunt and would have been a very good source of additional meat. The meat of one mature antelope (depending on type) could be equal to the meat from three to twelve sheep (Ikram 1995).

Antelope are depicted on several temple and tomb walls. In addition, skeletal remains bearing cut marks also suggest that antelope may have been consumed fairly regularly. Archaeological excavations at Karanis, Egypt, have revealed the remains of two species of antelope, one a small antelope belonging to the genus/species *Gazella dorcas*, and the other a hartebeest belonging to the genus *Alcelaphus*. Other types of antelope identified throughout time and space in Egypt are the oryx, the addax, the bubalis (hartebeest), and the gazelle. Early rock art sites in the Dakhleh Oasis, dated to the

Neolithic, depict antelope-like creatures.

4.3.6.2 Hare

Churcher (in prep) notes that hare bones are represented in the faunal assemblage from Kellis, but only in very small quantities. In the Nile Valley, iconographic evidence on tomb walls depict the hare in hunting scenes (Darby et al. 1977). There is no evidence from Egypt of domesticated rabbits, and it is probable that these animals were either hare or wild rabbit.

4.3.7 Birds

The variety of birds consumed in ancient Egypt is rich. Not only is the Nile valley a rich eco-environment for birds, but the geographical location of Egypt makes it a prime stop-over for migrating birds. Birds have been depicted in hieroglyphics, paintings, sculptures, and reliefs from the Predynastic to the Byzantine period. Birds are shown being captured in the wild; in domestic situations such as gardens and markets; as pets; being force-fed and slaughtered, and also as offerings.

Throughout history, Egyptians have always consumed birds in one form or another, and most everyone would have had access to birds, either by raising or hunting them. Chickens, pigeons, ducks and geese were the most popular birds. Not only do birds supply meat, but they also supply eggs, an excellent source of protein and daily nutrients. Duck and goose eggs, the richest in nutrients, were very common in Egypt. Evidence of ostrich eggs, although not common, has been found throughout the Nile Val-

ley, and evidence of Neolithic ostrich egg shell beads has been found in the west end of the Dakhleh Oasis (Churcher 1993). Mummified eggs wrapped in linen and covered with salt and bitumen have also been identified. One ostracon from Kellis (O.Kell.inv. D/6/19) records an order for twenty eggs. In addition to this the remains of several egg shells have been excavated from Kellis (Churcher, pers. comm.). It is difficult to comment on the importance of eggs to the diet of the inhabitants of the Dakhleh Oasis, due to the fragile nature and poor preservation of eggs. It is thought, however, that eggs were most likely consumed in large quantities, as it was a resource that was readily available for consumption.

4.3.7.1 Chickens

Although there is no evidence for chickens in the middle east until the Hellenistic period, chickens and eggs are very much a part of the diet by the Ptolemaic period. The KAB has several entries of chickens. Chickens in Kellis, however, were most likely used primarily for egg production. Churcher (pers. comm.) comments that archaeological finds of chickens from Kellis include feathers, desiccated heads, legs with tendons and scales, and all parts of the skeleton. Although both sexes are represented, cocks are rare. The morphology of the chicken skeleton suggests that primarily egg-layers are represented. These birds are small, and appear to be of one breed (sp. *Gallus*). Although not as important as pig or goat to the diet, the frequency of chicken remains suggests that they may have played an important role in the diet of the inhabitants of the Dakhleh Oasis.

4.3.7.2 Pigeons

Pigeons have always been and remain a very popular food source in Egypt. Although seven possible species of pigeon may have been available for consumption in ancient Egypt (Ikram 1995), only one species, *Columba livia*, has been identified in Kellis (Churcher 1993; in prep). Churcher (1993) notes that the inhabitants of the Dakhleh Oasis kept large flocks of pigeons which were probably a major source of protein. Architectural remains from Kellis and throughout the Dakhleh Oasis commonly feature pigeon-holes or large structures for raising pigeons on the roof tops (Mills 1984).

4.3.7.3 Ducks

Representations of ducks are very common in Egyptian art. They are depicted in both domestic and wild scenes, being reared and hunted. Mallard duck remains (*Anas platyrhynchos*) are present in the archaeological deposits in Kellis, but only in small amounts (Churcher 1993; in prep). Ducks would have provided a good source of protein and fat (Ikram 1995). In addition to meat, ducks also would have supplied eggs.

4.3.7.4 Geese

There are at least nine species of geese in ancient Egypt (Ikram 1995), but only one, the greylag goose (*Anser anser*), has been identified at Kellis (Churcher 1993; in prep). The skeletal remains of geese recovered from Kellis are rare, so it appears they were a very minor part of the diet. Geese were force fed wheat to fatten them and their livers were eaten as a delicacy (Wagner 1987). Geese provided meat, eggs and fat. Goose fat is useful for cooking, and has also been mentioned in the Eber Papyrus for use

against many illnesses (Ebbell 1937, c.f. Ikram 1995).

4.3.7.5 Ostrich

The wild ostrich (*Struthio camelus*) is known to have been hunted since the Pre-dynastic period in Egypt. Numerous rock carvings throughout Upper Egypt (Darby et al. 1977) and in the Dakhleh Oasis (Churcher 1993) depict ostriches. Ostrich meat and eggs would have been a good source of nutrition. Churcher (1993) comments that ostrich was available in the Oasis and has been identified in third millennium Neolithic sites in the Oasis. It is not known if the ostrich was a common bird in the Oasis by the Roman period, as only one possible specimen has been identified (Churcher, in prep).

4.3.8 Fish

Although it seems doubtful that fish would have made up a substantial part of the diet at the Dakhleh Oasis, there is some evidence to suggest that fish, particularly dried fish, were transported there. One published papyrus from Kellis, a private letter (P.Kellis inv. P.57.B) dated to the mid 4th century, asks Psais to accept "a little pot of fish" (Worp 1995). Whether or not this is in reference to dried fish or fish-sauce is unknown. Churcher (in prep) has identified three species of fish from deposits in Kellis. These include two species of Nile catfish, *Clarias sp.*, and *Synodontis sp.*, and one species of Nile perch, *Lates niloticus*.

Fish have been part of the ancient Egyptian diet since Pre-dynastic times, particularly for people those who lived near the banks of the Nile. Fish were caught using large nets or in conjunction with barricades, and with drop-lines, fishing rods, and

spears/harpoons (Darby et al. 1977). It is difficult to identify the exact species of fish that were available for consumption until the Greek and Roman travelers/historians started to provide literary evidence of fish consumption. Strabo (17, 2, 4) cites the following fish as best known in Egypt: oxyrhychus (elephant-snout fishes), lepidotus, latus, alabes, coracinus (also known as crow-fish), choerus, phagrorius, silurus, cithorus, thrissa, cestreus, lychnus, physa, and bos (Ikram 1995).

Iconographic evidence shows fish being prepared in several ways. Fish were broiled, chopped and shredded to make fish balls and cakes. More commonly, though, fish were sun dried, salted or pickled to preserve them for future use. During the Roman period, fish sauce was used as a condiment on foods (Davies 1989). It was prepared by layering fish in a ceramic pot, which was left out in the sun until the fish had fermented. The remaining liquid was removed and used as sauce. In most cases, Mediterranean fish were used. One of the most prized fish-sauces was called *garum*; however this sauce was very expensive and most commoners would have used a cheaper, inferior type called *muria*.

4.4 Agricultural Products in the Diet: Grain Crops, Fruit Crops, Sweeteners and Spices

The fertility of the Egyptian oases has been noted by many historical writers including Olympiodorus[9], Pliny the Elder[10], and Strabo the Geographer[11]. Practically any

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[9] Olympiodorus lived during the 5th century AD. He visited both Kharga and Dakhleh in 421 AD.

[10] Pliny the Elder of Verona lived from AD 29 to 79. He died in the eruption of Mt. Vesuvius.

[11] Strabo the Geographer (66 BC to AD 25) of Amasia, was a close friend and part of the entourage of Aelius Gallus, the prefect of Egypt from 25-24 BC.

crop that could be cultivated in the Nile Valley could also be grown in the oases, if the demand arose. Giddy (1987) comments that as far back as Pharaonic times agriculture production in the Egyptian oases was geared to the demand of the Nile Valley, though many plants were only cultivated for local consumption.

One of the major differences between agricultural practices in the Nile Valley and the Egyptian oases concerned the availability of water. Soil fertility in the Nile Valley depended on the annual flooding of the Nile River, and as such inhabitants of that region could only count on producing agricultural products during certain times of the year. The flooding of the Nile began each year in July, and the fields were flooded until October. The flooding left behind large amounts of sediment rich in nutrient minerals and organic matter.

The inhabitants of the Egyptian oases, however, depended on water sources from the Nubian Sandstone Series. Access to an unlimited water supply meant that the oasis dwellers could irrigate their fields all year long and continually produce crops. Farmers in the Oasis may also have used animal-generated fertilizer to add nutrients to their fields. Claiming it to be a practice handed down from antiquity, present day Oasis farmers collect manure from their animals' stalls and spread it on their fields to enhance the fertility of their crops and the soil (M. Woidich, pers. comm.).

4.4.1 Grain Crops

"Is it wheat or barley?"
- (popular saying for "Good or bad news?")

Although it is difficult to determine the exact number of species of grain grown in ancient Egypt, it is apparent that both emmer wheat (*Triticum dicoccum*) and barley (*Hordeum vulgare*) were a very important part of the diet. In the ancient Egyptian language there were many synonyms for grain. As well, the various travellers that recorded Egypt's history identified grains differently, and Egyptian conquerors also added their renditions to the vernacular. By the Ptolemaic period, the distinction between grain types becomes evident in the written documentation. Grain, particularly wheat, was a significant part of the economy. By the advent of the Roman period, Egypt was exporting large quantities of grain to the Mediterranean world. During the Roman period Rome was able to rely upon Egypt to produce a third of her annual grain requirements (Lewis 1983), although most was produced in the Nile Valley.

Archaeological evidence of grain consumption found throughout Egypt includes large storage baskets, earthenware jars, communal silos and granaries dating from Dynastic to Roman periods. Preserved remains of various grains have also been found associated with various storage containers. Images of grains adorn temple and tomb walls, and offerings of grains are recorded on walls and in various papyri.

4.4.1.1 Wheat

Wheat was one of the most important crops in Egypt, and particularly important

during Ptolemaic and Roman times. Wheat is divided into three groups based, on genetic differences (Darby et al. 1977). The first group is called diploid, and these grains are classified in the 14-chromosome group. Wild and cultivated einkorn are included in this group. Wheat of the second group contains 28-chromosomes, and is called tetraploid. This group includes wild and cultivated emmer (*Triticum dicoccum*) and durum (hard) wheat (*Triticum durum*). Plants of the last group contain 42-chromosomes and are called hexaploid. It is in this group that we find species of wheat used in ancient bread making, including *Triticum aestivum*. Tetraploid and the hexaploid wheat are identified as the dominant types consumed in ancient Egypt. Tetraploid hulled wheat (i. e., *Triticum dicoccum*) predominated in predynastic and Pharaonic Egypt. It was gradually replaced by wheat such as *Triticum durum* and *Triticum aestivum* from the Ptolemaic period onwards (U. Thanheiser, pers. comm).

At the beginning of the fifth century AD, Olympiodorus wrote that wheat grown in the Egyptian oases was better than any other and that its colour was whiter than snow (Wagner 1987). Further historical documents, written by the Roman geographer Strabo, do not mention wheat, but mention that cereals were produced in abundance by the inhabitants of the Kharga and Dakhleh oases. Additional information provided from ostraca reveal receipts of wheat transactions between farmers of the oases and individuals living in towns and cities in the Nile Valley (Wagner 1987). Ostraca written in the demotic language suggest that wheat has been cultivated in the Dakhleh Oasis since the Ptolemaic period. Archaeological evidence from the site of Ein el-Gazareen suggests

that emmer was present in the Oasis since the Old Kingdom period. Throughout the second, third and fourth centuries AD several personal letters also mention the trade of wheat along with orders for barley, fodder and oil (Wagner 1987). In addition any excess went to supply the Roman military stationed in the Oasis.

Several papyri from Kellis mention wheat. In a private letter dated to AD 330 (P. Kell. Inv. A/2/83), Pausanias writes to Gena asking him to buy pigs for a quantity of 'clean' wheat. P. Kell. Inv. P. 83, documents the lease of a room for two artabs of wheat per year. Worp (1995) comments that this room was most likely used for the storage of wheat and not as a living quarters. Another document (P. Kell. Inv. P. 85.A #4) records the loan of money in which the borrower is required to pay the interest of one artab of wheat if he did not pay off the principal loan in a set amount of time.

There are several mentions of wheat in the Kellis Agricultural Account Book and it appears that it was the largest single crop produced by the tenants of the estate (Bagnall 1997); it was also likely to have been the most important grain in the diet. Archaeological remains of wheat identified by Thanheiser add support to this argument. The main wheat species identified from Kellis are *Triticum aestivum* (bread wheat), followed by hard wheat (*Triticum durum*) and the occasional find of emmer wheat (*T. dicoccum*), the traditional wheat of pharaonic Egypt.

Herodotus (circa 450 BC) comments that bread in Egypt was made from *olyra*, a cereal grain that has been identified as emmer (White 1963; Bagnall 1993). Herodotus' claim is further substantiated by the appearance of the word *olyra* in several Ptolemaic

papyri. Emmer was likely the dominant cereal crop during the Pharaonic period. It was not until the end of the Ptolemaic period that the higher quality wheat called *Triticum aestivum* became popular.

During the Roman rule of Egypt, wheat was harvested from April to June in the Nile Valley, and the majority of the crop was exported to the city of Rome. However, the remainder of the wheat was thought to supply the Egyptians with one of their main staples, bread. A *prytanis* (a presiding officier of the boule) of Oxyrhynchos wrote to the prefect of Egypt that the main element in the feeding of the city was the bread supply. As such the government was ensured that the major cities and the military had bakeries supplied with wheat and workers (Bagnall 1993). Wheat was ground into flour and used to make breads, soup and porridge. One of the most prized breads was called "katharos" which translates to 'clean' or white bread (Bagnall 1993). These breads were eaten by the more privileged members of society, and the poorer individuals probably ate less refined bread that may have been made from lower quality wheat such as durum. Two types of army bread have also been described: a lower quality or normal standard bread (*panes militares castrenses*) that was most likely used to feed the common soldier; and a higher quality bread (*panes militares mundos*) which probably was eaten by the officers (Davies 1989).

4.4.1.2 Barley

Although archaeological and documentary evidence indicate that wheat was the dominant grain grown at Dakhleh, Wagner (1987) comments that barley was the most

commonly documented cereal grown in the oases. According to Olympiodorus, barley was sometimes sown twice a year in the Kharga and Dakhleh Oases (Wagner 1987). Many letters document that barley was transported from the oases to the nome of Oxyrhynchus. Barley is also mentioned as a military ration, but was most likely used as animal fodder as it was considered to be of poorer quality than wheat (Lewis 1983).

Barley appears in several papyri from Kellis (Worp 1995). It is mentioned as payment in P.Kellis inv. A/2/68, and also again in P.Kellis inv. A/2/61 +64. One papyrus (P.Kellis inv. P. 61.D) lists various commodities, including barley, which was used to feed animals. A wooden tablet (T.Kellis inv. A/5/106) dated to the 4th century AD appears to list arrears of money or commodities owed to the owner of the list. One of the entries describes "Mara daughter of Apollon, 5 modii of barley" (Worp 1995:163). A business letter (P.Kellis inv. P.85.A #3) dated to the mid 4th century, documents a request to Psais to send three and a half artabas of barley to an individual in Kellis.

Bagnall (1997) notes that barley is listed in the KAB on several occasions, however it does not appear to be as prevalent as wheat. Even though it was considered to be a less valuable crop, barley is much less vulnerable to fluctuations in water supply and salinity levels in the soil, and may have been better adapted to growing in the oasis environment. Barley is thought to be have been used as donkey and camel feed and also as military supplies (Bagnall 1997). Archaeological finds of barley include the two-rowed barley (*Hordeum vulgare ssp. distichum*) and the 4- and 6-rowed barley (*Hordeum vulgare ssp. vulgare*) (Thanheiser, pers. comm.). In terms of abundance, the archaeologi-

cal remains of barley appear in similar quantities as bread wheat (*Triticum aestivum*).

Barley was a prevalent grain in ancient Egypt. Archaeological finds of barley date to the Neolithic (ca. 4000 BC) period (Darby et al. 1977). What is thought to be the first written evidence of barley occurs as early as the first dynasty. Several documents and tomb inscriptions thereafter describe pharaohs leaving large offerings of barley to the gods, offering barley to the common people, and describe the role of barley in special feasts and festivities. Barley was used in making bread, as fodder for animals, for brewing beer, and in medicinal concoctions (Darby et al. 1977). By the time of Herodotus, however, barley may have been considered to be less desirable than wheat. Herodotus describes barley as "... a disgraceful food among the Egyptians..." (II, 36). It appears that this sentiment about barley had not changed by the Roman period. Athenaeus notes that barley was only consumed in a gruel type mixture three times a year. It must be cautioned, however, that the view of Herodotus and Athenaeus[12] most likely represents the views of the upper class and nobility, therefore excluding the common Egyptian who probably ate barley on a more regular basis.

Although the amount grown and its function is unclear, barley probably only made up 1/5 of the total cereal crops produced annually in Egypt during the Roman period (Bagnall 1993). Some of the barley crop was most likely used for bread, while the remainder may have been used as fodder for animals. A papyrus from Egypt dating to

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[12] Athenaeus of Naucratis (AD 170-230)

the Roman period states that 20,000 artabs of barley were needed each year to meet the requirements of an *ala*[13] (Davies 1989). It is most likely that this supply of barley would have been used to feed the horses, as it is thought that barley was normally only given to soldiers as a punishment (Watson 1969). There is some suggestion that barley was also used to make beer, apparently a favorite beverage of the Roman soldier (Davies 1989), but there is scant evidence of beer itself in Egypt in the papyri, especially after Diocletian's reign (Bagnall 1993).

4.4.1.3 Millet

In addition to the main cereal grains of wheat and barley, millets, and in particular pearl millet (*Pennisetum americanum*), have been identified in deposits from Kellis (U. Thanheiser, pers. comm.). Prior to the 1998-1999 field season in Dakhleh, only a very small sample of millet had been identified, and it is was not known whether it was cultivated for human consumption or animal fodder, or if it grew feral or as a weed. During this past season several kilograms of millet was found during excavations at Kellis in Area C/2/4, Rm 1, Bin 2, dated to the 2nd century AD. This came as a complete surprise as millet has not been mentioned either in papyri or the KAB. At this point no conclusions can be made about the quantity or significance of such a find at Kellis, neither is it known whether millet was grown or imported into the Oasis. It was a very important grain in parts of Nubia (Darby et al. 1977), so it is possible that millet could

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[13] An *ala* is one of the units that made up the auxiliary in the military. The *ala* was a cavalry unit which consisted of either regiments of 500 soldiers, or units of 1000 soldiers (Watson 1969; Wells 1992).

have been traded or introduced into the Dakhleh Oasis during the Roman period.

Although there is little evidence to suggest that millet was cultivated in Egypt prior to its introduction after the Arab Conquest in the 7th century AD (Darby et al. 1977), Wagner (1987) claims that millet was grown with great success at the Dakhleh Oasis. Millet was sowed and harvested three times a year according to Olympiodorus who visited Kharga and Dakhleh in AD 421. Olympiodorus' account is very important because it is one of the only recorded observations of millet in the ancient Egyptian literature. It is rarely mentioned in the papyri, and there is only one mention of it on the collar of a jar found in Karanis (Boak 1933). Wagner (1987) opines that because millet grows well in dryer environments, it only makes sense that it would have been extensively cultivated in the oases.

4.4.1.4 Sesame and Oil Plants

Oil from the seeds of the sesame plant was used to supplement olive oil in the diet. Written evidence suggests that the sesame plant was in use in Egypt during the third century BC. (Darby et al. 1977), and archaeological evidence suggests that sesame was in use as early as the 18th Dynasty (U. Thanheiser, pers. comm.). Wagner (1987) comments that sesame was grown during the Ptolemaic period in the Dakhleh Oasis and in the Kharga Oasis until the end of the fourth century AD. The quantities of sesame mentioned in the papyri from Dakhleh and Kharga are always small (i.e., 2 and 2.5 matia) (Wagner 1987). Specifically from Kellis, sesame has been noted in the papyrus P. Kell. V C. 44.7. It has also been noted in the KAB as being traded for cotton and

chicken, and bought in trade for wheat (Bagnall 1997). A small quantity of sesame has been identified in a domestic complex in Kellis dating to the 2nd century (U. Thanheiser, pers. comm).

Thanheiser (pers. comm.) notes that botanical remains from both safflower (*Carthamus tinctorius*) and linseed (*Linum usitatissimum*) are common throughout Kellis. Safflower would have been grown for oil production and perhaps dye. It is unknown, however, if linseed was grown for its oil bearing seeds, or for its fiber (flax).

4.4.2 Pulses

Legumes in ancient Egypt include the fava bean, chick peas, lentils, lupines, peas, and vetch. Most types of legumes have been present since the Pre-dynastic period (Darby et al. 1977). During the Roman period beans and lentils appear to have been very popular and are specifically mentioned on several papyri that list foods supplied to the local army units by villages in AD 199 (Davies 1989).

Only two groups of legumes are mentioned in the KAB. Bagnall (1997) comments that the absence of other pulses in the KAB is notable as there are no signs of chick pea, grass pea, lentil or lupine. One papyrus, P.Kell V C. 47.10, however, mentions lentils and lupine seeds. The legumes mentioned in the KAB are 'arakia' and vetch. It is not known exactly what species 'arakia' represents, but it is most likely the broad bean or fava bean (*Vicia faba L.*). Arakia is not recorded as a rent crop in the KAB but it is delivered once in exchange for cotton, and small quantities are noted in eight other transactions. Vetch is also mentioned in the KAB, but the entries are not

very informative. It is not a rent crop, and only appears on two lines.

Archaeological finds of legumes from Kellis include the broad or fava bean (*Vicia faba*), in its small seeded form (*Vicia faba ssp. paucijuga*) and lentil (*Lens esculenta*) (Thanheiser, pers. comm.). Among these pulses, the fava or broad bean is dominant and other species of pulses are rare (i.e., peas and lentils). Only a couple of peas have been found at Kellis and it is impossible to identify them as to whether they represent cultivated or wild peas. This is in direct contrast to other Roman period sites such as Mons Claudianus, where six species of lentils have been identified as an important staple food at this site (van der Veen 1998).

4.4.3 Vegetables

Several tomb inscriptions and papyri indicate that vegetables were held in high esteem during the Pharaonic period in Egypt. Bundles of vegetables were left by several Pharaohs as offerings to the gods. In addition there are reports of commoners being robbed of their vegetables, and soldiers under Seti I were given "vegetables without limit" (Darby et al. 1977). This written evidence is testament to the idea that vegetables were an important part of the Egyptian diet. Most upper class Egyptians had small gardens in which they grew their own vegetables. Peasants, however, whose living conditions were cramped and crowded, may not have the luxury of growing their own vegetables.

During the Roman period in Egypt, written documents attest to the importance of vegetables in the Roman soldier's diet. Several ostraca written by auxiliary soldiers

stationed at Wâdi Fawâkhir reveal that they had received additional foods, particularly vegetables, from their families (Davies 1989). A letter mentions plants such as purslane, cabbage, radishes, and mustard. Although it is not known if these vegetables were received from local Egyptian sources or from other provinces in the Roman Empire, the letters do signify that vegetables were considered to be important enough in the diet to write about them.

References to vegetables in papyri from the Dakhleh Oasis are scarce. One document from the 2nd century AD discusses a shipment of 'dry vegetables' that traveled on the back of a camel from the Fayum to the oases (Wagner 1987). It is thought that 'dried vegetables' referred to chick peas, beans and lupins. A journey from the Nile to the oases via camel caravans was so far that the vegetables had to be dried. Archaeological evidence of vegetables is also rather rare, but as Thanheiser (pers. comm.) comments, most vegetables are consumed before their fruit or seeds appear, and therefore their archaeological presence is rather low. Table 4.2 lists the possible vegetables that

Table 4.2. Vegetables consumed in Ancient Egypt and in the Dakhleh Oasis. Adapted from Darby et al. (1977), Bagnall (1997), and Thanheiser (pers. comm.).

Vegetables	Earliest Appearance	Evidence	Presence in Kellis	Evidence
Turnip	Unknown	Literary/botanical	Yes	Literary
Onion	Old Kingdom	Iconographic	Yes	Literary/botanical
Garlic	Predynastic	Archaeological	Yes	Literary/botanical
Artichoke	Byzantine	Literary/ archaeological	Yes	Botanical
Celery	Predynastic	Archaeological	Yes	Botanical
Gourds & Cucumbers	Old Kingdom	Iconographic/ Literary	Yes	Botanical

may have been consumed in ancient Egypt. All are represented by archaeological botanical remains or in the literary texts from Kellis.

4.4.3.1 Turnips

The earliest appearance of turnips in Egypt has not been determined. Several preserved turnips have been found in tombs in Thebes, but no date has been given to these finds (Darby et al. 1977). The first documentary evidence occurs in a papyrus dating from circa AD 1, in which pickled turnips are mentioned. Although no turnips have been found at Kellis, there are several mentions of it in the KAB (Bagnall 1997). The turnip does not appear to have been used as a rent crop, but for payment in kind, indicating that it was not considered to be as valuable as, for example, wheat.

4.4.3.2 Onions

Onions first appear in tomb drawings in the Old Kingdom and again in the New Kingdom, but actual archaeological specimens do not occur until after the Middle Kingdom (13th Dynasty) (Darby et al. 1977). By the 18th Dynasty finds of onions are numerous (U. Thanheiser, pers. comm.). After this time onions have been found placed in the armpits, eye sockets and body cavities of mummies. It was believed that onions helped to stimulate the deceased to breathe. Herodotus (II, 125) notes that the builders of Cheop's pyramid ate large quantities of onions. Apicius[14] also used the onion in several of his recipes (Solomon and Solomon 1950).

A brief reference to onions in Kellis papyri occurs in P.Kell. V C. 44.22. Refer-

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[14] M. Gabius Apicius lived sometime between 80 BC to AD 40. He compiled a collection of recipes from Italy and Egypt.

ences to onions only appear four times in the KAB, and they are recorded as expenditures (Bagnall 1997). Archaeological finds of onions (*Allium cepa*) in Kellis are rare, but they do exist (U. Thanheiser, pers. comm.).

4.4.3.3 Garlic

Clay models of garlic found in Pre-dynastic tombs indicate that garlic was a recognized part of the diet before the unification of Egypt (Darby et al. 1977). Preserved bulbs of garlic have also been found in a New Kingdom tomb, and also in Tutankhamon's tomb in the Valley of the Kings.

Garlic is known to have been grown in the Dakhleh Oasis, particularly during the Roman period. Wagner (1987) reports that garlic was grown in large enough quantities to permit trade with the Nile Valley. One particular papyrus dated to AD 75 documents the transport of garlic on donkey from the Oasis to Oxyrhynchus (Wagner 1987). Although garlic is not mentioned in papyri from Kellis or in the KAB, preserved bulbs of garlic (*Allium sativum*) have been found in Kellis (U. Thanheiser, pers. comm.).

4.4.3.4 Artichoke

Darby et al. (1977) comment that there is little evidence to suggest that the artichoke was part of the Egyptian diet prior to the Byzantine period. Even though there is no mention of artichokes in the papyri or in the KAB, nevertheless there is archaeological evidence of artichoke (*Cynara sp.*) in Kellis, albeit rare (U. Thanheiser, pers. comm.).

4.4.3.5 Celery

There is evidence to suggest that celery has been in ancient Egypt since the Pre-dynastic period (Darby et al. 1977). It has been found in several garlands adorning mummies, and several celery seeds have been found in tombs from Thebes that date to the New Kingdom. There is no direct evidence, either pictorial or written, to suggest that celery was a common food in ancient Egypt. During the Roman period, Apicius makes one mention of the use of celery seeds in sauces for grilled fish (Solomon and Solomon 1950). There is no mention of celery in the KAB or any papyri from Kellis, but a small number of seed remains (*Apium cf. graveolens*) have been identified from the site (U. Thanheiser, pers. comm.). Although celery appears to be uncommon, it may have been grown in gardens for local consumption.

4.4.3.6 Gourds and Cucumbers

Darby et al. (1977) note that ancient Egyptians did not make a clear distinction between gourds and cucumbers until the Ptolemaic and Roman period. A papyrus dating to circa AD 141 lists 20 gourds and 40 cucumbers (Lindsay 1966). Although cucumber is distinguished, it is not known whether or not 'gourd' is used in the same sense as today. There are no mentions of either gourds or cucumbers in the KAB or in papyri from Kellis, but Thanheiser (pers. comm.) has identified one species of bottle gourd.

Table 4.3. Fruit consumed in ancient Egypt. Adapted from Darby et al. (1977), Bagnall (1997), and Thankeiser (pers. comm.).

Fruit	Earliest Appearance	Type of Evidence	Present in Kellis/ Dakhleh	Type of Evidence
Palm, date	Pre-dynastic	Archaeological	Yes	Literary/botanical
Palm, doum	Pre-dynastic	Archaeological	Yes	Literary/botanical
Sycamore fig	Pre-dynastic	Archaeological	No	
Carob	1st/12th dynasty	Literary/Arch	Yes	Botanical
Jujube	1st dynasty	Archaeological	Yes	Literary/botanical
Fig	2nd dynasty	Image on Vessel	Yes	Literary/botanical
Grapes	3rd dynasty	Archaeological	Yes	Literary/botanical
Persea	3rd dynasty	Archaeological	No	
Pomegranate	12th dynasty	Archaeological	Yes	Botanical
Egyptian plum	18th dynasty	Archaeological	No	
Olive	18th dynasty	Archaeological	Yes	Literary/botanical
Watermelon	18th – 20th dynasty	Archaeological	No	
Apple	19th dynasty	Literary	Yes	Botanical
Peach	Ptolemaic/Roman	Archaeological	Yes	Botanical
Pear	Ptolemaic/Roman	Archaeological	No	
Apricot	Ptolemaic/Roman	Archaeological	Yes	Botanical
Cherry	5 BC	Literary	No	
Citron	2nd century AD	Literary	Yes	Botanical

4.4.4 Fruit

The repertoire of fruit in Egypt has continuously changed, and the list has become larger with each passing century. Certain fruits have been consumed in Egypt since the Pre-dynastic period, while others were introduced later during the dynastic, Ptolemaic and Roman periods. Table 4.3 lists all known fruit from Predynastic to the Roman period in Egypt, and lists their earliest known appearance in Egypt (based on archaeological and documentary evidence). The focus in this section is on fruit that ap-

pears in documentary evidence or in archaeological finds from the Dakhleh Oasis, shown in bold in Table 4.3.

4.4.4.1 Dates

Dates are mentioned several times in papyri from Kellis (Worp 1995; Bagnall 1997). The KAB records whole dates, along with crushed dates and date stones. Bagnall (1997) notes that crushed dates were most likely pitted dates that were molded into a block. The amounts recorded for crushed dates are modest, and only appear in five lines. The price recorded for them implies that they were valuable, being worth 2.5 times more than regular dates (Bagnall 1997). Date stones are also mentioned, but not as a rent crop. Date stones are paid to the estate in lieu of dates on three occasions, are delivered against "angareia" (payment for transportation) obligations on two occasions, and are recorded in small quantities on two other occasions. Date stones were a low valued item that were probably ground down into a flour which was then mixed into a paste used to feed camels. Date stone flour may have been used to extend wheat flour for bread making (Bagnall 1997).

There are abundant archaeological finds of dates and related products in Kellis. Whole dried fruit, stones, inflorescences, leaves, and wood are very common throughout the site (Thanheiser, pers. comm.). Preserved date stones are also often found through out the burial matrix of several graves in the Kellis 2 (East) cemetery.

The date palm (*Phoenix dactylifera*) was one of the most important trees grown in the Oasis. Dates were normally cultivated along with olives, acacias or grapes. Sev-

eral historical travelers have commented on the sweetness and the fleshiness of the oa-

ses' dates. Today, as in earlier times, dates from the oases are considered to be superior

to any other dates grown in Egypt.

Date palms are particularly suited to hot arid environments. For maximum pro-

duction, dates require a dry climate with continual temperatures of around 30°C for sev-

eral months of the year (Curtin 1984). Dates also require irrigation rather than rainfall,

which can actually cause considerable damage to the fruit. An old Arab phrase best

sums up the date's needs: "the date palm grows best with its feet in running water and its

head in the fire of the sky" (Naylor 1986). Alkaline soils, such as those found in the oa-

ses, are optimal and help to produce excellent dates. In optimum oasis conditions one

date tree can produce 40 to 80 kg of fruit per year and will produce fruit for 75 to 80

years (Curtain 1984; Naylor 1986). Dates are rich in vitamins A, B_1, D, and G, and they

contain iron, magnesium, potassium, phosphorus, calcium, and copper. They also con-

tain fructose and glucose and are a good source of energy (Naylor 1986). The sugar

content of dates is very high, approximately 50% sugar by weight (Curtin 1983). They

do not provide an adequate staple diet, however, and must be eaten with other foods to

meet dietary requirements.

The true value of dates for the inhabitants of Dakhleh came from the trade of

dates with the Nile Valley and the Fayum. Dates soon became such an important source

of food and trade for the Oasis inhabitants, that it became known as the "bread of the

desert" (Naylor 1986). Several papyri suggest that merchants in the Nile delta would

only purchase dates grown in the oases (Wagner 1987).

4.4.4.2 Doum Palm Nuts

The doum palm has been grown in Egypt since the Pre-dynastic period and possibly even earlier than that (Darby et al. 1977). The tree bears a glossy-brown, bumpy, irregular fruit that is about 7-8 cm long and 7 cm broad. The fruit is soaked in water and eaten raw, or made into a syrupy liquid. Remains of the doum palm have been found in several early sites, and preserved fruit has been found in several tombs, most notably that of King Tutankhamon.

Mention of doum palm nuts only occurs once in a papyrus from Kellis (P.Kellis I G. 52.5), and in the KAB (Bagnall 1997). In the latter a receipt was issued for 200 doums, when in fact only 60 were delivered. The archaeological remains of doum palm fruit are common in Kellis (U. Thanheiser, pers. comm.).

4.4.4.3 Olives

By the Ptolemaic and Roman period the olive tree was grown extensively in Egypt, and particularly in the oases (Giddy 1987). The olive culture, including the manufacture of olive oil, was important in all of the oases from the first to the forth centuries AD (Wagner 1987). Several documents report an oil called "l'huile Oasitique" (Wagner 1987:297), but which oasis the oil came from remains unclear. The production of olives came second after dates, with Dakhleh producing slightly more than Kharga (Wagner 1987). Demotic ostraca have demonstrated that olive oil production existed in the Dakhleh Oasis since the Ptolemaic period.

During the height of the Roman Empire there was a vast expansion of olive growing and oil production in the Mediterranean area, possibly for export to other areas of the Roman empire. During the Roman period, the Dakhleh Oasis experienced a large surge in settlement growth and Bagnall (1997) suggests it may have been caused in part by the need to cultivate olives for oil production for export to the Nile valley. Although this hypothesis can not be substantiated at this time, one of the main pieces of evidence to support such a claim is found in the KAB. Of all the more valuable food commodities listed in the KAB, Bagnall (1997) calculates that olives and olive oil represent more than four-fifths of the total value. This suggests that olives and olive oil were very valuable commodities in this estate, and may have been the primary way by which Faustianus made his fortune.

In addition to the evidence in the KAB, other indirect lines of evidence favor the growing of olives in the Dakhleh Oasis. Because most of the arable land in Egypt was not particularly well suited to growing olives, there must have been a demand for olive oil in Egypt by the largely hellenized population. Other papyri and ostraca from Kellis and the rest of the Oasis document the presence of olives and oil production. There are specific mentions of oil pressing, the making of oil from olives, and of olives them-selves (Worp 1995; Bagnall 1997). Archaeological evidence of olive stones and olive wood (*Olea europaea*) are abundant at the site of Kellis (U. Thanheiser, pers. comm.). Because of its importance as an export commodity, it is not known how much of a role olives would have played in the local diet; however, it is safe to assume that olives, and

particularly olive oil, were consumed as they appear to have been an important part of the diet in the rest of Egypt at this time.

The exact date of the first cultivation of the olive in Egypt is presently under debate. It appears that the olive was cultivated in Egypt by the Ramesside period (circa 1552-1069 BC), and it became an increasingly important crop by the Ptolemaic and Roman periods (Giddy 1987). Actual archaeological finds of the olive tree and fruit date to the eighteenth dynasty (Darby et al. 1977). Remains of wood, fruit, stones have been found in tombs; olive twigs were commonly used in garlands and wreaths placed on the dead.

4.4.4.4 Grapes and Wine

Although fresh grapes are not specifically mentioned in either the papyri or KAB from Kellis, there is one mention of dried grapes and there are several mentions of wine. A transportation receipt (P.Kellis inv. P. 7.A) acknowledges the arrival of one camel load which contained dried grapes. A private letter (P.Kellis inv. P. 85.B #2) dated to the mid-fourth century, makes specific mention of "... sweet new wine" (Worp 1995). Both *must* (new wine) and wine are documented in the KAB (Bagnall 1997). Archaeological finds of grape from Kellis include whole dried fruits, pips, leaves and tendrils (U. Thanheiser, pers. comm.). The abundance of archaeological botanical remains of grapes from Kellis suggest that they were consumed in large quantities.

Although grapes have primarily been used in the production of wine, grapes as a fresh fruit and dried as raisins were also consumed by the ancient Egyptians. Preserved

grapes and seeds have been found in many Old Kingdom tombs (Darby et al. 1977), so it is possible that the grape has been cultivated since the Pre-dynastic period. Several varieties of *Vitis vinifera* were developed and cultivated in Egypt, and papyri from the Nile valley attest to its importance as a cultigen.

During the Ptolemaic and Roman periods, the majority of the grape crop was used in the production of wine. Vineyards were often grown in association with date palms. Date palms provided much needed shade from the hot sun, as well as protection from marauding animals and blowing sand (Lewis 1983). After harvesting in August and September, the grapes were stamped, pressed, and the expressed liquid was cached in ceramic vessels. Exposure to the sun left the resulting wine thick and sweet (Davies 1989). Wine of all types, including *must*, was widely available and thought to have been commonly consumed by the middle and upper classes of Egypt. Several sources have listed wine as part of the basic diet of the Roman soldier in Egypt (Davies 1989). Strabo the geographer wrote that the Dakhleh and Kharga Oases were rich with good wine (Wagner 1987).

4.4.4.5 Figs

Figs are recorded in both papyri from Kellis and the KAB (Worp 1995; Bagnall 1997). Archaeological finds of figs (*Ficus carica*) are common in Kellis and include whole dried fruits, and nutlets (the seeds found inside the fruit) (U. Thanheiser, pers. comm.). The abundance of archaeological remains suggests that figs figured prominently in the diet at Kellis.

Figs, particularly sycamore figs, have been a part of the Egyptian diet since the Pre-dynastic period (Darby et al. 1977). Dried figs have been found in several dynastic tombs, and fig trees and fruit are commonly depicted in tomb paintings. The Greek historians also make note of the use of figs by the Egyptians. Herodotus comments that sacrificial animals were stuffed with, among other things, figs (II, 40). Pliny the Elder also describes a black variety of figs grown in the Alexandria region (XV, XIX, 70). Athenaeus (4, 149, F) also notes that figs were eaten in Naucratis during banquets.

4.4.4.6 Peach

The peach appears to be a relatively late introduction into Egypt and does not appear in the archaeological record until the Ptolemaic-Roman period. Theophrastus does not mention the peach tree in his history of plants, so it was probably not known until after the 4th century BC. During the 1st century AD, Pliny the Elder comments that peaches were introduced to Egypt from Italy not long before his travels in Egypt (XV, XIII, 45). There is no mention of peaches in either papyri from Kellis or the KAB, but there have been archaeological finds of peach pits (*Prunus persica*) at Kellis (Thanheiser, pers. comm.), and the fruit was most likely eaten fresh.

4.4.4.7 Pear

The pear (*Pyrus communis*) , like the peach, was another late introduction to the dietary repertoire of the ancient Egyptians. It does not appear in Egypt until the Ptolemaic and Roman period. Theophrastus dedicates 40 passages in his history of plants to this fruit, and Pliny the Elder also talks about this fruit being in Egypt. At this

point, however, there is no archaeological or documentary evidence from Kellis to suggest that the pear was consumed in the Dakhleh Oasis during the Graeco-Roman period.

4.4.4.8 Apples

The history of the apple in Egypt is poorly understood. Darby et al. (1977) report only two references to apples, both of which occur during the New Kingdom period (1552-1069 BC). Botanical remains appear to be scarce, and there is no published record of them in the Pharaonic period. Apples do not grow well outside of temperate zones, and hence those apples grown presently in Egypt are inferior in quality and size to those imported from more temperate zones. Apples are not mentioned in papyri from Kellis or in the KAB, but whole apples (*Malus sylvestris*) have been identified from Kellis (U. Thanheiser, pers. comm.). They most likely played a supplementary role in the diet.

4.4.4.9 Apricots

Apricots were introduced to Egypt during the Ptolemaic/Roman period. There is no mention of them in the papyri or in the KAB, but apricot stones (*Prunus armenica*) have been found to be preserved at Kellis (U. Thanheiser, pers. comm.).

4.4.4.10 Citron

Citron (*Citrus medica*) was the first of the citrus fruits to arrive in the Mediterranean. It was cultivated in Egypt during the Ptolemaic and Roman periods and used for medicinal purposes and as a condiment with meat dishes (van der Veen 1998). Citron has been identified in small quantities at Kellis (U. Thanheiser, pers. comm.).

4.4.4.11 Jujubes (a.k.a. Christ Thorn)

The jujube fruit (*Zizyphus spina-christi*) is an indigenous fruit found in Egypt and northern Africa. It is a small red fruit (about the size of a cherry), and a very good source of vitamin C. Jujube remains have been found in tombs as early as the 1st dynasty, and they continue to appear throughout history. They are a common funeral offering, and were also used for medicinal purposes (Darby et al. 1977). It appears that by the Roman period the jujube was considered to be an important fruit as it is documented in several literary sources (Worp 1995).

At Kellis, the jujube is mentioned in a list of expenses (P.Kellis inv. P. 51.E #2), with part of a wage paid in money and another paid in jujube fruit. Worp (1995) states that the jujube is also mentioned in several yet-to-be-published papyri and ostraca from Kellis. Jujubes are also documented as payment of dues in the KAB (Bagnall 1997). Stones of the jujube are very common at Kellis (U. Thanheiser, pers. comm.).

4.4.4.12 Pomegranate

The pomegranate is not specifically mentioned in the KAB or in the papyri from Kellis, but its preserved remains (*Punica granatum*) have been identified in Kellis (U. Thanheiser, pers. comm.).

The first documentary evidence of the pomegranate appears in an inscription on the tomb wall of Ani who lived during the reign of Tuthmosis I (New Kingdom, 18th dynasty, 1506-1493 BC). In this inscription the pomegranate is listed as one of the trees that Ani planted in his funerary garden (Darby et al. 1977). So, it is evident that the

pomegranate was present in Egypt before this period. The first archaeological remains of the pomegranate have been dated to the 12th dynasty. Theophrastus (2, 2, 7) mentions the pomegranate in his discussion of plants, and Pliny the Elder also discusses the pomegranate in Egypt (XIII, XXXIV, 113). Because the pomegranate preserved and traveled well, it was commonly used as a trading and bartering commodity during the Roman period.

4.4.5 Nuts

Several varieties of nuts were available for consumption in ancient Egypt: almonds, hazelnuts, pine nuts, walnuts and pistachios. During the Roman period nuts were eaten as appetizers and they were believed to neutralize the effects of alcohol. Pliny the Elder notes that nuts were used medicinally to treat jaundice (XXIII, LXXVI, 146). Of the nuts available for consumption, the remains of almond, hazelnut, walnut, pine nut, pistachio and carob have been found at Kellis.

The botanical remains of almonds have been found in Kellis (U. Thanheiser, pers. comm.). The antiquity of almonds in Egypt is questionable, but Pliny the Elder notes that the almond tree was established in Egypt by the time he visited, but was primarily used for producing oil (XIII, II, 8). There are very few archaeological finds of almonds that pre-date this period. Darby and colleagues (1977) note that 30 almonds were found in the tomb of Tutankhamon, which dates the almond as early as the 18th dynasty (New Kingdom).

Hazel nuts are thought to have been imported, not grown, in Egypt, although

their remains have been found at many Roman period sites (Darby et al. 1977). Hazel nut remains have been identified at Kellis (U. Thanheiser, pers. comm.). The cultivation of pine nuts is also thought to have been very limited, with the majority of pine nuts consumed in Egypt probably imported from Libya and Lebanon. Evidence for the consumption of pine nuts comes from recipes dating to the Roman period (Solomon and Solomon 1950). Pine nuts have been identified at Kellis (U. Thanheiser, pers. comm.).

Walnuts do not make an appearance into Egypt until the Ptolemaic period. Darby et al. (1977) report one letter from 205 BC requesting shoots of walnut trees.

Table 4.4. List of spices used in ancient Egypt. Those highlighted in bold have been identified in Kellis. Information for this table was taken from Darby et al. (1977); Bagnall (1997); and Thanheiser (pers. comm.).

Spices	Earliest Evidence	Documented in the KAB	Presence in Dakhleh[15]
Ami	1st century AD (Pliny)	No	No
Anise	Ptolemaic/Roman period	No	Yes
Caper	1st century AD (Pliny)	No	No
Cinnamon	New Kingdom (Ramses III)	No	No
Coriander	Eber's Papyrus & King Tut	No	Yes
Cumin	New Kingdom (Ramses III)	Yes	No
Dill	New Kingdom (18th dynasty)	No	No
Fennel	Eber's Papyrus	No	No
Fenugreek		Yes	No
Laurel	Ptolemaic/Roman period	No	No
Marjoram	Old Kingdom	No	No
Mint	New Kingdom	No	No
Mustard	12th dynasty	No	No
Pepper	Ptolemaic/Roman period	No	No
Rosemary	New Kingdom (Ramses III)	No	Yes
Saffron		No	No
Thyme	Eber's Papyrus	No	No

[15] Presence in the Dakhleh Oasis as demonstrated by the identification of botanical remains at Kellis.

Several archaeological specimens dating to the Roman period have also been found, including remains identified from Kellis (Thanheiser, pers. comm.). Although Darby et al. (1977) list the pistachio as a recent introduction into Egypt, there is evidence from the Dakhleh Oasis to suggest that the pistachio was consumed in that area during the late Roman period (U. Thanheiser, pers. comm.).

4.4.6 Spices and Herbs

The list of spices used in ancient Egypt is quite lengthy. Instead of discussing each spice individually, they are presented in Table 4.4 with information as to evidence of their first appearance and whether or not the particular spice may have been used in the Dakhleh Oasis. Botanical evidence of coriander (*Coriandrum sativum*) occurs frequently in habitation areas (U. Thanheiser, pers. comm.). Botanical remains of rosemary (*Rosmarinus officinalis*) and anise (*cf. Pimpinella anisum*) are present in Kellis, but they are rare. Both pepper (*Piper sp.*), fenugreek (*Trigonella foenum-graecum*) and cumin are mentioned in papyri and in the KAB (Bagnall, 1997).

Spices have always played an important role in the cuisine of the ancient Egyptians. Not only were spices used to enhance food, but they also served a more functional role. Lack of refrigeration caused foods to spoil quickly and spices and herbs could be used to cover up the smell of decomposing food. In addition, spices and herbs were mixed with ointments and oils to mask body odors before habitual bathing became a normal practice.

The demand for spices and herbs was enormous and therefore prices for them

were very high. Merchants who dared to dabble in the import and export of herbs and spices and to risk certain piracy at sea usually made incalculable fortunes. It is difficult to estimate the impact that the trade of spices had on the economy and politics of Egypt, but there are a few documented instances that show its importance. Queen Hatshepsut (1478-1458 BC) recorded in her famous temple at Thebes the details of an expedition she launched to the distant land of Punt to obtain the myrrh and spices demanded for the festivities of worshiping Amon. Later, Emperor Nero (AD 37-68) caused great distress among the people of Rome when he burnt a years supply worth of cinnamon at the funeral of Poppaea.

Apart from a few locally grown spices like anise, cumin and mint, most spices were imported into Egypt. Cinnamon was imported from Ceylon, India and China by way of the Red Sea or from the Levant; cloves came from the Mollucas, Amboina and Banda; pepper came from Ceylon, Malabar, Ethiopia (pepper from Ethiopia was considered to be of very high quality), Cochin, Sumatra, and Java; saffron was brought in from Persia, Cilicia and Spain; cardamon from Malabar by way of Aden; and ginger came from India, Arabia, Zanzibar, Madagascar and Turkey.

4.4.7 Sweeteners

Although there is no direct archaeological evidence to suggest apiculture in the Dakhleh Oasis, it is certain that honey was available. One private letter (P.Kellis inv. P. 82.C) requests Philammon to send nine sextarii of "good honey" as payment for a debt owed to the writer (Worp 1995). Honey is also mentioned in one entry in the Kellis Ac-

count's Book.

Sugar, either from sugarcane or from beets, is a relatively recent introduction to the diet. Before cane sugar became widely available, honey was one of the only natural sweeteners used. It has been used as a sweetener in Egypt since before the Old Kingdom period (Darby et al. 1977). During the beginning of the Old Kingdom period honey was collected from wild hives in the delta. It was therefore a prized, valuable commodity limited to the nobility. For those who could not afford honey as a sweetener, another option was to use fruit juice.

By the fifth dynasty apiculture appears to have been an accepted profession. Remains of honey and honey combs have been found in many tombs. Two jars marked "fresh honey" were found in Tutankhamon's tomb (Darby et al. 1977). Honey was also used as a sweetener in cakes and pastries, a primer in beer and wine, and as an ingredient in several medicinal recipes. It continued to be an important sweetener through time (Chouliara-Raïos 1989; Davies 1989).

3.5 Summary: Pulling It All Together - The 'Menu'

This chapter has focused on all the food items that may have made a significant contribution to the diet in Egypt. The intent is to determine what foods might have been available to the inhabitants of the Dakhleh Oasis during the Third Intermediate Period, the Ptolemaic period and the Roman period. Although the list of fruits and vegetables has expanded through time, it appears as though the primary sources of protein re-

Table 4.5. A list of possible food items that may have made up the menu of food choices during the Third Intermediate Period (ca. 800 BC) in the Dakhleh Oasis.

Animal Protein	Field Crops	Garden Plants	Fruits & Nuts	Other
Cows	Wheat	Turnips	Dates	Honey
Pigs	Barley	Garlic	Doum Palm Nuts	Cinnamon
Goats		Celery	Figs	Coriander
Donkeys		Legumes	Olives	Cumin
Camels		Onions	Pomegranates	Dill
Pigeons			Jujubes	Fennel
Geese			Carob	Marjoram
Ducks			Almonds	Mint
Wild Ostrich				Rosemary
Eggs				Safflower
Fish				Thyme
Gazelle				Mustard
Oryx				
Hartebeest				
Hare				

mained fairly constant, with the exception of hunted wild animals (Churcher 1993). Circa 800 BC, the inhabitants of the Dakhleh Oasis (those individuals from the 'ein Tirghi cemetery) most likely would have had access to the foods listed in Table 4.5. This list is based primarily on evidence from greater Egypt, so some foods in the table may not have been considered at the Oasis. It is interesting to note, however, that all of the plant foods fall into the C_3 category; therefore, even if these hypothesized dietary components do not completely reflect the true diet, the stable isotope signature of the inhabitants' bones should reflect a diet composed of C_3 plants.

During the Ptolemaic and Roman periods certain foods, particularly fruit and

Table 4.6. A list of the possible food items that may have made up the menu of food choices during the Ptolemaic and Roman periods in the Dakhleh Oasis. Foods that are new additions since the Third Intermediate Period are highlighted in bold.

Animal Protein	Field Crops	Garden Plants	Fruits & Nuts	Other
Cows	Wheat	Turnips	Dates	Honey
Pigs	Barley	Garlic	Doum Palm Nuts	Coriander
Goats	**Millet**	Legumes	Figs	Cumin
Donkeys	**Sesame**	Onions	Olives	Dill
Camels		**Cucumber**	Pomegranates	Fennel
Pigeons		**Gourds**	Jujubes	Marjoram
Geese		**Artichokes**	Carob	Mint
Ducks			Almonds	Rosemary
Eggs			**Apricots**	Safflower
Fish			**Peaches**	Thyme
Gazelle			**Pears**	Mustard
Oryx			**Cherry**	**Ami**
Hartebeest			**Citron**	**Anise**
Hare			**Apples**	**Caper**
Chickens			**Walnuts**	**Laurel**
			Pistachios	**Pepper**
			Hazelnuts	
			Pine Nuts	

vegetables, were added to the menu. Attention is focused specifically on these time periods because the cemeteries under analysis here are believed to be dated to them. Table 4.6 lists all the foods that may have been available to the occupants of Kellis during the Ptolemaic and Roman period. Most of the foods are the same as those listed in Table 4.5, and the new additions to the list are highlighted in bold.

Although these two menus appear to be very similar, the addition of millet to the

diet during the late Ptolemaic and early Roman period may have had a significant impact on isotopic signatures during the Roman period. As will be discussed further in Chapter 4, millet is a C_4 plant, and the $\delta^{13}C$ value is enriched in comparison to C_3 plants such as wheat and barley. Any significant consumption of this plant by humans, or by the animals

that were consumed by humans, may cause the human isotopic signal to shift. This possibility, and the ramifications of such a change in diet, are explored further in the Results and Discussion chapters.

Now that a menu of possible food choices has been established, the next step is to examine the by stable isotope analysis actual evidence for the 'meal' that was consumed by the inhabitants of the Dakhleh Oasis.

Chapter 5
The 'Meal':
Theoretical Concepts and Limitations of
Stable Isotope Analysis

5.1 Introduction

Chemical analysis, particularly stable isotope analysis, is a very useful tool in the detection of aspects of prehistoric diets. Although several studies state that stable isotope analysis is useful for 'reconstructing' prehistoric diets (e.g., Tieszen et al. 1992; Schwarcz et al. 1985; Schoeninger and DeNiro 1982), stable isotope compositions can only be used to distinguish certain food groups, rather than individual food items. Stable isotope analysis is a specific approach that requires additional lines of evidence because it essentially "...provides a method for testing and refining dietary reconstructions that are generated from the interpretations of other sources of evidence" (Keegan 1989:224). A more accurate description of stable isotope analysis would be to say that it provides 'consumption profiles', "... the isotopic signatures of the consumers, which reflects contributions to the diet from different food groups" (Keegan 1989:232). If we

use primary archaeological evidence to construct the 'menu' of foods available to the consumers, stable isotope analyses can then be used to create the consumption profile and the 'meal' that was selected from the 'menu' (Bumstead 1985). This, of course, must take into account issues of preservation, as there will be differential preservation of certain food remains (e.g., strawberries versus peaches).

Using methodology adopted from geochemistry, DeNiro and Epstein (1978; 1981) and van der Merwe and Vogel (1978) demonstrated that the carbon and nitrogen isotopic values of the diet are directly reflected in the tissues of the consumer. Several researchers have subsequently used stable isotope analysis to reconstruct environments (Ambrose and DeNiro 1987; 1989; Schoeninger et al. 1997; Sealy et al. 1987); to detect differential consumption of terrestrial vs. marine diets (Ambrose et al. 1997; Chisholm et al. 1982; Schoeninger and DeNiro 1984; Walker and DeNiro 1986); the introduction of maize into areas in North America (Schwarcz et al. 1985; Katzenberg et al. 1995); and patterns of human migration (Sealy et al. 1993; Sealy et al. 1995); and to examine patterns of infant and childhood health through studies of weaning (Fogel et al. 1989; Herring et al. 1998; Katzenberg 1993; Katzenberg and Pfeiffer 1995; Wright and Schwarcz 1998).

The purpose of this chapter is to discuss some of the theoretical concepts and limitations behind the use of stable isotope analysis in anthropological dietary studies. This description will be limited to carbon and nitrogen isotopes, as these are the two isotopes that are used in this study.

