UNIVERSITY OF SOUTHAMPTON

FACULTY OF ARTS

SCHOOL OF HUMANITIES

POPULATION BIO-CULTURAL HISTORY IN THE SOUTH AEGEAN DURING THE BRONZE AGE

(2 Volumes, Vol. I)

By

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"Why are the streets and meeting-places emptying,
and all the people lost in thought as they turn home?

Because the daylight fails, and the night comes,
but the barbarians come not. And there be
who from the frontier have arrived and said
that there are barbarians now at all.

And now what shall become of us without barbarians?
These people were in sooth some sort of settlement."

C.P. Cavafys: "Awaiting the barbarians"
(*translated by J.C.Cavafy*)

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ABSTRACT

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POPULATION BIO-CULTURAL HISTORY IN THE SOUTH AEGEAN DURING THE BRONZE AGE

By Argyro Nafplioti

This research reconstructs the bio-cultural history of the Bronze Age South Aegean population and addresses two widely debated archaeological questions in a bioarchaeological research framework. It responds to traditional culture history studies that frequently associate cultural discontinuity with population movements.

It applies morphological (metric and non-metric) analysis of the skeleton to the study of Bronze Age populations from Naxos (Cyclades), and principally the Argolid (Mainland) and Crete, in order to explore issues of intra-population variation and inter-population biodistance at the regional and inter-regional level. Analysis is oriented in time both vertically, providing time-depth, and horizontally, allowing the examination of inter-population biological relationships at the intra- and inter-regional level. The vertical analytical approach investigates discontinuity or continuity in the biological history of the populations and provides negative or positive evidence respectively for the arrival and admixture of biologically different population elements. The horizontal analysis assesses inter-population relationships (relatedness vs. divergence) in relation to the two principal archaeological questions examined. Concerning the biological relationship between the Argolid and Central Crete populations, analysis monitors how it fluctuates in the course of the Bronze Age. Finally, morphological skeletal analysis is supplemented by strontium isotope ratio analysis ($^{87}Sr/^{86}Sr$) that is a very efficient technique in detecting population movement.

The two principal archaeological hypotheses explored concern the arrival and settlement of people from the Argolid (Mycenaeans) on Crete and Naxos following the LMIB and LHIIIB-C destructions on Crete and the Mainland respectively. On the basis of the results of the morphological skeletal and strontium isotope ratio analysis both hypotheses were rejected. Thereby analysis demonstrated that the introduction of novel cultural features (cultural discontinuity) to Knossos (Crete) and the Chora of Naxos need not have resulted from the settlement of the people suggested to be the first to create them. Finally, this thesis contributes to a more comprehensive understanding of Bronze Age South Aegean population bio-cultural history through the regionally reconstructed inter-population biological relationships and their examination in conjunction with interpretations of the associated material culture evidence.

POPULATION BIO-CULTURAL HISTORY IN THE SOUTH AEGEAN DURING THE BRONZE AGE

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POPULATION BIO-CULTURAL HISTORY IN THE SOUTH AEGEAN DURING THE BRONZE AGE

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I should like to close these acknowledgements by thanking all these Aegean people whose history I believe I reconstructed in this thesis and I apologise for any inaccuracies.

ABBREVIATIONS

Used in the text

EBA	Early Bronze Age
MBA	Middle Bronze Age
LBA	Late Bronze Age
EH	Early Helladic
MH	Middle Helladic
LH	Late Helladic
EM	Early Minoan
MM	Middle Minoan
LM	Late Minoan
EC	Early Cycladic
MC	Middle Cycladic
LC	Late Cycladic
SIR	Strontium Isotope Ratio

CHAPTER 1

INTRODUCTION

I wish to open this thesis with the declaration that this is an archaeological study. The material on which it focuses is human skeletal remains, and it uses them to address archaeological questions from a well-defined archaeological perspective.

This study explores the bio-cultural history of the Bronze Age South Aegean within a bioarchaeological research framework. Studies of the Bronze Age South Aegean group cultural diversity of the region into three broad geographical-cultural units, namely the Mainland, Cyclades and Crete, and assign them the terms Helladic - "Mycenaean", Cycladic, and "Minoan" civilizations respectively (e.g. Warren 1969; French & Wardle 1988; Marinatos 1993; Cullen 2001). These studies have elaborated a plethora of theories that knit together the suggested origins of the three South Aegean populations and their genetic make-up, their material culture, associated ideologies and language, and draw inferences upon the ethnic identities of these South Aegean populations. Cultural discontinuities in the three geographical - cultural units in the course of time are frequently interpreted by evoking population movements in the form either of migrations or invasions (Davis 1992; Dickinson 1994; Rutter 2001; Watrous 2001; Rehak & Younger 2001; Schelmerdine 2001). These interpretative models stem from a deeply rooted monolithic and problematic equation of certain material culture characteristics with certain people with distinct ethnic identities, and the perception of population movement as the exclusive determinant of culture history. The origins of this model go back to nineteenth century archaeology (Hides 1995; Jones 1997).

Kossina (1911) suggested that specific archaeological cultures should be equated with certain 'ethnic' groups, and that cultural discontinuities in the archaeological record should be attributed to migration and diffusion of population groups. He argued further that in biological terms, people from different cultural groups are 'racially' different. These ideas were very influential in early archaeological thinking, resulting in a plethora of material culture studies interpreting cultural discontinuity by drawing inferences upon the biological history of the respective populations.

The equation, however, of certain material culture characteristics with specific "ethnic" groups and the assumption that the similarities or differences in the material culture can be deployed to establish inter-population relationships at the level of ethnicity, and determine the geographical location that specific population groups occupied at different periods in prehistory (Montelius 1903; Kossina 1911), is highly problematic. More recent archaeological and other related research has demonstrated coherently that the presence of pots or other material culture characteristics and ideologies cannot be equated with the physical presence of the people who are suggested to be the first to create them (Binford 1965; Flannery 1968; Renfrew 1972). The production and consumption of distinctive styles of material culture is not straightforward. It may reflect rather complex conditions, such as socio-political competition internal to the society, competitive emulation, and power justification (Schallin 1993). Therefore, cultural changes need not originate from outside the society, and the presence of certain non-local material culture at a site and/or ideologies need not imply the settlement of the people who are suggested to have been the first to create these.

When archaeologists are addressing questions of population movements and biological interaction, the analysis of the skeletal remains of past populations is the most appropriate 'tool'. After all, these are the people who are suggested to have moved peacefully or invaded and admixed with indigenous populations. Following this line of reasoning, the present study analyses human skeletal material for morphological and geo-chemical evidence (positive or negative) concerning the arrival of new population elements at a site, in cases that population movement has been suggested on material culture evidence.

Despite the recognition that bio-archaeology has received in the last three decades concerning its contribution to a more accurate reconstruction of the bio-cultural history of past populations (Renfrew 1996; Steadman 1998), to date it has not been adequately appreciated in Prehistoric Aegean Archaeology. Hence there is a dearth of modern bioarchaeological studies that explore in a systematic and scientifically sound mode questions of population biological variability and biodistance, population movements and biological interaction or isolation within the Bronze Age South Aegean context, or that discuss archaeological questions in a bioarchaeological research framework. The present study responds to this failing of archaeological research in Greece. It investigates the pattern of population biovariability and biodistance at the intra- and inter-regional level and how it fluctuates in the course of the Bronze Age, in order to accurately reconstruct the bio-cultural history of the South Aegean population in the examined period. Furthermore, it tests in a bioarchaeological research framework specific archaeological hypotheses implicating population movement to interpret cultural discontinuity in order to prove or disprove them. It concludes by exploring which elements of the tested hypotheses or which alternative hypotheses fit best the results of the present study, and endeavors to shed more light on the complex processes under which change occurs in prehistoric societies.

The fundamental assumption of this research is that there is variation in the human population and that the three Bronze Age South Aegean populations were biologically distant enough in order for the present analysis to be able to detect fluctuations in their biological relationship introduced by population movement and biological interactions. Since there is undisputed variation within the human species, the inter-population biological distance should be at least greater than the biological distance between individuals at the population level, to allow for the presence of non-indigenous among the native people to be detectable. This assumption was tested and confirmed by the results of the analysis of the skeletal morphology in Chapter 6.

The variation in the human species derives from the fact that, although all humans share the same type and number of genetic loci, there can be several different combinations of alleles at a single locus. Studies have established that within the human population at least 30% of the gene loci vary (Bodmer & Cavalli-Sforza 1976). Consequently, a measure of genetic distance between populations can be derived by exploring the frequency of certain alleles within the gene pool. This is directly provided by the study of the biochemical variables of the population and indirectly reflected in the morphological variation of the human skeleton. Although each morphological variant reflects the additive effect of a large number of loci and other genetic and non-genetic factors, studies of the variation in human and animal populations have demonstrated that inter-population biological relationships can be successfully reconstructed by analysis of skeletal morphology (see Chapter 4).

The present research focuses on the examination of the biological history of the Argolid on the Mainland, Central Crete and Naxos in the Cyclades populations (Figure 1.1). This is principally due to their complex bio-cultural history and in order to explore two of the most influential archaeological hypotheses of population movement in the Bronze Age Aegean, which are associated with cultural discontinuities. Analysis of the skeletal morphology is oriented in time both vertically, providing time-depth, and horizontally, allowing the comparative examination of contemporary but geographically distinct populations. The vertical approach, explores the biological history of the Argolid and Cretan populations separately through the assessment of intra-population variation and inter-population biodistance at the regional level in the course of the Bronze Age.

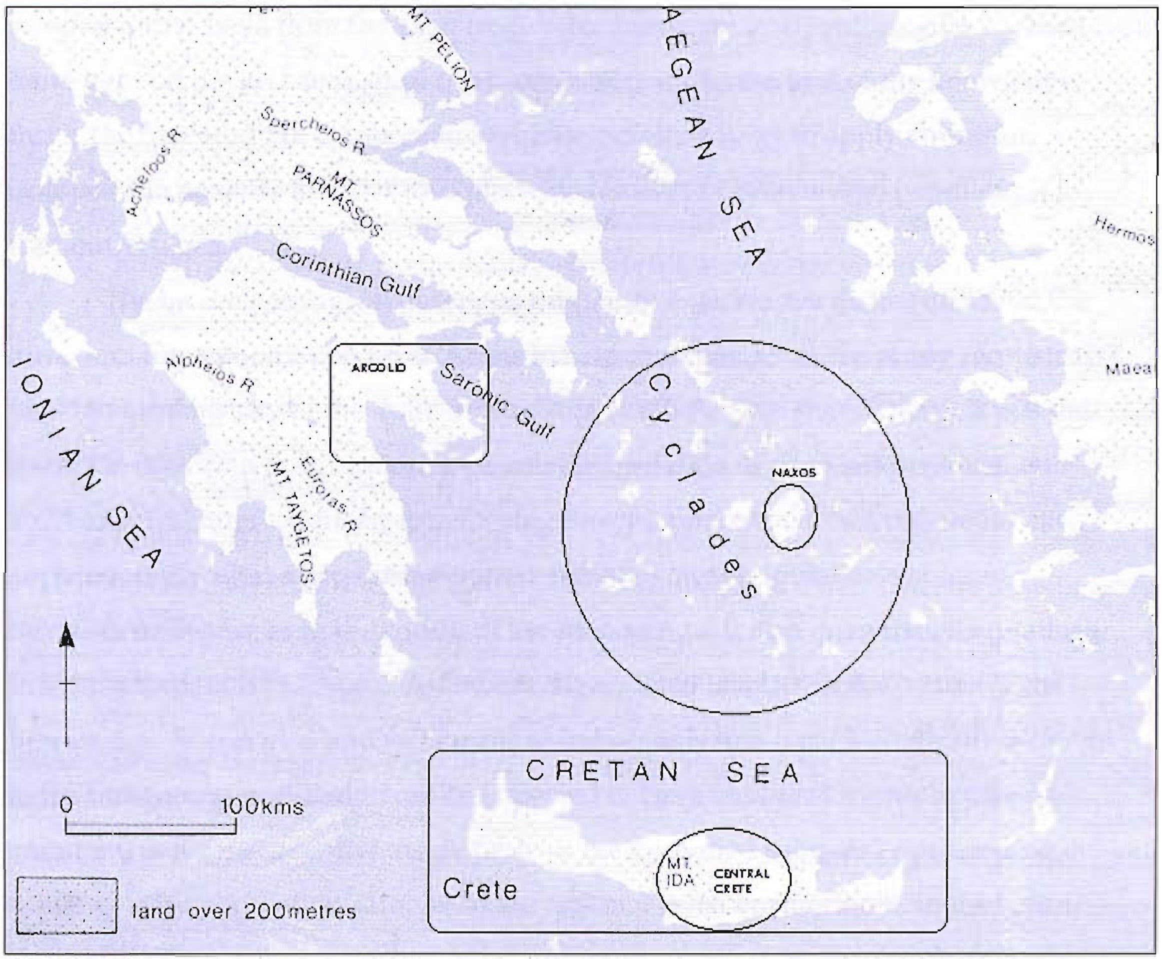

Figure 1.1 Geographical context of the research: focus of bioarchaeological analysis (after Dickinson 1994:24).

Thus it detects discontinuities or continuities in the population biological history, which provide positive or negative evidence respectively for the arrival and admixture of biologically different population elements from an extra-regional source. The horizontal approach monitors the biological relationship (relatedness vs.

divergence) between the Argolid, Central Crete and Naxian populations and how this relationship fluctuates in the course of the Bronze Age. The biological relationship between the Naxos population on one hand, and its (Naxos) contemporaries from the Argolid and Central Crete is less extensively explored, due to the comparatively poor preservation and completeness of the human skeletal material from Naxos available for analysis. Analysis for the Naxos population is confined to the Late Bronze Age.

Morphological skeletal analysis is supplemented by strontium isotope ratio analysis ($^{87}Sr/^{86}Sr$). This is a very efficient technique in detecting population movements and residential change (Price *et al.* 2002). Dental and bone samples from selected individuals from the examined collections were analysed in order to shed more light on the archaeological questions explored. To the best of my knowledge, this is the first study in the Aegean Prehistoric Archaeology to apply strontium isotope ratio analysis in order to explore movements of Bronze Age populations in the South Aegean.

The bioarchaeological questions this study explores are distinguished at the intra- and inter-population level. At the intra-population level, the study reconstructs the biological history of the three Bronze Age South Aegean populations. It sets the scene for exploring the question of population isolation or population movements and biological interactions by establishing how homogeneous/heterogeneous each population is within a given time-period and how intra-population variation increases or decreases in the course of the Bronze Age. It also quantifies fluctuations in inter-population biological distance at the regional level, over the course of the Bronze Age. The arrival and settlement of individuals that were biologically different to the indigenous population can be expected to have increased intra-population variation, and consequently, the distance of the examined samples to preceeding or contemporary population samples at the regional level. Furthermore, in the case of Crete, this thesis assesses the biological distance between contemporaneous population groups living within the same geographical region and how the reconstructed biological relationship relates to the expected one, according to studies of material culture evidence.

At the inter-population level, I explored the validity of the fundamental assumption of the study. In order to be able to monitor changes in the biological relationship between the Argolid and Central Crete populations, due to population movements and gene flow from one region to the other, the two Bronze Age populations need to be biologically distant enough. Therefore, morphological analysis tests whether the contemporary Bronze Age Argolid and Central Crete populations are biologically different enough or not for the study to be feasible. It explores the biological validity of the designations assigned by studies of the material culture to the populations from the Mainland and Crete, i.e. Mainlanders - "Mycenaeans" and "Minoans" respectively. Morphological analysis establishes whether the Argolid and Cretan populations are indeed biologically distant and homogeneous at the inter- and intra-population levels respectively, as the use of the respective designations implies. Moreover, the thesis assesses systematically positive or negative evidence for population movement and biological interactions between the Argolid, Naxos and Central Crete in the course of the Bronze Age.

Using a bioarchaeological research framework, the study explores specific archaeological questions, by testing on human skeletal evidence hypotheses formulated on material culture evidence. The tested hypotheses implicate the arrival and settlement of new population elements from extra-regional sources, following destructions and/or cultural discontinuity. The two principal archaeological questions investigated in this thesis are the following:

a. At the end of the Late Minoan IB (circa 1490/1470 BC), following widespread destructions on Crete, people from the Argolid (Mainland) settled at Knossos. Arrival took the form of military invasion and political domination of the site. Settlement involved a ruling class and its warrior aristocracy, who following their death, were interred into the so-called "warrior" graves in the Zapher Papoura, Ayios Ioannis, Mavrospelio and Sellopoulo cemeteries at the Knossos district (Sakellarakis 1972; Kanta 1980; Hood 1985; Barber 1987: 222; Doxey 1987: 301; Driessen 1990: 125; Popham 1994; Rehak & Younger 2001).

b. Following the Late Helladic IIIB-C (circa 1190/1180 BC) destructions and the demise of the palatial system on the Greek Mainland, Mycenaean kings and/or their aristocracy sought refuge to the Cyclades. These individuals have been associated with interments inside the rich in finds of royal and ritual connotations, Late Cycladic III tombs at the Aplomata and Kamini cemeteries on the island of Naxos (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

With regard to the second hypothesis, emphasis is placed upon the results of the strontium isotope ratio analysis, due to the poor preservation and completeness of the human skeletal material available for analysis from Naxos.

To avoid any misunderstanding of the objectives of the present research, it needs to be stated that the study does not aim to provide an answer to the ethnicity of the Bronze Age Aegean people, by assigning any ethnicity-related meaning to the results of biodistance analysis. Proving or disproving that the Argolid, Central Crete and Naxos populations were biologically distinct cannot, and should not, be read as evidence for the distinct ethnic identity of the inhabitants of the Mainland, Crete and the Cyclades. In the absence of direct access to the ideologies and perceptions of past people, ethnicity is a very elusive concept (Trigger 1977; Jones 1997), which is advised to be replaced by less pervasive interpretative terms of human behavior, such as "locality" or "identity" (Knapp 1998). This applies to the Archaeology of the Bronze Age South Aegean, where to date there is no known documentation of how the three populations perceived themselves and 'others'.

With regard to the relationship between biological and ethnic identities, the author of this thesis distances herself from theories, which propose 'racial' characteristics as the fundamental determinants of human behavior and culture, and identify cultural and ethnic variation with 'racial' differences (Kossina 1911). The biological relationship between the three South Aegean populations most probably reflects more than 'identity' differences or similarities, e.g. geographical proximity and ease/frequency of interactions. Demonstrating the biological homogeneity of the Cretan population does not constitute sufficient evidence to infer cultural and/or 'identity' relatedness for contemporary Cretan populations across the island. In the same line of reasoning, evidence for biological divergence between the Argolid and Cretan Bronze Age populations should not be equated to inter-population distance in terms of the way they defined themselves in relation to the 'others'. Recent anthropological work has suggested a more flexible and negotiable nature for ethnic identities, such that within a given context these are enacted (Bourdieu 1990).

The present study reconstructs the biological history of the Bronze Age South Aegean population by exploring issues of intra- and inter-population variation, biodistance, population mobility and biological interaction or isolation within a bioarchaeological research framework. It aims to achieve an accurate understanding of the bio-cultural history of the Bronze Age South Aegean population. This is the first study to explore two highly debated questions in the Aegean Prehistoric Archaeology that are traditionally investigated using material culture, in a systematic mode using morphological and chemical analysis of the skeletal remains of the respective populations. It tests archaeological hypotheses that implicate population movements in order to interpret cultural discontinuities and demonstrates that biological history is not dependant on cultural history. Therefore, it should not be reconstructed by reference to the last.

CHAPTER 2

BRONZE AGE SOUTH AEGEAN ARCHAEOLOGICAL RESEARCH FRAMEWORK

Chapter 2 outlines the cultural and theoretical framework of this research. It presents the chronological, geographical and cultural setting of the study. It reviews Bronze Age South Aegean Archaeology emphasizing those aspects that are pertinent to this research (i.e. movements of people and materials, inter- and intra-regional cultural relationships of the South Aegean populations, and destructions and cultural discontinuity that are traditionally associated with the arrival of new population elements), as well as the chronological systems applied to archaeological studies of the South Aegean Bronze Age. It discusses three widely debated questions of discontinuity in the archaeological record of the Bronze Age Aegean and the associated predominant interpretations. Chapter 2 closes by providing an outline of the principal archaeological hypotheses investigated in this thesis following a brief presentation of the two theories that have influenced both the conception of this research by questioning traditional reconstructions of the Bronze Age South Aegean culture history, and its design. Information on the environmental framework (climatic conditions and geology of the Bronze Age South Aegean) of this research is provided in Appendix A.

2. 1 Cultural Framework of the Research

The vast majority of material culture studies picture the Bronze Age South Aegean population as consisting mainly of three distinct, but interacting and mutually influencing population-cultural groups with identifiable ethnic or, more accurately, cultural identities. The boundaries of these population-cultural groups accord very well with the geographic partition of the South Aegean to the Mainland, Cyclades and Crete. The terms assigned to the Bronze Age societies on the Mainland, Cyclades and the island of Crete are Helladic-"Mycenaean", Cycladic and "Minoan" "civilizations" respectively, suggesting common and unifying processes at the regional level. These terms are not ethnonyms, reflecting the common perception of the Bronze Age inhabitants of the Mainland, Crete and the Cyclades of themselves in relation to the 'others' (Renfrew 1996). They constitute modern designations, interpretative terms ascribed by archaeological research. Teaching of the Bronze Age South Aegean Archaeology in Greek universities conforms to the tripartite division of Bronze Age South Aegean culture. The Helladic-"Mycenaean", Cycladic and "Minoan" civilizations are the object of study of "Mycenaean", Cycladic and "Minoan" Archaeology respectively. The viewing of these cultural units as civilizations, as well as the tripartite division of the Bronze Age to Early, Middle and Late periods, inspired by the evolutionary perception of gradual growth, maturity and decline, have rarely been questioned, due to the lack of extensive theoretical debate in the Aegean Archaeology (Hamilakis 2002a).

Particularly in early works, the more or less pervasive changes in the reconstructed cultural sequence of the three cultural units are frequently interpreted by invoking population movements and residential change, in the form either of migration or more often of invasion events (e.g. Tsountas 1898, 1899; Evans 1921; Pendlebury 1939). However, these are studies of material culture evidence and attempting to infer population biological history using material culture evidence alone should be treated as an over-interpretation.

2.1.1 Chronological/terminological systems

At present there is a consensus on the relative sequence, at least in outline, of cultural development in each region of the South Aegean during the Bronze Age based on the studies of ceramic forms and their seriated typologies, against stratigraphic contexts and thus time (Manning 1995). Intra-Aegean correlations of approximate relative chronologies have been established on the basis of material culture data suggesting cultural connections or interchange between the contemporary Aegean populations (e.g. the Early Minoan II phase is contemporary to the Early Helladic II and the Early Cycladic II). Nevertheless, there are minor disputes concerning the relative sequence or terminology as well as the synchronization of the Early, Middle and Late Bronze Age periods in the South Aegean (Barber 1983), which they do not have a great impact on this study. For convenience, this study adopts the traditional chronological framework (Table 2.1).

Table 2. 1 South Aegean Bronze Age Chronologies.

CRETE		MAINLAND			CYCLADES	
EARLY BRONZE AGE						
EM I	c. 3100/3000 - 2700 - 2650 BC	EHI	c. 3000/3000 - 2650 BC		EC I	c.3000/2800 – 2700 BC
EMIB/EM IIA Transition	c. 2700 - 2650 BC				ECI/II Transition	c.2700 - 2650 BC
EM IIA	c. 2650 - 2450/2350 BC	EHII (Early)	c. 2650 - 2450/2350 BC		ECII	c. 2650 - 2300BC
EM IIB	c. 2450/2350 - 2200/2150 BC	EHII (Late)	c. 2450/2350 - 2200 -2150 BC		ECIIIA	c. 2300 - 2200 BC
EM III	c. 2200/ 2150 - 2050/ 2000 BC	EHIII	c. 2200/2150 - 2050/2000 BC		ECIIIB	c. 2200 - 1800 BC
MIDDLE BRONZE AGE						
MM IA	c. 2050/ 2000 - 1925/1900 BC	MHI	c. 2200/2150 - 1950/1900 BC		MC	c. 1800 - 1550 BC
MM IB	c. 1925/1900 - 1900/1875 BC					
MM II	c. 1900/1875 - 1750/1720 BC	MHII	c. 1950/1900 - 1750/1720 BC			
MM III(A-B)	c. 1750/ 1720 -1700/1680 BC	MHIII	c. 1750/1720 - 1680 BC			
MM IIIB/LM IA Transition	c. 1700/ 1680 - 1675/1650 BC					
LATE BRONZE AGE						
LM IA	c. 1675/ 1650 - 1600/ 1550 BC	LHI	High Chronology	Low Chronology	LCI	c. 1550 - 1500 BC
			1680 - 1600/1580	1600 to 1510/1500		
LM IB	c. 1600/1550 - 1490/1470 BC	LHIIA	1600/1580 - 1520/1480	1510/1500 to 1440		
LM II	c. 1490/1470 - 1435/1405 BC	LHIIB	1520/1480- 1445/1415	1440 to 1390+	LCII	c. 1500- 1450 BC
LMIIIA:1	c. 1435/1405 - 1390/1370 BC	LHIIIA:1	1425/1390 - 1390/1370	1390+ to 1370/1360	LCIII	c. 1450 - 1050 BC
LM IIIA:2	c. 1390/1370 to 1360 - 1325 BC	LHIIIA;2	1390/ 1370 - 1340/ 1330	1360/1370 to1340/1330		
LM IIIB	c. 1360/1325 - 1200/1190 BC	LHIIIB	1340/1330 - 1190/ 1180	1340/1330 to 1185/1180		
LMIIIC	c. 1200/1190 -1065/1060	LHIIIC	1190/1180 - 1065/ 1060	1185/1180 to1065		

Table 2.1 illustrates the South Aegean Bronze Age chronologies. The chronologies for the "Minoan" Bronze Age and the Early and Middle Helladic period were taken from Manning (1995). The high chronology dates for the Late Helladic period derive from Manning & Weninger (1992) and Manning (1995), whereas the low dates from Warren & Hankey (1989). The chronologies for the Bronze Age in the Cyclades were taken from Barber (1987).

Inaccuracies inherent in the application of the tripartite division of the Bronze Age to the study of the Aegean culture, and the need for revision and modification of the terminological/chronological system, were recognized in investigations of intra- and inter-cultural correlations within the Bronze Age Aegean. Cadogan (1983) remarks on the inadequacy of the uniform application of Evan's terminology for the "Minoan" culture over the entire island, on the grounds of hiatuses and/or overlappings of culture between different regions of Crete. There have been long discussions over problems regarding the validity of certain chronological phases of the traditional system at the regional level. For instance, Warren (1980) outlines the absence of excavated MMII pottery from outside the palaces in Eastern Crete, suggesting a cultural hiatus for Eastern compared to Central Crete from MMIA to MMIII, or perhaps to LMI (Cadogan 1983).

Attempts to modify the traditional tripartite terminological system to best fit the evidence have been criticized for alleged methodological shortcomings. Watrous (1981) suggests that the stylistic, and hence chronological equation of LMII with LMIIIA1 pottery put forward by Niemeier (1979) is problematic. The invalidity of the argument of Neimeier lies in his methodology and, in particular, in his emphasis on the shapes and decorative designs that show continuity from LMII to LMIIIA1 and negligence of those that demonstrate change. Popham (1975) demonstrates evidence from centres outside Knossos (e.g. Malia, Phaestos, Chania) to support the validity of the LMII and its distinctiveness from the successive LMIIIA1 phase. Additionally, attempts of archaeologists to oversimplify history by suggesting contemporaneity for many destructions, natural, accidental, and/or of human agency that appear to have occurred within a relatively short time span, tend to be problematic (Popham 1975).

As an alternative to the Three Age System (Rodden 1981) of relative chronology (based on typological analysis of pottery), three contrasting terminological and/or chronological systems have been proposed for the description of the Bronze Age South Aegean culture: the culture system (Renfrew 1972; Doumas 1977); a four-stage system based on the history of the "palace" on Crete, namely, Pre-palatial, Old Palace, New Palace and Post-palatial periods (Platon 1949); and the absolute (calendar) dating system (Cadogan 1978). Barber & MacGillivray (1980) review the "culture" terminology proposed for the description of the Early Cycladic period and suggest that terminological systems are partly "a matter of taste" and the most important factor controlling the choice of terminology should be convenience of use (Barber & MacGillivray 1980:156). They judge as insufficient the evidence for genuine cultural distinctions within the EC period and propose as more appropriate the use of the traditional tripartite system (ECI, II, III) with minor modifications. Although the author of this thesis agrees with their conclusion, she thinks that the research methodology in studies of prehistoric archaeology should not be "a matter of taste", but the result of scientific testing.

2.1.2 Initial Population Events in the Three Regions

With regard to the initial population events in the Mainland, Crete and the Cyclades, different origin places have been suggested for the first inhabitants of the three geographical regions. Despite the evidence that the Aegean was being navigated as early as the Paleolithic and obsidian from Melos, in the Cyclades, was reaching the Greek Mainland by the Late Upper Palaeolithic (Perlés 1987), Crete and the Cyclades were not populated before the Early and the Late Neolithic respectively.

Mainland: In the Mainland, the first Neolithic communities appeared at the start of the seventh millennium BC. To date, there is no consensus as to whether the initial agriculturalist population originated from Western Anatolia, as in the case of Crete, and it admixed with the pre-existing Paleolithic and Mesolithic population (van Andel & Runnels 1995; Renfrew 1996; Colledge *et al.* 2004), or the agriculture and associated ideologies were locally adopted (Hallstead 1996).

Crete: Crete is a very good example of a purposeful maritime colonization and the introduction of agriculture in the aceramic Neolithic. On the available faunal and floral evidence from prehistoric Crete, the hypothesis for an indigenous transition from a pre-Neolithic to the aceramic Neolithic period is falsified (Broodbank & Strasser 1991; Halstead 1996). Both faunal (i.e. cattle, sheep, goat, pig) and flora domesticates [i.e. bread wheat, a hybrid between the domesticated tetraploid wheat and wild Aegilops squarrosa (Zohary & Hopf 1988)], given the absence of their wild prototypes on Crete, appear to have been introduced to the island by humans that arrived in this period (Broodbank & Strasser 1991). To date, there is no evidence for a pre-Neolithic human presence (Broodbank & Strasser 1991). Cherry (1990) provides a brief account of the evidence, which has been alleged to demonstrate a pre-Neolithic human presence on the island, but has been rejected following thorough re-examination.

Concerning the ultimate origin of the first settlers on Crete, the botanical evidence (i.e. the Knossian bread wheat (Triticum aestivum) that is present at Can

Hasan III and Çatal Hüyük (Mellaart 1975; Renfrew 1983), but is absent from the earliest Neolithic sites on the Greek Mainland), and material culture evidence (e.g. pottery, architecture), assign high probabilities to scenarios implicating the Anatolian coast (Broodbank & Strasser 1991; Renfrew 1996), or the East Aegean (Warren 1973).

Cyclades: Excavations in the Cyclades, dating from the late 1980s, have revealed a growing number of sites, which provide evidence for Late Neolithic human occupation or activities on the islands (Cherry 1990). Two notional initial colonizations of the Cycladic islands have been modelled. In the earliest (Late Neolithic, c. 5200-4200 BC), the colonists involved originated from the Southeast Aegean (starting from the Dodecanese), whereas in the second one (Final Neolithic, c. 4200-3200 BC), colonists probably moved simultaneously from the Greek Mainland (Attica and Euboia) and the Southeast Aegean (Davis 2001). On the basis of the present data, colonization of the Cycladic islands most probably did not involve incremental changes in specialist activities (e.g. obsidian acquisition from Melos, fishing). It appears to have resulted from decisions made in a few key areas on the two transitional zones (South-east Aegean islands and Attica and Euboia) where the edges of the Cyclades were negotiable, and the distinction between insular and non-insular landscapes is less clear, in order to use the islands in a new manner (Broodbank 2000:141).

Kondoleon (1961), one of the first archaeologists to excavate in Naxos, briefly reviews some ancient traditions referring to the relationship of the island with Crete and other regions in the Mainland, emphasizing the inherent difficulty of deducing real historical information from myths. In this context, according to one tradition, the first people to settle on Naxos were Thraces, originating from North-eastern modern Greece. These people later sought female mates in Thessaly, in East-central Mainland.

2.1.3 Bronze Age South Aegean Archaeology: An Outline

The beginning of the Bronze Age in the South Aegean is obscure and is suggested to have occurred under diverse conditions for the different regions. This obscurity should be attributed, principally, to the dearth of well-stratified sequences dating to this period. Moreover, the definition of the EBI phase is not conspicuously clearer, due to the considerable absence of crude evidence for the relative Aegean phasing. The most important changes in the EBA South Aegean concern a marked increase in settlement density, the rise of local centres of economic power and socio-political complexity, and the intensification of inter-regional contacts and exchange dominated by the Cyclades. Broodbank (2000:47) outlines the two most influential interpretations of the changes that occurred in the Aegean society, economy and technology in the EBA. Renfrew (1972) emphasized the social impact of the adoption of Mediterranean polyculture (i.e. olive and vine are introduced to the Neolithic repertoire of agricultural products), whereas van Andel & Runnels (1988) attributed the EBA changes to a "secondary products revolution", meaning the adoption of ox-plough and exploitation of sheep for wool and dairy products. Broodbank (2000:47) insightfully remarks that on present data, both hypotheses that implicate the cultivation of vine and olives, and the use of animals for wool and dairy products in the EBA are problematic. Thus it remains unclear precisely what combination of factors accounts for the changes in the EBA.

Surface surveys have resulted in a considerable increase in the number of sites on the Greek Mainland from the Neolithic to the Early Bronze Age. The Southern Argolid Survey of Stanford University showed that in the southern Argive peninsula (the Hermionid), the number of sites has increased from a maximum of 13 Neolithic sites to around 26 to 32 EHI/II sites (van Andel & Runnels 1987: 85). Bintliff (1977) notices a consistent preference of the EBA people for the areas with the best arable soils. Likewise, in both Laconia (Waterhouse & Hope-Simpson 1960) and Messenia (Mainland) (McDonald & Rapp 1972), there is an increase in the number of EBA sites compared to the Neolithic period.

In the EHI or early in the EHII, one more interesting change in the history of settlement in the Argolid occurs. Surface surveys suggest that in the course of the general increase in the total number of sites, during the EBA, the development of certain important sites is paralleled by the abandonment of smaller EHI sites, probably reflecting a process of political "nucleation" or "synoecism" (Wiencke 1989:499). In this case, fluctuations in population numbers are associated with economic changes. Runnels & van Andel (1987) do not assign self-sufficiency to the Argolid settlements. On the contrary, they envisage their development as being strongly dependant upon external 'markets'. According to their interpretative model, the population will increase as a response to the demand of the increasing agricultural production for greater labour force. The increase in the agricultural production is stimulated by external 'markets'. When 'markets' are cut-off, the population will decrease to eliminate production cost.

In all three Mainland regions (Argolid, Laconia, and Messenia) the status of the EBIII is problematic. In Laconia and Messenia, the EHIII is practically absent (Rutter 2001). Interestingly, while there is a significant drop in the size of the population reflected in the decline of the number and size of the settlements from the EHII to the EHIII (van Alden *et al.* 1986; Runnels & van Alden 1987; Wright *et al.* 1990; Forsen, pers.comm., cited by Runnels 2001, Mee, pers. comm., cited by Runnels 2001), there is no evidence for either a contemporary increase in the mortality rate manifested in the rise in the number of burials, or inferences for the emigration of Helladic population groups to other regions on the basis of the material culture data. A very interesting interpretation that has been put forward implicates shortcomings or inaccuracies in the dating of the EHII sites and argues on this basis for the less abrupt character of these changes (Forsen 1992). The alleged decline in the number of the EHIII sites could have started in the last phases of the EHII and probably peaked in the EHIII rather than commencing then (*ibid.*).

The burnt destruction horizon separating the EHII and EHIII phases in Lerna (Argolid), accompanied by major changes in the material culture (Caskey 1960), is not typical of this transitional phase in other sites on the Mainland (i.e Tiryns in the Argolid, Kolonna on Aegina, and Thebes in Boeotia). Moreover, recent research (for references see Rutter 2001:115) has called into question the suggested abrupt character of the changes in the material culture and argues for smoother changes characterized by the fusion of past and new cultural traits. For instance in Lerna, changes in the typology and techniques of the ceramic production are traced already to an early stage of the LHII and intensify in the later phases of the period. Social significance has been attributed to some of these changes, whereas for others there has been postulated an alteration in the behaviour or composition of the group of people employing certain pottery to the tasks they performed (Wiencke 1989). Additionally, a brief hiatus in the occupation of Lerna during the LHII-III transition has been challenged by the excavation results from other sites in the Argolid (Tiryns, Asine, Berbati) (Pullen 1987). Within the Argolid, significant inter-site differences in the material culture during the transition from the EHII to EHIII, should be interpreted as indicative of the differences in the transitional processes operating between the various sites, rather than by accepting arbitrarily any particular site during this period as the type-site in terms of its cultural sequence, and on the basis of this model assign relative dates to the other sites (Rutter 2001: 115). Moreover, it is plausible that the duration of the EHII culture in some sites/regions could have been longer than in others (Rutter 1979, 2001).

On the island of Crete, the reality of EBIII has been contested on published well-stratified EMII-MMI cultural sequences and a longer duration for the immediately succeeding period (MMI) has been favoured. At the end of the EMIIB many sites on Crete were abandoned. In some cases, there is a gap in the continuous occupation following the end of the EMIIB, e.g. at Myrtos Pyrgos (Cadogan 1977-78). Moreover, destructions by fire have been recorded at the end of the EMIIB at Vasiliki, Fournou Koriphi and Malia. In addition to evidence from larger sites for limited occupation during the EMIII (e.g. Phaistos, Kommos, Palaikastro), recent surveys at Gournia and the Isthmus of Ierapetra suggest that during this period the rural landscape was largely deserted (Watrous 2001).

Evidence for a hiatus in the use of the tombs from the EMIII till the MMIA accords well with the picture of abandonment of the settlements at the end of the EMIIB. The hypothesis for a gap or a shorter duration of the EMIII has gained considerable ground due to the work of Momigliano (1991). She revealed that the EMIII-MMIA definitions of the pottery assemblage at Knossos were highly problematic and she grouped together some of the previously defined MMIA material with EMIII pottery. It is worth mentioning that these definitions from Knossos have served as island-wide definitions. Likewise, more systematic studies of the EMIII East Cretan pottery at Mochlos (Andreou 1978), Gournia and other eastern sites (Watrous 2001), show that it (EMIII pottery) occurs without discrimination with Central Cretan MMIA pottery. Hence these studies conclude that the EMIII phase most probably represents a construct, an artefact of the traditional tripartite division of the chronological periods, rather than a chronological reality.

One of the crucial points in the debate on the Aegean Bronze Age chronology is the eruption of the Theran (Santorini) volcano in the Cyclades (Treuil *et al.* 1996). During the past decade, Kuniholm's Aegean Dendrochronology Project established a master ring sequence, which suggests the date of 1628/7 BC for the volcanic eruption (Manning 1995). This revised Aegean "high" chronology is in contradiction with the traditional "low" chronology. "Low" chronology derives from the cross-dating with other cultures of the Mediterranean, i.e. the Egyptian and Syro-Palestinian cultures.

The recovery of LMIA pottery from destruction deposits on Thera pushed back the beginning of the Late Bronze Age to an earlier date (c. 1700BC), and attributed a longer duration to the LMIB than previously thought (*ibid.*).

The physical effects of the volcanic eruption on Crete are highly debated. In the LMIA, significant destructions have been recorded at a number of sites on the island. Hood (1973) associated these destructions on Crete with the actual volcanic eruption. Destructions on Crete were followed by either complete or partial abandonment and shrinking of the depleted settlement, coupled with architectural modifications. For instance Vathypetro appears to have been abandoned after an LMIA catastrophic earthquake, whereas at Palaikastro, there is evidence for the deliberate demolition of buildings following the LMIA destructions, as well as the abandonment of some areas of the settlement (Tomlison 1995). Evidence from Palaikastro, however, suggests a gap between the earthquake that damaged a building in Area 6 and the deposition of the Theran ash. Hence the hypothesis for a causal relationship between the two (i.e. the earthquake and eruption) is rejected (MacGillivray & Sackett 1994).

In many cases, the LMIA destructions have been associated with earthquakes and tsunamis, which normally precede and accompany major eruption episodes. Of the more than fifty-five Neopalatial Cretan sites that Driessen & Macdonald (1997) discussed in their work, eighteen suffered from earthquakes and six from fire and possibly also earthquakes in the LMIA. Driessen & Macdonald (1997:89), however, questioned most of the suggested tsunami-related destructions of Cretan settlements, but did not exclude the possibility of flooding (due to tsunami) of coastal areas. Volcanic ash (tephra), most likely from the eruption of the Theran volcano, has been recovered from Cretan sites, but not from well-defined layers (Higgins & Higgins 1996: 199). Driessen & Macdonald (1997:87) associate the LMIA destructions on Cretan sites, Thera and the Dodecanese with a pre-eruption earthquake (probably tectonic) that preceded the actual eruption and that is contemporary with the early LMIA (LCI) "seismic destruction" of Akrotiri on Thera. Drawing upon historically documented eruptions of the Theran and other volcanoes in the world, they reconstructed the potential psychological, socio-political, climatic and economic effects of the eruption for LMIA Crete (*ibid.*).

Nevertheless, the most significant interruption of the Minoan culture has been argued for the end of the LMIB phase. At the end of the LMIB, there is substantial evidence for significant disruptions at a number of sites on Crete as well as at sites on the Cycladic islands, which appear conspicuously "Minoanised". These disruptions are most commonly manifested in a fire destruction layer frequently succeeded by the complete abandonment of the site until the LMIIIA (Watrous 2001). Interestingly, while major destructions have swept the island from West to East and from North to the South, at Knossos the palace bears no identifiable signs of LMIB destructions. At the same time, a number of buildings in the immediate vicinity of the palace (i.e. structures along the Royal Road and the Cult Basement) suffered damage or even complete destruction (Hood 1961, 1962; Driessen & MacDonald 1997: 156).

The LMIB destructions appear to be selective and targeted to the administrative centres. This is suggested by the isolated destruction of buildings housing Linear A documents, for instance the "mansion" at Myrtos-Pyrgos (Cadogan 2000) and the Building B2 at Mochlos (Watrous 2001). Several scenarios have been constructed to interpret these destructions. These are briefly discussed later in this chapter (section 2.1.5 Destructions and the Arrival of New Population Elements). The two most prevalent scenarios implicate an invasion by "Mycenaeans" who took over the political control of Crete with, or without, the collaboration of Knossos (Mellersh 1970; Hood 1985; Barber 1987), or inter-state warfare and a Knossian political domination of the entire island (Hallager 1988; Niemeier 1983).

On the Mainland, equally interesting regarding the disruption of the cultural sequence is the transition from the LHIIIB to the LHIIIC phase. Archaeological research in a great number of sites (e.g. Tiryns, Midea, Mycenae, Nichoria, Gla, Athens, and Thebes) has recorded destruction levels and abandonment of the settlement, occasionally confined to certain buildings or parts of the settlement dating to this period (Hope Simpson & Dickinson 1979). The first evidence for widespread damage dates to the end of the LHIIIB1. In some cases, sites on the Mainland went out of use without preceding destructions (e.g. Nichoria, Tsougniza). Noteworthy is that at Mycenae, Tiryns and Athens alterations were introduced to the fortification system following the LHIIIB destructions. At Mycenae and Pylos these are coupled with the increase of storage and working areas in the proximity to the palace (Wright 1984). Additionally, survey results suggest there is contemporary evidence for a dramatic depopulation occurring at this period (Shelmerdine 2001).

Although habitation continued at the citadels of Mycenae, Tiryns and Midea, the megaron units, centre of the palatial complex, went out of use in the first two cases, whereas the megaron at Midea was remodelled and put to serve different purposes (Åström 1994; Demakopoulou 1995). The demolition of the palatial administration is the most prominent change associated with these processes and this should probably form the basis for interpreting the above outlined changes. It is the highest rank of the Late Helladic society, which appears to be most severely depleted by the disasters of the end of the LHIIIB, whereas at the lower level, "Mycenaean" life does not show signs of discontinuity. Shelmerdine (2001) has discussed a range of interpretations for the LHIIIB-C destructions and cultural discontinuity on the Mainland and supported the plausibility of the theory of the "systems collapse" (Renfrew 1979), which argues for the economic decline of the Mycenaean administration system exacerbated by intra-regional competition of the contemporary states. This competition could have resulted in inter-Kingdom warfare and/or local uprisings and attacks to the palatial centres. Even though it does not explain adequately some of the changes during the latter half of the LHIIIB, this interpretation acknowledges the evidence for a more direct hit to the higher level of the LHIIIB society.

2.1.4 Inter-regional Contacts: Movement of People and Materials

This section reviews evidence for inter- and intra-population social interactions between the Argolid, Central Crete and Naxian populations. The movement of people can be monitored by line-tracing the movement of commodities, which delineates the so-called trade routes and by exploring cultural relationships, similarities and differences, at the regional and inter-regional level. Cultural homogeneity, in particular, is suggested to be consistent with the requirements and consequences of an interactive mating system, on the grounds that trade, exchange and cultural assimilation derive naturally from the operation of a regular network of social interactions (Manning 1994). Nevertheless, the dispersion and/or local imitation of pottery that is the most abundant of the exchanged commodities preserved, although it signifies interaction, it cannot provide more specific information regarding the nature of this interaction (Dickinson 1986). Therefore, many of the early hypotheses formulated concerning the politico-economic pre-eminence and control of the Aegean and Eastern-Mediterranean trade first by the

"Minoans", and then the Mycenaeans, need reassessment (Knapp 1993). In particular, the available evidence for the interpretation of certain Bronze Age Aegean settlements as Minoan or Mycenaean colonies-emporia should be subjected to close scrutiny to confirm their validity.

Although the operation of networks of contacts is a prerequisite for inter-population gene flow and genetic admixture, it is not obligatory. The movement of people and the establishment of social interactions between populations create the potential for biological interactions. If there are no contacts, there can be no biological interaction or at least, nothing more than a sporadic one. The more regular the gene-flow is between populations, the smaller their biological distance is.

Inter-connections between the three cultures of the South Aegean and the eastern Mediterranean have been thoroughly explored in studies of Bronze Age Aegean archaeology. A plethora of conferences in the last two decades have endeavoured to shed more light on this research area (Rehak & Younger 2001). During the course of the Bronze Age, the incentives and functions of trade were diverse, ranging from purely economic, to social and ideological. Demand for certain goods was never constant or uniform. During different time periods, the same goods travelled in numerous directions through different exchange mechanisms, and/or different means of transport (Knapp 1993). Moreover, all three major cultural units in the Aegean appear to have had the control of these transactions in different phases of the examined period; the Cyclades in the Early Bronze Age, Crete in the Middle Bronze Age with a peak from MMIII till the end of LMI, and the Argolid (Mainland) mainly in the middle Late Bronze Age.

Cyclades: The earliest evidence for inter-regional contacts in the South Aegean occurs before the Bronze Age. There appear to be strong links between the Final Neolithic to Early Minoan I on Crete on one hand, and pre-Troy I (Poliokhni Black, Kum Tepe I A-B, Samos Tigani), and Troy I-Yortan period in north-western Anatolia, on the other (Watrous 1980, 2001). As mentioned earlier in this chapter, obsidian from Melos is present in Late Upper Paleolithic contexts in the Southern Argolid (Mainland), at a time when there is no evidence for human settlement on the Cycladic islands. The same model of direct access has been also suggested to interpret the acquisition of obsidian in later periods, from the Neolithic to Early Bronze Age (Torrence 1982, 1986). This is justified on evidence of not just obsidian cores, but also raw blocks, débitage and finished products at some of these later sites.

Nevertheless, Manning (1994) suggests on the basis of the proportionally small number of Early Bronze Age artifacts from Crete and the Mainland that have been recorded in the Cyclades, compared to the number of Cycladic artifacts present in Crete and the Mainland, that it is more reasonable to infer a centralized distribution system of obsidian out from the Cyclades to coastal Crete and the Mainland.

Clay and stone vases, marble figurines and jewelry, locally produced in the Cyclades, occur in the Early Bronze Age archaeological contexts of the Mainland and Crete. Renfrew (1991) interpreted the occurrence of Cycladic artifacts on the coastal Mainland and Crete as the evidence of the operation of a network of exogamous communities, to which gift-exchange of fine ware and other valued artifacts was incorporated. The small size of even the largest Cycladic sites would have necessitated the participation of the island population in a network of social interaction on both an intra-and inter-island basis. Small- and middle-sized island populations would have benefited from this network, providing them with access to a wider population pool for mates (Davis 1987). Nevertheless, with the exception of islands in proximity to the coast of the Mainland, it would have been economically impractical to maintain such a broad exogamous network incorporating the coastal part of both Crete and the Mainland. Additionally, one of the most widely postulated consequences of the operation of an interactive mating system, the stylistic transfers and cultural assimilation (Manning 1994), is not adequately manifested between the Cyclades and Crete.

If the occurrence of Cycladic artifacts on Crete and Mainland in the Early Bronze Age is seen in conjunction with the dearth of Cretan and Mainland artifacts in the Cycladic islands dating to this period (Rutter & Zerner 1984), it could be indicative of the perishable nature of the cargoes traveling in the opposite direction (Manning 1994). Due to the suggested small size of the great majority of the Cycladic sites, subsistence products for the needs of such communities would not have been too large for a small boat (Manning 1994). The Cycladic islands demonstrate what Braudel (1972) observes about islands and island clusters, being places that amplify and polarize isolation and interaction, due to the complex symbiosis of land and sea. The marginal environments that the islands offer would have failed to prevent times of hardship, due to shortfalls in subsistence resources.

According to the model of prestige goods for social storage, craft specialization in the Cyclades developed as a buffering technique for the small island communities (Renfrew 1991). Although transportation of subsistence products for the needs of a small Cycladic community in a social storage model is not impossible via a small boat, interpretations implicating long-distance (extra-regional) trade in bulk subsistence resources have been characterized as anachronistic (Manning 1994). It is argued, instead, that trade and control were largely non-utilitarian, restricted to the elite and that craft specialization developed to serve in social competition and the legitimization and consolidation of power (Helms 1979). Movement of rare, non-utilitarian resources most probably exploited the earlier (Early Bronze Age I-II) established networks of social interaction (Manning 1994:227). Controllers of the long-distance trade and the principal beneficiaries of the exchange of prestige goods appear to have been special "trader" sites, such as Chalandriani on Syros, Ayia Irini on Kea and Daskalio-Kavos on Keros (Broodbank 1989, 1993), thereby challenging traditional views of seafaring freedom and freelance trade in the Early Bronze Age Cyclades (Manning 1994:229).

To the outward movement of locally produced Cycladic artifacts we should add that of Melian obsidian and Cycladic metals (Stos-Gale 1989). Broodbank argues that it is relatively unlikely that bulk subsistence goods from Crete were exchanged for Cycladic commodities, due to the modest capacity of the paddled dug-outs in rough seas. The island of Crete is at a significant sailing distance from the Cyclades. The minimum crossing from Thera, over 100km, would require, at paddle speed nights at sea out of sight of land. Therefore, most probably, Crete was visited only as a result of a purposeful mission undertaken by one of the major specialist 'trading' communities with a longboat (Broodbank 1993). The hypothesis for Cycladic exchanges for Cretan subsistence goods, however, should not be discarded given the widely accepted hypothesis for the successful maritime colonization of Crete, dating to the Early Neolithic, by people crossing the Aegean waters on longboats carrying on board faunal domesticates, seed crop, food and water supplies (Broodbank & Strasser 1991).

Broodbank (1993:326) goes further to suggest that Cycladic commodities were exchanged for "esoteric and exotic knowledge", hence the apparent lack or paucity of commodities traveling to the opposite direction. EBA Cycladers appear to have been more interested in customs and traditions compared to the actual objects of the extra-regional sites they visited, and this is probably reflected in the reproduction of drinking and pouring vessels of Mainland and Anatolian typology in local Cycladic material. According to Broodbank (1993), this should be associated with the introduction and adoption of social practices, exotic for the Cycladic context. Nevertheless, the validity of the hypothesis that the people from the Cyclades were traveling aiming to acquire knowledge of the extra-regional world and import new practices to the Cyclades cannot be tested using the available data. After all, it is reasonable to expect that ideas were traveling back to the Cyclades with the people that were moving. The acquisition of knowledge did not need to be travelers' prime motivator for maritime movement over distance.

Crete: Concerning the island of Crete, pottery connections with north-western Anatolia have been proposed for the Final Neolithic, which in the Early Bronze Age, expanded to encompass the islands of the east Aegean as well (Warren 1980). In Lerna (Argolid) there is evidence for interactions with Crete, dating to the EMIII and MMIA (Caskey 1957:144). EMIII and MMIA pottery from East and Central Crete respectively, has been recovered from Phylakopi on Melos (Cyclades) (Cadogan 1983; Rutter 1983). The Oxford Program of lead isotope analysis of EM metal objects suggests a heavy reliance of the Cretan metalworkers on Cycladic sources for their copper, silver and probably gold (Gale 1990). For instance, analyses have shown the Agia Photia metal to originate from the Cyclades, and the copper from the Mesara tombs to be primarily from Kythnos (Cyclades), but also Lavrion (Mainland) and possibly from Cyprus. Two examples from the Mesara tombs, however, suggest a local Cretan source (Stos-Gale & MacDonald 1991). The metal ores of Lavrion (Mainland) and Siphnos (Cyclades) are suggested to have been used for the lead objects recovered at Archanes and Mochlos (Stos-Gale & MacDonald 1991).

Already in the Early Bronze Age II period, Crete had entered the Eastern Mediterranean network of interactions. On present data, due to the relative lack of identifiable commodities from Crete traveling to the Near East or Anatolia, where objects recovered from Cretan contexts had originated from, a passive role in the Eastern Mediterranean trade is envisaged for EMII Crete (Manning 1994). In the following period (EMIII to MMIA), however, the situation changes and is characterized by strong internal incentive for foreign interactions. The local elite is suggested to have stimulated this change in order to access the network of long-distance trade that was seen as a resource to fuel competition in the Cretan socio-political context (Manning 1994). Concerning the commodities traveling from Crete towards the Eastern Mediterranean, amongst the strongest candidates are olive oil, wine, wool and textiles, timber, craft goods, and most importantly silver as raw resource and finished products (Warren & Hankey 1989). In contrast to Egypt, where silver is not naturally available in any quantity, the Aegean and particularly the Lavrion source in Attica, is very rich (Gale & Stos-Gale 1981). The inference is that Crete benefited from the control and supply to the Eastern Mediterranean trade network of both the raw resource of silver and finished silver products (Manning 1994).

On Crete, inter-regional contacts increase dramatically in the beginning of the Middle Bronze Age (Walberg 1983). An intensive internal trade on the Cretan island has been reconstructed for the MBA, on the basis of both regional imports and inter-regional similarities in the ceramic styles (Warren & Hankey 1989). It is suggested that the Minoan civilization grew more homogeneous in this period. Nevertheless, the local variations do not become extinct. Moreover, within the Aegean context, Cretans play the leading role in inter-regional contacts. On pottery evidence, in the MMII, the Cretans were trading with the population of many sites in the Cyclades, Dodecanese, Cyprus, the Eastern Mediterranean and Egypt (Barber 1984; Melas 1985:173; Barber & Hadjianastasiou 1989; Stos-Gale & Macdonald 1991:267). Their interest in metals and particularly tin must have been the prime motivator for their contacts with Anatolia and Syria, in both the Proto-palatial (MMIB-MMII) and Neo-palatial (MMIII-LMI) period (Mellaart 1971). Crete may have been the sole possessor of tin in the Aegean world, importing it from the East. A note should be made on the importance of this monopoly in terms of the production of bronze goods. Nevertheless, it is during the LMI that the contacts between Crete and Cyprus, the Levant and the Near East reach their peak.

A great amount of Cycladic, mainly Theran, pottery was recovered from LMI contexts in Eastern Crete (Watrous 1985). Cypriot pottery is also imported in some quantity and a great quantity of contemporary Minoan pottery travelled in the opposite direction, to Thera and Cyrpus and the Near East (Hankey 1973). Concerning the trade in the Neopalatial period (MMIII-LMIB) three major trade routes crossing the Aegean have been reconstructed (Rehak & Younger 2001). These are briefly outlined as follows and illustrated in Figure 2.1.

a. Crete to Messenia: The route connects Crete to the South-West of Messenia, passing from the island of Kythera and Lakonia on the Mainland.

b. "Western String": A Cycladic route passing from Thera, Melos and Kea to Lavrion (Mainland), where mines of copper and silver were accessible.

c. "Eastern String": An Eastern route passing through the Dodecanese and leading to Anatolia and further to the interior of the Mainland. From east to west, the route ascends the Levantine coast, leaving Cyprus and the coast of Anatolia to reach the islands of Rhodes and Karpathos. Herein following a southern direction, it reaches Cape Sidero on Crete. At this point the ships had two options: a. travel westwards along the north coast of the island and enter the Gulf of Mirambello, or b. continue sailing to the south and then at Kommos turn west and sail across the south coast of Crete. Alternatively, if the winds and currents were benevolent, ships could head further south across the Libyan Sea.

The Aegean contacts must have been facilitated by the establishment of emporia (trade stations) and colonies on islands controlling important trade routes. It is suggested that already in the EBII, the Cretans established a settlement-colony on the island of Kythera possibly serving in the trade with the Mainland. The concept of a Minoan "thalassocracy", meaning a maritime supremacy, during the MMIII to LMI, is deeply-rooted in prehistoric Aegean archaeology (Hägg & Marinatos 1984). The first historical reference to it (Minoan "thalassocracy") dates to the fifth century BC (Thucydides I, 3-8), but it is not yet clear how accurately it reflects historical reality. Nevertheless, even if the Cretans exercised control over the intra-Aegean trade, the idea of a Cretan economic-political pre-eminence in the eastern Mediterranean has been challenged (Branigan 1989; Knapp 1993).

Using material culture evidence, the arrival of immigrants from the Cycladic islands and even Western Anatolia has been suggested for many settlements of the North coast at the beginning of the Middle Minoan (Watrous 2001:190). New burial types were introduced at this period on the island, namely the cist graves and the pithos burial. The first is native to the Cyclades, where its use dates from the EBA. Pithos burials, however, are a characteristic Western Anatolian burial type (Wheeler 1974) with a wider dispersal than the cist graves, from Chania in the west, to Zakros in the east (Watrous 2001).

Figure 2.1 Trade routes crossing the Aegean (after Abulafia 2003:29).

Argolid (Mainland): Later, in the LHIIIA2-LHIIIB, the Mycenaeans dominate in trade interactions, and probably expand their commercial power to areas that were previously controlled by the Cretans, and further from these to new ones in the west. On the basis of pottery evidence from the Levant and Egypt to the east, and Italy, Sicily and Lipari to the west, Immerwahr (1960) attributed to the Mycenaeans a pre-eminent position in the Eastern Mediterranean trade, facilitated by the establishment of merchant colonies (emporia). Interpretations of a Mycenaean politico-economic domination of the trade in the Eastern Mediterranean have been formulated to a great extent by analogy with the later Athenian Thalassocracy (5th century BC). These hypotheses have been constructed predominantly upon pottery evidence; LHIIIA-B pottery is found on Cyprus, at Ugarit, at sites along the Levantine cost and in Egypt (Knapp 1993). Local imitations of the Mycenaean pottery at some of those Eastern Mediterranean sites have been interpreted as evidence for the settlement of Mycenaeans, who sought there refuge following the destructions on the Greek Mainland at the end of LHIIIB period (Tsountas & Manatt 1897). These interpretations, however, have been seriously challenged in more recent studies, which note that the local population could have been equally responsible for the imitations of the imported pottery. Hence there is no need to assume the permanent settlement of people from the Greek Mainland (Sherratt & Crouwel 1987).

Concerning the dispersal of Mycenaean pottery to the Eastern Mediterranean, the present evidence is too frail to suggest a dominant role of Mycenaeans in the trade in this region through colonies and emporia (Schallin 1993). Hankey (1967) proposed the 'down-the-line' model for the interpretation of the distribution of the Mycenaean pottery to the eastern Mediterranean. According to this model, Cyprus received the greatest portion of Mycenaean pottery, and the rest was traded from there, further to the south-eastern Mediterranean. On present evidence, distribution of the data fits the model well (Knapp 1993).

Stronger evidence for the prominent role of the Mycenaeans in the Bronze Age Eastern Mediterranean derives from the funerary and domestic architecture. For instance, the chamber tomb cemeteries near to Miletus (Anatolian coast) (Mee 1988) and the stone-built "Mycenaean" tombs at Ugarit (Schaeffer 1939, cited by Knapp 1993) have been associated with the presence of people from the Greek Mainland. Concerning the Miletus cemetery, however, although Gödecken (1988) recognizes that the architecture is not Anatolian, she judges that this evidence is inadequate to suggest the actual presence of immigrants from the Mainland. In the Dodecanese, in the LHII, on the basis of pottery and tomb architecture evidence, Mycenaeans are suggested to have settled at Cretan colonies (Mee 1982).

Despite the lack of direct reference to long-distance trade in the Linear B tablets (Killen 1985), the prevalent view is that inter-regional trade was palace-centred. The incentive for trade was given by the elites and their desire to acquire prestige, high-value goods to serve the legitimization of their political power. Palace-led transactions also mobilized the emergence of an independent mercantile economy. Within the Aegean, these merchants conducted transactions in parallel to those led by the palace, and continued following the demise of the palatial system at the end of LHIIIB period (Sherratt & Sherratt 1991:373).

To sum up, according to material culture evidence, the three Aegean populations did not exist in isolation. On the contrary, in the Early Bronze Age they already had established contacts based on the movement of goods, which were maintained until the end of the Bronze Age. Interestingly, despite the inter-regional imports and local imitations of extra-regional artifacts, the three geographical – cultural units appear to have preserved their distinct identities. With the exception of MBAIII-LBI Thera and Philakopi on Melos, inter-regional contacts did not allow for an intra-Aegean cultural homogeneity to develop and this should probably reflect a conscious decision, rather than a random, unintentional reality. This conscious preservation of inter-regional cultural diversity discredits the hypothesis for the operation of an interactive mating system at an inter-regional level, since cultural assimilation is one of its widely postulated consequences (Manning 1994). Therefore, studies of material culture deduce that inter-population biological interactions (gene-flow) could have been nothing more than irregular and occasional and hence inadequate to account for an inter-population genetic homogeneity.

2.1.5 Destructions and the Arrival of New Population Elements

Discontinuities in the archaeological record of the Bronze Age Aegean (destruction layers, abandonment of sites often followed by their complete or partial reoccupation and abrupt changes in pottery production especially when the novel pottery group has been associated with a population from a distinct geographical region) have most frequently been interpreted by postulating population movements. These new population groups could come either as immigrants or as invaders. The first case concerns peaceful movement and settlement of new people in the absence of signs of a forceful imposition of changes on the life of the local community and, specifically, on the political sphere. Invaders on the other hand, move in order to conquer the indigenous population and attack the preexisting political power of the society, in order to establish a new one. The most popular and best-presented cases for the arrival of new populations are briefly discussed here.

Lerna - Greek Mainland: Long debate has arisen about the nature of the transition from the EHII to EHIII phase on the Mainland. On basis of the results of the excavations at Lerna (i.e. a burnt destruction horizon and pervasive alterations of the material culture that were pronounced in the pottery), Caskey (1960) suggested the invasion of the Peloponnese by "bellicose" people at the end of EHII. The infiltration of new people continued in the MH period. Then, the region received smaller and less warlike population groups (Caskey 1960). Despite his reservation regarding invasionist hypotheses, in the interpretation of cultural changes Renfrew (1970) acknowledged the abrupt nature of the cultural changes in the EHII-III transition. The two most popular interpretations concerning the identity of the invaders suggest the following. The first proposes that the so-called "Proto-Hellenes/Greeks" who arrived at the Greek mainland originated from the Eurasian Steppe, north of the Black Sea (Blegen 1928; Gimbutas 1974). The second, using evidence for the contemporary abandonment of significant settlements on the islands of the northeast Aegean at the end of the EBII, coupled with data related to the shapes and techniques of pottery production, argues for the North-east Aegean islands as the origin of the newcomers (Renfrew 1996).

Angel (1971) studied the human skeletal material from the Lerna cemetery and commented on the remarkable intra-population biological heterogeneity. He argued that the EHIII and later intruders at Lerna were "on one hand, Iranian plus Eastern Alpine like the Trojan plus Cappadocian plus Pamphylian areas of Anatolia and on the other, Corded Nordic plus Mixed Alpine like the westernmost steppe populations of the N.E. Balkans and somewhat like later Illyrians". He suggested further that during the Middle Bronze Age at Lerna there is probable archaeological and skeletal evidence for the infiltration of people from Crete, the Western Balkans and the southern Cyclades.

Nevertheless, these more traditional hypotheses have been challenged in recent works. The publication of the stratified settlement sequences spanning the EHII-III transition from the major sites of Kolonna on Aegina, Thebes in Beotia and Tiryns in the Argolid show a clear inter-site variety in the circumstances under which cultural change occurred in this period. Therefore, it is suggested that the situation at Lerna is anything but typical of the archeological context in the Mainland (Rutter 2001). Relatively recently, Forsen (1992) reviewed Caskey's hypothesis. She examined evidence from 89 excavated sites in the Peloponnese and East-central Greece and pointed out that destruction levels extending to whole sites, which can be closely dated, do not cluster temporally or spatially. Thus it is probably more appropriate to accept that these destructions are not synchronous, but have occurred haphazardly throughout the EHII and EHIII phases. Moreover, the novel artefactual types, which Caskey associated with the invaders, appear at different times within the Mainland and seem to have entered the region from several different directions. Consequently, it is not very accurate to associate them with a single event of population movement (Rutter 2001).

Crete: In roughly the same period, at the end of the EMIIB, many sites on Crete were destroyed and abandoned. Destruction by fire is manifested at a number of sites and according to recent surveys there is evidence that the countryside was largely deserted during the EMIII. Surveys of Western Mesara, Gournia, Ierapetra, Agiopharango valley and other regions on Crete show that following the EMII, the rural landscape is resettled for the first time not earlier than the MMIA period (Watrous 2001). As mentioned earlier in this chapter, more recent interpretations of the archaeological evidence suggest a gap or a shorter duration for the EMIII on Crete. Nevertheless, Knossos is one of few sites with identifiable stratigraphic levels dating to this phase. MMIA is a period of population growth manifested by an increase in the number and the size of the settlements. Population growth peaked dramatically in the MMIB-II. On the basis of material culture evidence (e.g. cist graves and pithos burials, see page 28), the increase of the population has been interpreted as the result of migrations from the Aegean islands (Coleman 1992) and Western Anatolia (Mellink 1986).

The two strongest cases, however, for which population movements have been put forward to explain changes in the archaeological record concern the arrival and settlement of Mainlanders at the district of Knossos at the end of LMIB or later on during the LMIIIA (Kanta 1980; Hood 1985; Niemeier 1985: 218; Barber 1987: 222; Doxey 1987: 301; Hallager 1988: 15; Driessen 1990: 125; Warren 1991: 36-37; Dickinson 1994; Popham 1994: 93; Rehak & Younger 2001), and on the island of Naxos following the end of the LHIIIB phase (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

Knossos - Crete: In the first case, significant disruptions occur at a number of sites on Crete (e.g. Chania, Nerokourou, Phaistos, Ayia Triada, Mochlos) and those profoundly "Minoanized" ones in the Cyclades, at the end of the LMIB. Abandonment of the Cretan sites follows burning and in many cases there is little sign of resettlement until about 100 years later (LMIIIA-B). Archaeological evidence for the human agency of the LMIB fire destructions include the awareness of the LMIB people of an imminent danger implied in the abandonment of the settlements prior to the destruction; it is very rare that human skeletal remains have been recovered from LMIB destruction deposits, and some of the houses/rooms of houses on Crete were found almost empty (see discussion in Driessen & Macdonald 1997:109). The great number of fire destructions across the entire island in the LMIB, and the general absence of continuity in reoccupation suggests that the fires were not accidental. Moreover, isolated and hidden weapons (hoards) in destruction deposits, sings of plundering and selective destruction of certain buildings within the settlements are suggestive of the anthropogenic origin of the destructions (Driessen & Macdonald 1997).

Of great interest is that the LMIB destructions appear to have aimed at the operating administrative centres of the depleted sites. Settlements and specific buildings that house Linear A administrations suffered severe damage. For example at Mochlos, the ashlar Bulding B2 was destroyed, but not the artisans quarter, which continued into LMII (Rehak & Younger 2001). This most probably implies that the aggression was directed towards a specific segment of the society. At the same time, the absence of LMIB destruction deposits from the palace of Knossos is striking. Interestingly, although several buildings and structures in the vicinity of the palace yielded LMIB destruction deposits, the palace was spared identifiable destructions (Rehak & Younger 2001). However, the hypothesis that the palace of Knossos was deliberately devoid of destructions has been seriously questioned. Macdonald (2002) interpreted the absence of LMIB destruction deposits from the palace, or LMIB dump sites outside the palace, as the result of a massive rebuilding of the palace during the LMIB. At that period the palace was not fully functional and its rebuilding was interrupted by a catastrophic earthquake at the end of the LMIB.