5.1.1 Stable Isotopes and Definitions

Most elements in nature occur in more than one form. These alternative forms are called isotopes, and they occur in stable and radiogenic forms. Radiogenic, or unstable, isotopes are characterized by a well-defined rate of decay. For example, ^{14}C, the radiogenic isotope of carbon, has a decay constant corresponding to a half life of approximately 5730 years, and is used in radiocarbon dating. The two stable isotopes of carbon used in stable isotope analysis are ^{12}C and ^{13}C, and the stable isotopes of nitrogen are ^{14}N and ^{15}N. All isotopes of a given element possess the same number of electrons and protons, but they differ in the number of neutrons. Different isotopes of the same element also have the same chemical properties, however they differ in their mass because of the number of neutrons. For example, the stable isotopes of nitrogen, ^{15}N and ^{14}N, have 15 and 14 neutrons respectively. This number is also an indicator of isotopic mass, and as such ^{15}N is the heavier of the isotopes. The mass of the isotope will ultimately determine the speed at which it will react. Lighter isotopes have faster reaction rates than heavier isotopes and this dichotomy leads to isotope **fractionation**. Fractionation is defined as the difference in isotope ratio between the product and the substrate (which can be indicated by the use of the "Δ") (Schoeninger 1995). For example, the nitrogen fractionation factor between diet and collagen ($\Delta_{diet-collagen}$ is reported to be +3 ‰ (DeNiro and Epstein 1981). There are two kinds of fractionation, kinetic isotope fractionation and equilibrium isotope fractionation (Schoeninger 1995). Kinetic isotope fractionation occurs during a biochemical reaction. For example, in the synthesis of

collagen, enzymes will determine the magnitude of fractionation. Equilibrium isotope fractionation occurs during some physical process, such as evaporation or crystalliza- tion, and the magnitude depends on temperature. An example of this would be bone mineral synthesis, in which temperature controls the degree of fractionation.

The actual fractionation that occurs during most reactions involving carbon and nitrogen is very small. In order to express the small ratios in larger terms geochemists use a special notation to express their data. The isotope ratio of a sample is expressed relative to the isotope ratio of an international standard using a 'δ' notation (DeNiro 1987). The resulting isotope value is expressed in parts per thousand (‰). Using car- bon as an example, the formula used to calculate the isotope ratio is:

Equation 5.1.   Formula for calculating the iso- tope ratio for carbon.

$$\delta\ ^{13}C = \left[\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{standard}} - 1 \right] \times 1000\ ‰$$

The standard used for carbon is the calcium carbonate in the shell of fossil belemnite from the PeeDee Formation in South Carolina, normally abbreviated PDB. The formula for the nitrogen ($^{15}N/^{14}N$) isotope ratio ($\delta^{15}N$) follows the same structure as that for carbon. The standard for nitrogen is AIR (atmospheric N_2). A 'δ' value that is negative indicates that the sample is depleted in the heavier isotope relative to the stan- dard, and conversely a sample that is positive is enriched in the heavier isotope relative to the standard. Biological samples tend to have negative $\delta^{13}C$ values because the stan-

dard (PDB) has more ^{13}C relative to ^{12}C than most biological material. The opposite is true for $\delta^{15}N$ as most biological sample contain more ^{15}N than the standard (Schoeninger 1995).

5.2 Carbon Isotopes

Carbon isotopes are commonly used to distinguish between diets based on C_3 or C_4 plants. Terrestrial plants can be divided into three groups based on their ability to concentrate carbon (Ambrose and DeNiro 1986a). C_3 plants use the enzyme ribulose bisphosphate carboxylase to fix atmospheric carbon, resulting in a compound with three carbon atoms (DeNiro 1987; Smith and Epstein 1971). These plants have $\delta^{13}C$ values ranging from -22 ‰ to -33 ‰, with a mean of -26.5 ‰. C_3 plants include varieties such as wheat, rice, beans, tubers, nuts, most fruits and vegetables (DeNiro 1987), forest, montane, and wetland grasses, trees, and most shrubs (Lee-Thorp et al. 1989).

Plants that are categorized as C_4 utilize the enzyme phosphoenol pyruvate carboxylase, which after fixation creates a compound with four carbon atoms (Tieszen 1991; Smith and Epstein 1971). Because of their smaller fractionation of atmospheric carbon, the $\delta^{13}C$ value for C_4 plants is enriched in comparison to C_3 plants. The $\delta^{13}C$ values of modern C_4 plants range from -16 ‰ to -9 ‰, with a mean value of -12.5 ‰. C_4 plants include maize, sorghum, some millets, amaranth, chenopodium, sugar cane, teosinte, and tropical grasses (Schwarcz et al. 1985; DeNiro 1987; Lee-Thorp et al. 1989).

The last group of plants are called CAM, an acronym for crassulacean acid metabolism. These plants can use both enzymes to fix carbon, but the environment in which they grow will determine which enzyme they use. In arid environments CAM plants will utilize the enzyme phosphoenol pyruvate carboxylase, while in more humid environments they can also use the enzyme ribulose bisphosphate carboxylase (DeNiro 1987). The $\delta^{13}C$ value of a plant will depend on the photosynthetic pathway in use, but mean values are reported as -19‰ (Ambrose and DeNiro 1986a). Plants in this category include xeric plants such as cacti, euphorbias, agave, bromeliads (i.e., pineapple), yucca and prickly pear (Ambrose and Norr 1993).

The $\delta^{13}C$ value of a plant will depend directly on the $\delta^{13}C$ value of the atmospheric carbon. There has been a detectable change in the $\delta^{13}C$ value of atmospheric CO_2 since the beginning of the industrial revolution. The burning of fossil fuels ($\delta^{13}C$ <-26‰) directly influenced atmospheric carbon, resulting in a decrease of 1.5‰ (Marino and McElroy 1991). Plants grown before the 1800's reflect $\delta^{13}C$ values that are approximately 1.5 ‰ heavier than their modern counterparts.

The carbon isotope patterns established in plants are passed on throughout the food chain. The fact that the carbon isotope ratio of an animal's tissues is related to the $\delta^{13}C$ of their diet has proven to be very useful in the detection of prehistoric diet. It has been established that there are no differences in human isotope fractionation between males and females or different ages that are due to physiological processes (Lovell et al. 1981; DeNiro and Schoeninger 1983; Ambrose and Norr 1993); hence, any differences

found can be attributed to consumption of different diets. This has allowed for the detection of the introduction of C_4 plants such as maize into a diet that was previously dominated by C_3 plants (Schwarcz et al. 1985; Katzenberg et al. 1995). It is also possible to determine the proportion of C_4 plants in the diet using the formula presented in Schwarcz et al. (1985) and used by White and Schwarcz (1989)[1]. White and Schwarcz (1994) and White (1993) also demonstrate the usefulness of using $\delta^{13}C$ values of soft tissues to detect seasonal variation in diet. The $\delta^{13}C$ values of human tissue have also been used to detect the differences between terrestrial and marine based diets (Walker and DeNiro 1986; Ambrose et al. 1997). Marine organisms are enriched in ^{13}C, therefore they demonstrate higher $^{13}C/^{12}C$ ratios than terrestrial animals.

5.2.1 Bone

Carbon isotopes can be measured from virtually every tissue. Tissue $\delta^{13}C$ values may differ within the same individual because of the differences in tissue composition, secondary fractionation rates, turnover rates, and synthesis from different parts of the diet (Lee-Thorp et al. 1989). Since soft tissue is not normally preserved in the archaeo-

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[1] The percentage of C_4 plants in the diet can be approximately estimated using the following formula:

$$PC_4 = \frac{(\delta_c - \delta_3 + A_{dc})}{(\delta_4 - \delta_3)} \times 100$$

δ_c is the measured value of collagen sample

δ_3 is the average $\delta^{13}C$ value for C_3 plants (usually $-26.5\permil$)

δ_4 is the average $\delta^{13}C$ value for C_4 plants (reported as $-11.5\permil$ for sorghum and millet by White and Schwarcz 1994; and $-9\permil$ for maize by Schwarcz et al. 1985).

A_{dc} is the fraction factor between diet and collagen ($+5\permil$)

White and Schwarcz (1994) note that they apply this formula with caution in recognition of the controversy over the number of sources which may contribute to collagen (i.e., plants, or plant eating animals), and because of the role of macronutrient transfer which influences the isotopic signals of different tissues (discussed further in this chapter).

logical record, $\delta^{13}C$ values are usually determined for either the organic or inorganic portion of bone. Collagen, the largest constituent of the organic portion of bone, is most commonly used for carbon isotope analysis. The turnover rate for adult bone collagen is estimated to be almost 25 years (Stenhouse and Baxter 1979), and prehistorically or even today, this amount of time may represent the life span of an individual; hence, the $\delta^{13}C$ values may reflect the average total diet of the adult individual. Turnover rates for infants and children have not been reported.

The inorganic portion of bone can also be used for carbon isotope analysis. Using the mineral portion of bone for isotopic analysis has an advantage over collagen in that it survives much longer in the burial environment. Another advantage is that bone carbonate is derived from the total dietary pool of ingested carbon (Tieszen and Fagre 1993; Schwarcz 1999). The inorganic portion of bone is made up of a poorly crystallized form of hydroxyapatite. Carbon is present in the form of carbonate ions in at least two locations in the apatite: 1) as absorbed carbonate which may occur on the crystal surface and is easily exchanged in the burial environment; and 2) as structural carbonate which substitutes for phosphate in the apatite crystal lattice, and is more resistant to diagenetic change (Lee-Thorp et al. 1989; Ambrose and Norr 1993). In 1981, Sullivan and Krueger proposed that the carbonate extracted from apatite could be successfully used to infer aspects of diet. Schoeninger and DeNiro (1982) challenged this assumption by asserting that the carbonate ions located on the surface of the apatite structure can undergo exchange with carbon found in the burial environment, either from soil

CO_2 or bicarbonates. Any exchange incurred during the diagenetic process would alter the structure and affect the $\delta^{13}C$ values obtained during carbon isotope analysis. Since this time several methods have been proposed for pre-treating the bone to remove any diagenetic material. Lee-Thorp and colleagues (1989) comment that once pretreatment has been completed there still may be alteration of the structural carbonate, but the effects are only significant in very old specimens (>100 ka). Lee-Thorp and van der Merwe (1991) have demonstrated that the apatite in tooth enamel is more resistant to diagenetic alteration than apatite in bone, and may be the best material to use for dietary reconstruction in very old fossil material.

The difference in isotopic composition between human diet and human collagen ($\Delta_{diet-collagen}$) is reported as being between +4.7 ‰ to 6.1 ‰ (Ambrose and Norr 1993). Most researchers accept that collagen is enriched by 5 ‰ over the diet (van der Merwe and Vogel 1978; Lee-Thorp et al. 1989). In bone, apatite is more enriched in ^{13}C than bone collagen. The diet-apatite fractionation in apatite has been reported as +12 ‰ (Krueger and Sullivan 1984; Lee-Thorp et al. 1989). If it is assumed that the $\Delta_{diet-collagen}$ is +5 ‰, then the $\Delta_{apatite-collagen}$ would be +7 ‰. This equation is adequate for describing the relationship between diet and tissue composition if the tissue being analyzed represents an animal that only consumed plants. It becomes more complicated when considering the relationship between collagen and apatite for carnivores and omnivores.

5.2.2 Other Tissues

In situations where soft tissue such as hair, muscle and skin is preserved, $\delta^{13}C$

values reflect a much shorter period of time. The turnover rate for such tissues is re-

ported as being weeks to months, and as such $\delta^{13}C$ values should represent the protein

portion of the diet of the individual just before they died (Katzenberg and Krouse 1989;

Tieszen et al. 1983; Krueger and Sullivan 1984). These tissues also show offsets rela-

tive to diet. The fractionation factor in $\delta^{13}C$ for hair ($D_{hair-diet}$) is reported to be 1‰ in

controlled animal studies (DeNiro and Epstein 1978; Tieszen et al. 1983), while values

ranging from 1.3 to 3.4 ‰ have been reported for wild animals (Katzenberg and Krouse

1989). Tieszen et al. (1983) found that de-fatted muscle tissue differed from the diet by

less than 1‰ in their controlled diet study of gerbils and comment that the $\delta^{13}C$ value of

muscle is one of the most direct indicators of diet.

Although the preservation of hair is rare in archaeological sites, there are cases,

such as the Dakhleh Oasis, in which it is possible to analyze hair for its isotope values.

Hair is a good tissue to sample for several reasons: it grows at a relatively constant rate

(1 cm/month), therefore making it possible to obtain average dietary information over

several months to a year if the hair length is long enough. In living populations, hair is a

tissue that can be obtained non-invasively (Yoshinaga et al. 1996). In addition, several

studies on modern populations have revealed that the carbon isotopic composition of

human hair is consistently 1‰ heavier than of the diet, irrespective of dietary composi-

tion (Minagawa 1992; Yoshinaga et al. 1996; Nakamura et al. 1982). The $\delta^{15}N$ of hu-

man hair was also found to be reflective of diet in modern human populations.

Other tissues such as mummified skin and muscle have also been reported to be offset from diet by a near constant rate. Although there have been no controlled studies to determine the offset between diet and either skin or muscle, White (1991) found the offset between diet and skin to be 1-2‰. White and Schwarcz (1994) report mean differences in $\delta^{13}C$ of approximately 1‰ between skin and muscle tissue for Nubian mummies. Mean collagen $\delta^{13}C$ value was found to be very similar to the mean $\delta^{13}C$ value of skin for both males and females, while muscle was consistently enriched in ^{13}C. Skin and hair samples from Egyptian mummies from the Kharga Oasis show that hair samples were consistently enriched in ^{13}C (White et al. 1998).

5.2.3 Dietary Sources of Carbon

Herbivores, carnivores and omnivores may receive carbon from different components in their diet. Therefore it is important to recognize where the carbon in collagen and apatite comes from. Diet is composed of three important macronutrients: carbohydrates, lipids, and proteins. Each of these macronutrients is used differently by the body and has unique isotopic characteristics. Carbohydrates provide the largest single source of carbon in all but carnivore diets. They are used for energy metabolism or are stored as glycogen for later use. Most carbohydrates are respired to produce CO_2 which is transported largely as blood bicarbonate to the lungs and expired (Ambrose and Norr 1993). Those tissues that incorporate carbon via blood bicarbonate will be influenced by the isotopic characteristics of the carbohydrates in the diet. In bone, apatite incorpo-

rates carbon from blood bicarbonate (Krueger and Sullivan 1984).

Lipids provide the second largest source of carbon in most diets and are a major source of carbon in carnivore diets. Lipids are metabolized to meet energy requirements (Krueger and Sullivan 1984). In bone, the carbon from lipids is incorporated into the apatite via the same route as carbon from carbohydrates. The isotopic signal of lipids is depleted in ^{13}C relative to carbohydrates by 2‰ (Krueger and Sullivan 1984).

Protein is the third major source of carbon in the diet. Protein is essential for growth and carbon from this source is incorporated into bone collagen. Protein is enriched by approximately 4‰ over carbohydrates (Krueger and Sullivan 1984). In a healthy adult animal the majority of protein is used to replace tissues that are being recycled. A controlled study of rat diets suggests that collagen carbon is mainly derived from dietary protein (Ambrose and Norr 1993). The authors determined that the δ^{13}C value of rat collagen reflects the δ^{13}C value of the dietary protein and that it is poorly correlated to that of the whole diet. The significance of this finding is that δ^{13}C values of collagen will reflect the protein component of the diet (when protein is sufficient), therefore may not accurately reflect the total diet. It is important to note, however, that these findings are based on animal studies and may not be an accurate reflection of what happens in human physiology. In addition, it should be noted that the carbon from protein is also incorporated into the blood bicarbonate, where it is then incorporated into the tissues.

5.2.4 Herbivore, Carnivore and Omnivore Diets

Because herbivores only eat plant material, their diets are the easiest to understand in terms of macronutrients. The herbivore diet is mainly composed of carbohydrates plus small intakes of lipids and proteins. As carbohydrates provide the primary source of energy and carbon for the herbivore, it would be expected that the isotopic signature is best reflected in the carbonate of the apatite. Lipids only provide a small amount of carbon and this is not sufficient to influence the isotopic ratio of carbon in bone apatite but usually suffices to meet dietary requirements for growth and tissue turnover. The distribution of amino acids may not be adequate for tissue turn over or growth and, as such, it would be expected that a great deal of amino acid synthesis would occur. This would assure that the collagen of the herbivore would closely reflect the isotopic composition of the herbivore's diet.

The diet of a carnivore is almost opposite to that of the herbivore, with an abundance of protein and lipids and almost no carbohydrates. Because of the abundance of protein, little or no amino acid synthesis is necessary for tissue growth and turnover. Amino acid requirements are met directly from the diet and thus the carbon isotope signal in carnivore tissue should closely resemble the protein of the animals they have consumed (Krueger and Sullivan 1984). The major source of energy in carnivores is supplied by lipids; consequently, the isotopic signature in apatite reflects the carbon of lipids. Carbohydrates are almost absent from the carnivore diet and therefore do not influence the isotope ratio of the carbonate in apatite.
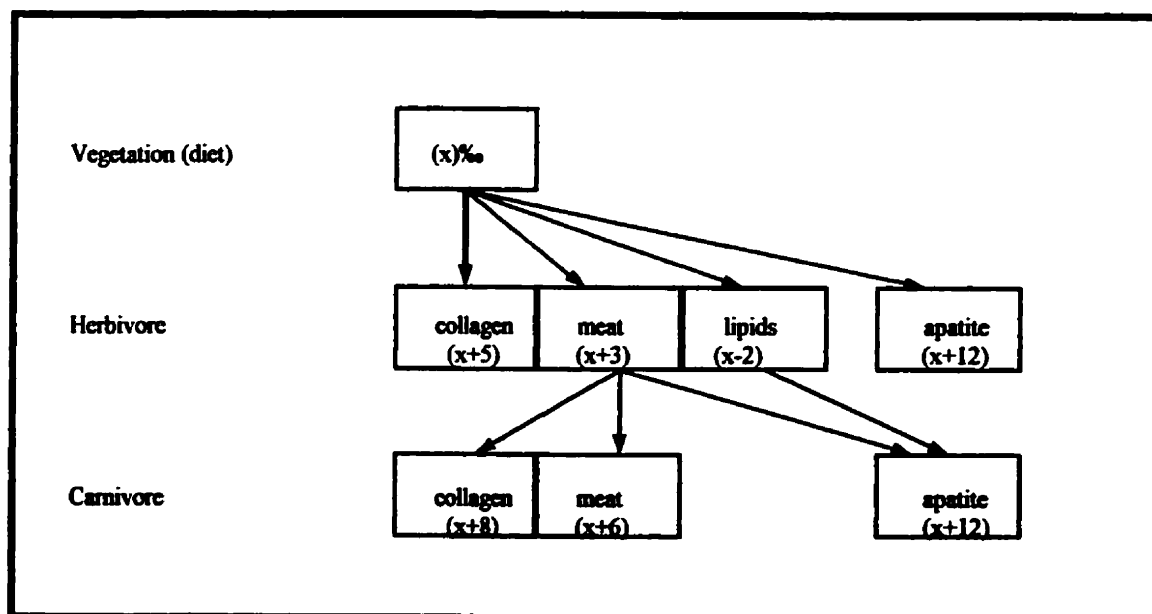
Figure S.1. Theoretical model for fractionation in the food chain for herbivores and carnivores. Model proposed by Lee-Thorp et al. (1989).

Both Krueger and Sullivan (1984) and Lee-Thorp and coworkers (1989) have proposed theoretical models for the A_{apatite-collagen} of carnivores. Krueger and Sullivan (1984) hypothesize that carnivore collagen is 5 ‰ enriched with respect to the diet, and that carbon in apatite principally reflects the isotope composition of the lipids of the prey. These arguments were formulated in response to the need to explain their observed data.

> Since lipids in meat are known to be about -6 ‰ relative to protein in the same meat, and protein is +5 ‰ relative to the plant diet of the prey animal, the average ^{13}C of the energy portion of the diet would be about +1 ‰ relative to the plant diet of the prey. Allowing for the +7 ‰ fractionation associated with respiration..., we would thus expect a ^{13}C value of about +8 ‰ relative to the diet of the prey in the apatite of carnivores, rather than the +12 ‰ of herbivores" (Krueger and Sullivan 1984:215).

Lee-Thorp et al. (1989) point out some important shortcomings of the Krueger and Sullivan (1984) model concerning secondary fractionation in carnivores and propose an alternative model (Figure 5.1). First, Krueger and Sullivan equated the $\delta^{13}C$ value of carnivore dietary protein with that of herbivore collagen. Carnivores get the majority of their protein from meat, however, and meat has been noted to be 2-3‰ more depleted than collagen from the same animal (DeNiro and Epstein 1978). Second, Lee-Thorp et al. (1989) note that herbivore lipids are more depleted than assumed in the model, on the order of -2‰ over diet. They further suggest that there is secondary fractionation between herbivore tissues and carnivore collagen of approximately +4.5‰, which results in a +12‰ enrichment in carnivore apatite over diet.

The diets of omnivorous animals, including humans, are more complicated as they include carbon from plant and animal sources. The major source of dietary carbohydrates, particularly in past populations, is mainly of plant origin. Human diets also include large portions of meat which supplies protein. In modern humans, it has been demonstrated that diets contain enough protein to assure tissue turnover, and therefore there is little need for the involvement of carbohydrates in protein synthesis. As a result, the carbon isotopes of collagen may not reflect the diet in total, but only the meat portion of the diet (Krueger and Sullivan 1984). Humans receive their energy requirements from the lipid, carbohydrate and protein in their diet. At one point it was believed that the isotopic signature of carbonate in the apatite would only reflect the carbohydrates of the diet, with a small contribution from lipids. This would have had im-

portant implications for the reconstruction of human diet. Using only one method of carbon isotope analysis (i.e., collagen or apatite) would give results that consider only one aspect of the total diet. It was thought that the use of both collagen and apatite allows for the differentiation of the energy and growth components of the diet, and as such gives a more complete picture of the total diet (Krueger and Sullivan 1984; Lee-Thorp et al. 1989). Paired $\delta^{13}C$ values for apatite and collagen were also thought to prove useful as an indicator of the importance of meat in the paleodiet, and may also allow for the calculation of difference in growth and energy contributions of the diet (Lee-Thorp et al. 1989). Lee-Thorp et al. (1989) stressed in their conclusions that the realization that carbon from collagen and apatite represent different components of the diet illustrates that $\delta^{13}C$ values obtained from apatite are not an alternative to collagen $\delta^{13}C$ values for very old or degraded specimens in which collagen cannot be obtained. This statement is true, but not because apatite excludes part of the dietary sources of carbon, but because collagen does.

Contrary to the previous arguments that carbon from carbohydrates and lipids are routed to the carbonate portion of bone apatite, Schwarcz (1999) argues that in fact the $\delta^{13}C$ value of bone carbonate should reflect a weighted average $\delta^{13}C$ from all consumed foods. The rationale behind this argument is that there is little if any fractionation between blood bicarbonate (HCO_3^-) and carbonate in apatite; hence, the $\delta^{13}C$ of apatite should reflect the total diet, as HCO_3^- gets carbon from all dietary sources, including protein. As such, all foods become "energy foods", not just carbohydrates and

lipids. This argument flows counter to what is presented by Ambrose and Norr (1993) and Krueger and Sullivan (1984), who state that apatite only receives carbon from carbohydrates and lipids, therefore representing the "energy" portion of the diet.

In addition, Schwarcz (1999) makes an interesting argument about the carbon sources of collagen. The protein structure of collagen is made up primarily of three non-essential amino acids (nEAAs): proline, glycine and hydroxyproline. These three nEAAs constitute approximately 78% of the amino acids in collagen. nEAAs can be synthesized by the body, although this is not necessary if the amino acids are obtained through dietary sources. The $\delta^{13}C$ value of a nEAA is dependent on the $\delta^{13}C$ value of its synthetic precursor. What is most interesting about this is that nEAAs and their precursors can get carbon from several sources, including fatty acids and carbohydrates. For example, proline, which makes up approximately 13% of the amino acids in collagen, is synthesized from α-keto glutarate, which gets its carbon from either fatty acids or carbohydrates. This observation indicates that the $\delta^{13}C$ value of collagen may, in fact, be influenced by several macronutrients, and not just by protein. Schwarcz (1999) argues that the 'routing' phenomenon described by Krueger and Sullivan (1984) and Ambrose and Norr (1993) may not be as straightforward as presented and that several factors must be considered before statements can be made both about carbon sources and about what portion of the diet is represented in collagen or apatite. Schwarcz, nevertheless, agrees that in diets with adequate protein, the $\delta^{13}C$ value of collagen will primarily reflect that of dietary protein. The argument set forth by Schwarcz (1999) also indicates

that there will be a variable $A_{diet-collagen}$ spacing depending on the nature of the diet; a

$A_{diet-collagen}$ of 5‰ is only valid when all nEAAs are synthesized. This issue will be considered when interpreting the diet of the individuals from the Dakhleh Oasis.

5.2.5 $\delta^{13}C$ Values, Ecology, and Climate

Recent research indicates that $\delta^{13}C$ values of plants may be affected by environmental factors such as climate and microenvironment (Francey and Farquhar 1982; Lajtha and Marshall 1994; Yakir et al 1994; Lipp et al. 1996; Schoeninger 1995). This may have important consequences for the interpretation of $\delta^{13}C$ values. In their examination of the $\delta^{13}C$ values of tree rings Francey and Farquhar (1982) found that higher precipitation and humidity is associated with wider ring widths and more negative $\delta^{13}C$ values. In contrast, warm and dry conditions are associated with narrow tree rings and more positive $\delta^{13}C$ values. Francey and Farquhar (1982) postulate that dry, arid conditions cause water stress in plants, which results in stomatal closure and consequently reduced CO_2 uptake by the plant. Yakir and colleagues' (1994) study of $\delta^{13}C$ and $\delta^{18}O$ values for ancient tamarix trees used by the Romans to construct a siege rampart at Masada, Jerusalem in AD 70-73 indicates that the trees were depleted in ^{13}C by ~ 3 ‰ compared to their modern counterparts at Masada. The same trend towards depleted ^{13}C values was noted when comparing modern tamarix trees in the Negev Desert to those found in central Israel. The authors conclude that, because the $\delta^{13}C$ values of the ancient tamarix trees were lighter than their modern counterparts, the environment dur-
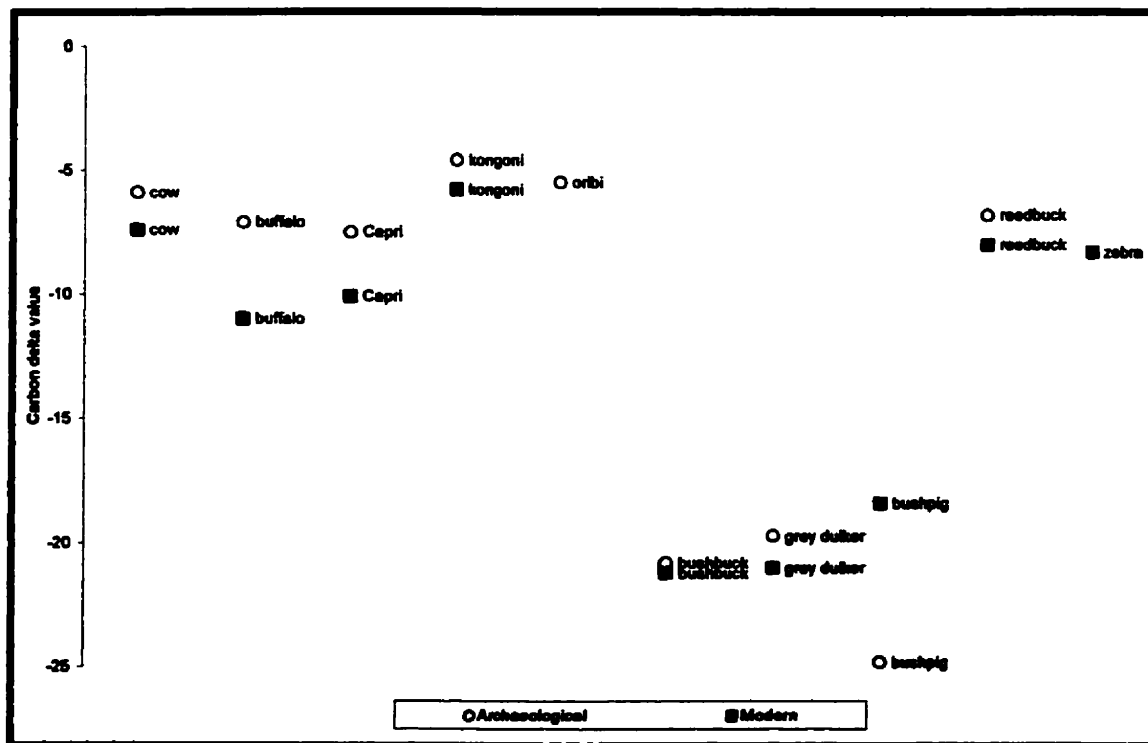
Figure 5.2. $\delta^{13}C$ values for archaeological and modern African herbivore samples. This graphs demonstrates the shift in $\delta^{13}C$ from the early Holocene to modern times for like species. The datum points represent mean values for multiple animals. Data from Ambrose and Deniro (1989).

ing AD 70-73 was less arid than the modern environment. Yakir et al. (1994) further suggests that the combination of $\delta^{13}C$ and $\delta^{18}O$ values for cellulose may be useful for detecting regional climatic change.

Lipp et al. (1996) subsequently developed an equation that utilizes $\delta^{13}C$ values to determine the relative humidity of an environment. Using data presented in Yakir and colleagues' 1994 article, $\delta^{13}C$ values for the modern tamarix trees showed a relative humidity of 46%, which is very close to the actual recorded value of 48%. The relative humidity calculated for the ancient tamarix trees was 65%, indicative of a much more humid environment than exists today. Ambrose and DeNiro (1989) note similar trends

in the $\delta^{13}C$ values for prehistoric African herbivores (Figure 5.2). They determined that the climate was wetter in the earlier Holocene than present, and as a result $\delta^{13}C$ values were more positive than found in modern day herbivores in the same location. The $\delta^{13}C$ shift between modern and archaeological animal samples appears to be in the 1 to 3‰ range. In addition to a change in climate, these data may also be shifting as a result of a change in diet.

The environmental influence of humidity/aridity on $\delta^{13}C$ values may have a significant impact on the $\delta^{13}C$ values from the Dakhleh Oasis. During the Neolithic period conditions in the Oasis were much more humid than they are presently, and the landscape supported animals that lived in savanna conditions (Churcher 1993). It may be possible that environmental conditions during the Third Intermediate, Ptolemaic and Roman periods were more humid than they are today. This assumption will be tested in this thesis by comparing modern and archaeological botanical and faunal remains from the Dakhleh Oasis (Chapters 7 and 8).

Closed microenvironments may also have a direct effect on the amount of carbon readily available for fixation by plants. $\delta^{13}C$ values for plants located in closed-canopy environments indicate that plants are depleted in ^{13}C because of the recycling of carbon into CO_2 from the oxidation of forest litter (Schoeninger 1995). Any animal feeding on the plants of the canopy will reflect the $\delta^{13}C$ values of the plants and will therefore also be depleted in ^{13}C. This principle has been used to determine the amount of forest cover in the habitats of monkeys in Costa Rica. Monkeys living in closed can-

opy environments had lower $\delta^{13}C$ values than those living in open-forest habitats (Schoeninger et al. 1994; Schoeninger et al. 1997). This suggests that $\delta^{13}C$ values may be useful indicators of paleoecology and paleoenviroment.

The fact that climate and environment may influence the $\delta^{13}C$ values of plants has important implications for paleodiet reconstruction. It is essential to reconstruct the food chain at every level to effectively interpret $\delta^{13}C$ values of organisms at the top of the foodweb. In many cases researchers have used modern plants to reconstruct $\delta^{13}C$ values for ancient plants (e.g., White and Schwarcz 1994); however, if there were a shift in climate or habitat over time, the reconstructed values for plants might in fact be erroneous and lead to false conclusions. Although it is not always possible to obtain archaeological plant material that is representative of the whole diet, researchers should be aware of the fact that climatic and habitat shifts through time may result in differing $\delta^{13}C$ values. The literature seems to indicate that this is more of a problem in arid and closed environments, rather than in more temperate regions (Schoeninger 1995). Because of the extremely arid conditions in modern Dakhleh, this phenomenon will be taken into account when assessing the $\delta^{13}C$ values of modern and archaeological botanical and animal remains.

5.3 Limitations of using $\delta^{13}C$ and $\delta^{15}N$ in Anthropological Studies

One of the major limitations of using both collagen and carbonate for dietary reconstruction is diagenesis. Diagenesis refers to chemical and physical alteration in bone

and tissues after their deposition. One of the most common contaminants of collagen is humic acid, which is the result of decayed plant material. Fungi are also noted as contaminants for collagen (Schwarcz and Schoeninger 1991). This type of contamination can be removed either chemically or mechanically before analysis. Collagen is also subject to postmortem degradation, which ultimately affects the collagen yield. Low collagen yields have been associated with aberrant carbon and nitrogen isotope values (Schoeninger et al. 1989).

Diagenesis of collagen can be detected in two ways, either through amino acid analysis or using C:N ratios. Through amino acid analysis we can compare amino acid profiles of ancient and modern bone. As collagen degrades, amino acids characteristic of non-collagenous proteins increase in proportion in the profile and the amino acid profile becomes dominated by non-collagenous proteins (Katzenberg 1992). DeNiro (1985) demonstrated that collagen degradation could also be detected using C:N ratios. The range for fresh collagen is 2.7 - 3.6, and any samples that fall outside this range should not be used for analysis. Very low ratios indicate collagen degradation, while those that are very high indicate that there is contamination most likely in the form of humic acids. Although these changes will directly affect the $\delta^{13}C$ values, they tend to have a greater effect on the $\delta^{15}N$ values of bone.

Apatite is also susceptible to diagenetic alteration. Surface carbonate is easily altered by exchange with groundwater after burial. Processes of dissolution and recrystallization may also alter structural carbonate. Acetic acid pretreatment has been used

to remove carbonate precipitated in the bone during burial. Techniques such as x-ray diffraction and infrared spectroscopy have been used to detect diagenetic carbonate (calcite) that was not removed by acid pretreatment (Lee-Thorp and van der Merwe 1991). Infrared spectroscopy is used to "...measure the absorption of infrared radiation by the sample at the vibrational frequencies of its component molecular bonds, allowing characterization of its structural sites" (Wright and Schwarcz 1996). This method also can be used to calculate the 'crystallinity index', which gives an indication of the size of crystals in the apatite structure. High crystallinity indices in bone may indicate post burial-growth of crystals, or the selective dissolution of small crystals. Wright and Schwarcz (1996) contend that an evaluation for diagenetic changes should be completed for each specimen as preservation of apatite may differ drastically over time and space.

Although diagenesis has been a major limitation in the past (Sillen et al. 1989), methods have been developed to deal with the problem. Because diagenesis is present in most burial environments there may be situations in which no treatment, particularly for bone samples, can prevent the exclusion of samples from the analysis. In this case dietary reconstruction from carbon isotopes would not be possible. Tooth enamel is the only biological structure that is very resistant to diagenesis. Tooth enamel is preferred over bone samples for isotope analysis, particularly in situations where diagenesis is evident.

Issues of preservation must be considered for samples from the Dakhleh Oasis. The arid condition of the Oasis has provided an environment that should provide sam-

ples that are well preserved. C:N ratios from all of the animal and human bone samples indicate that this is the case, and that issues of preservation do not affect the stable isotope results presented in this dissertation.

5.4 Nitrogen Isotopes

Nitrogen isotope values are commonly used to differentiate between terrestrial and marine based diets. The $\delta^{15}N$ of animal tissue is directly correlated with the $\delta^{15}N$ of the diet. $\delta^{15}N$ values also divide terrestrial plants into two distinct groups: legumes and non-legumes. Legumes fix nitrogen from the atmosphere via bacterial nodules located on the roots of the plant. There is little fractionation involved in this process and most legumes will have $\delta^{15}N$ values that are very similar to the $\delta^{15}N$ value of air (around +1‰). Leguminous plants include peas, peanuts, beans, mesquite, and acacia (Schoeninger 1995; DeNiro 1987). Non-legumes, on the other hand, do not fix nitrogen but take it up from the soil that receives nitrogen as the result of bacterial break down of organic material. $\delta^{15}N$ values for non-legumes tend to be enriched over atmospheric air, and therefore are more positive than those for legumes. It is also important to note that because of the recent widespread use of chemical fertilizers modern non-leguminous plants will have lower $\delta^{15}N$ values than their prehistoric counterparts. Earlier non-leguminous plants most likely had a $\delta^{15}N$ values that averaged to about +9‰ (DeNiro 1987).

The $\delta^{15}N$ values of marine plants are distinct from terrestrial plants. Marine

plants are unable to fix nitrogen and instead take up nitrogen from dissolved nitrate and ammonium (DeNiro 1987). The $\delta^{15}N$ values for marine plants vary with the location and conditions in the ocean, but generally the average $\delta^{15}N$ for marine plants is +7‰ (DeNiro 1987). Marine animals may be enriched as much as +10 ‰ over terrestrial animals, which reflects the fact that the marine food chain is much longer than the terrestrial food chain (see below). Coral reef ecosystems show much lower $\delta^{15}N$ values because coral reefs are nitrogen fixers (Keegan and DeNiro 1988). Animals feeding on coral have $\delta^{15}N$ values close to those of animals feeding on non-leguminous terrestrial plants (Keegan and DeNiro 1988; Schoeninger et al. 1983). Human populations that subsist on terrestrially-based diets have very different $\delta^{15}N$ values than those that consume a marine based diet. Individuals with exceptionally high $\delta^{15}N$ values (+15 to +20‰) usually have a diet heavily dependent on marine resources (Walker and DeNiro 1986).

5.4.1. Trophic Level Effect

One important note regarding nitrogen isotope fractionation is that there is a consistent fractionation amount between each level of the food chain. There is a step-wise increase in $\delta^{15}N$ of about 3‰ from one level of the food chain to the next. This is the result of a trophic level effect in nitrogen consumption (Ambrose 1986; DeNiro and Epstein 1981; Katzenberg 1989).

An interesting aspect of the trophic level effect is that the $\delta^{15}N$ value of a nursing human infant will be enriched by 3-4‰ over its mother (Fogel et al. 1989). Actu-

ally, an infant can be considered to be a carnivore feeding off of its mother's tissues in the form of milk and thus the infant is one trophic level above its mother. After weaning the infant's $\delta^{15}N$ values will change to reflect its new diet. Thus, $\delta^{15}N$ analyses have been used to determine the 'age at weaning' in past populations (Schurr 1998; Katzenberg and Pfeiffer 1995; White and Schwarcz 1994; Katzenberg 1993). In many cultures, however, solid food is gradually introduced into the infant's diet and breast-feeding does not suddenly cease. This defines weaning as a process, rather than as an event (Herring et al. 1998; Martin 1984). Another potential problem is the inexact knowledge regarding bone turnover rates in young individuals. To make estimates about the timing of the weaning process, knowledge about nitrogen turn over times in tissue is also necessary (Katzenberg et al. 1996).

5.4.2 $\delta^{15}N$ Values and Climate

One of the major complications associated with using $\delta^{15}N$ values to reconstruct diet is that the $\delta^{15}N$ values of an animal's tissues can be affected by environmental factors. Heaton et al. (1986) note that there is a strong correlation between the annual amount of precipitation and the $\delta^{15}N$ values of herbivores. In this case, animals residing in habitats that experienced minimal rainfall had higher $\delta^{15}N$ values than others living in wetter environments. Heaton et al. (1986) suggest that the observed increase in nitrogen isotope fractionation likely occurred within the animal itself. Ambrose and DeNiro (1986a) report similar findings for 238 large mammals in East Africa and observed variation in $\delta^{15}N$ within and between species of the same trophic level that could not be

accounted for solely by dietary differences. They found that drought-adapted animals (e.g., eland, gazelle, duiker, impala) had much higher $\delta^{15}N$ values than those that were water-dependent (e.g., cattle, buffalo, reedbuck, wildebeest, donkey).

Sealy et al. (1987), found a similar link between environmental and isotope values in their study of 300 marine and terrestrial animals from the southwestern Cape in South Africa. While the $\delta^{15}N$ values of marine organisms were similar to those reported in the literature, the $\delta^{15}N$ of terrestrial animals increased with decreasing precipitation. Herbivores with $\delta^{15}N$ values greater than +10‰ lived in areas with less than 400 mm/ year of rain. They conclude that in this particular geographic area nitrogen isotopes can not be used to distinguish between a marine or terrestrial based diet, but can be used as an indicator of the trophic level of foods consumed.

Data on humans living in arid environments lend further support to this phenomenon. Aufderheide and colleagues (1988) studied three different cultural groups from the Atacama Desert in northern Chile (dating between AD 400 and 1875). They found that individuals with lower $\delta^{15}N$ values lived in less arid environments than those with more enriched $\delta^{15}N$ values. Tieszen et al. (1992) report similar $\delta^{15}N$ values for human skeletal material from seven cultural groups from the Arica region of the Atacama Desert in northern Chile. The authors report that there are significant differences in $\delta^{15}N$ values between cultural groups, with group means ranging from 15.5‰ to 23‰; however, the authors link the enriched values to a strong dependence on marine resources and do not consider the possibility that the arid environment may have had an

effect on the ^{15}N enrichment.

Based on previous studies, Ambrose and DeNiro (1989) used nitrogen isotope values to evaluate prehistoric climate and environment, concluding that during the later Holocene, climates at two Kenyan sites were basically the same as today. Lower herbivore $\delta^{15}N$ values indicate, however, that during the early Holocene the climate was much wetter. In their study of North American white tail deer, Cormie and Schwarcz (1996) found that higher $\delta^{15}N$ values are correlated with low amounts of precipitation only if the C_4 plant component of the animal's diet was more than 10%. The majority of their sample did not reveal a correlation between $\delta^{15}N$ values and precipitation. This finding may be related to the fact that North American white tail deer subsist mainly on C_3 plants that are high in protein and water content. The implications of this study are discussed in the next section (5.4.3), but this finding implies that the quantity of C_4 plants consumed may indirectly affect the $\delta^{15}N$ of the animal.

All studies to date indicate that there is significant variation within and between habitats in herbivore $\delta^{15}N$ values that cannot be accounted for by diet alone (Ambrose 1991). The question remains: why do $\delta^{15}N$ values increase with decreasing precipitation? Two models have been proposed to account for this variability. The first model, proposed by Ambrose and DeNiro (1986b; 1987) suggests that the difference in $\delta^{15}N$ values between drought-tolerant and water dependent animals is caused by variation in the amount of urea excreted by these animals. The second model, proposed by Sealy et al. (1987), suggests that animals that consume a low protein diet must obtain additional

protein from symbiotic bacteria in the animal's digestive tract. This process is likely to cause secondary fractionation of nitrogen isotopes that would, in combination with increased urea output, serve to further enrich the animal's tissues in ^{15}N. Cormie and Schwarcz (1996) indicate that the type and amount of plant consumed (C_3 vs. C_4) may in fact be an important trigger for the physiological processes involved with water conservation. The switch from eating leaves to eating grasses may signal the animal's body that there is a need to conserve water. Neither Ambrose and DeNiro (1986b; 1987) nor Sealy et al. (1987) consider the proportions of C_4 plants in either browsers' or grazers' diets.

5.4.3 Urea Excretion and Nitrogen Balance Model

The model proposed by Ambrose and DeNiro (1986b; 1987) posits a key role for water conservation in relation to increased tissue δ^{15}N values in herbivores. The model is based on the fact that in water conserving animals urine becomes more concentrated and urea output is dramatically increased during times of water stress. As urea output increases, nitrogen loss through urea also increases (Rankin and Davenport 1981). Excreted urea is depleted in ^{15}N relative to diet, hence, any increase in the excretion of urea in response to water stress has an effect on the animal's nitrogen isotope mass balance. The trophic level effect is a direct result of this physiological mechanism, even in non-water stressed animals. In water stressed animals the kidney's osmotic pump exchanges urea for water. In order to conserve water, increased amounts of urea must be excreted. Thus, this model predicts that in dry environments, browsers should have

higher $\delta^{15}N$ values than grazers. Since more of the ^{14}N is excreted in animals that conserve water, their tissues in turn should be enriched in ^{15}N. Sealy and colleagues (1987:2713) remark that the following predictions can be made from this model: "(1) In any given environment, obligate drinkers should have lower $\delta^{15}N$ values than drought tolerant animals; (2) Grazers should have lower $\delta^{15}N$ values than browsers; and (3) These differences should be more noticeable in arid areas than in well-watered areas".

In times of water stress animals must consume a diet high in protein in order to maintain their nitrogen balance. During the dry season, dicot leaves are higher in protein than dry grasses, and as such browsers generally consume more protein that grazing animals. Browsers, in comparison to grazers, are able to supply their kidneys with urea during times of water stress. Browsers are also able to concentrate their urine to a greater degree than grazers and therefore are more drought-tolerant.

Ambrose (1991) adds to this model by noting that animals consume less food while under water and heat stress. From the following four facts outlined by Ambrose and DeNiro (1986b; 1987) and Ambrose (1991) a slightly revised model is proposed by Ambrose: "(1) Urea is the major form of excreted nitrogen; (2) Urea is depleted in ^{15}N relative to the diet; (3) The total amount of urea excreted increases under heat and water stress; and (4) food intake decreases under heat and water stress" (1991: 307). The model proposed states that, "Under stress, when animals excrete more ^{15}N-depleted urea, and eat less food, the pool of nitrogen that is not excreted and is available for tissue synthesis must have significantly more ^{15}N than the diet. Conversely, in unstressed

animals excreting less ^{14}N-depleted urea, while eating more food, the pool of nitrogen available for tissue synthesis must have significantly less ^{15}N" (Ambrose 1991:307). According to this model, animals that have the capacity to concentrate their urine should have higher tissue δ^{15}N values than those animals that cannot conserve water by concentrating their urine. It should also hold true that animals in hotter, more arid climates should have higher δ^{15}N values than the same species that inhabits a more humid, cooler environment. If all animals in arid environments, including humans, excrete increased amount of ^{15}N-depleted urea then this model will also successfully explain the ^{15}N enrichment between the trophic levels that is reported in Ambrose and DeNiro (1986b) and Sealy et al. (1987).

The proposed physiologic response to arid environments must be taken into account when considering the δ^{15}N values from the Dakhleh Oasis. Because the Dakhleh Oasis environment is presently so arid, it is not surprising that both animal and human δ^{15}N values are very high. It may be that the physiological response to this environment is causing the enrichment.

5.4.4 Nitrogen Recycling

Sealy and coworkers (1987) found that in grazers and browsers from Addo National Park in South Africa, browsers had higher δ^{15}N values than browsers, the reverse of that reported by Ambrose and DeNiro (1986b). Since Sealy et al. (1986) had expected that the browser/grazer, and obligate drinker/drought-tolerant dichotomy would be much clearer in increasingly arid environments, they proposed that in addition to in-

creased urea excretion, there are other physiological mechanisms that play an important part in nitrogen isotope enrichment.

Animals that eat low protein diets such as camels, humans and cows, show a marked decrease in the excretion of urea. Low protein diets require the animal to recycle nitrogen in order to maintain a healthy population of microbes (Nolan and Stachiw 1979; Kennedy and Hume 1978) that will synthesize the protein that the animal needs. A decrease in urea excretion serves to provide the necessary nitrogen for this purpose. In ruminants, there is actually a recycling of urea from the bloodstream back into the rumen, where it provides the raw material necessary to spawn protein-synthesizing microbes. This process also occurs in the hindgut of herbivores that experience hindgut fermentation. Sealy and coworkers (1987) hypothesize that each cycle of protein synthesis serves to increase the $\delta^{15}N$ value of the animal's tissues.

Herbivores that live in arid environments tend to consume diets that are low in protein. This is especially true of grazing herbivores, and hence they would become more dependent on the recycling of urea to provide their body with the necessary nitrogen that is needed for the synthesis of protein. If grazers did rely more on recycling their urea, then they should exhibit tissue $\delta^{15}N$ values that are enriched compared to the tissues of browsers. Although this model needs to be tested further, it does explain the differences in $\delta^{15}N$ values reported by Sealy and coworkers (1987) for grazers and browsers.

Ambrose (1991) believes that there are two potential flaws with this argument.

The first is that the urea that supplies the nitrogen for microbial protein synthesis most likely is depleted in ^{15}N relative to diet. Even if there were further fractionation caused by microbial activity, there would be no overall net enrichment in the tissues. The second problem with this model is that Sealy and co-workers do not take into consideration the overall isotopic mass balance of the entire animal. Ambrose (1991) makes the point that no tissue enrichment can occur until ^{15}N-depleted urea is excreted. If intensive urea recycling is occurring and an animal never excretes much nitrogen, then it may be impossible to create tissues that are enriched in ^{15}N. In fact, Ambrose (1991) proposes that if this is the case, then urea-recycling herbivores could actually expect to have lower tissue δ^{15}N values than non-urea recycling herbivores.

Both of these models presuppose, however, that browsers are not mutually exclusive from drought-tolerant animals, and that grazers are synonymous with obligate drinkers. This is not the case, as grazers and browsers can be either obligate drinkers or drought-tolerant. Also, as mentioned previously, neither model takes into consideration that the amount of C_3 vs. C_4 plants in the diet may play an important role in nitrogen balance. Recall that Cormie and Schwarcz (1996) found that North American white tail deer that consumed a diet consisting mainly of C_3 plants did not have tissue δ^{15}N values that correlated with rainfall. On the other hand, animals that consumed a diet with more than 10% C_4 plants did exhibit δ^{15}N values that were correlated with rainfall. From these results, Cormie and Schwarcz (1996) propose that the consumption of significant amounts of C_4 may be a physiological signal of nutrient and water stress that causes the

animal to excrete increased amounts of urea and therefore produces a concomitant increase in nitrogen recycling. In light of Ambrose's (1991) criticism of urea recycling, it is unknown whether or not both of these physiological mechanisms would actually work together. Cormie and Schwarcz's (1996) observations, nevertheless, may provide an important clue as to why the grazers in Sealy et al. (1987) study had higher $\delta^{15}N$ values than the browsers. In this situation the grazers may have been consuming more C_4 plants such as xeric grasses, while the browsers may have been eating more shrubs and leaves that are classified as C_3 plants.

Speculation as to the processes underlying the negative correlation between diminished precipitation and high $\delta^{15}N$ values has focused primarily on the metabolic response of the animal in a drought situation. Another clue to what causes high nitrogen values in arid environments may actually come from the base of the food chain. Preliminary studies from the Dakhleh Oasis (Dupras et al. 1999; Schwarcz et al. 1999) indicate that the ^{15}N enrichment throughout the food chain can be attributed to ^{15}N enrichment in arid-region plants, which in turn may be the result of ^{15}N enrichment in desert soils. Schwarcz and colleagues (1999) comment that in order for this magnitude of ^{15}N enrichment to occur, an animal would have to lose more than 95% of its nitrogen (Hoefs 1997); therefore, animals who show this trend may actually be reflecting an increase in $\delta^{15}N$ of plants with decreasing precipitation. Heaton (1987) has noted this trend in South African plants. This enrichment in plants can be directly linked to ^{15}N enrichment in desert soils. Schwarcz et al. (1999) suggest that the ^{15}N enrichment in the soil

may be the result of evaporation of ammonia from the soil, which is depleted in ^{15}N

with respect to nitrate and organic nitrogen species (Letolle 1980). This problem and

the data from the Dakhleh Oasis are explored further in Chapter 8.

5.5 Summary

The main purpose of this chapter is to present the fundamentals of stable

isotope theory and how it applies to the determination of paleodiet. The fundamentals

presented in this chapter provide the basis upon which interpretations of the data from

Dakhleh Oasis are made in Chapter 8. Several key issues, such as environmental condi-

tions and diagenesis, were also discussed. These issues are important when considering

possible climatic effects on the stable isotope results for the Dakhleh Oasis data. Before

these key issues and data from the Dakhleh Oasis can be discussed, sample description

and analytical methodology must be considered.

Chapter 6

Materials and Methods

6.1 Introduction

The primary purpose of this chapter is to present descriptions of the sites and samples used in this study. In addition, the methodology and statistics used to analyze the samples from the Dakhleh Oasis are considered in-depth.

6.2 Site and Sample Description

6.2.1 'ein Tirghi Cemetery

The 'ein Tirghi cemetery (site 31/435-D5-2) is located about 8km SW of the village of Balat in the Dakhleh Oasis, Egypt (Figure 6.1). The cemetery was discovered by members of the DOP while surveying the East End of the Oasis during the 1982-83 season. The cemetery is made up of a number of tombs (possibly up to 200) dug out of several large curving mounds of red gypsiferous shales of the Turonian Taref Formation which rise up to about 8m above the surrounding plain (Frey 1986). Many shallow depressions, from one to several meters in diameter, uniformly cover the surfaces of the mounds. These depressions were intentionally created over the centuries for a variety of

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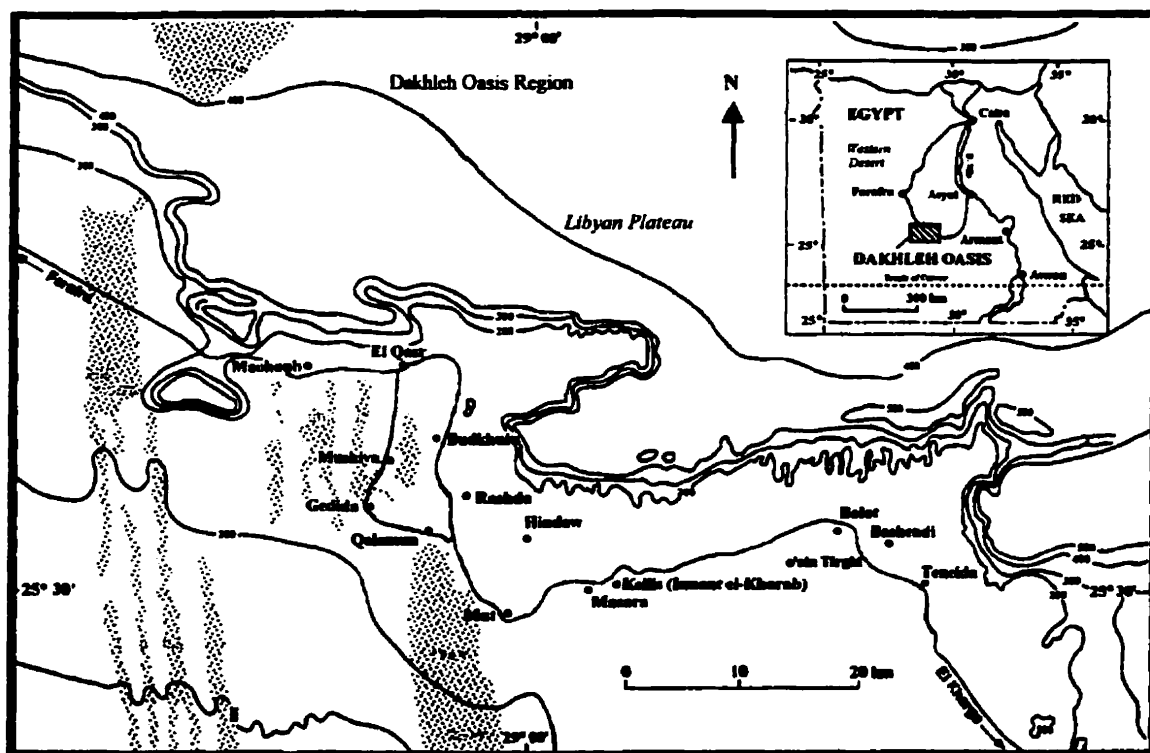
Figure 6.1. Map showing the location of 'ein Tirghi and Kellis within the Dakhleh Oasis, Egypt. This map was modified from the original created by M. Kleindienst and C.S. Churcher.

reasons - originally for tomb construction, then for tomb reuse, and finally for locating tombs for plundering. Although the exact size of the cemetery is not known, 37 tombs have been excavated thus far. To date, no settlement site associated with the cemetery has been located, however this may be due to the fact that modern fields are obscuring any signs of a settlement.

Tombs in this cemetery have been described as being of two distinct types. The first type consists of "... an oblong pit with steps leading to a mud-brick lined, arched doorway and a rectangular subterranean chamber" (Frey 1986:93). This tomb type was originally identified as belonging to the Second Intermediate Period; however there

have been many debates over the dates of this cemetery (E. Molto, pers. comm.). A second type of tomb appears later in time. Tombs from the earlier period were commonly reused and enlarged to contain one or more vaulted mud-brick chambers set into pits.
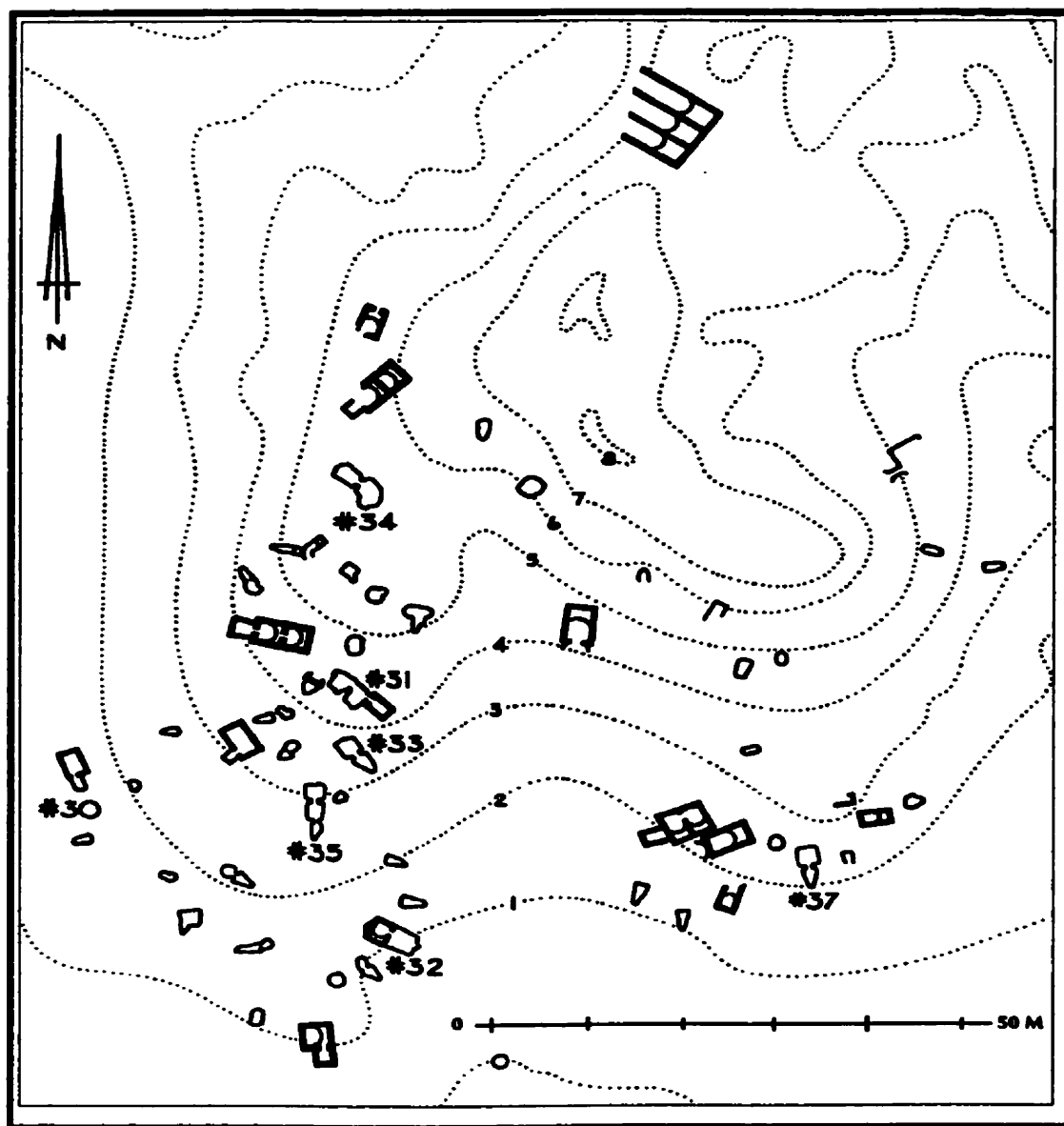
Figure 6.2. Site map illustrating the locations of Tombs 30-35, and 37 in the 'ein Tirghi cemetery, Dakhleh Oasis, Egypt (modified from Frey 1986). Note the location and structure of Tomb Dk-31. Thick lines on tombs represent secondary structures, while thin lines represent original tomb structures. (Note: the original map did not specify what elevation the contour lines represent, but most likely represent 1 meter in elevation)

This tomb type was originally thought to have been created during the Roman period, or possibly earlier (Frey 1986). Subsequent ^{14}C dates have shown that this tomb type actually dates to the 3rd Intermediate period (Molto, in press). One tomb in particular, Dk-31, has been identified as this type of tomb (Figure 6.2). Excavated in 1986, this tomb originally consisted of a roughly hewn subterranean chamber. Tomb Dk-31 was subsequently modified, with the enlargement of the entrance pit, and the construction of a mud-brick vaulted room within the entrance pit. This chamber was then thoroughly plundered and used as an entrance to two additional axial chambers (Frey 1986). These two axial chambers were found to contain 40 relatively undisturbed burials. Originally, the lack of grave goods, with the exception of coffins and amulets on some of the infants, was thought to place the burials in the "...transitional phase from late Roman to the Christian Period (circa 400-500 AD), a time when the belief in the efficacy of funerary offerings was finally giving way" (Frey 1986:100). Since this interim report was published, two calibrated ^{14}C dates (Molto, in press) have shown that the individuals in this tomb are from the 3rd Intermediate period (circa 800 BC)[1].

Frey (1986) notes that one of the most interesting characteristics of the burials in Dk-31 is the density and random placement of the individuals within the tomb. "Bodies are deposited in all directions in whatever way best fits the available space. When more space was needed, earlier burials were often summarily pushed aside or heaped up against the walls" (Frey 1986:96). Another noticeable feature of the burials was the vari-

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[1] The two ^{14}C dates for Tomb DK-31 come for burial #25, with a date of 795 ± 70 BC, and burial #36, with a date of 800 ± 60 BC (Molto, in press). Dating was conducted at Isotrace Lab in Toronto, Canada.

ety of methods used to prepare the bodies for interment. Some were placed in wooden coffins, some in ceramic coffins, and most commonly, individuals were wrapped only in linen. No evidence of artificial mummification was found.

Although it is believed that these people were interred over a relatively short time span, and may share a bond of kinship (Melbye 1983; Molto 1986), two particular individuals are thought to be grave robbers. They suffered an awful fate when the roof collapsed on them as they pillaged the tomb (Figure 6.3). Frey (n.d.; c.f. Fairgrieve 1993) describes them as being very distinct compared to the other individuals in the tombs. The first of these two individuals (Ind. #2) is described as follows:

"No cloth or bandaging was found on the skeleton, which was covered with a mass of red clay collapse, probably from the ceiling. The position of the skeleton suggests that the individual was kneeling, the upper body angled backward in the confined space between coffin and ceiling, when the collapse pushed him down and smothered him. Some of the long planks of the coffin had been pulled up and removed, and it seems probable that Ind. 2 was in the act of rifling the tomb when he was trapped" (n.d. Frey, c.f. Fairgrieve 1993).

The second individual (Ind. #3) is described in much the same manner:

"The individual lies on the back, legs extended but the arms, unlike the normal funerary position with hand over pelvis, are extended out on either side. The right arm, and significantly the hand, is articulated and therefore in its original position. The radius and ulna are crossed but this may have occurred under pressure of overburden. The head was found rotated 90° upward so that the base of the skull was "facing front". It had also been pushed down over the shoulder region. Again no trace of wrapping of cloth was found, and again a considerable mass of clay chunks and debris overlay the body. These observations coupled with the unusual position of the body suggest that Ind. 3 may well have been an accomplice to Ind. 2, sharing the same fate. He would have been sitting and
leaning back, or lying, with legs outstretched and head back, probably looking upward" (n.d. Frey, c.f. Fairgrieve 1993).
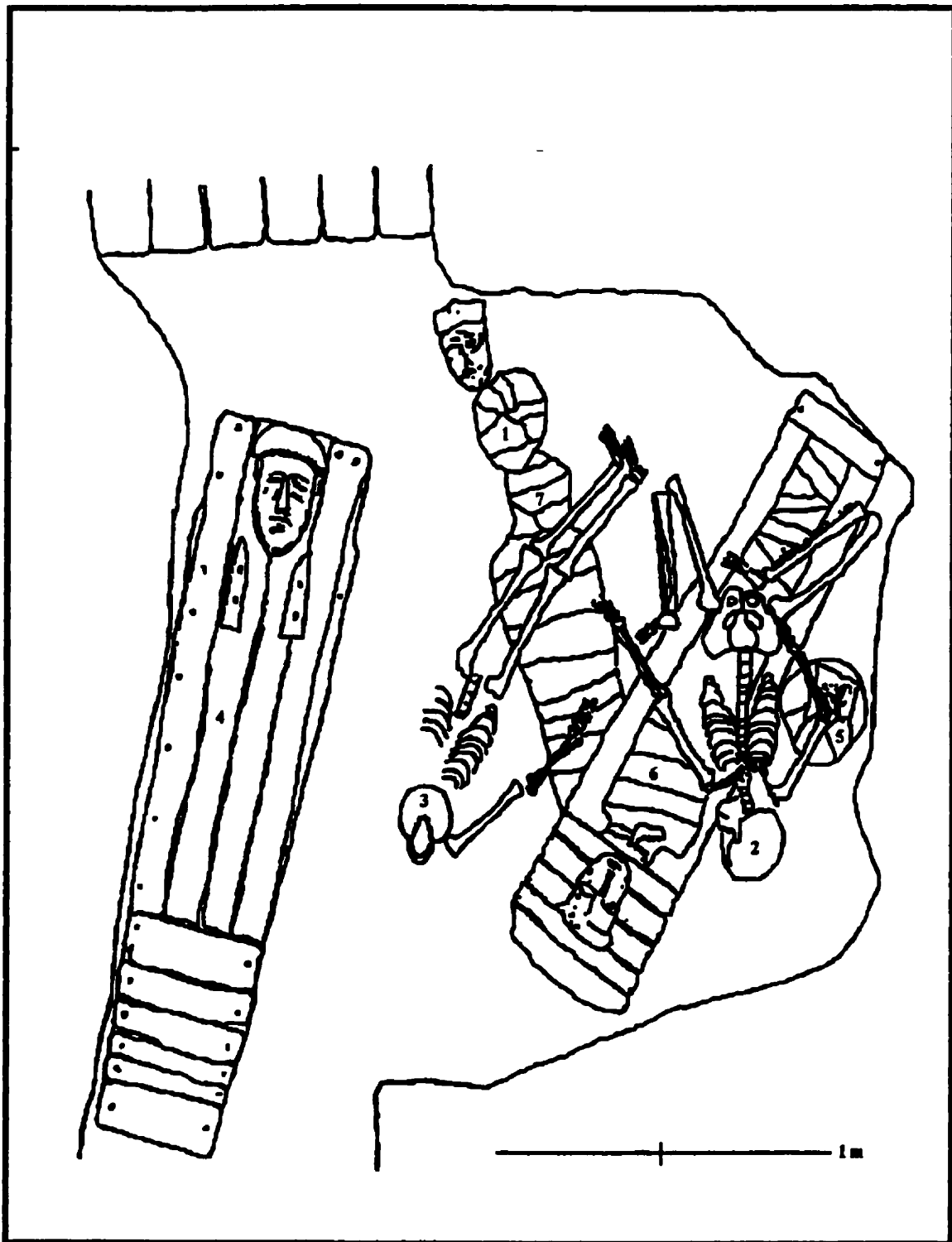
Figure 6.3. Illustration depicting the placement of individuals in Chamber 1, First Level, of Tomb 31 in the 'ein Tirghi cemetery, in the Dakhleh Oasis, Egypt. Note the position of individuals #2 and #3. Modified from Frey, n.d., c.f. Fairgrieve (1993).

may have lived in a different temporal period than those who were intentionally buried in the tomb. On the other hand, the grave robbers may have also been from the same time period, as there is evidence that suggests that plundering cemeteries was a common practice in all eras (E. Molto, pers. comm.).

Molto (1986) found the population of Dk-31 to be relatively healthy. One of the most common pathologies in the sample is dental disease. Although the population is characterized by a low rate of caries, there appears to be a high rate of antemortem trauma, attrition, tooth loss and periodontal disease. This type of dental pathology is likely linked to food preparation techniques, which most definitely included the unintentional introduction of abrasives (i.e., sand) into the food. The grit would have served as an abrasive which gradually wore down their teeth, leading to a rapid decline in dental health after the age of 30. In addition to dental disease, Molto (1986) found a high incidence of porotic hyperostosis and enamel hypoplasia (nearly 100% incidence). One case of hyperparathyroidism of unknown cause has also been noted in this sample (Cook et al. 1988) and may be the cause of "skinny bones" noted by Sheldrick (1980a, b) in skeletons from other locals in the Oasis. Although several types of pathology are noted for this population (trauma, some periostitis, degenerative joint disease, ankylosis, spina bifida, and spondylolysis), it is unusual to find so little evidence of bone infection (ie., osteomyelitis or periostitis). Only the juveniles (N=11) were affected by infection, while no adults (N=29) showed signs of infection. This may be the result of another food preparation technique involving the storage of grain in clay pots. Prolonged grain

storage allows desert bacteria, particularly Streptomycetes, to react with the grain to form the antibiotic tetracycline. Tetracycline is then consumed in the form of bread and/or beer and is incorporated into the bone mineral structure. Its presence can be visualized due to its fluorescence in thin section. Cook et al. (1989) studied a suite of bone samples from the site of 'ein Tirghi and found that all bones contained tetracycline. This labeling was not continuous, suggesting occasional or seasonal ingestion. This may provide evidence for the use of stored grain during part of the year when fresh crops were unavailable for consumption. This frequent ingestion of tetracycline may have afforded extra protection against the development of infections in this population.

The demographic composition of the tomb presents an almost equal number of females and males, and juveniles (Table 6.1). Independent estimates of age at death and sex estimates were made by Molto (1986) and Fairgrieve (1993). Sex determination was based on cranial morphology (Bass 1987) and changes in pubic symphysis morphology (Phenice 1969). Sex can not be determined with any accuracy for individuals who are not yet sexually mature (Bass 1987), hence the sex of juvenile remains is unknown (there was no preservation of soft tissue present). Dental eruption was used to assess the age at death of juveniles following Ubelaker's (1978) criteria. Age at death was as-

Table 6.1. Demographic profile of Tomb Dk-31, in the 'ein Tirghi cemetery, Dakhleh Oasis, Egypt (from Fairgrieve 1993).

Age	Males	Females	Infants/Juveniles
< 15	-	-	11
15-44	15	9	-
45+	-	5	-
Total	15	14	11

sessed using pubic symphyseal changes (Katz and Suchey 1986; Suchey 1979) and also

through assessments of dental attrition. The age at death and sex estimates assigned by

Fairgrieve (1993) and Molto (1986) are used in this thesis.

The samples from DK-31 analysed in this thesis were collected by Fairgrieve

during the 1990 field season. They (N=40) were analysed by Fairgrieve (1993) to deter-

mine a link between amino acid composition and cribra orbitalia. The initial lab meth-

odology of collagen extraction for this sample was completed by Fairgrieve and T. Oost

at Laurentian University. From this population a total of 38 individuals were sampled
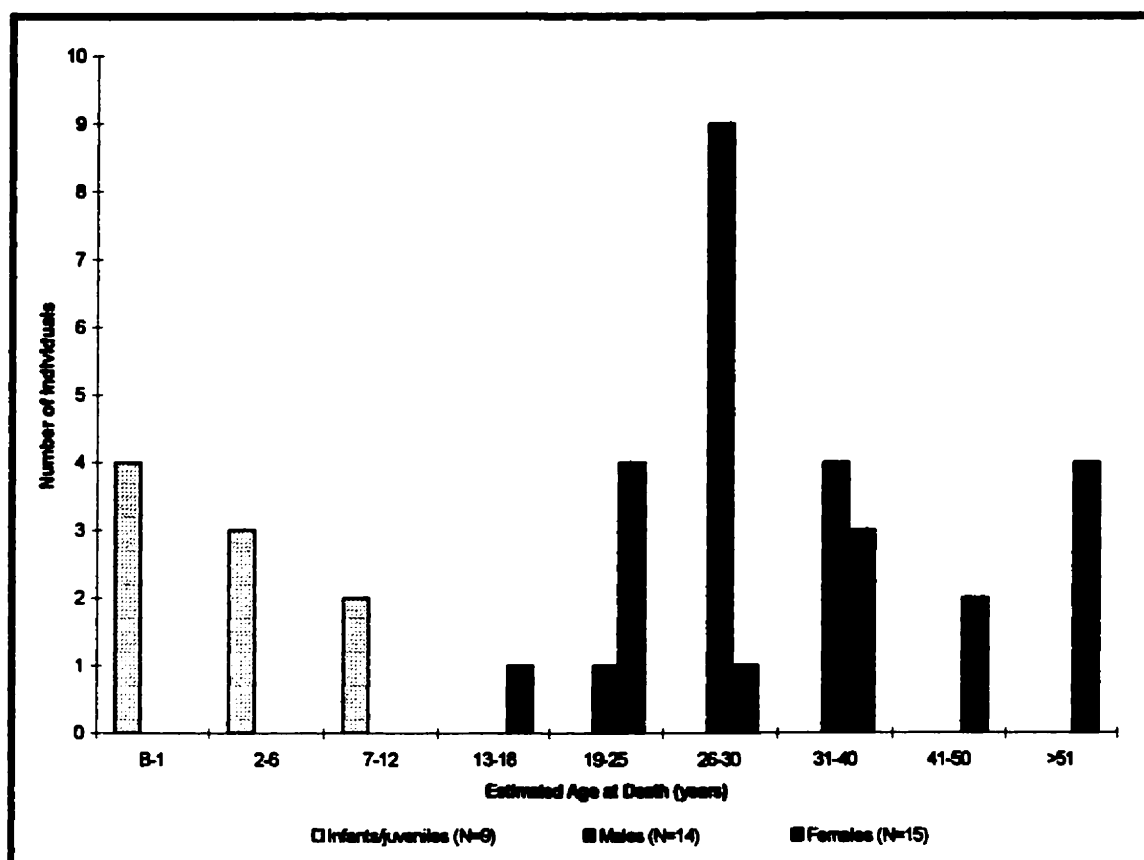
Figure 6.4. Estimated age at death histogram showing the distribution of male, female, infant/juvenile individuals from tomb Dk-31, 'ein Tirghi cemetery, Dakhleh Oasis, Egypt. The samples represented in the histogram are those that were used for stable isotope analysis.

for stable isotope analysis (two individuals were not included due to inadequate sample to perform analyses). The demographic information for the sample analysed is shown in Figure 6.4.

6.2.2 Kellis 1 Cemetery

The Kellis 1 cemetery (31/420-C5-1) is located West of the ancient village of Kellis (modern Ismant el-Kharab). The cemetery was discovered during a walking survey in 1992, when scraps of burial shroud and human bone were noticed on several small slopes. The cemetery itself is made up of rock cut tombs located in the low lying hills around the village (Figures 6.5 and 6.6). Although the majority of the tombs are single chambered, a few have more than one chamber. They have very low ceilings and contain from 1 to 20 individuals. It is not known how large this cemetery is, and to date only 21 tombs have been excavated. Several radiocarbon dates from individuals in Tombs 2, 3, 4, 8, 12 and 21 indicate that this cemetery was used primarily during the Ptolemaic period (circa 332 to 30 BC) (A. Aufderheide pers. comm., 1998). As very limited artifactual evidence from this period has been identified in the adjacent village site, these dates are regarded with suspicion by many members of the project. Even so, the style of burial and treatment of the dead strongly suggests that the cemetery was used during the Ptolemaic and/or the early Roman period and thus falls in between the dates of the 'ein Tirghi and the Kellis 2 cemeteries.

The tombs in Kellis 1 contain both skeletal and artificially mummified human remains. Although there appears to be no pattern as to who was mummified, it has been

Figure 6.5. Illustration of the Kellis 1 cemetery located west of the village of Kellis. The dark dirt pile marks the entrance to the tomb being excavated.

suggested that they may represent familial units (Cook 1994). DNA research to be carried out in the near future may shed light on this question.

The artificial mummification of individuals in the tombs was carried out in the ancient Egyptian fashion. All of the internal organs and the brain, except the heart and lungs, were removed. The chest cavity was filled with resin soaked rags to hold the shape of the body, then the entire body was treated with resin. It is believed that this resin was made up of tree sap, among other ingredients (White et al. 1998). The body was then wrapped in several layers of finely woven cotton burial shroud. A layer of gypsum plas-
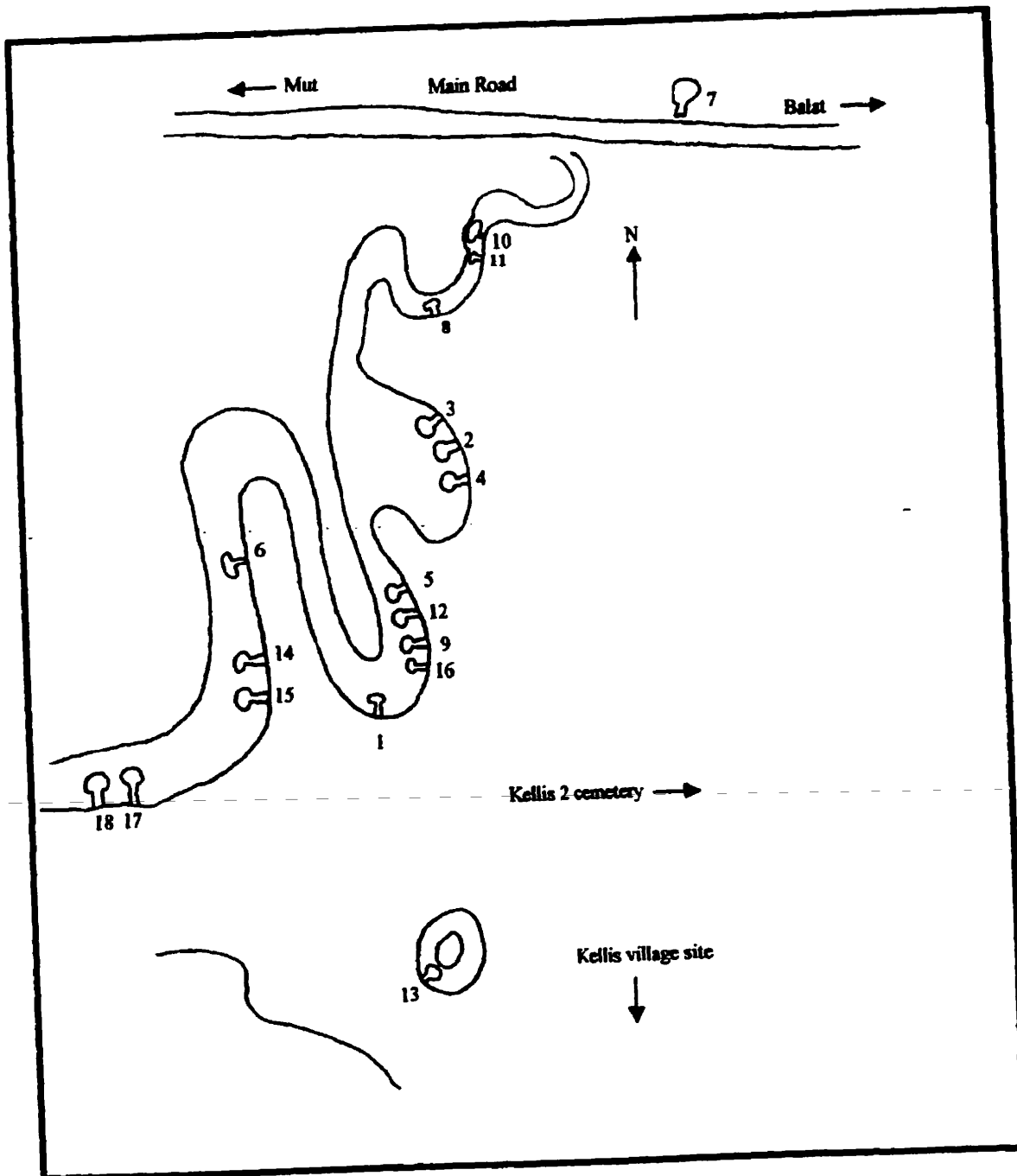
Figure 6.6. Location of Tombs 1 to 18 in the Kellis 1 cemetery, Dakhleh Oasis, Egypt. This map is only a basic site plan (sketch) and the scale can not be estimated. Map courtesy of P. Sheldrick.

ter, called cartonnage, was applied to the ventral surface of the body, particularly over the head, shoulders and feet, and what is believed to be a facial likeness of the person was then painted on the head region. Several depictions of Egyptian gods were then painted on the chest and leg region of the plaster.

Unfortunately, all of the excavated tombs have been disturbed, resulting in a jumbled mixture of burial shrouds, skeletal elements and mummified body parts (Figure 6.7). Remnants of gold painted cartonnage have been found in the debris pile, leading excavators to believe that most of the cartonnage and grave goods were looted (P. Sheldrick, pers. comm., 1997). In one case the grave robbers had broken into one tomb and then proceeded to cut through the walls into two other tombs. Excavators found that material from one tomb had been deposited into another, making reconstruction of individuals nearly impossible (Figure 6.7).

Preliminary analyses of the state of health at the time of death of 41 individuals from Tombs 1 to 6 have been described by Cook (1994). Although spinal pathology has been noted, the majority of pathological characteristics are directly linked to the fact that these individuals lived in a desert environment. Most individuals exhibited extreme dental wear, presumably a result of eating food laden with grit. The strong, persistent winds in the Oasis make it very difficult to shelter food from wind-blown sand and dust. Another pathology commonly noted in the sample is sand pneumoconiosis. Examination of lung tissue under polarized light has revealed "...particles of silica mixed with anthracotic pigment... This condition could lead to pneumonia, fibrosis and consolida-
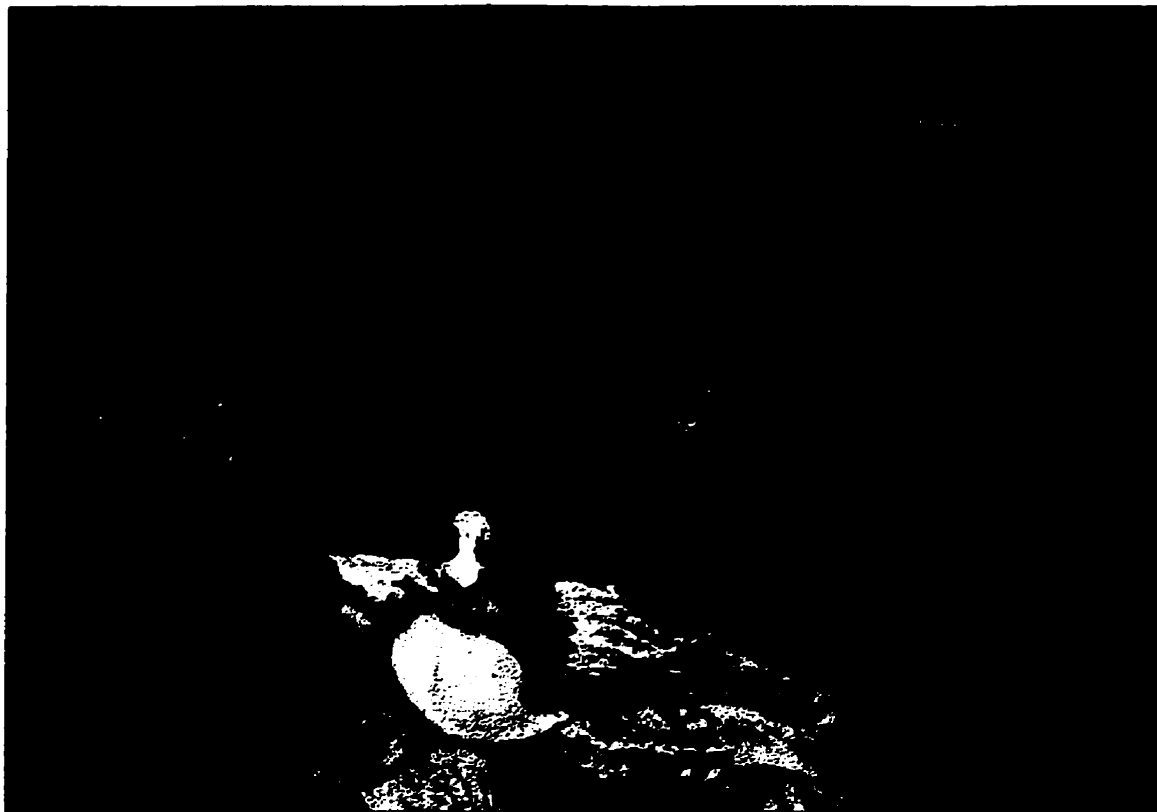
Figure 6.7. An illustration of the co-mingled state of the Kellis 1 tombs. Both artificially mummified remains are mixed with burial shroud, skeletonized remains, and rock that fell from the ceiling.

tion of the lungs. Individuals could also be predisposed to cancer and infections" (Cook 1994:274).

Although it was possible to reconstruct some of the mummified individuals, the majority of the skeletal remains were not sorted. Because of the mixed condition of the remains, it has been nearly impossible to determine the age at death and sex of the individuals in the tombs. Those rare individuals whose skeletons were complete were sampled more than once, with different skeletal elements being sampled to determine the different isotopic values of various skeletal elements, and ultimately to determine if

sampling location would affect the isotopic results. Ribs, femora, humeri, and ilia were sampled. Skeletal elements that appeared to be impregnated with resin were not sampled to avoid any isotopic interference from resin. Certain skeletal elements were also tested twice to control for precision and accuracy. When possible, estimates of age at death and sex were made by M. Cook. Age at death for juveniles was estimated using long bone length and dental eruption. Age at death for adults was estimated using osteon aging techniques for the rib (Stout and Paine 1992) and/or the tibia (Thompson 1979). In some cases it was possible to determine the sex of children (usually impossible to do with skeletal remains) and adults who were artificially mummified, due to the preservation of the external genitalia. For the purposes of this study, a total of 42 indi-
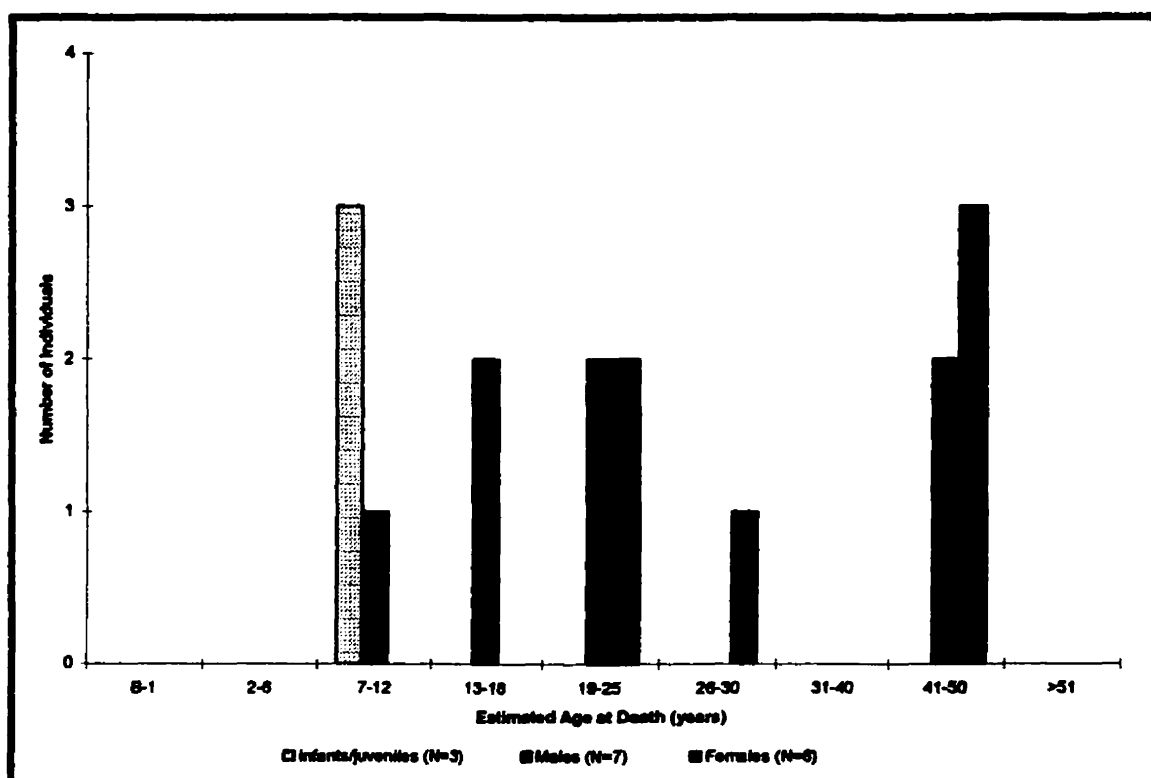
Figure 6.8. The age at death and sex of 'whole' individuals sampled for stable isotope analysis. All are from Tombs 1-14 in the Kellis 1 cemetery, Dakhleh Oasis, Egypt.

viduals were sampled, although it was only possible to determine age at death and sex for 16 of them (Figure 6.8).

6.2.3 Kellis 2 Cemetery

The Kellis 2 cemetery (31/420-C5-2) is located east of the ancient town of Kellis. The cemetery was discovered in 1991 during a walking survey when skeletal elements were found on the surface. Extensive wind erosion had exposed several graves in the West part of the cemetery. This cemetery consists of single interment burials, in an East-West orientation, with the head of the burial facing West (Figure 6.9). At present 278 burials have been excavated, but it is estimated that the cemetery may contain more than 2500 burials (E. Molto, pers. comm., 1997). Several ^{14}C dates indicate that the cemetery was in use during the Romano-Christian period (circa 250 to 450 AD) (Table 6.4).

The burial style reflects a change from the pagan burial style seen in Kellis 1, to a Christian burial style. The map in Figure 6.10 shows the burials excavated from 1992 until January of 1997 (N=228). The burials with the "*" were sampled for this study.

Three burial types have been noted in the Kellis 2 cemetery. The majority consist of a plain grave with the individual in an extended position with hands placed on the abdomen or hips (Figure 6.11). Some were wrapped in burial shrouds (Figure 6.12). Those interred with some sort of burial shroud commonly had naturally mummified tissue (desiccated) such as muscle, skin, hair, finger and toe nails still present. Only one grave good has been discovered in this cemetery (a blue glass bottle), although several

Figure 6.9. Kellis 2 cemetery located east of the town of Kellis. The cemetery consists of single interment burials, with heads facing west.

of the burials had been disturbed, and particularly at the west (or head) end. This led

excavators to believe that grave robbing in this cemetery was committed by individuals

with privileged knowledge regarding which people were buried with grave goods.

None of the undisturbed burials contained grave goods. The single grave good may

Table 6.2. Calibrated radiocarbon dates for individuals from the Kellis 2 cemetery, Dakhleh Oasis, Egypt. Dates provided by E. Molto. Istotrace, Toronto was the original source of this data (Isotrace #'s are currently unavailable).

Burial #	Sample	Calibrated Age	68.8% C.L	95.5% C.L
5	rib	215 AD	120-250 AD	65-340 AD
6	rib	405 AD	340-430 AD	315-535 AD
6	rib	435 AD	415-540 AD	415-540 AD
95	rib	340 AD	315-405 AD	315-405 AD
96	rib	80 AD	60-135 AD	0-230 AD
116	rib	445 AD	420-545 AD	390-605 AD
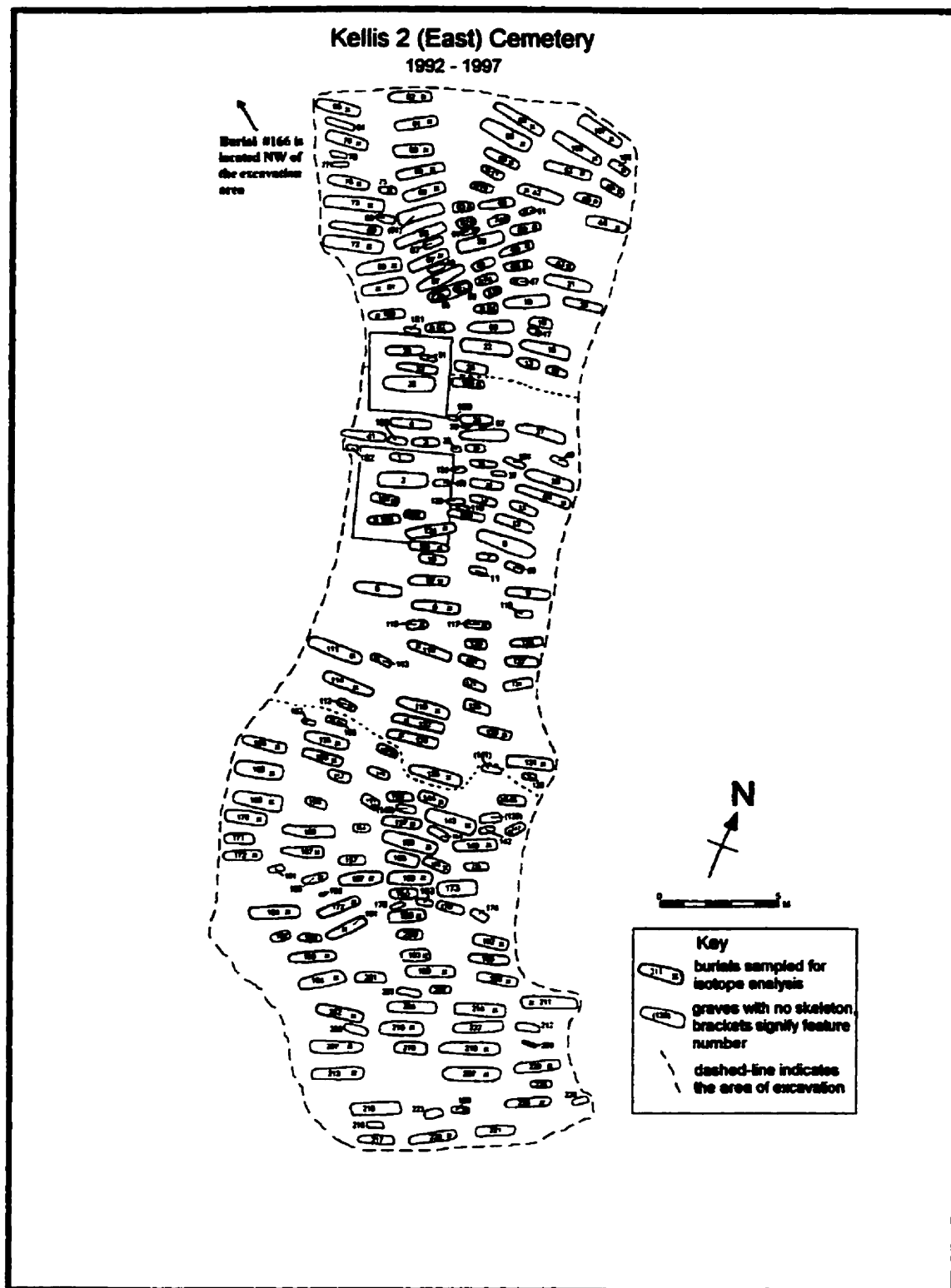
Figure 6.10. Site map illustrating the area of the Kellis 2 cemetery (Dakhleh Oasis, Egypt) excavated from 1992-1997 (up to burial #228). Map is courtesy of the Dakhleh Oasis Project.
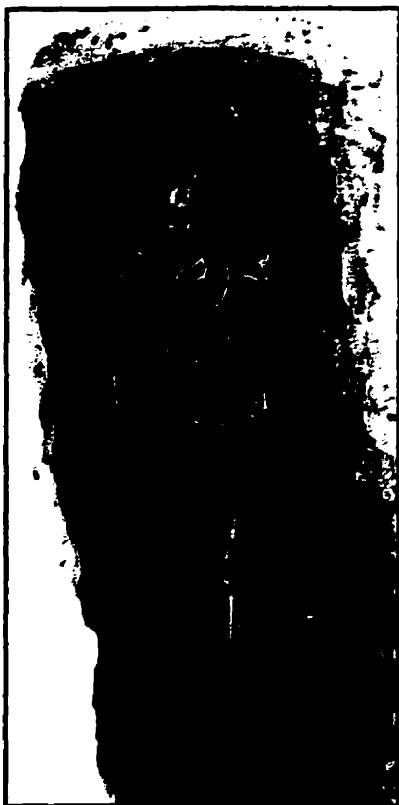
Figure 6.11. Single interment burials in Kellis 2. Note the natural preservation of the hair.

have been deemed unworthy by the looters as the handle had been broken off prior to burial.

Another feature typical of some burials was the inclusion of a mud-brick sub-structure and the creation of a false bottom on top of the mud-brick structure (Figure 6.13). Once the body was placed in the grave, a layer of mud brick was built up around it. A roof structure of mud bricks in the shape of an A-frame was placed on top of the layer of bricks. The roof structure was then covered with a mixture of dirt, stones and gypsum plaster, creating a façade which mimicked the actual bottom of the grave. The resulting layer was very hard to penetrate, thus creating the illusion of hard bedrock. Several of these structures had been damaged however, particularly at the west end, lending further credence to the idea that grave robbers had prior knowledge of who was buried with grave goods and who was not.
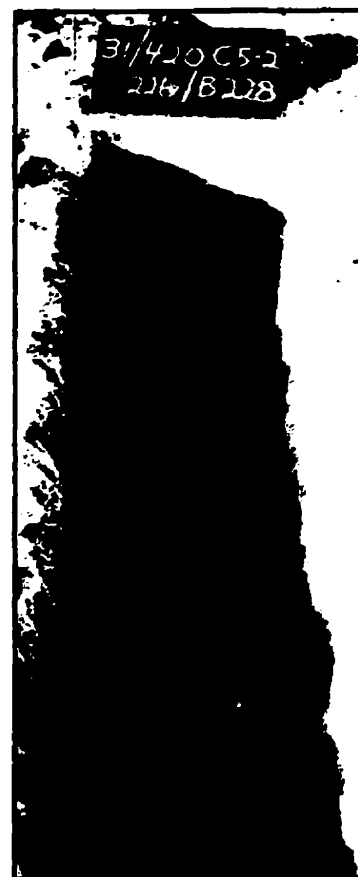
Figure 6.12. Representation of individuals found with burial shrouds in Kellis 2 cemetery.

The last burial style encountered in this cemetery involved the inclusion of pigeon and water pots near the surface of the grave. Pigeon pots were typically used for raising pigeons, while water pots were used to hold a variety of liquids and dry goods (Hope 1985). Although it was more common for infants or young children to have one pot placed near the top of the grave, one adult (Burial 159) had 6 pots, both pigeon and water pots, on her grave (Figure 6.14). Two of the water pots were in perfect condition, and one contained gypsum plaster around its mouth with a

Figure 6.13. Burial and brick A-frame substructure in Kellis 2 cemetery.

fabric impression on the surface, leading archaeologists to believe that the pot was once sealed with cloth and plaster.

Estimates of sex and age at death were made by E. Molto. Dental eruption and long bone lengths were used to determine the age at death of juveniles. A combination of suture closure, dental wear, and pubic symphysis morphology (Katz and Suchey 1986; Suchey 1979) was used to estimate the age at death of the adults. The Phenice technique (1969) was used to estimate the sex of adults. A total of 116 individuals, 27 males, 37 females, 51 infants/juveniles, and 1 adult individual of unknown sex and age was sampled for isotopic analysis (Figure 6.15). In most cases samples were taken from the midshaft of the left humerus. For some of the individuals more than one sample was

taken from various skeletal elements, as was done with individuals from Kellis 1.

6.2.4 Human Hair Samples

In addition to skeletal samples, it was possible to obtain hair samples in some cases. A total of 41 hair samples were taken from the Kellis 2 cemetery, and 2 samples were taken from Kellis 1. If the hair sample was long enough (i. e., over 6 mm long), it was divided into 2 mm segments and analysed to detect any seasonal differences in diet; otherwise, it was analysed results from the bone.

Figure 6.14. Illustration of pots placed over an individual in the Kellis 2 cemetery.

simply to corroborate the isotope

The two hair samples from Kellis 1 were collected by A. Aufderheide during the 1993 field season. Dr. Aufderheide generously offered the isotopic data for comparison to the samples collected from Kellis 2. The comparison is discussed in Chapter 7.

6.2.5 Animal Samples

Animal samples were collected for stable isotope analysis so that an isotopic food chain could be constructed. All of the archaeological animal samples used for stable isotope analysis were excavated from the ancient village of Kellis. The samples

Figure 6.15. Histogram of the estimated age at death and the distribution of sex for the samples from the Kellis 2 cemetery, Dakhleh Oasis, Egypt. The sample of unknown age and sex is not represented on this graph.

came from sections A, C, and D, (see Figure 2.3) and were identified by C.S. Churcher

during the 1997 season. The bones can be dated to the late 4th and early 5th centuries

AD (C. Hope, pers. comm.) and are most likely contemporaneous with the individuals

buried in the Kellis 2 cemetery. The animals sampled represent those deemed most

likely to have been consumed by the inhabitants of the Oasis. Animal remains found in

abundance include pig, cow, goat, and chicken, while those rarely found include donkey

and gazelle (Churcher 1993). Other animals, such as sheep and camel, have been iden-

tified by their fecal droppings and horns, but bone samples were not available for analy-

Table 6.3. Archaeological animal samples used for stable isotope analysis. All remains were excavated from the village site of Kellis, Dakhleh Oasis, Egypt.

Area	House	Room	Animal	Bone Type
A	7	East Nave, S.	Chicken	Long bone
C	1	3A (1)	Chicken	Humerus
C	1	4 (1A)	Donkey	Metapodial
C	1	4 (2B)	Cow	Rib
C	1	4 (2B)	Goat	Metapodial
C	1	5 (3B)	Pig	Long bone
D	8	12 (3)	Chicken	Humerus & pelvis
D	9	Gateway Central	Cow	2nd phalanx
D	10	Locus 1 (2)	Gazelle	metatarsal

sis. In some cases more than one sample was taken from a particular genus (i.e., cows and chickens). All samples, however, were found in different sections of the site and none is believed to have belonged to the same individual (Table 6.5). Many of the animal bones showed cut marks, indicating that they were consumed by people in the houses in which they were found.

T. Oost and the author collected several modern animal samples from the Oasis during the 1994 to 1997 field seasons. They were collected from surface finds throughout the Oasis and were identified by R. Churcher. Although not completely representative of all the animals found in the Oasis today, they are used in this study for comparison with the archaeological faunal material. The samples include bones from two different camels, cow, donkey, goat and fox (N = 6).

6.2.6 Plant Samples

All archaeological botanical remains sampled for isotope analysis were ex-

Table 6.4. Archaeological plant samples collected from the village of Kellis, Dakhleh Oasis, Egypt.

Plants	Part Sampled
wheat	shaft
Fava bean	shell
barley	shaft
grape	seed
olive	seed
date	seed
fig	stem
Doum palm nut	seed

cavated from the site of Kellis during the 1997 field season under the supervision of C.

Hope, and were identified by U. Thanheiser (Vienna University). The botanical re-

mains sampled represent some of the food remains found to be most abundant at the

Table 6.5. List of English and Arabic modern plant remains collected from the Dakhleh Oasis, Egypt. Also listed are the plant parts sampled for stable isotope analysis.

English Plant Name	Arabic Plant Name	Plant Part Sampled
(no known name)	Ghertah	Seed
Alfalfa		Leaf
Barley		Seed
Black Mustard	Libsan	Stem
Date		Seed, fruit
Dill		Stem
Parsley		Leaf
Pea		Leaf, seed, shell
Rice		Seed
Rocket	Gergir	Stem (root)
Safflower	Courtoum	Leaf
Sorghum	Dura beladi	Leaf, seed
Sweet Basil	Rihan	Leaf
Turnip		Seed
Wheat		Seed

site, and also those mentioned in the KAB. While they constitute only a very small percent of all the plants identified at the site, they are thought to have provided the majority of nutrients to the Oasis inhabitants: wheat, barley, broad beans, grapes, olives, dates, figs and doum palm nuts. Unfortunately, millet was unavailable for sampling at the time of collection . In most cases seeds were sampled. If seeds were not available, the stem, or seed casing was collected. In general, $\delta^{13}C$ and $\delta^{15}N$ will be similar in both (Lajtha and Marshall 1994). Like the archaeological animal remains, the botanical samples are thought to date to the late 4th and early 5th century AD (C. Hope, pers. comm., 1997). Table 6.6 provides a list of archaeological plant remains sampled for this study.

In addition to archaeological plant remains, several samples of modern plants were collected by T. Oost and P. Sheldrick during the 1994 field season (Table 6.7). The modern plants serve as a comparison for the ancient remains analysed in this study, and add to our knowledge of plant isotopic configurations in arid climates. The English translation for all the Arabic plant names was provided by M. Woidich. Only one species of plant, ghertah, was not identifiable in English. The samples collected (N=14) are only a small portion of all the plants grown in the Oasis today and represent species that were in season at the time (i.e., December/January). All parts of the plant were analysed and in some instances (e.g., date, peas, sorghum) more than one section of the plant was tested for stable isotope analysis (e.g., leaf, fruit, pit, stem, and shell) to test for possible differences in isotopic composition throughout the plant. Differences in isotopic composition between parts of the same plant were found to be less than 0.5‰.

6.3 Analytical Methodology

6.3.1 Collagen Extraction: Human and Animal Bone

Collagen was extracted using methods first described by Longin (1971) and later modified by Chisholm et al. (1982). The bone sample was washed under tap water and scrubbed with a brush to removed any surface dirt. The bone sample was then placed in a beaker with de-ionized water and ultrasonicated to remove any extraneous material trapped inside or missed during brushing. The water was replaced repeatedly until it remained clear. All trabecular bone was removed with a file. The sample was then dried overnight in an oven at 60°C. Once dry, the bone was crushed into small chunks using a porcelain mortar and pestle. Approximately 3g of crushed bone material (if this amount was available) was weighed and recorded. The weight of the bone is used at a later time to estimate the yield (%) of collagen.

The weighed crushed bone was placed in 50 ml plastic centrifuge tubes and covered to the 40 ml mark with 0.25 M hydrochloric acid (HCl). The HCl is used to dissolve the mineral (calcium phosphate and other minerals) portion of the bone. After slight agitation using a glass stir rod the tube is left to sit for 20 minutes (or longer), until the pH is greater than 1. After centrifugation, the spent acid is decanted and replaced with fresh acid. This procedure is repeated until the mineral is dissolved. The HCl solution used is not strong enough to damage the protein structure of the collagen. This process may take between 6 to 20 acid washes, depending on the type of minerals present in the bone. Once the mineral is completely extracted (leaving behind soft, collagenous

pseudomorphs), the remaining material is washed three times with de-ionized water.

The remaining material is then treated with 0.125 M sodium hydroxide (NaOH) to remove any humic or fulvic acids that may be present. Each tube was filled to the 20 ml mark with NaOH, agitated and left to sit for 20 minutes. The NaOH solution turns light brown to black depending on the amount of humic acid in the sample. After 20 minutes the tube is centrifuged and the liquid decanted. If the solution were a dark brown to black colour, the collagenous material was re-suspended in NaOH for another 20 minutes to remove any remaining humic acids. The sample was then washed four times with de-ionized water to remove the NaOH. The sample was then neutralized (or left slightly acidic) by doing one last wash of 0.25 M HCl.

The next step of the extraction procedure is sometimes referred to as 'melting' the collagen, or re-fluxing the sample. In its natural state, collagen is not soluble in water as it is a triple helix structure that contains several hydrophobic compounds on the exterior of the helix. Suspending the collagen pseudomorph in boiling water changes the structure of the collagen into a water soluble form, and when it cools it will not revert back to the collagen form but will set as a gel; hence, it is important to heat the collagen to induce a physical change in the helix bond. This process of changing collagen into a gel form is known as gelatinizing the collagen. To start this process, the remaining 'pellet' was washed out of the plastic centrifuge tube with de-ionized water and transferred into a 50 ml glass centrifuge tube. The tube was topped up with water and sealed with plastic wrap and tape to stop the loss of water vapour in the oven. The tube

was agitated and placed into a 400 ml glass beaker. The glass beaker holds the sample upright and contains the sample in the event that one of the tubes brakes. The beaker was then placed in a convection oven at 90°C for a minimum of 6 hours. The 'melted' sample was then centrifuged and the liquid was decanted into a Teflon beaker. The Teflon beaker with the liquid collagen was then placed in a drying oven (~ 60°C) over night to evaporate the water. The residual pellet was covered once again with de-ionized water and placed in the oven for another 6 hours, and then centrifuged. The supernatant liquid was decanted and added to the Teflon beaker. After drying, the Teflon beakers contain a light amber to dark brown gelatin. A small amount of de-ionized water (3 ml) is placed in the beaker to dissolve the gelatin. This liquid is removed from the beaker using a glass or plastic pipette and placed into a small glass or plastic storage vial.

The final drying of the gelatin is completed in small pre-weighed glass or Teflon vials. The vials are labeled with permanent marker and weighed prior to receiving the liquid gelatin. The vial with the gelatin liquid is placed in the drying oven until the gelatin is dry (this may take several days). The vial and the lid is then weighed. The weight of the gelatin is determined by subtracting the weight of the vial from the weight of the vial + gelatin. The gelatin yield is then calculated by using the weight of the gelatin in the storage vial and the amount of bone used at the beginning of the procedure. The formula is as follows:

Equation 6.1. Equation used to determine the percent yield of gelatin (collagen) after the extraction procedure is finished.

$$(wt. \; of \; gelatin/wt. \; of \; bone) \; x \; 100 \; = \; \% \; yield$$

The dry gelatin was then scraped with a dental pick to create a fine powder. The powder was measured into 3 mg quantities for carbon analysis and 9 mg quantities for nitrogen analysis. The samples were loaded into 6 mm Pyrex tubes with a small quantity of cupric oxide (CuO). The tubes were evacuated on a vacuum line to remove the air and water and then combusted at $550°$ C for 2 1/2 hours. The high temperature of the oven triggers a chemical reaction between the compounds of the collagen and the CuO. The oxygen from the CuO reacts with carbon of the protein chain to form carbon dioxide. The hydrogen converts to water and the nitrogen compounds break down into N_2. The CO_2 and N_2 were then subjected to stable isotope analysis on a SIRA mass spectrometer. Diagenetic change in collagen determined by C:N ratios (after DeNiro 1985) which were measured on a Carlo-Erba C,N analyser (model 1500).

6.3.2 Extraction of Bone Apatite: Human Bone

A small sample of individuals (N = 33) from the Kellis 1 and Kellis 2 cemeteries were analysed for the ^{13}C isotopes in the carbonates of bone mineral (apatite). The methodology used to isolate the apatite portion of bone was modeled after Sullivan and Kreuger (1983), and Lee Thorp and van der Merwe (1987). Each sample was washed and scrubbed with a wire brush and file to remove any extraneous surface material, then dried in an oven at moderate heat ($60°$ C). The dry bone was placed in liquid nitrogen for 30 seconds and then crushed into small pieces (1 to 2 mm in size) using a steel mortar and pestle. The liquid nitrogen facilitated the fracturing of the bone, as most of the

bone resembled fresh bone and was otherwise very hard to crush into small fragments. Approximately 0.1 g (~100 mg) of crushed bone was weighed out and placed in a plastic centrifuge tube. Ten milliliters of 1 M acetic acid was added to each centrifuge tube to dissolve any traces of diagenetic carbonates and was then left to react with the bone for 1 hour. If substantial reaction was still occurring after one hour the acid was drained off the sample and new acid was added and left to sit until the reaction was finished. The acid was drained off and then rinsed three times with distilled water. The centrifuge tubes were then put in a drying rack and placed in a moderate heat oven (60° C) over night.

After the sample was dried, it was weighed to determine how much of the surface carbonates were removed. Twenty ml of sodium hypochlorite (bleach, i.e., Javex-5™) was then added to the dry bone sample to remove the bulk of the organic material (the collagen) from the sample. The sample was left to sit for 24 hours, then washed with distilled water six times to remove and neutralize the bleach solution. The samples were then placed in the drying oven (60° C) over night. The dried sample was weighed again to determine the amount of organic material that had been removed during the sodium hypochlorite treatment. The bone was then crushed again into a fine powder with a porcelain mortar and pestle.

Between 20 and 40 mg of bone powder is weighed out for each sample. The sample was placed in a small glass sample cup, then into a numbered holder. When 12 samples had been weighed out the sample holder was placed in a large bell desiccator.

Using a special volumetric titration tube (dispenser), twelve 9 mm Pyrex tubes were filled with 1 ml of 100% phosphoric acid (H_3PO_4). The small glass sample cups were carefully placed into the 9 ml tubes so that none of the bone powder came in contact with the phosphoric acid. The tubes were then placed on a vacuum line to remove any water or air in the sample. The vacuum line was opened very slowly to prevent the sample from being displaced from the sample cup. The tubes were left on the vacuum line for a minimum of six hours. After torching the tubes off from the vacuum line, they were placed upright into a plastic rack in a water bath (25°C). After the samples had equilibrated for about an hour, the tubes were turned over quickly to disperse the bone powder into the phosphoric acid. After another hour the tubes were turned again so that the phosphoric acid would flow into the sample cup, therefore reacting with any sample that had not come out of the sample cup. The phosphoric acid reacts with the carbonate in the sample and releases carbon dioxide gases into the tube. The tubes remained in the water bath for a week, and the tubes were turned daily. Once the sample was completely dissolved the tubes were removed from the water bath and the CO_2 gases were transferred into 6 mm tubes using a transfer line. Carbon isotopes were then measured on an Optima Mass Spectrometer.