Nevertheless, assessments of the LMIB destructions on Crete have been modified in more recent years by the lack of a consensus on whether the LMIB destructions are all contemporary or not. It is possible that they do not represent a single horizon, but that they took place over years or decades (Popham 1975). On the basis of archaeological evidence from Palaikastro, Mochlos and the Cycladic islands, and the different dates assigned by archaeomagnetic studies to the destructions in Eastern and Central Crete, Driessen & Macdonald (1997:106) suggest for the LMIB destructions a broad contemporaneity of one or two generations. Moreover, many sites show evidence of destructions throughout the preceding LMIA phase (Rehak & Younger 2001).

Finally, LMIB destructions are considered to signal discontinuities in the "Minoan" culture. During the LMII-LMIIIA, new features appear in many aspects of the material culture on Crete, which are similar to contemporary developments on the Mainland. Changes are recorded in the writing and administration, domestic and funerary architecture, the sphere of religion, ritual and mortuary practices, everyday utilitarian artifacts, and the thematography of the representational art (Treuil *et al.* 1996; Rehak & Younger 2001).

In order to interpret the generalized destructions on the island of Crete at the end of the LMIB, and the subsequent cultural upheaval, several models have been proposed:

a. Natural causes such as earthquakes and subsequent fires are responsible for the LMIB destructions. The hypothesis that these destructions are linked to the eruption of the volcano at Thera, dated to the LMIA (Marinatos 1939), has been questioned by studies of the pottery, which suggest a significant time difference between the events on Thera and Crete (Doumas 1978; Davis & Cherry 1984). Nevertheless, archaeomagnetic dating of mud walls fired during the burning of buildings on Crete and the volcanic ash from the volcanic eruption on Thera suggest that the two events are contemporary (Higgins & Higgins 1996). Attempting to reconcile the two discrepant results, Higgins & Higgins (1996) note that destructions on Crete may not have directly resulted from the volcanic eruption, but from earthquakes and tsunamis, which commonly precede and accompany major eruptions. Warren (1985:103) initially suggested the possibility that the LMIB destructions on Crete derived from earthquakes and other phenomena generated by the volcanic eruption. Later, having accepted the chronological discrepancy of the two events, he attributed then LMIB destructions to a major earthquake, which was succeeded by the abandonment of Eastern Crete, social disruptions and a Mycenaean political domination of the island (Warren 1991). The author of this thesis agrees with Driessen & Macdonald (1997) who suggest an anthropogenic origin for the LMIB destructions and the observation that earthquakes and tsunamis do not appear to explain adequately the cultural upheaval that follows these events (Manning 1994).

b. The destructions and cultural discontinuity are attributed to military invasion and political domination of Knossos by Mainlanders from the Argolid. The Mycenaean invaders are said to have come principally as the ruling class surrounded by their warrior aristocracy. These were interred into the so-called "warrior" graves following their death (Sakellarakis 1972; Kanta 1980; Hood 1985; Popham 1994; Rehak & Younger 2001). The Mainlanders either collaborated with the Knossians or they were even invited by them to the island. For that reason the invaders spared the palace of Knossos from identifiable destructions (Hood 1985). "Treasures" of bronzes and evidence of looting, and signs of violent death in the archaeological record (Wall *et al.* 1986), are used to substantiate the hypothesis for the anthropogenic origin of the destructions.

The Mycenaean identity of the invaders is postulated on the basis of the nature of the cultural change that follows the LMIB destructions. Characteristic of the cultural upheaval of the LMII-LMIIIA is the introduction of novel features that are suggested to originate from the Mainland (Popham 1994: 93-4; Rehak & Younger 2001: 441). Two of the most important ones are the introduction of the Linear B writing system (Driessen 1990), and the so-called "warrior" graves (Matthäus 1983). There has been a long-lasting debate, however, over the date of the final destruction of the palace at Knossos and the conflagration of the majority of Linear B tablets from the palace. Niemeier (1985), based on the LMIIIB dating of the Linear B tablets at Knossos, placed the settlement of Mycenaeans at the site and associated changes in the character of the society, not earlier than the LMIIIA1 destruction of the palace.

"Warrior graves" or "burials with bronzes" which occur for the first time in the Mainland (Popham 1974: 255), have been excavated at sites mainly in Central

Crete, and their presence outside Mainland has been associated with settlement by Mainlanders (Popham 1994:93-4; Driessen & MacDonald 1984: 66; Doxey 1987: 303; Driessen 1990: 124-5). It was Sinclair Hood the first to use the term "warrior graves" to describe the importance attributed to the bronze weapons in graves dating from the end of LMIB (Alberti 2004: 129). It is argued, however, that the emphasis given to militarism that is ascribed to the Mainlanders, in the early part of the Late Bronze Age is more of a general trend in the Aegean rather than a novel feature in the Cretan society following the LMIB destructions (Rehak & Younger 2001: 441). Niemeier (1985: 226) very insightfully expressed his scepticism about equating discontinuities in burial customs to population invasion, and argued that the "warrior graves" do not need to belong to Mycenaeans. Even if this hypothesis is true, a Mycenaean presence does not necessarily imply Mycenaean conquest; clustering of these graves in rather small groups could be indicative of "a professional caste of foreigners" (*ibid.*). Finally, it is not yet adequately determined whether this incursion took the form of a military episode, or was accompanied by a preceding or succeeding migration event, with women following the men to the new settlement (Renfrew 1996). Opinions of the research community concerning the "Mycenization" of the island are diverse (Driessen & MacDonald 1997:118).

c. LMIB destructions are suggested to have resulted from inter-state warfare and a Knossian takeover of the island of Crete. The disruption of the "Minoan" culture and introduction of Mycenaean cultural traits need not have taken place with the military conquest and physical presence of people from the Mainland on the island. In the absence of identifiable destruction layers in the palace of Knossos at a time when there is evidence for destructions at settlements spread over the entire island, scholars have suggested a Knossian takeover of its contemporary centres (Niemeier 1983; Hallager 1988). The intensification of the centralization of the power of Knossos over the entire island could have resulted from a shortage of necessary supplies on Crete in this period, and inter-state competition (Manning 1994). The strongest critique of this model derives from the fact that it fails to interpret adequately the destructions at cites in the Cyclades under strong "Minoan" influence (Warren & Hankey 1989), as well as centres close to Knossos and most probably under its domain (Rehak & Younger 2001).

With respect to the last point, however, it should be noted that the nature of Bronze Age "states", like Knossos, and their relationship with nearby centres and contemporary "states" is not yet absolutely elucidated. In his paper on the Malia-Lasithi state, Knappett (1999) explores the relationship between Malia and Myrtos Pyrgos, a site suggested to fall within the political and economic control of the state of Malia. He attributes to Malia an ideological rather than economic power over Myrtos Pyrgos and he argues that it is very inaccurate to ascribe the terms "state" and "chiefdom" and their politico-economic connotations to early complex societies, such as those of Minoan Crete. Interpretations of this kind can potentially mask the variability of political organizations under rigid and inappropriate classifications. For the same reason, Hamilakis (2002a: 7) suggested the abandonment of cultural evolutionist and neo-evolutionist models and the classification of prehistoric societies according to a unilinear evolutionary scheme to bands, tribes, chiefdoms and states, as explanatory tools for Bronze Age Cretan Archaeology. Studies of the material culture, and specifically of architecture and administrative documents, outline fluctuations in the inter-state relationships and the role of Knossos as the political and economic centre of the whole island from the Protopalatial to the Neopalatial (Rethemiotakis 2002). Regionalism and self-sufficiency is suggested for the LMIB centres on Crete (Schoep 1999). Nevertheless, a political and/or ideological control exercised by one major centre upon the others should not be negated on the basis of evidence for economic and administrative autonomy of the major Cretan centres (Schoep 1999).

d. More recent approaches emphasize factors "internal" to the society and social competition as responsible for the generalized upheaval. Rehak & Younger (2001) see in the selective destruction of administrative sites and elite objects, the possibility of a revolution of the lower class and a rejection of the ruling elite and the emblems of their power and authority. Driessen & MacDonald (1997:112) attributed the social unrest and LMIB rebellion on Crete to the combined consequences (psychological and economic) of the pre-eruption LMIA earthquake and the actual volcanic eruption. On the basis of available iconographic and burial evidence from the period, Driessen (2002) argues for the plausibility of a horizontal rather than vertical hierarchical organization of the pre-LMIB Cretan societies, as well as the absence of royalty. Hamilakis (2002b) examines four lines of archaeological evidence: inter-site/regional settlement patterns and spatial organization, intra-site spatial organization, record-keeping technologies and the conspicuous consumption of material culture. He demonstrates how the prevailing hypotheses for the socio-political organization of pre-LMIB Cretan societies fail to account satisfactorily for its extremely complex nature and puts forward an alternative hypothesis using the concept of faction and factional competition. Competing factions might have operated in and around major palatial sites and at the regional level, occasionally including clusters of palatial sites or other monumental buildings. Political territories might not have been rigidly defined. The size and membership of factions probably fluctuated and their spheres of influence were shifting. Knossos might have exercised ideological and cosmological power over its region and the greatest part of the island from the Early Bronze Age and even earlier. It is very likely that some factions would have attempted to translate this to political power, leading to reactions and confrontation with other factions, within or outside their region. In this line of reasoning, the adoption of symbols and practices from the Mycenaean world could be interpreted as symbolic entrainment, meaning the implementation by local political leaders of a foreign symbolic system perceived as superior to the local one in order to justify the political change (Schallin 1993).

Naxos - Cyclades: The second case of population movement(s) associated with cultural discontinuity is concerned with the widespread destructions that the Mycenaean world suffered at the end of the LHIIIB, and the subsequent movement of high status individuals from the Argolid (Mainland) to Naxos (Cyclades). The LHIIIB-C destructions on the Mainland, which appear to select for fortified sites, or sites where palaces or other conspicuous buildings, which probably had comparable functions, were already by 1978 well documented (Hope Simpson & Dickinson 1979). These were preceded by less extensive destructions in the middle of LHIIIB in the settlement of Mycenae outside the fortifications (Shear 1987; French 1998) and the citadel of Tiryns (Iakovides 1983). Destructions recorded at Gla date to perhaps slightly later (Shelmerdine 2001). Of relevance to the etiology of these destructions, is the subsequent extension of the fortification walls at Mycenae and Tiryns. The construction of imposing Cyclopean walls is compatible with an attempt to enhance their defense against an immediate enemy and manifest their strength (Schallin 1993; Shelmerdine 2001), rather than with theories identifying a response to the threat of earthquakes (Iakovides 1986). The validity of the interpretation of the destructions that implicates human agency is strengthened by evidence for an increase in the centralization of resources and personnel manifested in the increase of storage and working areas in the vicinity of the palace (Shelmerdine 2001). In Athens, the construction of the original fortification wall dates to the early LHIIIB1 (Iakovides 1983). At Midea, the construction of some segments of the wall is dated to the later part of LHIIIB1 and LHIIIB2 (Åström 1992; Welberg 1992).

Mycenae, Tiryns and Midea were destroyed at the end of the LHIIIB, but LHIIIC pottery testifies to their immediate reoccupation (Shelmerdine 2001). In contrast, Zygouries was destroyed at the same period, but was not reoccupied in LHIIIC (Drews 1993). Nichoria, Tsougniza, Prosymna, Berbati and probably Lerna were evacuated without apparent evidence of destruction (Desborough 1964; McDonald & Wilkie 1992; Wright *et al.* 1990). Among other settlements in the Mainland, Pylos also appears to have been destroyed during the LHIIIB/IIIC transition and was probably briefly abandoned. Nevertheless, the exact date of the destruction of Pylos is debated (Shelmerdine 2001).

Following the LHIIIB2-C destructions many sites were abandoned and a dramatic depopulation, not only of the Mainland, but also of the islands (Schallin 1993), is manifested in the decline in the number and size of the settlements (McDonald & Rapp 1972). The "megaron", center of the palatial complex, was either abandoned or remodeled thus documenting the collapse of the palatial administration (Shelmerdine 2001). Nevertheless, at the sites where settlement continues in the LHIIIC, there is no evidence to suggest significant discontinuity in the form of novel material culture or practices introduced immediately after the destructions (Shelmerdine 2001).

The stronger, or more popular of the theories proposed for the interpretation of the LHIIIB-C destructions are the following:

a. Natural causes such as earthquakes account for the recorded destructions. Killian (1988) supported this interpretation not only for Tiryns and the Argolid, but also for the entire Peloponnese. However, as Shelmerdine (2001) insightfully comments, earthquakes fail to adequately explain important aspects of the destructions and their aftermath, i.e. destructions targeted principally to palatial centres, enhancement of the defensive power of the settlements, abandonment or change of the use of the "megaron", and the demise of the palatial administration.

b. The enemy that the Mycenaeans perceived and by whom they were destroyed, were the Sea Peoples, mercenaries or pirates, who caused great damage to Egypt, the Levant and Cyprus in the late 13th-early 12th century (Sandars 1978), or northern invaders from the Balkans. According to Drews' (1993) brief account of the history of the theory of the Dorian invasion, by the early 20th century archaeologists and historians, under the influence of Gaston Maspero's thesis, attributed the LHIIIB-C destructions in the Mainland to the invasion of the Dorians. In the last decades, however, old views concerning the timing and starting point of the Dorian invasion have been largely reconsidered. It is now believed that there is no evidence for an invasion responsible for the LHIIIB-C destructions. If there was population movement from the Balkans dating close to the LHIIIB-C destructions, there is no reason to suggest that this was either extensive or greater than in the previous periods (Wells 1992).

c. The highly centralized control of resources and industries documented by the Linear B tablets, coupled by the construction of storage and working areas in the vicinity of the palace, are indicative of the weakened Mycenaean administration and economic decline (Betancourt 1976). A regional disruption of agriculture resulting from consecutive weather problems (Betancourt 2000), competition for increasingly scarce metal resources and/or other imported commodities could have accounted for a "systems collapse". Destructions of the palatial centres are attributed to local uprisings or inter-state warfare fuelled by competition over the available resources. The explanatory power of the theory of "systems collapse" for the LHIIIB-C destructions is significant, because it takes into account perhaps the most important aspect of these destructions; that is that they impacted more directly on the highest stratum of the Mycenaean society, while the life of the lower stata continues more or less normally (Shelmerdine 2001).

At the end of the 19th century, scholars working in the field of prehistoric Aegean archaeology, proposed the hypothesis for a Mycenaean "empire". In other words, they suggested a Mycenaean colonization and political control over the Aegean that was established following the demise of the "Minoan" political/economic dominance at the end of LMIB (e.g. Tsountas & Mannatt 1897; Mackenzie 1904; Mee 1988). Using material culture evidence, Schallin (1993) tested the hypothesis for a Mycenaean politico-economic domination of the Aegean (Desborough 1964; Caskey 1969: 442; Barber 1978). He explored hypotheses related to the nature of the Mycenaean presence (i.e. political, economic, or social and religious power) in the islands of the Aegean and suggested an overall continuity of local traditions in the Late Bronze Age Cyclades. Although he identified evidence of contacts with the Mainland, he concluded that there is no substantial evidence to suggest either a colonization of the islands, or a political and/or economic takeover by people from the Mainland. The Cycladic material culture evidence demonstrates continuity during the Late Bronze Age (Desborough 1964; Schallin 1993). Moreover, the Cyclades offer no evidence for destructions contemporary with those at the end of LHIIIB in the Mainland (Drews 1993). The destructions at the citadel of Koukounaries on the island of Paros are dated by Schilardi, director of the excavations, to the transition of LHIIIB2 to LHIIIC, slightly later than those that occurred in the Mainland (Catling 1981).

The presence of Mainlanders on the island of Naxos, following the destructions at the end of the LHIIIB, has been argued primarily on evidence related to funerary architecture, the associated with the interments artifacts and mortuary practices. Refugee Mycenaean kings/aristocracy are suggested to be represented among the mainland "expatriates" settled on the island (Barber 1987). This hypothesis is founded on the richness of the grave goods, and, principally, the royal and ritual symbolism of the gold leaf lions and bulls associated with the interments in the LCIII tombs at Aplomata (Kondoleon 1958, 1959) and Kamini (Zafeiropoulos 1960). Nevertheless, these finds can be interpreted as the result of competitive emulation and symbolic entrainment, meaning the adoption of a foreign symbolic system perceived as superior to the local one by local political leaders (Schallin 1993).

2.1.6 Archaeological Background to the Case Studies

Due to the great interest that the Bronze Age South Aegean has attracted, there is a plentiful bibliography on the archaeology of this geographical-temporal context. Archaeological interest is rooted in the first excavations of Heinrich Schliemann, Christos Tsountas and Sir Arthur Evans at Mycenae, Tiryns and Crete respectively, at the end of the 19th century.

The history of archaeological research in Greece is marked by the parallel activity of Foreign Archaeological Schools and the Greek Archaeological Service, frequently at the same or nearby sites. It would be impractical to review in this chapter the history of archaeological research in the Bronze Age South Aegean. Therefore, brief background information is provided mainly for those excavations that uncovered skeletal material used in the current study. The criteria for the selection of potential skeletal collections and additional factors that influenced the composition of the material analysed are provided in section 5.1.1.1. The geographical position of the examined sites in the South Aegean and the dating of the analysed collections are given in Figure 2.2 and Table 2.1 respectively.

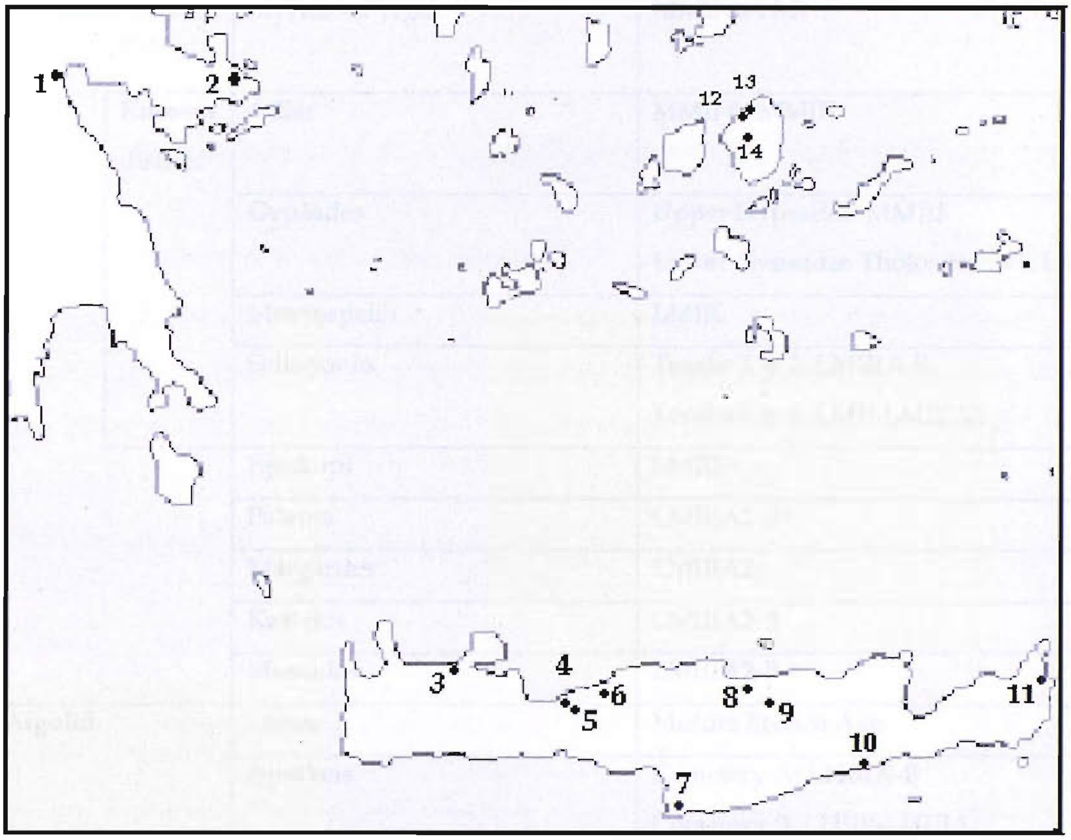

Figure 2.2 Map of the study area indicating the location of sites used in this thesis.

Key to numbers on the map: 1: Lerna, 2: Apatheia Galatas, 3: Chania (Odos Palama), 4: Margarites, 5: Kastelos, 6: Maroulas, 7: Moni Odigitria, 8: Knossos District (Ailias, Gypsades, Sellopoulo, Mavrospelio), 9: Episkopi, 10: Myrtos Pyrgos, 11: Palaikastro, 12: Aplomata, 13: Kamini, 14: Tsikniades

Table 2.2 Dating of the analysed skeletal collections.

Geographical Region		**Skeletal Collection**	**Dating**
Crete		Moni Odigitria	Tholos B: EMII-MMI
		Palaikastro	EMII-MMII
		Myrtos - Pyrgos	MMII to LMI
	Knossos district	Ailias	MMII to MMIII
		Gypsades	Upper Gypsades: MMIII Lower Gypsades Tholos tomb 1: LMI.
		Mavrospelio	LMIII
		Sellopoulo	Tombs 1 & 2: LMIIIA-B Tombs 3 & 4: LMII-LMIIIA1
		Episkopi	LMIII
		Palama	LMIIIA2-B1
		Margarites	LMIIIA2
		Kastelos	LMIIIA2-B
		Maroulas	LMIIIA2-B
Argolid		Lerna	Middle Bronze Age
		Apatheia	Cemetery A: LHIIIA-B Cemetery B: LHIIB-LHIIIA
Naxos		Aplomata	LCIIIC
		Kamini	LCIIIC

2.1.6.1 Sites in the Argolid (Mainland)

Over the last 20 to 30 years the archaeology of the Argolid region on the Mainland, has benefited by both continuing and new excavation projects and surface surveys. The first intensive survey in the Southern Argolid dates back to 1972. It represents, however, nothing more than a single season of work (Jammeson 1976). In 1979, a continuous survey program was initiated in the same area. Later, in the 1980s, the Methana Peninsula Survey was undertaken. The Berbati-Limnes project conducted in the 1980s has recently been published (Shelmerdine 2001). References for the publication of the results of these projects are provided by Rutter (2001: 99).

In this research, the Argolid Bronze Age population is represented by the Middle Bronze Age skeletal collection from Lerna and the Late Bronze Age collection from Apatheia Galatas.

Lerna: Lerna in the Argolid was excavated by Caskey (American Archaeological School), during consecutive annual campaigns from 1952 to 1957; brief reports are available in the Hesperia (Caskey 1953, 1954, 1955, 1956, 1957, 1958). At present, there is a great volume of published studies of various categories of archaeological material (e.g. buildings-architecture, pottery, lithics, bones) from prehistoric Lerna (e.g. Wiencke 1986, 1998; Hartenberger & Runnels 2001; Snyder & Klippel 2003). Although the site was occupied from the Neolithic until the Late Bronze Age, the entire human skeletal material analysed here, dates to the Middle Bronze Age. Angel (1971:1) reports four infants and one man dating to the Early and Late Bronze Age respectively. The Middle Bronze Age skeletal collection was recovered from pit and cist graves. Burials were intra-mural and artefacts associated with the interments suggest that Middle Bronze Age Lerna was a prosperous community (Caskey 1958). In total 235 MBA graves were excavated, producing the skeletal remains of 234 individuals. Skeletons were articulated and 35% of these were very incomplete (Angel 1971). Since MBA people buried their dead next to, or under to floor of their houses, it is archaeologically inferred that neighbouring burials belong to the same family unit. Therefore, although analysis did not involve the entire excavated skeletal material for reasons related to the preservation and completeness of the material, and due to time constraints, the most complete skeletons from the entire excavated area were selected for analysis. Forty-one skeletons were selected to span the entire area of the Lerna settlement in order to sample variation from the entire MBA Lerna population. The skeletal collection is curated in the Archaeological Museum at Argos (Argolid).

Apatheia Galatas: Excavations of the Greek Archaeological Service at Galatas also in the Argolid, were conducted under the directorship of Ms E. Konsolaki. These began in the mid 1980s at Apatheia Galatas (Konsolaki-Yannopoulou 2001) and continued in the late 1990s at Magoula Galatas (Konsolaki-Yannopoulou 2003). At Apatheia, two cemeteries (cemeteries A and B) of chamber tombs were recovered. The use of the five tombs at cemetery A dates to the LHIII (Tombs A1, A2, and A3 were used in LHIIIA2 and Tombs A4 and A5 in LHIIIA2-B1/2), whereas the interments in cemetery B are slightly earlier, dating from the LHIIB to LHIIIA1-2. Of the examined Apatheia tombs, tomb 5 in cemetery A yielded the most skeletal material. Most of the material recovered from this tomb represents completely or partially disarticulated skeletons and was interpreted by the excavator as a single episode of secondary burials derived from the cleaning of other tombs in the cemetery (Konsolaki-Yannopopoulou 2001). The material from the other four chamber tombs in cemetery A represents one primary burial (articulated skeleton) and two to four secondary ones (i.e. earlier burials that were pushed aside to make room for the latest one, the primary burial) in the interior of each burial chamber. Unfortunately, the skeletal material from the chamber tomb in cemetery B was collected and curated with no attempt to keep separately primary and secondary burials. It was therefore all treated as commingled burials. All the available skeletal material from the tombs at Apatheia was recorded for the purposes of this study.

The skeletal collection from the three Magoula Galatas tholos tombs was not included in the present study, due to its comparatively poor preservation and completeness. The cemeteries of Magoula and Apatheia Galatas are situated at 2km distance from each other and were probably used by the same community (Konsolaki-Yannopoulou 2003:160). Both collections are kept in the Archaeological Museum at Poros.

2.1.6.2 Sites on Crete

Systematic excavations on Crete began at the turn of the 20th century. These were conducted by Foreign Archaeological Schools and the Greek Archaeological Service. Since the 1950s, following the end of the Word War II, there has been a proliferation in the number of excavations and surface surveys on the island. Surveys (of extensive type) were introduced by Pendlebury's work (Pendlebury 1939). Although, his survey was less systematic and consistent than the later ones, it had a significant contribution to "Minoan" archaeological research. Concerning the archaeology of Crete, one should note the impressive vastness of the bibliography on various thematic categories, with some very specialized studies. Hiller's bibliography on "Minoan" studies lists 443 articles and books just for the period between 1965 and 1977 (Hiller 1977: 17-39).

This study used the Early Bronze Age skeletal collections from Palaikastro and Moni Odigitria, the Middle Bronze Age Ailias collection, the Middle Bronze Age to Late Bronze Age I collections from Myrtos Pyrgos and Gypsades, and the Late

Bronze Age II-III collections from Sellopoulo, Mavrospelio, Maroulas, Kastelos, Margarites and Palama, in order to investigate the biological history of the Bronze Age Cretan population, and the biological relationships between this and the contemporary Argolid and Naxos populations.

Palaikastro: At Palaikastro (Eastern Crete), the crania from EMII-MMII Rousolakos ossuaries No 1 and No 2, and the enclosure at Patema were recovered in 1902 and 1903 by Bosanquet (project director). The recovery of the commingled skeletal material was supervised by the physical anthropologist, Duckworth (1902-3). Although Duckworth (*ibid.*) reported 58 male and 20 female crania and post-cranial elements from the two ossuaries and the enclosure, at the time of the present study, only 13 female and 14 male crania from that collection were present in the warehouses of the Archaeological Museum at Herakleion. Unfortunately, there is no record of other skeletal material from Palaikastro kept in this museum. All 27 analysed crania were securely identified from markings on the bone surface. For the purposes of this study, the Palaikastro collection was moved to the Stratigraphical Museum at Knossos, where it is currently curated.

Myrtos Pyrgos: In South-eastern Crete, the settlement, tomb and ossuaries of Myrtos Pyrgos were excavated by Cadogan. Excavations took place in 1970, 1971, 1973 and 1975, with intermittent and subsequent study seasons. The skeletal material recovered from the ossuaries dates to the MMII-III and represents commingled burials, whereas the skeletons from the tomb chamber are probably later, dating to the LMI (Cadogan 1977-78). The last represent primary burials. This study recorded all the skulls from the Myrtos Pyrgos collection. Preservation and completeness of skeletons are very good compared to the other analysed Cretan material. The Myrtos Pyrgos skeletal collection is kept in the Stratigraphical Museum at Knossos.

Knossos district: From the Knossos district, the Ailias and Gypsades skeletal collections were selected to represent the MM to LMI Knossos population, i.e. before the suggested LMIB migration of individuals from the Argolid. The LMII-III Sellopoulo and the LMIII Mavrospelio collections were selected to represent the Knossos area population following the suggested migration. All four skeletal collections are curated in the Stratigraphical Museum at Knossos.

Ailias: In the period 1950 to 1955, Hood excavated the very important MMII-MIII cemetery at Prophetes Elias (Ailias) (Hood & Smyth 1981). This is located on the slopes east of the Kairatos river, less than 1km from the "palace" of Knossos. In the first two years (1950 and 1951) two chamber tombs were recovered by a joint excavation undertaken by the Greek Archaeological Service and the British School at Athens, under the directorship of Alexiou and Hood respectively. In 1952, Hood, with de Jong, continued excavations at the cemetery. More tombs were revealed by the excavations of 1953 and 1955 (Cook & Boardman 1954). In total, six tombs were excavated in the Ailias cemetery from 1950 to 1955 (Hood & Boardman 1955). Their use is dated from the MMII to the end of MMIII. Unfortunately, apart from the very brief excavation reports, to date, there has been no full publication of the cemetery. The dead were interred into pithoi or larnakes (i.e clay coffins) and the skeletons were recovered and collected separately. In 1960, parts of these skeletons (i.e. the os coxae, mandibles and a large number of loose teeth) were reported to be on loan to the Duckworth Laboratory in Cambridge for research purposes (Carr 1960). Although this material was lent on the condition to be returned to the Archaeological Museum at Herakleion upon completion of the research, to date it has not been returned. This study used all the skeletal material (crania, maxillary teeth associated with the crania, one mandible with teeth and long bones) from the Ailias tombs that was kept in the Archaeological Museum at Herakleion at the time of the study (it did not use the Ailias material kept in the Duckworth Laboratory in Cambridge). For the purposes of this study the collection was moved to the Stratigraphical Museum at Knossos.

Mavrospelio: In the vicinity of the Ailias cemetery, the Mavrospelio chamber tomb cemetery is located on succeeding levels on the Ailias hill, at 600 km from the "palace" of Knossos. Evans excavated the first six tombs and in the 1920s he passed the excavation and publication rights to Forsdyke. The twenty-one tombs of Mavrospelio span the period from the MMIIB to the beginning of the LMIIIB. Supplementing the rather concise publication of the excavations results by Forsdyke (1926-27), the study of the pottery from the tombs of Mavrospelio by Alberti (2004a) has contributed greatly to the better understanding of changes in the burial practices and associated ideologies, within the period of the use of the cemetery (MMIIB to LMIIIB), and more accurate dating of the introduction of novel architectural features (i.e. the single-chamber vs. multi-chamber tombs) to the Cretan funerary repertoire.

Unfortunately, at the time of this study, only seven crania were available for analysis. These crania date to the LMIII period. Although in the publication of the excavation results (Forsdyke 1926-7), there is no information about the size and composition of the skeletal collection recovered from the tombs, the good preservation of the seven studied crania, the absence of mandibles or post-cranial elements from the studied collection, and the size of the cemetery suggest that the analysed collection most probably represents a very small portion of the recovered skeletal material. For more information on the archaeological practices of the early 20th century and their impact on the composition of the recovered skeletal collections see section 5.1.1.1.

Gypsades: In Knossos district, the Upper Gypsades MMIII and LMIII cemetery of chamber tombs situated at about 1km south of the Knossos "palace" was discovered accidentally in 1954 during deep ploughing of a field. The Upper Gypsades cemetery was excavated in 1955 by Hood, Huxley and Sandars. The use of Tomb XVIII, whose skeletal material has been analysed for the purposes of this study, dates to the early part of MMIII (Hood *et al.* 1958-9). Hood *et al.* (1958-9) reported nine primary burials in the main chamber with little sign of disturbance of the earlier on the occasion of later ones. On the site care was taken to collect each burial separately. All the skeletal material from Tomb XVIII was recorded for the purposes of this study. However, the very scanty and poorly preserved skeletal remains recovered from the interior of the LMIII tombs of the Upper Gypsades cemetery did not qualify for the purposes of this research.

In 1957, at Lower Gypsades Hood excavated the LMI tholos tomb and a rectangular enclosure opposite the entrance of the tomb (Catling 1957). The rectangular enclosure was used as an ossuary. Therefore, the recovered material represents commingled burials. The material from the interior of the tomb represents burials inside larnakes or deposition of the dead directly on the floor of the tomb. Care was taken to collect burials separately. This study used all the available skeletal material from the Lower Gypsades tomb and rectangular enclosure.

Sellopoulo: During the 1950s and 1960s, four LMIII chamber tombs were excavated at Sellopoulo, less than 2km north from Knossos. In 1957, Huxley and Platon, from the British School at Athens and the Greek Archaeological Service respectively, excavated two LMIII chamber tombs (Sellopoulo Tombs 1 and 2) (Popham *et al.* 1974). Apart from few illustrations of material recovered from the interior of the two Sellopoulo tombs, there has been no published report of these excavations. The following year, in 1958, Hood excavated one LMII-IIIA shaft grave at Sellopoulo. The full publication of the excavation of the shaft grave is being currently under preparation (Hood pers. comm. 2006). Later, in 1967, Popham excavated two more chamber tombs at the same site (Sellopoulo Tombs 3 and 4). The use of these tombs was dated to the LMII-IIIA1 and they were classified as "warrior graves" (Popham *et al.* 1974). In 1950s, Hood was the first to use the term "warrior grave" to describe the importance attributed to the bronze weapons in graves dating from the end of the LMIB (Alberti 2004:129)."Warrior graves" have been interpreted as evidence for the physical presence of Mycenaeans at Knossos (Popham *et al.* 1974:255-7, 1990; Hood 1985; Doxey 1987; Driessen 1990:124-5). This hypothesis is still very influential in Aegean Archaeology (e.g. Driessen & MacDonald 1984: 66, 1997; Alberti 2004).

For the purposes of the present study, I analysed all the skeletal material available from all four Sellopoulo chamber tombs. The skeletal material from tomb 4 and portion of the material from tombs 1 and 2 represents primary burials. The rest of the material from tombs 1 and 2 represents commingled burials, recovered from burial pits (bothroi) on the floor of the chamber. These pits were used as ossuaries. Also, the scanty skeletal remains in tomb 3 were disturbed by looters and were treated as commingled burials. Preservation and completeness of the skeletons are better for tombs 1 and 2 than tombs 3 and 4.

Episkopi: The skeletal material from the LMIII chamber tombs at Episkopi Pediados (Central Crete) was recovered in 1952 by Platon (1952), then director of the Greek Archeological Service on Crete. The seven crania and three mandibles with teeth used in this study derive from chamber tomb B and represent commingled burials. The post-cranial skeleton of the studied individuals is poorly represented in the studied collection; only a few long bone fragments were present. This should probably be associated with the archaeological practices of the first half of the 20th century in the Aegean (see section 5.1.1.1.). There was no skeletal material available for analysis from the other Episkopi chamber tombs. For the purposes of this study, the Episkopi skeletal collection was moved from the Archaeological Museum at Herakleion to the Stratigraphical Museum at Knossos, where it is currently curated.