6.3.3 Cleansing and Analysis of Hair Samples

The methodology for cleaning the hair samples was adopted from White et al. (1998). Each hair sample was microscopically examined to determine if there was any extraneous material coating the hair. Samples procured from the artificially mummified

individuals in the Kellis 1 cemetery were commonly coated with a resinous substance that was used to toughen and moisture proof the body (Peck 1980). Samples from Kellis 2 were also found to have a substance coating the hair, although different from that found on the Kellis 1 burials. The substance coating the hair contained silica particles that originated from the surrounding burial matrix.

Each sample was placed in a piece of filter paper and the scalp end was marked. The sample was then placed in a Petri dish with 20 ml of a methanol:chloroform:water (10:5:4) solution. The Petri dish was placed in an ultrasonic bath for 20 minutes. This procedure cleaned many of the samples; however a few still retained a great deal of extraneous material. These samples were immersed once again, but large encrustations of material still remained. White et al. (1998) noted this same problem when attempting to clean hair samples from artificially mummified individuals from the Kharga Oasis in Egypt. The authors found that successive treatments of 0.25N HCl, methanol, ethyl alcohol and acetone removed approximately 90% of the extraneous material, but discrete chunks of material remained intact and would not dissolve. These chunks had to be manually removed. The samples for this study that remained coated were also manually cleaned and those with a great deal of extraneous material were discarded. Hair from only two individuals from the Kellis 2 cemetery was deemed suitable for analysis.

After successful cleaning, the hair samples were cut into sections using a stainless steel scalpel. Starting from the scalp end of the hair, sections of approximately 2 cm in length were cut, representing a growth period of approximately 2 months. This

calculation is based on an estimated scalp hair growth rate of 0.35 mm/day (Saitoh et al. 1970; Yoshinaga et al. 1996). Although factors such as hormones, physiology, nutrition and health may affect hair growth rates, it is not possible to control their effects in a sample of this nature. The sequence of hair sections was labeled from the proximal to the distal end.

Each subsection of hair was weighed into 3 mg and 10-15 mg samples for carbon and nitrogen analysis, respectively, loaded with CuO into a 6 mm Pyrex tube, evacuated on a vacuum line, and then combusted at 550°C for 2 1/2 hours. Nitrogen and carbon isotopes were measured on a SIRA mass spectrometer.

6.3.4 Cleansing and Analysis of Plant Material

Each plant sample, including both archaeological and modern samples, was examined microscopically to determine if any extraneous material adhered to the surface that needed to be removed. In many cases archaeological plant material had been contained in clay jars and therefore remained protected from extraneous materials. These plants were found to be relatively clean and were submerged in acetone and agitated in an ultrasonicator for one minute. Some plants, however, were found to have large encrustations of dirt adhering to the surface (particularly the fig, doum palm nut and date seeds). These plants were also treated with acetone and then a soft brush was used to remove the remaining dirt. Whenever possible, a scalpel was used to remove the outer surface of the plant so that only previously unexposed plant material remained for sampling.

Modern samples were also cleaned using acetone in an ultrasonicator. This procedure was used to remove any dirt, animal waste or pesticides that may have been used before the plant was harvested. Although drying of modern plant material was attempted in the field, some samples had mould on their surfaces. Sections that contained moulds were eliminated from the isotopic analysis.

Small sections of each plant were removed with a stainless steel scalpel. A sample of 3 mg was measured for carbon analysis. Samples of 15 mg were measured for nitrogen analysis. Because plant material contains very little nitrogen, it was necessary to load the maximum amount of plant material (15 mg) to be able to measure nitrogen isotopes. Loading more than 15 mg of sample into a tube runs the risk of releasing too much CO_2 during combustion, thereby causing the tube to explode. Each sample was loaded with CuO into a 6 mm Pyrex tube. The tube was then evacuated on the vacuum line and then combusted at 550° C for 2 1/2 hours. Both carbon and nitrogen isotopes were measured on a SIRA mass spectrometer.

6.4 Statistical Analysis

All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences) for Windows (Version 7), and Corel Quattro Pro (Version 8). Descriptive statistics, including mean, standard error, standard deviation, variance, and confidence interval (95%), were completed for each cemetery sample as a whole, and then for subgroups of adult males, adult females, subadults (juveniles, children and in-

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Chapter 7

Stable Isotope Analysis Results

7.1 Introduction

An examination of the documentary, iconographic, archaeological botanical and faunal evidence from the site of Kellis and greater Egypt offer indirect evidence that allowed for the development of a menu of food items that the inhabitants of the Dakhleh Oasis may have eaten. Although these sources provide a list of foods that were available for consumption, this does not mean that the inhabitants of the Oasis would have chosen to eat everything on the menu. Stable isotope analysis makes it possible to determine what people actually ate. This chapter presents the results of the stable isotope analyses conducted on the samples outlined in the previous chapter.

7.2 Precision and Reproducibility

7.2.1 Precision of the Stable Isotope Analyses

To determine the precision of both carbon and nitrogen analyses, several bone collagen samples were analysed multiple times. For carbon isotope analysis, five samples were run between 4 to 6 times each, and were reproducible to within 0.08 ● 0.09‰. For nitrogen, 3 samples were run seven times each and agreed to within 0.28 ● 0.29‰. These values are comparable to the precision of isotope analyses reported in the literature (Ambrose and DeNiro 1986; 1989; White and Schwarcz 1994).

7.2.2 Reproducibility Within Skeletal Elements

In six cases multiple skeletal elements from individuals from the Kellis 1 cemetery were analysed to determine if there was any significant differences in isotope values between skeletal elements. The skeletal elements tested for each individual included femora, ilia, and ribs. For carbon isotope values, the largest range in values within one individual was 1.2‰. The ranges for carbon values for the other 5 individuals ranged from 0.06‰ to 0.88‰. For nitrogen isotope values, the largest range within an individual is 1.07‰. The ranges for nitrogen values for the other 5 individuals range from 0.08 to 0.74‰, that is, better than or equal to reproducibility for the same sample. Within each of these individuals, the dispersion in isotopic values amongst skeletal elements is comparable to the precision of analysis, and as such, isotopic values from one skeletal element can be taken as being representative of the entire skeleton.

7.3 Sample Preservation

Bone preservation was determined by examining the C:N ratios for each sample. Refer to Appendices D, E, and F for the C:N ratios for each cemetery. The C:N ratios for all samples were found to be within the acceptable range (2.9-3.6) defined by DeNiro (1985).

7.4 'ein Tirghi Cemetery Sample

7.4.1 Descriptive Statistics

Descriptive statistics, including mean, standard error, standard deviation, variance, and confidence interval were calculated for the 'ein Tirghi sample as a whole, for males and females, and for subadults for both carbon and nitrogen stable isotopes

Table 7.1. Descriptive statistics for carbon stable isotopes for the 'ein Tirghi cemetery sample, partitioned by age group and sex.

Sample	Sample Size	Mean $\delta^{13}C$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	31	-18.88	0.09	0.56	0.31	0.19
Adult Females	12	-19.08	0.07	0.27	0.07	0.15
Adult Males	13	-19.08	0.03	0.11	0.01	0.06
Subadults (< 15)	6	-18.05	0.27	0.79	0.64	0.64

Table 7.2. Descriptive statistics for nitrogen stable isotopes for the 'ein Tirghi sample, and partitioned by age group and sex.

Sample	Sample Size	Mean $\delta^{15}N$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	37	17.21	0.24	1.5	2.27	0.49
Adult Females	15	16.89	0.25	0.95	0.91	0.48
Adult Males	13	17.17	0.29	1.09	1.18	0.59
Subadults (<15)	9	17.79	0.84	2.51	6.30	1.64

(Tables 7.1 and 7.2). It was not possible to break the age categories down more finely, as is done for the Kellis 2 sample, due to the absence of children under 5 years of age from these tombs. All of the raw data, including percent collagen and C:N ratios, are listed in Appendix C. The Mahalanobis Distance statistic was used to identify outliers in the $\delta^{13}C$ and $\delta^{15}N$ data. For $\delta^{13}C$, Individual #2 in Chamber 1 is identified as an outlier (-17.39‰), as is Individual 40 from Chamber 2 (-16.84‰). Individual #40 from Chamber 2 is also identified as a $\delta^{15}N$ outlier (21.6‰).

A comparison of adult male and female means for both carbon and nitrogen stable isotopes revealed no statistically significant differences between the two groups at a p-value of 0.05. A T-test for carbon, which assumed equal variance, showed no statistically significant differences (p= 0.964). A T-test for nitrogen, once again assuming equal variance, revealed a p-value of 0.216. Figure 7.1 shows a scatter plot for adult males and females from 'ein Tirghi.

T-tests to compare adults and sub-adults were performed on both carbon and nitrogen isotope data. Figure 7.2 illustrates the data for adults and sub-adults. Statistically significant results were found when comparing carbon isotope values for sub-adults and adults (p=0.000); however, there are no significant findings between sub-adults and adults for nitrogen values (p=0.416). When carbon values from children aged 0 to 2 years old were compared to adult values, a significant difference was found (p=0.000).

When older children were taken out of the sample, however, and only

Figure 7.1. Scatter plot showing the $\delta^{13}C$ and $\delta^{15}N$ data for adult males and adult females from the 'ein Tirghi cemetery.

Figure 7.2. δ¹³C and δ¹⁵N isotope values for sub-adults, adult females and males from the 'ein Tirghi cemetery.
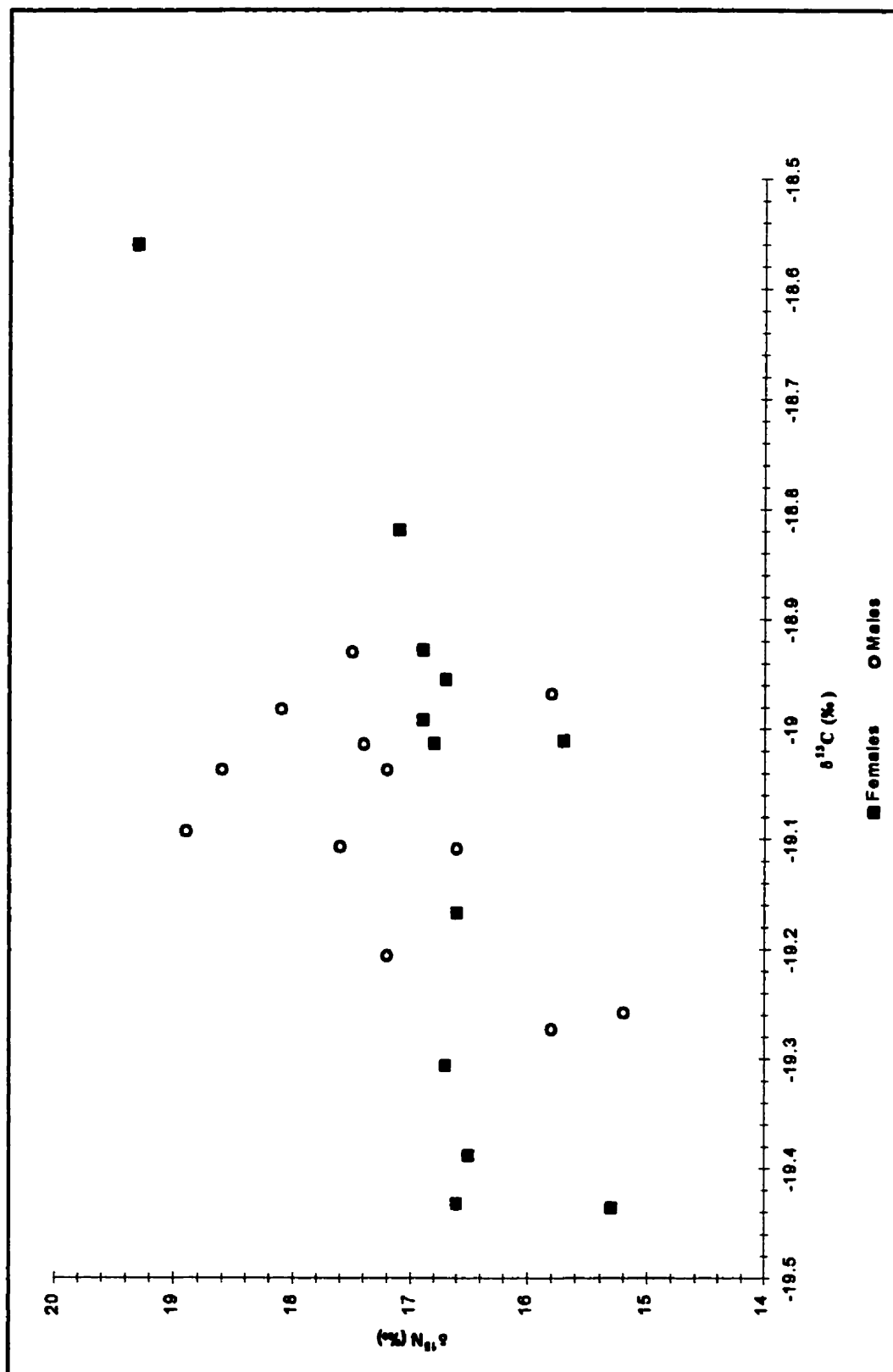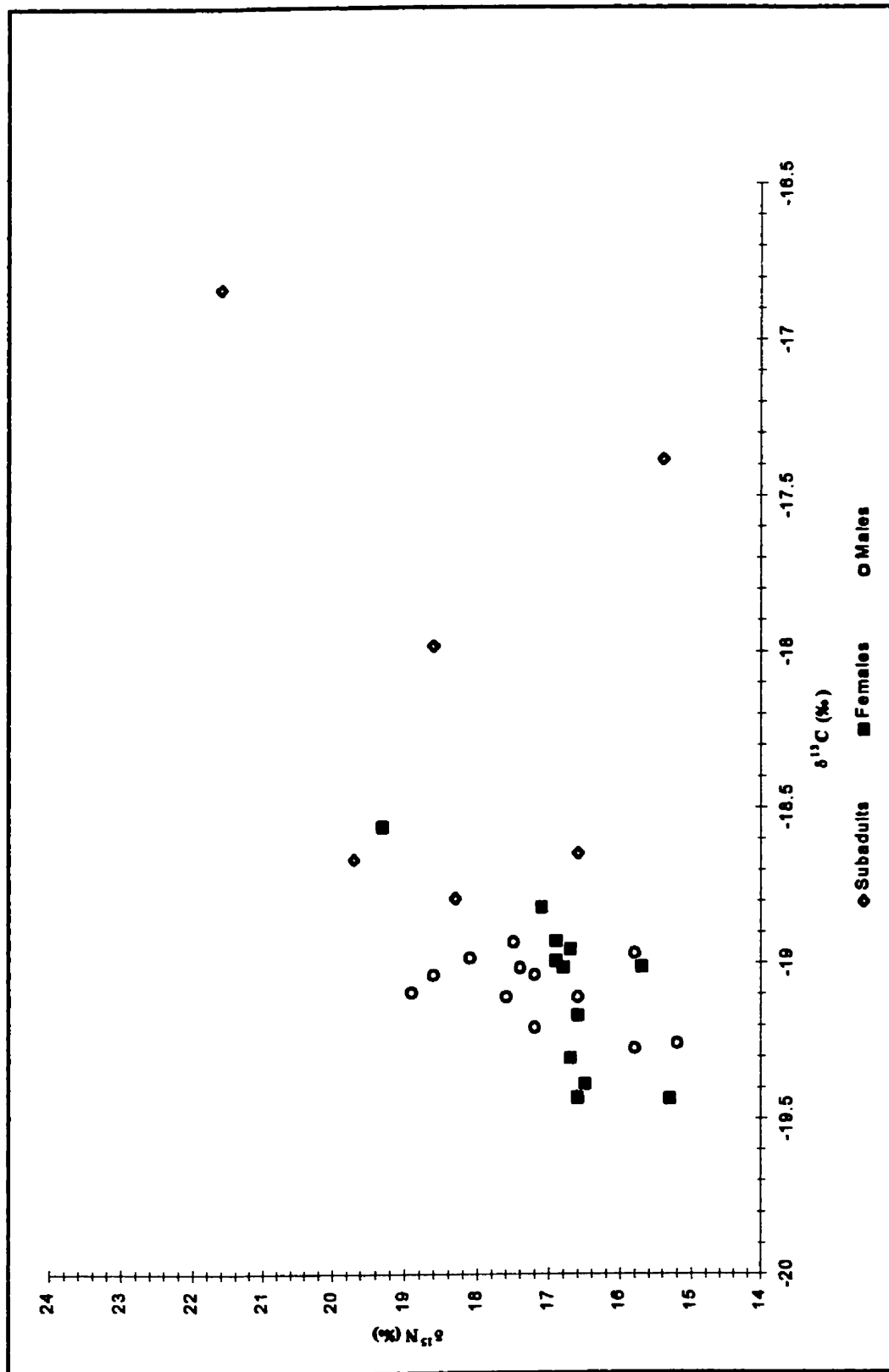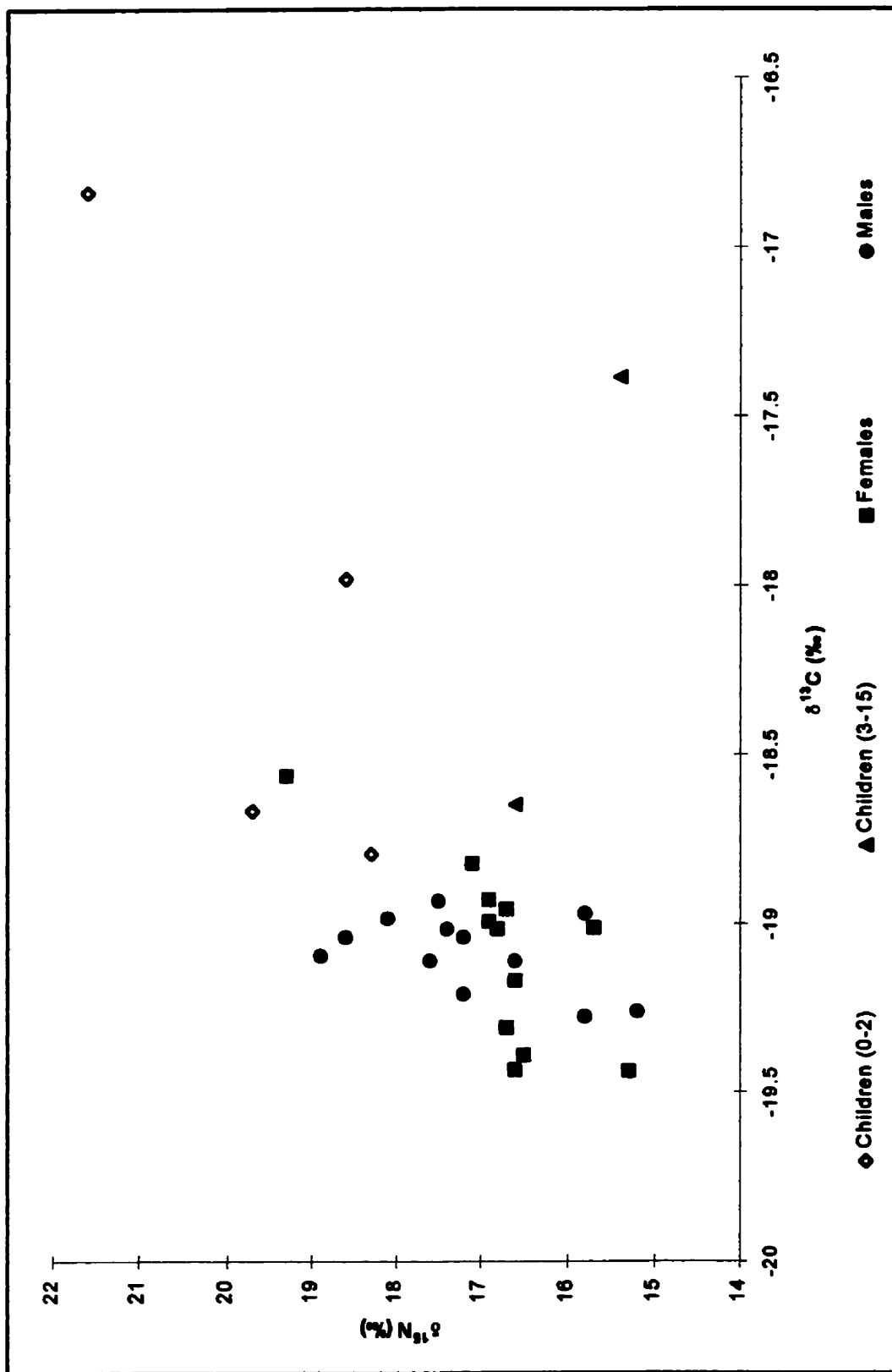
Figure 7.3. $\delta^{13}C$ and $\delta^{15}N$ isotope values for children and adult male and females from the 'ein Tirghi cemetery.

newborns to 2 years of age were compared to adults for their nitrogen values, there was a statistically significant difference between the two subgroups (p=0.031). Statistically significant results were found between children and adults for carbon isotope values (p=0.000), but no statistically significant results were identified for nitrogen (p=0.072). Figure 7.3 shows the relationship of nitrogen and carbon isotope values for children under two years of age, children 2 to 15 years of age, females and males.

A graph of nitrogen isotope values plotted against estimated age at death (years) shows that children under 2 tend to be enriched in nitrogen over adults (Figure 7.4). With the exception of the extreme outlier ($\delta^{15}N=14.9\%$, no $\delta^{13}C$ value available) in this subset, all the under 2 nitrogen values are significantly different from the adults. The former show nitrogen values approximately 3% higher (mean $\delta^{15}N=19.7\%$) than the adults (mean $\delta^{15}N=16.8\%$). After two years of age the nitrogen values drop significantly to a mean value of approximately $+17\%$.

The carbon isotope values, when plotted against estimated age at death (years), also show an interesting pattern (Figure 7.5). The children under 2 (mean $\delta^{13}C=-18.06\%$) appear to be enriched in carbon over the adults (mean $\delta^{13}C = -19\%$). This difference just reaches statistical significance (p=0.05). After 2 years of age carbon isotope values are less enriched and appear to level out at around 15 years of age.

7.5 Kellis 1 Cemetery Sample

7.5.1 Descriptive Statistics

The nature of the Kellis 1 cemetery makes it somewhat difficult to conduct
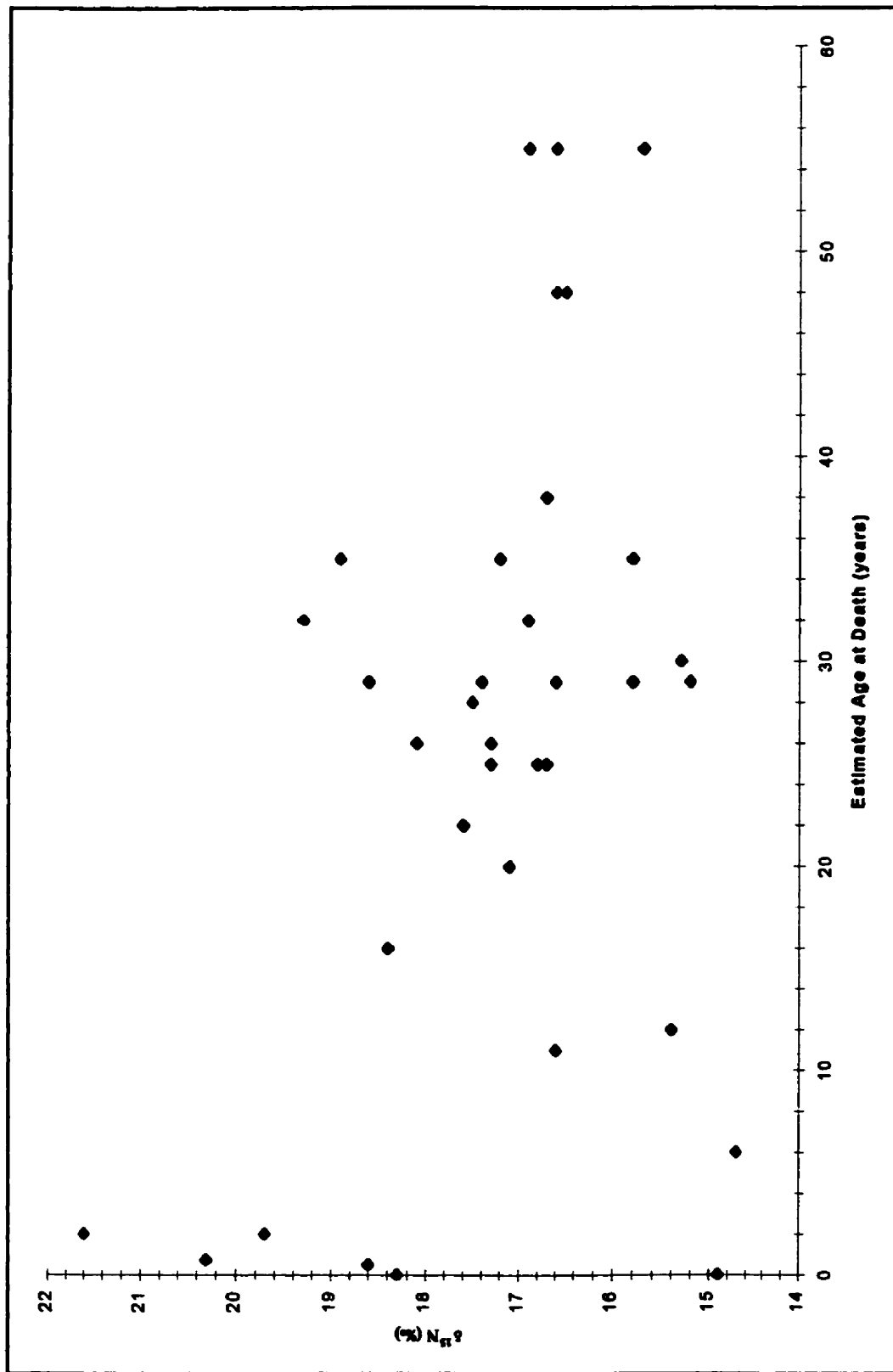
Figure 7.4. $\delta^{15}N$ isotope values versus estimated age at death for all samples from the 'ein Tirghi cemetery.
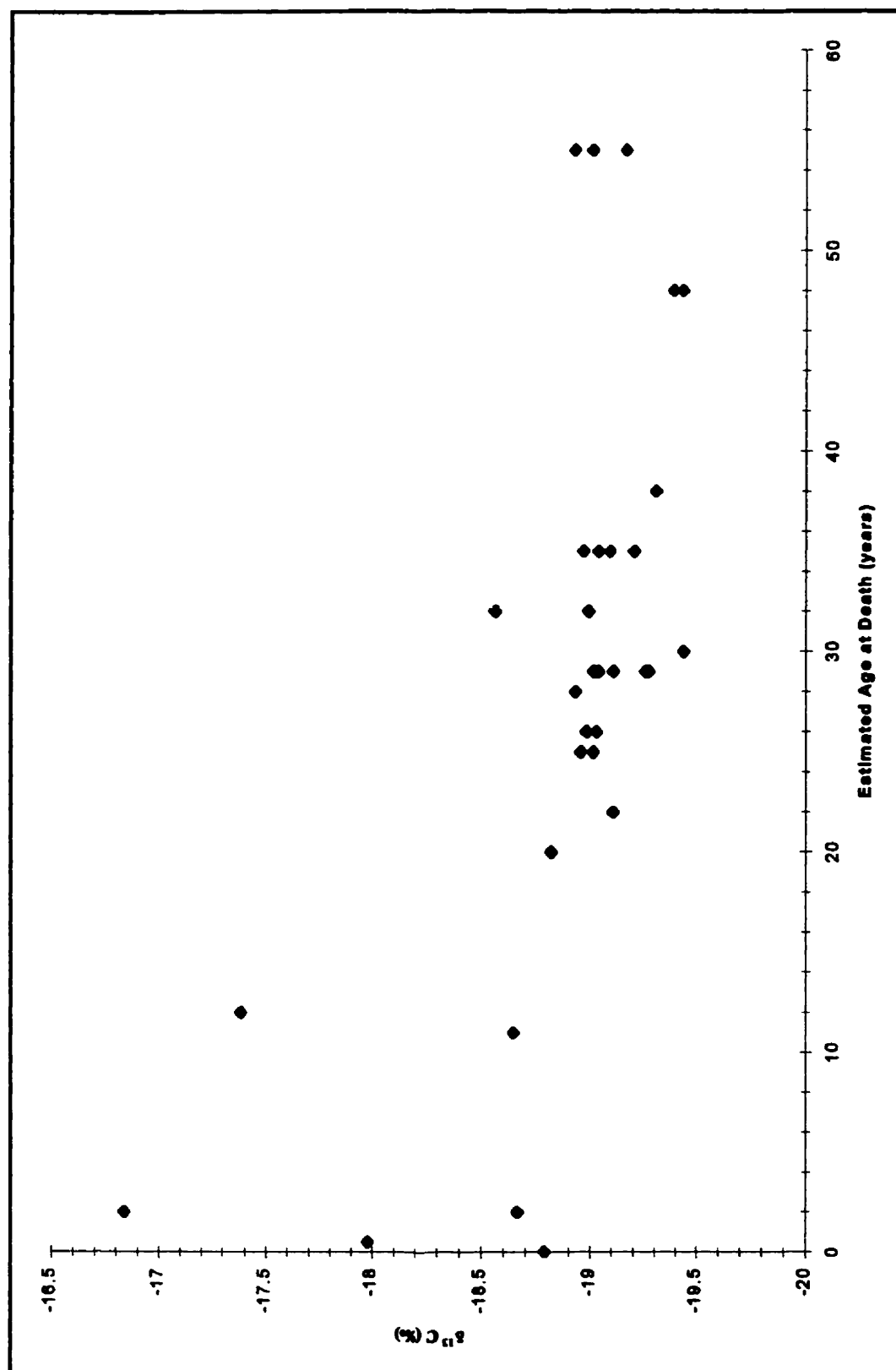
Figure 7.5. $\delta^{13}C$ isotope values versus estimated age at death (years) for all samples from the 'ein Tirghi cemetery.

statistical tests on all individuals. Of the 42 samples, the sex of only 13 could be identi-

fied as to sex, and in most cases estimations of age at death could not be made. No in-

fants, however, have been identified in these tombs, and the youngest individual has

been estimated to be approximately 5 years of age. In this case, the subadults were not

separated from the adults for statistical analysis. By the age of 5 both carbon and nitro-

gen stable isotope values tend to be the same as adult values, so I felt that it was not

necessary to compare subadults and adults at Kellis 1.

Table 7.3. Descriptive statistics for $\delta^{13}C$ isotope values for all of the Kellis 1 cemetery individuals, and for females and males (including both subadults and adults).

Sample	Sample Number	Mean $\delta^{13}C$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	42	-19.325	0.147	0.956	0.915	0.289
Females	6	-19.45	0.105	0.259	0.067	0.207
Males	7	-19.6	0.101	0.267	0.071	0.197

Table 7.4. Descriptive statistics for $\delta^{15}N$ isotope values for all of the Kellis 1 cemetery individuals, and for females and males (including adults and subadults).

Sample	Sample number	Mean $\delta^{15}N$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	42	17.78	0.25	1.62	2.61	0.49
Females	6	18.31	0.21	0.52	0.27	0.41
Males	7	18.19	0.10	0.27	0.07	0.19

Table 7.5. Descriptive statistics for $\delta^{13}C_{(apatite)}$ values for all of the Kellis 1 cemetery individuals, and for females and males (including adults and subadults).

Sample	Sample number	Mean $\delta^{13}C_{(apatite)}$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	16	-13.24	0.15	1.00	1.01	0.49
Females	4	-13.64	0.16	0.39	0.15	0.39
Males	5	-13.12	0.38	1.01	1.02	0.88

Basic descriptive statistics for carbon and nitrogen stable isotopes are listed

in Table 7.3 and 7.4 for all individuals and then for males and females. Table 7.5 lists

the basic descriptive statistics for the carbon apatite results. Refer to Appendix E for a

list of raw data, percent collagen, and C:N ratios. Once again, the Mahalanobis Dis-

tance Statistic was used to identify outliers in the $\delta^{15}N$ and $\delta^{13}C$ data. Individual #9

from Tomb 13 was identified as an outlier for $\delta^{13}C$ (-15.97‰). Individual #11 from

Tomb 13 was identified as an outlier for $\delta^{15}N$ (13.05‰).

7.5.2 Subgroup Comparisons

T-tests assuming equal variance were performed to determine if there were

any statistically significant differences between adult male and female subgroups in the

Kellis 1 cemetery population for both $\delta^{13}C$ and $\delta^{15}N$ values. A T-test was also per-

formed to determine if there was a difference between sub-adult and adult carbon and

nitrogen values. The tests failed to reveal statistically significant differences between

adult males and females for $\delta^{13}C$ values ($p= 0.654$); neither were significant differences

found between adult males and females for nitrogen values ($p=0.670$). Similarly, no

differences were detected between sub-adults (age 5 to 15) and adults (both males and

females grouped together) for either carbon ($p=0.177$) or nitrogen ($p=0.993$). Figure 7.6

plots sub-adult and adult male and female data for both nitrogen and carbon values.

This figure shows that the there is a relatively tight clustering of the data points between

a narrow range of values: between –19‰ and –20‰ for $\delta^{13}C$ and between 17.5‰ and

19.2‰ for $\delta^{15}N$.
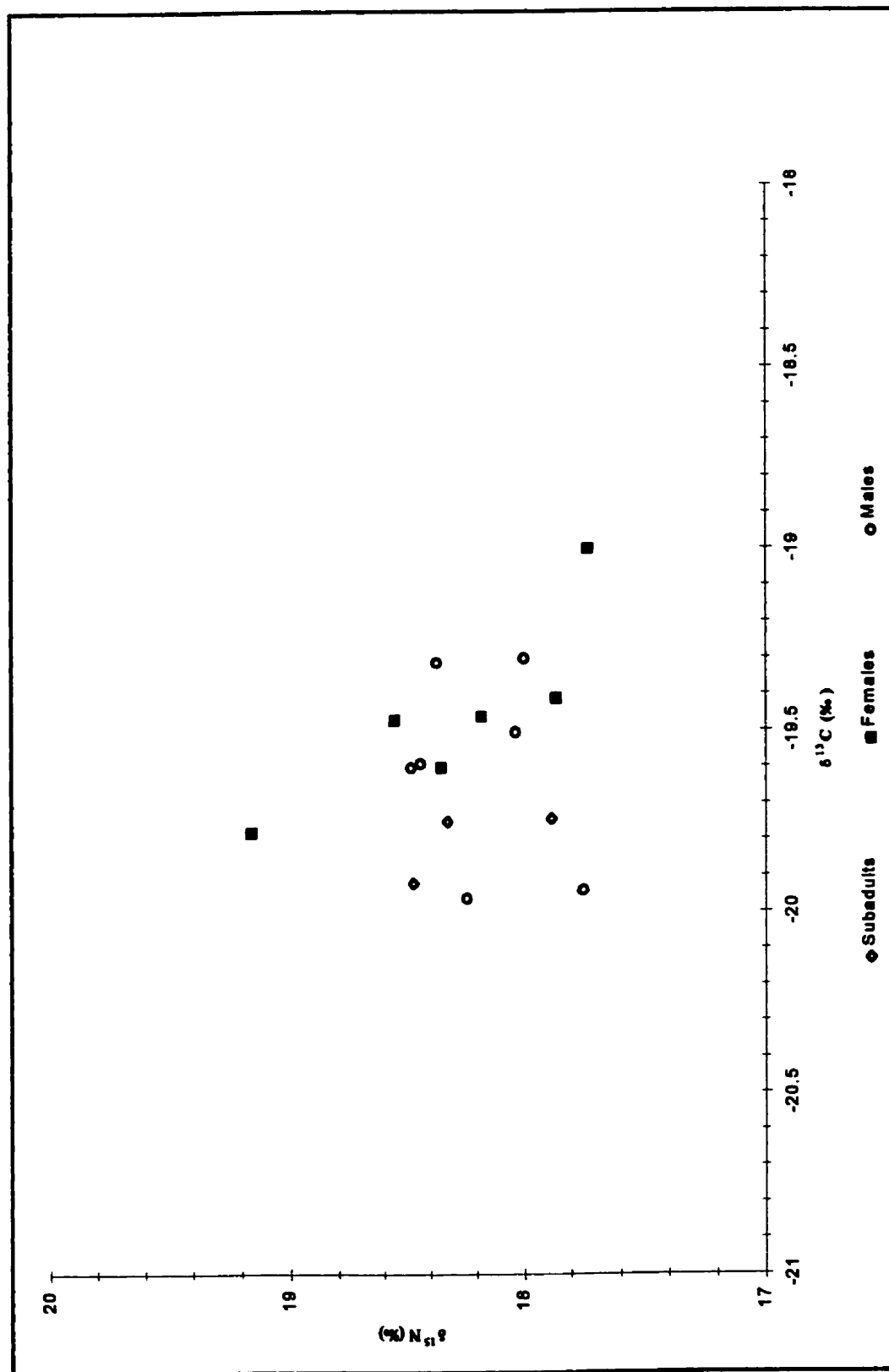
Figure 7.6. Sub-adult versus adults carbon and nitrogen values for individuals identified by age and sex in the Kellis 1 cemetery population.
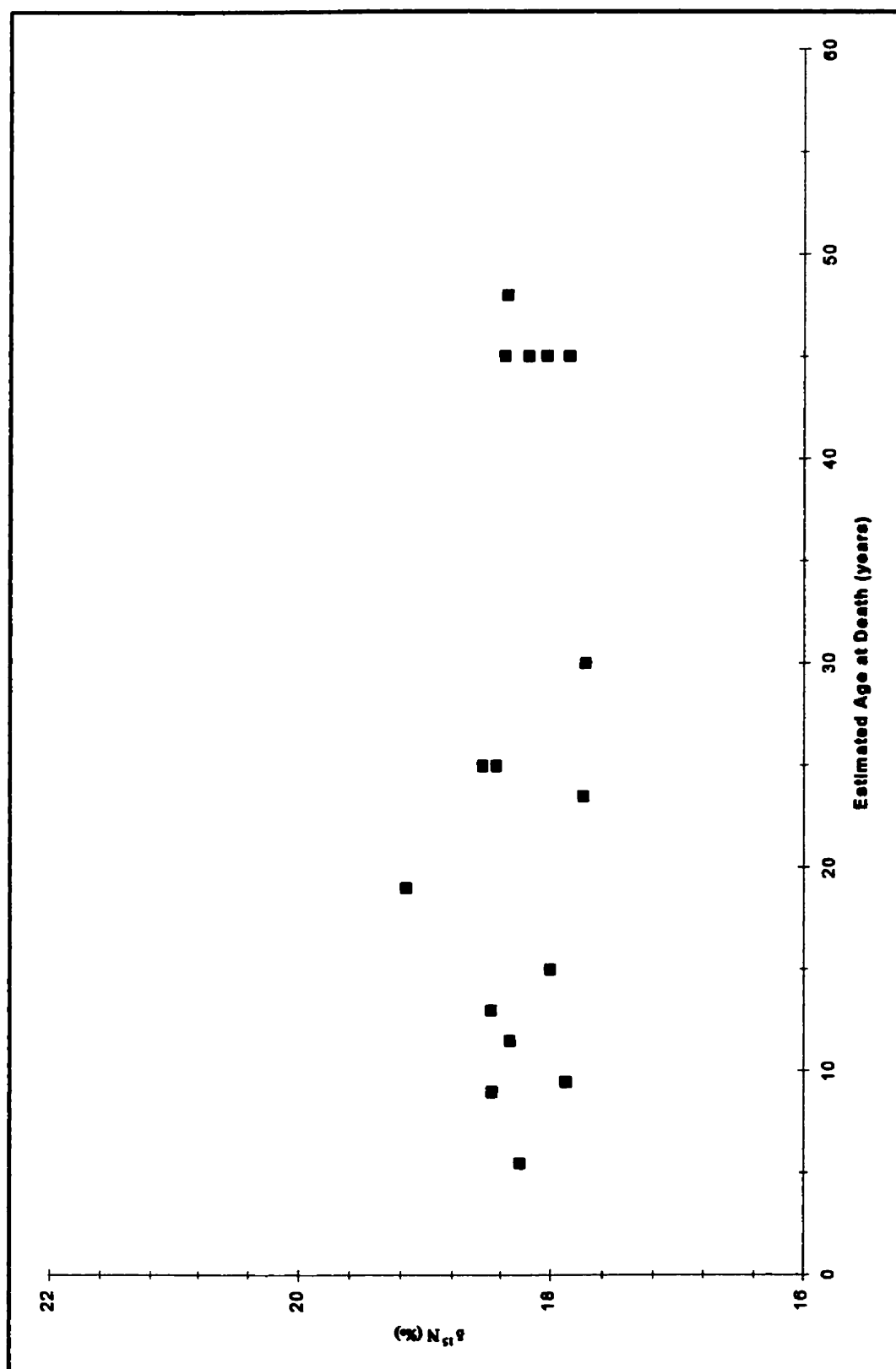
Figure 7.7. Estimated age at death (years) versus δ¹⁵N values for the Kellis 1 cemetery sample.

Figure 7.7 illustrates the relationship between estimated age at death (years) and nitrogen values and shows that there is very little variation in the nitrogen isotopes by age. There are no noticeable trends in the data, as was the case in the 'ein Tirghi cemetery sample. Because there are no children under 5 in the sample, no differences were expected. Another interesting note about Figure 7.7 is the lack of individuals in the 30-45 age range. This may be one of the effects of a small sample size, and may also reflect the inability to more precisely age co-mingled remains of adults.

Figure 7.8 illustrates the relationship between estimated age at death (years) and carbon values. There is slightly more variation in carbon values than in nitrogen values, but on the whole there is very little variation and, once again, no significant difference in carbon values by age. There is also a lack of data for the 30 to 45 year age category, as discussed previously.

Comparisons between $\delta^{13}C$ of apatite and collagen were made (Figure 7.9) to illustrate the spacing between the $\delta^{13}C$ values of bone carbonate and bone collagen. The mean difference between carbon apatite values and carbon collagen values is 6.32‰. The correlation coefficient between these two data sets is 0.613. There is only a weak linear relationship between the two variables ($r^2=0.375$). Removal of the two outliers (Tomb 13 Ind. 7; Tomb 3 Body N1) does not significantly alter the extent of the linear relationship ($r^2=0.435$), but it changes the correlation coefficient to −0.659. That is, it reverses the relationship from positive to negative.
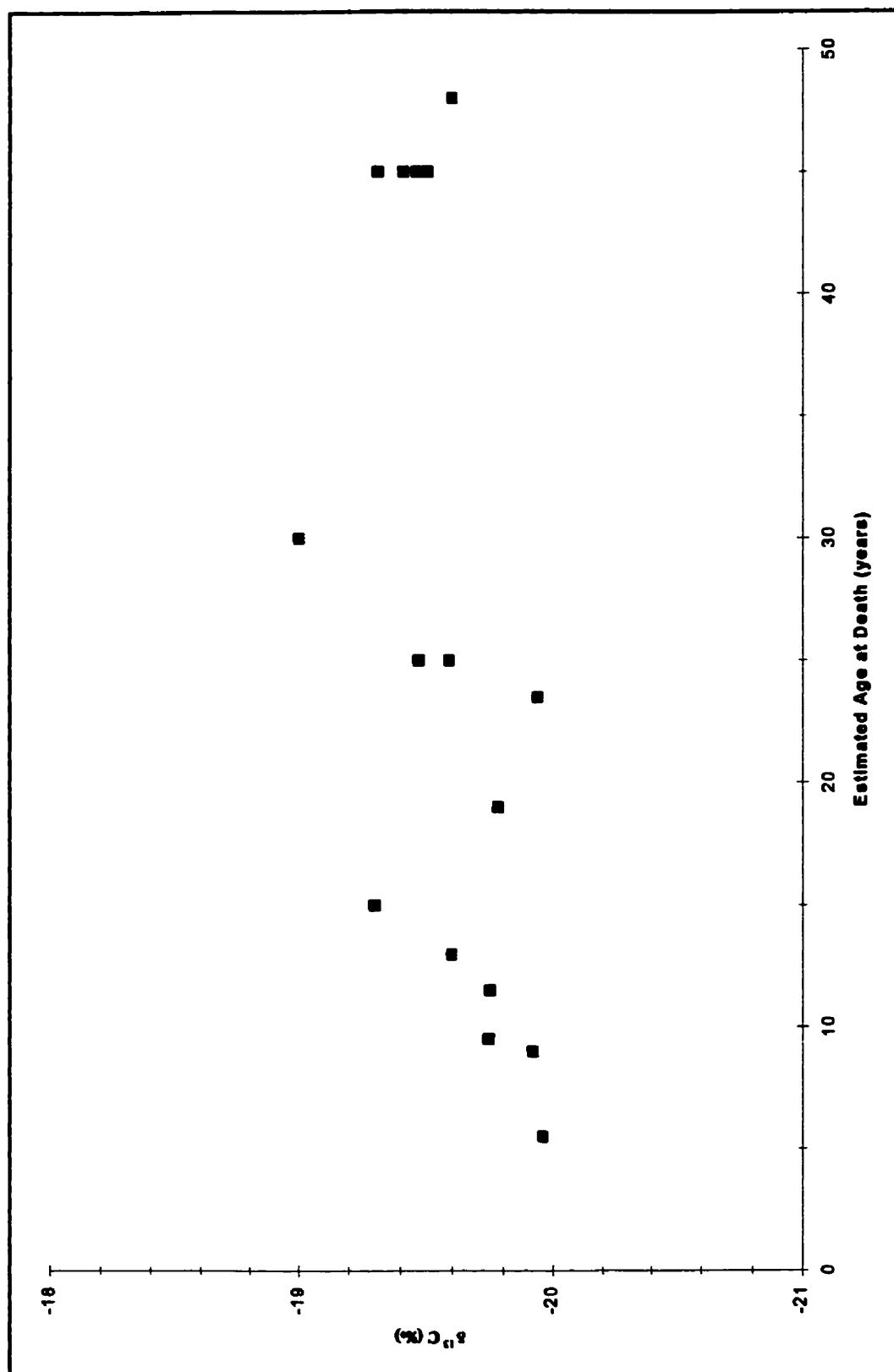
Figure 7.8. Estimated age at death (years) versus δ¹³C values for the Kellis 1 cemetery sample.
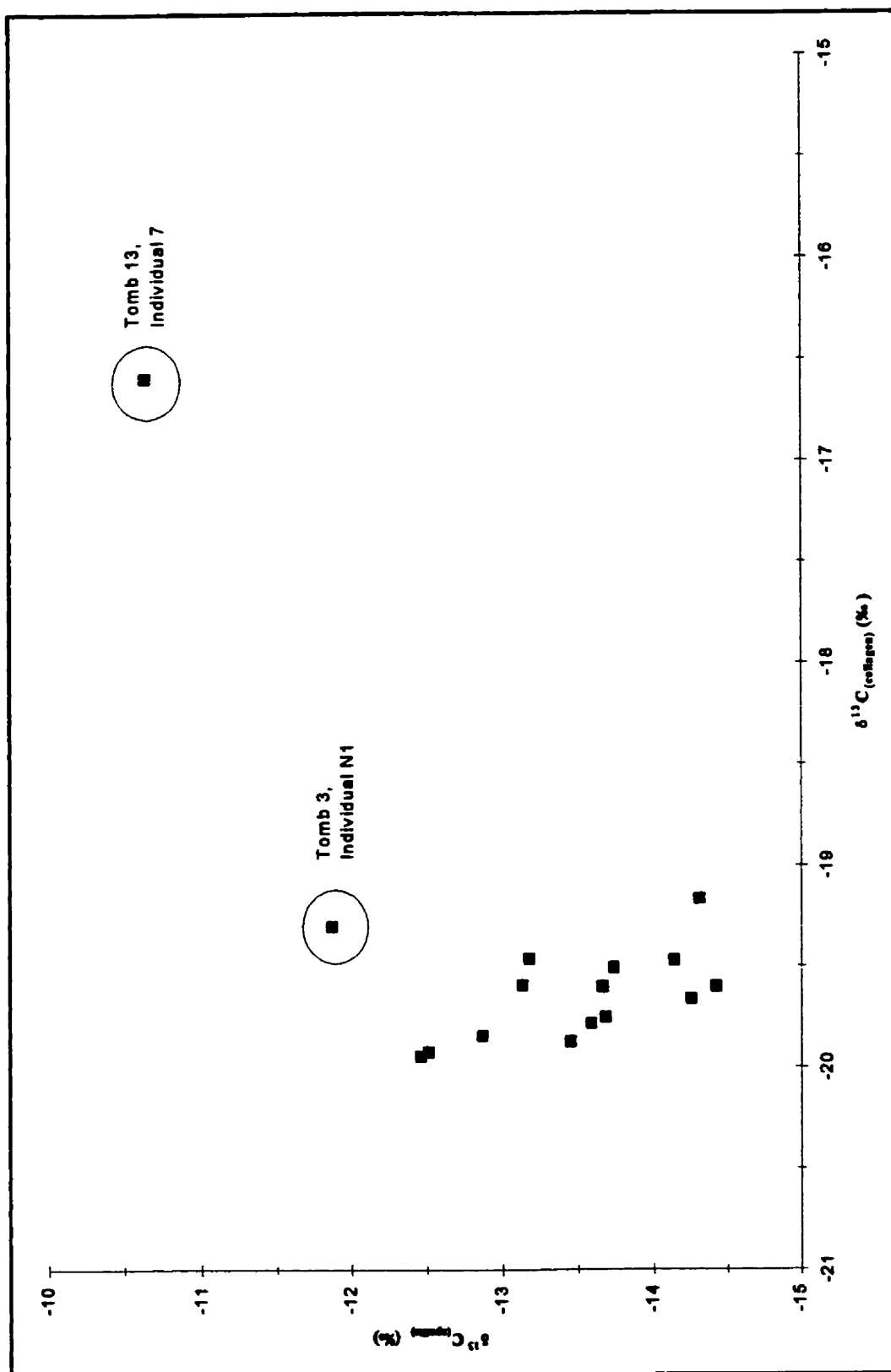
Figure 7.9. δ¹³C collagen values versus carbon apatite values for individuals from the Kellis 1 cemetery.

7.6 Kellis 2 Cemetery Sample

7.6.1 Descriptive Statistics

Descriptive statistics for $\delta^{15}N$, $\delta^{13}C$ of apatite and collagen values were determined for the whole population, adult females and males, the two categories of children (0-1.9, 2-10), and juveniles. Because of the large size of the sampled population and the opportunity to estimate sex and age at death, it was possible to break down the sample into smaller subsets. Tables 7.6, 7.7 and 7.8 list the descriptive statistics for carbon, nitrogen, and carbon apatite stable isotopes for the whole group, both categories of

Table 7.6. Descriptive statistics for $\delta^{13}C$ for the Kellis 2 cemetery sample by age, and sex (adults only).

Sample	Sample Number	Mean $\delta^{13}C$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	113	-18.84	0.05	0.50	0.25	0.09
Children (0-1.9)	27	-18.76	0.17	0.91	0.82	0.34
Children (2-10)	19	-18.68	0.08	0.34	0.11	0.15
Juveniles (11-16)	4	-18.75	0.05	0.11	0.01	0.11
Adult Females	35	-19.05	0.03	0.17	0.03	0.06
Adult Males	27	-18.78	0.05	0.25	0.06	0.09

Table 7.7. Descriptive statistics for $\delta^{15}N$ for the Kellis 2 cemetery sample by age, and sex (adults only).

Sample	Sample Number	Mean $\delta^{15}N$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	110	18.65	0.15	1.59	2.52	0.29
Children (0-1.9)	22	20.75	0.25	1.29	1.67	0.54
Children (2-10)	19	18.62	0.26	1.14	1.30	0.51
Juveniles (11-16)	5	18.91	0.67	1.49	2.24	1.32
Adult Females	37	18.03	0.16	0.99	0.99	0.32
Adult Males	26	17.75	0.24	1.22	1.49	0.47

Table 7.8. Descriptive statistics for carbon apatite values for the Kellis 2 cemetery sample by age and sex (adults only).

Sample	Sample Number	Mean δ¹³C (apatite) (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Total Sample	17	-12.75	0.05	0.57	0.32	0.27
Children (0-1.9)	3	-12.90	0.12	0.71	0.50	0.80
Children (2-10)	5	-12.60	0.09	0.39	0.16	0.35
Juveniles (11-16)	1	(-12.16)	-	-	-	-
Adult Females	6	-12.66	0.10	0.63	0.39	0.51
Adult Males	2	-13.43	0.03	0.18	0.03	0.24

children, juveniles, and male and female adults. Refer to Appendix E for raw data, C:N ratios and percent collagen. Both Tables 7.6 and 7.7 have one extra sample in the total sample number than appears when summing the sample numbers together for the sub-groups because one individual was represented by only a pair of lower legs (Burial 140). No sex or age, beyond the adult category, could be assigned to this individual. Refer to Appendix F for a list of the raw data, percent collagen, and C:N ratios. The Mahalano-bis Distance statistic was used to identify any outliers in the carbon and nitrogen data. The following individuals have been noted as being outliers in the nitrogen data: B67,

Table 7.9. T-test results comparing δ¹⁵C of collagen for subsets from the Kellis 2 cemetery sample.

	Children (0-1.9)	Children (2-10)	Juveniles (11-16)	Adult Females	Adult Males
Children (0-1.9)	-	0.698	0.981	0.074	0.943
Children (2-10)	-	-	0.675	0.000	0.260
Juveniles (11-16)	-	-	-	0.002	0.849
Adult Females	-	-	-	-	0.000
Adult Males	-	-	-	-	-

Significance level was set to p ≤ 0.05.
* significant differences are bolded

Table 7.10. T-test results comparing δ¹⁵N values for subgroups of the Kellis 2 cemetery population.

	Children (0-1.9)	Children (2-10)	Juveniles (11-16)	Adult Females	Adult Males
Children (0-1.9)	-	0.000	0.010	0.000	0.000
Children (2-10)	-	-	0.637	0.51*	0.021
Juveniles (11-16)	-	-	-	0.262†	0.072
Adult Females	-	-	-	-	0.337
Adult Males	-	-	-	-	-

Significance level was set to $p \leq 0.05$.
* significant differences are bolded
† T-test assuming unequal variance

B90, B143, B116, and B73. The following individuals have been identified as outliers in the carbon data: B101, B169, and B107.

7.6.2 Comparisons Between Subgroups

T-tests were used to evaluate differences between the subgroups for both carbon and nitrogen isotope values for the Kellis 2 cemetery. Table 7.9 lists the p-values for comparisons between each subgroup for carbon stable isotope values. Statistical significance was set at $p \leq 0.05$. Statistically significant comparisons are bolded. Significant differences were found between adult females (>18 years) and children (2-10 years old), where p=0.000, and between adult females and juveniles (10 to 16 years), where p=0.002. Adult males and females also show significant differences, where p=0.000. Figure 7.10 illustrates the nitrogen and carbon data for both categories of children, juveniles, and adult males and females.