Moni Odigitria: The EMI-MMIA cemetery at Moni Odigitria (South-central Crete) was excavated by Dimopoulou and Vasilakis (for the Greek Archaeological Service), in 1979 and 1980 respectively. This cemetery contains two tholos tombs that were looted, and two ossuaries. Due to time constraints, this research used the twenty-one most complete and better-preserved crania recovered from tomb B only, the bigger of the two tholoi. Tholos tomb B dates to the EMII-MMI (Vasilakis 1989-90: 64-65), and the studied material represents commingled burials. The Moni Odigitria skeletal collection is also kept in the Stratigraphical Museum at Knossos.

Palama: In Western Crete, rescue excavations at building plot 4 in Palama Street at Chania, undertaken in 1987 by the Greek Archaeological Service under the directorship of Andreadaki-Vlasaki and Hadjidaki, recovered seventeen tombs. Three different types of tombs are represented in the excavated cemetery. These are the chamber tomb, pit grave and pit cave. The use of the cemetery is dated from the LMIIIA2 to LMIIIB1 (Hallager & McGeorge 1992).

All the available adult skeletal material from the Palama tombs was recorded for the purposes of this research. The studied collection consists of material recovered from all three tomb types. It represents six primary adult burials and eight secondary adult burials. The last were reconstructed from commingled skeletal material of not more than two adults in each tomb. The skeletal collection is curated in the Archaeological Museum at Chania.

Kastelos and Margarites: In the last ten years, rescue excavations directed by Papadopoulou for the Greek Archaeological Service, recovered at Kastelos and Margarites (Western Crete) one chamber and one tholos tomb respectively. The use of the chamber tomb at Kastelos was assigned to the LMIIIA2 and LMIIIB (Papadopoulou pers. comm. 2006). The skeletal material recovered from the interior of the chamber represents one double burial inside a larnax and secondary burials in a pit on the chamber floor. The collection is kept in the Archaeological Museum at Rethymnon.

Small fragments of larnakes recovered from the interior of the Margarites Tholos tomb suggest that interments were made inside larnakes (Papadopoulou 1997). The tomb was used in the LMIIIA2 (*ibid.*). Unfortunately, the skeletal material was severely disturbed by looters and flooding of the burial chamber, and thus it was treated as commingled. The minimum number of individuals represented by this material is six adults and one sub-adult individual. Additionally, due to the very poor completeness and preservation of the skeletons, the collection from Margarites was not used for morphological analysis, but was sampled for strontium isotope ratio (SIR) analysis. The skeletal collection is kept in the Archaeological Museum at Chania.

Maroulas: In 2001 rescue excavations at Maroulas in north-central Crete, revealed seven unlooted and two looted LMIIIA2-B chamber tombs. The tombs were excavated by Papadopoulou (Greek Archeological Service). Interments were made inside larnakes in the burial chambers. Unfortunately, for reasons related to the poor preservation and incompleteness of the recovered skeletal material (3 adults), it did not qualify for meaningful morphological (cranial and dental) analysis, but like the Margarites material, it was sampled to measure the SIR. The collection is kept in the Archaeological Museum at Rethymnon.

2.1.6.3 Sites on Naxos (Cyclades)

In the present study, the Bronze Age Naxos population is represented by Early Cycladic skeletal collections from Aplomata and Tsikniades, and two collections from the Late Cycladic cemeteries at Aplomata and Kamini at the Chora of Naxos. All recorded human skeletal material from Naxos was recovered by excavations of the Greek Archaeological service and is kept in the Archaeological Museum at the Chora of Naxos. There is, however, a striking absence of fully excavated and published sites dating to the Bronze Age period.

Aplomata: In 1958 and 1959, Kondoleon excavated two LCIII chamber tombs at Aplomata (Kondoleon 1958, 1959). In the same cemetery, Lambrinoudakis excavated one more chamber tomb in 1970, which is suggested to be contemporary with the earlier excavated ones (Lambrinoudakis 1970). Later, in 1972, Kondoleon excavated a group of Early Cycladic tombs in the same cemetery. On the basis of the rich finds from the excavated graves and the disturbance that Aplomata has suffered, it is assumed that the recovered Early Cycladic cist graves represent only a small portion of a substantially larger burial ground (Broodbank 2000: 220). One additional LCIII chamber tomb excavated in 1986, by Philaniotou-Hadjianastasiou in the Vasalakis building plot, 120 m away from the three chamber tombs that were excavated earlier in the Aplomata cemetery by Kondoleon and Lambrinoudakis, is considered to belong to the same cemetery (Hadjianastasiou 1996). The studied skeletal material from the Vasalakis tomb represents commingled burials; skeletons are incomplete and poorly preserved.

Kamini: At Kamini, at approximately 500m distance from the Aplomata cemetery, Zapheiropoulos excavated three and a probable fourth chamber tombs dating to the LCIII period during two excavation periods, in 1959 and 1960, (Zafeiropoulos 1960). Both LCIII cemeteries at Aplomata and Kamini are associated with the neighbouring, contemporary and prosperous settlement of Grotta (Hadjianastasiou 1996). On the basis of the richness and the ritual and royal symbolism of the finds from the LCIII chamber tombs at Aplomata and Kamini, the interments have been associated with refugee Mycenaean kings/aristocracy who settled on the island following the LHIIIB-C destructions on the Mainland (Barber 1987:237-238).

At the time of this study, the skeletal collection available for analysis from both the Aplomata (the tombs excavated by Kondoleon and Lambrinoudakis) and Kamini tombs was very incomplete compared to the description given in the excavation reports. It appears that part of the two collections is misplaced inside the museum. Also, due to the poor preservation of the material available for study, only two crania from the recorded Bronze Age Naxos skeletal material qualified for meaningful morphological analysis. All studied collections, however, were sampled for SIR analysis.

Tsikniades: The Early Cycladic cemetery of Tsikniades in the central part of Naxos, was excavated by Philaniotou in 1989 and 1990. Excavation of the cemetery was incomplete and revealed 125 cist graves. The cemetery suffered extensive looting and associated destruction, probably even since the antiquity. The associated artifacts suggest a long period of use for the Tsikniades cemetery, dating from ECI to ECIIIA1 (Philaniotou in press). The number of the burials inside each grave ranges from one to six. The majority of graves contain commingled skeletal remains of more than two individuals. Individuals are principally represented by long bone shafts. Cranial fragments and teeth are underrepresented in the collection, and there is no cranium complete enough to allow for some basic measurements. The material, however, was sampled for strontium isotope ratio analysis.

Finally, the number of individuals from each sample used in cranial and dental morphological analysis is given in Table 5.1 (section 5.1.1.1). Also, Table 7.1, Appendix F provides information about the samples analysed from each collection in order to measure the strontium isotope ratio.

2. 2 Theoretical Framework to the Present Research

Despite the long history of archaeological research in Greece, dating from the late 19th century (e.g. Schliemann 1886; Tsountas 1898), there has been comparatively poor advancement in the theoretical research background. The culture-historical approach has been the predominant one for the greatest part of the history of research and was described by Renfrew (1980) as "the Great Tradition". The Emergence of Civilization by Renfrew (1972) constitutes the first major processual work in the field. Despite the critique it received, it had an undoubtedly significant impact on the Aegean Archaeology. Concerning research on prehistoric culture change, New Archaeology challenged traditional theories of migrations or invasions by introducing environmental, economic, social and political factors to the Aegean research agenda (e.g. Betancourt 1976; Renfrew 1979; Kuniholm 1990). Compared to processual (New Archaeology) there are less post-processual works in the field (e.g. Kotsakis 1991).

With regard to the present research, beneficial is the use of the example of the Mycenaean civilization among other examples of "systems collapse" in Renfrew's discussion of the explanatory power of catastrophe theory over discontinuous behavior of systems in archaeological studies (Renfrew 1978). Equally illuminative is the incorporation of the Mycenaean and "Minoan" civilizations as examples of relatively ephemeral and persistent civilizations respectively, in Bintliff's brief discussion of the implications of chaos-complexity theory for archaeology (Bintliff 1994).

In this section I will present briefly the two theories, Catastrophe Theory and Complexity Theory that have influenced the concept and design of this research. To a great extent this research is concerned with the issue of cultural continuity and change and explores human skeletal evidence for the association of culture change with population movement. Earlier in this chapter (section 2.1.5 Destructions and the Arrival of New Population Elements) were outlined two of the most influential in the Bronze Age Aegean Archaeology hypotheses of population movement associated with culture change at Knossos and Naxos in the Late Bronze Age. Invocation of population movement in order to interpret abrupt and pervasive changes in the material culture at a site with, or without associated evidence for a site-wide destruction, is rather common in studies following a culture-historical approach (e.g. Tsountas 1898, 1899; Evans 1921, 1928, 1930, 1935; Pendlebury 1939; Hood 1986).

Although destructions and cultural upheaval may result from the arrival of new population elements, progress in archaeological and related research fields has demonstrated coherently that population movement cannot be considered as the exclusive determinant of population culture history and that it is inaccurate to equate the presence of certain material culture with the physical presence of the people who are suggested to have created it (Binford 1965; Flannery 1968; Renfrew 1972). On the other hand, Catastrophe Theory and Complexity theory provide a more accurate description and explanation of the cultural discontinuity that followed the destructions on Crete and the Argolid at the end of LMIB and LHIIIB-C respectively (Renfrew 1978; Bintliff 1994).

Despite the great potential of Catastrophe Theory to describe and explain abrupt changes, it has rarely been exploited in the understanding of discontinuities in the archaeological record (Renfrew 1978). Catastrophe theory originates in the field of pure mathematics. It was formulated by Rene Thom and represents an attempt to go beyond the confines of classical physics by providing a mathematical framework for describing types of discontinuous processes (Woodcock & Davis 1988; Casti 1994). It has a broad application to a large variety of scientific fields, from the majority of natural sciences and engineering fields to the humanities, including sociology, linguistics (Castrigiano & Hayes 1993) and archaeology (Renfrew & Cooke 1979) with convincing, but controversial results.

Why is Catastrophe Theory such an appropriate 'tool' for understanding cultural discontinuities/changes? According to human intuition and common sense, minor, gradual changes in causes introduce minor, gradual changes in effects. This fundamental principle underlies structural stability, which is a crucial property identifiable in the majority of the mathematical descriptions of natural phenomena. Nevertheless, not all phenomena of our concern are structurally stable or continuous, meaning that a small change in the input can lead to dramatic changes in the final result (Casti 1994).

Since human systems are unstable, Catastrophe theory describes more accurately human behavior and change in human systems compared to classical physics. Concerning the application of Catastrophe theory to Archaeology, it explains abrupt changes in social formations that have no identifiable abrupt causes, but originate from interacting factors, which change in a gradual and continuous mode (Renfrew 1978). In this line of reasoning, it is probable that in the absence of significant changes in the relevant parameters of the system, meaning external forces that can influence the trajectory of the human community (e.g. inter-population contacts, natural of human-induced destructions, invasions), the human community will meet at some stage its catastrophical point and change by adopting new symbols and practices. It is important to note that it is in the properties of the system that this can produce a catastrophical change, under certain combinations of given conditions (Renfrew 1978; Casti 1994). In other words, the change originates from inside rather than from outside the system.

The greatest critique Catastrophe theory received already in the 1970's concerns its applicability to extra-mathematical scientific fields (Zahler & Sussmann 1977). Catastrophe theory, however, although formulated in the field of pure mathematics, it describes discontinuous processes in unstable systems not exclusively within the realms of mathematics. Human systems are unstable, hence the application of Catastrophe theory to the description of human-related phenomena is legitimate. There are inherent difficulties of course in the application of mathematical models to human conduct. Renfrew (1978: 220) acknowledged that some of the problems and challenges of its (Catastrophe Theory) application to social sciences, and particularly to archaeology, concern our capacity to discern how many and which control variables operate to produce discontinuous behaviour. However, these difficulties have been shown not to be impossible to successfully overcome (Renfrew 1978:220; Renfrew & Cooke 1979) Finally, concerning the critique about its scientific inconsistency and failure to provide direct quantitative predictions (Kolata 1977), it is rather unrealistic to expect to directly translate mathematics to social reality. The applicability of Catastrophe theory to archaeology derives from the possibility it offers to interpret drastic changes arousing from subtle modifications in the control variables.

Bintliff (1994) identified as the particular advance of research into Complexity compared to Catastrophe theory the fact that it demonstrated small differences to be a constant component of structure that threaten the dissolution of structure at arbitrary moments of time. Dissolution becomes more immediate, the more complex a system becomes. Then the system is nearer to the "edge of chaos" (Bintliff 1994). At this point, Complexity as Catastrophe theory, contradicts theories that refute abrupt collapses of civilizations, with the exemption of those that result from natural disasters (e.g. Yoffee 1988). Renfrew (1978, 1979) and Tainter (1988) note that some early civilizations appear to collapse suddenly, when they are at their peak. They attribute this phenomenon to factors related to increasing instability and stress as the society becomes more complex and hierarchical, as well as to the cost of controlling extensive areas or the danger of structure disintegration, inherent in the decentralization of power (Manning 1994). For a complex structure, such as the "Minoan" civilization, to maintain temporal persistence, it should have achieved significant resistance to its inherent recurrent variabilities, through continual reinforcement of the structure by its constituent human agents, adaptability of complex social structures, and the ability of the structure to capture additional energy flows to ensure its sustenance (Bintliff 1994). In this line of reasoning, the "Minoan" civilization must have been disrupted when its mechanisms of temporal persistence failed to circumvent its dissolution induced by the enhancement of minor perturbations in its internal structure and the external context.

Catastrophe theory and Complexity theory apply very well to the reconstruction of cultural discontinuity on LMII Crete and LHIIIB-C Mainland. They provide a deep understanding of the mechanisms of socio-political processes by emphasizing factors internal rather than external (i.e. population movement) to the cultural system, in the description–explanation of system's disruption. Hence Catastrophe theory and Complexity theory challenge traditional hypotheses of population movement introducing cultural discontinuity. Therefore, this thesis tests using human skeletal remains the validity of two highly debated, but very influential hypotheses of population movement in Aegean Archaeology that were put forward to interpret cultural discontinuity in Late Bronze Age Crete and the Mainland.

2. 3 Archaeological Hypotheses

The two specific archaeological questions that the present study investigates concern the two major cases of suggested population movement in the Bronze Age Aegean Archaeology, following destruction events on Crete and the Mainland at the end of LMIB and LHIIIB respectively. These hypotheses, formulated on material culture evidence, are explored in this thesis through the morphological analysis of the skeleton, supplemented by the chemical analysis of bone and dental tissue in order to measure the strontium isotope ratio. Strontium isotope ratio analysis is applied to explore positive or negative evidence for the presence of non-locals among the individuals interred into tombs at Knossos (Crete) and the Chora of Naxos (Cyclades) that were suggested using material culture evidence to belong to Mycenaeans.

The two highly-debated, but still very influential in the archaeological thinking hypotheses explored here are the following:

a. At the end of the LMIB, people from the Argolid (Mainland) arrived at Knossos. Arrival took the form of military invasion and political domination of the site. Settlement involved a ruling class and its warrior aristocracy. There is no substantial evidence for an active mainland colonization of the island, dating to this period. These Argolid warriors were interred in the so-called "warrior" graves that were introduced to Crete from the Mainland for the first time at this period. At the district of Knossos, "warrior" graves are present in the cemeteries of Zapher Papoura, Ayios Ioannis, Sellopoulo and Mavrospelio (Sakellarakis 1972; Kanta 1980; Hood 1985; Barber 1987: 222; Doxey 1987: 301; Driessen 1990: 125; Popham 1994:93; Rehak & Younger 2001).

b. Following the LHIIIB-C destructions in the Mainland and the demise of the palatial system, Mycenaean kings and/or their aristocracy sought refuge in the Cyclades. To these Mycenaean refugees are attributed interments made in the rich in finds of royal and ritual connotations, LCIII tombs at the Aplomata and Kamini cemeteries of Naxos (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

Due to the small number and poor preservation of the available skeletal material for analysis from Late Cycladic Naxos, the examined archaeological hypothesis for population movement from the Argolid to the island, was investigated primarily using the results of the strontium isotopic ratio analysis.

CHAPTER 3

RESEARCH ON BIODISTANCE IN THE BRONZE AGE SOUTH AEGEAN

To date, the analysis of human and animal osteological material has not received adequate consideration in studies of the Bronze Age Aegean. The majority of traditional archaeologists have exhibited very limited interest in this line of archaeological evidence. This results largely from the fact that archaeology in Greece is related more directly to history, rather than to anthropology. Therefore, skeletal remains were not identified as the subject of archaeology, but of medical and biological sciences. As early as the start of the 20th century, Buxton (1920) highlighted the underestimation of the skeletal remains as a valuable data source on the part of the archaeologists working in the Eastern Mediterranean context, and related it with the impressive nature of the available material culture evidence (e.g. domestic and funerary architecture, artifacts, arts). The lack of interest from archaeologists translated into the recovered skeletal remains being later reburied or simply discarded (Buxton 1920:92), or the selective collection of the crania from the available skeletal material (Agelarakis 1995:158). The first bioarchaeological studies in the Bronze Age South Aegean date to early 20th century (e.g. Duckworth 1903; Buxton 1920; Charles 1965) and are characterized by the selective analysis of the cranium in order to reconstruct the biological history of the Aegean populations. Because this is a biodistance study, it is important that the brief review of bioarchaeological research in the Bronze Age South Aegean emphasizes on earlier biodistance studies in this context.

3.1 History of Bioarchaeological Research in the Bronze Age Aegean

From the foundation of the Anthropological Museum at the Medical School of the University of Athens in 1886, the vast majority of researchers that have worked with Aegean archaeological skeletal material have come from a medical or biological background, with no archaeological-historical training (Agelarakis 1995). It is worth-mentioning that three of the first researchers who played a role in establishing Physical Anthropology as a discipline taught in Greek universities -Koumaris, Pitsios and Xerotiris- were trained in Germany. Hence their special interest in human population variation, population movements and the ethnic origins of populations they examined (Agelarakis 1995).

The boundaries between archaeology and physical anthropology are to a great extent preserved by the conspicuous absence of the study of physical anthropology from the departments of Archaeology and History in Greek universities[1]. Researchers from biological and medical sciences have been called to cover the lack or scarcity of osteoarchaeologists in the field. Additionally, the incomplete training of archaeologists in Greek universities regarding the recovery, conservation and storage of skeletal remains, often results in the loss of valuable information and hampers the potential contribution of the analysis of this material to the reconstruction of the past. Unfortunately, very few cemetery excavations have involved the participation of a human or animal bone specialist.

Even today, it is not often well understood that the information derived from the analysis of osteological material is essential to the successful reconstruction of palaeodemography, palaeopathology, health, diet, activity patterns and biological history of past populations and that this information cannot be substituted by any other category of archaeological data. Because skeletal material has not been identified as pertaining to archaeological research, or at least it is considered less directly related to archaeology compared to material culture evidence, analysis of skeletal material is not incorporated into the publication of all excavated cemeteries. In the case that analysis of skeletal material contradicts archaeological hypotheses and interpretations formulated on material culture evidence, archaeologists assign more credit to the material culture. In the same line of reasoning, but from the opposite "camp", Koumaris (1955), Professor Emeritus of Anthropology in the Medical School of the University of Athens, in his review of the anthropological research in Greece during the years 1952-54, argued that the excavation of cemetery sites should be better classified into the branch of anthropological (meaning physical anthropology), rather than archaeological research. Even in those cases that archaeological skeletal material has been analysed, the results are normally not adequately integrated with those derived from the analysis of other lines of archaeological evidence.

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[1] The Department of Mediterranean Studies in the Aegean University is the only one to offer lectures on human osteology as part of the training of Archaeology students and these have begun in 2005.

As in archaeology, the primary aim of the first physical anthropology studies in the Aegean was to explore the issue of ethnogenesis and establish the origins of the Aegean populations, investigate inter-population relationships, population movement and biological interaction. In general, they endeavored to reconstruct the biological history of the Aegean populations. This research interest stimulated a number of studies (e.g. Duckworth 1903; Buxton 1920; Charles 1965), which are characterized by the selective study of the cranium through indices calculated using measurements taken from it, and the disregard of the post-cranial skeleton. The cranium was thought to convey the most relevant information for the reconstruction of the ethnic-racial origins of the examined populations (Howells 1989).

The majority of osteological reports on South Aegean material tend to read more like forensic anthropology works, establishing the number of individuals represented by the material, their sex and age at death, stature, pathologies and traumas experienced during life, and lack a strong archaeological perspective. Although some studies have attempted to integrate material culture information in the discussion of the skeletal evidence (e.g. Musgrave 1990), to date, the complex relationship between mortuary practices and skeletal remains has not been adequately explored for the reconstruction of past bio-cultural processes.

More recent works have identified the lack of integration of material culture and skeletal evidence, and contributed significantly to the advancement of our understanding of this research topic by integrating paleodemographic, paleopathological and the results of chemical analyses undertaken in order to reconstruct dietary practices of past populations on one hand, and the results of the analysis of mortuary practices, on the other (e.g. Papathanasiou 2001; Triantaphyllou 2001). In her PhD thesis, Triantafyllou (2001) stated clearly her intention to view the occupants of the graves she examined as bodies of once human beings and not as bodies of discard, as is often the case in traditional studies of tomb architecture, grave goods and burial practices.

The dominant tendency of bioarchaeological studies in the Aegean is to focus on individual cases and/or single assemblages and allow the material to speak (descriptive studies), rather than study the given collections to explore specific archaeological issues. The literature on South Aegean bioarchaeology is dominated by studies of human skeletal remains recovered from conspicuous (i.e. royal or ritual) tombs/contexts (e.g. Angel 1973a, Musgrave *et al.* 1985; Musgrave 1990, 1995).

The greatest deficiency of bioarchaeological research in Greece is the dearth of synthetic and systematic studies of skeletal material, selected using solid scientific criteria to answer archaeological questions, set at the onset of the investigation. Musgrave emphasizes the need for anthropologists working with archaeological material to explore "more fundamental questions" (Musgrave & Evans 1980:53), such as questions of population movement. Concerning archaeological questions of population movements, Musgrave states that these cannot be accurately answered from material culture evidence alone. Hypotheses of population movement need to be tested on both material culture and skeletal evidence for greater reliability of results.

The main research questions that studies of human skeletal material from the Bronze Age Aegean have explored to date concern paleodemography (e.g. Halstead 1977, McGeorge 1988), the quality of biological life, meaning nutrition, health, skeletal pathology, activity patterns, traumas (e.g. Angel 1971,1973a, 1973b, 1977, 1982b; Bisel 1982; McGeorge 1983, 1988; Hallager & McGeorge 1992; Papathanasiou 2001; Triantaphyllou 2001), and biovariability and biodistance at the intra- and inter-population level (e.g. Angel 1971; McGeorge 1983). With regard to studies of biovariability and biodistance, there is a marked distinction between past and current approaches to analysis of biodistance. Early biodistance studies aimed to assign humans to delineated races. Racial classification involved the identification of certain morphological traits on the examined skull that were considered representative and exclusive for the respective race (Brace 1982). On the other hand, more recent approaches to biodistance have rejected racial classification and are concerned with the biological continuities or discontinuities at the inter- and intra-population level, which can be either temporal or spatial (Larsen 1999). A more detailed discussion of the disparity between past and modern biodistance studies can be found in Chapter 4.

3.2 Studies of Population Biodistance in the Bronze Age South Aegean

In the South Aegean context, the works of Buxton (1920), Charles (1965) and Angel (1971, 1973a, 1973b, 1982) are representative of early approaches in biodistance. In the South Greek Mainland, Angel (1971) assessed the biovariability of the Middle Bronze Age population of Lerna through a variety of morphological types (e.g. Mediterranean, Dinaroid, Alpine, Basic White). He suggested a mainly local origin for the population, deriving from the Neolithic and later pre-Greek populations. These pre-Greek populations originated from the Near East and from Upper Paleolithic Central and Eastern Europe population sources. He also identified a double intrusion of people during the EHIII and immediately after its end. These 'intruders' probably came from two directions, from the east, originating from Iran and the steppe country, and from the north, deriving from the steppe country and the Balkan Mountains. He also suggested the presence among the indigenous Lerna population of Minoan intruders of Linear Basic White plus Eastern Alpine type and of South Cycladic intruders with an Iranian Mediterranean and Eastern Alpine blend. Despite the masking effect that racial classification has on population biological variability, his work suggests a wide range of biovariability for the Middle Bronze Age populations of Lerna (Angel 1971), Asine (Angel 1982) and the MMIII-LHI population group buried in the Grave Circle B at Mycenae (Angel 1973a). Intra-population variation for the Mycenae sample was estimated at 20% above normal, where normal variability is that recorded for the other roughly contemporary populations. Angel himself recognized the limitations and shortfalls of his system of morphological types, by arguing that these types describe growth tendencies rather than the actual genetic components of skull growth, which are revealed by ongoing research on twins and families (Powell 1989).

Concerning the Cretan population, Charles (1965) conducted a racial classification study of a great number of skeletal collections recovered from Bronze Age contexts. He studied a large series of human skeletal remains, predominantly crania, and classified them to pre-existing morphological types on the basis of metric data. Where the completeness of the skull was adequate, he provided a brief description of its shape. Both Charles and Angel provided measurements and various indices calculated using measurements from the cranium and elements of the post-cranial skeleton, to allow for comparability with relevant data from other populations.

On the other hand, modern approaches in biodistance studies are represented by the works of Musgrave & Evans (1980), McGeorge (1983) and Powell (1989). Musgrave & Evans (1980) assessed the biological distance between populations from different geographical and temporal contexts. Among other material, Musgrave & Evans (1980) studied skeletal collections of varying size from Crete, spanning a broad time period, from the Early Bronze Age to historic times. With regard to the Aegean skeletal material, they used cranial measurements to explore widely debated archaeological questions concerning the relationship of the Bronze Age Cretans with their contemporaries from the Greek Mainland and Eastern Mediterranean and the origins of both the Bronze Age and modern Cretan populations. Musgrave & Evans (1980: 74-75) rejected the hypothesis that the Bronze Age Cretan population came from Egypt and suggested that the Bronze Age populations from Attica and the Argolid on the Mainland, belong to a single, homogeneous population. Nevertheless, until more analyses were conducted, they were reluctant to reach any clear conclusion concerning the biological relationship between the Cretan populations dating to the period before and following the suggested arrival of people from the Argolid (Mainland) on Crete at the end of the LMIB. However, the inclusion in the analysis of data recorded by more than one researcher that was culled from published reports, casts reasonable doubt on the validity of the calculated inter-population distances as a result of inter-observer error. (For more information on inter-observer error see section 5.1.2.4.1, Chapter 5).

McGeorge's (1983) PhD thesis is entitled "The Minoans: physical variation and affinities". It is, however, more of a general discussion of physical anthropology of Crete in the 3rd and 2nd millennium B.C., as the author declares in the abstract of that work, rather than a solid biodistance study, as implied by its title. The greatest part of the analysis is devoted to paleodemography and paleopathology. Moreover, despite the worth-while examination of a big body of skeletal material from Crete dating largely to the LMIII phase (i.e. Armenoi, Pyrgos, Palaikastro, Platyvola, Ailias, Chrysolakkos, Gypsades, Monasteriako Kephali, Pyrgos, Nochia, Agios Syllas, Deliana, Galia, Pigi, Phaphlagos, Sellopoulo and Stavromenos skeletal collections), and the application of multivariate statistical analysis to the recorded craniometric data, the investigation of the biological relationship of the "Minoan" population to other past populations from the Aegean and Eastern Mediterranean is not devoid of methodological shortcomings. The reconstructed inter-population distances are of questionable biological value, due to the considerable time discrepancy of the comparatively examined samples (Neolithic to Early Christian). Inter-observer error was introduced to analysis, since comparative data from all but one skeletal collection were obtained from published reports. Moreover, McGeorge's interpretations of the reconstructed inter-population relationships lack a deep understanding of the compound effects of other than gene flow micro-evolutionary forces (i.e. genetic drift), on the shaping of the assessed relationships. Furthermore, although she applied methods of analysis modern for that time, following past ideological trends, she interpreted inter-population biological similarity by referring to the "ethnic" origin of the respective populations (McGeorge 1983:154).

Powell (1989) also analysed a great amount of skeletal material from ancient Greece and Africa in order to discuss the highly debated question of the superiority of metric over non-metric traits concerning their efficacy to measure accurately the genetic distance between past populations. The Greek collections she studied span a very broad geographical and temporal framework, from Northern to Southern Greece and from the Middle Bronze Age to the Early Christian period. On the results of her analysis she argued for the greater accuracy of the metric compared to non-metric traits in the reconstruction of inter-population genetic relationships. A significant methodological shortcoming common in the studies of McGeorge (1983) and Powell (1989) concerns the use of data recorded by other researchers (i.e. inter-observer error), in order to maximize their data set.

Even in the cases, however, that racial classification was rejected as a means of quantification of the biological distance at the intra- and inter-population level, past studies of biodistance in the South Aegean context are lacking a strong archaeological research perspective and well-defined archaeological questions, selection of human skeletal collections in order to explore specific archaeological questions, and a scientifically-sound testing of the examined hypotheses.

To conclude, the study of skeletal remains from past human populations in the South Aegean context is not very advanced and it is deprived of a strong archaeological perspective. Although researchers have pointed out the potential contribution of bioarchaeology to the more reliable reconstruction of the bio-cultural history of past populations, to date archaeological human skeletal material has not been fully appreciated as a source of archaeological knowledge, equal to that derived from the analysis of the material culture. The study of the skeletal remains is rarely included in the research design of cemetery sites' excavations. Therefore, only a small number of excavations have involved the participation of a human or animal bone specialist, setting the standards and supervising the recovery, conservation and storage of the excavated material. Lastly, it is rather uncommon that the publication of the results of the excavation and study of cemetery sites incorporates a section where the skeletal material is presented, analysed and discussed within its context.

CHAPTER 4

BIODISTANCE ANALYSIS OF SKELETAL MORPHOLOGY: A REVIEW

4. 1 The Genesis of Biodistance Studies

From our every day visual experience we can appreciate how variable the human species is. Biological distance or biodistance analysis explores this variability by analyzing it both quantitatively and qualitatively and by addressing the factors inducing it. It refers to the measurement and the interpretation of relatedness or divergence between populations or subgroups within populations (Buikstra *et al.* 1990). Under the terms biological distance and biological variance are grouped both genotypic and phenotypic variance, which are assumed to be proportional (Konigsberg & Ousley 1993, 1995). Those populations which share variants are suggested to be more closely related in biological terms than populations expressing many differences in this respect (Larsen 1999).

During the 19th century, the operating historical processes promoted biodistance analysis as the dominant type of skeletal biological research. In the greatest part of Europe throughout the whole of this century, archaeology was associated with nationalism and ethnicity. Racial doctrines suggesting that biological, rather than socioeconomic and political disparities accounted for ethnic differences replaced the prevalent 18th century idea of intellectual and emotional similarity of different ethnic groups and of the environmental conditions operating as the principal factor inducing physical and behavioural differences (Trigger 1989). This was not, however, the first time that biological and ethnic identities have been associated. In the 6th century B.C., Herodotus, (Βιβλίον Η) writing about the Hellenic ethnos, proposed as one of the three fundamental binding elements, the "ὁμαιμον", which translates to 'same blood', meaning common genetic identity. Nevertheless, it would be unfair to equate all the more recent work exploring the relationship between ethnicity and human biology with these early studies. Blom *et al.* (1998) declare their awareness of the fact that bioarchaeology fails to address the most critical aspect of ethnicity that is ascription. However, they suggest that group membership and ethnic boundaries are also maintained through rules controlling biological interaction. These often take the form of taboos and marriage rules acting to preserve the integrity of the boundaries between different ethnic groups (Macbeth 1993).

Darwin's theorizing of human evolution, suggesting cultural and biological evolution to be inseparable (Darwin 1998 [1859]), was considered to have offered scientific credibility to the belief in the inequality of races and also the foundation for Kossina's (1911) outrageous racist views. Not only did Kossina claim cultural and ethnic variations to be rooted in racial differences, but also that more advanced cultures are an expression of biological superiority. The interest in the history of the culture of past populations stimulated research interest in their biological history as a complement to culture studies. Later, following similar ideological trends to those, which influenced archaeology, emphasis in skeletal biology has shifted to health and diet reconstruction studies and biodistance studies lost their popularity (Buikstra *et al.* 1990).

The first biodistance studies exploring inter-population biological relationships used cranial indices calculated on measurements taken on a population level (Retzius 1842). Cranial index became the yardstick for the correct classification of populations to races. Early researchers had enormous confidence in the value of the skull shape in the correct classification of humans to their ancestral stock. There was a general consensus in physical anthropology that the races had been fixed separate and unequal entities (Brace 1982) and they were considered either to have been differentiated following the creation of a common humanity or to have resulted directly from a divine polygenesis. According to the polygenist theory Adam is the final progenitor of the superior white race, whereas all the other inferior races originate from several earlier Pre-Adams (Gould 2003: 135). In the first half of the 19th century, Samuel Morton, passing from the first to the second position, endorsed both in the course of his work. Each race was alleged to have a different evolutionary trajectory and races were organized hierarchically (Coon 1962).

The hierarchical classification of races was founded either on the hypothetical differences in the timing and degree of their evolution or the innate biological superiority of some populations over others (Kossina 1911). At the end of the 19th century, Galton founded the Eugenics movement. He aimed to avert the imminent decline of the human species and supported the idea of breeding from the best representatives of the human species, while sterilizing those with poor inheritance (Jones 2000: 5). In 1905 the Gesellschaft für Rassenhygien (Society for Race Hygiene) was founded. Drawing upon the idea of qualitative differences between the human races and led by the desire to regain the purity of their supreme race, Nazis had all mixed marriages in German South-West Africa annulled by 1908. They also deprived those involved in mixed marriages of their citizenship (Jones 2000: 259).

4.2 Population Biodistance Revisited

Nevertheless, although some population substructure exists in the human species, studies dating from the 1960s and 1970s to date (Lewontin 1972; Cavalli-Sforza *et al.* 1988; Jorde *et al.* 1995; Barbujani *et al.* 1997) have scientifically questioned the biological basis for race and treat races as defining discontinuous sets of individuals within a species. The clustering of populations in groups is a frequent find in studies exploring inter-population biological relationships. This clustering, however, need not be interpreted in terms of racial relationships. It could be an artifact of the spatial distribution of the populations under the effect of isolation by distance for geographically distinct populations, and common environmental conditions for geographically clustered populations. It could also reflect other processes such as divergence from a shared population history. All these should be taken into consideration in interpretations of inter-population biological distances. Eller's (1999) work on population substructure and isolation by distance in sub-Saharan, African, East/Southeast Asian and European populations, is an example of a scientifically sound biodistance analysis, due to its care to introduce to its methodology tests assessing the fit between the genetic distances on one hand, and geographic and linguistic ones on the other.

Studies on both genetic and morphological data point out that the greatest portion of human variability occurs at the intra-population, and not the inter-population level, as has been traditionally thought. Barbujani *et al.* (1997) analysed human molecular diversity using 109 DNA markers in sixteen populations. They partitioned genetic variance at three hierarchical levels of population subdivision (intra-population, intra-continent and inter-continent) and calculated the differences between members of the same population to 84.4% of the total variation. This result is in remarkable congruence with the results from studies of protein polymorphism (Lewontin 1972; Latter 1980; Ryman *et al.* 1983, cited by Barbujani *et al.* 1997). Barbujani *et al.* (1997) in their treatment of the implications of their results for the racial basis of the genetic diversity between human groups, aware of the potential error from the small sample sizes, argue that no matter whether inter-population differences are defined on racial or geographical terms, they represent only a small portion of global genetic diversity. They recorded regions of abrupt genetic change not between large population groups at the inter-continental level, but occurring irregularly within the continents and even within single countries. On these results, Barbujani *et al.* (1997) challenge the supporters of the biological basis of races to provide evidence for the credibility of their argument.

Humans are not identical clones and the variation within the human population has been shown to have regional and temporal dimensions. More than 80% of the variation in the human species, however, occurs at the population level. Humans, compared to other animals, are very uniform creatures as a result of their relatively recent evolution. Therefore, the genetic difference between the snail populations of two neighboring Pyrenean valleys is much greater than that between Australian aboriginals and Europeans (Jones 2000: 263). Contemporary approaches in human biodistance make no use of the terms race or type and their qualitative implications for human populations. Instead, they are concerned with the biological continuities or discontinuities between populations or within populations, which can be either temporal or spatial (Larsen 1999).

4.3 Principles of Biodistance Analysis

In modern studies, a clear distinction is made between living and past populations in the methodologies used for biological distance analysis. In the first case, the distances are generally established using biochemical variants, which assess the actual gene frequencies in a population. By contrast, in archaeological material these distances are most commonly reconstructed by assessing the morphological variation of the skeleton. Post-mortem degradation of DNA due to endogenous nucleases results in the preservation of little, or often no, DNA information in ancient tissues. In addition, the prevalence in the environment of modern human DNA, the required controlled conditions for the collection of the material from the site, and the danger of contamination of ancient DNA and distortion of the results (Hofreiter *et al.* 2001) are important factors which have rendered the application of ancient DNA analysis to biodistance studies problematic. Finally, DNA analysis is very expensive.

4.3.1 Analysis of Skeletal Morphology: Categories of Data

Concerning morphological variation, two broad categories of polygenic traits used in the assessment of biological relationships can be distinguished on the basis of their continuous or discontinuous/quasi-continuous expression. Metric or continuous variables are obtained by linear measurements or indices calculated from measurements and are used to describe the size and shape of skeletal elements. Non-metric or quasi-continuous anatomical variables are often expressed as gradations from absence to full expression (Musgrave & Evans 1980; Saunders 1989; Larsen 1999).

Although the analysis of non-metric traits had already been introduced in early 20th century studies of racial classification (Wood-Jones 1931), it is only in the last 20 to 30 years that it has gained popularity over studies of metric variation. This appears to result largely from the impact that the work of Berry & Berry (1967) had in the scientific community (Donlon 2000). Berry & Berry (1967) proposed the superiority of non-metric over metric traits in studies of population biological relationships on the grounds of the lack of correlations between trait frequencies and age, sex, side or other traits that they deduced from their study. Some additional advantages they suggested for non-metrics include ease of scoring and scoring even on fragmentary material, and a strong genetic component in their etiology. Since the 1970s and particularly in the 1980s, there has been a long-standing debate over which of the two categories of traits is the most reliable in reconstructions of inter-population biological relationships (see Powell 1986; Coppa *et al.*1998). Studies following the publication of the work of Berry & Berry (1967) have not reached a consensus over the efficiency of non-metric vs. metric analysis to accurately reconstruct the biological relationships of past populations (Prowse & Lovell 1996). Nevertheless, it appears that non-metrics are generally viewed as having better applicability and greater efficiency in biodistance studies (White & Folkens 2000).

4.3.2 Polygenic Traits: Etiology

Polygenic traits are considered to represent the additive effect of a large number of polymorphic loci, which are further modified by environmental influences (Berry & Berry 1967; Cheverud 1988). Hence polygenic traits are influenced by intrinsic genetic as well as both local and general epigenetic and environmental factors (Relethford & Lees 1982). The strongest critique that biodistance studies using polygenic traits have received derives from the multifactorial nature of these traits. It concerns the fact that polygenic traits directly assess phenotypic inter-population relationships. The observation that two populations are distinguishable or indistinguishable on the results of the analysis of polygenic traits is a phenotypic one, and should not be equated simply to the genetic homogeneity or heterogeneity of the analysed material (Saunders 1989). Yet, studies have shown the congruence of results of phenotypic anthropometric analysis with those derived from quantitative genetic analysis (Konigsberg & Ousley 1995). Since phenotypic correlations are the weighted sums of genetic and environmental components, genetic and phenotypic correlations will be similar (in both their magnitude and pattern), regardless of the level of heritability (defined as the proportion of phenotypic variance attributable to additive genetic variance).

Higher heritabilities, however, increase the proportional contribution of genetic to phenotypic correlations and thus result in greater similarity of population phenotypic and genetic correlations (Cheverud 1988). Moreover, sample size is negatively correlated with average differences between genetic and phenotypic correlations. Cheverud (1988) assessed similarities between genetic and phenotypic correlations on 41 pairs of phenotypic and genetic correlation matrices from 23 agricultural genetic and evolutionary studies. The material of these studies ranged from humans to amphipods and the traits on which relationships were explored ranged from morphological to cognitive (Cheverud 1988). Devor (1987) explored the genetic signal underlying the observed phenotype and estimated heritabilities for anthropomentric dimensions of the face and the head. These estimated heritabilities were averaged by Relethford (1995) to $h^2=0.55$. Najem's study of craniofacial variation in sibling pairs using latelar cephalograms (Najem 1997) estimated the heritability in cranial dimensions to range from 0.03 to 1.0, with an average of $h^2=0.69$. The results of these studies show that the proportionality of genotypic and phenotypic variance is a reasonable assumption in studies of this kind.

In addition, studies assessing phenotypic variation to establish biological relationships between populations, regard the fact that environmental variation with respect to analysed traits is random as more significant than the fact that heritability of traits may be low (Buikstra *et al.* 1990). Thus, by applying to the analysis a large and variegated group of variables one can ensure greater validity for the estimated distances (Sokal 1966). Skull measurements show a high degree of independence from infra-cranial ones, therefore, one should obtain a sufficiently varied data set simply by recording metric variables from both skeletal regions (Hiernaux 1972). The same principle underlies the recording of non-metric traits in biodistance studies (Hiernaux 1972). However, when multiple variables are analysed to explore biological distances, it is very important that the examined population sample is of an adequate size. Cheverud (1988) suggests that an effective population sample comprises at least 40 individuals.

Analysis of skeletal morphology in order to investigate genetic distance and variability between past populations is based on two fundamental assumptions. Under the assumption that genotypic covariance is related to phenotypic covariance in the relationship $G=h^2P$, population samples that are shown to be similar in morphological terms, are genetically similar as well (Cheverud 1988; Williams-Blangero & Blangero 1989; Konigsberg & Ousley 1993, 1995, Powell & Neves 1999). The second assumption concerns the representative power (in terms of sex, age, socio-economic composition) that the sample has over the original population from which it derives (Stefan 1999; Irish 2005). The smaller the size of the sample is, the less representative it is of the population from which it derives (Stefan & Chapman 2003).

Although genotypic and phenotypic variation appear to have the potential to reveal information about population history and structure, it is difficult to determine which of the two, or both, are reflected in the results of biodistance analysis (Powell & Neves 1999). Population structure refers to the allotment of genetic variation among interbreeding demes due to processes such as gene flow and genetic drift. Population history on the other hand, refers to genetic changes attributable to non-recurrent historic events such as range expansion, range contraction, and population replacement (Templeton *et al.* 1995). Population structure and population history are not, however, mutually exclusive forces accounting for the variation in craniofacial form through time and space (Powell & Neves 1999). Genetic differentiation between any two human populations may represent the interplay of gene flow, genetic drift and historical events (Templeton 1998).

Due to the complex nature of biodistance analysis and identification of meaningful patterns of biological variation that distinguish population groups, great consideration has been given to related theoretical and methodological issues in the literature (Larsen 1999). Theoretical issues are discussed separately for metric and non-metric analyses below. Methodological issues are discussed in the methodology section of Chapter 5.

4.3.2.1 Metric Traits in Biodistance studies

In numerous studies focusing on different spatial and temporal contexts, craniometric data have been analysed disproportionately to infra-cranial metric variables aiming to explore intra- and inter-population biological relationships (e.g. Howells 1973, 1989; Key 1983; Relethford & Harpending 1994; Hanihara 1996; Ishida & Kondo 1998; Hemphill 1999; Powell & Neves 1999; Gonzalez-Jose *et al.* 2001; Varela & Cocilovo 2002; Ross 2004; Schillaci & Stojanowski 2005). Many factors account for the emphasis on the study of the skull region predominantly in early studies in the field. As discussed earlier in this chapter the focus of biodistance research on the cranium was mainly dictated by the conspicuous place of ethnogenesis in the archaeological agenda of the first half of the 20th century. The aim of this research was to determine the ethnic/racial identity of past populations and the cranium was thought to convey information pertinent to this research objective (Jacobs 1993). With regard to studies of skeletal material recovered by early excavations (end of 19th to the beginning of 20th century), frequently there could be no option for the skeletal region for analysis. This period is characterized by the selective recovery of the cranium by archaeologists, and the lack of interest in the collection and curation of the rest of the skeleton (Buxton 1920). A common finding in the skeletal collections assessed for purposes related to the present research was that the skull is better preserved and more complete than the post-cranial skeleton. This could derive from the preferential treatment that the skull received following its recovery. Additionally, numerous studies have demonstrated how reliable human cranial morphology is for reconstructing successfully intra- and inter-population biological relationships, particularly when the results of morphological analysis can be cross-validated with cultural, linguistic or biochemical data (e.g. Vecci *et al.* 1987; Stefan & Chapman 2003).

4.3.2.1.1 Cranial Metric Traits in Biodistance studies

Howells (1973) outlined the advantages of craniometry in assessing the biological relationship between populations or population groups. He suggested that it allows an exactness and reproducibility in measurement considerably greater than that achieved by anthropometry, meaning the metric analysis of living human beings. Despite the adaptability of the form of the skull to various environmental factors, important aspects of cranial form are genetically persistent over considerable periods of time. In other words there is high heritability of morphological traits of the cranium. Furthermore, because measurements are continuous and correlated variables, they are amenable to the best methods of multivariate analysis and therefore promising of a more reliable estimation of the biodistance between populations, when compared to anthroposcopic or serological data (Howells 1973).

Human craniofacial morphology reflects both phylogenetic and non-phylogenetic factors. Phylogenetic factors with an impact on the form of the skull are genetic drift, gene flow and gene mutation as well as the genetic variation of the founder population/s. Therefore, studies of craniofacial variation can reveal information about the genetic structure and history of skeletal populations (Templeton *et al.* 1995). Recent studies have contributed greatly to the more accurate understanding of the genetics of complex features of the craniofacial morphology (Richman 1995). On the other hand, non-phylogenetic factors that influence cranial morphology through gene-environment interactions refer to developmental constraints (Enlow 1990; Angel 1982a), functional loading of the teeth and mandible (mastication) (Boyd 1988), as well as adaptation to changing climatic conditions (Jantz *et al.* 1992). It has been suggested that the cranium, the mandible and the teeth are the skeletal region where the effects of natural selection and consequently of micro-evolutionary changes can be most easily detected (Musgrave & Evans 1980). Additionally, craniofacial variation can also derive from other factors, such as intentional cranial deformation, but this is easy to differentiate (e.g. Neumann 1942; Blackwood & Danby 1955).

Despite the indirect evidence for the impact of environmental factors on morphology, of the facial skeleton in particular (Jantz *et al.* 1992), the strong genetic component in variation of cranial morphology has been confirmed by the results of animal breeding studies, family studies and studies of human populations with known or easily reconstructed biological relationships (Mays 1998). Family studies of skull morphology employ measurements taken either directly from the heads of the volunteers, or from radiographs. These studies generally suggest a high degree of inheritance for skull dimensions (Kohn 1991). Congruence between the results of the analysis of biochemical genetic data and cranial morphological data with regard to the reconstructed inter-population biological relationships has given additional credit to the study of the cranial morphology as an accurate means of reconstruction of inter-population biological relationships (Vecci *et al.* 1987).

Recent studies demonstrate high awareness of the distorting effect of environmental factors on the reconstruction of inter-population genetic relationships and a great concern to control for it. As the study of Stefan & Chapman (2003) demonstrated, interpretation of the results of the biodistance analysis is much clearer for populations sharing similar climatic and environmental conditions. In such cases, adaptation to different environmental conditions through gene-environment interaction can be exempted from the potential factors accounting for the observed inter-population craniofacial variation. Variation is then associated with other evolutionary forces such as isolation, genetic drift, gene flow and non-random mating (Stefan & Chapman 2003).

4.3.2.1.2 Post-cranial Metric Traits in Biodistance studies

As in the case of cranial variation, the etiology of post-cranial morphological variation is complex and multifactorial (Susanne 1975). Human height is a complex trait under the control of both genetic and environmental factors (Zakrewski 2003). Variation in body size and shape derives from genetic, dietary, climatic and activity-related factors (Weinstein 2005). It is suggested that linear and epiphyseal measurements, compared to diaphyseal cross-sections of long bones, are more genetically controlled (Ruff 1988, Ruff *et al.* 1991; Jacobs 1993).

The degree to which post-cranial dimensions reflect phylogenetic as well as functional information, has often been underestimated, particularly with regard to cross-sectional properties of long bones diaphyses. Most studies exploring the origin of modern humans using the morphology of the post-cranial skeleton have interpreted morphological differences between specimens as the result of differences in adaptations, neglecting that these differences could also reflect phylogenetic information (Pearson 2000). Experimental work has demonstrated that cortical bone of the cranium and post-cranial skeleton thickens as a response to higher activity levels (Lieberman 1996; Frost 1997). Nevertheless, the notion that ancient hominin hunter-gatherers were more active than recent populations is not an empirical fact, but an assumption based on their more robust skeleton. It is legitimate to expect bone robusticity to reflect genetic or hormonal differences, as well as differences in the mechanical loading of the skeleton (Pearson 2000).

Platymeria, a condition that produces a relatively low index of anterior-posterior to mesio-lateral diameter of the sub-trochanteric femoral shaft (Capasso *et al.* 1998:114) is a good example of the complex etiology of post-cranial morphological variation. The strong mechanical component in the etiology of playtymeric femora is implied by the greater mesio-lateral strength of platymeric compared to eurymeric femora that fortifies them against great impact stress induced through the femoral head, as well as high abduction forces (Ruff *et al.* 1984). Hence platymeria has been predominantly associated with specific subsistence strategies and types of stress (Ruff & Hayes 1983). Nevertheless, it has also been demonstrated to result from nutritional deficiencies (Buxton 1938), and to relate to the geographical/genetic origins of the respective individuals (Schofield 1959; Gilbert & Gill 1990).

Bone linear measurements and stature estimates, as well as cross-sectional properties, also reflect the quality of the individuals' diet during bone growth. For individuals sharing a similar growth potential, those having received a better diet during development are expected to have higher stature than the deprived ones (Wilkinson & Norelli 1981). Secular changes in body height of human populations in the last century are frequently associated with improvements in living conditions (Pretty *et al.* 1998). As far as diaphyseal cross-sections of long bones are concerned, studies of skeletal growth patterns have demonstrated clearly that nutritional stress results in the reduction of cortical area, due to the expansion of the medulary cavity. This is compounded either by a reduction of the overall periosteal diameter (Himes *et al.* 1975), or a minor expansion of the subperiosteal area as a means of compensation for the endosteal reduction to maintain bone integrity (Garn *et al.* 1969).

Post-cranial morphology is also influenced by climatic and general environmental conditions. According to well-established thermoregulatory principles, the distal element of both the upper and lower limbs, namely the radius and the tibia, is more disproportionate (i.e. shorter) to the upper element of the respective limb in cold-adapted than in warm adapted populations (Roberts 1973). As a result, the brachial (radius length/humerus length) and crural (tibia length/femur length) indices are lower in cold-adapted compared to warm-adapted populations (Jacobs 1993).

4.3.2.1.3 Dental Metric Traits in Biodistance studies

The value of the study of tooth morphology for the reconstruction of the biological history of past populations began to be appreciated in the first half of the 20th century, due to the successful results of studies exploring inter-continental population biological affinities (for a thorough review see Scott & Turner 1988). Variation in tooth crown size and shape is generally assessed by two measurements that describe the mesio-distal and bucco-lingual tooth crown diameters (Hillson 2002). Crown height (Moorrees 1957) is not a very useful measure of tooth size and shape, due to its great susceptibility to tooth wear. Tooth-crown diameters are phenotypic characteristics that result from the interaction between the genotype of an individual with the environment in which the individual grew and developed (Hillson 2002: 79). Nevertheless, family and twin studies have shown high heritabilities for crown diameters and thus confirmed the strong genetic component of their etiology. The degree of heritability of crown diameters varies between the teeth of the same individual (Osborne *et al.* 1958; Potter *et al.* 1968). The polar teeth per tooth class (i.e. Molar 1, Premolar 3, Incisor 1) are expected to represent the underlying genotype more accurately than the more distal members of the respective tooth class, because they are less sensitive to fluctuating asymmetry and environmental variance (Dahlberg 1945).

Stojanowski (2003) provides a comprehensive account of the advantages and disadvantages of dental morphometrics in the reconstruction of inter-population biological relationships. In his study of differential phenotypic variation among the Apalachee mission populations of La Florida, he argues for the appropriateness of the analysis of tooth crown dimensions on the grounds of their high heritabilities, their resistance to ontogenetic variation and their long history in evolutionary applications. Teeth are under strong genetic control. Although they are not purely genetic products and their mode of inheritance is very complex, because they are formed early in the life of the individual and they do not remodel thereafter, teeth compared to other skeletal elements are the least subject to environmental modifications.

On the other hand, teeth are suggested to be highly responsive to slight modifications in the selective forces operating on them (Brace 1980). Concerning the reduction of sexual dimorphism in the size of the canine over the course of human evolution, many interpretations have been put forward. The most prevalent implicates a convergence in the requirements of the economic and socio-political roles of males and females. Over the course of human evolution, the dimorphic niche to which hominins have adapted has become increasingly monomorphic (Frayer & Wolpoff 1985).

Studies of dental morphology in Europe, China, India, North Africa and North America have demonstrated a trend towards the reduction of tooth size in the course of time (for a discussion Scott & Turner 1988). Smaller teeth are suggested to be selected for, in order to conform to the reduction of the size of the mandibles. In Neolithic populations, smaller teeth of less complex morphology are selected for because they are less susceptible to dental caries associated with their carbohydrate rich diet, compared to the earlier hunter-gatherers. Also, changes in the subsistence strategies and diet of the Neolithic populations, and the improvements of food preparation techniques devalued the advantage of large-toothed individuals (Scott & Turner 1988).

In addition to the high genetic component in the etiology of dental morphology, analysis of dental morphology for the purposes of reconstruction of inter-population biological relationships is advantageous over osseous material due to their better preservation in archaeological skeletal collections (Coppa *et al.*1998). Dental enamel is more resistant to chemical degradation in comparison to bone (Brace 1980). Falk & Corruccini (1982) have, however, questioned the advantageous position of dental morphometric analysis by assigning to this less discriminatory power than that of skeletal measurements. Due to inter-correlations between crown diameters, these measurements duplicate one another in discriminatory power and the efficiency of dental morphometric analysis to reconstruct inter-population distances is reduced (Kieser 1990). Nevertheless, it has been confirmed that there are differences in the pattern of tooth crown diameters between different populations and that these differences can be used to accurately distinguish between them (Harris & Rathbun 1991).

It is common in studies of dental morphology that crown bucco-lingual and mesio-distal dimensions are used to calculate dental indices that summarize occlusal form. The most widely analysed dental indices are: the Crown module (MD + BL diameters)/2, Crown area (or Robustness index: MD X BL) and Crown index (100 x BL/MD) (Hillson 2002). The first two indices measure the size and the third the shape of the tooth crown (Lukacs 1985). Brace (1980) argues that tooth crown area is a very useful variable for exploring inter-population relationships, because it is the best indicator of tooth size. Therefore, crown area is the actual trait on which natural selection operates. Because tooth size varies in response to techno-cultural conditions, researchers recommend substitution of tooth size with tooth shape analysis in studies of inter-population biological interactions and biological relatedness vs. divergence (Matsumura & Hudson 2005).

4.3.2.2 Non-Metric Traits in Biodistance studies

Non-metric traits take four forms: ossicles which occur within the cranial sutures and result from the presence of additional ossification centers; proliferate ossifications, which produce bony bridges and spurs; ossification failures such as the metopic suture on the frontal bone; and variation in the number and the location of foramina. The first two categories are termed hyperostotic and the third hypostatic traits (Buikstra & Ubelaker 1994). Hyperostotic traits result from an excess of bone growth, whereas the hypostatic ones derive from incomplete osseous development and represent a retention of a previous developmental stage into adulthood (Hauser & De Stefano 1989). The separation between hyperostotic and hypostotic traits is not always very clear. For instance, grooves may represent a hypostotic failure of ossification of a canal, but they could also result from the disproportionate increase in the length of the nerves to the expansion of the cranium (*ibid.*).

More than 200 variants have been described for the skull (Ossenberg 1976) and an approximately equal number for the infra-cranial skeleton (Saunders 1989). For ease, non-metric traits are usually recorded as absent or present. Nevertheless, their dichotomous nature often becomes less clear when, upon closer examination, more than one grade in the manifestation of the traits can be identified (Saunders 1989). Even in the case of the sutural bones that are scored as present or absent, there are apparent differences in the size, shape, position, as well as their number.

Chambellan (1883) studied the sutural bones on the cranium and was the first to suggest the applicability of these traits to studies of population biological variation and biodistance. The application of non-metrics to studies of comparative anatomy and phylogeny from the late 19th century to date has confirmed their potential in assessing population genetic variation in time and space. Later, the work of Grüneberg (1952) on non-metrics in mice demonstrated the genetic component in the etiology of non-metric traits. Nevertheless, even though non-metric traits had been explored extensively by the 1980s, it was only then that they enjoyed a wider application to population biodistance studies (Buikstra & Ubelaker 1994; Donlon 2000). Donlon (2000) attributes the shift in emphasis of biodistance studies from metric to non-metric morphological analysis mainly to the impact that the work of Berry & Berry (1967) had on the research field. The principal objective of their study was to demonstrate the advantages of the analysis of non-metric over metric morphology.

Studies of non-metric traits assume that these are primarily under strong genetic control, despite non-genetic factors that are also implicated in their etiology (Saunders 1989). Grüneberg (1952) investigated the presence/absence of the 3rd molar in mice laboratory populations and concluded that tooth size is the inherited characteristic and not presence or absence of the trait. The development of the 3rd molar depends on the size of the tooth germ achieved by a certain stage in the growth of the mouse. With his work he demonstrated clearly how the formation of the third molar is both genetically and environmentally determined. Quasi-continuous is a descriptive term for the two processes involved in the determination of these traits. On one hand, there is the underlying continuous variable (size of tooth-germ), which is influenced by the action of genes, and on the other, there is a discontinuity in the development of these traits. This discontinuity is imposed by the existence of alternative possible end-results of development. The development of non-metrics is the epigenetic consequence of the interaction and competition between different developmental processes. The epigenetic component in their etiology can be affected by both genetic and non-genetic factors. Examples of non-genetic factors are parity or maternal physiology, nutrition and other environmental factors.

In relation to the two processes that are suggested to be involved in the development of non-metrics, other terms that have been assigned to these variants are: "quasi-continuous traits" (Grüneberg 1952) and "epigenetic traits" (Berry & Searle 1963), or "discontinuous traits" (Ossenberg 1969), "discrete traits" (Rightmire 1972) and "discreta" (Rosing 1982). The first two terms emphasize the underlying continuity, whereas the last three stress the discontinuity in the manifestation of the traits (Saunders 1989).

The results that Sofaer (1969) derived for a molar cusp variant he analysed in a laboratory mice population were similar to those of the study of Grüneberg (1952). Concerning the mode of inheritance of the analysed cusp variant, Sofaer argued further that the examined non-metric trait is inherited under the effect of more than one gene. More recently, however, genetics have identified a whole spectrum of modes of inheritance of non-metrics, from purely Mendelian to oligogenic and polygenic (Strachan & Read 1996). Nevertheless, if a quasi-continuous mode of inheritance for the non-metric traits is true, then all the factors that influence inheritance of the continuous variables should apply to the inheritance of non-metric as well (Hillson 2002).

Nevertheless, the strong genetic component in the etiology of non-metric traits has been demonstrated indirectly in studies of wild and laboratory mice populations. These studies confirmed the efficacy of non-metric traits to convey genetic information as well as the validity of the estimated inter-population distances using the results of non-metric traits analysis (Grüneberg 1963;

Cheverud & Buikstra 1981; Mays 1998). Direct evidence for the genetic basis of the non-metrics derives from traits that develop before birth (El-Najjar & Dowson 1977) and from twin studies (Hillson 2002), as well as studies of living and past human populations with documented official records of familial relationships (Pietrusewsky & Douglas 1993). Hauser & De Stefano (1989) present the following arguments for the genetic basis of non-metrics. Firstly, these traits occur in different frequencies in human populations of different genetic constitutions. Secondly, indirect evidence for their genetic basis derives from experimental analysis on animal populations (e.g. Grüneberg 1952; Self & Leamy 1978). Thirdly, particular traits appear to be associated with particular inherited syndromes.

Studies that provide direct evidence for the genetic component in the etiology of non-metrics demonstrate that the heritabilities vary between traits (Berry & Searly 1963; Tyrrell & Chamberlain 1998). Cheverud and Buikstra (1981) found that the heritability of hyperostotic and hypostotic traits is significantly higher than that of the foraminal non-metrics. Some of the non-metrics, such as the shovelling of the incisors (Berry 1978), the absence/presence of the 3rd molar (Berry 1968), the metopic suture (Torgersen 1951), the lamboid ossicles and the ossicle at lamba (Torgersen 1951; Sjovold 1984), have a significant genetic component in their etiology. A practical way to determine which non-metric traits carry a higher genetic component in their etiology is to select those traits that are developmentally connected to structures which are highly canalized in ontogeny. Dental non-metric traits are formed relatively early in development and they are not subject to skeletal remodelling or functional constraints. Dental structures are under relatively strong stabilizing selection. Therefore, dental non-metric traits are likely to be subject to less environmental effects than other traits of the skeletal morphology (Tyrell & Chamberlain 1998).

A second assumption in biodistance studies using non-metrics is that different traits reflect variation at different loci. The low phenotypic correlations among cranial non-metrics provide validation of this assumption (Hertzog 1968). Cheverud & Buikstra (1981) explored the phenotypic, environmental and genetic correlation structure for cranial non-metrics and their results suggested that the pleiotropic effects of loci affecting trait values are principally local. Therefore, by using a large number of traits distributed widely on the cranial surface, it is possible to sample variation at a significant number of loci.

In studies of population biodistance using non-metric traits, the application of cranial and post-cranial non-metrics analysis is disproportional. Donlon (2000) relates the small number of biodistance studies using post-cranial non-metrics to the fact that the rise of research interest in post-cranial non-metrics coincided with a decline in studies of biological distance from 1965 to 1980. Although some post-cranial non-metrics have been associated with biomechanical adaptations (e.g. tibial squatting facets), or pathological conditions (e.g. spina bifida), non-metric studies (e.g. Finnegan 1974; Saunders 1978; Anderson 1968; Winder 1981) confirmed that the efficacy of the analysis of post-cranial non-metrics to reveal reliable information concerning inter-population biological relationships is equal to that of cranial non-metrics.

An indisputable advantage of non-metric over metric traits is the fact that they can be scored on fragmentary material. The strongest claims, however, for their superiority to metric traits are founded upon the strong genetic component in their etiology. In general non-metric traits are considered to be more reliable discriminators between genetically different populations in comparison to metric ones, due to the proportionately stronger genetic component in their etiology and the more conservative nature of their evolution (Larsen 1999).

4.4 Biodistance Analysis: Case studies

Biodistance studies of metric and/or non-metric skeletal morphology frequently combine both categories of polygenic traits in the assessment of intra- and inter-population biological variation and biodistance (e.g. Higa *et al.* 2003; Stefan & Chapman 2003; Matsumura & Hudson 2005). The questions explored through biodistance analysis of skeletal morphology can be divided into the inter- and intra-population level. At the inter-population level, the vast majority of studies aim to investigate the origins of a particular population and reconstruct its biological history by exploring its relationship with supposed genetically related populations (e.g. Hemphill 1999; Hanihara 1997). The question of continuity vs. discontinuity (in the form of population replacement or gene flow into an existing gene pool) is prominent in reconstructions of the biological history of past populations (e.g. Irish 2005, 2006). Inter-population studies also explore biological interactions and gene flow between populations in order to investigate the relationship between inter-population cultural and biological interactions and the impact, if any, of cultural, social and geographic barriers upon the biological interactions between analysed populations (e.g. Coppa *et al.* 1998; Ross 2004; Stefan & Chapman 2003). At the intra-population level, research has emphasized the investigation of social and economic organization through the reconstruction of marital patterns (e.g. Wilkinson & Novelli 1981). Particularly in the case of non-metric trait variation, analysis has been applied in order to explore genetic distances between populations, principally at the regional level, rather than between populations from different continents (Donlon 2000).

This section presents briefly some biodistance case studies in order to demonstrate the efficacy of biodistance analysis of metric and non-metric skeletal morphology for the assessment of intra- and inter-population biological relationships, and the role this can play in a more comprehensive reconstruction of past populations' bio-cultural history. The selected case studies represent all types of biodistance analysis of skeletal morphology in terms of the applied methodology (i.e. metric and non-metric analysis of cranial, dental and post-cranial elements). Case studies are grouped into inter- and intra-population biodistance studies. Inter-population studies are divided to studies that explore inter-population relationships in order to reconstruct population biological history, and to studies that emphasize the relationship between inter-population cultural and biological interactions.

The value of inter-population studies of biodistance has been demonstrated by a plethora of studies. Powell & Neves (1999) examined comparatively a series of Paleoindian and Archaic crania from North and South America, and a large world-wide sample of late Holocene crania in order to investigate the origins of the Native American population. They applied both model-free and model-bound analyses to the data and they derived discrepant results. They suggested the assumptions of migration/founder models to be unrealistic and concluded that the process of colonization of America was more complex than previously thought on basis of differences in variation patterns in the North and South American Paleoindian samples.

Hanihara & Ishida (2001a,b,c,d) undertook the first systematic analysis of frequencies of cranial non-metric traits in populations throughout the world in order to investigate the origin and diversification of modern human populations. They analysed hypostotic, hyperostotic and vessel and nerve related non-metrics and showed that the patterns of side difference, inter-traits associations, and sex differences are inconsistent among population groups. Moreover, they demonstrated how various cranial non-metrics show patterned geographic variation between major regions. With regard to modern human differentiation, they agreed with Lahr (1995, 1996) that it occurred at different rates and to different extents in different groups, and argued that founder effects, genetic drift and population structure are at least partly implicated in the etiology of the inter-regional variation in cranial non-metrics they analysed.

Finnegan (1974) compared at the inter-population level 30 post-cranial with cranial non-metrics and discussed the advantages of the analysis of the former over the later trait category. Donlon (2000) addressed post-cranial skeletal non-metric variation in the study of intra- and inter-population biological relationships and provided additional confirmation of the efficacy of post-cranial non-metrics to reconstruct successfully inter-population biological relationships. He compared inter-population distances calculated using infra-cranial non-metrics with distances reconstructed using cranial metrics, as well as genetic markers. Analysed samples represented populations from Australia, Africa, East Asia, Europe and Polynesia and the reconstructed relationships were in agreement with the results of the analysis of genetic markers and cranial metric data.

Jacobs (1993) explored the pattern of metric variation of the post-cranial skeleton of Mesolithic and Neolithic individuals from Ukraine. The higher skeletal robusticity of the Ukrainian Neolithic compared to Mesolithic samples contradicts the theoretical expectation for continuous gracilization of the skeleton in the course of time (Debets 1961, cited by Jacobs 1993). The heightened robusticity of the Neolithic compared to the Mesolithic Ukrainian population was interpreted as the result of hybridization of the indigenous Neolithic population with robust newcomers to the region (Kruts 1984, cited by Jacobs 1993).

Due to the high mechanical component in the etiology of the post-cranial morphology (Frost 1997) (see section 4.3.2.1.2), the relevant literature is dominated by studies exploring the relationship between post-cranial metric variation, particularly changes in levels of bone robusticity on the one hand, and techno-economic changes on the other (e.g. Ruff *et al.* 1984; Bridges 1989; Jacobs 1993; Stock & Pfeiffer 2001). Metric studies of post-cranial morphology have successfully distinguished between contemporaneous populations with known different subsistence strategies (e.g. marine versus terrestrial mobility) (Stock & Pfeiffer 2001). Compared to the terrestrial activity pattern, the marine one was found to introduce to the skeleton higher upper limb diaphyseal cross-sectional properties. On the other hand, the terrestrial activity pattern is responsible for the higher robusticity of diaphyses of the lower limbs compared to marine populations (*ibid.*). Moreover, biomechanical analyses of long bone diaphyses have even detected shifts in activity levels within specific subsistence economies. The study of skeletal material from west-central Illinois demonstrated a clear link between different stages in the development of agricultural economy and the different patterning of the biomechanical variables of long bone diaphyses of the population (Bridges *et al.* 2000). The researchers admitted, however, that interpreting the structure of bone diaphysis with reference to certain activities can be complicated when more than one activity is involved (Bridges *et al.* 2000).

Concerning population biodistance analysis using dental metric variables, the study of Perzigian (1984) confirmed the higher taxonomic accuracy of inter-population distances estimated using tooth-shape rather than tooth-size variables. He calculated inter-population distances for forty-two samples of both skeletal and living populations by analyzing both tooth size and shape. Although tooth-size variation discriminated between large-toothed (*Homo erectus*, Neanderthals, modern Australian natives) and medium to small-toothed sample groups, in some cases, distances calculated using tooth-size differences suggested a close biological relationship shared by samples distant in time and space. On the other hand, inter-population distances calculated using tooth-shape variation were in agreement with the theoretical expectations of the study based on the geographical and temporal distribution of the samples. For instance, 17 native American samples that were not associated in the dendrogram based on tooth-size variation, were shown to cluster together in the dendrogram produced using information on tooth-shape.