Table 7.10 lists the p-values for comparisons between each subgroup for ni-
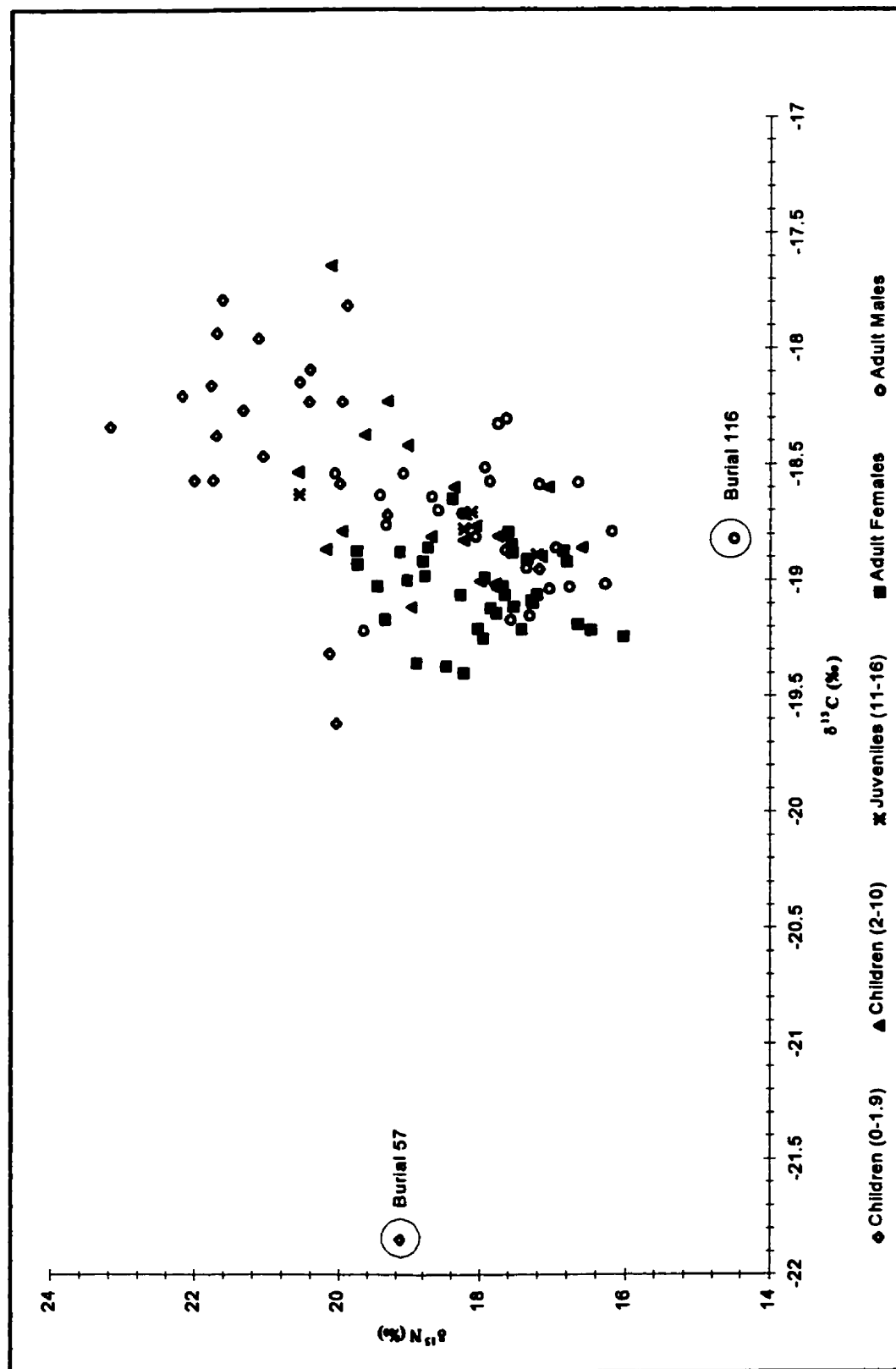
Figure 7.10. Carbon isotope values plotted against nitrogen isotope values for children, juveniles, and adult females and males from the Kellis 2 cemetery sample.

Figure 7.11. δ¹⁵N values plotted against estimated age at death (years) for all samples from the Kellis 2 cemetery sample.
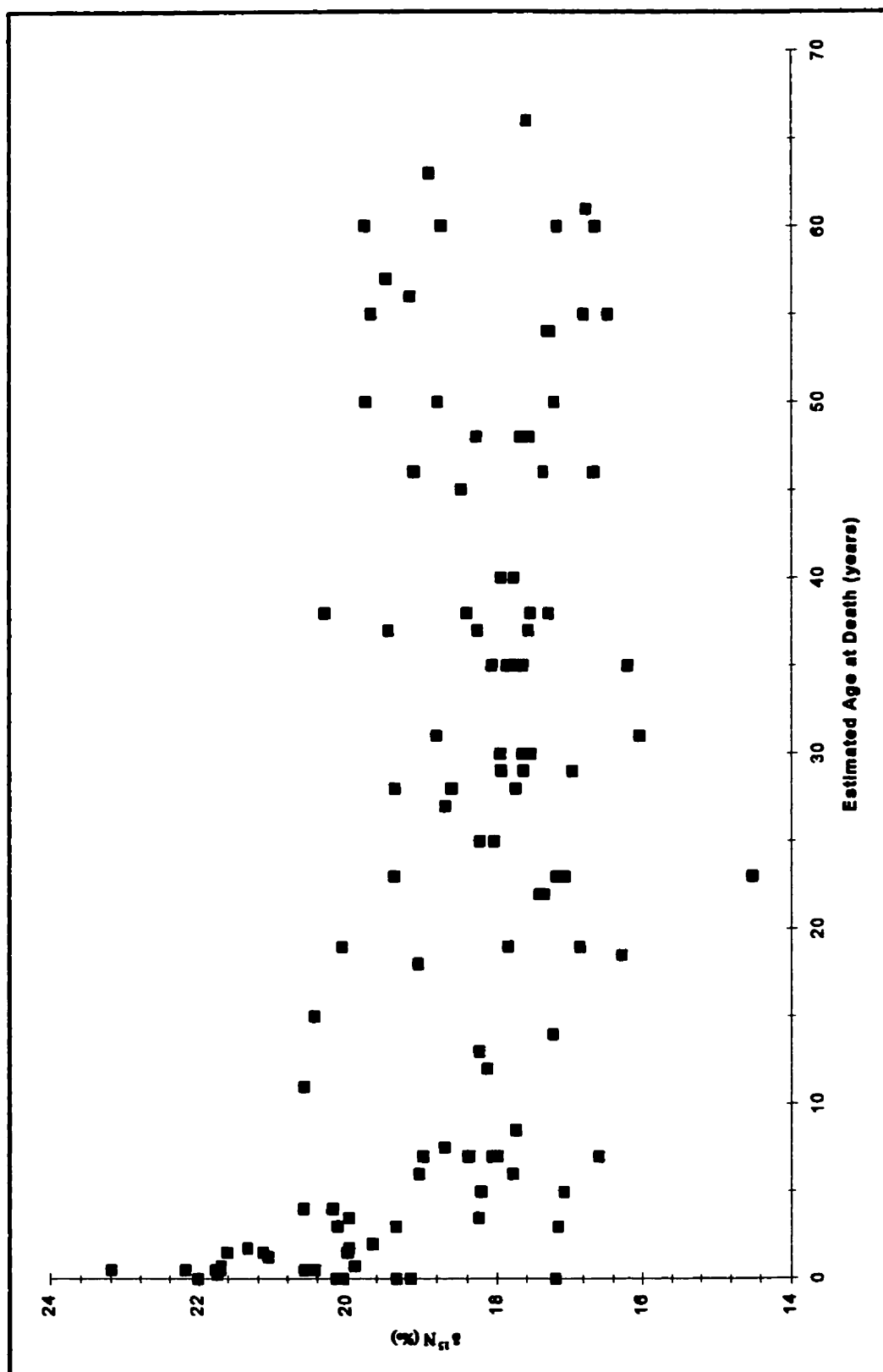
trogen stable isotope values. Statistically significant differences (p≤ 0.05) are high-

lighted in bold. For all comparisons, equal variance was assumed, with the exception

of the juvenile versus adult females. The difference between the variances was large

enough to run the test assuming unequal variances.

Statistically significant results were found between children (0-1.9 years)

and all other age categories. In all cases infants are significantly enriched in ^{15}N in

comparison to children, juveniles and adults. Children (2-10 years) were also found to

be significantly different than adult males and females, and are significantly enriched in

^{15}N over adults.

A plot of nitrogen values against estimated age at death shows that there is a

pattern worth exploring (Figure 7.11). Infants between the age of newborn (0) and ap-

proximately one year of age appear to have higher nitrogen values; after age one, nitro-

gen values tend to decrease by 2‰ to 3‰. To determine if $\delta^{15}N$ is decreasing as a

function of age, the infant category was broken down into smaller age categories. Each

age category represents 0.25 of a year, thus the categories are 0 (new born), 3 months, 6

months, 9 months, 15 months, 18 months, 21 months and 24 months. I selected these

age categories to be able to more accurately pinpoint when infants were experiencing

changes in their dietary regime. A 12 month age category was not included as none of

the infants was estimated to be this age. The mean $\delta^{15}N$ value for each age category

was then plotted to determine if there was a recognizable pattern (Figure 7.12).

Figure 7.12 shows the mean values for nitrogen plotted against estimated
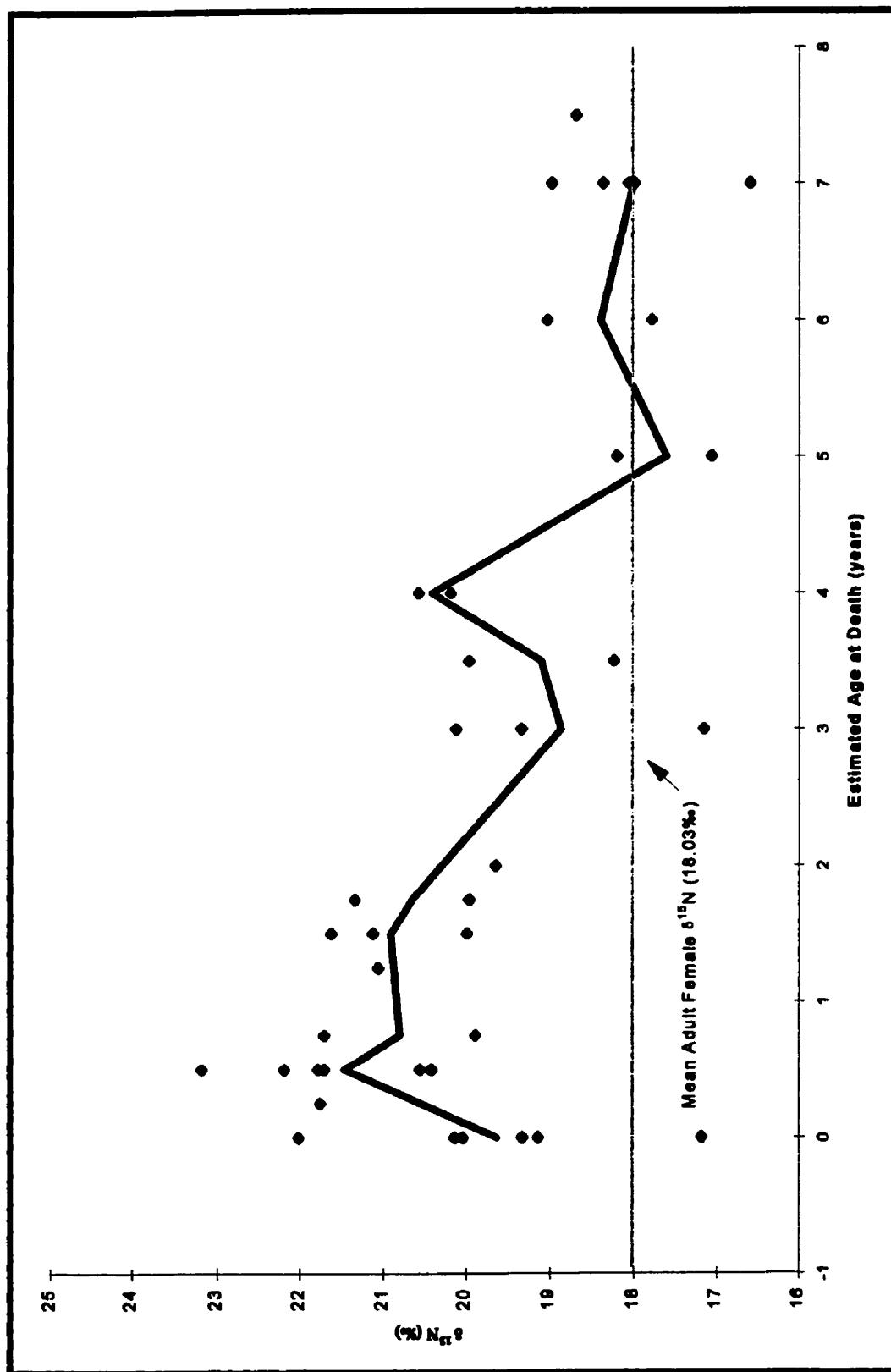
Figure 7.12. δ¹⁵N values with with mean value represented by the dark line for each age category plotted against estimated age at death for infants and children for the Kellis 2 cemetery sample.
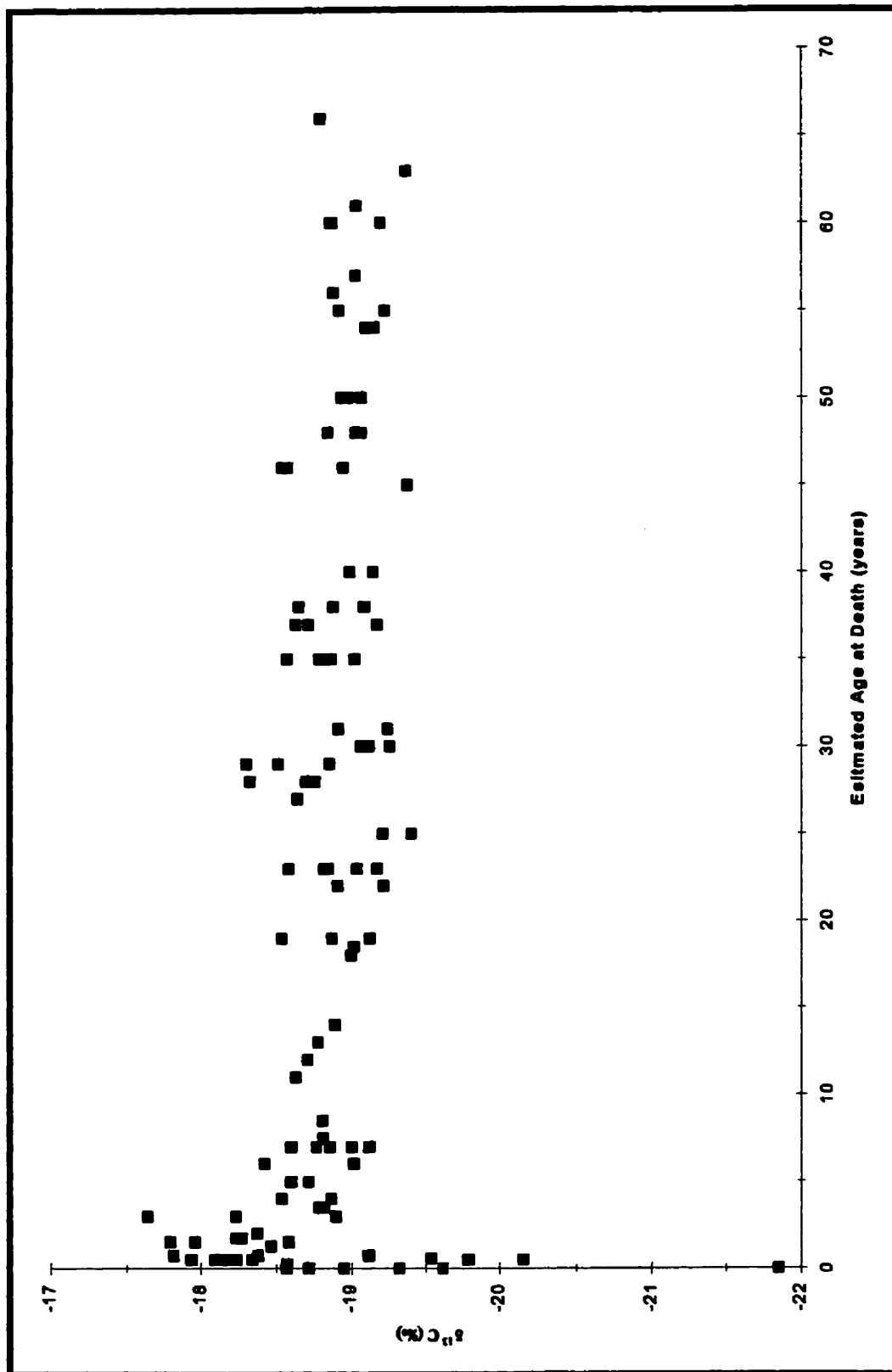
Figure 7.13. $\delta^{13}C$ plotted against estimated age at death (years) for all samples in the Kellis 2 cemetery sample.
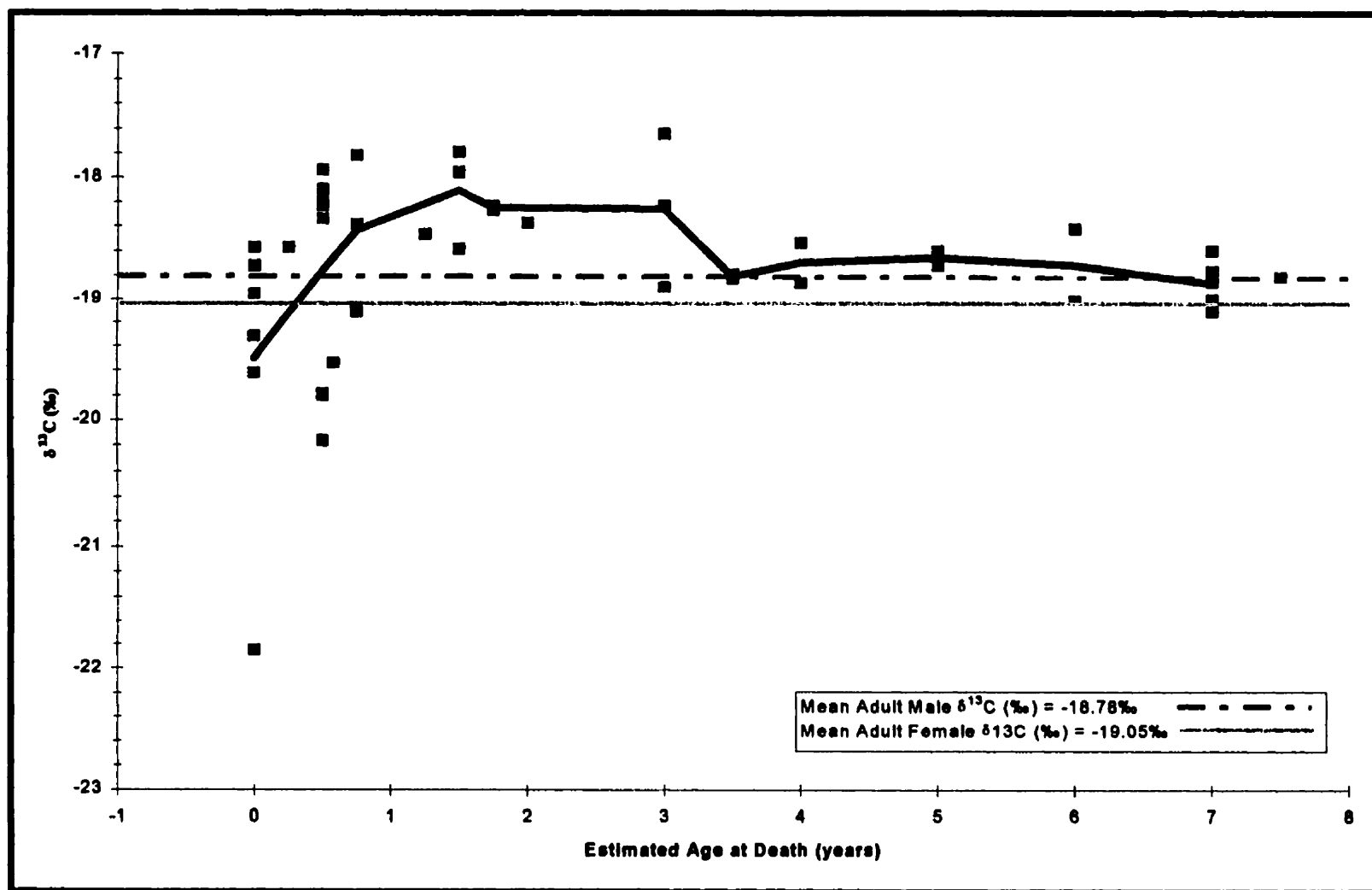
Figure 7.14. $\delta^{13}C$ values with the mean indicated by the solid black line for each age category plotted against estimated age at death (years) for infants and children for the Kellis 2 cemetery sample.

age at death for age categories from newborn to 7 years of age. The plotted means show that newborns reflect an isotope value (~19‰) that is similar to adult females (adult females mean $\delta^{15}N$ = 18.03‰); by approximately 6 months of age, however, there is a substantial increase in $\delta^{15}N$. After 6 months of age $\delta^{15}N$ begins to decline. By seven years of age $\delta^{15}N$ reflects adult values (males mean $\delta^{15}N$=17.75‰).

A similar pattern is noted in the $\delta^{13}C$ value of the children under 2 (Figure 7.13). Figure 7.14 shows the mean values for each subgroup of this age category, plotted against their estimated age at death. Newborn infants have a mean carbon value of −19.51‰, which is similar to the mean carbon value of the adult females in the group (-19.05‰). $\delta^{13}C$ increases steadily from birth, levelling out at about 24 months, and then abruptly drops to near-adult values at 3 years of age. From 3 to 14 years $\delta^{13}C$ drops gradually by about 0.2‰, reaching adult values by age 15.

After testing for differences between all subgroups of the 0-2 age category, statistically significant differences are found between newborn (0 years) and 18 month old infants (1.5 years) (p=0.019), and also between newborn and 21 month old infants (1.75 years) (p=0.026). Newborns have $\delta^{13}C$ values that are slightly depleted in comparison to that of adult females (-19.05‰). This changes by 1.5 years of age, when $\delta^{13}C$ becomes significantly enriched over that of newborns. This significant enrichment is still present at 21 months of age, but thereafter $\delta^{13}C$ begins to decrease steadily until it reaches adult values after about 6 years of age.

When the age pattern for carbon values is compared to the pattern for
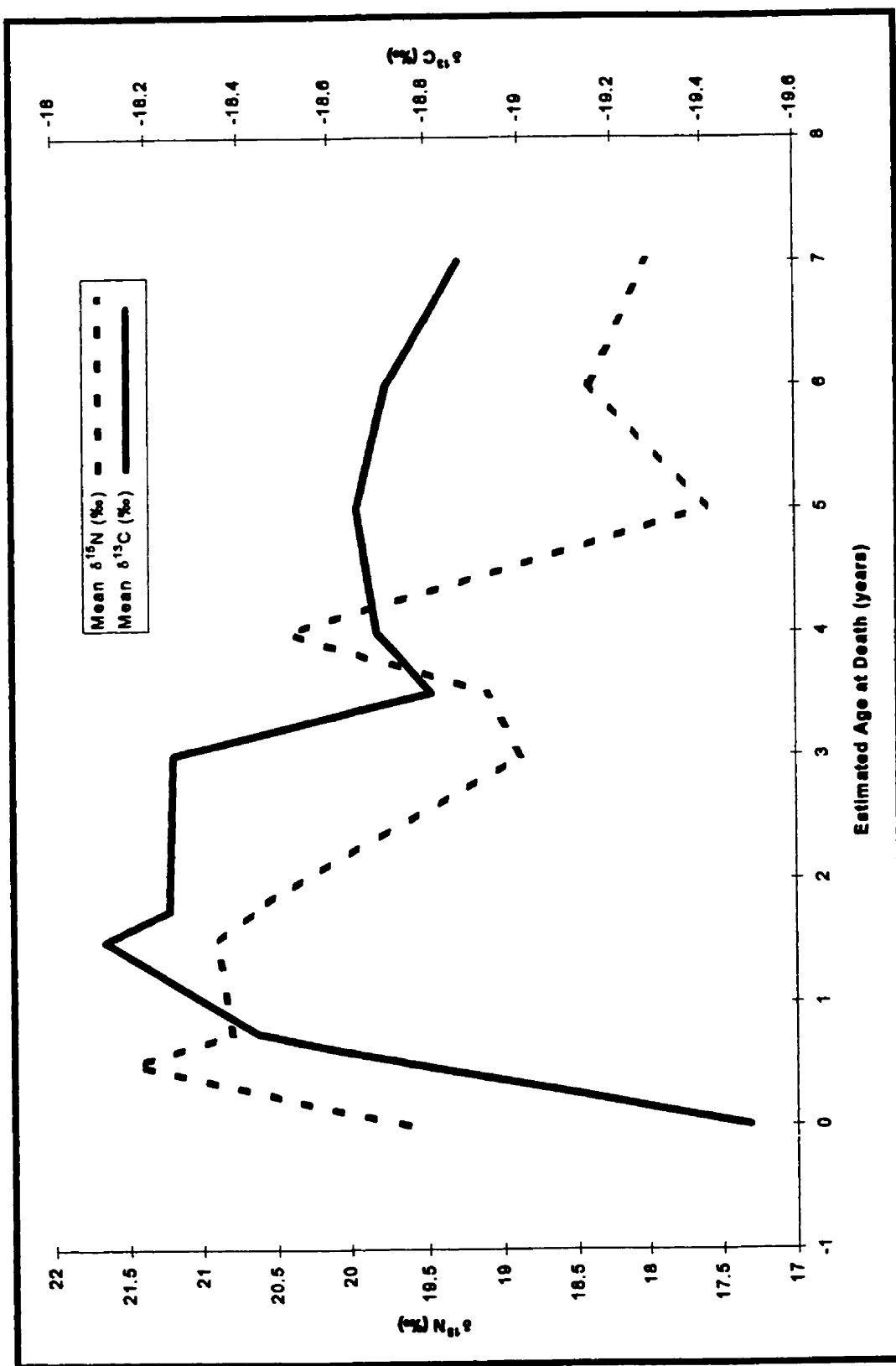
Figure 7.15. Trend lines for $\delta^{13}C$ superimposed on the trend line for $\delta^{15}N$ for infant and children from the Kellis 2 cemetery sample.

Figure 7.16. $\delta^{13}C$ of apatite plotted against $\delta^{13}C$ of collagen for both adults and subadults from the Kellis 2 cemetery sample.
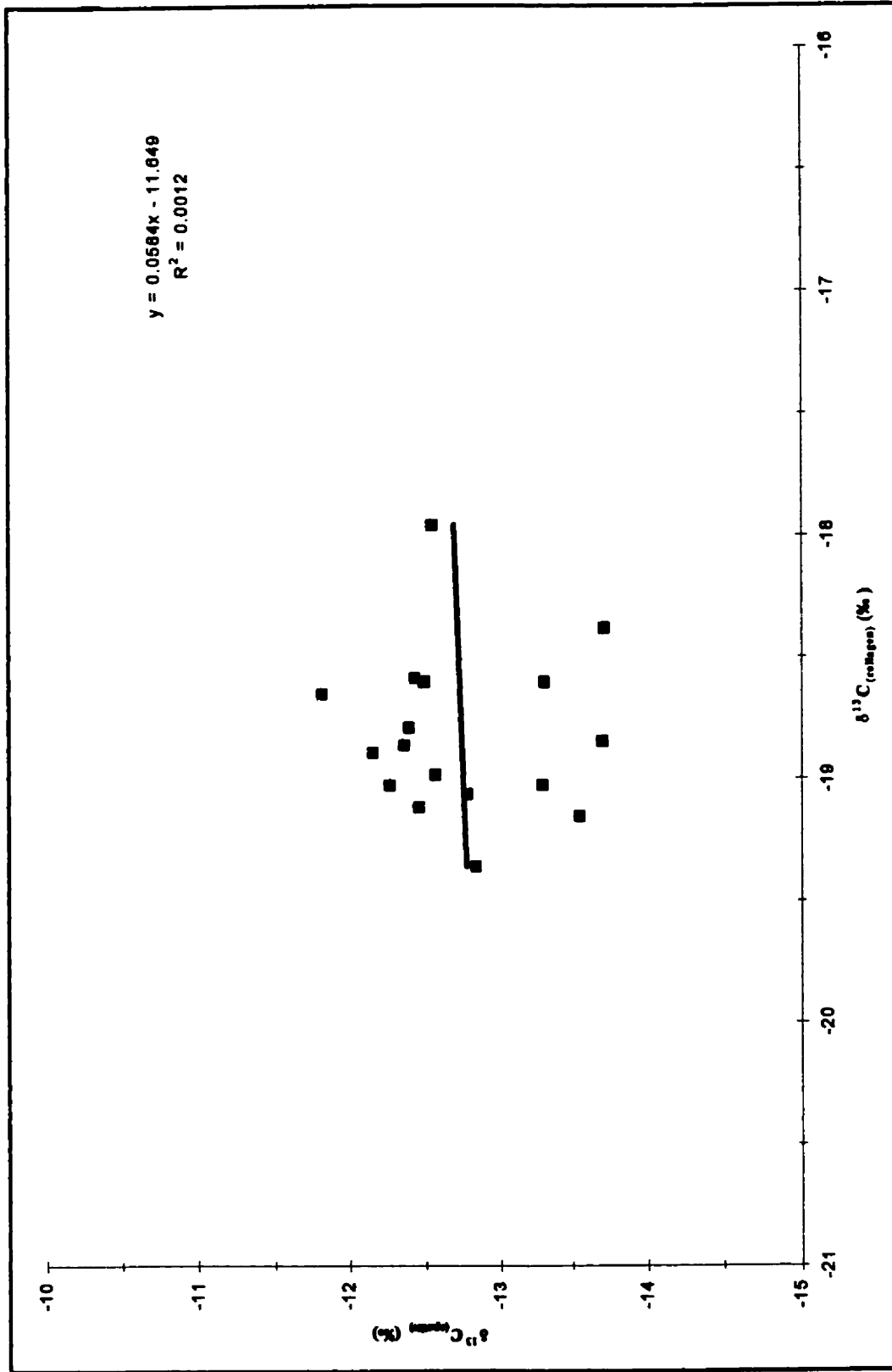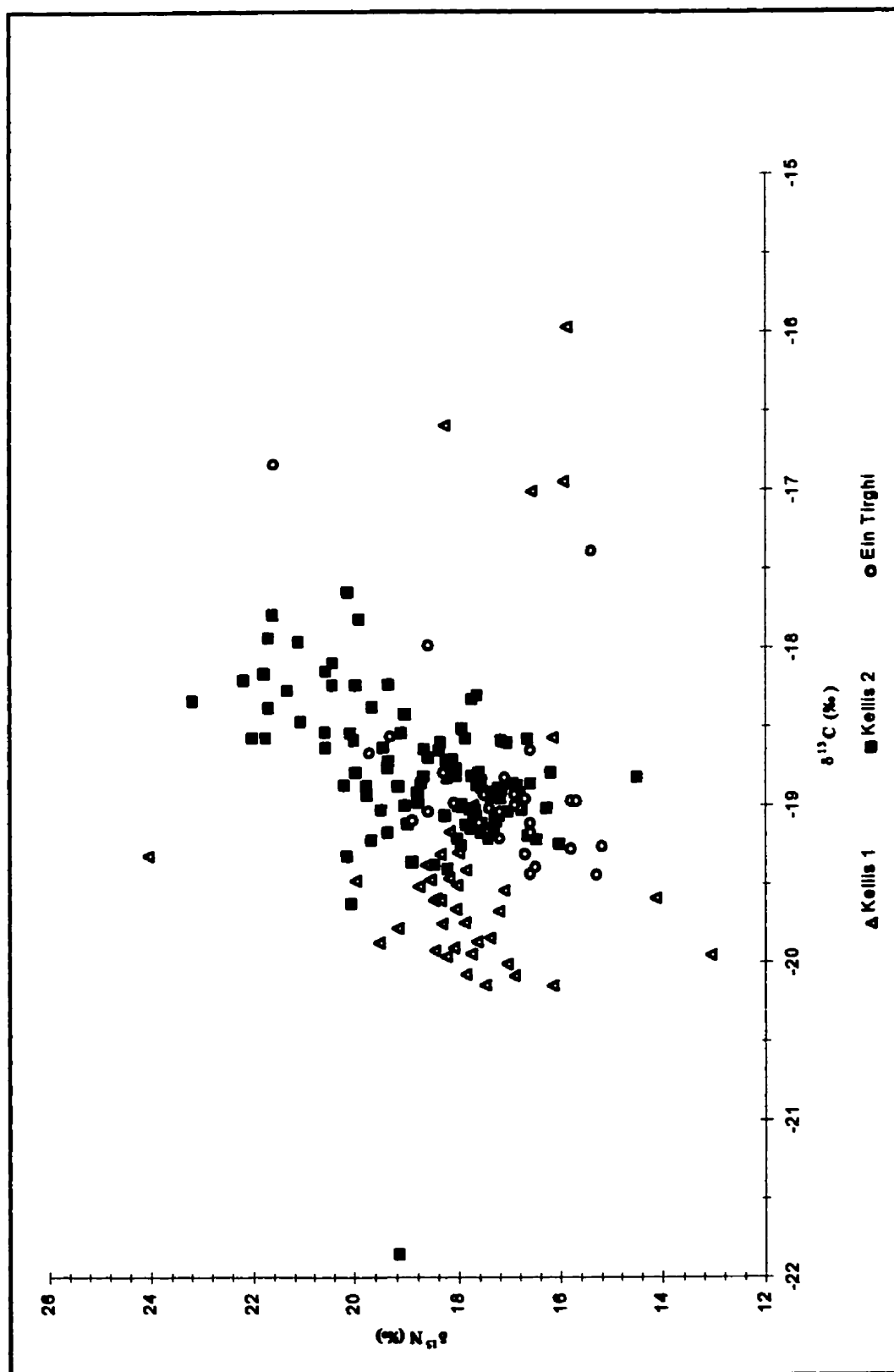
Figure 7.17. δ^{15}N values plotted against δ^{13}C values for all samples from all three cemetery samples.

Table 7.11. P-values for T-test comparisons for $\delta^{15}N$ values by cemetery.

	'ein Tirghi	Kellis 1	Kellis 2
'ein Tirghi	-	0.449	0.000
Kellis 1	-	-	0.000
Kellis 2	-	-	-

Significance level was set at 0.05.
* *results that are significant to p ≤ 0.05 are bolded*
† *T-test assuming unequal variance*

nitrogen, an interesting trend emerges. As the nitrogen values begin to decrease to reflect adult values, we see an enrichment in carbon values (Figure 7.15).

Comparisons between $\delta^{13}C$ of apatite and collagen were made (Figure 7.16). No distinctions were made between adults and sub-adults, nor were there any distinctions made between the sexes (r^2=0.001). The mean difference between $\delta^{13}C$ of apatite and collagen is 6.07‰.

7.7 Comparisons Between Cemeteries

Figure 7.17 illustrates all $\delta^{15}N$ and $\delta^{13}C$ data for all three cemetery samples. From this figure, it appears that Kellis 1 and Kellis 2 differ in $\delta^{13}C$ values, as do Kellis 1 and 'ein Tirghi cemeteries. Kellis 1 and Kellis 2 cemeteries also differ in $\delta^{15}N$. This

Table 7.12. P-values for T-test comparisons for carbon isotope values by cemetery.

	'ein Tirghi	Kellis 1	Kellis 2
'ein Tirghi	-	0.016	0.838
Kellis 1	-	-	0.000
Kellis 2	-	-	-

Significance level was set to 0.05.
* *results that are significant to p ≤ 0.05 are bolded*
† *T-test assuming unequal variance*

difference is most likely due to the inclusion of a large number of infants in the Kellis 2 sample.

T-tests were used to test for statistical differences between the three cemetery samples for $\delta^{15}N$, $\delta^{13}C$ of collagen and $\delta^{13}C$ of apatite. Table 7.11 lists the p-values for $\delta^{15}N$ values between each cemetery samples. Significance levels were set at 0.05. Statistical results, where p≤ 0.05, are highlighted in bold. The T-test results show that when all samples are included in the analysis, Kellis 2 is significantly different from both Kellis 1 and 'ein Tirghi, but Kellis 1 and 'ein Tirghi are not different from each other.

Table 7.12 lists the p-values for T-test comparisons made for $\delta^{13}C$ of collagen between each cemetery. Significance levels were set at 0.05. Where p≤ 0.05, the results are highlighted in bold. The results indicate that there are statistically significant differences in $\delta^{13}C$ values between the Kellis 1 and Kellis 2 cemetery populations (p=0.000), and Kellis 1 and 'ein Tirghi (p=0.016).

Some of these differences for both $\delta^{13}C_{collagen}$ and $\delta^{15}N$ values may be due to

Table 7.13. Values for T-tests to determine statistical differences in $\delta^{15}N$ between cemetery populations, excluding children up to age 5 years.

	'ein Tirghi	Kellis 1	Kellis 2
'ein Tirghi	-	0.099	0.001
Kellis 1	-	-	0.099
Kellis 2	-	-	-

Significance level was set at 0.05
* results that are significant to p ó 0.05 are bolded
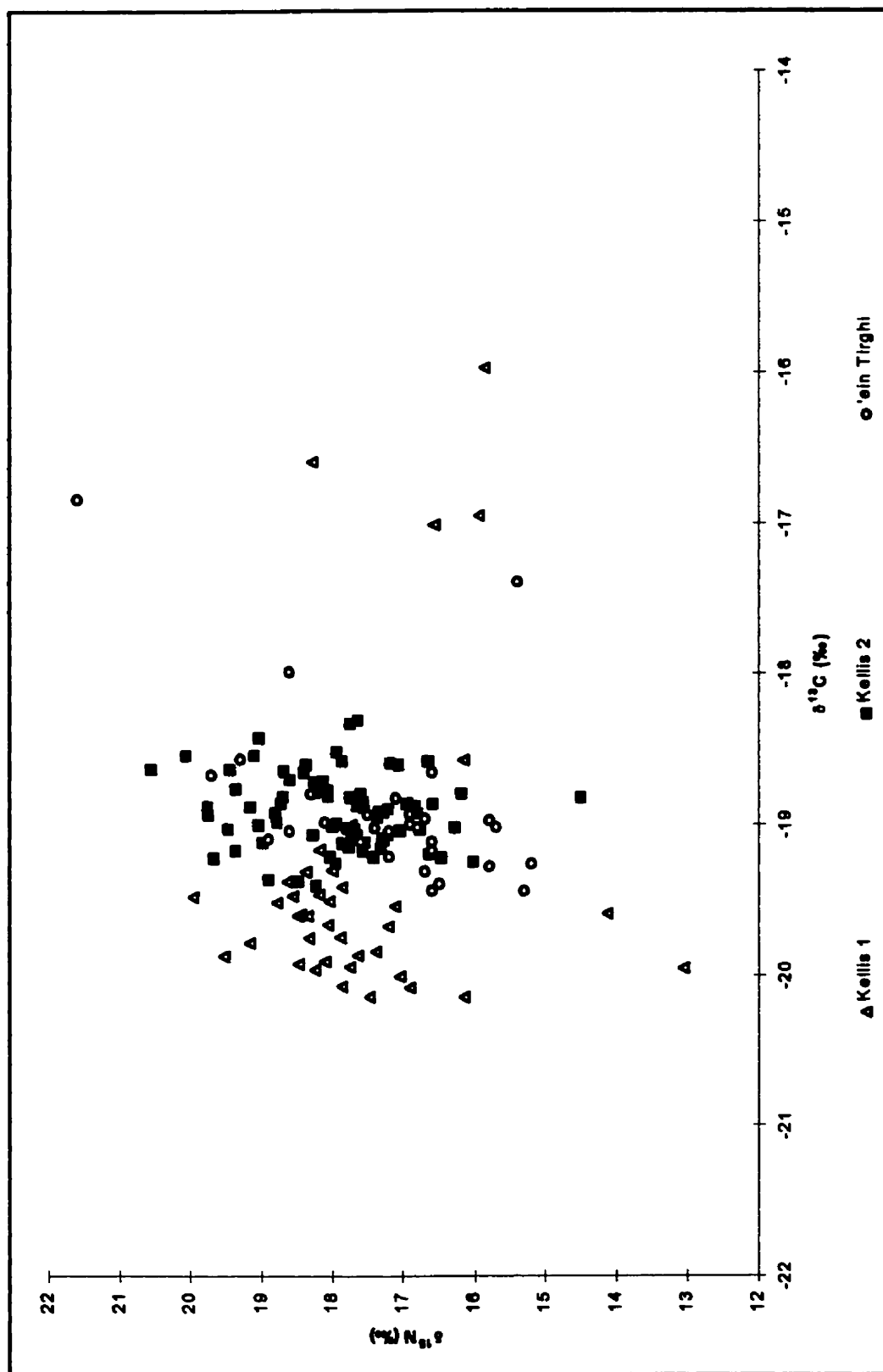
Figure 7.18. δ¹⁵N values plotted against δ¹³C values for all three cemetery populations, excluding children under 5 years of age.

Table 7.14. Values for T-tests to determine statistical differences in $\delta^{13}C$ between cemetery populations, excluding children under age 5 years

	'ein Tirghi	Kellis 1	Kellis 2
'ein Tirghi	-	0.067	**0.000**
Kellis 1	-	-	0.293
Kellis 2	-	-	-

Significance level was set at 0.05.
results that are significant to p ≤ 0.05 are bolded

the differential presence or absence of children under age 5. Figure 7.18 plots $\delta^{15}N$ against $\delta^{13}C$ for all three populations, excluding children under 5 years of age. The Kellis 2 and 'ein Tirghi populations appear to be generally enriched in ^{13}C in comparison to the Kellis 1 population, with the exception of the four outliers from the Kellis 1 population which are very enriched over the rest of the population. The variation in $\delta^{15}N$ values diminish once the children's values are excluded.

T-tests were used to determine if there are any statistically significant differences between populations once children under 5 years are removed. Table 7.13 lists the p-values for comparisons of nitrogen isotope values between cemetery populations. The p-value significance was set at 0.05 and significant results are bolded. When children are removed statistically significant differences remain between Kellis 2 and 'ein Tirghi (p=0.001).

Table 7.14 lists the p-values for T-tests conducted on $\delta^{13}C$ for all populations excluding children up to the age of 5 years. Statistical differences where $p \leq 0.05$ are highlighted in bold. Significant differences were only found between Kellis 1 and

Figure 7.19. δ¹³C of apatite plotted against δ¹³C of collagen for Kellis 1 and Kellis 2 cemetery samples.
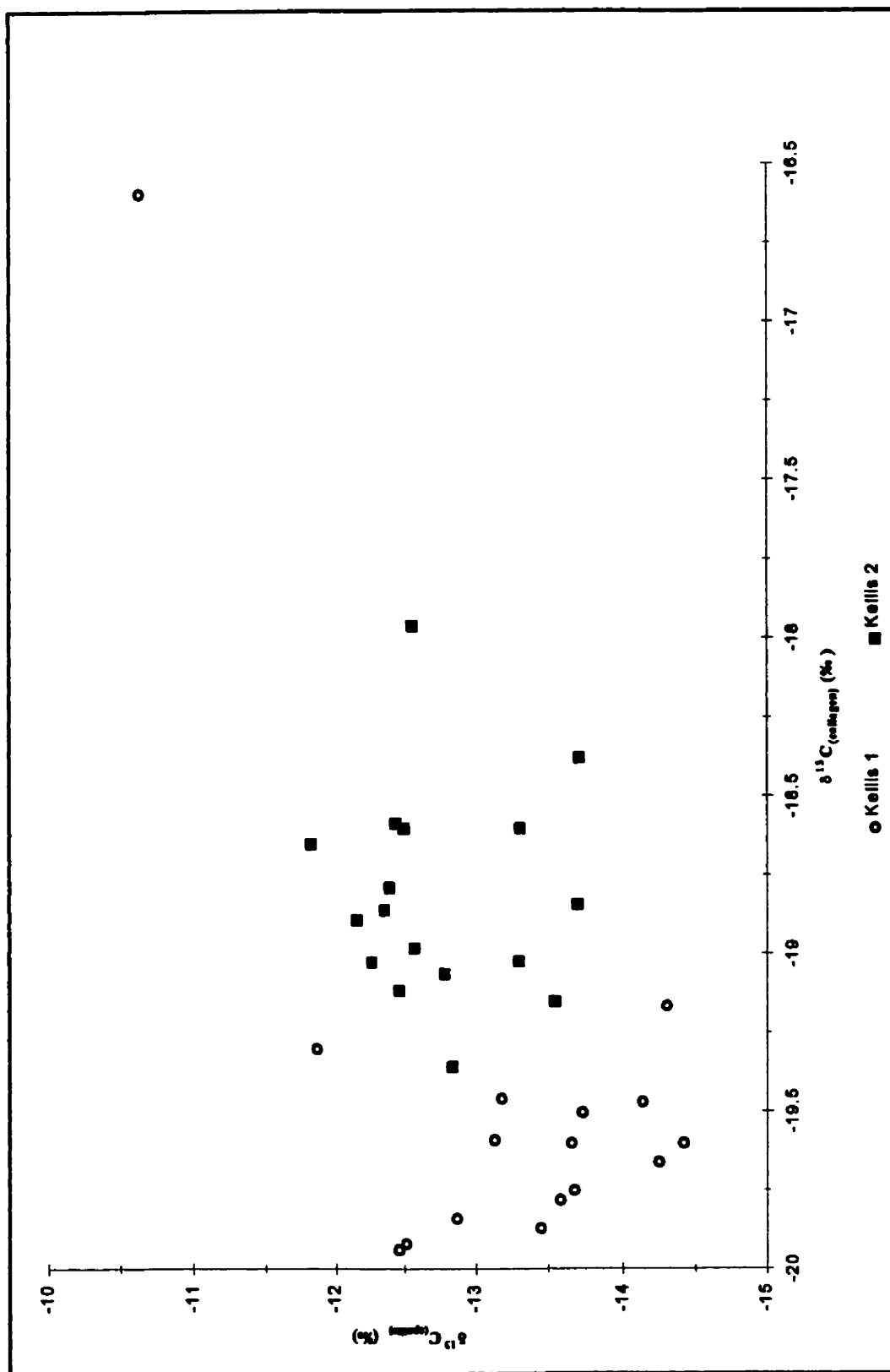
Kellis 2 (p=0.00).

Carbon apatite values were compared for the Kellis 1 and Kellis 2 cemetery. Figure 7.19 illustrates the placement of the two data sets in terms of $\delta^{13}C$ of apatite against $\delta^{13}C$ of collagen. There is a clear separation of the data on the X-axis, representing $\delta^{13}C_{collagen}$ values. This separation is not surprising as there is a statistically significant difference between these two populations for $\delta^{13}C$ of carbon (see Tables 7.12 and 7.14). When considering each site separately (Figures 7.9 and 7.16), $\delta^{13}C_{apatite}$ was not significantly correlated with $\delta^{13}C_{collagen}$. This may be because the number of samples was not sufficient at either site to detect a significant correlation. When both sites are considered together (Figure 7.20) there appears to be a significant positive linear correlation, with a slope of approximately 1. Regression of $\delta^{13}C_{apatite}$ on $\delta^{13}C_{collagen}$, shows a weaker relationship with a slope of 0.693, and $R^2=0.31$ (Figure 7.20).

7.8 Hair Samples

Of the human hair samples collected from Kellis 1 and Kellis 2, only 4 samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$. All samples were from adult females. Two sam-

Table 7.15. Descriptive statistics for $\delta^{13}C$ for hair samples from Kellis 1 and Kellis 2 cemeteries.

Sample	Sample Number	Mean $\delta^{13}C$ (‰)	Standard Error	Range	Variance	Confidence Interval (95%)
Kellis 2 B168	8	-19.62	0.05	0.43	0.02	0.09
Kellis 2 B190	4	-19.96	0.06	0.28	0.02	0.12
Kellis 1 EG10	10	-20.21	0.04	0.35	0.01	0.07
Kellis 1 EG4	10	-20.59	0.04	0.39	0.02	0.08
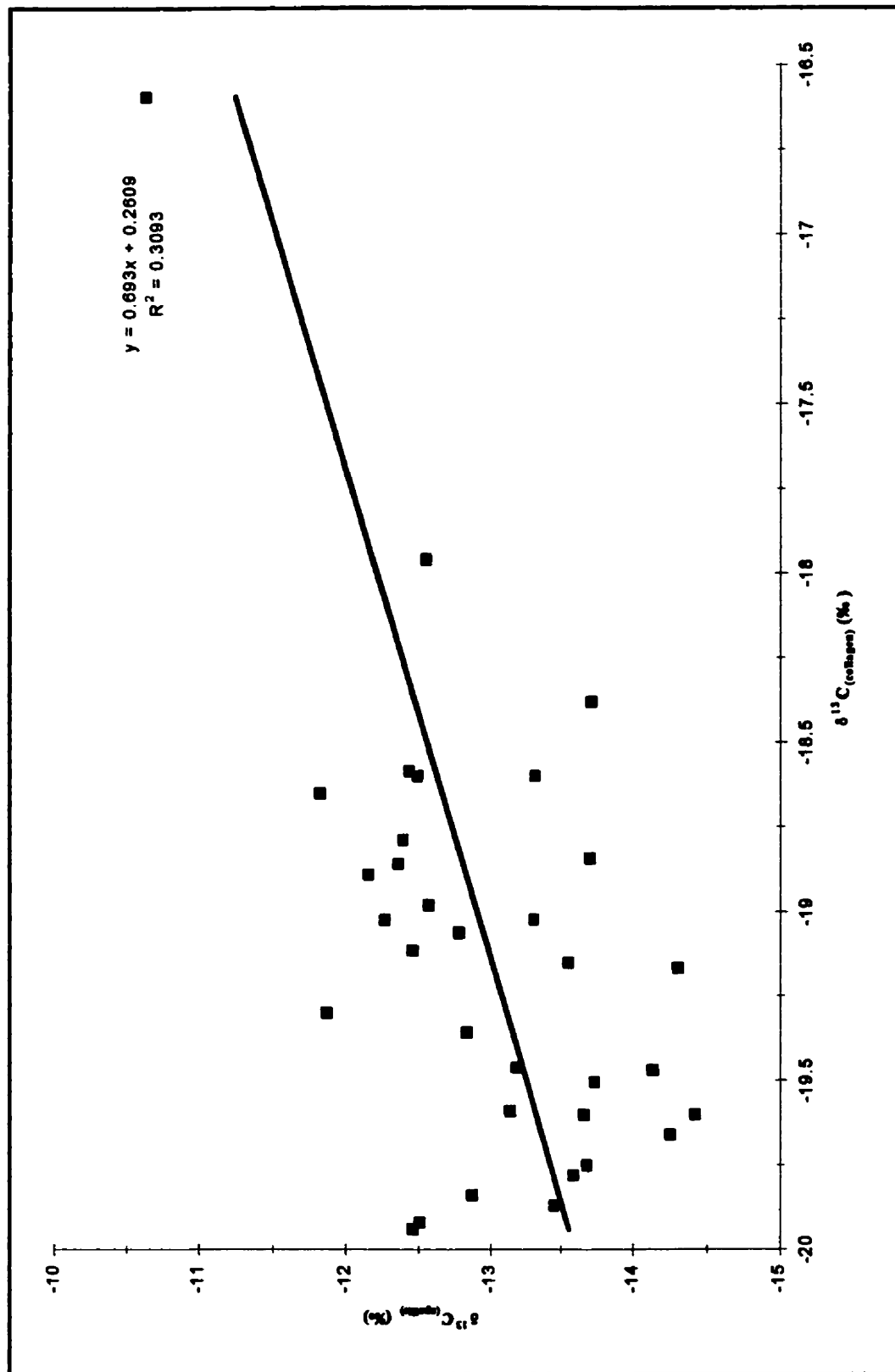
Figure 7.20. Linear regression of δ¹³C of apatite on δ¹³C of collagen for combined Kellis 1 and Kellis 2 samples.
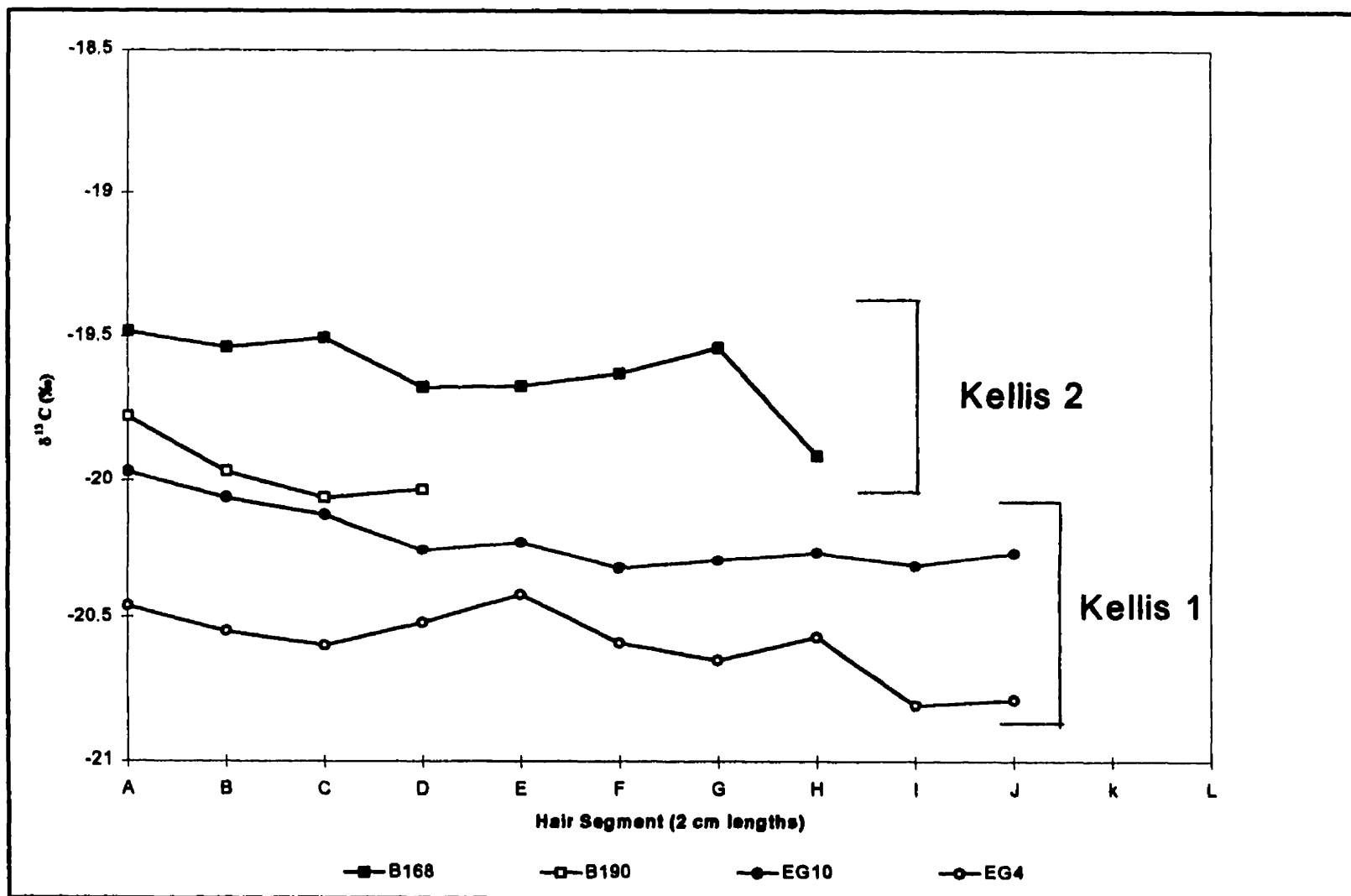
Figure 7.21. $\delta^{13}C$ *values for successive hair segments from Kellis 1 and Kellis 2 cemetery samples. Segment A represents the scalp end of the hair, and the last segment is the distal end.*

Table 7.16. Descriptive statistics for δ^{15}N for hair samples from Kellis 1 and Kellis 2 cemeteries.

Sample	Sample Number	Mean δ^{15}N (‰)	Standard Error	Range	Variance	Confidence Interval (95%)
Kellis 2 B190	3	18.31	0.12	0.43	0.05	0.24
Kellis 2 B192	3	18.08	0.08	0.26	0.02	0.15
Kellis 1 EG10	10	17.14	0.12	1.2	0.14	0.23
Kellis 1 EG4	10	19.31	0.14	1.2	0.19	0.27

ples from the Kellis 1 cemetery (EG 4 and EG10) and two from the Kellis 2 cemetery (B168 and B190) provided hair samples which were long enough to analyze several consecutive segments. The two samples from Kellis 1 were collected and analyzed by Dr. A. Aufderheide. Table 7.15 lists the descriptive statistics for carbon isotope values, while Table 7.16 lists the descriptive statistics for nitrogen isotope values. The number of hair segments available for analysis for each hair sample is listed under "sample number".