Hanihara and Ishida (2005) analysed mesio-distal and bucco-lingual tooth crown diameters from 72 major human population groups in order to assess population variation in terms of dental metric morphology within and between world regions. With care to eliminate the effects of overall tooth size that is asserted to be exposed to natural selective forces (Brace *et al.* 1991), from the calculated odontometric variation, they effectively demonstrated the patterning of odontometric variation among major geographic populations to be consistent with the results of the analysis of genetic and craniometric data.

Matsumura & Hudson (2005) analysed both dental metric and non-metric data from 42 prehistoric and historic samples from East Asia, Southeast Asia, Australia, and Melanesia. They investigated the "two layer" immigration hypothesis which proposed that Southeast Asia was initially occupied by an "Australo-Melanesian" population that later admixed genetically with East Asian immigrant agricultural populations. Their results from the analysis of variation in dental size and the frequencies of 16 dental non-metrics confirmed the immigration hypothesis. On basis of these results, Matsumura & Hudson (2005) stated the need for future research to determine the time of prehistoric population diffusion into Southeast Asia. Jacobs (1993) associated an increase in tooth size of the Ukraine population during the Mesolithic-Neolithic transition with the adoption and intensification of agro-pastoralist economies and attributed it to gene flow from central European groups.

Tyrrell & Chamberlain (1998) undertook analysis of dental non-metrics in order to explore the biological relationship between 11 modern human populations representing a global sample, and the Krapina Neandertals. The results were cross-validated by comparison with earlier morphometric studies and by mtDNA analysis. They showed the modern human populations falling into clusters that reflect their present day geographic distribution. Additionally, all modern human populations form a global cluster that is clearly separated from the Krapina Neandertals.

Studies have emphasized the correlation between inter-population biological relationships, and inter-population relationships reconstructed using other lines of evidence, such as material culture, linguistics or ethnohistorical information (e.g. Varela & Cocilovo 2002; Stefan & Chapman 2003). Spielman & Smouse (1976) analysed nine cranial and three infra-cranial measurements from living Yanomama Indians from southern Venezuela and northern Brazil. These populations live in clusters of villages occupying an area of about 200 to 300 Km. Metric data distinguished successfully between individuals from different clusters of villages. Inter-cluster difference expressed by the tested craniometric variables was very clear; therefore, almost 60% of the cases were correctly classified.

The study of Stefan & Chapman (2003) offers an additional example of successful integration of different sets of information aiming to elucidate the bio-cultural history of past populations. They explored the biological heterogeneity of the Marquesas islands' populations using both metric and non-metric cranial traits in order to determine whether the northwest/southeast division of the islands manifested mainly in linguistic and less clearly in material culture data, is evident in the morphology of the cranium. Despite the very similar climatic and general environmental conditions for the Marquesas islands, cranial morphology separates the islands' populations into two clusters, the northern and southern one. The division is in accordance with that suggested by linguistic and material culture data and is attributed to increasing isolation by geographic distance. Gene flow is suggested to account for the stronger affinities shared between the Southern Marquesas and the island of 'Ua Huka, compared to the biological relationship of the population of 'Ua Huka with the population of the Northern islands, with which 'Ua Huka island is geographically grouped. 'Ua Huka island, situated between the northwestern and southeastern islands, was suggested to have served as a waypoint in the prehistoric system of networking in the Marquesas. Rightmire (1976) studied both metric and non-metric cranial variation of six different population groups from southern and eastern Africa. He also showed that the inter-group biological relationships he reconstructed accord well with the associated historical and linguistic data.

Ross (2004) assessed the pattern of craniometric variation between roughly contemporary population samples of American whites, Bosnians, Croatians, Greeks and "Macedonians" dating to the 20th century. Genetic isolation induced by culturally imposed religious segregation, coupled with the effect of minor environmental adaptation, were suggested to account for the considerable craniometric variation measured among groups of European ancestry in the Balkan region, especially for the variation between Bosnians and Croatians.

At the intra-population level of biodistance analysis, Varela & Cocilovo (2002) reconstructed the biological history of a prehistoric Chilean population in the Azapa valley and coast. Their results are in congruence with archaeological and ethnohistorical evidence for the socio-economic life of this population. In the light of these results, they stress the importance of integrating bio-anthropological, archaeological and ethnohistorical information for a more reliable account of the biological history of past populations. Perhaps it would have been more accurate here to substitute the term 'bio-cultural' for 'biological' history, because from this integration it is not only the study of biological history that is benefited. There is equal benefit for the study of the material culture and other lines of evidence that aim to reconstruct the history of past populations.

Questions of social mobility and status achievement vs. status ascription have been explored through marital patterns (class-endogamy vs. class-exogamy) (Wilkinson & Novelli 1981). Prowse & Lovell (1996) used cranial non-metric traits in order to explore the biological relationship between one elite and two non-elite population samples from predynastic Naqada and shed more light on the development of social complexity in ancient Egypt. The results of their analysis confirmed those derived from an earlier analysis of dental non-metrics applied to the same samples (Johnson & Lovell 1994). Analysis of cranial and dental non-metrics suggested that the two non-elite samples represent a biologically homogeneous population and that they are biologically divergent from the elite population. The operation of genetic drift or class endogamy (inbreeding) of the elite population was suggested to account for the biological divergence between elite and non-elite individuals of the Naqada population. Prowse & Lovell (1996) suggested that the reconstructed intra-population biological relationships are conducive to social differentiation in predynastic Naqada resulting from intra-population biological differences, i.e. endogamous ruling families or lineages.

4. 5 Metric vs. Non-Metric traits in Biodistance Analysis

Claims to the superiority of metric over non-metric traits or vice-versa, should be treated with extreme reservation. Konigsberg (1987) notes that recent work has revealed the close interrelationship of the two categories of traits. On this basis it is difficult, if not impossible, to argue that one category appears to have higher heritabilities/ degree of genetic control than the other. Ongoing research has shown that for both theoretical and methodological reasons, non-metric traits need not necessarily be better than the metric ones in discriminating between genetically different populations.

In the 1980s researchers started to question more thoroughly the widespread notion of the strong genetic component in the etiology of non-metric traits. According to the quasi-continuous etiological model, developmental and environmental factors are implicated in the etiology of non-metric traits together with genetic factors (Relethford & Lees 1982). Hallgrímsson *et al.* (2004) note that since the manifestation of non-metric traits has been shown to relate to some underlying continuous variation, metric and non-metrics traits most probably share similar genetic bases. Richtsmeier & McGrath (1986) studied mice populations and they assigned significant heritability values to only four of the recorded thirty-five traits. Likewise, Powell (1989) compared the results of her analysis of non-metric morphological traits with the expected genetic or taxonomic distances on one hand, and the available archaeological information on the other, and suggested that metric morphological variation is a more reliable indicator of population biological relationships than non-metric variation.

It is highly probable that in studies applying both metric and non-metric morphological skeletal analysis, the more accurate reconstruction of population biological relationships attributed to non-metrics could be an artifact of inaccuracies in the methodology of the comparative metric analysis. For instance, Coppa *et al.* (1998) suggest that the analysis of dental non-metric traits is more useful in the assessment of population affinities compared to the analysis of dental dimensions. They decided to assess dental metric morphology by analyzing merely the Bucco-Lingual tooth crown diameter for reasons related to dental attrition and intra-observer error. This way, however, they are not assessing the shape of the tooth crown that is associated with higher taxonomic accuracy (Perzigian 1984). Therefore, the discrepancy between the results of metric and non-metric analysis should be attributed, at least partially, to shortcomings in the methodology of their metric analysis.

To sum up, a review of the literature on biodistance does not attribute any clear advantage to either metric or non-metric analysis of skeletal morphology in terms of their efficacy to reconstruct past populations' biological relationships. When analysis of either metric or non-metric traits fails in this respect, causes should first be sought in shortcomings of the research methodology of the particular study. Nevertheless, what the plethora of biodistance studies have demonstrated clearly is that biodistance analysis, when undertaken in a scientifically sound mode, has the potential to reliably reconstruct the biological history of past populations. It is preferable that both metric and non-metric analyses are applied to the study of the skeletal morphology of the examined population samples, as appropriate. Finally, biodistance studies of human skeletal morphology, used in conjunction with studies of material culture and other sources of information, have been shown to address archaeological questions in a more comprehensive mode and achieve a more rounded reconstruction of the bio-cultural history of past populations.

CHAPTER 5

MATERIALS AND METHODS

This chapter discusses the selection of the human skeletal collections that were analysed for the purposes of the current project. It also outlines the methods of data collection and data preparation prior to its analysis. Analysed material and analytical methods are presented separately for the analysis of the skeletal morphology and the strontium isotope ratio analysis.

5.1 Analysis of Skeletal Morphology

5.1.1 Materials

5.1.1.1 Selection of population samples

Population samples were selected in order to reconstruct the biological history of the Bronze Age South Aegean populations by exploring the inter-population biological relationships between the populations of the Argolid, Central Crete and Naxos during the Bronze Age, and the biological history of the first two populations separately in the course of the Bronze Age. For the Cretan population analysis is expanded to consider inter-population relationships of contemporary populations within the island of Crete. It addresses questions of biological distance between contemporary Cretan populations from different regions of the island in relation to their cultural relationships, as they have been reconstructed using material culture evidence. Lastly, analysed samples were selected in order to explore the two principal archaeological questions addressed by this research that implicate the settlement of people from the Argolid at Knossos (Crete) and the Chora of Naxos following the LMIB destructions and at the LHIIIB-C respectively. According to the predominant models for the interpretation of the material culture in Aegean Archaeology, certain burials in the Kamini and Aplomata cemeteries at the Chora of Naxos (Kondoleon 1958, 1959; Kardara 1977; Barber 1987) and the Sellopoulo and Mavrospelio cemeteries in the Knossos district on Crete (Hood 1985; Popham 1994; Alberti 2004a) are associated with individuals from the Mainland.

The selection of samples was also influenced by a number of factors outlined below.

Lack of cemetery populations spanning the entire Bronze Age without interruption: Due to the lack of skeletal populations from excavated cemeteries with continuous use from the Early to Late Bronze Age in any of the three study regions, the geographical framework of the study was slightly broadened. This was undertaken with concern not to affect the integrity of the reconstructed inter-population biological relationships and the validity of the results of the investigation of the specific archaeological questions. For example, the lack of Early Bronze Age skeletal material from Knossos was solved by analysing the Moni Odigitria Early Bronze Age skeletal collection from the wider region of Central Crete, within which Knossos is situated. Unfortunately, there was not any available Early Bronze Age skeletal collection from the Argolid and Naxos that could qualify for the purposes of this study. The collections that substituted for those not available from each region were selected on the basis of their geographical proximity to the collections for which they substituted, in order to represent biologically similar populations with a shared similar biological history and similar environmental conditions. Despite the variety of microclimates and ecosystems in the South Aegean, intra-regional variation in the climatic conditions is not expected to have been enough to introduce different selection pressures and biological heterogeneity to the populations at the regional level. For more information on the climatic conditions of the Bronze Age South Aegean see Appendix A, section A.1.

Archaeological Bias: The selection of the samples was further influenced by archaeological bias, accessibility and the state of preservation and completeness of the excavated material. Archaeological bias refers to the poor representative power that a skeletal assemblage could have over the population it derives from, due to the incomplete excavation of cemetery sites and/or the possibility that one population may have been using more than one cemetery that may have escaped recovery (Wood *et al.* 1992). This could result in the excavated and analysed skeletal assemblage not being adequately representative of the original population from which it derives.

In order to eliminate the potential error that stems from the studied sample representing only a portion of the range of the biological variability of the original population and tackle the problem of small sample size that is exacerbated by poor preservation and incompleteness of the skeletons, it was decided not to focus on a single site and a single cemetery population within each of the three geographical regions (Argolid, Naxos, Knossos on Crete). For example, the Late Bronze Age population at Knossos is represented by skeletal material from the tholos tomb at Lower Gypsades (LMI), the chamber tombs at Sellopoulo (LMII-III) and Mavrospelio (LMIII). All three cemeteries are situated in the Knossos district, less than 2km from each other. In this way, the probability of deriving a more reliable measure of the biological variability of the Bronze Age Knossos human population are, in theory, maximized.

Accessibility of skeletal collections: Selection of samples analysed for the purposes of this research was also influenced by the inaccessibility of some potential human skeletal collections from the Argolid, Crete and Naxos. These could not be studied due to either the restoration and expansion of the museum where these were kept, or the reorganization of the exhibition of finds of the museum for the 2004 Olympic Games held at Athens. Concerning the skeletal material from the tombs at Mycenae (Wace 1921-23, 1950,1953a, 1953b, 1954, 1955,1956), my request for a study permit was rejected because the curator of the warehouse where the material was kept was not available to assist me with my request. Additionally, some material (the skeletal collection from Tiryns in the Argolid, and Agios Charalambos on Crete) could not be studied prior to the completion of its study and/or publication by other researchers, who had been granted this permit prior to my application. Finally, for some of the collections that were recovered early in the 20th century (Zapher Papoura at Knossos, Aila on Naxos) or later (Agioi Anargyroi on Naxos) either there is no record of where they are kept at present, or they were "lost" inside the Museum!

Early 20th century archaeological practices: Archaeological practices of the late 19th to early 20th century in the South Aegean influenced the composition of skeletal collections that were recovered and stored at that period, hence the available material for this study. When the South Aegean started to be explored by means of excavation, the vast majority of archaeologists did not adequately appreciate the potential contribution of the study of the skeletal remains to understanding past populations. As discussed in Chapter 3, frequently, they chose to preserve the skulls and discarded the post-cranial skeletal elements, thus conforming to the prevailing ideological trends in the historical/archaeological research of the period and the prevailing notion that the morphology of the skull can assist in the racial identification of past populations. As a result, it is rather uncommon to find skeletal collections excavated early in the history of Aegean Archaeology that consist of both cranial and post-cranial elements. Even when archaeologists chose to collect post-cranial skeletal material, it was recovered and packed with no care for keeping individual burials separately. The work of Sinclair Hood constitutes a remarkable exception to the norm of recovery of skeletal material from the Bronze Age Aegean context during the 1950s and 1960s. Care was taken in the identification and separate collection of individual burials. Luckily, ethics and practices regarding the excavation and treatment of archaeological skeletal material have been modified in the following decades. Nevertheless, there are still many improvements to be made in this area. Therefore, where possible, skeletal material excavated in the last two decades (i.e. Palama, Maroulas, Kastelos, Margarites, Vasalakis, Tsikniades and Apatheia Galatas collections) was analysed for the purposes of this research.

Preservation and completeness of the skeletal material: The state of preservation and completeness of Bronze Age skeletal collections from the study region influenced greatly their selection for data recording. The soil constitution of the South Aegean is not conducive to the good preservation of the deposited skeletal material. This is particularly the case for the skeletal material from the Gypsades cemetery at the district of Knossos (Higgins & Higgins 1996). In addition to taphonomic processes, curation and storage of the skeletal material had a significant impact on the selection of the samples. It was rare to find that the analysed skeletal material had received any minimal treatment such as washing, following its collection and prior to storage, even in cases where it had been studied in the past. In some cases, because the soil had not been removed from the bone surface for many decades, by the time it was studied it had become too hard to remove it mechanically (e.g. material from Naxos). Moreover, due to the inappropriate storage of most of the skeletal collections, packed in commercial cardboard boxes, placed one on top of the other, the preservation of the bones has deteriorated in the years between their storage and the present study. Some of the skeletal material, mainly skulls, which had been studied in past decades, had to be excluded from the analysis, due to their inappropriate reconstruction and the subsequent distortion of their shape. Consequently, skeletal collections that were initially selected following the results of a literature search on Bronze Age Aegean Archaeology, were not incorporated in the present study. Following brief assessment of their preservation and completeness it became clear that they were inadequate for the purposes of this research.

Despite the high mechanical component in the etiology of the post-cranial morphology, this research aimed initially to undertake the morphological analysis of both the cranial and post-cranial skeleton of each individual. Due to the poor preservation and incompleteness of the post-cranial material from most of the analysed skeletal collections and in order to ensure meaningful comparison and interpretation of population skeletal morphology at the regional and inter-regional level, in this thesis morphological skeletal analysis was confined to the cranium and dentition. Confinement of analysis to cranial and dental morphology is not expected to have affected the reliability of the reconstructed intra- and inter-population biological relationships and the outcomes of this research. Cranial and dental morphology has been demonstrated to reflect more accurately the underlying genotype compared with post-cranial morphology (Musgrave & Evans 1980:55) (see sections 4.3.2.1.1 and 4.3.2.1.2 in Chapter 4).

5.1.1.2 Analysed material: Number of Individuals from each sample

Information on the number of individuals from each sample that were analysed for cranial and dental metric and non-metric traits is provided in Table 5.1.

According to the standards of preservation and completeness for Bronze Age skeletal material from the South Aegean (e.g. Angel 1959, 1971, 1973b, 1982b; Charles 1965; McGeorge 1983), the overall condition of the analysed in this study material is moderate. Small bones such as carpals, metacarpals, hand and foot phalanges were, however, very rarely preserved. Fragments of ribs and vertebrae were only occasionally represented in the material. Long bones are most frequently fragmented and damaged on their articular ends.

As a result of the very poor completeness of the recorded Bronze Age skeletal material from the Chora of Naxos, only two crania from the Aplomata and Kamini cemeteries were entered into morphological skeletal analysis. Three of the morphologically analysed skeletal collections (i.e. Margarites, Maroulas, Tsikniades) did not qualify for meaningful morphological analysis, but were sampled for SIR analysis.

The number of individuals given in Table 5.1 is the minimum number (MNI) entered into cranial and dental metric and non-metric analysis. Concerning dental traits, however, the number given for the individuals from the Apatheia Galatas and Myrtos Pyrgos samples in Table 5.1 is probably higher than the actual number of individuals represented by the material, due to entering into the analysis small sets of loose teeth as separate individuals following the excavational information. This however, does not affect the results of dental morphological analysis because in the performed tests individuals did not need to be represented by more than one variable at a time.

Table 5.1 Skeletal material used in the morphological analysis.

Morphological Data	Geographical Region		Skeletal Collection	Chronological Period	Number of Individuals		
					♂	♀	Unsexed
Cranial Metric	Argolid (Mainland)		Lerna	MH	23	14	0
			Apatheia Galatas	LHIIB-LHIII	14	11	0
	Crete - Central		Moni Odigitria	EMII-MMI	13	7	0
	Crete - Eastern		Palaikastro	EMII-MMII	14	13	0
			Myrtos Pyrgos	MMII-LMI	16	11	0
	Crete - Central	Knossos district	Ailias	MMII-MMIII	41	22	0
			Gypsades	MMIII-LMI	13	9	0
			Sellopoulo	LMII-LMIII	3	3	0
			Mavrospelio	LMIII	4	3	0
			Episkopi Pediados	LMIII	5	2	0
	Crete - Western		Kastelos	LMIII	2	2	0
			Palama	LMIII	6	5	0
	Naxos		Aplomata	LCIII	0	1	0
			Kamini	LCIII	1	0	0
Cranial Non-metric	Argolid (Mainland)		Lerna	MH	21	20	0
			Apatheia Galatas	LHIIB-LHIII	17	15	0
	Crete - Central		Moni Odigitria	EMII-MMI	13	8	0
	Crete - Eastern		Palaikastro	EMII-MMII	14	12	0
			Myrtos Pyrgos	MMII-LMI	18	21	24
	Central - Crete: Knossos district		Ailias	MMII-MMIII	43	29	0
			Gypsades	MMIII-LMI	22	24	0
			Sellopoulo	LMII-LMIII	8	4	0
			Mavrospelio	LMIII	4	3	0
	Crete - Western		Kastelos	LMIIIA2-B	0	1	0
			Palama	LMIIIA2-B1	6	7	0
Dental Metric	Argolid (Mainland)		Lerna	MH	21	17	0
			Apatheia Galatas	LHIIB-LHIII	22	20	17
	Crete - Central		Moni Odigitria	EMII-MMI	5	2	0
	Crete - Eastern		Palaikastro	EMII-MMII	1	1	0
			Myrtos Pyrgos	MMII-LMI	21	15	38
	Crete - Central : Knossos district		Ailias	MMII-MMIII	6	2	0
			Gypsades	MMIII-LMI	13	12	5
			Sellopoulo	LMII-LMIII	7	7	0
	Western Crete		Palama	LMIII	7	5	0

Morphological Data	Geographical Region	Skeletal Collection	Chronological Period	Number of Individuals		
				♂	♀	Unsexed
Dental Non-metric	Argolid (Mainland)	Lerna	MH	21	17	0
		Apatheia Galatas	LHIIB-LHIII	22	19	17
	Crete - Eastern	Myrtos Pyrgos	MMII-LMI	20	16	37
	Crete - Central : Knossos district	Gypsades	LMIII-LMI	13	12	5
		Sellopoulo	LMII-LMIII	6	7	1
	Crete - Western	Palama	LMIII	6	6	0

5.1.1.3 Preparation of Samples

As mentioned earlier in this chapter, the bones from the majority of the studied collections had not even been washed following their recovery and prior to storage. Therefore a considerable amount of time was invested by the author in the preparation of the skeletal material for analysis. It was not infrequent, however, that special treatment had been given to skulls. These were washed, restored and packed securely in separate boxes. Unfortunately, some of the previously reconstructed crania, had to be excluded from the analysis, because distortion of the original shape of the skeletal elements had occurred. Where possible, the elements were taken back to their fragmentary state by applying small amounts of pure acetone to delude the glue, then they were reconstructed using masking tape in order to be measured and the tape was removed before reboxing. In the majority of older excavations, the paper or linen bags were worn and perforated, and the information on paper or carton tags associated with the material had become very difficult to read. In the course of the present study, the old bags and tags were replaced by new ones to prevent any further loss of contextual information.

5.1.2 Methods of Analysis

5.1.2.1 Determination of the age at death

Selected individuals needed to have completed their growth by the time of their death because the metric and the majority of non-metric traits of the skeleton vary with growth (Hauser & De Stefano 1989:9; Donlon 2000). By confining analysis to adults, the potential danger that the population biological distances calculated on the results of analysis of the skeletal morphology could reflect differences in growth patterns and the age composition of the compared samples was minimized. Adulthood was determined by means of visual examination of well-established age-related morphological changes of the skeleton. It was established on the fusion of the spheno-occipital synchondrosis, and the complete epiphysial fusion of all the post-cranial elements (Krogman & İşcan1986; McKern & Stewart 1957; Buikstra & Ubelaker 1994).

A more precise age-estimate was provided for those individuals that were represented by the dentition and the os coxae. The eruption of at least one of the 3rd molars was taken as evidence that the examined individual had reached adulthood by the time he/she died (Ubelaker 1989). Age at death for adults was estimated by analysis of dental attrition (Molnar 1971; Brothwell 1981). Dental attrition is suggested to be a reliable method of age-determination for a variety of living and dead populations (Mays 1998). Age-estimates derived from dental wear were calibrated using data from the age-related morphological changes on the auricular surface (Lovejoy *et al.* 1985) and the pubic symphysis (Brooks & Suchey 1990) on the os coxae. Cranial suture fusion was scored following Buikstra & Ubelaker (1994). Because the timing and degree of suture fusion is population-specific (Perizonius 1984), information derived from the suture fusion was used in conjunction with age-estimates derived from the assessment of other modifications of the skeletal morphology. Lastly, the adult skeletons were assigned to two broad age-categories (17-45 and 45+). Individuals aged over 45 years at the time of their death were removed from the analysis in order to isolate the effects of natural degeneration (the ageing process) on the skeletal morphology. Although it would have been desirable to explore population relationships for different age categories separately, individuals aged 17 to 45 years were pooled to maximize sample size.

5.1.2.2 Determination of biological sex

The effects of sexual dimorphism can distort inter-population distances, if the two sexes are unequally represented in the tested samples. In order to explore sexual-dimorphism in the studied collections and therefore be able to measure and control the effect of sex-differences on the results of data analysis by ensuring an equal representation of the two sexes in the tested samples, biological sex was determined for all analysed individuals. The most reliable determinants of the biological sex of skeletally represented individuals are certain morphological features of the cranium and mandible, the os coxae and sacrum. Sex was assigned following standard osteological techniques (Brothwell 1981; Buikstra & Ubelaker 1994).

Visual assessment of the cranial morphology focused on the prominence of the glabella and supraorbital ridges, the inclination of the forehead, the degree of development of the nuchal crest and the overall volume of the mastoid process. Using the mandibular morphology sex was determined from the squareness of the anterior region of the mandibular body, its gonial flaring, and to lesser extent from the prominence of the mental eminence.

Assessment of the morphology of the os coxae is considered to be particularly reliable (White & Folkens 2000:366). The examined features were the degree of the greater sciatic notch and the angle of the subpubic concavity, the presence or absence of the ventral arch and the sharpness of the subpubic ramus ridge (Buikstra & Ubelaker 1994). The shape of the curvature of the sacrum differs distinctly between the two sexes. The deepest point of the sacral curvature occurs on the third sacral body for the males, whereas for the females it occurs lower, resulting in the comparatively more vertical shape of the female sacrum (Brothwell 1981). When both the skull and os coxae were available, more credit was given to the determination of sex derived from the morphology of the os coxae.

Because, within any human population female individuals tend to be smaller and more gracile in comparison to the larger and more robust males (White & Folkens 2000:362), and sexual dimorphism is population specific (Ascadi & Nemeskéri 1970), individuals/specimens from each sample separately, were seriated from the definite female to the definite male. Seriation of specimens allows for a more accurate understanding of the range and pattern of sexual dimorphism within the given population. Following Buikstra & Ubelaker (1994) a five grade robusticity range was used, starting from 'definite female', passing to 'probable female', 'ambiguous sex', 'probable male', to end up to the 'definite male', at the opposite edge of the series.

Individuals for which both the skull and os coxae were available, and which thus received a more reliable sex-determination, were set as examples for the determination of the sex of individuals represented merely by skulls.

5.1.2.3 Data Recording

5.1.2.3.1 Metric Data

Cranium: Metric analysis of the cranium aims to provide an accurate description of its size and shape by means of a mutually consistent and coherent set of measurements distributed across its entire region (cranial vault and facial skeleton). In the light of Howells' (1973) classic study of cranial variation in human populations, the present study adopted Howells' set of fifty-seven cranial measurements (Appendix B, Tables 5.1 and 5.2). The appropriateness of the set of measurements he defined for studies exploring biological variability in human populations expressed in the morphology of the cranium has been demonstrated by a plethora of subsequent biodistance studies that have successfully reproduced them (e.g. Musgrave & Evans 1980; Brace *et al.* 1989; Powell 1989; Brace 1990; Zakrzewski 2001). Measurements were taken following Howells' definitions (Howells 1973), and are provided in Appendix B, Table 5.3.

The cranium was measured using four types of instruments, as appropriate. When both landmarks had to be instrumentally determined (e.g. Glabello-Occipital length) a spreading caliper was used, whereas a digital sliding caliper was employed for a measurement taken directly from one landmark to the other (e.g. Nasion–Prosthion height). A coordinate caliper was used to measure chords, subtenses and fractions (e.g. the Nasion–Bregma chord, subtense and fraction). Lastly, a radiometer was used for measurements taken from the transmeatal axis of the cranium (e.g. the Vertex Radius). Measurements were taken to 1mm, when using a spreading caliper. When using a sliding caliper, coordinate caliper, or radiometer measurements were taken to 0.1mm.

Bilateral cranial measurements were taken from the left side of the skeleton for standardization (e.g. dimensions of the mastoid process, dimensions of the eye-orbit, mandibular condyle or coronoid process height). When the left side measurement could not be taken, it was substituted by the right side. Substitution of the left side by the right side measurements was undertaken in order to maximize the data recorded for each individual and thus minimize the number of individuals removed from multivariate analysis.

Dentition: Metric analysis of dental morphology used the Mesio-Distal (MD) (Length) and the Bucco-Lingual (BL) (Breadth) diameters of the tooth crown from both maxillary and mandibular teeth (Appendix B, Table 5.4). Although the two tooth crown diameters are demonstrated to be asymmetrically affected by dental wear (i.e. the MD more severely than the BL) (Hillson *et al.* 2005), by confining odontometric analysis to BL diameter data only, the reconstructed inter-sample distances express inter-sample differences in tooth size, that is asserted to have been exposed to natural selective forces (Brace *et al.* 1991). In this thesis, no major differences in the selective forces are expected between contemporary Cretan and Southern Mainland populations that could account for inter-regional variation in tooth size.

Tooth-crown diameters were measured to 0.1mm using a vernier sliding caliper. The mesio-distal diameter was measured with care to include in the estimate both the most mesial and most lateral contact areas of the tooth (Buikstra & Ubelaker 1994). The measurement was taken with the flat arms of the caliper positioned so as to form the two sides a virtual rectangle enclosing the tooth. The Bucco-Lingual tooth crown diameter was measured perpendicular to its mesio-distal diameter and the highest reading was recorded. When the teeth had no associated alveolar bone, the orientation of the root was used to determine the most probable position of the tooth in the maxilla/mandible. The MD and BL measurements were then taken as for teeth with associated alveolar bone. Right and left sides were recorded separately, as there is no adequate justification for the assumption that side asymmetry in tooth crown dimensions is random (Hillson 2002:77).

5.1.2.3.2 *Non-Metric Data*

Non-metric morphological traits were recorded for the cranium and dentition (Appendix B, Tables 5.5 and 5.6). In order to reveal meaningful patterns of population relationships, care is required over the selection and scoring of non-metrics (Donlon 2000). To sample variation at a significant number of loci and with concern for inter-trait correlation, a large number of cranial non-metrics distributed over its entire surface was selected for recording on each skeleton (Hallgrímsson *et al.* 2004). Following Hallgrímsson *et al.* (2004), all non-metrics were scored as dichotomous traits, as present (1), absent (0) or unobservable (9). Non-metrics were scored as present, if any degree of trait expression was observed. Scoring of incomplete trait expression as present is common practice in biodistance studies and is legitimate since both slight and clearer expressions of non-metric traits reflect the same underlying genotype (Hauser & De Stefano 1989).

Concerning scoring of bilateral non-metric traits, Stefan & Chapman (2003) discuss the three most common methodologies. Firstly, bilateral traits are sampled by individual; the trait is recorded as present, if it is present on at least one side of the individual. Secondly, right and left side traits are treated as separate variables and are they are scored accordingly. Thirdly, although both sides are scored separately, the side used for each individual is randomized. This study did not use the first method, because sampling by individual increases the attribute frequency in the examined populations and this may distort the calculated inter-population relationships. Side-interdependence in the occurrence of bilateral traits although strong, does not appear to be perfect and varies between non-metrics and samples (Saunders 1989). Furthermore, non-metrics have been shown to be influenced by directional asymmetry, wherein there is a greater development of a trait on one side of the skeleton (Molto 1983, cited by Donlon 2000), and Hanihara & Ishida (2001a, b, c, d) have demonstrated that the patterns of side difference in the development of cranial non-metrics are not consistent among population groups. Because information about asymmetrical occurrence of traits is lost when the side by which each individual is represented in the analysis is randomized, in this study the second method is preferred.

Cranium: The list of fifty-five cranial non-metrics employed in the present study is an adaptation of the list formulated by Powell (1989) for the purposes of her study of metric versus non-metric traits as indicators of genetic distance. Five non-metric traits (i.e. nasal sill sharp, cribra orbitalia, os Japonicum trace, frontal grooves and pharyngeal fossa) from Powell's list were not used in the assessment of population biological distances in this study, due to the probable significant environmental component in their etiology, strong age-dependency, low trait frequency or scoring difficulties. Table 5.5, Appendix B, provides a list of the recorded cranial non-metrics and brief definitions for these. The first thirty in the list derive from the study of Berry & Berry (1967). Definitions for the remaining twenty are provided by Ossenberg (1970), Czarnetzki (1971), cited by Powell 1989, and Corrucini (1974). Following Hallgrímsson *et al.* (2004), non-metrics were scored as present, if any degree of trait expression was observed.

Dentition: Twelve and eleven dental non-metric traits were scored on the maxillary and mandibular teeth respectively (Appendix B, Table 5.6). Right and left sides were scored separately. Definitions for the dental non-metrics employed in this study derive from Turner *et al.* (1991). This study, however, departed from the standardized Arizona State University Dental Anthropology System (ASUDAS) only in that gradations in the expression of dental non-metrics were not scored. Instead, for simplification, it was decided to score merely the presence or absence of traits (for the equivalence between the scoring system employed in the present research and ASUDAS see Appendix B, Table 5.6). Both slight and clearer expressions of non-metric traits reflect the same underlying genotype (Hauser & De Stefano 1989). Thus, by scoring non-metrics for presence or absence only, samples' sizes are maximized and intra-observer error is minimized. With regard to intra-observer error, scoring of grades in the expression of dental non-metrics might be straightforward in juvenile dentitions. In the dentitions of adults, however, it is more difficult and in some cases impossible, due to dental wear.

Finally, in practice, the number of metric and non-metric variables recorded from each skeleton was smaller than anticipated, due to the poor preservation and incompleteness of the studied collections.

5.1.2.4 Data Analysis

5.1.2.4.1 Preparation of data prior to analysis

Each skeleton was recorded in a separate recording form (a copy of that form is given in Appendix B, Table 5.7). Prior to analysis, metric and non-metric data was checked for errors.

The most frequent types of error in metric and non-metric data analysis are the following:

a) Inter-observer error: Despite the relatively easy replication of the majority of the selected measurements, due to their very explicit definition, it is probable that different researchers will interpret it differently, place the skull in a different position, hold the measuring instrument in a different mode, or identify the landmarks differently. This will result in different readings (data) for the same sample. In order to avoid any probable distortion of the results of the study, introduced by inter-observer error, all analyzed data (metric and non-metric) was recorded by the author.

b) Intra-observer error: This could derive from a poor understanding of the exact skeletal location where a measurement should be taken from, and it could be exacerbated by the intervention of time between data recording from different collections. To eliminate this error, before starting the collection of data from the Bronze Age Aegean collections, the author practiced on skeletal material kept at the Laboratory of Human Osteology, of the Archaeology Department in the University of Southampton, in order to standardize her recording techniques. Intra-observer error was checked by repeating the cranial measurements for 20 individuals from the Myrtos Pyrgos collection, 3 months following the first recording. No significant difference was found between the first and second recordings.

c) Instrument error: All instruments were calibrated before the beginning of data recording from each collection.

d) Reading and Recording error: At the end of each working day, the recorded data was checked for unusual values. When such values were spotted, they were cross-validated the following day by assessing the respective skeletal material.