Figure 7.21 plots the δ^{13}C values for each successive hair segment. Segment A represents the hair closest to the scalp (the hair that was growing directly before death occurred), while consecutive hair samples follow alphabetical order to the distal tip. Figure 7.21 shows that there is a clear difference in the overall range of δ^{13}C values for hair samples from Kellis 1 versus Kellis 2 cemeteries. The average enrichment in ^{13}C of bone collagen from Kellis 2 over Kellis 1 is 0.7‰. This is comparable to the magnitude of the difference between the respective hair samples from the two sites. Interestingly, although there does not appear to be any detectable seasonal pattern in the δ^{13}C values in each sample, in all samples the δ^{13}C values tend to decrease from the
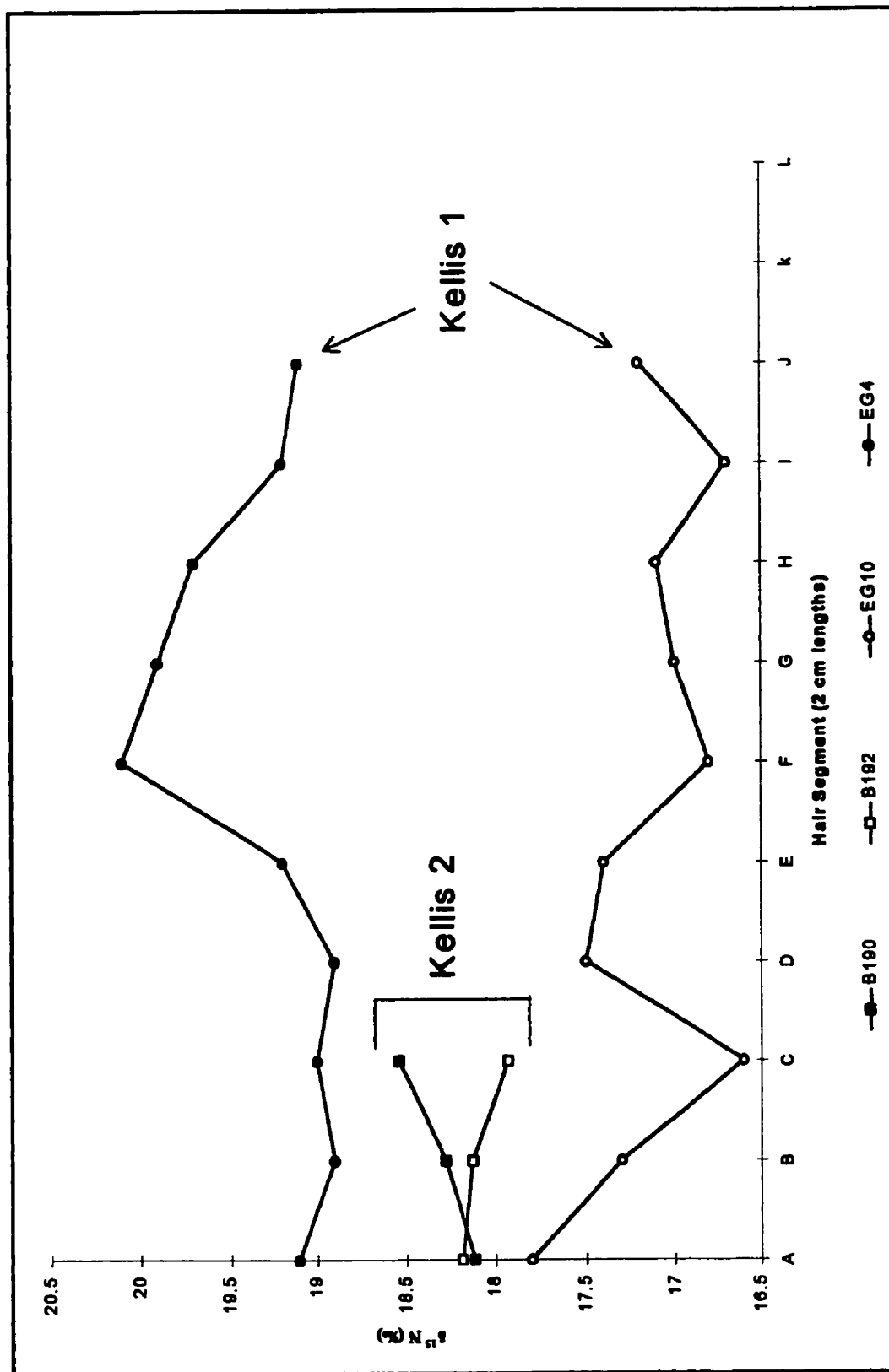
Figure 7.22. $\delta^{15}N$ values for successive hair segments from Kellis 1 and Kellis 2 cemetery samples. Segment A represents the scalp end of the hair and the last segment is the distal end.

scalp to the distal end.

Figure 7.22 illustrates the $\delta^{15}N$ values for hair samples from Kellis 1 and Kellis 2. As with the carbon isotope data, Segment A represents the proximal end of the hair, with consecutive segments ending at the distal end of the hair. Each segment is in 2 cm lengths and represents approximately 2 months of growth (Saitoh et al. 1970). Figure 7.22 shows a very different pattern than seen in the $\delta^{13}C$ data. There is no clear separation in the data between cemeteries, but this is not surprising as there was no significant difference in $\delta^{15}N$ of collagen between the cemeteries. There are no consistent identifiable trends within all of the hair samples.

7.9 Archaeological and Modern Faunal Remains

7.9.1 Descriptive Statistics

Descriptive statistics were calculated for both archaeological faunal remains and modern faunal remains. Descriptive statistics were calculated for the whole sample and then for herbivorous and carnivorous animals in order to test for a trophic level difference between them. Table 7.17 lists descriptive statistics for $\delta^{13}C$ of collagen for each group of animals. Table 7.18 summarizes descriptive statistics for $\delta^{15}N$ for archaeological and modern animal samples. Refer to Appendix G for a complete list of faunal data, including C:N ratios and percent collagen.

Table 7.17. Descriptive statistics for δ¹³C for modern and archaeological faunal remains.

Animal Sample	Sample Number	Mean δ¹³C (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Modern Animals						
Total	5	-16.96	1.45	3.55	12.58	3.11
Herbivorous	4	-16.33	1.88	3.76	14.13	3.68
Carnivorous	1	(-19.48)	-	-	-	-
Archaeological Animals						
Total	9	-17.18	0.49	1.46	2.13	0.95
Herbivorous	6	-16.56	0.57	1.40	1.96	1.12
Carnivorous	3	-18.40	0.29	0.51	0.26	0.58

7.9.2 Sample Comparisons

Figure 7.23 illustrates the placement of modern versus archaeological faunal remains for both δ¹³C and δ¹⁵N values. The placement of the carnivores' δ¹³C values are very similar for both groups, but their δ¹⁵N values appear to differ significantly. The δ¹⁵N values for the modern herbivores are lower than those of archaeological faunal samples. There appear to be no systematic differences in the δ¹³C values for each

Table 7.18. Descriptive statistics for δ¹⁵N for modern and archaeological faunal remains.

Animal Sample	Sample Number	Mean δ¹⁵N (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Modern Animals						
Total	6	10.22	2.03	4.97	24.73	3.98
Herbivorous	5	9.03	2.01	4.49	20.15	3.94
Carnivorous	1	(16.21)	-	-	-	-
Archaeological Animals						
Total	9	14.14	0.52	1.56	2.43	1.02
Herbivorous	6	13.12	0.16	0.38	0.15	0.31
Carnivorous	3	16.18	0.12	0.21	0.04	0.24
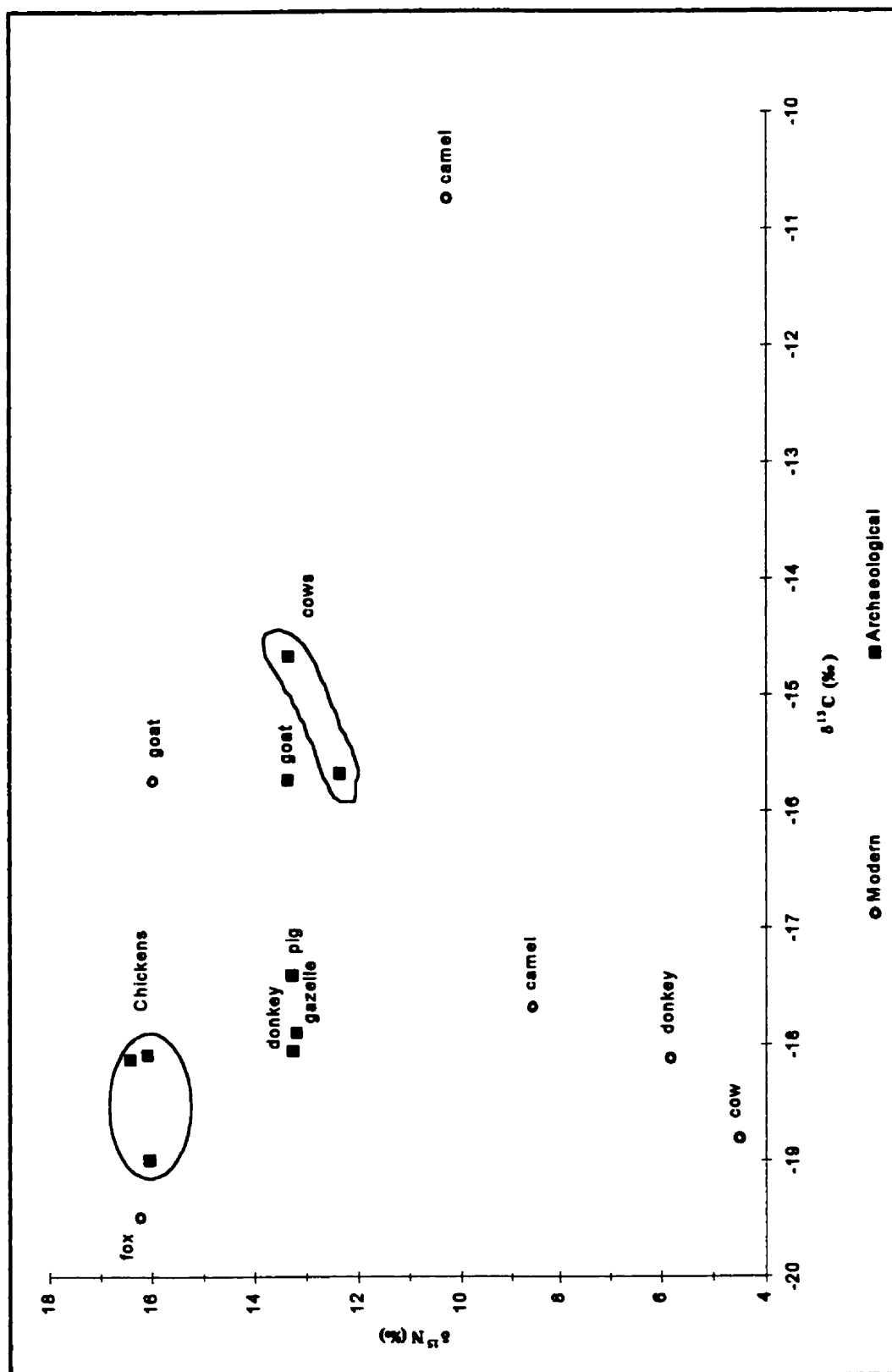
Figure 7.23. Modern versus archaeological faunal samples for both δ¹⁵N and δ¹³C values.

group.

T-tests were used to determine if there were any statistical differences between modern and archaeological samples for both carbon and nitrogen isotope values. When comparing the total samples for $\delta^{13}C$, assuming unequal variance, there were no statistical differences between the modern and archaeological faunal samples (p=0.903). Comparison of $\delta^{13}C$ between archaeological and modern herbivores also showed no statistical differences (p=0.913). Comparisons were not made between carnivores as there was only one carnivore sample for the modern faunal group. Comparison of $\delta^{15}N$ between the total archaeological and modern samples reveal results that are not statistically significant (p=0.114). Although the means are quite different, this is compensated for by the large variance in each data set. Comparisons between archaeological and

Table 7.19. Descriptive statistics for $\delta^{13}C$ data for both modern and archaeological botanical remains.

Sample	Sample Number	Mean $\delta^{13}C$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Modern	27	-25.14	0.88	4.75	22.56	1.79
Archaeological	8	-23.27	0.49	1.39	1.94	0.96

Table 7.20. Descriptive statistics for $\delta^{15}N$ data for both modern and archaeological botanical remains.

Sample	Sample Number	Mean $\delta^{15}N$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
Modern	15	3.39	0.99	5.36	28.78	2.71
Archaeological	8	15.31	0.90	2.55	6.51	1.77

modern herbivores also reveal similar results, the p-value failed to reach statistical significance (p=0.111). Once again, comparisons were not made between carnivore sam-

Figure 7.24. δ¹⁵N plotted against δ¹³C values for archaeological botanical remains.

ples as there was only one modern carnivore sample.

7.10 Archaeological and Modern Botanical Remains

7.10.1 Descriptive Statistics

Descriptive statistics for both nitrogen and carbon isotope values for archaeological and modern botanical remains are listed in Tables 7.19 and 7.20. Refer to Appendix I for a complete list of botanical isotope data.

Figure 7.24 illustrates $\delta^{15}N$ plotted against $\delta^{13}C$ values for archaeological botanical remains. With the exception of the doum nut, the archaeological plant remains are very similar in their $\delta^{13}C$ (variance = 1.9‰). The range in $\delta^{13}C$ values is 4.5‰. There is a great deal more variability between the modern and archaeological samples in

$\delta^{15}N$ (variance = 6.5‰), and the range, 7.1‰, is also larger.

Figure 7.25 illustrates $\delta^{15}N$ plotted against $\delta^{13}C$ for modern botanical remains. The variance for $\delta^{13}C$ is very high (22.6‰), as is the range of values (20.5‰). The main reason for the large variance and range is the inclusion of the two samples of sorghum, which are designated as C_4 plants (mean $\delta^{13}C$ of −11.53 ● 0.31‰ as opposed to -27.62 ± 2.1‰ for the remaining C_3 plants). There is also a significantly large variance (28.8‰) and range (17.9‰) for nitrogen isotope values. The values for modern plants are spread out across the entire range of $\delta^{15}N$.

Figure 7.25. δ¹⁵N plotted against δ¹³C values for modern botanical remains. Mean δ¹⁵N and δ¹³C values for C₃ and C₄ are also shown with one standard deviation.

Figure 7.26. δ¹⁵N plotted against δ¹³C values for modern and archaeological botanical remains.

7.10.2 Comparisons between Archaeological and Modern Plants

Figure 7.26 shows $\delta^{15}N$ plotted against $\delta^{13}C$ for archaeological and modern botanical samples. There appears to be a separation in the data for both $\delta^{15}N$ and $\delta^{13}C$ data. There are no C_4 plants included in the archaeological botanical remains, making the separation clearer. The values of $\delta^{13}C$ for the majority of the modern plants lie between -25% and -30%, while the values for archaeological plant remains fall between -20% and -25%. There is an even clearer separation in $\delta^{15}N$ between the modern samples and archaeological plant remains. The archaeological plant remains are clearly enriched in nitrogen over the modern botanical remains. With the exception of the modern sorghum samples, there appears to be a well defined linear correlation be-

Table 7.21. Descriptive statistics for $\delta^{13}C$ for all archaeological human, plant and animal samples.

Sample	Sample Number	Mean $\delta^{13}C$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
'ein Tirghi	31	-18.88	0.09	0.56	0.31	0.19
Kellis 1	42	-19.33	0.15	0.96	0.96	0.29
Kellis 2	113	-18.84	0.05	0.50	0.25	0.09
Animals	9	-17.18	0.49	1.46	2.13	0.95
Plants	8	-23.27	0.49	1.39	1.94	0.96

Table 7.22. Descriptive statistics for $\delta^{15}N$ for all archaeological human, plant and animal samples.

Sample	Sample Number	Mean $\delta^{15}N$ (‰)	Standard Error	Standard Deviation	Variance	Confidence Interval (95%)
'ein Tirghi	37	17.21	0.24	1.51	2.28	0.49
Kellis 1	42	17.78	0.25	1.62	2.61	0.49
Kellis 2	110	18.65	0.15	1.59	2.52	0.29
Animals	9	14.14	0.52	1.56	2.43	1.02
Plants	8	15.31	0.90	2.55	6.51	1.77

tween $\delta^{13}C$ and $\delta^{15}N$ for the combined data sets. The R^2 value for this relationship (excluding the two outliers) is 0.63, and the formula for the linear relationship is $\delta^{15}N = 2.1\,(\delta^{13}C) + 61.9$.

T-tests were used to test for statistically significant differences in carbon and nitrogen isotope values between archaeological and modern plant samples. There is a statistically significant difference in carbon isotope values between modern and archaeological plant remains (p=0.029) and also for nitrogen isotopes (p=0.00).

7.11 Humans, Animals and Plants

7.11.1 Descriptive Statistics

Basic descriptive statistics for carbon and nitrogen isotope values for all human collagen and archaeological botanical and faunal bone collagen samples are summarized in Tables 7.21 and 7.22.

Figure 7.27 shows all the data for $\delta^{15}N$ and $\delta^{13}C$ for all human, plant and animal samples. The different groups are separated to varying degrees in their overall $\delta^{13}C$ values. Human and animal collagens are clearly enriched in ^{13}C compared to plants, but human collagen is not significantly enriched with respect to animal collagen. Animals, on the whole, appear to be more enriched in ^{13}C than humans. Considering $\delta^{15}N$ values, humans are clearly enriched in ^{15}N over both plants and animals, with the exception of the carnivorous animals. There is no clear separation, however, between animals and plants, as would be expected due to the trophic level effect. This may be
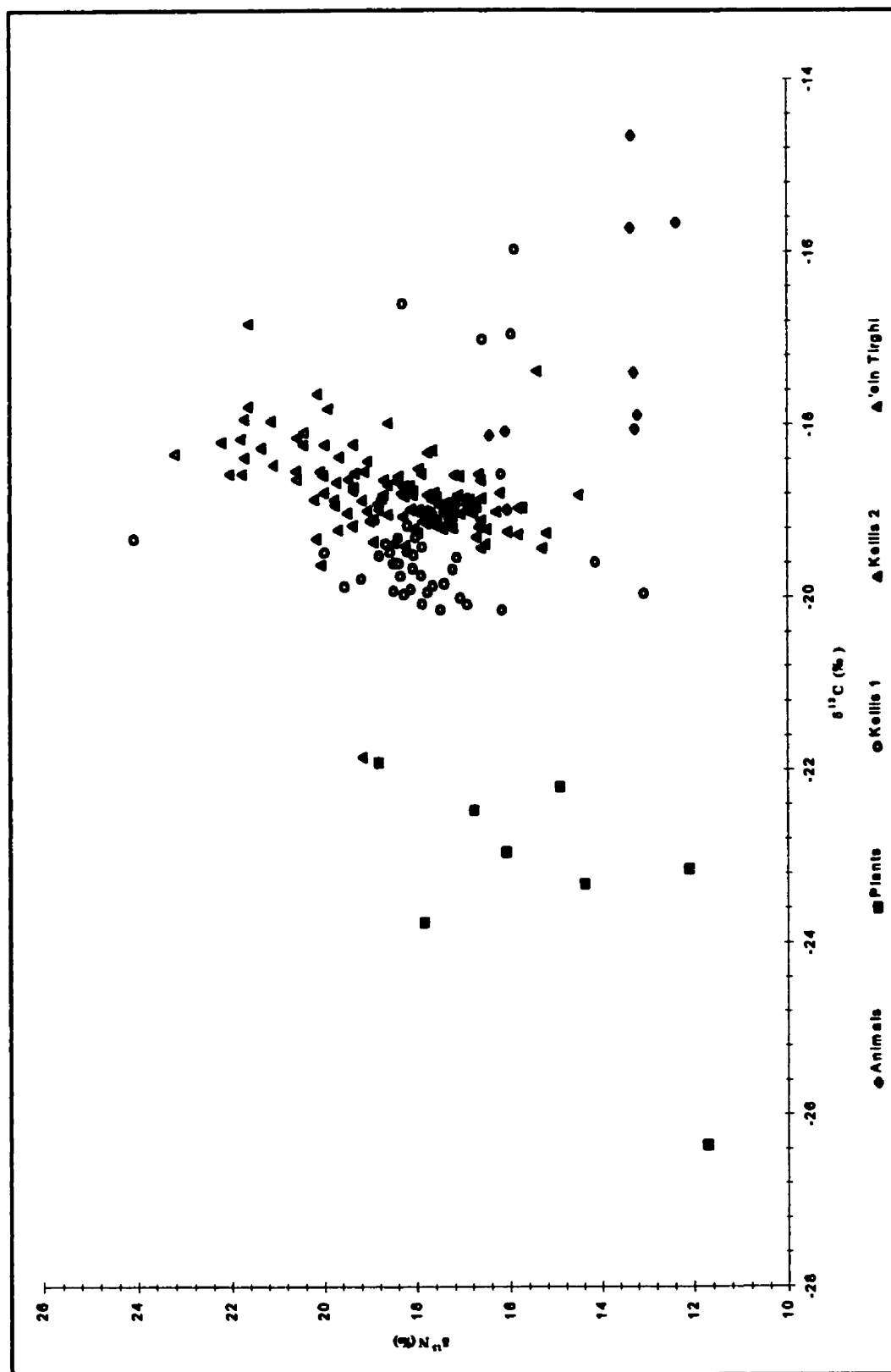
Figure 7.27. $\delta^{15}N$ plotted against $\delta^{13}C$ for all human, plant and animal samples.
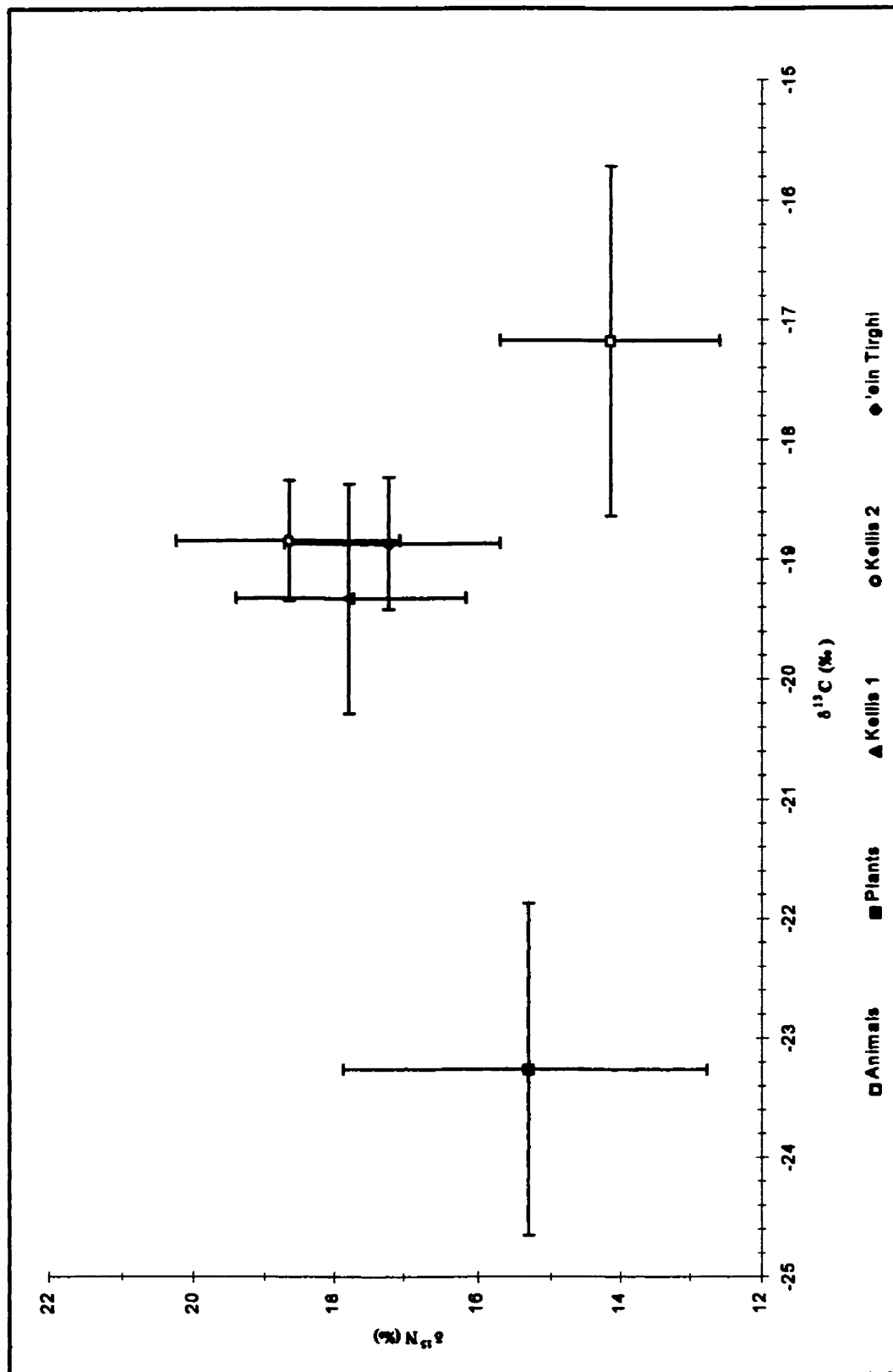
Figure 7.28. Average δ¹⁵N values plotted against average δ¹³C values for humans, plants, and animals. One standard deviation is shown around each mean value.

due, in part, to the fact that the plants with the higher nitrogen values are mostly trees, and the animals would not have browsed on the trees or their fruit, but would have eaten grasses, which are not represented in these samples. The average nitrogen and carbon values for each group (humans, plants and animals) are clearly separated in both carbon and nitrogen isotope values (Figure 7.28).

7.12 Summary

The purpose of this chapter was to present the isotopic analyses for human, animal and plant samples from the Dakhleh Oasis. For the 'ein Tirghi cemetery sample, no differences were found to exist between both $\delta^{15}N$ and $\delta^{13}C$ in adult males and females. The only age related difference found was in $\delta^{13}C$ between children under 2 and adults. The results for the Kellis 1 cemetery sample revealed no differences in either $\delta^{15}N$ or $\delta^{13}C$ for adult males and females, and differences between age categories could not be determined in this sample.

The sample size and type of cemetery at Kellis 2 allowed for a more in-depth analysis. Differences in $\delta^{13}C$ were found between males and females, with males being more enriched in ^{13}C. Differences in age categories, particularly children under two, were significant. Children under 2 were found to be elevated in both $\delta^{15}N$ and $\delta^{13}C$ in comparison to adults. This pattern of enrichment in both ^{15}N and ^{13}C is interesting, with peak enrichment in ^{15}N beginning to decline as $\delta^{13}C$ values begin to increase.

Comparisons between the three cemeteries reveal differences in $\delta^{13}C$ between both 'ein Tirghi and Kellis 1, and between Kellis 1 and Kellis 2. The isotopic

values from 'ein Tirghi were found to be very similar to those of Kellis 2.

Isotopic analyses of hair samples from Kellis 1 and Kellis 2 revealed patterns similar to that seen in bone collagen. There were no detectable changes in isotopic values along the hair strands.

Archaeological and modern botanical remains show differences in both $\delta^{15}N$ and $\delta^{13}C$, with archaeological C_3 plants enriched in both ^{15}N and ^{13}C in comparison to C_3 modern plants. Isotopic analyses of archaeological and modern faunal remains revealed a similar pattern, with archaeological faunal remains enriched in ^{15}N.

If the isotopic results for humans, plants and animals are considered in the context of both documentary evidence and previous research in stable isotope analysis there are some remarkable findings in these data. Chapter 8 considers all of the isotope data with respect to past isotopic studies and the menu of foods developed in Chapter 4.

Chapter 8
What Did They Eat?
Putting It All Together

8.1 Introduction

This chapter explores the relationship between the menu of foods developed in Chapter 4 and the results of the stable isotope analysis presented in Chapter 7. In addition to general observations regarding the stable isotope information, data for each cemetery are considered, including possible dietary differences related to sex and age, and then comparisons are made between the cemeteries. Faunal and botanical remains are discussed in relation to overall diet and comparisons between archaeological and modern remains are also considered.

8.2 General Observations

8.2.1 Issues of Preservation

The issue of preservation of the bone samples has been dealt with in other sections of this thesis (see sections 5.3 and 7.2); however a visual examination of

the data also supports the idea that the bone samples are well preserved. For example, in Figure 7.12 there is a non-random, clearly defined pattern. If the samples were not well preserved then this pattern would not be detectable.

8.2.2 Very high $\delta^{15}N$ Values

One of the first, important observations that can be made about the human isotope results is that the $\delta^{15}N$ values are extremely high. The mean values for $\delta^{15}N$ for each sample range from 17.21‰ for 'ein Tirghi to 18.65‰ for Kellis 2. In a temperate environment $\delta^{15}N$ values this high would indicate a population that was heavily reliant on marine foods (Walker and DeNiro 1986; DeNiro 1987). The location of the Dakhleh Oasis precludes significant access to marine resources; in fact there have been no marine foods identified in faunal remains of the site to date (R. Churcher, pers. comm.). It is the arid environment of the Dakhleh Oasis, not diet, that accounts for the elevated $\delta^{15}N$ values of the inhabitants.

With an annual precipitation of less than 1 mm, the Dakhleh Oasis is an extremely arid environment. The negative linear relationship between annual precipitation and $\delta^{15}N$ values documented by Heaton et al. (1986) can be seen in this geographical location. When the average $\delta^{15}N$ values for each cemetery are plotted against the values reported by Heaton and colleagues (1986), they describe a linear relationship (Figure 8.1). Further research into this phenomenon (Ambrose and DeNiro 1986a; 1987; Sealy et al. 1987; Ambrose 1991) indicates that the increasing enrichment in ^{15}N associated with increasingly arid climates can not be accounted for by diet alone. As
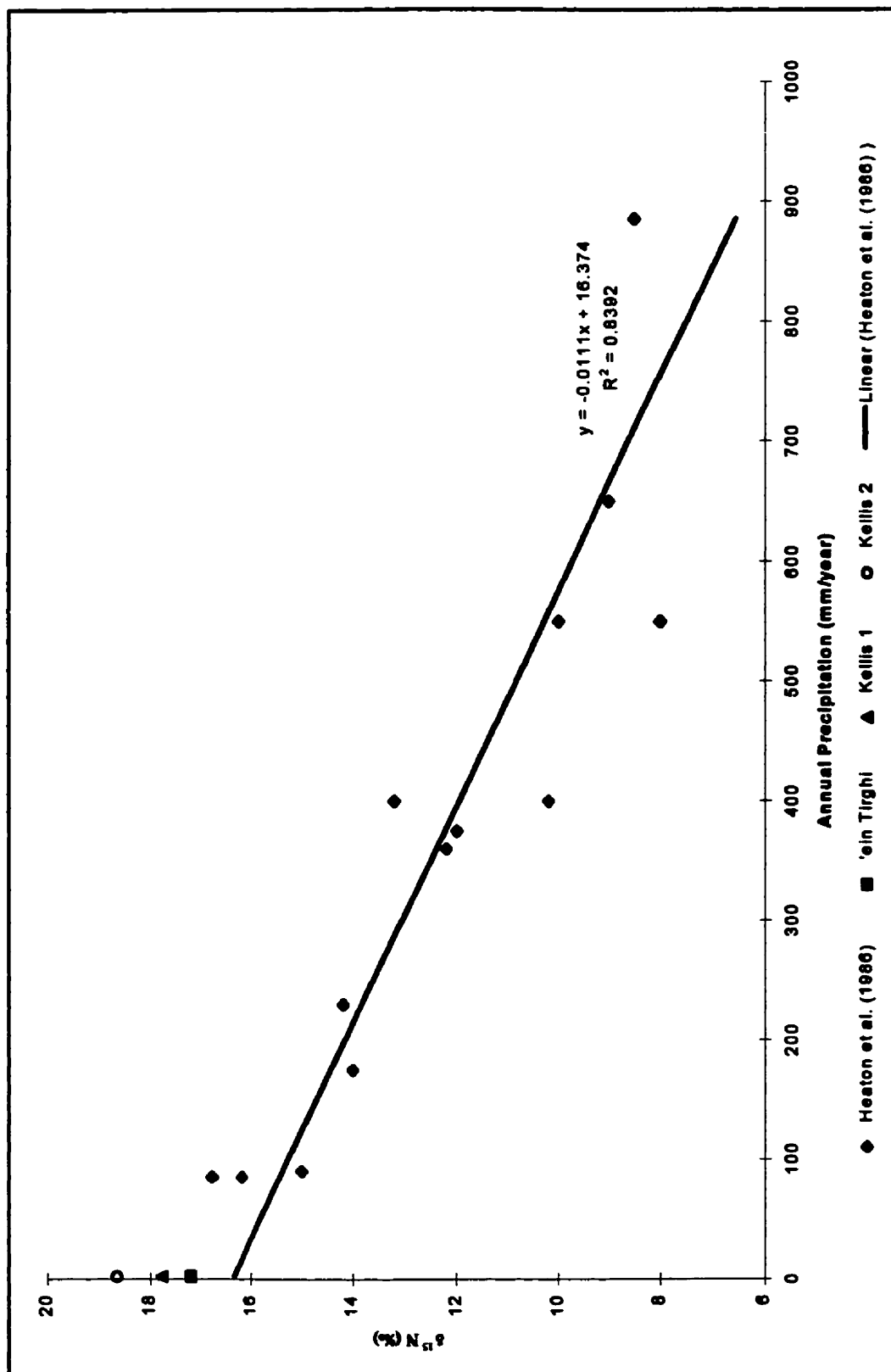
Figure 8.1 Average δ¹⁵N values plotted against annual precipitation (mm/year) for 'ein Tirghi, Kellis 1, Kellis 2 cemeteries and human values extrapolated from Heaton et al (1986).

y = -0.0111x + 16.374
R² = 0.8392

Annual Precipitation (mm/year)

δ¹⁵N (‰)

◆ Heaton et al. (1986)   ■ 'ein Tirghi   ▲ Kellis 1   ○ Kellis 2   ——Linear (Heaton et al. (1986))

discussed earlier (Chapter 5) both Ambrose and DeNiro (1986a; 1987) and Sealy (1987) explain that the enrichment is due to a physiologic response in animals that is linked to water conservation, while Cormie and Schwarcz (1996) indicate that this physiological response may in fact be triggered by the amount and type of food that is being consumed by animals.

All of these studies focus solely on the animal contribution to the high $\delta^{15}N$ values; none considers the nitrogen pool that occurs at the base of the food chain. Ambrose (1991) found that plants found in arid regions are also enriched in ^{15}N as a result of ^{15}N enrichment in the soil. He suggests that analyses of the entire food chain, from the soil to carnivores, should be performed in order to differentiate between physiological and environmental influences on nitrogen isotope ratios. He also comments that the relationship between trophic levels is irrelevant in arid ecosystems. Using data from this thesis, Schwarcz and colleagues (1999) analysed the entire food chain in the Dakhleh Oasis to determine whether or not this enrichment in the $\delta^{15}N$ also occurs at the base of the food chain, and whether or not the trophic level is maintained. The results from the analysis support Ambrose's contention that the soil and plants are enriched in ^{15}N in comparison to plants and soil found in temperate regions. Unfortunately, the $\delta^{15}N$ data for soil in the Dakhleh Oasis is not yet available, but the high $\delta^{15}N$ values of the archaeological botanical remains from the Oasis imply that the Oasis soil was also enriched in ^{15}N. This enrichment would be carried out through the rest of the food chain, resulting in high human $\delta^{15}N$ values.

The question regarding the maintenance of the trophic level effect in arid regions can also be addressed using data from the Dakhleh Oasis. Figures 7.27 and 7.28 illustrate the relative placement of $\delta^{15}N$ values for plants, animals and humans. The figures show that the mean $\delta^{15}N$ value for archaeological botanical remains is 15.31‰, while the mean $\delta^{15}N$ value for archaeological faunal remains is 14.14‰. If only the mean $\delta^{15}N$ values for the plants and animals that made up the main components of the diet are considered (i.e., wheat/barley; pigs and goats), the mean $\delta^{15}N$ value for plants is 15.2‰, while the mean $\delta^{15}N$ value for animals is 13.32‰. The mean values for humans range from 17.21‰ to 18.65‰. While these values do not support a trophic level effect between plants and animals, there is a trophic level effect of approximately 3‰ between plants and humans and between animals and humans if it is considered that the elevated $\delta^{15}N$ values for children under 2 are factored into the mean values for humans.

One of the primary reasons why the trophic level effect is not seen between animals and plants may be because the eating habits of both pigs and goats are quite indiscriminate; they consume almost anything that they are fed. Their $\delta^{13}C$ values are quite different, with pig $\delta^{13}C$ values at −17.4‰, and goat at −15.7‰. $\delta^{13}C$ values suggest that goats were fed large quantities of millet. Pigs may have had a small portion of millet in their diet, however the majority of their diet consisted of C_3-based foods, and exactly which C_3 plants they consumed is difficult to determine. It is possible that the foods (most likely scraps from household consumption) used to feed the pigs and these may not have been analysed for this thesis. With these two factors in mind (the diffi-

culty of identifying animal diet, and the inability to analyse all possible food sources), the trophic level effect would not be apparent in these data.

It is also possible that post-depositional degradation of the archaeological botanical remains may cause an enrichment in ^{15}N. DeNiro and Hastorf (1985) noted that the δ^{15}N values of carbonized plant remains were very similar to those of modern plants. Uncarbonized plant remains, however, were found to be 10 to 20‰ and as much as 35‰ higher in their δ^{15}N values than those of modern plants. The authors are unable to make any comments as to the mechanism that accounts for the ^{15}N enrichment in un-carbonized botanical remains. If it is the case that isotopic fractionation is occurring during the post-depositional process in arid sandy environments, then a trophic level effect between plants and animals will not be detectable. Future research on carbonized plant remains from the site of Kellis may provide an answer to this question.

8.2.3 Variation in Adult Diet

It is a common misperception that in the past all people ate the same type and quantity of food, with the possible exception of dietary differences due to status or sex. Research involving dietary reconstruction commonly describes the diet of the group, not considering that there would be any inter-individual variation (Schoeninger 1995). For example, it is commonly thought that all adult males of upper status would have eaten the same types and quantity of foods. This assumption can not be made for the inhabitants of the Dakhleh Oasis. An examination of the distribution of δ^{15}N and δ^{13}C for humans from each cemetery shows that there is variation in the types and quan-

tities of foods that were eaten by adults (see Figures 7.1, 7.6, and 7.10). If all individuals ate the same type and quantity of food, then these data would be clustered tightly, with very little variation. This does not appear to be the case for the three cemeteries analysed here.

In some cultures there are recognized changes in diet with age (e.g., Katzeberg and Saunders 1990). Other isotope studies have found that stable isotope values do not correlate with age (Lovell et al. 1981; White and Schwarcz 1989). If children under 2 are excluded, these data from the three cemeteries in the Dakhleh Oasis reveal that there are no apparent shifts in diet with age (e.g., Figures 7.5, 7.7, 7.8, and 7.13). There is some variation in diet within age categories, but the general pattern of isotope values does not vary much with age. Similar results for Nubians are reported by White and Schwarcz (1994).

8.3 'ein Tirghi Cemetery Sample

The results of the descriptive and comparative statistics demonstrate that there are no significant differences between adult females and males for both $\delta^{13}C$ and $\delta^{15}N$ values, indicating that both sexes were consuming the same types of foods. There is little difference between the variances for $\delta^{13}C$ between adult males and females, with $\delta^{13}C$ values indicating a diet heavily reliant on C_3 foods. The variances for $\delta^{15}N$ between adult males and females are also quite similar, even though adult males appear to show more variation in their $\delta^{15}N$ values (Figure 7.1). This indicates that there are no

biological differences in the physiological processing of isotopes between adult males and females. A similar finding is reported for Nubians (White and Schwarcz 1994).

When subadults are compared to adults, it becomes apparent that there are differences in both $\delta^{13}C$ and $\delta^{15}N$ values (Figures 7.2 and 7.3). When subadults are divided down into children under 2 years of age and children aged 3-15 there is a statistically significant difference between children under 2 and adults for $\delta^{15}N$ and $\delta^{13}C$, with children under 2 showing enriched values over adults. A significant difference in $\delta^{15}N$ is not surprising as children under 2, particularly those who are still breastfeeding, are normally expected to be approximately 3‰ higher than adults (Fogel et al. 1989; Katzenberg and Pfeiffer 1995). The sample of children under 2 from this tomb is not large enough to make any specific comments regarding the weaning process (i.e., duration or age of weaning) in this population.

The enrichment in ^{13}C seen in children under 2 is somewhat unexpected. This enrichment indicates that they had access to foods that were enriched in ^{13}C, essentially C_4 foods such as millet. On the other hand, dietary reconstruction (see Chapter 4) indicates that during the Third Intermediate period, the inhabitants of the Oasis would not have had access to C_4 foods. Considering the discrepancy between the potential menu of foods and the $\delta^{13}C$ values, a closer examination of the tomb structure is warranted to determine if there is another reason for enrichment in ^{13}C in some individuals.

As discussed in Chapter 6, there has been considerable debate over the dating of tomb DK-31. It was originally dated to the Second Intermediate period based on

tomb structure, then to the Roman period (once again based on tomb structure), and then to the Third Intermediate period (based on ^{14}C dates). This thesis was written based on the information that this particular tomb was dated to circa 800 BC (Third Intermediate). If the structure and the way in which individuals were interred in this tomb is taken into consideration an interesting picture emerges. This particular tomb consisted of two chambers in which individuals were stacked atop each other. Chamber 1 contained four levels of individuals, while Chamber 2 contained only two levels. Individuals buried in Level 1 (considered to be the youngest layer as it is the upper most layer) are enriched in ^{13}C over those found in Levels 3 and 4 (the oldest layers) indicating that individuals interred near the top had access to C_4 foods. The percentage of C_4 foods in the diet of these individuals (determined using the formula by Schwarcz et al. 1985) decreases steadily from 19.7% in Level 1 to 15.3% in Level 4. Figures 8.2 and 8.3 illustrate $\delta^{13}C$ and $\delta^{15}N$ for each level of individuals in Chamber 1. The two individuals who were ^{14}C dated are both from the bottom levels in chambers 1 and 2; these results suggest that individuals in the bottom levels of the tomb represent the Third Intermediate period, while those towards the top are from a later period. It should be noted that the levels were assigned by R. Frey as she excavated the tomb, and therefore the levels may not be truly distinctive. I would argue that from this evidence that no distinction should be made between individuals in Level 1 and Level 2. To substantiate this hypothesis, an additional sample from Individual #7 (Chamber 1, Level 1) has been sent to Isotrace (Toronto) for ^{14}C dating.
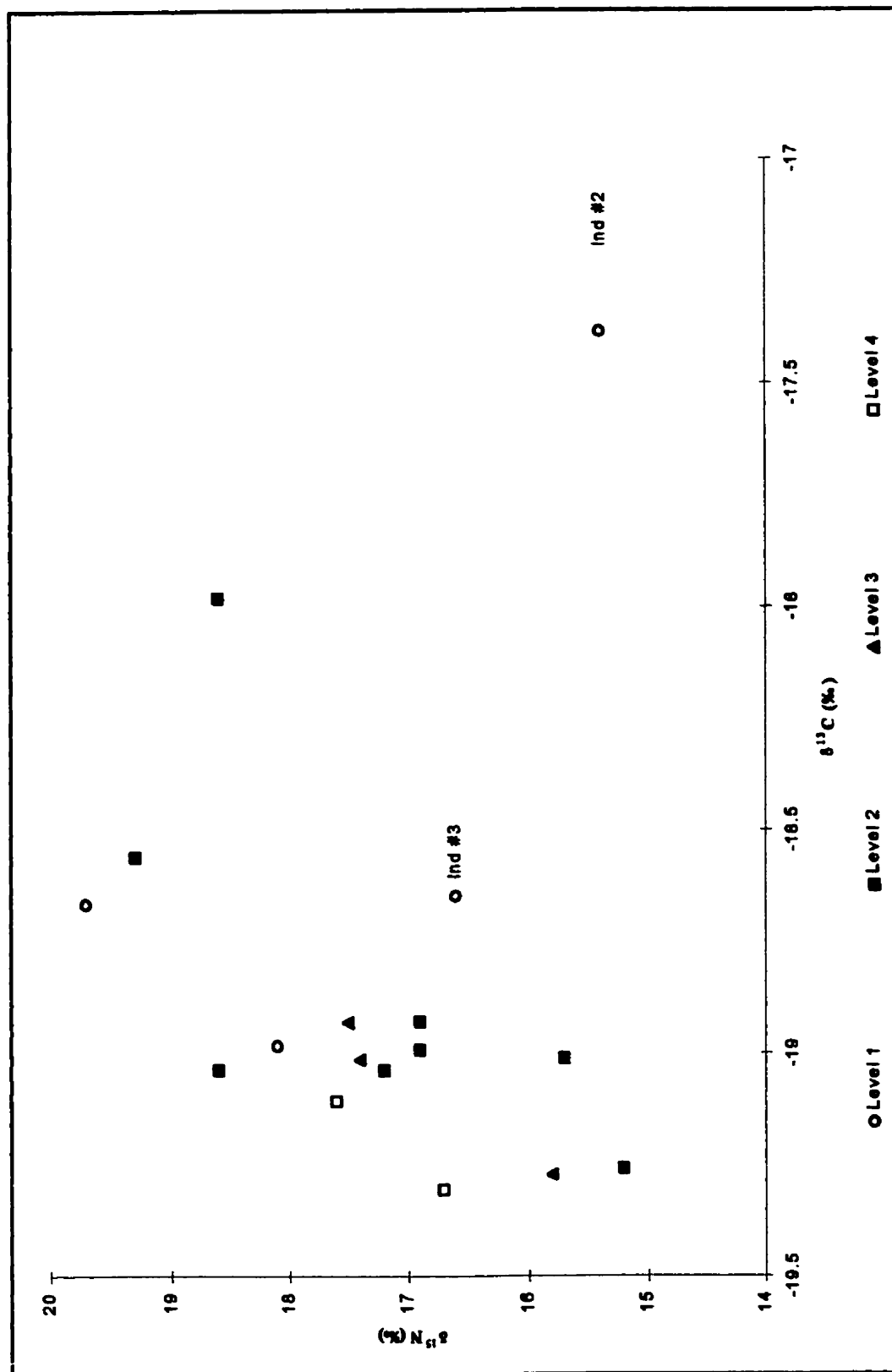
Figure 8.2. $\delta^{13}C$ and $\delta^{15}N$ values for each level of individuals in Chamber 1, Tomb Dk-31, 'ein Tirghi cemetery, Dakhleh Oasis, Egypt. Individuals #2 and #3 are marked as they have been identified as potentially being from another time period.
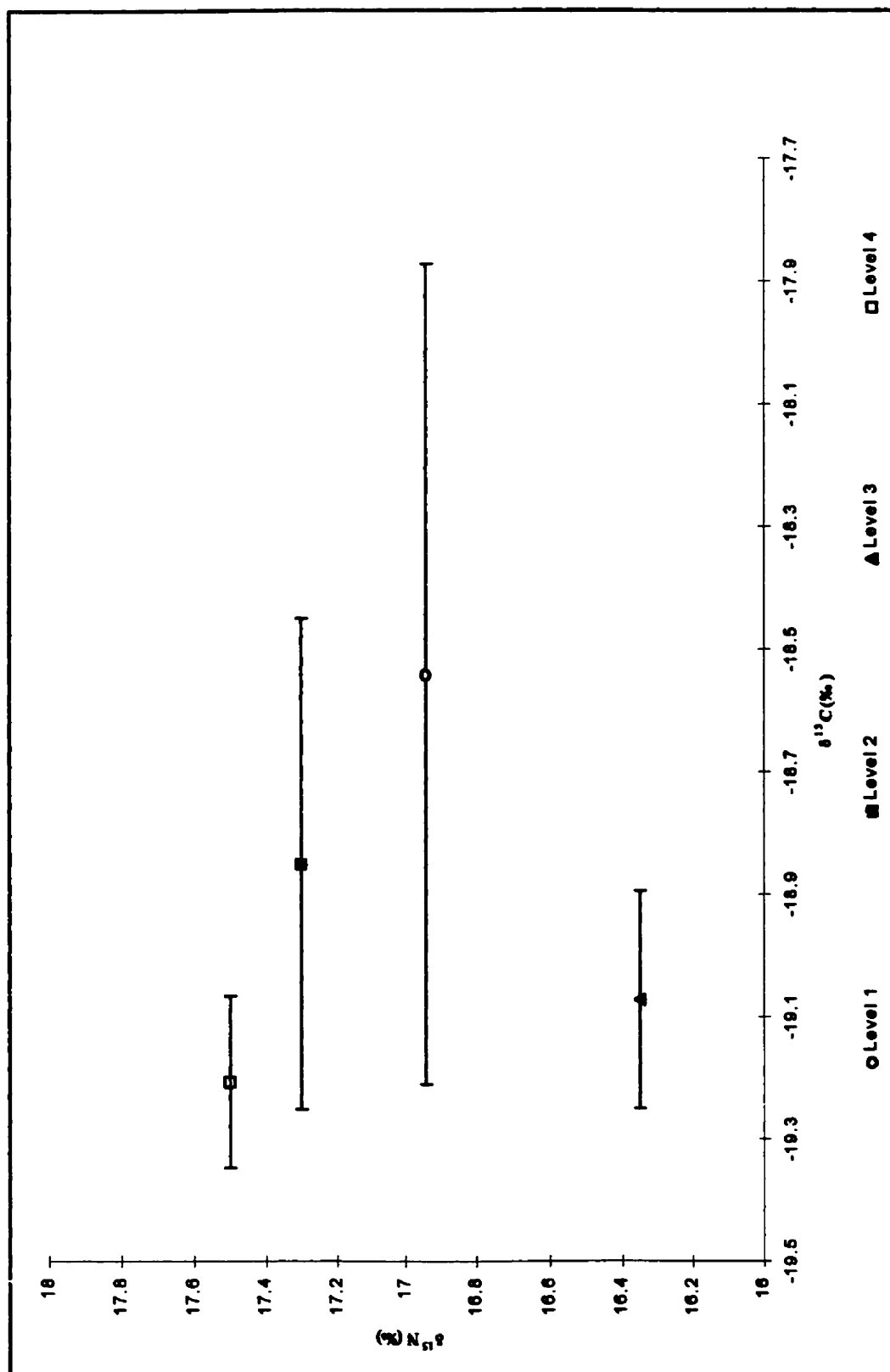
Figure 8.3. Mean δ¹³C and δ¹⁵N values plotted with one standard deviation for δ¹³C. Each level of individuals is plotted for Chamber 1, Tomb Dk-31, 'ein Tirghi cemetery, Dakhleh Oasis, Egypt.

It is also important to note that the $\delta^{13}C$ values of Individuals #2 and #3 (Chamber 1, Level 1; see figure 6.3 and 8.2) are enriched over individuals from lower levels. As discussed previously (Chapter 6), these two burials may represent tomb robbers or even tomb workers who were small enough to fit into the confined space of the tomb. The fact that their $\delta^{13}C$ values are enriched over individuals from the lower levels lends support to the idea that this tomb holds individuals from more than one time period.

Tomb re-use has been a common practice in Egypt since the Pharaonic period, and thus it would not be surprising if tombs built during the Third Intermediate period were reused subsequently. The labour involved in tomb construction can be considerable (depending on the matrix), so it is not unfathomable that tombs were reused to save time and labour. It is also possible that this tomb represents a tomb in which family members were interred over hundreds of years (Melbye 1983; Molto 1986). DNA testing in the future will hopefully shed further light on this question.

8.4 Kellis 1 Cemetery Sample
8.4.1 Sample Bias

One of the first things that should be discussed regarding the Kellis 1 cemetery is the possible bias in sampling. As discussed in Chapter 6, both skeletonized and artificially mummified remains were recovered from tombs. Because contamination may have occurred during the mummification process, samples where taken only from completely skeletonized individuals. This procedure may have introduced a bias into

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the sample. Artificial mummification was an expensive process and only the upper classes of Egyptian society were ritually mummified (Andrews 1984). Even though the individuals interred in these tombs may represent familial units (Cook 1994), the possibility exists that the individuals who were artificially mummified were of a higher status than those who are represented by skeletonized remains. As a result, the dietary information presented in this thesis may only be representative of the lower class during this particular time period.

8.4.2 Age and Sex Differences

The co-mingled nature of the Kellis 1 cemetery makes it difficult to make meaningful comparisons between age categories and sex. As there are no infants under the age of 5 years in the tombs, no comparisons can be made between ages, nor can any comment be made regarding breast feeding and weaning practices.

For the small number of samples whose sex was identifiable, there appears to be neither differences in $\delta^{13}C$ or $\delta^{15}N$ between the sexes (Figure 7.6) nor substantial variation within male and female samples. This indicates that males and females were eating similar foods. $\delta^{13}C$ values indicate, with the exception of five individuals (Figure 7.9), that this population subsisted mainly on C_3 foods. This is consistent with the dietary reconstruction based on documentary sources presented in Chapter 4. The five individuals with enriched $\delta^{13}C$ values could not be identified as to age (beyond being skeletally mature) or sex. The enriched $\delta^{13}C$ values indicate that their diets included a C_4 component, either C_4 plants or meat of animals that fed on C_4 plants. In fact, their

percentages for C_4 plants range from 19.5% to 36.9%, compared to a mean percentage of 12.8 for the rest of the population. It is possible that these people were recent migrants to the Oasis from areas where C_4 plants were readily available for consumption. Iacumin and colleagues (1996) present $\delta^{13}C$ values ranging from –18.8‰ to 20.1‰ for human skeletal material from the Nile Valley. One individual, however, was substantially enriched in ^{13}C with a $\delta^{13}C$ value of –13.9‰. These authors suggest that this individual migrated to the Nile Valley from a totally different environment and died shortly after his arrival. On the other hand, this individual may have been living in Egypt after the introduction of millet and sorghum, and may not have been a migrant. Both millet and sorghum are thought to have been grown and consumed in Nubia beginning sometime before the end of the Meroitic period (350 BC to AD 350) (Iacumin et al. 1998; White and Schwarcz 1994).

Another explanation for the occurrence of individuals in Kellis 1 with high $\delta^{13}C$ values is that, as seen in 'ein Tirghi, the tomb may have been reused, or used over several hundreds of years by familial groups (Cook 1994) extending into the period when C_4 foods are known to have been present. Individuals who are enriched in ^{13}C may have actually lived in the Oasis during the advent of the introduction of millet to the Oasis.

The disturbed condition of the tombs makes it nearly impossible to reconstruct the nature of the burials, neither is it possible to examine the $\delta^{13}C$ and $\delta^{15}N$ data in relation to how and where individuals where interred in each tomb. It would be hard

to confirm whether the individuals who have elevated $\delta^{13}C$ values are from a different time period without additional information on dates for these skeletons.

8.4.3 Collagen-Apatite Differences

As shown in Figure 7.9, the limited range in $\delta^{13}C$ if the Kellis 1 samples does not allow us to see a relationship between $\delta^{13}C$ of apatite and collagen. Figure 7.20 makes it clear however that there is an overall linear relationship between them with an off-set of approximately 6.2‰. This mean difference is close to the reported $\Delta_{apatite-collagen}$ of +7‰ (Lee-Thorp and van der Merwe 1989; Kruger and Sullivan 1984). The relationship between the $\delta^{13}C$ if apatite and collagen is discussed in depth in sections 8.5.3 and 8.6.3.

8.5 Kellis 2 Cemetery Sample

8.5.1 Differences in $\delta^{15}N$ and $\delta^{13}C$ Related to Sex and Disease

The size of the sample representing the Kellis 2 cemetery makes it possible to characterize relationships between diet and both sex and age. Sex-related differences in diet can only be discussed for adults. No significant differences are found in $\delta^{15}N$ between males and females. The mean $\delta^{15}N$ value is 17.9 ± 1.09‰. There are 8 individuals who fall below one standard deviation of the mean (< 16.8‰), and 1 individual who is 2 standard deviations below the mean (< 15.7‰) (Table 8.1). $\delta^{15}N$ values that are substantially lower than the sample as a whole may indicate individuals who were not originally from such an arid environment. Because complete bone turnover may take

Table 8.1. Individuals from the Kellis 2 cemetery who's $\delta^{15}N$ values are more than one standard deviation below the mean for the adult population.

Burial	Sex	Age	$\delta^{15}N$ (‰)	Pathological Characteristics
B049	unknown	7	16.59	Cribra orbitalia, periositis
B059	Male	46	16.65	Osteoperiostitis (treponematosis?)
B111	Male	35	16.19	Healed fracture (right fibula)
B114	Male	61	16.77	Osteoporosis, healed fracture (1st sacral body)
B116	Male	23	14.50	Leprosy
B132	Male	18.5	16.28	
B165	Female	55	16.47	Dental pathology, osteoporosis
B166	Female	31	16.03	Periostitis

almost 30 years (Stenhouse and Baxter 1979), the $\delta^{15}N$ values of these individuals would represent the diet and in some cases the environment in which they spent much of their lives. Individuals with substantially lower $\delta^{15}N$ values spent a good portion of their lives eating foods from a food chain that was not as enriched in ^{15}N as the food chain in the Dakhleh Oasis. It is very likely that they originally came from areas such as the Nile Valley and Nubia, as was suggested for Kellis 1. The anomalous $\delta^{15}N$ values from the Kellis 2 cemetery population are close to the upper end of the ranges reported for skeletal material from the Nile Valley and Nubia, lending support to the idea that these individuals represent migrants to the Dakhleh Oasis. As a result of skeletal remodeling, they could have acquired some degree of ^{15}N-enrichment through the part of their lives spent living in the Dakhleh Oasis.

Further support for the migration hypothesis comes from observations on burial #116, a young male who is 2 standard deviations below the mean. He shows os-

teologic features associated with the classic pathological characteristics of lepromatous

leprosy (E. Molto, pers. comm). In their preliminary mtDNA analyses of materials from

the Kellis 2 cemetery, moreover, Parr and colleagues (1998) have noted that Burial 116

does not appear to share any maternal genetic characteristics with any of the burials ana-

lysed thus far, indicating that he may in fact be a recent migrant to the Oasis. Recently

Katzenberg and Lovell (in press) found that bone with certain pathological conditions,

particularly wasting diseases such as osteomyelitis in which deposition of newly formed

bone is involved, have enriched $\delta^{15}N$ values in comparison to normal bone. This con-

sideration must be kept in mind when dealing with pathological bone specimens as this

may have been a contributing factor in the reduced $\delta^{15}N$ of burial #116 relative to the

rest of the sample.

There is a statistically significant difference in $\delta^{13}C$ between males and fe-

males (p=0.00), and Figure 7.10 also illustrates this separation in the data. Adult males

appear to be enriched in ^{13}C compared to adult females; females consumed 16.3% of

C_4 plants in their diet while males consumed 18.2%. This separation in data may indi-

cate that the adult males ate more meat, particularly cow or goat, compared to the fe-

males. Females may have relied more heavily on grains such as wheat or barley as their

main dietary staple, with some millet or cow or goat meat. The low standard deviations

for $\delta^{13}C$ in both males (1.2‰) and females (1.0‰) indicates that there is little dietary

variation with each sex, and it can be suggested that individuals in each group were eat-

ing similar foods.

8.5.2 Age Related Differences in $\delta^{13}C$ and $\delta^{15}N$

Age related differences in both $\delta^{13}C$ and $\delta^{15}N$ in this population are evident, particularly among children under two. When children under 2 are excluded, however, there does not appear to be any variation in diet with age, although there is variation in diet within specific age categories. Thus diet does not appear to have changed with age such that, for example, elderly people did not eat different foods than young adults. Although the there are no statistically significant differences between children under 2 and adults for $\delta^{13}C$, Figure 7.10 shows that children under two are clearly separated in both $\delta^{13}C$ and $\delta^{15}N$ from the rest of the sample. The lack of statistical difference between adults and children under 2 can be accounted for by the large age-dependent variation in child isotope values (children < 2 $\sigma^2 = 0.82\%_0^2$). Plotting $\delta^{15}N$ against age at death (Figure 7.11) demonstrates that children under 2 are considerably enriched in ^{15}N over the rest of the population. The mean difference in $\delta^{15}N$ between children under 2 and adult females is $2.72\%_0$, reflecting the $3\%_0$ difference reported for breastfeeding children in other studies (e.g., Schurr 1997; Katzenberg and Pfeiffer 1995). The plot of $\delta^{15}N$ values for each subgroup of children (Figure 7.12) reveals that infants exclusively breastfed for up to 6 months. After this age $\delta^{15}N$ values begin to gradually decrease until 3 years of age. This indicates that these infants began a gradual weaning process at around 6 months of age, and that this process was complete by 3 years of age. There is an unexpected increase in $\delta^{15}N$ at 4 years of age. There are only two individuals which make up this mean value, so there may be a bias due to the small sample size.

These data also reveal that children under two are enriched in ^{13}C over the rest of the population (Figure 7.13). The percentages for C_4 foods in the diet range from 0% to 24.7% in children under 2, and range from 14% to 21.3% in adults. Although there is a large range of percentage of C_4 foods in the diet of children, the majority of children under two have at least 20% of their diet comprised of C_4 foods, higher than the mean percentage of 17.2% for adults. When $\delta^{13}C$ values for the children are plotted against age categories an interesting pattern emerges (Figure 6.14). From birth to approximately 1.5 years of age there is a gradual enrichment in ^{13}C, with a mean difference of 1.38‰ from birth to 1.5 years of age. After 1.5 years of age, the $\delta^{13}C$ values gradually begin to decline until age 3.5, where the values are basically reflective of adult values of approximately -19‰.

The enrichment in ^{13}C suggests that around 6 months of age infants were no longer exclusively breastfed, and foods enriched in ^{13}C were introduced to the diet. The milk of cows and goats are the only food sources very enriched in ^{13}C that were likely to have been fed to infants during this time period (Figure 7.23). It is therefore most likely that either cow or goat's milk was introduced to infants at 6 months of age. Fildes (1986) notes that both cow's and goat's milk have been identified in documentary evidence as the food of choice for infants during the Roman period. Soranus recommended that a mixture of honey and goat's milk be fed to infants in addition to breast milk until the infant was old enough to have solid foods. Although the Greeks considered goat milk to be superior to that of cow's milk for making cheese, the Romans con-

sidered cow's milk to be superior (Davies 1989); thus it is difficult to determine if one animal milk would have been favored over the other. It is difficult to determine whether Hellenistic or Roman beliefs and practices influenced infant feeding practices at the Dakhleh; however, the presence of the Roman army (Wagner 1987) shows that Roman practices were present.

This finding contrasts with research reported by Wright and Schwarcz (1998; in press) for prehistoric Guatemala. In their study of dental enamel and dentine using $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ values, they found that teeth formed during the first year of life were depleted in ^{13}C in comparison to teeth formed at older ages. The authors suggest that this depletion is due to the ingestion of lipid-rich breast milk. Infants under 6 months of age from the Kellis 2 cemetery show the opposite pattern. They are enriched in ^{13}C compared to the adults and juveniles. This suggests that they were introduced to supplementary foods quite quickly, and that the dietary contribution of lipid-rich breast milk was minimal after 6 months of age. It is important to note that Wright and Schwarcz's (1998; in press) samples consisted of adults who had survived through the infant period, thus removing a possible childhood mortality bias from their data.

When both the $\delta^{13}C$ and $\delta^{15}N$ data for infants are considered together (Figure 7.15) these data show that as the $\delta^{15}N$ values peak and begin to decline at 6 months of age, the $\delta^{13}C$ values begin to increase. At 3 years of age, when $\delta^{15}N$ values of children have almost decreased to the level of adult values, $\delta^{13}C$ values are still elevated. Both the $\delta^{13}C$ and $\delta^{15}N$ data indicate that infants were breast-fed exclusively un-

til approximately 6 months of age; thereafter supplementary foods (either goat or cow's milk) were introduced into the diet. $\delta^{15}N$ values suggest that the weaning process was complete by approximately 3 years of age, while $\delta^{13}C$ values indicate that infants were weaned completely onto adult food by approximately 3.5 years of age.

This fascinating relationship between infant $\delta^{13}C$ and $\delta^{15}N$ values has never been documented before. It is the unique coincidence of three occurrences at Dakhleh Oasis during the Roman period that makes the observation possible: 1) The introduction of millet to the Oasis during the Roman period; 2) the feeding of millet to both cows and goats; and 3) ideology concerning infant feeding and weaning practices. In addition, another contributing factor is the large sample size available for this research. The majority of studies concerning breastfeeding and weaning practices utilizing stable isotope analysis only deal with small samples, either as a result of poor preservation or cost (Schurr 1997; 1998; Katzenberg and Pfeiffer 1995). These factors make it possible to infer the timing of the weaning process, as well as the food onto which infants and children were weaned.

8.5.3 Collagen-Apatite Differences

When Kellis 2 data are considered separately from the other cemetery sites, the mean difference between $\delta^{13}C$ of apatite and $\delta^{13}C$ of collagen is 6.01‰, which is very close to the reported Δ_{a-c} difference of +7‰ for omnivores (Krueger and Sullivan 1984; Lee-Thorp and van der Merwe 1989). Research by Bocherens et al. (1995) concludes that omnivorous and carnivorous animals have very similar Δ_{a-c} values (hyaena =

6.1‰; bear = 6.7‰), thus making it very difficult to utilize $\Delta_{apatite-collagen}$ values to distinguish between diets dominated by meat or vegetables. Nevertheless, Roksandic et al. (1988) report substantial differences in Δ_{a-c} between populations subsisting on a terrestrial diet (Δ_{a-c} = 5.8‰), and those subsisting on a marine based diet (Δ_{a-c}= 2.7‰). Saliège et al. (1995) report mean Δ_{a-c} differences of 6.0‰ for humans from Niger who subsisted mainly on milk and C_4 plants. The $\Delta_{apatite-collagen}$ values from both Kellis 1 and Kellis 2 cemeteries suggest that on the whole the people ate an omnivorous diet. This is substantiated by both documentary evidence and botanical and faunal remains recovered from the site of Kellis.

As was the case for Kellis 1, there does not appear to be a significant relationship between the $\delta^{13}C$ of collagen and the $\delta^{13}C$ of apatite at Kellis 2 (Figure 7.16). This is surprising as it has been proposed, on the basis of diet, that these two variables are linearly related and should show a slope of approximately 1 (Ambrose and Norr 1993; Tieszen and Fagre 1993). Consequently, as the $\delta^{13}C$ of collagen changes, the $\delta^{13}C$ of apatite should change correspondingly. When both Kellis 1 and Kellis 2 samples are considered together (Figure 7.20) the linear relationship becomes stronger (R^2 = 0.31), however the slope is 0.69. So the question is, why is the slope less than 1?

If one segment of the Dakhleh Oasis community has a different diet than another (i.e., adult females versus adult males), then this may be reflected in the relationship of the $\delta^{13}C$ of collagen and apatite. There is a statistically significant difference between males and females for $\delta^{13}C$ of collagen, and Figure 7.10 shows that adult

males tend to be enriched in ^{13}C over adult females. This indicates that adult males were eating a diet that was enriched in ^{13}C, and the only dietary components thus far that have been identified as being enriched in ^{13}C are cows and goats, who were most likely fed millet. Unfortunately the pooled sample from Kellis 1 and 2 cannot be broken down into sex and age because of the nature of the Kellis 1 sample, and because the sampling procedure for Kellis 2 created a very unbalanced sample (only 2 adult males are represented). Therefore the sample is not large enough to detect any statistically significant differences between sex or age categories.

Another way to examine potential differences in diet is to examine the δ^{15}N values against the $\Delta^{13}C_{apatite-collagen}$, both of which are considered to be trophic indicators. Figure 8.4 demonstrates that there is a weak relationship between these two variables; however, although the slope is only –0.5, the direction of the slope is what would be expected in this type of a relationship. Individuals who had consumed large amounts of meat in their diet should have δ^{15}N and $\Delta^{13}C_{apatite-collagen}$ values that are located in the upper left quadrant of the scatter plot because they should have a higher trophic level than individuals who consumed large quantities of grain. Individuals who consumed a diet dependent on grains should be located in the lower right quadrant, reflecting a larger $\Delta^{13}C_{apatite-collagen}$ value and a lower δ^{15}N, essentially a lower trophic level. Interestingly, the two individuals who are located in the upper left quadrant are children under 2 years of age. It is expected that breastfeeding children should be high in terms of trophic level as they are essentially consuming a carnivorous diet. Although the relationship is
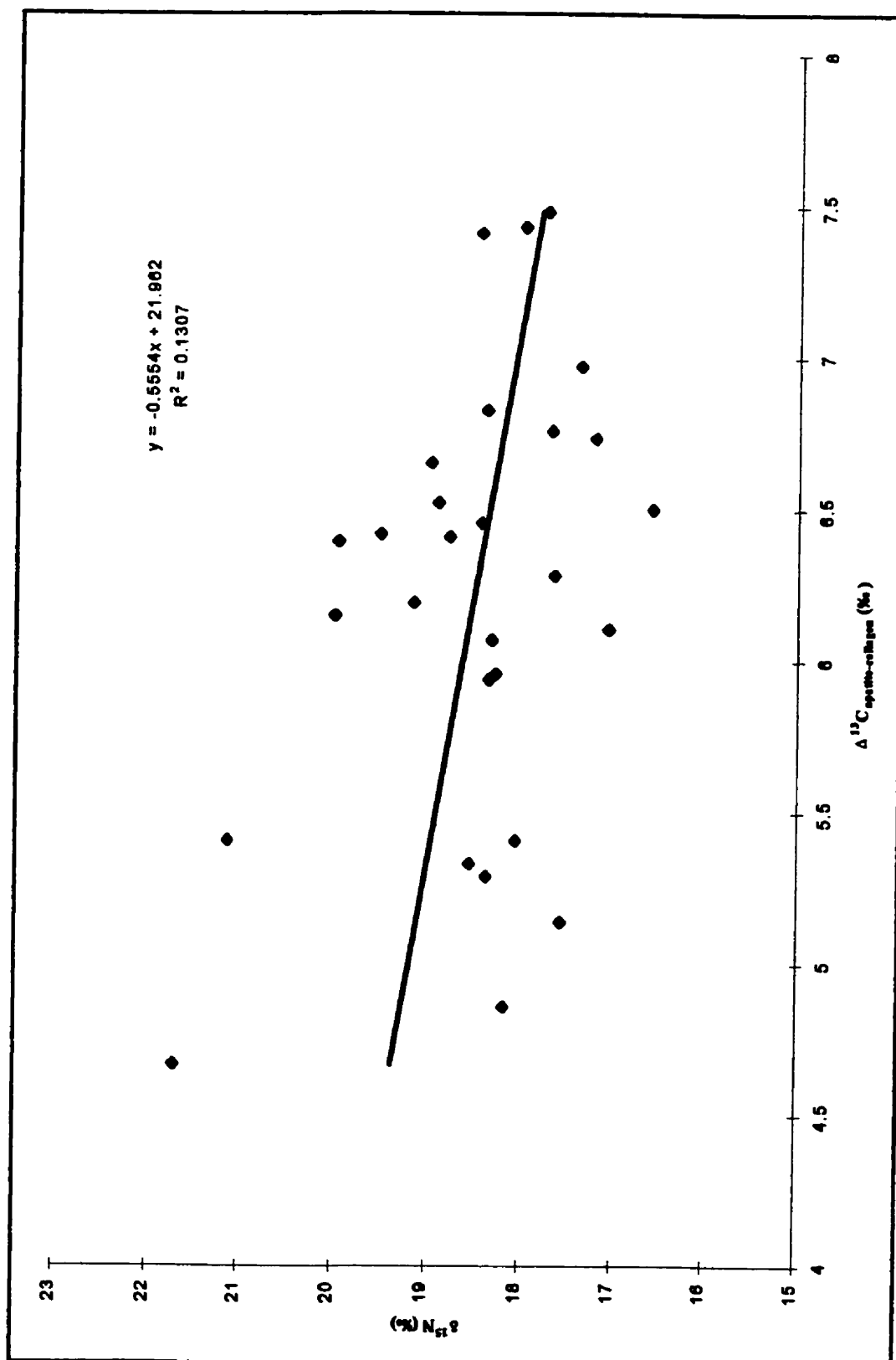
Figure 8.4. $\delta^{15}N$ plotted against $\Delta^{13}C_{apatite-collagen}$ for both Kellis 1 and Kellis 2 cemetery populations.

not a strong one, there is a definite trend in these data. The comparison of these two variables supports the notion that individuals from Kellis 1 and Kellis 2 ate an omnivorous diet.

8.6 Dietary Differences between Time Periods

8.6.1 Differences in $\delta^{13}C$

When $\delta^{13}C$ values are considered for all three cemeteries, an intriguing pattern emerges (Figures 7.17 and 7.18). When a menu of foods was developed for each of the time periods, it was surmised that the diets of individuals from both the 'ein Tirghi cemetery and Kellis 1 would be similar, resulting in similar $\delta^{13}C$ values for each cemetery, reflecting a diet based on C_3 foods. Because of the introduction of millet during the Roman period it was hypothesized that people from Kellis 2 would show $\delta^{13}C$ values that were elevated in comparison to the $\delta^{13}C$ values from 'ein Tirghi and Kellis 1, reflecting the introduction of a C_4 plant into the diet. T-tests, however, show statistically significant differences in $\delta^{13}C$ between Kellis 1 and 'ein Tirghi, and also between Kellis 1 and Kellis 2. When the children under 5 years of age are taken out of the sample, T-test results indicate that there is also a statistically significant difference between 'ein Tirghi and Kellis 2. Figures 7.17 and 7.18, however, illustrate that the samples from 'ein Tirghi and Kellis 2 are very similar in their $\delta^{13}C$ values, reflecting a diet that included either C_4 plants or meat from animals that were fed C_4 plants. In comparison, the sample from Kellis 1 is depleted in ^{13}C, reflecting a population that subsisted mainly on a C_3 food chain.

These findings once again call into question the dating of the 'ein Tirghi cemetery. The similarity between the $\delta^{13}C$ values for both cemeteries indicates that some of the individuals interred in the 'ein Tirghi cemetery are from the same time period as those interred in Kellis 2. If this is the case, and there are people from later time periods buried in the tombs of 'ein Tirghi and Kellis 1 (as discussed in section 8.4.2), then it is possible that there are two different burial practices co-existing during the Romano-Christian period. It is during this time period that the population of the Oasis grew rapidly (Mills 1984; Shaaban 1988) and the likelihood that a population with two different burial practices existed is possible. The people who had existed in the Oasis for centuries may have continued to bury their dead in tomb structures, while those who migrated to the Oasis during this time period brought with them Christian ideologies and burial practices. This is one possible explanation for the elevated $\delta^{13}C$ values for both cemeteries.

8.6.2 Differences in $\delta^{15}N$

When children under 5 years of age are excluded, statistically significant differences were found in $\delta^{15}N$ between 'ein Tirghi and Kellis 2, a phenomenon also apparent in Figure 7.18. Individuals from Kellis 2 appear to be enriched in ^{15}N over individuals from the 'ein Tirghi cemetery. This suggests that the amount of animal protein consumed by individuals from Kellis 2 was higher than that of people from 'ein Tirghi. On the other hand, it is also possible that there was a change in climate in the 1000 years between the individuals from the lower levels of 'ein Tirghi and those interred in

Kellis 2. Faunal evidence from the late Neolithic indicates that the environment in the

Dakhleh Oasis was much more humid and Savannah-like, and became increasingly

more arid as time passed (Churcher 1993). It is very possible that the amount of pre-

cipitation in the Dakhleh Oasis decreased from circa 800 BC to the Roman period, thus

increasing aridity and enriching the soil in ^{15}N.

8. 7 Seasonal Differences in Diet

In contrast to bone collagen, which measures an average diet over 25 to 30

years of an individual's life (Stenhouse and Baxter 1979), hair can be used to detect the

diet of an individual just before their death (Nakamura et al. 1982). Hair has a very fast

turn-over rate, such that the scalp end of the hair registers a dietary signal from a few

days prior to an individual's death. Because hair lays down carbon in a linear fashion, it

can also be used to detect short term variation, or lack of variation, in diet over the last

year of an individual's life (White et al. 1999; White 1993; White and Schwarcz 1994).

Six samples of hair from Kellis 1 and Kellis 2 cemeteries were analysed for δ^{13}C and

δ^{15}N to determine if there were any detectable variations in diet along the strands of

hair. The δ^{13}C values from these four individuals show a similar pattern to that ob-

tained from collagen analyses, that is, the hair from both individuals from Kellis 2 is en-

riched in ^{13}C in comparison to the hair from the individuals from Kellis 1. This indi-

cates that individuals from Kellis 2 were consuming a diet that included more C_4 foods

than were consumed by individuals from Kellis 1. This adds further support to the hy-

pothesis that there are differences in diet between these two time periods, consistent

with the menu of foods suggested by scrutiny of the documentary and archaeological remains (Chapter 4).

Figure 7.21 and Table 7.15 illustrate that there is very little variation in $\delta^{13}C$ along each strand of hair. The range of $\delta^{13}C$ values along each strand is very small (the largest range of values is in B168, 0.43‰). White et al. (1999) report similar findings for $\delta^{13}C$ of hair samples from a sample of mummies from the Kharga Oasis. It appears as though the diets of these particular individuals from Kellis 1 and Kellis 2 were consistent throughout the year. The only detectable pattern in these data is that $\delta^{13}C$ appears to decrease from the root end of the hair to the distal tip, suggesting increasing enrichment in ^{13}C before each of these individuals died. This trend may be due to small variations in meat versus grain consumption during the year. In addition, the small sample size may also mask such a pattern.

It was expected that the $\delta^{13}C$ values for individuals from Kellis 1 would be fairly consistent and reflect a diet dominated by C_3 foods. With the introduction of millet to the Dakhleh Oasis during the Roman period, it was hypothesized that the $\delta^{13}C$ of hair samples from individuals from Kellis 2 would reflect a similar pattern to that found by White (1993) for Nubian samples. White (1993) found that the $\delta^{13}C$ value of hair samples reflected a seasonal rotation of C_3 and C_4 crops, with winter crops of wheat/ barley, and summer crops of millet and sorghum. If millet was grown or traded into the Oasis during specific times of the year, the $\delta^{13}C$ of hair from individuals from Kellis 2 should reflect this pattern of consumption. In contrast, these hair data from Kellis 2

suggest that the diet was consistent throughout the year, and consisted mainly of C_3 foods and small quantities of either millet or millet-fed animal meat.

Individuals from Kellis 1 and Kellis 2 can not be separated in time on the basis of their $\delta^{15}N$ values for hair. The range in $\delta^{15}N$ values along each strand of hair is larger than detected in the $\delta^{13}C$ values. The variance, particularly for individuals from Kellis 1, is also larger than observed in the $\delta^{13}C$ data. Unfortunately, the hair strands from Kellis 2 were not long enough to determine if there were any detectable patterns of variation in $\delta^{15}N$ along the shaft of the hair. Although the hair samples from Kellis 1 do not show any consistent trends in $\delta^{15}N$, there are locations along each strand where the hair is suddenly enriched by 1‰. This enrichment in ^{15}N may represent changes in diet or changes in environmental conditions (i.e., fluctuations in precipitation), but this cannot yet be determined. Yoshinaga et al. (1996) reported elevated hair $\delta^{15}N$ values in a coastal population of modern Papuans but account for this enrichment as high consumption of marine foods. If the environmental conditions at Dakhleh during the Roman period were slightly more variable and humid than they at present, then this enrichment in ^{15}N may represent periods during the year when the Oasis was drier than normal. The alternative explanation is that this enrichment represents a shift in diet, and that more protein was consumed during certain times of the year.

8. 8 Faunal Remains

8.8.1 Archaeological Faunal Remains

An examination of the $\delta^{13}C$ and $\delta^{15}N$ values for archaeological faunal re-

mains (Figure 7.23) shows that there was a variable diet among the animals tested. $\delta^{13}C$

values indicated that animals, with the exception of goats and cows, ate a diet com-

prised mainly of C_3 foods. Goats and cows are enriched in ^{13}C over pigs, donkeys, ga-

zelle and chickens. This indicates that goats and cows were fed large amounts of millet.

The percentage of C_4 plants in the animals' diets indicates that cows' diet contained ap-

proximately 43% C_4 plants, while goats' diet was comprised of approximately 39% C_4

plants. This compares to a range of 16% to 27% for the rest of the archaeological ani-

mal samples. Ambrose and DeNiro (1986) found that grazers are enriched in ^{13}C over

browsers, as grazers are more likely to eat arid-adapted grasses which are, in most cases,

C_4 plants. This does not hold true for the animal samples from Dakhleh. While cows

are grazers and goats are browsers, there is little difference in their respective $\delta^{13}C$ val-

ues in this particular geographical area and environment. This is because no plants sur-

vive in the desert conditions without intervention from humans. Consequently, any ani-

mals existing in this type of an environment must have been fed by humans. Even if

they were allowed to roam freely and graze/browse, they would only be able to eat foods

intentionally planted by humans. As a result, the $\delta^{13}C$ values of the animals reflect the

unique oasis environment in which they lived.

Herbivores (gazelle, donkey, cows and goat) and omnivores (pig) are clearly

separated from chickens in their $\delta^{15}N$ values. While gazelle, donkey, cows, goat, and

pig display very little variation in $\delta^{15}N$, chickens, which can be thought of as omnivo-

rous, are enriched in ^{15}N by approximately 3‰ over all the other animals and they ap-

pear to be one trophic level higher than the rest. One reason for this may be that chickens, particularly if they are free-ranging, obtain much of their protein by eating insects. Therefore, although they eat grain, chickens are one trophic level above the rest of the animals with respect to their nitrogen source.

8.8.2 Modern Faunal Remains

The $\delta^{15}N$ and $\delta^{13}C$ for modern faunal remains are quite different than what we see in the archaeological remains (Figure 7.23). In most cases the $\delta^{13}C$ values of the herbivores (camel, donkey, cow) in this sample are quite similar, reflecting a diet of mainly C_3 plants. The exception to this is a single camel which is very enriched in ^{13}C in comparison to the rest of the animals. A calculation of the percentage of C_4 plants in the diet indicates that this camel's diet consisted of approximately 72% C_4 foods. The only other animal with a high percentage of C_4 plants in its diet is the goat (39%). The contribution of C_4 plants to the diets of the rest of the animals range from 13% (fox) to 25% (camel), indicative of diets consisting mainly of C_3 plants. It is important to note that the two camel samples, which are considerably different in their $\delta^{13}C$ values, are from different locations in the Oasis. It is possible that the owners of these animals fed them different diets. The camel that is considerably enriched in ^{13}C was either fed large amounts of millet or sorghum, both of which are C_4 plants found in the Dakhleh Oasis today (Mills 1979). The other camel has a $\delta^{13}C$ value that indicates it was fed a diet of mainly of C_3 plants.

The $\delta^{15}N$ values for the modern faunal sample are much more variable than their $\delta^{13}C$ values. This variability suggests that these animals were eating different types and quantities of foods. The $\delta^{15}N$ values of the plants that the herbivores were eating are reflected in the animals' $\delta^{15}N$ values. As a result, the variability in the animals' $\delta^{15}N$ values is partly reflecting variability in the $\delta^{15}N$ of plants. While $\delta^{15}N$ values for herbivores (camel, donkey, and cow) are consistently low, the values for the one omnivore (goat) and one carnivore (fox) are extremely high. They are more than two trophic levels above the rest of the animals. It is expected that the fox sample would be higher than the rest of the animals as it is a carnivore, higher on the food chain than the herbivores. What is surprising, however, is the $\delta^{15}N$ value of the goat sample. Although goats are known to eat a variety of foods, it is highly unlikely that this animal was eating a carnivorous diet. Currently, there is no explanation for the high $\delta^{15}N$ of the goat sample.

8.8.3 Archaeological versus Modern Faunal Remains

Figure 7.23 illustrates that while $\delta^{13}C$ values for archaeological and modern faunal remains are similar, there is a substantial difference in $\delta^{15}N$ values between these two samples. With the exception of the modern fox and goat samples, the archaeological faunal sample is enriched in ^{15}N by over 3‰. This separation in the data is not surprising as it is known that because of the present-day wide spread use of chemical fertilizers archaeological plant remains commonly have $\delta^{15}N$ values that are enriched over their modern counterparts (DeNiro 1987). Chemical fertilizers contain nitrate and am-

monium derived from atmospheric N_2 and therefore usually have a $\delta^{15}N$ value of approximately 0‰. Use of such fertilizers lowers the $\delta^{15}N$ value of the soil, which then changes the $\delta^{15}N$ values of the plants. Animals eating these plants would also show $\delta^{15}N$ values which are lower. Chemical fertilizers are widely used today in the Dakhleh Oasis (M. Woidich, pers. comm.). It is possible that the wide separation in $\delta^{15}N$ between archaeological and modern faunal remains stems from this phenomenon.

8.9 Botanical Remains

8.9.1 Archaeological Botanical Remains

All of the archaeological botanical remains, with the exception of the doum palm nut, have very similar $\delta^{13}C$ values with a small amount of variance ($\sigma^2 = 1.94‰^2$) (Figure 7.24). These values are within the range of $\delta^{13}C$ values usually given for C_3 plants (Tieszen 1993; van der Merwe 1982). The mean $\delta^{13}C$ value for archaeological botanical remains, -23.3‰, is very close to the mean value of -26.5‰ which is commonly cited for C_3 plants (White and Schwarcz 1994; DeNiro and Epstein 1978).

The $\delta^{15}N$ values for the archaeological botanical remains are much more variable ($\sigma^2 = 6.51‰^2$). In this case it is possible that the level of post-depositional degradation caused isotope fractionation, therefore enriching the remains in ^{15}N (DeNiro and Hastorf 1985). The $\delta^{15}N$ values may vary according to the amount of post-depositional degradation that has occurred in each sample. It is also possible that the $\delta^{15}N$ values of the plants is correlated with root depth and spread. Schwarcz et al.

(1999) postulate that soil enrichment in arid environments is due to ammonia volatilization near the soil's surface, therefore plants with shallow root systems or wide-spread root systems may be enriched in ^{15}N in comparison to plants with deeper root systems.

8.9.2 Modern Botanical Remains

The range of $\delta^{13}C$ values for modern C_3 and C_4 botanical remains falls within the reported $\delta^{13}C$ ranges for both C_3 and C_4 plants (Tieszen 1993; DeNiro and Epstein 1978) (Figure 7.25). The mean $\delta^{13}C$ value for the C_3 plants, -27.62‰, is very close to the reported mean value of -26.5‰ (DeNiro and Epstein 1978). The mean $\delta^{13}C$ value of the two C_4 plants, -11.53‰, is also within the range of values reported for C_4 plants (Schwarcz et al. 1985; White and Schwarcz 1994). The variance and range for the $\delta^{13}C$ values of the total modern botanical sample is very high ($\sigma^2 = -22.56‰^2$, range=22.6‰), however it is the $\delta^{13}C$ values of the two C_4 plants (sorghum) that contribute to this large range and high variance.

The $\delta^{15}N$ values of the modern plant remains from Dakhleh are quite variable ($\sigma^2 = 28.8‰^2$), and the range is quite large (range = 17.9‰). Because these samples have not been exposed to a post-depositional environment, the large variation in $\delta^{15}N$ cannot be attributed to taphonomic processes. The range in $\delta^{15}N$ values is most likely due to a combination of plant physiology and exposure to chemical fertilizers (DeNiro 1987). The plant's root system and mechanism for nitrogen uptake from the soil, and the amount of ^{15}N in the soil, will affect the $\delta^{15}N$ of each plant. Variation in the amount of chemical fertilizer used during agriculture will also affect a

plant's $\delta^{15}N$ value. The use of chemical fertilizers in the Dakhleh Oasis varies from farmer to farmer, particularly because many of them do not have much disposable income for purchasing chemical fertilizers. As a result, the actual amount of chemical fertilizer used by each farmer will vary, thus varying the amount of ^{15}N in the soil.

8.9.3 Archaeological versus Modern Botanical Remains

There is a distinction between both $\delta^{13}C$ and $\delta^{15}N$ values when archaeological and modern botanical remains are compared (Figure 7.26). With the exception of the two sorghum samples, the archaeological botanical remains are enriched in ^{13}C in comparison to the modern sample. The mean $\delta^{13}C$ values for modern C_3 plants is – 27.6‰, and the mean $\delta^{13}C$ value for archaeological C_3 plants is –23.27‰, a difference of 4.33‰. Changes in climatic or soil conditions, particularly changes in humidity, have been observed to cause variations in the $\delta^{13}C$ of plants. Factors such as drought, increasing aridity or salinity will result in plants not discriminating against ^{13}C uptake, resulting in ^{13}C enrichment, and more positive $\delta^{13}C$ values (Francey and Farquhar 1982; Brugnoli and Lauteri 1991; Gordon et al. 1992). Water stress causes stomatal closure in plants, therefore dramatically reducing CO_2 uptake, which then causes an enrichment in ^{13}C. Yakir et al. (1994) observe differences in the magnitude of 3‰ in $\delta^{13}C$ between ancient tamarix trees and their modern counterparts. The ancient tamarix trees were depleted in ^{13}C in comparison to the modern sample. They found similar differences when comparing the $\delta^{13}C$ values of tamarix trees from the Negev desert and those from the

more temperate climate of central Israel. The authors conclude that the tamarix trees from ancient Masada grew in less arid climatic conditions than occur in modern times. If the data presented by Yakir et al. (1994) are used as a guide, the $\delta^{13}C$ data from the modern and archaeological botanical remains from the Dakhleh Oasis suggest that the environment during the Romano-Christian period was more arid than it is today. This is quite surprising, given the aridity of the modern environment of the Dakhleh Oasis, which has a mean daily temperature of 24°C, and humidity ranging from 23 to 30% from March to September, and 33 to 50% from October to February (Doering and Gericke 1984). It is highly unlikely that the climate was more arid during the Romano-Christian period; if anything, it may have been slightly more humid.

Increasing salinity can produce an enrichment in ^{13}C in plants. Salinity effectively reduces the amount of water available to plants because the concentration (i.e., chemical activity) of water is lowered when salt is dissolved in it. Plants do not absorb salt, however, and it just stays in the soil. The net result is the same as lowering the water supply – there is stomatal closure and increased ^{13}C enrichment. Guy and colleagues (1980) report the $\delta^{13}C$ values for two species of C_3 plants grown under controlled and natural situations. They found that increasing $\delta^{13}C$ values were strongly correlated with increasing salinity in the soil. In natural conditions, as salinity increased shifts in $\delta^{13}C$ values from 5.3‰ to 3.4‰ were reported. In controlled situations, shifts in $\delta^{13}C$ from 8.0‰ to 10.8‰ were recorded. Brugnoli and Lauteri (1991) found that under controlled conditions of increasing salinity, both cotton and bean plants were increasingly

enriched in ^{13}C. In some species of plants high concentrations of salt in the soil reduces photosynthesis (also because of stomatal closure) as a result of mesophyll resistance to CO_2 fixation, resulting in an enrichment in ^{13}C (Longstreth and Nobel 1979). This is a more likely explanation for the difference encountered between modern and archaeological plant remains from the Dakhleh Oasis. It is likely that the fields surrounding Kellis gradually acquired high levels of salt, a common problem in the desert oasis environments (A. Mills, pers. comm., 1999). Increasing salinity in the fields around Kellis, in fact, may have contributed to the ultimate demise of the village of Kellis. Possible causes of site abandonment have centered around failing water supplies, sand encroachment, external threats (Hope 1985), or general reductions in population (Mills 1985). The possibility of field degradation resulting from increasing levels of salinity has not been considered as a possible contributor to site abandonment. Increasing salinity in crop fields would have been a serious problem, as eventually the fields would have been unusable and there would not have been sufficient food to sustain a large population. Although this probably was not the sole reason for abandoning Kellis in the 4th century AD, it could have been a very important consideration.

There is also a clear separation in $\delta^{15}N$ values between modern and archaeological botanical remains (Figure 7.26) and a statistically significant difference between the two samples. Archaeological botanical remains are enriched in ^{15}N compared to the modern sample. There is a difference of approximately 12‰ in $\delta^{15}N$ values between these two groups. As was discussed in section 8.8.3, the use of chemical fertilizers has

resulted in modern plant $\delta^{15}N$ values being isotopically lighter in ^{15}N in comparison to archeological plant remains (DeNiro 1987). The present use of chemical fertilizers in the Dakhleh Oasis may account for this (M. Woidich, pers. comm.). The level of post-depositional degradation that the archaeological botanical remains may have experienced must also be considered. DeNiro and Hastorf (1985) found that the $\delta^{15}N$ of uncarbonized plant remains more closely resembled their modern counterparts. Uncarbonized remains were found to be significantly enriched in ^{15}N, indicating that some level of fractionation occurred in the post-depositional environment. It is unknown whether the archaeological botanical remains from Kellis are affected in a similar manner, but it seems clear from the animal and human values that there probably was minimal degradation, if any, in this sample.

8.10 Putting it all together: a Consideration of the Documentary, Archaeological and Stable Isotope Evidence for Diet

In chapter 4 the documentary and archaeological evidence for food was discussed in terms of a menu of foods that would have been available for consumption by the inhabitants of the Dakhleh Oasis. This chapter has focused on the direct evidence for diet using stable isotope analysis. All three of these lines of evidence present complementary information regarding diet; taken separately they do not provide the same information.

If dietary information was constructed from the Kellis Agricultural Account

Book and other papyrological sources alone, the menu of foods would reflect a diet based solely on C_3 foods (i.e., wheat/barley, fruits, cow and goat). Both the archaeological and stable isotope evidence indicate that by the Roman period, millet (a C_4 plant) was present in Kellis. It is important to note that there is no documentary evidence for the presence of millet in Kellis during this time. This is an important discrepancy between the various lines of evidence, and reinforces the need to integrate as many sources as possible.

The archaeological and stable isotope evidence for diet are very similar. The archaeological botanical and faunal remains reflect a diet largely based on C_3 foods, with the addition of millet. Millet was not identified as part of the botanical repertoire prior to the 1998/1999 excavation season. A previous suggestion that the stable isotope data revealed the presence of a C_4 food in the diet was met with skepticism by various members of the Dakhleh Oasis Project because there had been no C_4 plants identified to that point. After several kilograms of millet were identified, the stable isotope data became more acceptable. This tends to be a problem when only one line of evidence is considered. When dealing with archaeological evidence it is important to remember that "Absence of proof is not proof of absence" (Sagan 1977).

Although each line of evidence has its inherent strengths and weaknesses, when taken together the archaeological, documentary and stable isotope data are complementary sources of information that form an overall picture of diet. Where documentary evidence provides important information about quantity and relative value of

different food commodities, archaeological data provides direct evidence for foods that were actually consumed in the Oasis. Stable isotope data detect changes in diet over time, and differences in diet between age and sex categories. When all these independent sources are used in conjunction, the picture formed about diet is much stronger than if each were just considered independently.

8.11 Summary

The main thrust of this chapter was to examine the carbon and stable isotopes values of the human, animal and plant samples from the Dakhleh Oasis over time and between subgroups and to consider the results in relation to the menu developed in Chapter 4. Consideration of individual cemetery samples revealed dietary differences between children under 2 and adult constituents of the population in both the 'ein Tirghi and Kellis 2 cemeteries. There were also differences in diet between adult males and females in the Kellis 2 population, with males being enriched in ^{13}C in comparison to females. Data from the Kellis 2 infants revealed that they were introduced to supplementary food, most probably either cow or goat milk, at an early age. The weaning process was gradual, beginning by 6 months of age and ending around 3 years of age.

Differences in $\delta^{13}C$ were found between Kellis 2 and Kellis 1, and also between Kellis 1 and 'ein Tirghi. Individuals from 'ein Tirghi and Kellis 2 had similar $\delta^{13}C$ values, calling into question the dating of the 'ein Tirghi cemetery. The $\delta^{13}C$ values of individuals from these two cemeteries suggest that they had a high percentage of C_4 foods in their diet. For Kellis 2 this finding is supported by archeological evidence

for the presence of millet in the Dakhleh Oasis during the Romano-Christian period. It was therefore surprising that individuals from 'ein Tirghi, who had been dated to the Third Intermediate Period (ca. 800 BC), had values similar to individuals from Kellis 2, given that there were no C_4 plants in the Oasis at that time. This finding once again brings to question the dating of the tomb, suggesting the possibility of either tomb re-use or continual familial use over generations.

Hair samples from Kellis 1 and Kellis 2 failed to reveal seasonal differences in diet, in contrast to what has been documented for Nubian populations to the south (White and Schwarcz 1994).

A comparison of $\delta^{13}C$ and $\delta^{15}N$ values from modern and archaeological faunal and botanical remains was also revealing. Archaeological faunal and botanical remains are enriched over in ^{13}C in comparison to modern faunal and botanical remains. A common problem faced by farmers in a desert environment is increasing soil salinity. Increasing salinity has been correlated with enrichment in ^{13}C. It is possible that the fields around Kellis suffered from increasing salinity, contributing to the eventual demise and abandonment of the site in the 4th century AD. The pattern illustrated in the botanical $\delta^{13}C$ values is consistent with the $\delta^{13}C$ values of the faunal remains. $\delta^{15}N$ values are also significantly different between these two groups. Archaeological botanical remains are enriched in ^{15}N compared to modern plants. This enrichment, which is also reflected in the faunal remains, may be due to the lack of chemical fertilizers or fractionation that occurred in the post-depositional environment.

Chapter 9
Conclusions

9.1 Important Isotopic Findings

The isotopic analyses conducted for this dissertation revealed many significant results. Isotopic data analysed by sex for the 'ein Tirghi cemetery revealed no significant differences in the diets of adult males and females. Children under 2 were enriched in both ^{13}C and ^{15}N compared to adults. Children under 2 years of age were expected to be enriched in ^{15}N; however the enrichment in ^{13}C was surprising as no foods enriched in ^{13}C have so far been identified in the archaeological or documentary evidence. These isotopic data suggest that this tomb may have been reused over the centuries, or was in continual use by one family, calling into question its date of 800 BC.

Although sample size and poor preservation hampered evaluations of sex and age effects in the Kellis 1 cemetery, no such problems were found at Kellis 2. At Kellis 2 there is a noticeable difference in $\delta^{13}C$ between adult males and females, with males being more enriched in ^{13}C. $\delta^{13}C$ values, in combination with archaeological evi-

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dence suggests that millet, a C_4 plant, was introduced to the Dakhleh Oasis during the Roman period. In addition to millet, both cows and goats were enriched in ^{13}C. This provides an isotopic label for meat that suggests that males may have eaten diets richer in the flesh of cows and/or goats than did females. $\Delta^{13}C_{apatite-collagen}$ also revealed a detectable difference in diet between adult males and females, suggesting that males ate more meat, and females eating a more vegetarian diet; however, the sample size is too small to make any definitive statements.

Comparisons between age categories revealed some striking results for young children. Children under two years of age were found to be significantly enriched in both $\delta^{15}N$ and $\delta^{13}C$ values in comparison to adults. Although the enrichment in ^{15}N was expected, the enrichment in ^{13}C is very unusual. This suggests that ^{13}C enriched supplementary foods were introduced before 6 months of age. As the only identified foods enriched in ^{13}C were millet, and the flesh of goats and cows, infants were most likely fed cow's and/or goat's milk. The $\delta^{13}C$ data, taken in conjunction with the $\delta^{15}N$ data, indicate that the weaning process was gradual – children were introduced to supplementary foods by 6 months of age, and completely weaned by 3 years of age. This finding is important as the sample size for children is quite large in comparison to other studies that attempt to reconstruct breastfeeding and weaning patterns in past populations (i.e., Schurr 1997; 1998). The sample size used in this research is large enough to illustrate any possible variation in breastfeeding and weaning practices.

The isotopic results further indicate that C_4 foods were introduced by the

Roman period. The archaeological evidence supports this finding, with the identification of pearl millet at the site of Kellis. It should be noted, however, that the KAB did not record the presence of millet at Kellis. This is an important point, as it demonstrates the necessity of multiple lines of evidence when reconstructing diet. The introduction of millet into the Oasis during the Roman period is a reflection of the increase in foreign trade experienced in greater Egypt during the Ptolemaic and Roman periods. This finding disputes the idea that the Oasis was an insular community, and this area was not isolated, either genetically or socially.

The marked ^{13}C enrichment in archaeological C_3 plants in comparison to modern C_3 plants is a significant finding. It suggests that the agricultural fields surrounding Kellis had accumulated high levels of salt during the Roman period. Increasing salinity would have limited farmers' ability to produce enough food to support the population at Kellis. Although it may not have been the only factor that contributed to the ultimate demise and abandonment of this site in the 4th century AD, increasing salinity and concomitant reduced productivity of the land could have been an important factor. There is no direct evidence of salination of soils here, but this is a common problem where desert soils are under cultivation.

9.2 Contributions to Isotopic Studies of Paleodiet

The research and results presented in this dissertation make several valuable contributions to the literature concerning isotopic paleodietary studies. When dietary reconstruction is attempted using stable isotope analysis, there is rarely substantial ar-

chaeological or documentary evidence against which to compare the results. One unique aspect of this study was the opportunity to combine the results of the stable isotope analysis with both archaeological and documentary evidence for diet. Other studies have attempted to utilize historical documentation in addition to stable isotope analysis to reconstruct dietary practices (i.e., Katzenberg and Pfeiffer 1995); however, none have had the opportunity to integrate associated historical documentation such as the KAB, nor have they had access to exceptionally well preserved faunal and botanical remains.

The combination of infant $\delta^{15}N$ and $\delta^{13}C$ values also tell a story that has never been documented before using stable isotope analysis. Past studies in stable isotope analysis have used child $\delta^{15}N$ values to determine breast feeding and weaning practices in prehistory (e.g., Schurr 1998; Katzenberg and Pfeiffer 1995). Because of the special circumstances of feeding practices in the Dakhleh Oasis during the Roman period, for the first time it has been possible to use $\delta^{13}C$ values to describe the supplementary foods introduced during weaning.

This research also contributes to our knowledge about stable isotope analysis in arid environments. Few studies have used stable isotope analysis to reconstruct the diet of individuals who lived in arid environments; in addition, it is unusual to be able to analyse each level of the food chain in arid environments (Ambrose 1991; Ambrose and DeNiro 1987; Aufderheide et al. 1988; Heaton 1987; Heaton et al. 1986). The $\delta^{15}N$ values for the entire food chain suggest that the trophic level effect is main-

tained, despite the elevated values. In addition, the very high human $\delta^{15}N$ values at Dakhleh make it possible to identify possible migrants into the Oasis from other locations such as the Nile Valley or elsewhere in the Mediterranean. This once again speaks to the issue of isolation, and indicates that the Dakhleh Oasis was not an isolated geographical area. Entwined in this whole issue is also the intriguing fact that two individuals diagnosed with lepramatous leprosy have $\delta^{15}N$ values which indicate that they were migrants to the Oasis. This issue will be explored further in section 9.4

9.3 Contributions to Anthropology

Diet and food choices are intimately connected to almost every aspect of social life. This study has revealed important social factors and cultural practices that existed at the Dakhleh Oasis, and also demonstrates that isotopic studies in paleodiet are site and culture specific. It was shown in the Kellis 2 cemetery sample, for instance, that adult males and females most likely consumed different diets. This dietary difference may reflect social conditions during this period, indicating that males may have had preferential access to meat, while the female diet was comprised mainly of grains. The reconstruction of the feeding practices of children under two from the Kellis 2 cemetery sample also reveals ideas about appropriate breast feeding and weaning behaviour, as well as information on the types of food used to supplement breast feeding. The high human nitrogen values also make it possible to identify possible migrants to the Oasis. This speaks to the issue of the Dakhleh Oasis being socially and genetically isolated – the Oasis appears to have been open to trade and migration. This finding im-

pacts on future interpretations of the Oasis' history.

9.4 Future Research Considerations

Future stable isotope analysis research at the Dakhleh Oasis will include:

1) investigating weaning practices using the teeth of children and adults; 2) expanding

the sample size for the analysis of $\delta^{13}C$ of apatite; and 3) initiating a combined study of

$\delta^{15}N$ values, pathological characteristics and DNA evidence in relation to possible mi-

gration patterns. A very interesting pattern was revealed when Kellis 2 infant $\delta^{13}C$ and

$\delta^{15}N$ values were examined. These values suggest that the weaning process began very

early (before 6 months of age) and lasted until approximately 3 years of age. This sam-

ple and these data may be the result of a mortality bias (Wood et al. 1992) - children

may have been sick and thus fed in a different manner than healthy children. If this

were the case, then the feeding practices and weaning process documented for this sam-

ple would represent only a small portion of children at Dakhleh. One of the ways to test

for this bias would be to reconstruct the weaning process from individuals who survived

childhood. This is best attacked by examining the $\delta^{13}C$ of enamel from teeth that were

developing during the infant period (after Wright and Schwarcz 1998). Enamel is a

static tissue and does not turn-over; hence, it houses a permanent record of the diet that

was consumed while the enamel was forming. Because teeth form at different times,

the examination of successively forming teeth should reveal weaning patterns. This

pattern may also be detected by analyzing the $\delta^{13}C$ and $\delta^{15}N$ of the organic portion of

dentine. Dentine is not as static as enamel, but the turn-over rate is extremely slow,

thereby representing a snap-shot of an individual's diet.

An expansion of the size of the sample of individuals analysed for $\delta^{13}C$ apatite will also be attempted in order to be able to be able to make definitive statements about differences in diet between males and females. The $\delta^{13}C$ of collagen revealed that males were enriched in ^{13}C in comparison to females. If this difference reflects the fact that males were eating more meat, particularly cow or goat, while females were eating proportionally more C_3 grains, then this discrepancy should be more clearly defined by studying the $\Delta^{13}C_{apatite-collagen}$ between males and females.

Another fascinating finding of this study is that $\delta^{15}N$ values can potentially be used to identify migrants to the Oasis. One of the individuals who had substantially lower $\delta^{15}N$ values displayed the typical characteristics of lepramatous leprosy. Preliminary DNA studies also identified this individual as genetically distinct from the rest of the population. It has been surmised that the Oasis may have been used either as a safe haven for individuals suffering from disease, or that it may have been a location to which individuals stricken with this type of disease may have been banished. In addition to the two individuals diagnosed with leprosy in this study, there are three other individuals diagnosed with leprosy in Kellis 2 (E. Molto, pers. comm.). Dzierzykray-Rogalski (1978) reports the identification of four male crania from a Pharaonic period site near Balat in the Dakhleh Oasis that have the characteristic pathological changes associated with leprosy. It does not appear that the occurrence of leprosy in the Oasis is a random event. A logical progression of this research would be a marriage of the stable

isotope data with DNA evidence and pathological characteristics in order to determine

if there are any detectable patterns indicating that migrants were outcasts from other

geographical locations. Other isotopic markers of origin can also be investigated, spe-

cifically, $\delta^{18}O$ of bones and teeth (Stuart-Williams et al. 1998; White et al. 1998).

Appendix A:

Chronology of Egyptian Rulers From the 3rd Intermediate to the Byzantine Period (1069 BC – AD 395)

(based on Bagnall 1993; Wells 1992; and Darby et al. 1977)

Date	Period	Dynasty	Ruler
1069-702 BC	3rd Intermediate		
1070-1055 BC		Dynasty XXI	
1069-1043 BC		Dynasty XXI	Smendes
1054-1032 BC		Dynasty XXI	
1054-1046 BC		Dynasty XXI	
1045-992 BC		Dynasty XXI	
1043-1039 BC		Dynasty XXI	Amenemnisu
1039-993 BC		Dynasty XXI	Psusennes I
993-984 BC		Dynasty XXI	Amenemope
992-990 BC		Dynasty XXI	
990-969 BC		Dynasty XXI	
984-978 BC		Dynasty XXI	Osorkon the Elder
978-959 BC		Dynasty XXI	Siamun
969-945 BC		Dynasty XXI	
959-945 BC		Dynasty XXI	Psusennes II
945-924 BC		Dynasty XXII	Shoshenq I
924-889 BC		Dynasty XXII	Osorkon I
890-889 BC		Dynasty XXII	Shoshenq II
889-874 BC		Dynasty XXII	Takelot I
870-860 BC		Dynasty XXII	Harsiese
874-850 BC		Dynasty XXII	Osorkon II
850-825 BC		Dynasty XXII	Takelot II
825-773 BC		Dynasty XXII	Shoshenq III
825-773 BC		Dynasty XXIII	Pedubastis I
787-759 BC		Dynasty XXIII	Osorkon III
773-767 BC		Dynasty XXII	Pimay
764-757 BC		Dynasty XXIII	Takelot III
767-730 BC		Dynasty XXII	Shoshenq V
757-754 BC		Dynasty XXIII	Rudamon
754-715 BC		Dynasty XXIII	Iuput II
747-525 BC	Late Period		
747-716 BC		Dynasty XXV	Piankhy
727-716 BC		Dynasty XXIV	Tefnakht
716-715 BC		Dynasty XXIV	Bocchoris
716-702 BC		Dynasty XXV	Shabaka
702-690 BC		Dynasty XXV	Shebitku
690-664 BC		Dynasty XXV	Taharqa
672-664		Dynasty XXVI	Necho I
664-		Dynasty XXV	Tantamani

Date	Period	Dynasty	Ruler
664- - 656 BC		Dynasty XXVI	Psammetichus
610-595 BC		Dynasty XXVI	Necho II
595-589 BC		Dynasty XXVI	Psammetichus II
589-570 BC		Dynasty XXVI	Apries
570-526 BC		Dynasty XXVI	Amasis
526-525 BC		Dynasty XXVI	Psammetichus III
525-404 BC	1st Persian Period		
525-522 BC		Dynasty XXVII	Cambyses II
522-486 BC		Dynasty XXVII	Darius I
486-465 BC		Dynasty XXVII	Xerxes I
465-424 BC		Dynasty XXVII	Artaxerxes I
424-405 BC		Dynasty XXVII	Darius II
405-359 BC		Dynasty XXVII	Artaxerxes II
404-399 BC		Dynasty XXVIII	Amyrtaeus
399-393 BC		Dynasty XXIX	Nepherites I
393 BC		Dynasty XXIX	Psammuthis
393-380 BC		Dynasty XXIX	Achoris
380 BC		Dynasty XXIX	Nepherites II
380-362 BC		Dynasty XXX	Nectanebo I
362-360 BC		Dynasty XXX	Tachos
360-343 BC		Dynasty XXX	Nectanebo II
343-332 BC	2nd Persian Period		
343-338 BC		Dynasty XXX	Artaxerxes III Ochos
338-336 BC		Dynasty XXX	Arses
336-332 BC		Dynasty XXX	Darius III Codoman
333 BC		Dynasty XXX	Khababash
332-304 BC	Macedonian Dynasty		
332-323 BC			Alexander the Great
323-316 BC			Philip Arrhidaeus
316-304 BC			Alexander IV

Date	Period	Dynasty	Ruler
304-30 BC	Ptolemaic Period		
323-285 BC			Ptolemy I (Soter I, Lagides)
285-247 BC			Ptolemy II (Philadelphus I)
247-221 BC			Ptolemy III (Euergetes I)
221-205 BC			Ptolemy IV (Philopater)
205-181 BC			Ptolemy V (Ephipanes)
181-145 BC			Ptolemy VI (Philometor)
169-116 BC			Ptolemy IX (Euergetes II)
130-101 BC			Cleopatra II
116-80 BC			Ptolemy X (Soter II, Lathyros)
108-88 BC			Ptolemy XI (Alexander I)
80 BC			Ptolemy XII (Alexander II)
80-51 BC			Ptolemy XIII (Neos Dionysos)
51-48 BC			Ptolemy XIV
48-44 BC			Ptolemy XV
51-44 BC			Cleopatra VII
27BC - AD395	Roman Period		
27 BC-AD 14		Julio-Claudian dynasty	Augustus
AD 14-37		Julio-Claudian dynasty	Tiberius
AD 37-41		Julio-Claudian dynasty	Gaius (Caligula)
AD 41-54		Julio-Claudian dynasty	Claudius
AD 54-68		Julio-Claudian dynasty	Nero
AD 68-69		'year of the 4 emperors'	Galba

Date	Period	Dynasty	Ruler
AD 69		'year of the 4 emperors'	Otho
AD 69		'year of the 4 emperors'	Vitellius
AD 69-79		'year of the 4 emperors' Flavian dynasty	Vespasian
AD 78-81		Flavian dynasty	Titus
AD 81-96		Flavian dynasty	Domitian
AD 96-8			Nerva
AD 98-117			Trajan
AD 117-138			Hadrian
AD 138-161			Antoninus Pius
AD 161-180			Marcus Aurelius
AD 161-169			Lucius Verus (co-emperor)
AD 178-193			Commodus (178-80 co-emperor with his father)
AD 193			Pertinax
AD 193			Didius Julianus
AD 193-211			Septimius Severus
AD 198-217			Caracalla (198-211, co-emperor with his father)
AD 209-212			Geta (209-11, co-emperor with father and brother; 211-12, with brother alone)
AD 217-218			Macrinus
AD 218-222			Elagabalus
AD 222-235			Severus Alexander
AD 235-238			Maximinus
AD 238-284			(about 20 emperors)
AD 284-305			Diocletian and colleagues
AD 395- 642	Byzantine Period		

Appendix B:

Egyptian Nomes in 4th Century AD[*]

(based on Bagnall 1993)

[*]Nome names, areas and boundaries have changed
continually through history

Nome	Greek Capital Name	Modern Capital Name	Geographical Area
UPPER EGYPT			
Ombite	Ombos	Kom Ombo	72 km^2
Apollonopolite	Apollonopolis Magna	Edfu	137 km^2
Latopolite	Latopolis	Esna	225 km^2
Hermonthite	Hermonthis	Armant	Unknown
Diosplite/Theban	Diospolis/Thebes	Luxor	284 km^2
Koptite	Koptos	Qift	331 km^2
Tentyrite	Tentyra	Dendera	300 km^2
Diospolite Parva	Diospolis Parva	Hiw	306 km^2
Great Oasis	Kysis		
Thinite	Thinis	El Birba	613 km^2
Panopolite	Panopolis	Akhmim	575 km^2
Antaiopolite	Antaiopolis	Qaw el-Kebir	531 km^2
Hypselite	Hypsele	Shutb	125 km^2
Apollonopolite Parva	Apollonopolis Parva		206 km^2
Lykopolite	Lykopolis	Asyut	250 km^2
Koussite	Koussai	El-Qusiya	272 km^2
Hermopolite	Hermopolis	El-Ashmumein	1140 km^2
Antinoite	Antinoopolis	Sheikh Ibada	
Kynopolite	Kynopolis	Sheikh Fadl	110 km^2
Oxyrhynchite	Oxyrhynchos	El-Bahnasa	780 km^2
Herkleopolite	Herkleopolis	Ihnasya el-Medina	643+ km^2
Arsinoite	Arsinoe	Medinet el-Fayum	900 km^2
Nilopolite	Nilopolis	Unknown	133 km^2
Aphroditopolite	Aphroditopolis	Atfih	200 km^2
LOWER EGYPT			
Memphite	Memphis		281 km^2

Appendix C:

Weights and Measures

(based on Bagnall 1993)

Weights and Measures

Artabas: the unit used to measure commodities such as wheat, barley and other dry goods. According to Rathbone (1983) an artaba of wheat weighed the equivalent of approximately 30 kilograms. Bagnall (1993) reports that the common artabas was equal to about 38.78 liters.