The number of metric and non-metric variables that were actually recorded on each skeleton was generally smaller than anticipated, due to the state of preservation and completeness of the examined material. Multivariate analysis is significantly affected by missing values, since it requires that all analysed cases are represented by values for all tested variables. Otherwise, cases are automatically removed from the analysis. Deleting cases from the analysis results in the loss of information and it can possibly affect the representative power that the tested sample has over the population from which it derives (Stefan & Chapman 2003). Substituting missing values by sample means, or predicting them using multiple regressions was not performed in the present study in order to avoid the reduction of intra-sample variation, which may result from such practices. The problem of missing values was treated by substituting left by right side measurements, as applicable (see section 5.1.2.3.1), or by removing from the analysis metric and non-metric variables of low frequency in the recorded material, in order to maximize the completeness of the analysed data matrix (Powell & Neves 1999).

Following Irish (2005), small population samples were not removed from the analysis. For reasons relating to the preservation and completeness of the available for analysis skeletal material from the examined Bronze Age South Aegean regions, small samples are introduced to the analysis and the results are interpreted with caution for their probable low representative power over the population from which they derive.

5.1.2.4.2 *Metric Data Analysis*

Skeletal metric data were analysed using both univariate and multivariate analytical techniques (SPSS version 12.0). Multivariate analysis allows for the complex inter-relationships between cranial variables and the more comprehensive understanding of intra- and inter-population variation in terms of skeletal metric morphology. The properties of univariate analysis should not, however, be underestimated. The present study applied univariate analysis in order to achieve some understanding of similarities and differences between the tested population samples and the patterning of the variation in skeletal morphology. It serves as the initial point of departure for multivariate analysis by detecting the variables that express the greatest variance at the intra- and inter-population level of analysis. Univariate analysis is not affected as much as multivariate analysis by missing data and incomplete matrices. Therefore, it is preferable in studies of incomplete material (Stojanowski 2003).

The most frequently applied univariate analysis in this study is One-way ANOVA. Analysis explores inter-sample differences in means of the tested variables, to explore the null hypothesis that the examined samples derive from populations with the same mean for the tested variables. A fundamental assumption of this analysis is that the tested samples derive from populations with equal variances. Therefore, the Levene test of equality of variances was also employed to explore the null hypothesis that several population variances are equal. If the intra-sample variances and the sizes of the tested samples are significantly unequal, the more robust tests of variance, the Welch and Brown-Forsythe tests, are employed (Norušis 2003:143). In one case, the paired t-test was used to explore side-differences in the mean values for dental metric variables because it makes no assumption concerning the homogeneity of variance and is considered to be very efficient in detecting side-differences (Potter *et al.* 1981).

Cranial and dental measurements were used to calculate Cranial and Dental Indices respectively. The Cranial, Upper Facial, Height-Breadth and Height-Length indices describe the size and the shape of the cranium. Due to the poor preservation and incompleteness of the material, the original formulae for the Upper Facial, Height-Breadth and Height-Length indices were modified by substituting the less frequently recorded variables in the samples by more frequently occurring one, which describe the same cranial region (Appendix B, Table 5.2). Tooth crown mesio-distal and bucco-lingual diameters were used to calculate the Crown and Robustness (or Crown area) Indices. The first measures the shape and the second the size of the tooth crown (Lukacs 1985; Hillson 2002:72). In order to control for inter-population variation induced by techno-cultural factors, the Robustness Index is preferred to the Crown Index in biodistance studies of dental morphology. Analysis of the Crown Index is considered more appropriate for odontometric taxonomy (Kieser 1990). Hierarchical Cluster Analysis was applied to dental metric data (measurements and indices calculated from measurements) in order to provide a visual representation of inter-population relationships reconstructed using Squared Euclidean Distances calculated from the tested variables. Finally, it is applied to Strontium isotope ratio values in order to explore group membership for the examined individuals.

Principal Components Analysis (PCA) was the most frequently undertaken multivariate data analysis. PCA is a form of factor analysis, which assesses the covariation between the tested variables and summarizes the original set of variables and their relationship into a smaller number of (new) variables. The first component produced by PCA is the linear combination of the tested variables that accounts for the greatest portion of variance in the data (Shennan 1997; Norušis 2003:403).

Discriminant Function Analysis (DFA) aims to assign group membership to the tested individuals using a number of predictors. It presupposes that the observations can be divided into two or more groups and attempts to find ways (functions) to distinguish between these groups on the basis of the independent criterion that is derived from the data (Shennan 1997). This study applies DFA to explore the hypothesis for a Mycenaean presence at the Chora of Naxos following the LHIIIB-C destructions on the Mainland. It investigates group membership for two crania from the Kamini and Aplomata cemeteries that are suggested to consist of burials of Mycenaean high-status individuals. DFA is also employed to cross-validate the results of the PCA and investigate how accurately the tested metric variables can discriminate between different skeletal samples.

Squared Mahalanobis Distance (D^2) is used to measure the distance of the tested samples to the regional population centroid using cranial metric data. It is the distance from the values of a case for the predictor variables to the average of the values for the group to which the case is assigned (Norušis 2003:300).

5.1.2.4.3 *Non-Metric Data Analysis*

Non-metric data from the right and left sides were entered to the analysis as separate variables. Mean Measure of Divergence analysis was applied to the data in order to measure the genetic distance between two populations on the basis of the frequency of occurrence of non-metric morphological traits. The Mean Measure of Divergence between two populations is defined as: $MMMp=\Sigma(\Theta_{1j}-\Theta_{2j})^2/t$ and an unbiased sample estimate of it as: $MMMp=\Sigma(\theta_{1j}-\theta_{2j})^2/t- \Sigma(1/n_{1j}+1/n_{2j})/t$ (Tyrell 2000).

For t non-metric traits recorded on the material, let x_{ij} be the number of the individuals in a sample n_{ij} of a population i, scored to possess trait j. Then an estimate of the frequency of trait j in a population i is derived from the following equation: $p_{ij}=x_{ij}/n_{ij}$. The variance of p_{ij} depends on P_{ij}, i.e. the frequency of that trait in the entire population. One simple transformation to stabilize the variance of p_{ij} is: $\theta_{ij}=\arcsin(1-2p_{ij})$. The value for the MMD analysis was standardized by dividing it by its standard deviation (Lloyd-Jones 1997). The standard deviation was calculated using the equation provided by Green & Suchey (1976): $s.d.=(1/n_{1j}+1/n_{2j})^{2}$. Hierarchical Cluster Analysis was applied to the values of the Mean Measure of Divergence Analysis of dental non-metric traits in order to provide a visual representation of inter-sample distances (Squared Euclidean distance) calculated on the basis of trait frequencies.

5.2 Analysis of Strontium Isotope Ratio ($^{87}Sr/^{86}Sr$)

5.2.1 Principles of Analysis

Studies of stable isotope ratios of oxygen (White *et al.* 1998, 2000), lead (Carlson 1996; Gulson *et al.* 1997), and strontium (Sealy 1989; Price *et al.* 1994, 1998, 2000, 2001; Ezzo *et al.* 1997) have been used in archaeology for two decades to investigate questions of residential change of past populations and, at a broader level, to map their geographical movement. Strontium isotope ratio analysis is preferred to oxygen for reasons related mainly to problems with the identification of the specific water sources (the primary source of $^{18}O/^{16}O$) that the examined individuals exploited during their lives and the difficulty to determine local vs. non-local individuals due to the high variation in oxygen isotope ratios (Price *et al.* 2000).

Strontium isotope ^{87}Sr comprises c. 7.04% of total strontium and is the product of the radioactive decay of ^{87}Rb, which has a half-life of approximately 4.7×10^{10} years. In nature, strontium occurs in the form of three additional stable isotopes, ^{88}Sr (c. 82.53%), ^{86}Sr (c. 9.87%) and ^{84}Sr (c. 0.56%), none of which is radiogenic (Faure 1986). Variation in ^{87}Sr abundances in the Earth's crust are expressed as $^{87}Sr/^{86}Sr$ ratios and the ratio depends on the relative abundance of Rb and Strontium and the age of the rocks. This principle was employed initially by geologists to the determination of the age of various geological formations (Faure 1986; Faure & Powell 1972). $^{87}Sr/^{86}Sr$ ratios vary between 0.700 and 0.750. Older geological units (>100 million years), which have high original Rb/Sr ratios, will have higher $^{87}Sr/^{86}Sr$ ratios than younger units (1-10 million years) with low Rb/Sr ratios (Rogers & Hawkesworth 1989). At first instance this variation (0.700 to 0.750) may appear small, but it is remarkably large from a geological standpoint and in terms of the analytical error (± 0.00001 and ± 0.000008).

Strontium in bedrock passes into soil and groundwater and into the food chain. Therefore, strontium concentrations and, more accurately, isotope ratios in rock, groundwater, soil, plants and animals reflect the local geology (Graustein 1989). Since Strontium Isotope Ratio (SIR) ($^{87}Sr/^{86}Sr$) reflects the local geology and it passes to human skeletal tissues through the consumed food and water, analysis of dental and osseous tissue should show very similar strontium isotope ratio to that measured in the local geological material (Steele & Bramblett 1988).

One major advantage of the analysis of strontium stems from the fact that strontium isotope composition in not fractionated by biological processes, due to the very small relative mass differences between ^{87}Sr and ^{86}Sr (Graustein 1989). Therefore, despite the variation in local levels of elemental strontium in plant and animal tissue, the isotope composition is the same for both and reflects the isotope composition of the local geology, which is assumed to pass to the dental and osseous tissue of the human population through the food and water they consume (Price *et al.* 2002).

SIR analysis in studies of population movements uses human tissues formed at different ontogenetic stages (Price *et al.* 1994, 2000). Bone undergoes continuous replacement of its inorganic phase and measurements of bone strontium reflect the last years of the life of the individual. The half-life for turnover in cortical bone is approximately 23.1 years (Parfitt 1983). On the other hand, tooth enamel, a cell-free tissue, forms during childhood and does not remodel thereafter (Hillson 2002:148). Since Sr in tooth enamel is taken up during early childhood and is not remodeled thereafter, and the Sr content of the bones represents the Sr uptake of the last 7 to 10 years prior to death, significant differences between Sr isotope ratios in the two tissues indicate that the examined individual spent his/her childhood in a location geologically and isotopically different to his/her residence prior to death.

On the basis of the differences between the local geology of the Argolid, Naxos and Crete (outlined in Appendix A, section A.2), this study assumes differences between the three regions in terms of the range of the local biologically available strontium isotope ratio and applies strontium isotope ratio analysis to explore hypotheses for the movement of people from the Argolid to Knossos (Crete) and Naxos. The assumption is tested by determining the local at the three regions (Mycenae, Knossos and Chora of Naxos) biologically available strontium isotope ratio from archaeological and modern animal tissue and archaeological human bone.

5.2.2 Problems and Treatment

Three problems that emerge in studies of strontium isotopic ratio are: first, distinguishing between biogenic and diagenetic strontium and the recovery of the original biological signal instead of post-depositional contaminants (Koch *et al.* 1990; Price *et al.* 1992, 2000), second, establishment of the biologically available strontium within the investigated geographical area (Price *et al.* 2000, 2002) and third, distinction between locals and migrants (Ezzo *et al.* 1997; Price *et al.* 2002).

Although archaeological skeletal material is subject to diagenesis, it is studies of trace elements that are more susceptible to post-depositional contamination, rather than studies of stable isotopes (Price *et al.* 1992). In this context, it has been suggested that dietary studies of bone should better be based on isotope analysis, since trace elements contents of archaeological bones are highly variable and subject to diagenesis (Henderson *et al.* 1987). Even if there is contamination of bone by strontium isotopes (e.g. post-depositional Sr contamination of archaeological bone by groundwater), this will not alter the local isotope value of the bone, since the "contamination" is the same as the biologically available solution in the food chain (Grupe *et al.* 1997). Contamination from local ground water, however, could possibly narrow the local range for the biologically available SIR resulting in exaggerating the number of individuals identified as non-locals (Horn & Müller- Sohnius 1999). Nevertheless, a number of techniques have been developed to eliminate the impact of contamination. These involve the removal of any surface contaminants on teeth and bones by the mechanical and chemical cleaning of the analysed material, with deionised water and acetic acid respectively. In the present study, bone samples were extracted from the inner cortical area. The outermost bone layers are more susceptible to post-depositional contamination (Price *et al.* 1992; Koch *et al.* 1997). On the other hand, tooth enamel is a denser and more inert tissue in comparison to bone. Therefore, it is much less susceptible to diagenesis (Hillson 2002; Kohn *et al.* 1999; Price *et al.* 2002).

Studies of local soils record a range of values for the SIR ($^{87}Sr/^{86}Sr$), thus rendering inaccurate the equation of local strontium isotope ratio values with those measured for bedrock geology at the studied area (Faure 1986; Price *et al.* 2002). The range of $^{87}Sr/^{86}Sr$ values for the local soils results from the differential weathering of the various minerals within the rocks, as well as the mixing of various sources of sediment in the soil. Additionally, the groundwater could alter to some extent, the local isotope value, if it incorporates deeper, older waters (Jorgensen *et al.* 1999). In the light of local variability in strontium isotope levels (Sillen *et al.* 1998), the problem of determining the biologically available strontium isotope ratio at the studied area is frequently considered in investigations of animal and human migration. Price *et al.* (2002:122-29) provide a thorough treatment of the problem summarizing the results of past researches in the field. They discuss the species of the animals sampled, whether modern or fossil, bone or dental enamel samples and propose measuring the strontium isotope ratio in tooth enamel from archaeological animals from the site under consideration, and comparing it to measurements taken from modern animals, with concern for sample contamination from imported food, pollutants and/or soil fertilizers. Ideally, samples should be taken from small and large animals or animals of the same species from across the postulated food catchment area of the past human populations. Teeth from pigs are selected for controls because pigs are suggested to have a diet comparable to that of the humans and to be rather immobile (*ibid.*).

In the present study, local biologically available SIR was determined from the measurements of SIR taken from teeth of mammals (2 sheep/goats, 2 pigs and 1 cow) contemporary with the studied collections, the shell of modern and archaeological snails, dental enamel from one modern rabbit, and from archaeological human bone. Dental enamel is less susceptible to post-mortem physical and chemical contamination compared to bone (Price *et al.* 2000, 2002; Bentley 2006). SIR analysis of dental enamel and shell samples from modern animals was undertaken with concern to control for contamination. The modern rabbit was bred on a special diet that excluded industrialized food and/or chemically contaminated vegetables. Likewise, a non-contaminated diet is assumed for the modern snails that were collected from areas of wild vegetation, with no sign of cultivation by humans in the immediate vicinity in order to control for contamination by fertilizers. Human bone was selected to determine the local biologically available SIR (as in Price *et al.* 1994; Price *et al.* 2002: 131 and Ezzo *et al.* 1997) because its isotope ratio ($^{87}Sr/^{86}Sr$) reflects the long-term assimilation of the locally available $^{87}Sr/^{86}Sr$, through the consumption of the available food and water resources in the diet catchment area of the examined human population (Price *et al.* 2000, 2002). With concern for the presence of non-locals within the tested human sample, who could have migrated to the site recently enough for their bone not to have calibrated completely to local geology, human bone SIRs were cross-validated by the SIR measured in dental enamel and shell from archaeological and modern animals from the area of investigation. For the collections that SIR was not measured from animal dental enamel or shell, the range of local biologically available SIR determined from archaeological human bone is used with caution.

Identification of migrants within the studied population samples using SIR is complicated when a range of values for the isotope ratio in bone and teeth is recorded in that population (Ezzo *et al.* 1997; Price *et al.* 2000). In that case, characterization of extreme values as non-locals is fairly straightforward, but classification is obscure for values closer to the centre of values' distribution (Price *et al.* 2002). An objective criterion for the distinction between local and non-local individuals employed in studies of past populations' movement using this type of analysis is the mean value for the local biologically available SIR ± two standard deviations (Price *et al.* 2002). As described above, local biologically available SIR is determined in the present study from human bone and animal tissue.

With regard to the probable categories of residents at a site, the first distinction is made between locals and non-locals. Life-long residents at a site are classified as locals, whereas individuals born at a different site from the one they were disposed at are classified as non-locals. Non-locals can be further distinguished as recent and non-recent immigrants. Differences in the length of time for which immigrants have resided at the examined site will produce variation in strontium isotope values measured in the tested bone samples. This variation is associated with the remodeling of bone throughout the life of the individual. The rate of bone remodeling depends on the type of bone and the specific skeletal element (Price *et al.* 2002). If adequate time has elapsed from the migration of the individual to the site of his/her disposal, the SIR of his/her bone will have calibrated to local geology. One additional source of variation in bone SIR values is multiple residence, meaning that an individual may have had more than one residence during his/her lifetime (Price *et al.* 2000).

5.2.3 Materials

A total of seventy-five human bone and tooth enamel samples from the studied collections, 5 archaeological and 1 modern animal teeth, 2 archaeological and 8 modern snails were analyzed by the author. Samples were extracted from all morphologically studied skeletal collections from Naxos and Crete. Choice of samples took into account archaeological information and the results of the morphological analysis of the skeletal collections, undertaken prior to sampling. It was determined from to the two principal archaeological questions investigated in the thesis, the complementary status of SIR to the analysis of skeletal morphology in the present study, completeness of the skeletal collections, the active at the time of analysis Greek archaeological law for sampling from archaeological material and last but not least, the cost of the SIR analysis.

In order to investigate the hypotheses for the settlement of Mycenaeans at Knossos and the Chora of Naxos at the end of the LMIB and LHIIIB-C respectively, the emphasis of the analysis is placed upon the skeletal collections from the cemeteries at Sellopoulo in the district of Knossos, Aplomata and Kamini on Naxos. On the basis of the material culture evidence Sellopoulo, Aplomata and Kamini cemeteries are suggested to include burials of individuals from the Mainland (Popham *et al.* 1974; Hood 1985; Barber 1987). Strontium Isotope Ratio analysis investigates the validity of these two hypotheses.

Collections from Western, Central and Eastern Crete were sampled for two reasons. Firstly, sampling was undertaken to establish the local biologically available SIR at as many sites as possible throughout Crete, in order to be able to detect the origin of immigrants in the event of intra-island population movement. This was essential due to the lack of previous research on population movement in the Aegean using SIR analysis and the sporadic character of geological studies that measured SIR at a lower level of accuracy (3rd decimal digit) (Pe-Piper & Piper 2002) than that needed for the purposes of the present study (4th decimal digit). Secondly, Cretan collections from outside the Knossos district were sampled to explore the question of population movement in other than Knossos population samples, and compare these results to those derived from the analysis of skeletal morphology. In the Palama cemetery (Western Crete), burials in pit caves have been associated on material culture evidence with an "ethnically" different population group (Hallager & McGeorge 1992). SIR analysis in this study investigates this hypothesis. No samples were analyzed from the Mainland collections, due to the negative reply of the relevant Archaeological service to my formal request. The local at Mycenae biologically available strontium isotope ratio, however, was determined using modern snails in order to test the assumption that it is different from the local at the Knossos district biologically available SIR to allow for the monitoring of population movements between the two regions.

Due to the maximum permitted number of samples extracted from each collection being 10 (Greek archaeological law for sampling from archaeological material), not more than three individuals per collection are represented in the SIR analysis by both tooth and bone samples, so as to measure SIR in as many individuals as possible. Concerning the investigation of the two archaeological questions, biologically available SIR at the district of Knossos on Crete and Chora of Naxos was determined from both human bone and animal tissue (both archaeological and modern). Archaeological animal tissue (snail shell) was also analysed to determine the biologically available SIR at Tsikniades (Central Naxos). For the rest of the Cretan sites, biologically available strontium was determined solely from human bone for the reasons outlined earlier in this section.

For the purposes of SIR analysis, enamel and cortical bone were removed from the first molar (M1) and the femur (anterior mid-shaft region) respectively. The M1 was sampled because the crown of the M1 is formed in early childhood (i.e. crown development is completed by the fifth year of life of the individual) (Ubelaker 1989). The cortical bone from the femoral shaft region remodels more slowly compared to trabecular bone (Parfitt 1983; Hill 1998). In five cases, that these elements were not available for sampling and the inclusion to the analysis of the respective individual was important, femur was substituted by the tibia (individuals SELI,III and KAM A1), due to the very similar for the two elements turnover rates (Hill 1998). The first molar (M1) was substituted by the second molar (M2) (individuals LGI, F and KAM3) or the fourth premolar (PM4) (individual LGI, F5), because their crowns are formed within roughly the same period of life of the individual (Ubelaker 1989). A description and provenance of the analyzed human samples are provided in Appendix F, Table 1.

5.2.4 Methods of Analysis

Preparation and analysis of samples for the measurement of the SIR was undertaken by the author following training at the National Oceanography Centre in Southampton. In order to remove surface contamination, all teeth and bone specimens were placed in an ultrasonic bath for 30 minutes. The bath was interrupted every 10 minutes to allow for the specimens to be mechanically cleaned using a toothbrush and ultra pure water (resistivity of 18.2Ω). Specimens were dried overnight in an oven (60 °C).

Enamel samples of at least 20mg were extracted from each tooth using a scalpel. Any adhering dentine was thoroughly removed mechanically from enamel samples using a dremel tool. In one sample (individual APL XXIII) where traces of dentine could not be removed from the enamel sample using the dremel tool, fragments of enamel from the Early Cycladic Aplomata collection were placed dentine side down in concentrated hydrochloric acid for 15 minutes and heated for a further 5 minutes in order to dissolve as much dentine as possible. The same minimum amount (20mg) of bone powder was extracted from the inner cortical area of the selected specimens. Using a dremel tool specimens were bisected and the inner cortical bone was drilled out and collected as fine powder on glassine paper. Tools were cleaned with ultra pure water before being applied to each specimen. Tooth and bone samples were placed in the ultra sonic bath for a further 20 minutes and rinsed using ultra pure water. In order to remove diagenetic strontium, tooth and bone samples were leached in 2 ml of 5% acetic acid overnight. Samples were then rinsed four times and dried in an oven (60 °C). All leachates were retained in order to check for diagenesis, in case odd values were measured for any of the tested samples.

Strontium columns were prepared by filling small Teflon columns up to the neck with cleaned Sr resin. The columns were cleaned with 1.5ml of H_2O followed by 1.5ml of SB 3 molar HNO_3. This was repeated once more. Bone and tooth samples were digested in 300µl 3 molar HNO_3 and 6 molar HNO_3 respectively on a hotplate. 300µl of ultra pure water was then added to tooth samples to make a solution of 600µl 3 molar HNO_3. Samples were then loaded onto the resin into each column. The matrix and everything except Sr and Rb was eluted with 2.5ml 3 molar nitric acid. The Sr was released by passing through 1.5 ml of ultra pure water. The collected strontium was dried down on the hot plate and the strontium fractions were loaded onto a single tantalum filament with Ta-activator.

Finally, the samples were loaded in a Thermal Ionisation Mass Spectrometer, where they were heated in a high vacuum until the sample evaporated and the atoms evaporated as positive ions. The positive ions were then accelerated by a voltage (800V) towards the mass analyser (the magnet), which separated out the ions according to their m/z (m= mass, z= charge) ratio. In the VG Sector 54 situated at the end of the flight tube were a series of seven collectors, which could be positioned to detect ions of a specific m/z ratio. The voltages caused by the impact of the ions in the collector were detected, amplified and measured, and used to determine the isotopic ratio of strontium in the analysed samples (Faure 1986). Strontium isotope ratio was measured at six decimal digits.

CHAPTER 6

RESULTS OF MORPHOLOGICAL SKELETAL ANALYSIS

In this chapter, I will present the analysis and interpretation of metric and non-metric morphological traits recorded from Bronze Age South Aegean skeletal collections.

Presentation and discussion of the results are arranged in three parts, according to the level of analysis, i.e. intra-regional (sections 6.1: Argolid, 6.2: Crete) and inter-regional (section 6.3: Argolid, Cretan and Naxos samples: Inter-regional Analysis of Skeletal Morphology). Analysis and interpretation have been further organized according to skeletal element, i.e. cranium and dentition, and method of analysis employed, i.e. metric and non-metric analysis. The parts on cranium and dentition are disproportionately represented in this chapter, i.e. the parts on metric and non-metric morphological analysis of the cranium are more extensive than those on teeth, as a result of poor preservation of dental material. A very small number of teeth from the Moni, Palaikastro and Ailias collections was analysed (Table 5.1), whereas the scanty dental material recorded from the Episkopi, Maroulas, Kastelos, Aplomata and Kamini collections was unsuitable for meaningful analysis.

Thus the results of the analysis of population skeletal morphology are presented and discussed separately for the Argolid and Crete in sections 6.1 and 6.2 respectively. Section 6.3 investigates the biological relationship between the Argolid, Cretan and Naxos populations using results of analysis of cranial metric (section 6.3.1: Argolid, Cretan and Naxos samples: Inter-regional Analysis of Cranial Metric Morphology), cranial non-metric (section 6.3.2: Argolid and Cretan samples: Inter-regional Analysis of Cranial Non-metric Morphology), dental metric (section 6.3.3: Argolid and Cretan samples: Inter-regional Analysis of Dental Metric Morphology), and dental non-metric (section 6.3.4: Argolid and Cretan samples: Inter-regional Analysis of Dental Non-metric Morphology) morphology. Section 6.3.5 provides a summary of the results of the morphological analysis undertaken at the inter-regional level and the suggested interpretations.

Metric analysis of cranial morphology is used to explore intra-population biological variation in each population sample separately. Sex variation is one form of intra-population variation and a considerable portion of cranial metric analysis is devoted to the assessment of sexual dimorphism in the examined samples from both Argolid and Crete for two reasons. Sexual dimorphism in the analysed samples was assessed, in order to decide whether it is legitimate to pool together the two sexes to maximize the size of the samples in the examination of inter-sample biological relationships at the intra- and inter-regional level. If the level of sexual dimorphism is low, the two sexes can legitimately be pooled together to maximize the size of the samples. Also, because studies have shown that there is great inter-population variation in the magnitude of sex differences (Ascadi & Nemeskéri 1970; Potter 1972; Richman *et al.* 1979) and that it could be used to determine successfully the geographical origin of a skeletal sample (Frayer & Wolpoff 1985), the Argolid and Central Crete Middle and Late Bronze Age populations were compared in terms of the pattern and magnitude of sexual dimorphism in order to establish how similar or different they are in this respect. Due to low size, the Naxos population sample (1 male and 1 female) used in the present morphological analysis, did not qualify for meaningful assessment of sex differences in cranial metric morphology.

Inter-population biological variation and distance are explored between population samples within the same broad geographical context (i.e. Argolid and Central Crete). At the regional level, inter-sample analysis of biological variation and biodistance examines the hypothesis that two Argolid samples are biologically distant from each other. This hypothesized to be due, principally, to gene flow from extra-regional sources into the Lerna sample. Analysis also examines evidence for discontinuity in the biological history of the Bronze Age Central Crete population in relation to the hypothesis of the arrival and settlement at Knossos of biologically different individuals from the Argolid at the end of LMIB. At the inter-regional level, biological distance is explored between cotemporary Bronze Age population samples from the Argolid and Central Crete. In order to examine further the hypothesis of a Mycenaean migration to Knossos, for which an adequate data set was available from both regions, analysis is undertaken to quantify fluctuations in the biodistance between the Argolid and Central Crete populations over the course of the Bronze Age. For reasons relating to the poor preservation and completeness of available skeletal material from Bronze Age Naxos (see section 5.1.1.2), investigation of the hypothesis that refugee Mycenaean high-status individuals settled on Naxos in the LHIIIB-C is briefly investigated using metric analysis of cranial morphology.

6.1 Argolid

Study of the biological history of the Bronze Age population from the Argolid on the Greek Mainland was undertaken by analysis of the Middle Helladic sample from Lerna and the Late Helladic sample from Apatheia Galatas. It was impossible to monitor the population biological history of the Early Bronze Age population due to a dearth of excavated Early Bronze Age skeletal assemblages from the region. Intra-sample variation and inter-sample distance for the Argolid samples were investigated using results of analysis of cranial metric and non-metric morphology in sections 6.1.1 and 6.1.2 respectively. Section 6.1.3 presents and discusses the results of the analysis of dental morphology of the two Argolid samples undertaken in section 6.1. Finally, section 6.1.4 summarizes the results of morphological skeletal analysis of the Lerna and Apatheia samples presented in section 6.1, emphasising the biological relationship between the tested samples and the validity of the examined hypotheses.

6.1.1 Argolid: Cranial Metric Morphological Analysis

In this section, the results of metric morphological analysis of the cranium of Argolid population samples are presented and discussed. Cranial morphology is analysed by applying both univariate and multivariate analysis to the metric data. Univariate analysis provides understanding of population samples' similarities and differences and the patterning of the variation in cranial shape. Multivariate analysis, on the other hand, allows for the complex inter-relationships between cranial variables and more comprehensive understanding of intra- and inter-population variation in terms of cranial metric morphology. Multivariate analysis of metric variables follows univariate analysis of measurements and indices calculated from measurements.

6.1.1.1 Sexual Dimorphism in the Apatheia and Lerna samples: One-way Anova

In order to establish whether it is legitimate to pool together the two sexes for examination of the inter-sample biological relationship, sexual dimorphism was assessed for the two Argolid sites separately.

Lerna: In the Lerna sample, 23 individuals were identified as males and 14 as females using the methodology outlined in section 5.1.2.2 (the sex and age of the analysed Lerna individuals is given in Appendix C, Table 6.1). Sex differences in the mean values for the cranial variables were tested using One-way ANOVA. If the variance of the sample means reaches the significance level, the null hypothesis that the samples come from populations with the same mean for the tested variables is rejected (Norušis 2003). One of the fundamental requirements to apply ANOVA is that the recorded data should be independent random samples from normal populations with equal variances. If the sizes of the samples are significantly different and the smaller ones happen to show the higher variances, it is highly probable that the null hypothesis will be rejected, when it is actually true. The equality of the intra-sample variances can be confirmed using the Levene test.

Due to size differences between the tested sex groups of the Lerna sample and the inequality of the variances of the two sex-groups suggested by the Levene test for ZYB (p=0.020), JUB (p=0.026), DKS (p=0.006), SOS (p=0.007), OCF (p=0.026) (Appendix D, Table 6.1), sexual dimorphism was further tested using the more robust tests of variance, the Welch and Brown-Forsythe tests (Appendix D, Table 6.2) (Norušis 2003). Sexual dimorphism reached the level of significance (p<0.05) for the following variables: GOL (p<0.001), NOL (p=0.001), BNL (p=0.021), STB (p=0.003), MDB(p=0.042), GLS (p=0.001), FRC (p=0.001), FRF (p=0.001), OCC (p=0.010), VRR (p=0.020), NAR (p=0.002), PRR (p=0.016), DKR (p=0.032) and ZMR (p=0.012). These variables describe the cranial length and height, the frontal breadth, the breadth of the mastoid process, as well as the protrusion of the facial skeleton at the upper-facial, mid-facial and subnasal region.

Apatheia Galatas: One-way ANOVA was also performed to test for sexual dimorphism in the Apatheia sample. Although the two sex groups do not differ considerably in size (14 males and 11 females, Appendix C, Table 6.2), the Levene test showed significant inequality of intra-group variances for the following three variables: AUB (p=0.007), ASB (p=0.017) and WMH (p=0.002) (Appendix D, Table 6.3). Welch and Brown-Forsythe tests were applied to the data to check for sex differences in AUB, ASB, and WMH, but failed to show significant differences between the two sex groups (Appendix D, Table 6.4). One-way ANOVA suggests significant differences (p<0.05) for GOL (p=0.027), NOL (p=0.013), FMB (p=0.048), PAC (p=0.014) and PRR (p=0.001) (Appendix D, Table 6.5). These variables describe the cranial length and upper facial breadth, and the facial protrusion at the subnasal region.

If the two Argolid samples are compared in terms of sexual dimorphism, it is clear that the number of variables for which sexual dimorphism reached significance is higher for the Lerna sample. In both Lerna and Apatheia samples, however, the results of One-way ANOVA showed that sexual dimorphism reaches significance for cranial length and the measurements describing the morphology of the facial skeleton (i.e. facial breadth and protrusion). It is well-established that generally, males tend to be bigger in size and more robust than females of the same population (White & Folkens 2000:362). Males tend to have larger crania and more pronounced certain morphological features of the facial skeleton (i.e. supraorbital ridges, glabella) compared with females (Brothwell 1981; Buikstra & Ubelaker 1994; Mays 1998).

The smaller number of significantly sexually dimorphic variables for Apatheia in comparison with Lerna cannot be accounted for by systematic reduction in dimorphism over the course of human biological history (Frayer & Wolpoff 1985), as no major changes in male and female roles are known between Middle and Late Bronze Age societies. In interpreting this result, it is important to note, firstly, the larger size of the Lerna sample and secondly, the more unequal representation of the two sexes in the Lerna sample (23 males and 14 females) relative to the Apatheia sample (14 males and 11 females). In relation to the first point, it could be argued that the tested data from the Apatheia sample may not represent the whole range of sexual dimorphism in the respective population as accurately as in the case of the larger Lerna sample (i.e. archaeological bias). Nevertheless, since all the tombs of the Apatheia cemetery have been sampled for the present analysis, there is no reason to believe that a segment of the community using this cemetery is not represented by the analysed material. Moreover, the time-depth of the Lerna sample is higher compared to Apatheia (Angel 1971; Konsolaki-Yannopoulou 2001) and this has implications for the intra-sample variation of the two sites (see discussion, section 6.1.1.10).

The results of One-way ANOVA indicate that sexual dimorphism is greater for the Lerna than the Apatheia sample.