Matia: It is commonly reported that 10 matia make up one artaba. However, Bagnall (1997) that 23 matia were equal to one artaba in the Kellis Agricultural Account Book.

Sextarius: approximately 0.546 liters.

Roman pound: about 327 grams.

Appendix D:

'ein Tirghi Cemetery Sample

Data

| ID	Chamber	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	C:N ratio	% yield
5	1	0	unknown	-	14.9	3.12	5.12
39	2	0	unknown	-18.79	18.3	3.15	18.47
20	1	0.5	unknown	-17.98	18.6	3.65	22.37
30	2	0.75	unknown	-	20.3	-	0.70
1	1	2	unknown	-18.67	19.7	3.33	0.75
40	2	2	unknown	-16.84	21.6	3.31	18.03
21	1	6	unknown	-	14.7	-	22.39
3	1	11	unknown	-18.65	16.6	3.18	13.18
2	1	12	unknown	-17.39	15.4	3.28	15.41
6	1	26	Male	-19.03	-	3.19	22.76
24	1	22	Male	-19.11	17.6	3.21	11.31
4	1	26	Male	-18.98	18.1	-	-
25	1	26	Male	-	17.3	-	6.87
19	1	28	Male	-18.93	17.5	3.29	2.41
16	1	29	Male	-19.26	15.2	3.38	17.19
10	1	29	Male	-19.27	15.8	3.25	20.24
12	1	29	Male	-19.01	17.4	3.67	15.99
14	1	29	Male	-19.04	18.6	3.26	9.02
37	2	29	Male	-19.11	16.6	3.3	28.55
31	2	35	Male	-19.21	17.2	3.37	19.13
36	2	35	Male	-19.09	18.9	3.61	7.23
7	1	35	Male	-19.04	17.2	3.38	25.44
28	2	35	Male	-18.97	15.8	3.47	3.33
23	1	16	Female	-	18.4	-	18.24
29	2	20	Female	-18.82	17.1	3.26	9.73
33	2	25	Female	-19.01	16.8	3.31	30.54
32	2	25	Female	-18.96	16.7	3.34	26.16
38	2	30	Female	-19.44	15.3	3.38	8.18
9	1	32	Female	-18.56	19.3	3.29	46.98
8	1	32	Female	-18.99	16.9	3.30	1.45

ID	Chamber	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	C:N ratio	% yield
13	1	38	Female	-19.31	16.7	3.31	-
35	2	48	Female	-19.43	16.6	3.11	14.41
34	2	48	Female	-19.39	16.5	3.32	26.98
11	1	55	Female	-19.01	15.7	3.19	24.52
18	1	55	Female	-18.93	16.9	3.38	6.54
27	2	55	Female	-19.17	16.6	3.35	-

Appendix E:

Kellis 1 Cemetery Sample Data

Tomb	Burial	Age	Sex	$\delta^{13}C$	$\delta^{13}C_{ap}$	$\delta^{15}N$	$\delta^{18}O$	C:N ratio	% yield
2	Body B	45	F	-19.41	-	17.86	-	3.21	10.74
2	Body D	45	M	-19.31	-	18.37	-	3.18	20.41
2	Body D	45	M	-19.50	-13.74	18.03	-3.44	-	60.69
2	Body E	5.5	M	-19.96	-	18.24	-	3.41	20.13
2	Body P	45	F	-19.46	-13.18	18.18	-4.25	3.28	17.03
3	Body A	13	M	-19.6	-14.42	18.48	-2.28	-	20.28
3	Body B	25	M	-19.59	-13.13	18.44	-4.32	3.24	19.26
3	Body C	9.5	?	-19.74	-	17.88	-	3.18	20.21
3	Body D	-	-	-19.17	-14.31	18.17	-4.76	3.53	26.53
3	Body H	23.5	M	-19.94	-12.46	17.75	-4.55	3.34	18.38
3	Body J	11.5	?	-19.75	-13.68	18.32	-1.69	3.59	8.76
3	Body K	48	F	-19.60	-13.66	18.35	-2.40	3.48	19.88
3	Body N1	15	M	-19.30	-11.87	18.00	-6.11	3.26	20.10
3	Body N2	9	?	-19.92	-12.51	18.47	-4.61	-	18.68
3	Leg O	-	-	-19.87	-13.45	19.52	-3.34	3.72	16.03
4	Body E	19	F	-19.78	-13.59	19.16	-2.22	3.27	13.12
8	Body 4	25	F	-19.47	-14.14	18.55	-4.03	3.47	19.13
8	Body 5	30	F	-19.00	-	17.73	-	3.29	20.72
10	body 6	-	-	-19.32	-	24.06	-	-	2.18
12	Body 1	-	-	-19.84	-12.87	17.38	-5.20	-	19.69
13	1	-	-	-19.59	-	14.12	-	-	14.10
13	2	-	-	-19.66	-14.25	18.05	-2.00	-	14.29
13	3	-	-	-18.92	-	17.28	-	-	19.87
13	4	-	-	-16.95	-	15.95	-	-	12.76
13	5	-	-	-18.57	-	16.16	-	-	13.18
13	6	-	-	-20.14	-	17.47	-	-	10.12
13	7	-	-	-16.59	-10.64	18.28	-4.67	-	16.62
13	8	-	-	-19.54	-	17.11	-	-	20.03
13	9	-	-	-15.97	-	15.87	-	-	17.11
13	10	-	-	-19.67	-	17.21	-	-	16.82
13	11	-	-	-19.95	-	13.05	-	-	13.13
13	12	-	-	-19.91	-	18.10	-	-	16.96

| Tomb	Burial	Age	Sex	$\delta^{13}C$	$\delta^{13}C_{ap}$	$\delta^{15}N$	$\delta^{18}O$	C:N ratio	% yield
13	13	-	-	-19.87	-	17.63	-	3.25	4.13
13	14	-	-	-20.01	-	17.04	-	3.44	16.54
13	15	-	-	-20.08	-	16.90	-	3.54	16.77
13	16	-	-	-20.14	-	16.15	-	3.51	12.95
13	17	-	-	-20.07	-	17.86	-	-	13.64
13	18	-	-	-19.51	-	18.78	-	-	19.93
13	19	-	-	-17.01	-	16.57	-	3.37	15.48
13	20	-	-	-19.48	-	19.95	-	3.34	17.77
13	21	-	-	-19.10	-	17.66	-	3.31	6.95
17	7	-	-	-19.38	-	18.64	-	3.20	18.32

Appendix F:

Kellis 2 Cemetery Sample Data

Burial	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C_{sp}$	$\delta^{18}O$	C:N ratio	% yield
B006	29	M	-18.87	16.95	-	-	3.17	17.36
B042	46	M	-18.54	19.10	-	-	3.16	12.18
B043	5	unknown	-18.60	17.06	-12.49	-3.14	3.17	13.71
B044	63	F	-19.30	18.90	-12.84	-6.07	3.34	14.87
B045	1.5	unknown	-17.96	21.12	-12.55	-2.70	3.18	15.19
B046	1.5	unknown	-18.50	19.99	-12.43	-1.04	3.15	16.47
B047	0.75	unknown	-18.38	21.70	-13.71	-1.26	3.28	2.74
B048	1.75	unknown	-18.27	21.33	-	-	3.52	19.56
B049	7	unknown	-18.86	16.59	-12.36	-1.10	3.18	13.33
B050	7	unknown	-18.60	18.37	-13.31	1.21	3.51	19.01
B051	0	unknown	-18.72	19.34	-	-	3.45	4.80
B052	30	F	-19.06	17.65	-12.78	-4.59	3.16	14.11
B053	38	F	-18.65	18.39	-11.82	-5.63	3.52	15.23
B054	0	unknown	-19.62	20.04	-	-	-	1.81
B057	0	unknown	-21.85	19.14	-	-	3.31	3.29
B058	48	F	-18.84	17.56	-13.70	-3.58	3.49	20.94
B059 T	46	M	-18.58	16.65	-	-	3.16	18.21
B060 T	37	M	-18.71	18.25	-	-	3.25	17.4
B061 T	0	unknown	-18.57	22.01	-	-	3.29	7.71
B062 T	0.25	unknown	-18.57	21.75	-	-	3.29	3.84
B063 T	0.5	unknown	-17.94	21.70	-	-	3.28	18.32
B064 T	7	unknown	-19.01	18.00	-	-	3.26	0.079
B066	13	unknown	-18.78	18.23	-	-	3.06	4.41
B067 T	11	unknown	-18.63	20.56	-	-	3.28	0.27
B068 T	31	F	-18.92	18.80	-	-	3.21	0.16
B069 T	28	M	-18.76	19.35	-	-	3.26	0.27
B070 T	1.5	unknown	-17.79	21.61	-	-	3.26	0.22
B071 T	3	unknown	-17.64	20.12	-	-	3.20	0.17
B072 T	60	F	-18.88	19.75	-	-	3.25	0.21
B073 T	38	F		20.28	-	-	3.28	18.65
B074 T	1.25	unknown	-18.47	21.06	-	-	-	2.71
B075 T	0.5	unknown	-18.09	20.41	-	-	3.33	31.24
B076 T	38	F	-18.88	17.55	-	-	3.19	2.38

Burial	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C_{sp}$	$\delta^{18}O$	C:N ratio	% yield
B079 T	55	M	-19.22	19.67	-	-	3.38	-
B080 T	50	F	-18.93	19.74	-	-	3.29	15.35
B081 T	37	M	-18.63	19.44	-	-	3.23	14.51
B082 T	60	F	-18.86	18.73	-	-	3.12	16.28
B085 T	48	F	-19.06	18.27	-	-	3.31	15.81
B086 T	5	unknown	-18.72	18.20	-	-	3.32	14.41
B090 T	15	unknown	-	20.42	-	-	-	1.68
B091 T	56	F	-18.88	19.15	-	-	3.21	21.04
B092 T	0.58	unknown	-19.54	-	-	-	-	1.27
B093	23	M	-18.85	-	-	-	-	-
B094 T	0.5	unknown	-18.16	21.77	-	-	3.53	5.1
B095 T	0.5	unknown	-18.21	22.18	-	-	3.47	6.2
B096 T	0	unknown	-19.32	20.14	-	-	3.54	2.8
B097 T	6	unknown	-19.02	17.79	-	-	3.16	21.79
B098 T	7.5	unknown	-18.81	18.69	-	-	3.26	7.04
B100 T	1.75	unknown	-18.23	19.96	-	-	3.35	10.73
B101	6	unknown	-18.42	19.03	-	-	3.26	13.51
B102 T	0.5	unknown	-19.80	-	-	-	-	1.58
B103 T	0.5	unknown	-18.23	20.42	-	-	3.25	9.02
B105	57	F	-19.03	19.47	-	-	3.27	19.10
B106 T	0.5	unknown	-18.15	20.55	-	-	3.14	12.61
B107 T	28	M	-18.33	17.75	-	-	3.27	21.07
B108 T	2	unknown	-18.37	19.65	-	-	3.24	16.21
B111	35	M	-18.79	16.19	-	-	3.19	21.38
B112 T	0.5	unknown	-19.79	-	-	-	-	0.67
B113 T	0.75	unknown	-19.12	-	-	-	-	0.85
B114	61	M	-19.03	16.77	-	-	3.45	20.23
B115 T	0.5	unknown	-20.16	-	-	-	-	1.62
B116	23	M	-18.82	14.50	-	-	3.17	20.40
B117-T	0.5	unknown	-18.34	23.18	-	-	-	9.15
B119	37	M	-19.17	17.57	-	-	3.16	18.82
B124	27	M	-18.64	18.68	-	-	3.06	21.3
B129	4	unknown	-18.87	20.19	-	-	3.52	15.86

Burial	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C_{sp}$	$\delta^{18}O$	C:N ratio	% yield
B131	25	F	-19.21	18.03	-	-	3.51	15.34
B132	18.5	M	-19.02	16.28	-	-	3.23	16.01
B135	40	F	-18.99	17.94	-	-	3.51	17.7
B136	29	M	-18.51	17.94	-	-	3.44	17.52
B137	7	unknown	-18.77	18.06	-	-	3.17	17.58
B138	46	M	-18.95	17.36	-	-	-	11.58
B139	29	M	-18.30	17.64	-	-	-	11.70
B140	adult	unknown	-19.06	17.72	-	-	3.12	10.2
B141	40	F	-19.14	17.77	-	-	3.61	12.84
B143	19	M	-18.54	20.06	-	-	3.26	9.52
B144	3	unknown	-18.23	19.34	-	-	3.28	10.97
B145	0.75	unknown	-17.82	19.89	-	-	-	0.84
B146	3	unknown	-18.90	17.15	-	-	3.12	26.14
B149	12	unknown	-18.71	18.13	-	-	3.09	19.36
B155	3.5	unknown	-18.79	19.97	-12.39	-3.53	3.16	22.19
B159	18	F	-19.00	19.04	-	-	3.20	13.91
B160	22	F	-19.21	17.42	-	-	3.15	1.56
B164	0	unknown	-18.95	17.18	-	-	2.97	2.45
B165	55	F	-19.22	16.47	-	-	3.54	16.11
B166	31	F	-19.24	16.03	-	-	3.14	12.04
B167	60	F	-	17.17	-	-	-	-
B168	19	F	-18.87	16.84	-	-	3.35	14.73
B169	25	F	-19.40	18.23	-	-	3.22	14.67
B170	30	F	-19.25	17.95	-	-	3.36	10.02
B172	45	F	-19.37	18.47	-	-	3.53	11.20
B175	3.5	unknown	-18.83	18.24	-	-	3.26	6.11
B177	55	F	-18.92	16.80	-	-	3.48	17.36
B184	22	F	-18.91	17.34	-	-	3.44	18.72
B187	14	unknown	-18.89	17.22	-12.16	-4.33	3.21	20.12
B189	50	F	-18.98	18.78	-12.57	-4.76	3.46	0.91
B190	19	F	-19.12	17.85	-	-	3.45	17.22
B191	48	F	-19.03	17.69	-12.27	-3.40	3.45	17.74
B192	7	unknown	-19.12	18.98	-12.46	-3.38	3.40	21.53

Burial	Age	Sex	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C_{ap}$	$\delta^{18}O$	C:N ratio	% yield
B193	4	unknown	-18.54	20.57	-	-	3.42	19.44
B194	23	M	-19.04	17.04	-	-	3.50	15.39
B195	8.5	unknown	-18.81	17.75	-	-	3.24	18.99
B198	38	F	-19.09	17.28	-	-	3.45	19.68
B199	35	M	-18.81	18.06	-	-	3.22	18.29
B202	66	F	-18.79	17.61	-	-	3.08	15.54
B207	60	F	-19.19	16.64	-	-	3.40	12.51
B208	30	F	-19.11	17.53	-	-	3.20	16.4
B210	54	F	-19.10	17.26	-	-	3.15	15.4
B211	50	F	-19.06	17.21	-	-	3.22	18.25
B213	54	M	-19.15	17.31	-13.55	-3.42	3.54	17.29
B214	23	F	-19.17	19.36	-	-	3.03	15.8
B218	28	M	-18.70	18.59	-	-	3.40	19.31
B220	35	M	-19.02	17.77	-13.30	-3.64	3.25	14.04
B225	35	M	-18.87	17.65	-	-	3.24	5.8
B227	23	M	-18.59	17.18	-	-	3.36	17.31
B228	35	M	-18.57	17.86	-	-	3.36	11.24

Appendix G:

Archaeological and Modern Faunal

Data

Archaeological Faunal Remains

ID	location	Animal	% yield	$\delta^{13}C$	$\delta^{15}N$	C:N ratio
S96.16	D/10 Locus 1 (2)	gazelle	3.37	-17.89	13.18	3.16
S96.145	D/9 gateway central	cow	1.18	-15.67	12.35	-
n/a	C/1 Rm 4 (2B)	goat	13.38	-15.73	13.35	3.13
n/a	C/1 Rm 4 (2B)	cow	1.39	-14.66	13.33	3.62
S97.128	C/1 Rm 3A (1)	chicken	8.45	-18.08	16.08	3.06
S97.184	C/1 Rm 5 (3B)	pig	14.07	-17.40	13.27	3.13
S97.142	C/1 Rm 4 (1A)	donkey	1.73	-18.05	13.25	3.11
S96..152	A/7 East Nave, S.	chicken	2.07	-18.13	16.42	3.09
S97.2	D/8 Rm 12 (3)	chicken	1.18	-18.99	16.03	-

Modern Faunal Remains

ID	location	Animal	% yield	$\delta^{13}C$	$\delta^{15}N$	C:N ratio
modern	canyon	camel	13.18	-10.74	10.28	2.91
modern	Dakhleh	camel	10.98	-17.67	8.55	3.03
modern	Bashendi	cow	8.07	-18.81	4.51	3.33
modern	Bashendi	donkey	7.47	-18.12	5.83	3.35
modern	Bashendi	goat	5.09	-15.73	15.97	3.35
modern	Bashendi	fox	7.99	-19.48	16.21	3.24

Appendix H:

Archaeological and Modern Botanical Data

Archaeological Botanical Remains

Plant	Part sampled	δ¹³C	δ¹⁵N
wheat	shaft	-22.95	16.06
Fava bean	shell	-23.15	12.08
barley	shaft	-23.32	14.36
grape	seeds	-22.46	16.76
olive	seed	-21.91	18.79
date	seed	-22.19	14.91
fig	stem	-23.77	17.82
Doum palm nut	seed	-26.36	11.70

Modern Botanical Remains

Plants	Part sampled	δ¹³C	δ¹⁵N
peas	leaf	-27.83	1.02
sorghum	leaf	-11.75	-0.80
sorghum	seed	-11.31	-1.14
libsan	leaf	-30.03	-6.81
alfalfa	leaf	-27.32	-0.54
courtoum	leaf	-29.03	7.40
rihan	leaf	-28.83	11.05
parsley	leaf	-28.14	2.83
date	pit	-26.07	-
date	fruit	-25.78	-
barley	seed	-25.94	3.42
dill	stem	-29.46	7.84
Ghertah	seed	-31.78	-
rice	seed	-26.68	7.68
peas	seed	-27.68	-0.68
peas	shell	-29.17	-0.71
wheat	seed	-22.91	10.04
turnip	leaf	-25.32	10.36
Gergir	stem	-27.58	-

References Cited

Adair, L.S. (1987) Nutrition in the Reproductive Years. In Johnston (ed.): Nutritional Anthropology. Alan R. Liss, Inc., New York. Pp. 119-154.

Ambrose, S.H. (1986) Stable carbon and nitrogen analysis of human diet in Africa. *Journal of Human Evolution*, vol. 15:707-731.

Ambrose, S.H. (1991) Effects of Diet, Climate and Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs. *Journal of Archaeological Science*, vol.18:293-317.

Ambrose, S.H., Butler, B.M., Hanson, D.B., Hunter-Anderson, R.L., and Krueger, H.W. (1997) Stable Isotopic Analysis of Human Diet in the Marianas Archipelago, Western Pacific. *American Journal of Physical Anthropology*, vol. 104(3): 343-362.

Ambrose, S.H., and DeNiro, M.J. (1986a) Reconstruction of African Human Diet Using Bone Collagen Carbon and Nitrogen Isotope Ratios. *Nature*, vol. 319: 321-24.

Ambrose, S.H., and DeNiro, M.J. (1986b) The isotopic ecology of East African mammals. *Oecologia*, vol. 69:395-406.

Ambrose, S.H., and DeNiro, M.J. (1987) Bone Nitrogen Isotope Composition and Climate [Letter]. *Nature*, vol. 325:201.

Ambrose, S.H., and DeNiro, M.J. (1989) Climate and habitat reconstruction using stable carbon and nitrogen isotope ratios of collagen in prehistoric herbivore teeth from Kenya. *Quaternary Research*, vol. 31: 407-422.

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 Lambert, J.B., and Grupe, G. (eds.): Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin. Pp. 1-37.

Andrews, C. (1984) Egyptian Mummies. Harvard University Press, Cambridge, Massachusetts.

Apicius (1977) Cookery and Dining in Imperial Rome. Translated by J.D. Vehling. Dover Publications, Inc., New York.

Aufderheide, A.C., Tieszen, L.L., Allison, M.J., Wallgren, J. and Rapp, G. (1988) Chemical Reconstruction of Components in Complex Diets: A Pilot Study. In Kennedy, B.V., and LeMoine, G.M. (eds.): Diet and Subsistence: Current Archaeological Perspectives, The University of Calgary, Archaeological Association, Calgary.

Bagnall, R.S. (1993) Egypt in Late Antiquity. Princeton University Press, Princeton, New Jersey.

Bagnall, R.S. (1995) Reading Papyri, Writing Ancient History. Routledge, London.

Bagnall, R.S. (1997) The Kellis Agricultural Account Book (P.Kell.IV Gr.96). Dakhleh Oasis Project: Monograph 7. Oxbow Monograph 92, Oxford.

Bass (1987) Human Osteology: A Laboratory and Field Manual of the Human Skeleton. 3rd Ed. Missouri Archaeological Society, Columbia.

Bevan, E.R. (1968) The House of Ptolemy: A History of Egypt under the Ptolemaic Dynasty. Ares Publishers, Inc., Chicago.

Blume, H.P., Alaily, U., Smettan, U., and Zielinski, J. (1984) Soil Types and Associations of Southwest Egypt. In Klitzsch, E., Said, R., and Schrak, E. (eds.): Research in Egypt and Sudan. Verlag von Dietrich Reimer, Berlin. Pp. 293-302.

Boak (1933) Karanis: The Temples, Coin Hoardes, Botanical and Zoological Reports Seasons 1924-31. University of Michigan Studies, Ann Arbor, Michigan.

Bocherons, H., Fogel, M.L., Tuross, N., and Zender, M. (1995) Trophic structure and climatic information from isotopic signatures in Pleistocene cave fauna of southern England. Journal of Archaeological Science, vol. 22: 327-340.

Boesseneck, J.and von den Driesch, A. (1988) Tierknochenfunde vom Tell Ibrahim Awad Im Ostlichen Nildelta. In van den Brink, E.C.M. (ed.): The Archaeology of the Nile Delta., Amsterdam. Pgs. 117-122.

Bowman, A.K. (1986) Egypt after the Pharaohs 332 BC - AD 642. University of California Press, Los Angeles, California.

Brugnoli, E., and Lauteri, M. (1991) Effects of salinity on stomatal conductance, photosynthetic capacity, and carbon isotope discrimination of salt tolerant (Gossypium hirsutium) and salt sensitive (Phaseolus vulgaris) C₃ non-halophytes. Plant Physiology, vol. 95: 628-635.

Bulliet, R.W. (1975) The Camel and the Wheel. Harvard University Press, Cambridge, Massachusetts.

Bumstead (1985) Past Human Behavior from Bone Chemical Analysis – Respects and Prospects. Journal of Human Evolution, vol. 14: 539-551.

Casson, L. (1984) Ancient Trade and Society. Wayne State University Press, Detroit.

Charlesworth, M.P. (1926) Trade Routes and Commerce of the Roman Empire. Ares Publishers Inc., Chicago.

Chisholm, B.S., Nelson, D.E., and Schwarcz, H.P. (1982) Stable carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. Science, vol. 216: 1131-1132.

Chouliara-Raios, H. (1989) L'abeille et le miel en Egypte d'apres les papyrus grecs. Parartema 30, Ioannina, Dodone.

Churcher, C.S. (1983) Dakhleh Oasis Project Palaeontology: Interim Report on the 1988 Field Season. Journal of the Society for the Study of Egyptian Antiquities, vol. XIII(3): 178-187.

Churcher, C.S. (1993) Romano-Byzantine and Neolithic Diets in the Dakhleh Oasis. Bulletin of the Canadian Mediterranean Institute, vol. XIII (2): 1-2.

Cook, M.A. (1994) The Mummies of Dakhleh. In Herring, A., and Chan, L. (eds): Strength in Diversity: a reader in physical anthropology. Canadian Scholar″s Press Inc., Toronto.

Cook, M., Molto, E., and C. Anderson (1988) Possible Case of Hyperparathyroidism in a Roman Period Skeleton From the Dakhleh Oasis, Egypt, Diagnosed Using Bone Histomorphometry. *American Journal of Physical Anthropology*, vol. 75: 23-30.

Cook, M., Molto, E., and C. Anderson (1989) Flourochrome Labelling in Roman Period Skeletons From Dakhleh Oasis, Egypt. *American Journal of Physical Anthropology*, vol. 80: 137-143.

Cormie, A.B., and Schwarcz, H.P. (1996) Effects of Climate on Deer Bone $\delta^{15}N$ and $\delta^{15}N$: Lack of Precipitation Effects on $\delta^{13}C$ for Animals Consuming Low Amounts of C_4 Plants. *Geochimica et Cosmochimica Acta*, in press.

Curtin, P.D. (1983) Nutrition in African History. *Journal of Interdisciplinary History*, vol. 14(2):371-382.

Curtin, P.D. (1984) Cross-Cultural Trade in World History. Cambridge University Press, Cambridge, UK.

Davies, R.W. (1989) Service in the Roman Army. Edinburgh University Press, Edinburgh, UK.

Darby, W.J., Ghalioungui, P., and Grivetti, L. (1977) Food: The Gift of Osiris: Volumes 1 and 2. Academic Press, London.

DeNiro, M.J. (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction. *Nature*, vol. 317: 806-809.

DeNiro, M.J. (1987) Stable Isotopy and Archaeology. *American Scientist*, vol.75:182-191.

DeNiro, M.J. and Epstein, S. (1978) Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, vol.42: 495-506.

DeNiro, M.J. and Epstein, S. (1981) Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta*, vol. 45: 341-351.

DeNiro, M.J., and Hastorf, C. (1985) Alteration of $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios of plant matter during initial stages of diagenesis: studies utilizing archaeological specimens from Peru. *Geochimica et Cosmochimica Acta*, vol. 49: 97-115.

DeNiro, M.J., and Schoeninger, M.J. (1983) Stable Carbon and Nitrogen Isotope Ratios of Bone Collagen: Variations Within Individuals, Between Sexes, and Within Populations Raised on Monotonous Diets. *Journal of Archaeological Science*, vol. 10: 199-203.

Doering, H.W. and Gericke, R. (1984) Practice and Problems of Agricultural Land Use in the South East Sahara. In Klitzsch, E, Said, R., and Schrank, E. (eds.): Research in Egypt and Sudan. Verlag von Dietrich, Berlin. Pp. 325-334.

Donadoni, S. (1997) The Egyptians. University of Chicago Press, Chicago.

Dupras, T.L, Schwarcz, H.P., and Fairgrieve, S.I. (1999) Dining in the Dakhleh Oasis: Dietary Reconstruction using Stable Istotope Analysis. In Weisman, M. (ed.): Proceedings from the 2nd Biannual Dakhleh Oasis Project Symposium, submitted.

Dzierżykray-Rogalski, T. (1978) Rapport sur les Recherches Anthropologiques Menée dans L'Oasis de Dakhleh en 1977 (IFAO-Balat). *Bulletin de l'Institut Français d'Archéologie Orientale*, vol. 78: 141-145.

Dzieroykray-Rogalski, T. (1989) Sur la paléodemographie de l'oasis de Dakhleh (Egypte). In Krzyzaniak, L., and Kobusiewicz, M. (eds.): Late Prehistory of the Nile Basis and theSahara. Poznan Archaeological Museum.

Ellis, W.M. (1994) Ptolemy of Egypt. Routledge, London.

Epstein, H. (1971) The Origin of the Domestic Animals of Africa, 1. New York.

Fairgrieve, S.I. (1993) Amino Acid Residue Analysis of Type I Collagen in Human Hard Tissue: An Assessment of Cribra Orbitalia in an Ancient Skeletal Sample from Tomb 31, Site 31/435-D5-2, Dakhleh Oasis, Egypt. Ph.D. Dissertation, University of Toronto.

Fakhry, A. (1973) The Oases of Egypt: Volume 1: Siwa Oasis. The American University in Cairo Press, Cairo.

Fakhry, A. (1974) The Oases of Egypt: Volume 2: Bahriyah and Farafra Oases. The American University in Cairo Press, Cairo.

Fildes, V. (1986) Breast, Bottles and Babies: A History of Infant Feeding. Edinburgh University Press, Edinburgh.

Fildes, V. (1988) Wet Nursing: A History from Antiquity to the Present. Basil Blackwell, New York.

Francey, R.J., and Farquhar, G.D. (1982) An explanation of $^{13}C/^{12}C$ variations in tree rings. *Nature*, vol. 297:28-31.

Frey, R. (1986) Interim Report on Excavations at the 'ein Tirghi Cemetery. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XVI (3/4): 92-102.

Fogel, M.L., Tuross, N., and Oswley, D.W. (1989) Nitrogen isotope tracers of human lactation in modern and archaeological populations. Carnegie Institute., Washington. Yearbook, pp. 111-117.

Giddy, L.L. (1987) Egyptian Oases: Bahariya, Dakhla, Farafara and Kharga During Pharaonic Times. Aris & Phillips Ltd., London.

Gilbert (1988) Zooarchaeological observations on the slaughterhouse of Meketre. *Journal of Egyptian Archaeology*, vol. 74: 69-89.

Gordon, A.G., Richards, R.A., and Farquahar, G.D. (1992) The effect of variation in soil water availability, vapour pressure deficit and nitrogen nutrition on carbon isotope discrimination in wheat. *Australian Journal of Agricultural Research*, vol. 43: 935-947.

Grimal, N. (1992) A History of Ancient Egypt. Blackwell, Oxford, England.

Guy, D.R., Reid, D.M., and Krouse, H.R. (1980) Shifts in carbon isotope ratios of two C_3 halophytes under natural and artificial conditions. *Oecologia*, vol. 44: 241-247.

Heathcote, R.L. (1983) The Arid Lands: Their Use and Abuse. Longman, New York.

Heaton (1928) A History of Trade and Commerce. Thomas Nelson & Sons, Ltd., Toronto.

Heaton, T.H.E. (1987) The $^{15}N/^{14}N$ ratios of plants in South Africa and Namibia: relationship to climate and coastal/saline environments. *Oecologia*, vol. 74: 236-246.

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*, vol. 322: 822-23.

Herodotus (1996) The Histories. Translated by A. de Sélincourt. Penguin Books, London.

Herring, D.A., Saunders, S.R., and Katzenberg, M.A. (1998) Investigating the Weaning Process in Past Populations. *American Journal of Physical Anthropology*, vol. 105: 425-439.

Hope, C.A. (1985) Dakhleh Oasis Project: Report on the 1986 Excavations at Ismant el-Gharab. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XV (4): 114-125.

Hope, C.A. (1986) Dakhleh Oasis Project: Report on the 1987 Excavations at Ismant el-Gharab. *Journal for the Society of the Study of the Egyptian Antiquities*, XVI (3/4): 74-91.

Hope, C.A. (1987) The Dakhleh Oasis Project: Ismant el-Kharab 1988-90. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XVII (4): 157-176.

Hope, C.A., Kaper, O.E., Bower, G.E., and S.R. Patten (1989) Dakhleh Oasis Project: Ismant el-Kharab 1991-92. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XIX: 1-26.

Iacumin, P., Bocherens, H., Chaix, L., and Marioth, A. (1998) Stable Carbon and Nitrogen Isotopes as Dietary Indicators of Ancient Nubian Populations (Northern Sudan). *Journal of Archaeological Sceince*, vol. 25: 293-301.

Iacumin, P., Bocherens, H., Mariotti, A., and Longinelli, A. (1996) An isotopic palaeo-environmental study of human skeletal remains from the Nile Valley. *Palaeogeography, Palaeoclimatology, Paleoecology*, vol. 126: 15-30.

Ikram (1995) Choice Cuts: Meat Production in Ancient Egypt. Uitgeverij Peeters en Departement Oosterse Studies: Leuven.

Jaffre, J., and Durou (1978) La Caravane du Sel. Editions Denoel, Paris.

Johnston, F.E. (1987) Nutritional Anthropology. Alan R. Liss, Inc., New York.

Kaper, O.E. (1997) Temples and Gods in Roman Dakhleh: Studies in Indigenous Cults of an Egyptian Oasis. Proefschrift (Doctoral Dissertation), Rijksuniversiteit Groningen.

Katz and Suchey (1986) Age Determination of the Male Os Pubis. *American Journal of Physical Anthropology*, vol. 69: 427-435.

Katzenberg, M.A. (1989) Stable isotope analysis of archaeological faunal from southern Ontario. *Journal of Archaeological Science*, vol. 16: 319-329.

Katzenberg, M.A. (1992) Advances in stable isotope analysis of prehistoric bones. In Saunders, S.R. and Katzenberg, M.A. (eds): Skeletal Biology of Past Peoples: Research Methods. Wiley Liss Inc., New York. Pp.105-119.

Katzenberg, M.A. (1993) Age differences and population variation in stable isotope values from Ontario, Canada. In Lambert, J.B., and Grupe, G. (eds.): Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin. Pp. 39-62.

Katzenberg, M.A., and Krouse, H.R. (1989) Application of stable isotope variation in human tissues to problems of identification. Canadian Society of Forensic Science Journal, vol. 22: 7-19.

Katzenberg, M.A., and Lovell, N.C. (1999) Stable Isotope Variation in Pathological Bone. International Journal of Osteoarchaeology, in press.

Katzenberg, M.A., and Pfeiffer, S. (1995) Nitrogen Isotope Evidence for Weaning Age in a Nineteenth Century Canadian Skeletal Sample. In Grauer, A.L. (ed.): Bodies of Evidence, John Wiley & Sons, Inc. Pp. 221-235.

Katzenberg, M.A., Herring, D.A., and Saunders, S.R. (1996) Weaning and Infant Mortality: Evaluating the Skeletal Evidence. Yearbook of Physical Anthropology, v. 39: 177-199.

Katzenberg, M.A., and Saunders, S.R. (1990) Age differences in stable carbon isotope ratios in prehistoric maize horticulturists. American Journal of Physical Anthropology, vol. 81: 247 (abstract)

Katzenberg, M.A., Schwarcz, H.P., Knyf, M., and Melbye, J. (1995) Stable Isotope Evidence for Maize Horticulture and Paleodiet in Southern Ontario, Canada. American Antiquity, vol. 60(2): 335-350.

Keegan, W.F. (1989) Stable Isotope Analysis of Prehistoric Diet. In Iscan, M.Y., and Kennedy, K.A. (eds): Reconstruction of Life from the Skeleton. Alan R. Liss, Inc., New York. Pps. 223-236.

Keegan, W.F., and DeNiro, M.J. (1988) Stable Carbon- and Nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. American Antiquity, vol. 53(2): 320-336.

Kees, H. (1961) Ancient Egypt. A Cultural Topography. Faber and Faber, London.

Kemp, B.J. (1984) Amarna Reports, 1-5. London.

Kemp, B.J. (1989) Ancient Egypt: Anatomy of a Civilization. Routledge, London.

Kennedy, P.M. and Hume, I.D. (1978) Recycling of urea nitrogen to the gut of the tammar wallaby (*Macropus eugenii*). *Complete Biochemistry and Physiology*, vol. 61A: 117-121.

Kitchen, K.A. (1986) The Third Intermediate Period in Egypt (1100-650 BC). Aris & Phillips Ltd., Warminster, England.

Kohl, D.H., Shearer, G., and Harper, J.E. (1980) Estimates of N_2 Fixation Based on Differences in the Natural Abundance of ^{15}N in Nodulating and Nonnodulating Isolines of Soybeans. *Plant Physiology*, vol. 66: 61-65.

Krueger, H.W., and Sullivan, C.H. (1984) Models for Carbon Isotope Fractionation Between Diet and Bone. In Turnland and Johnson (eds.): Stable Isotopes in Nutrition, ACS Symposium, Washington: American Chemical Society. Pp. 205-220.

Lajtha, K., and Marshall, J.D. (1994) Sources of variation in the stable isotope composition of plants. In Lajtha, K., and Michener, R.H. (eds.): Stable Isotopes in Ecology and Environmental Science. Blackwell Scientific Publications, Oxford. Pgs. 1-22.

Lee-Thorp, J.A., and Sealy, J.C. (1986) On Australian aboriginal diets. *Current Anthropology*, vol. 27: 54.

Lee-Thorp, J.A., and van der Merwe, N.J. (1987) Carbon Isotope Analysis of Fossil Bone Apatite. *South African Journal of Science*, vol. 83: 712-715.

Lee-Thorp, J.A., and van der Merwe, N.J. (1991) Aspects of the Chemistry of Modern and Fossil Biological Apatites. *Journal of Archaeological Science*, vol. 18: 343-354.

Lee-Thorp, J.A., Sealy, J.C., and van der Merwe, N.J. (1989) Stable Carbon Isotope Ratio Differences Between Bone Collagen and Bone Apatite, and Their Relationship to Diet. *Journal of Archaeological Science*, vol. 16: 585-599.

Letolle, R. (1980) Nitrogen-15 in the natural environment. In Fritz, P., and Fontes, J.C. (eds): Handbook of Environmental Isotope Geochemistry, Vol. 1, The Terrestrial Environment. Elsevier, Amsterdam, pp. 45-62.

Lewis, N. (1983) Life in Egypt Under Roman Rule. Clarendon Press, Oxford.

Lewis, N., and M. Reinhold (1990) Roman Civilization: Selected Readings. Volume II: The Empire, 3rd Ed. Columbia University Press, New York.

Lindsay, J. (1966) Leisure and Pleasure in Roman Egypt. Barnes & Noble, New York.

Lipp, J., Trimborn, P., Edwards, T., Waisel, Y., and Yakir, D. (1996) Climatic effects on the $\delta^{18}O$ and $\delta^{13}C$ of cellulose in the desert tree *Tamarix jordanis*. *Geochimica et Cosmochimica Acta*, vol.16 (17): 3305-3309.

Longin (1971) New Method for collagen extraction for radiocarbon dating. *Nature*, vol. 230: 241-242.

Longstreth, D.J., and Nobel, P.S. (1979) Salinity effects on leaf anatomy. Consequences for photosynthesis. *Plant Physiology*, vol. 63: 700-710.

Lovell, N.C., Nelson, D.E., and Schwarcz, H.P. (1981) Carbon Isotope Ratios in Palaeo-diet: Lack of Age or Sex Effect. *Archaeometry*, vol. 28(1): 51-55.

Marino, B.D., and McElroy, M.B. (1991) Isotopic composition of atmospheric CO_2 inferred from carbon in C4 plant cellulose. *Nature*, vol. 349: 127-131.

Martin, P. (1984) The Meaning of Weaning. *Animal Behaviour*, vol. 32(4): 1257-1259.

McDougall, E.A. (1985) The View from Awdaghust: War, Trade and Social Change in the Southwestern Sahara, from the Eighth to the Fifteenth Century. *Journal of African History*, 26:1-31.

Meinzer, F.C., Saliendera, N.Z., and Cristosto, C.H. (1992) Carbon isotope discrimination and gas exchange in *Cofea arabica* during adjustment to different soil moisture regimes. *Australia Journal of Plant Physiology*, vol. 19: 171-184.

Melbye, J. (1983) Human Remains from a Roman Period Tomb in the Dakhleh Oasis, Egypt: A Preliminary Analysis. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XIII (3): 193-199.

Miller, J.I. (1969) The Spice Trade of the Roman Empire (29 BC to AD 641). Clarendon Press, Oxford.

Miller, R.L. (1990) Hogs and Hygiene. *Journal of Egyptian Archaeology*, vol. 76: 125-140.

Mills, A.J. (1984) Research in the Dakhleh Oasis. In Krzyzaniak, L., and Kobusiewicz, M. (eds.): Origin and Early Development of Food-Producing Cultures in North-Eastern Africa. Polish Academy of Sciences, Poznan Archaeological Museum.

Mills, A.J. (1990) The Dakhleh Oasis Project: Report on the 1988-1989 Field Season. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XX: 1-23.

Minagawa, M. (1992) Reconstruction of human diet from $\delta^{13}C$ and $\delta^{15}N$ in contemporary Japanese hair: a stochastic method for estimating multi-source contribution by double isotopic tracers. *Applied Geochemistry*, vol. 7: 145-158.

Molto, J.E. (1986) Human Skeletal Remains from the Dakhleh Oasis, Egypt. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XVI (3/4): 119-127.

Molto, J.E. (in press) The comparative Skeletal Biology and Paleoepidemiology of the People from Ein Tirghi and Kellis, Dakhleh, Egypt.

Morkot, R. (1990) 'Nb-M3't-R' — United-with-Ptah. *Journal of Egyptian Studies*, vol. 49: 323-337.

Nakamura, K., and Schoeller, D.A. (1982) Geographical Variations in the Carbon Isotope Composition of the Diet and Hair in Contemporary Man. *Biomedical Mass Spectrometry*, vol. 9(9): 390-394.

Naylor, K. (1986) Bread of the Desert: a Look at Date Growing in Tunisian Oases. *Geographical Magazine*, vol. 58: 188-191.

Nelson, H. (1934) Medinet Habu-III. Chicago.

Newberry, C. (1928) The pig and the cult animal of Set. *Journal of Egyptian Archaeology*, vol. 14: 211-225.

Nibbi, A. (1981) Ancient Egypt and Some Eastern Neighbours. Noyes Press, Park Ridge, New Jersey.

Nolan, J.V., and Stachiw, S. (1979) Fermentation and nitrogen dynamics in Merino sheep given a low-quality-roughage diet. *British Journal of Nutrition*, vol. 42: 63-80.

Parr, R.L., Dupras, T.L., Walters, S., Capricci, J., and Molto, E. (1998) A Tale of Two Lepers From the Dakhleh Oasis, Egypt: A Preliminary Report on Chemical and Molecular Analysis. Poster Presentation at the Palaeopathology Annual Meetings, Salt Lake City, Utah.

Peck, W.H. (1980) Mummies of Ancient Egypt. In Cockburn, A., and E. Cockburn, (eds): Mummies, Disease and Ancient Cultures. Cambridge University Press, London.

Petrie, W.M. Flinders (1924) Social Life in Ancient Egypt. Constable & Company Ltd., London.

Phenice, T.W. (1969) A newly developed visual method of sexing the os pubis. American Journal of Physical Anthropology, vol. 30: 297-301.

Pliny the Elder (1991) Natural History. Translated by J.F. Healy. Penguin Books, London.

Price, M. (1985) Introducing Groundwater. George Allen & Unwin, London.

Rankin, J.C., and Davenport, J. (1981) Animal Osmoregulation. John Wiley and Sons, New York.

Robins, G. (1993) Women in Ancient Egypt. Harvard University Press, Cambridge.

Roksandic, Z., Minagawa, M., and Akazawa, T. (1988) Comparative analysis of dietary habits between Jomon and Ainu hunter-gatherers from stable isotopes of human bone. Journal of the Anthropological Society of Nippon. Vol. 96: 391-404.

Sagan, C. (1977) The Dragons of Eden: Speculations on the Evolution of Human Intelligence. Random House, New York.

Saitoh, M., Uzuka, M., and M. Sakamoto (1970) Human Hair Cycle. Journal of Investigative Dermatology, vol. 54: 65-81.

Saliège, J.F., Person, A., and Paris, F. (1995) Preservation of $^{13}C/^{12}C$ original ratio and 14C dating of the mineral fraction of human bones from Saharan Tombs, Niger. Journal of Archaeological Science, vol. 22: 301-312.

Schoeninger, M.J. (1995) Stable Isotope Studies in Human Evolution. Evolutionary Anthropology, vol.4 (3): 83-98.

Schoeninger, M.J., and DeNiro, M.J. (1982) Carbon Isotope Ratios of Apatite from Fossil Bone Cannot be Used to Reconstruct Diets of Animals. Nature, vol. 297:577-78.

Schoeninger, M.J., and DeNiro, M.J. (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochimica et Cosmochimica Acta, vol. 48:625-639.

Schoeninger, M.J., DeNiro, M.J., and Tauber, H. (1983) Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science*, vol. 220: 1381-83.

Schoeninger, M.J., Iwaniec, U.T., and Glander, K.E. (1994) Stable Isotope Variation in Costa Rican primates: Implications for diet selectivity. *American Journal of Physical Anthropology Suppl.* vol. 18:113.

Schoeninger, M.J., Iwaniec, U.T., and Glander, K.E. (1997) Stable Isotope Ratios Indicate Diet and Habitat Use in New World Monkeys. *American Journal of Physical Anthropology*, vol. 103(1): 69-84.

Schoeninger, M.J., Moore, K.M., Murray, M.L., and Kingston, J.C. (1989) Detection of bone preservation in archaeological and fossil samples. *Applied Geochemistry*, vol. 4: 281-292.

Schurr, M.R. (1997) Stable isotopes as evidence for weaning at the Angel Site: a comparison of isotopic and demographic measures of weaning age. *Journal of Archaeological Science*, 24: 919-227.

Schurr, M. R. (1998) Using stable nitrogen-isotopes to study weaning behavior in past populations. *World Archaeology*, vol. 30(2):327-342.

Schwarcz, H.P. (1999) Some biochemical aspects of carbon isotopic paleodiet studies. In Ambrose, S. and Katzenberg, M.A. (eds.): Isotopic Aspects of Paleodiet. Plenum Press Series: Advances in Archaeological and Museum Science, in prep.

Schwarcz, H.P., Dupras, T.L., and S.I. Fairgrieve (1999) ^{15}N enrichment in the Sahara: In search of a Global Relationship. *Journal of Archaeological Science*, vol. 26: 629-636.

Schwarcz, H.P., and Schoeninger, M.J. (1991) Stable Isotope Analyses in Human Nutritional Ecology. *Yearbook of Physical Anthropology*, vol. 34: 283-321.

Schwarcz, H.P., Melbye, J., Katzenberg, M.A., and Kynf, M. (1985) Stable Isotopes in Human Skeletons of Southern Ontario: Reconstructing Paleodiet. *Journal of Archaeological Science*, vol. 12: 187-206.

Sealy, J., Armstrong, R. and Schrire, C. (1995) Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity*, vol.69: 290-300.

Sealy, J.C., Morris, A.G., Armstrong, R., Markell, A., and Schrire, C. (1993) An Historic Skeleton From the Slave Lodge At Vergelegen. *South African Archaeological Society Goodwin Series*, vol. 7:84-91.

Sealy, J.C., van der Merwe, N.J., Lee-Thorp, J.A., and Lanham, J. (1987) Nitrogen isotope ecology in southern Africa: implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta*, vol. 51: 2707-2717.

Shaaban, M.M. (1988) Palaeodemography of a Pre-Roman Population from El-Dakhleh, Egypt: Evidence from the Skeletal Remains at Site 31/435-D5-2. Ph.D. Dissertation, University of Toronto.

Sharpe, J.L. (1987) The Kellis Codices. *Journal of the Society for the Study of Egyptian Antiquities*, vol. XVII (4): 192-197.

Sheldrick, P. (1980a) Dakhleh Oasis Project: Human Remains from the Dakhleh Oasis. *Journal of the Society for the Study of Egyptian Antiquity*, vol. X (4): 423-427.

Sheldrick, P. (1980b) Skinny Bones from the Dakhleh Oasis. *Paleopathology Newsletter*, no. 30: 7-10.

Sillen, A, Sealy, J.C., and van der Merwe, N.J. (1989) Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity*, vol. 54(3): 504-512.

Smith, B.N., and Epstein, S. (1971) Two Categories of $^{13}C/^{12}C$ Ratios for Higher Plants. *Plant Physiology*, vol. 47: 380-84.

Smith, G. (1985) Statistical Reasoning, 3rd Edition. Allyn and Bacon, Boston, Massachusetts.

Solomon, J., and Solomon, J. (1950) Ancient Roman Feasts and Recipes Adapted for Modern Cooking. E.A. Seemann Publishing, Inc., Miami, Florida.

Soranus (1st/2nd Century AD) Soranus' Gynecology. Translated by O. Tempkin (1956). Baltimore.

Stenhouse, M.J. and Baxter, M.S. (1979) The uptake of bomb ^{14}C in humans. In Berger, R., and Suess, H. (eds.): Radiocarbon Dating. University of California Press, Berkley. Pgs. 324-341.

Stout, S.D. and Paine, R. (1992) Brief Communication: Histological age estimation using rib and clavicle. *American Journal of Physical Anthropology*, vol. 87: 111-115.

Stuart-Williams, H. Le Q., Schwarcz, H.P., White, C.D., and Spence, M.W. (1996) The isotopic composition and diagenesis of human bone from Teotihuacan and Oaxaca, Mexico. *Paleogeography, Paleoclimatology, Paleoecology*, vol. 126: 1-14.

Suchey, J.M. (1979) Problems in the aging of females using the os pubis. *American Journal of Physical Anthropology*, vol. 51: 467-470.

Sullivan, C.H., and Krueger, H.W. (1983) Carbon isotope analysis of separate chemical phases in modern and fossil bone. *Nature*, vol. 292: 333-335.

Thomas, B.E. (1957) Trade Routes of Algeria and the Sahara. University of California Publications in Geography, vol. 8(3): 165-288. University of California Press, Berkeley.

Thompson, D.D. (1979) Age-related changes in osteon remodeling and bone mineralization. PhD Thesis, Farmington, University of Connecticut.

Tieszen, L.L. (1991) Natural Variations in the Carbon Isotope Values of Plants: Implications for Archaeology, Ecology, and Paleoecology. *Journal of Archaeological Science*, vol. 18: 227-248.

Tieszen, L.L. and Chapman, M. (1992) Carbon and nitrogen isotope status of the major marine and terrestrial resources in the Atacama Desert of Northern Chile. Proceedings of the 1st World Congress on Mummy Studies, Tomo 1. Museo Arqueologico y Etnografico de Tenerife, Tenerife, Canary Is. pp. 409-426.

Tieszen, L.L., and Fagre, T. (1993) Effect of Diet Quality and Composition on the Isotopic Composition of Respiratory CO_2, Bone Collagen, Bioapatite, and Soft Tissues. In Lambert, J.B., and Grupe, (eds.): Prehistoric Human Bone Archaeology at the Molecular Level. Springer-Verlag, Berlin.

Tieszen, LL, Iversen, E., and Matzner, S. (1992) Dietary Reconstruction Based on Carbon, Nitrogen and Sulfur Stable Isotopes in the Atacama Desert, Northern Chile. Proceedings of the 1st World Congress on Mummy Studies, Tomo 1, . Museo Arqueologico y Etnografico de Tenerife, Tenerife, Canary Is. pp. 427-442

Tieszen, L.L., Boutton, K.G., Tesdahl, K.G., and Slade, N.A. (1983) Fractionation and turnover of stable carbon isotopes in animal tissues: Implications for $\delta^{13}C$ analysis of diet. *Oecologia*, vol.57: 32-37.

Ubelaker (1978) Human Skeletal Remains: Excavation, Analysis and Interpretation. Taraxacum, Washington, D.C.

van der Merwe, N.J. and Vogel, J.C. (1978) ^{13}C content of human collagen as a measure of prehistoric diet in woodland North America. *Nature*, vol. 276: 815-16.

van der Veen, M. (1998) A life of luxury in the desert? The food and fodder supply to Mons Claudianus. *Journal of Roman Archaeology*, 11: 101-116.

Vikor, K.S. (1985) An Episode of Saharan Rivalry: The French Occupation of Kewar, 1906. *International Journal of African Historical Studies*, 18 (4): 699-715.

Vischer, H. (1910) Across the Sahara from Tripoli to Bornu. Edward Arnold, London.

Wagner, G. (1987) Les Oasis D'Égypte: L'Époque Grecque, Romaine et Byzantine D'Après Les Documents Grecs. Institut Français D'Archéologie Orientale Du Caire.

Walker, P.L., and DeNiro, M.J. (1986) Stable Nitrogen and Carbon Isotope Ratios in Bone Collagen as Indices of Prehistoric Dietary Dependence on Marine and Terrestrial Resources in Southern California. *American Journal of Physical Anthropology*, vol. 71: 51-61.

Walton, K. (1969) The Arid Zones. Hutchinson University Library, London.

Watson, G.R. (1969) The Roman Soldier. Cornell University Press, New York.

Wells, C. (1992) The Roman Empire, 2nd Ed. Fontana Press, London.

White, C.D. (1991) Isotopic analysis of multiple human tissues from three ancient Nubian populations. PhD Dissertation, Dept. of Anthropology, University of Toronto.

White, C.D. (1993) Isotopic Determination of Seasonality in Diet and Death from Nubian Mummy Hair. *Journal of Archaeological Science*, vol. 20: 657-666.

White, C.D., Longstaffe, F.J., and K.M. Law (1999) Seasonal Stability and Variation in Diet as Reflected in Human Mummy Tissues from the Kharga Oasis and the Nile Valley. *Paleogeography, Paleoclimatology, Paleoecology*, vol. 147: 209-222.

White, C.D., and Schwarcz, H.P. (1989) Ancient Maya Diet: as Inferred from Isotopic and Elemental Analysis of Human Bone. *Journal of Archaeological Science*, vol. 16: 451-474.

White, C.D., and Schwarcz, H.P. (1994) Temporal Trends in Stable Isotopes for Nubian Mummy Tissues. *American Journal of Physical Anthropology*, vol. 93: 165-187.

White, C.D., Spence, M.W., Stuart-Williams, H. Le 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*, vol. 25: 643-655.

White, J.M. (1963) Everyday Life in Ancient Egypt. Capricorn Books, G.P. Putnam's Sons, New York.

Wilkins, J., Harvey, D., and M. Dobson, eds. (1996) Food in Antiquity. University of Exeter Press, Exeter, UK.

Wilkinson (1854) The Ancient Egyptians: Their Life and Customs, vols. 1 & 2. Random House, London.

Wood, J.W., Milner, G.R., Harpending H.C., and Weiss, K.M. (1992) The Osteologic Paradox: problems of inferring prehistoric health from skeletal samples. *Current Anthropology*, vol. 33(4): 343-370.

Worp, K. (1995) Greek Papyri from Kellis : I (*P.Kell.G.*), Nos. 1-90. Dakhleh Oasis Project: Monograph No.3. Oxbow Monograph 54, Oxbow Books, Oxford.

Wright, L.E., and Schwarcz, H.P. (1996) Infrared evidence for diagenesis of bone apatite at Dos Pilas, Guatemala: paleodietary implications. *Journal of Archaeological Science*, vol. 23: 933-944

Wright L.E., and Schwarcz, H.P. (1998) Stable Carbon and Oxygen Isotopes in Human Tooth Enamel: Identifying Breastfeeding and Weaning in Prehistory. *American Journal of Physical Anthropology*, vol. 106(1): 1-18.

Wright, L.E., and Schwarcz, H.P. (1999) Correspondence Between Stable Carbon, Oxygen and Nitrogen Isotopes in Human Tooth Enamel and Dentine: Infant Diets at kaminaljuyu. *Journal of Archaeological Science*, vol. 26, in press.

Yakir, D., Issar, A., Gat, J., Adar, E., Trimborn, P., and Lipp, J. (1994) ^{13}C and [18]O of wood from the Roman siege rampart in Masada, Israel (AD 70-73): Evidence for a less arid climate for the region. *Geochimica et Cosmochimica Acta*, vol. 58(16): 3535-3539.

Yoshinaga, J., Minagawa, M., Suzuki, T., Ohtsuka, R., Kawabe, T., Inaoka, T., and T. Akimichi (1996) Stable Carbon and Nitrogen Isotopic Composition of Diet and Hair of Gidra-Speaking Papuans. *American Journal of Physical Anthropology*, vol. 100 (1): 23-34.