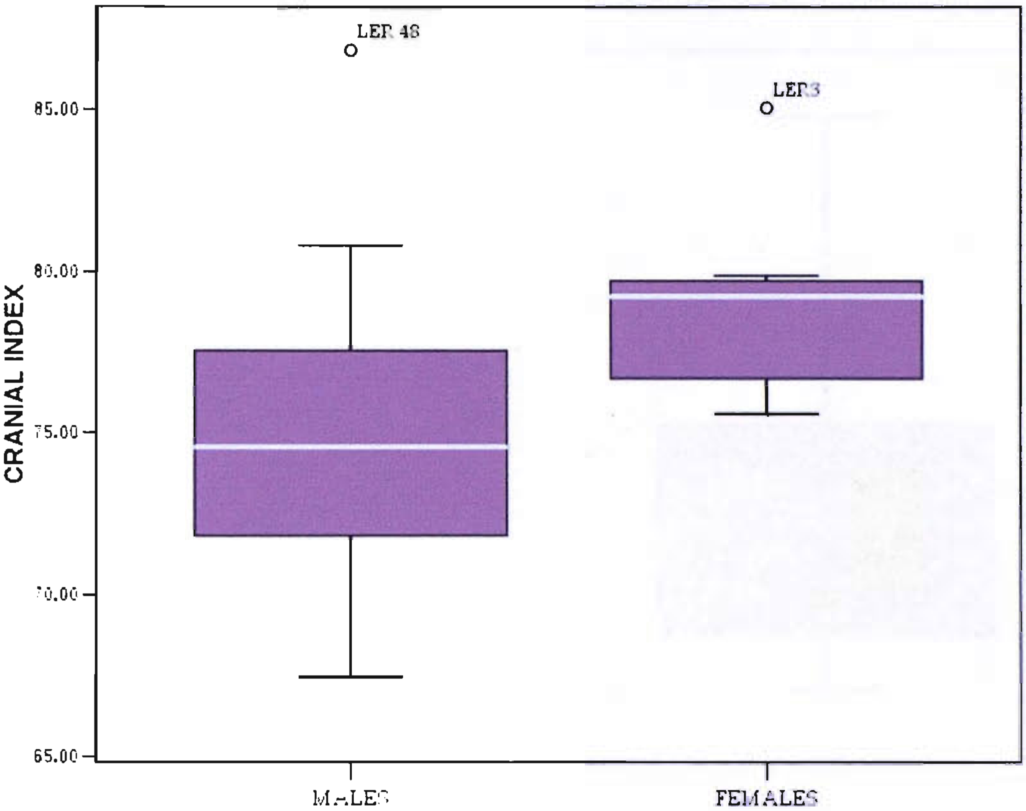
6.1.1.2 Sexual Dimorphism in the Apatheia and Lerna samples: Cranial Indices

Cranial index (CI= 100*XCB/GOL): The Cranial Index summarises information on the shape of the cranium and is employed to understand the patterning of sex-variation in the cranial shape of the two Argolid samples. Differences in the means of the two sex-samples were tested using One-way ANOVA. More robust tests of variance (i.e. Welch and Brown-Forsythe tests) are used when sample size is low or when there is significant inequality in intra-group variances.

Lerna: The Welch and Brown-Forsythe tests detected significant sex-differences for the Cranial Index in the Lerna sample (p=0.03 for both tests). These were applied, due to unequal representation of the two sexes in the tested sample (7 females and 17 males) (Figure 6.1.1). The inferior and superior sides of the boxes in Figure 6.1.1 represent the 25th and 75th percentiles. The horizontal line in the interior of each box is the category median, the 50th percentile, meaning that half of the values fall below and the other half above this line. The whiskers that extend from the superior and inferior sides of the boxes represent the largest and smallest values that are not outliers (Norušis 2003:99). When the median is in the centre of the box, the distribution of the values for the tested variable is symmetric. If the median is closer to the superior or inferior side of the box, the data are said to be negatively or positively skewed respectively (Norušis 2003:100).

Plotting of the data in Figure 6.1.1 suggests a negatively skewed distribution of the values for the female individuals and a narrower range of variance in comparison to the males. The narrower range of values for the Lerna females, compared to the males from the same sample could be the result of their comparatively smaller number. Cranial Index values for the male sample appear to be distributed normally.

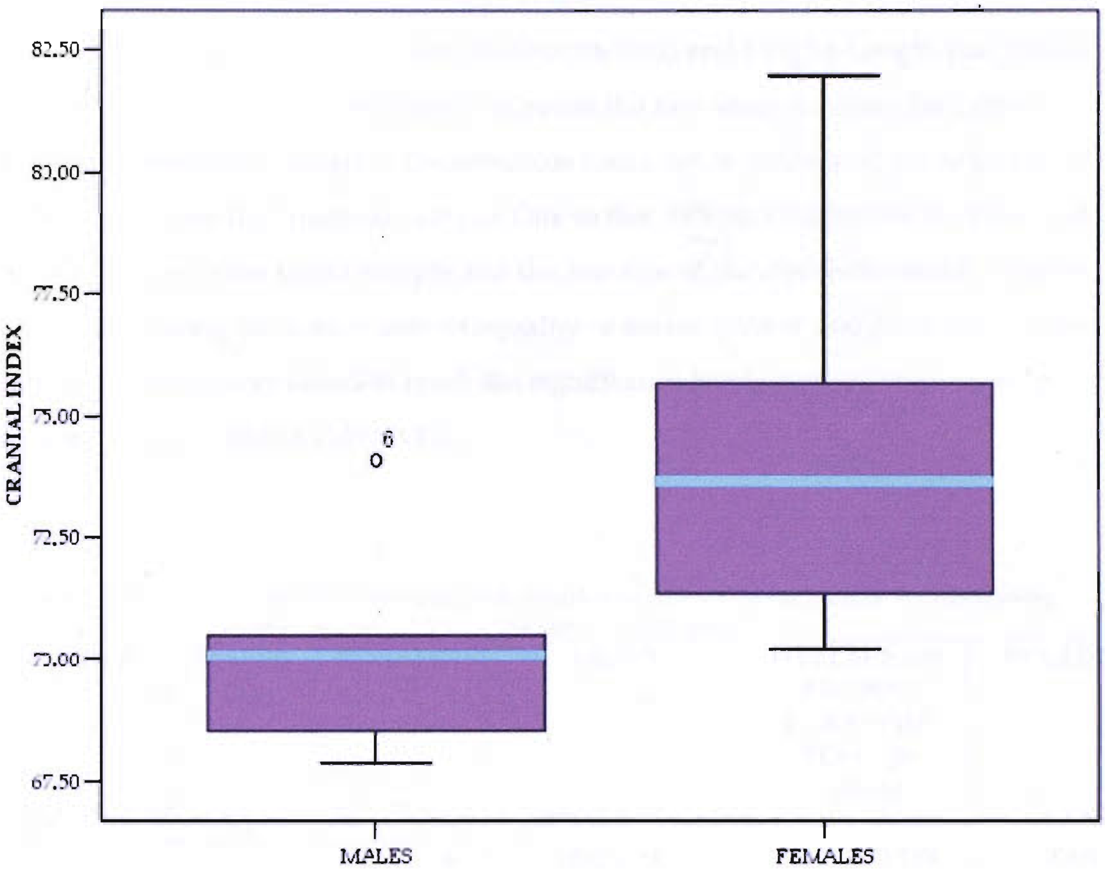
Figure 6.1.1 Box and whisker plot of sexual dimorphism in the Lerna sample, Cranial Index.



Apatheia: For the Apatheia sample, the difference between males and females for the Cranial Index did not reach significance (p=0.077). Due to the low size of the tested sample (7 females and 5 males), Welch and Brown-Forsythe tests of variance were applied to the data set and the results suggested that sexual dimorphism for the Cranial Index is very close to statistical significance (p=0.058 for both tests). Data distribution is negatively skewed for males, whereas it is more or less symmetrical for the females (Figure 6.1.2). Moreover, the females show a greater range of variance in comparison to the males for the same variable and this could be associated with the larger size of the female sample.

In both Argolid samples, the calculated Cranial Index is higher for the females than the males. Females tend to have crania that are less long for their breadth relative to the males. This means that the shape of the female cranium is more rounded than that of the males.

Figure 6.1.2 Box and whisker plot of sexual dimorphism in the Apatheia sample, Cranial Index. Case 6, a male outlier, is individual A from tomb A5.



Upper Facial, Height-Breadth and Height-Length Indices: In addition to the Cranial Index, the Upper Facial (UFI=100*NPH/ZYB), Height-Breadth (HBI=100*BBH/XCB) and Height-Length (HLI=100*BBH/GOL) Indices were also calculated. Due to the relatively poor preservation and incompleteness of the material, the original formulae for all three cranial indices were modified by substituting the less frequently recorded variables with more frequently occurring ones describing the same cranial region (Appendix B, Table 5.2). For example, in order to calculate an Index equivalent to the Upper Facial Index (UFI), Cheek Height (WMH) and Bifrontal Breadth (FMB) were selected to substitute for the Nasion-Prosthion Height (NPH) and Bizygomatic Breadth (ZYB) respectively, which are used in the original formula (UFI(md[1]) =100*WMH/FMB). Likewise, the Height-Breadth and the Height-Length Indices were modified by substituting BBH in the

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[1] md stands for modified.

original formulae with VRR and the modified formulae are the following: HBI(md^1)= 100*VRR/XCB and HLI(md^1)=100*VRR/GOL.

The Upper Facial (md), Height-Breadth (md) and Height-Length (md) Indices were not found to differ significantly between the two sexes in either the Lerna or Apatheia population samples. These indices could not be calculated for more than 10 individuals from the Apatheia sample. Due to size difference between the male and female groups in the Lerna sample and the low size of the Apatheia sample, indices were tested using the robust tests of equality of means (Welch and Brown-Forsythe tests). Sex-differences failed to reach the significance level ($p<0.05$); the results (p values) are provided in Table 6.1.1.

Table 6.1.1 Sexual dimorphism in the Lerna and Apatheia samples, Cranial Indices. Assessed using Welch and Brown-Forsythe tests (p values are the same for both tests).

SAMPLE	MALES (N)	FEMALES (N)	INDEX	WELCH AND BROWN-FORSYTHE TESTS (p values)	STATISTIC
LERNA	12	7	UPPER FACIAL	0.249	1.528
	16	4	HEIGHT-BREADTH	0.189	2.430
	15	5	HEIGHT-LENGTH	0.217	1.886
APATHEIA	2	3	UPPER FACIAL	0.146	7.149
	3	4	HEIGHT-BREADTH	0.290	1.521
	4	3	HEIGHT-LENGTH	0.105	4.697

KEY: N=Number of Individuals

6.1.1.3 Sexual dimorphism in the Apatheia and Lerna samples: Multivariate Analysis

Lerna: Sexual dimorphism in the Lerna population was explored also by applying Principal Component Analysis (PCA) to variables describing the length and breadth of the cranium and the morphology of the frontal bone (i.e. GOL, XCB, FRC, FRS, FRF, and XFB). The tested variables were chosen in order to describe the overall shape of the cranium and the midline curvature of the frontal bone as it is widely used as a reliable morphological criterion in the determination of the sex of skeletal populations (e.g. Brothwell 1981). PCA is a form of factor analysis, which assesses the covariation between the variables and explores whether the original set of variables and their relationships can be summarised by a smaller number of variables. Frequently the original variables are closely related to one another and the PCA aims to identify the underlying (new) variables, which explain the pattern of correlations within the original set of variables (Shennan 1997).

Tables 6.1.2 and 6.1.3 show the amount of variance explained by the two extracted components, and the component loadings for PCA of cranial length and breadth and the morphology of the frontal bone (N=20). A visual examination of the results (Figure 6.1.3) suggests a clear separation between males and females on the basis of the tested variables. Allowing for the small number of the tested females, it appears that females tend to have smaller crania in both length and breadth measurements than males (Figure 6.1.3).

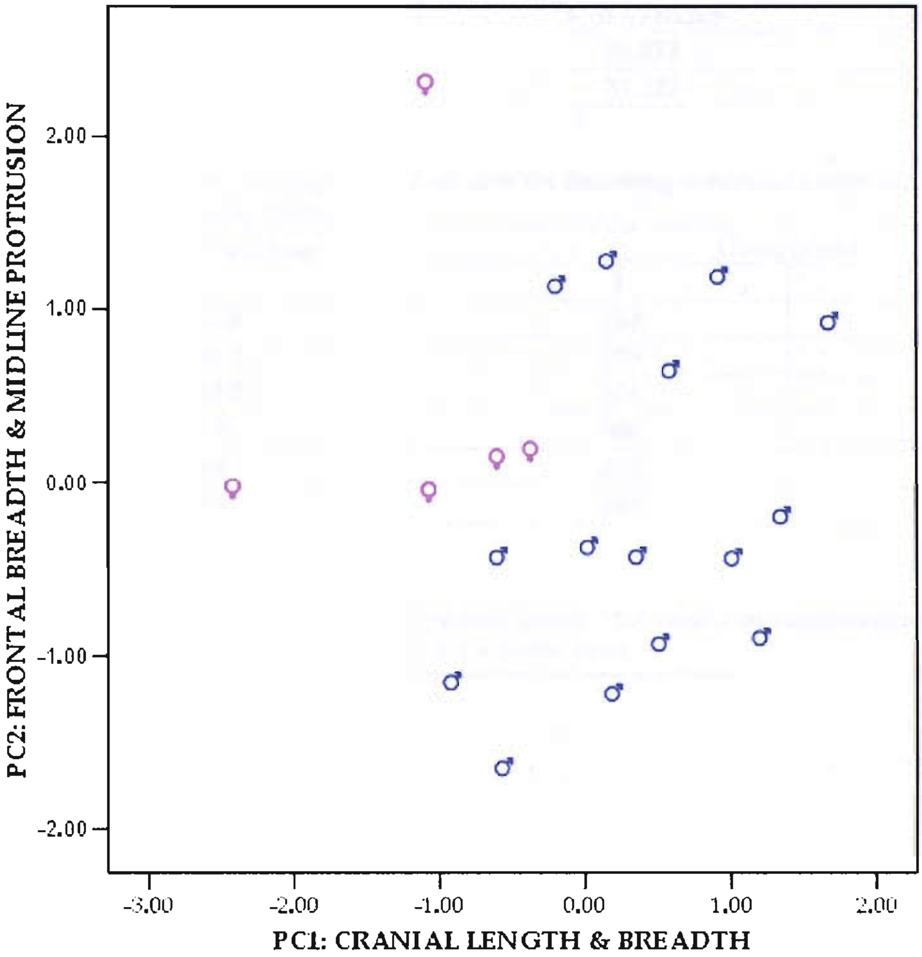
Table 6.1.2 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.108	51.800	51.800
2	1.546	25.761	77.561

Table 6.1.3 Component loadings for PCA of variables describing the cranial length and breadth and the morphology of the frontal bone.

	Components	
Cranial Metric Variables	1	2
GOL	.741	-.583
XCB	.743	.452
FRC	.909	-.133
FRS	.605	.483
FRF	.636	-.670
XFB	.641	.549

Figure 6.1.3 Sexual dimorphism in the Lerna sample: PCA results for variables describing cranial length and breadth and the morphology of the frontal bone.



Principal component analysis was performed for the Apatheia sample (N=9) using the same variables as for the Lerna sample. Tables 6.1.4 and 6.1.5 present the amount of variance explained by the two extracted PCs and the component loadings for the PCA of cranial size and shape respectively. Patterning of the data in Figure 6.1.4 suggests that females tend to have crania broader for their length in comparison with males. Moreover, regarding the morphology of the frontal bone, the separation between the two sexes is more distinct when the midline curvature of the bone is assessed. The curvature of the frontal bone is smoother (the angle is more obtuse) in males than in females. This results in the more vertical forehead of the females, which is suggested and widely used as a reliable morphological criterion in the determination of the sex of skeletal populations (e.g. Brothwell 1981). Nevertheless, these results and associated interpretations are tentative, due to the small number of individuals that qualified for the analysis (N=9).

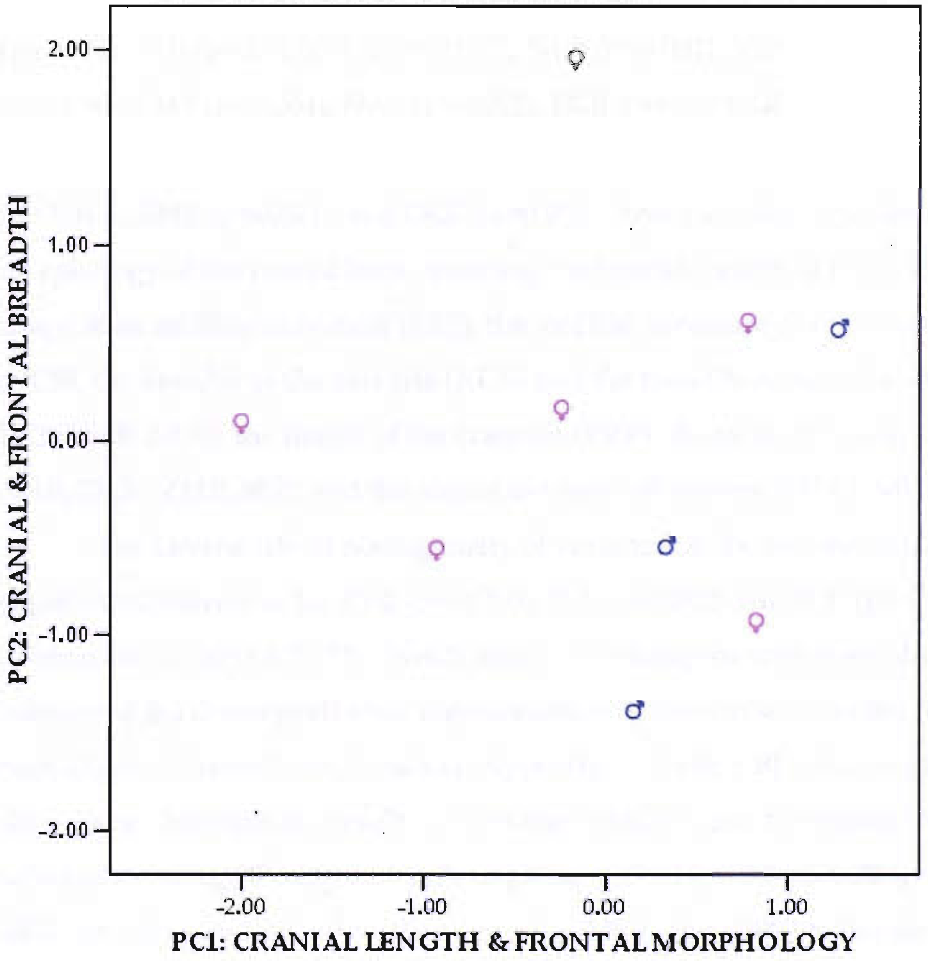
Table 6.1.4 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.112	51.873	51.873
2	1.868	31.127	82.999

Table 6.1.5 Component loadings for PCA of variables describing the cranial length and breadth and the morphology of the frontal bone.

Cranial Metric Variables	Component	
	1	2
GOL	.753	-.430
XCB	.223	.935
XFB	.521	.819
FRC	.900	-.325
FRS	.817	.118
FRF	.864	-.133

Figure 6.1.4 Sexual Dimorphism in the Apatheia sample: PCA results for variables describing the cranial length and breadth and the morphology of the frontal bone.



6.1.1.4 Sexual dimorphism in the Argolid population, Apatheia and Lerna samples pooled: One-way Anova

Univariate and multivariate analysis of craniometric data suggested a very similar pattern of sexual dimorphism in the two Argolid samples. Therefore, the Lerna and Apatheia samples were pooled to form two groups, of 25 females and 37 males respectively. Pooling the two samples permits comparison of the Argolid population with the population from Central Crete in terms of sexual dimorphism (section 6.1.3). This is particularly beneficial for those cranial regions for which sexual dimorphism could not be reliably assessed, due to low sample size.

In order to explore sexual dimorphism in the overall Argolid population (Apatheia and Lerna samples pooled), the pooled data were tested for significant sex differences in the mean values of cranial metric variables using One-way ANOVA ($p< 0.05$) (Appendix D, Table 6.6). The variables that rendered significant differences between the two sex groups are the following: GOL ($p <0.001$), NOL ($p<0.001$), BNL ($p=0.015$), STB ($p=0.047$), JUB ($p=0.007$), NLB ($p<0.001$), MDH ($p=0.019$), MDB ($p=0.036$), FMB ($p=0.004$), NAS ($p=0.012$), EKB ($p=0.039$), GLS ($p<0.001$), FRC ($p<0.001$), FRF ($p<0.001$), VRR ($p=0.013$), NAR ($p=0.001$), SSR ($p=0.024$), DKR ($p=0.043$), ZMR ($p=0.021$), and OCC ($p=0.05$). These variables describe the morphology of the frontal bone, meaning the frontal breadth (FMB, STB) and the shape of its midline curvature (FRF), the midline curvature of the occipital bone (OCS), the breadth of the calvaria (AUB) and the breadth of the facial skeleton (JUB, EKB, FMB, NLB), the height of the cranium (VRR), the facial protrusion (BNL, NAS, NAR, DKR, ZMR, SSR) and the size of the mastoid process (MDH, MDB).

The Levene test of homogeneity of variances in the two sex groups showed significant differences for ZYB ($p= 0.020$), JUB ($p=0.002$) and SOS ($p= 0.038$) (Appendix D, Table 6.7). The Welch and Brown-Forsythe tests were also employed because of the disproportionate representation of the two sexes in the Argolid population (25 females to 37 males) (Appendix D, Table 6.8). Concerning the discrepancy between the results of One-way ANOVA and the robust tests, the latter failed to show significant sexual dimorphism in STB ($p= 0.066$), JUB ($p= 0.086$) and EKB ($p= 0.056$), or OCC ($p= 0.053$), but added PAC ($p= 0.037$) to the list of significantly sexually dimorphic variables.

6.1.1.5 Sexual dimorphism in the Argolid population, Apatheia and Lerna samples pooled: Cranial Indices

Sex-variation in the Cranial Index (CI=100*XCB/GOL), the Upper Facial (md) Index (UFI(md)=100*WMH/FMB), the Height-Breadth(md) Index (HBI(md)=100*VRR/XCB), and the Height-Length(md) Index (HLI(md)=100*VRR/GOL) was explored using One-way ANOVA. Analysis failed to detect significant differences in the mean values between males and females. With the exception of the Upper Facial (md) Index, the size of the male sample was considerably higher than that of the female sample for all three tested Indices (Table 6.1.6). Variance was, therefore, further explored using the Welch and the Brown–Forsythe tests. These results, however, also failed to reject the null hypothesis for all four tested variables (Table 6.1.6). Analysis of variance for all the calculated cranial indices failed to detect significant sexual dimorphism in the cranial morphology of the Argolid population.

Table 6.1.6 Sexual Dimorphism in the Argolid population (samples pooled), Cranial indices. Assessed using One-way ANOVA and the Welch and Brown-Forsythe tests, (p values).

INDEX	MALES (N)	FEMALES (N)	ONE-WAY ANOVA	WELCH AND BROWN-FORSYTHE TESTS (p values are the same for both tests)
CRANIAL	22	14	0.095	0.086
UPPER FACIAL	14	10	0.551	0.565
HEIGHT-BREADTH	19	8	0.091	0.093
HEIGHT-LENGTH	19	8	0.1	0.097

KEY: N=Number of Individuals

Presentation of the data using box and whisker plots suggests that, for both males and females, the distribution of values for the Cranial Index is more or less normal (Figure 6.1.5), whereas data distribution for the Upper Facial (md) Index is negatively skewed (Figure 6.1.6). The distribution of the values for the Height-Breadth (md) (Figure 6.1.7) and the Height Length (md) Indices (Figure 6.1.8) is positively skewed for the males, whereas for the females it is negatively skewed and roughly symmetrical for the Height–Breadth (md) and the Height–Length (md) Indices respectively.

Figure 6.1.5 Box and whisker plot of sexual dimorphism in the Argolid population (samples pooled), Cranial Index.

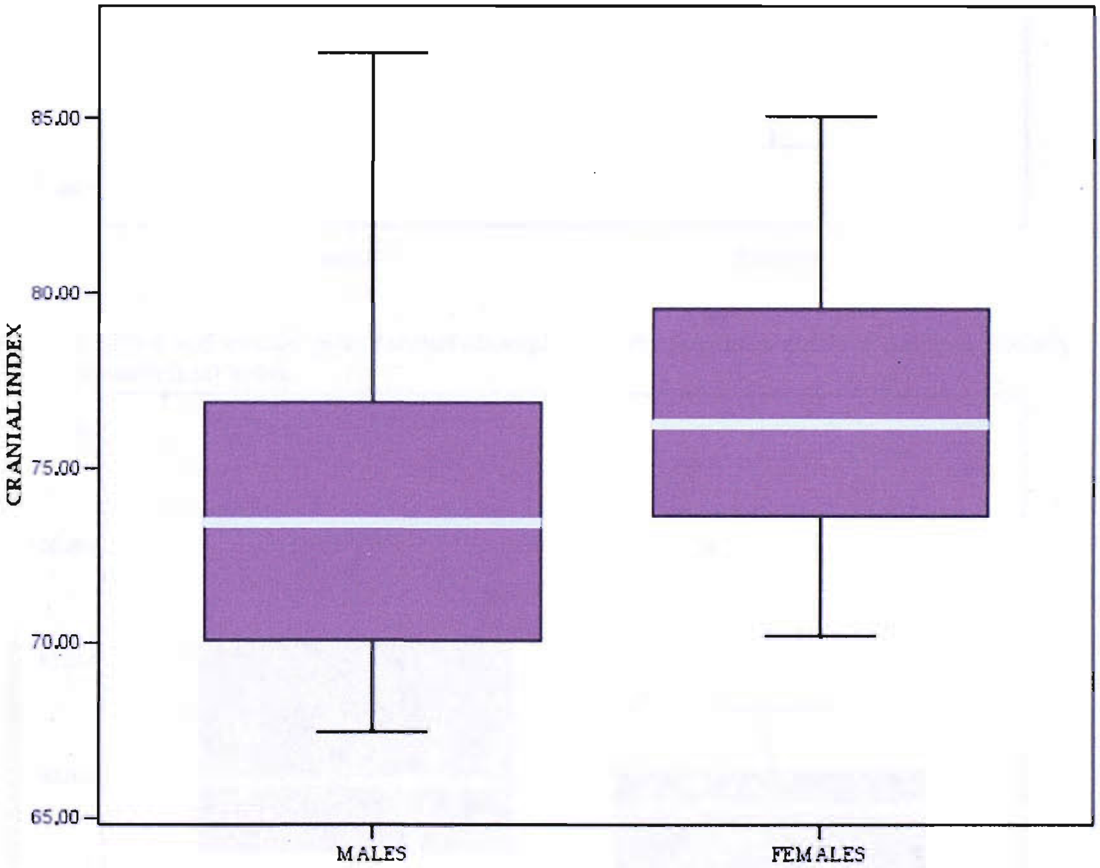


Figure 6.1.6 Box and whisker plot of sexual dimorphism in the Argolid population (samples pooled), Upper Facial (md) Index.

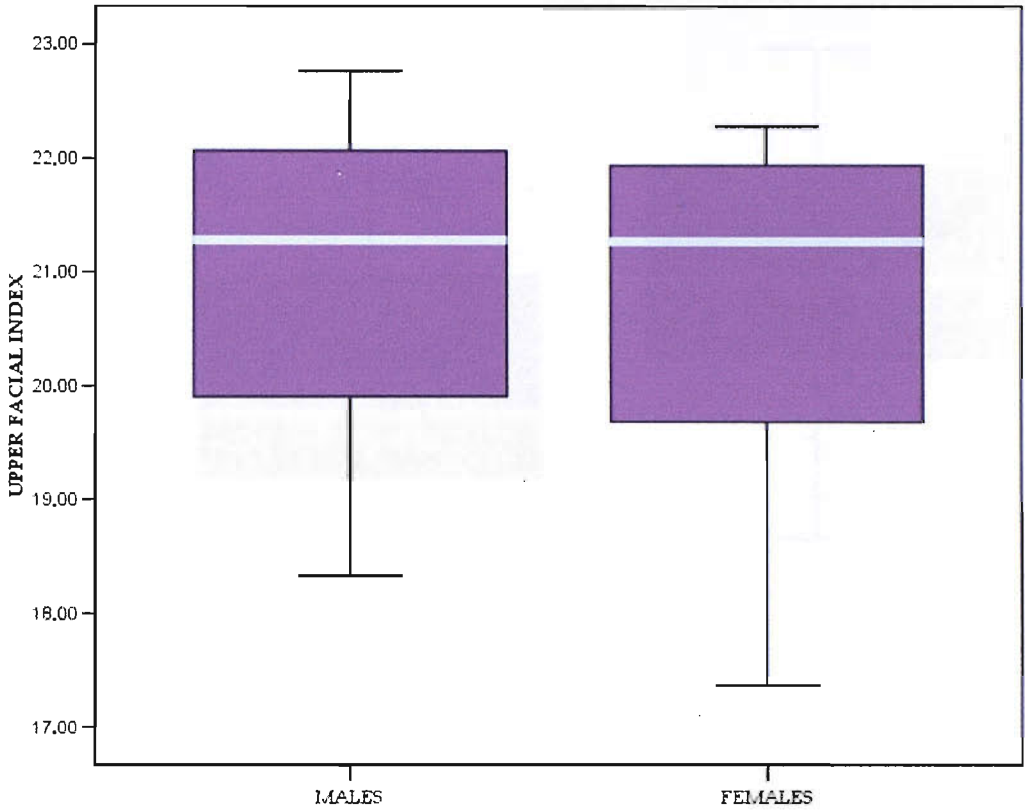


Figure 6.1.7 Box and whisker plot of sexual dimorphism in the Argolid population (samples pooled), Height-Breadth (md) Index.

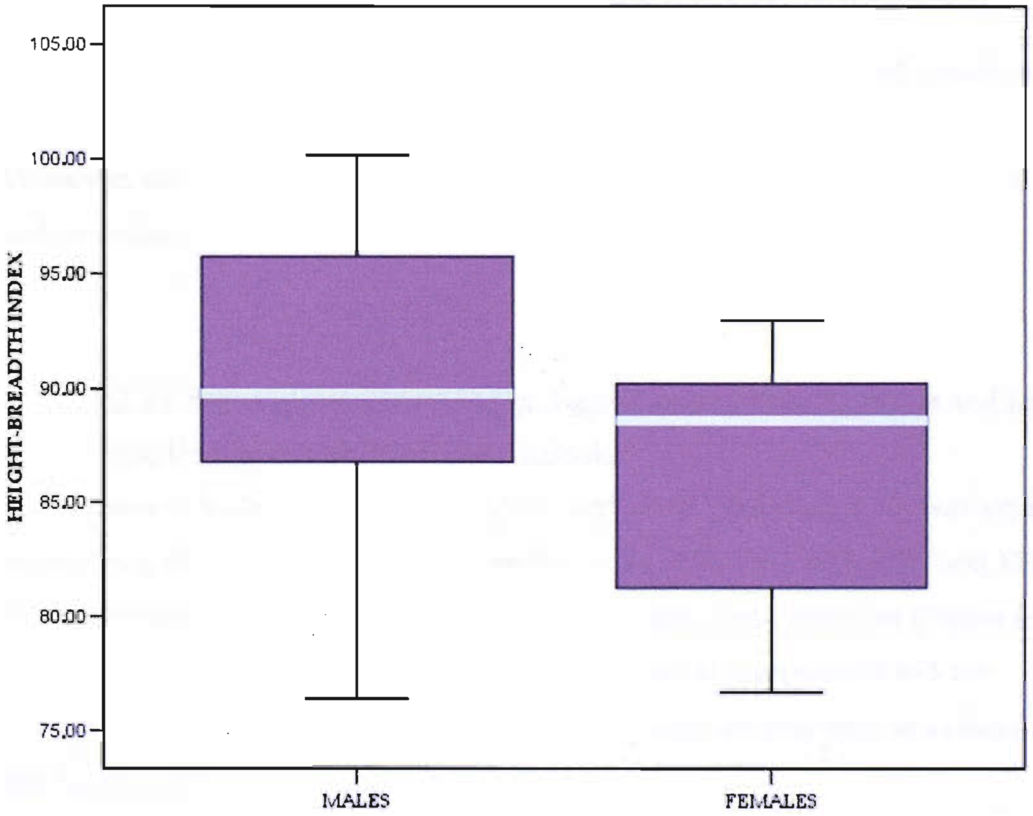
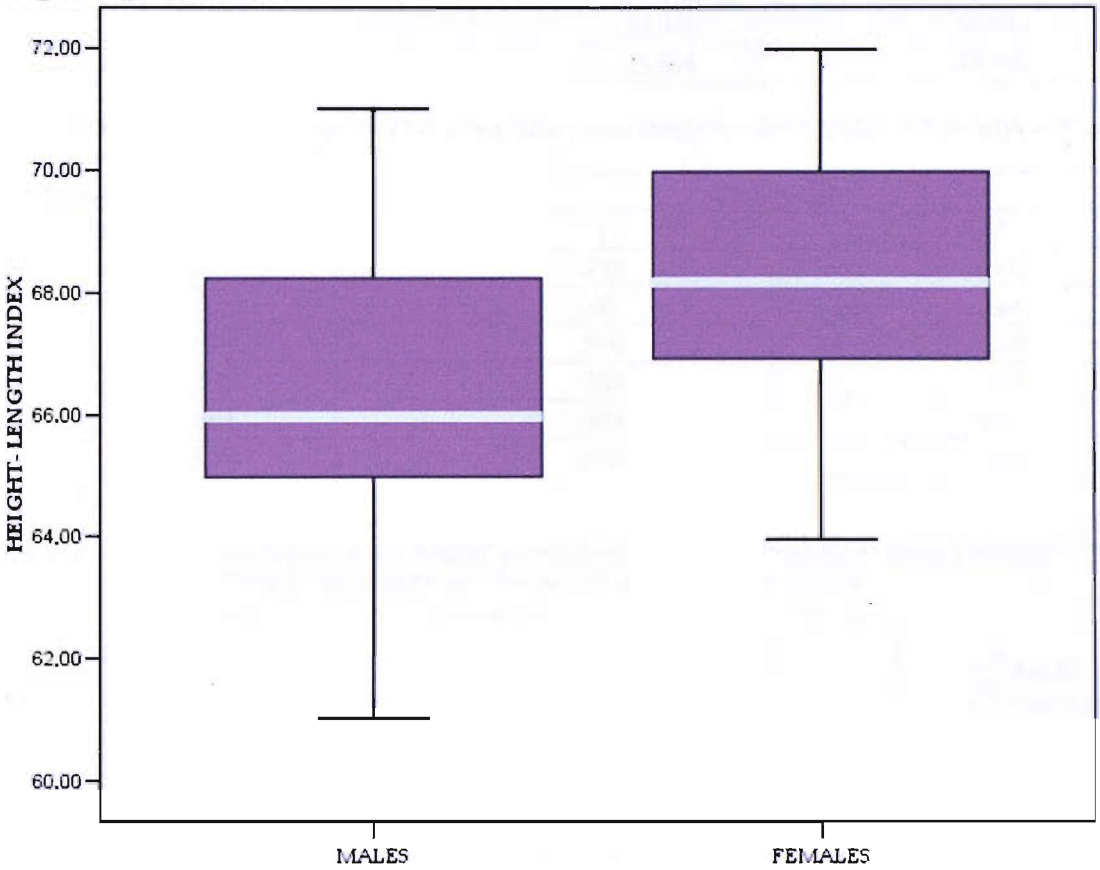


Figure 6.1.8 Box and whisker plot of sexual dimorphism in the Argolid population (samples pooled), Height-Length (md) Index.



Plotting of the calculated cranial indices suggests that Argolid female crania are usually broader for their length and height compared with male crania. Moreover, the female cranium appears to be quite high for its length relative to the male cranium.

6.1.1.6 Sexual dimorphism in the Argolid population, Apatheia and Lerna samples pooled: Multivariate Analysis

Sexual dimorphism in the Apatheia and Lerna pooled samples was explored by applying PCA to the following variables: GOL, XCB, FRC, FRS, FRF, and XFB (N=29). Separation of the two sexes is very clear using these variables (Figure 6.1.9). The amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape are provided in Tables 6.1.7 and Table 6.1.8.

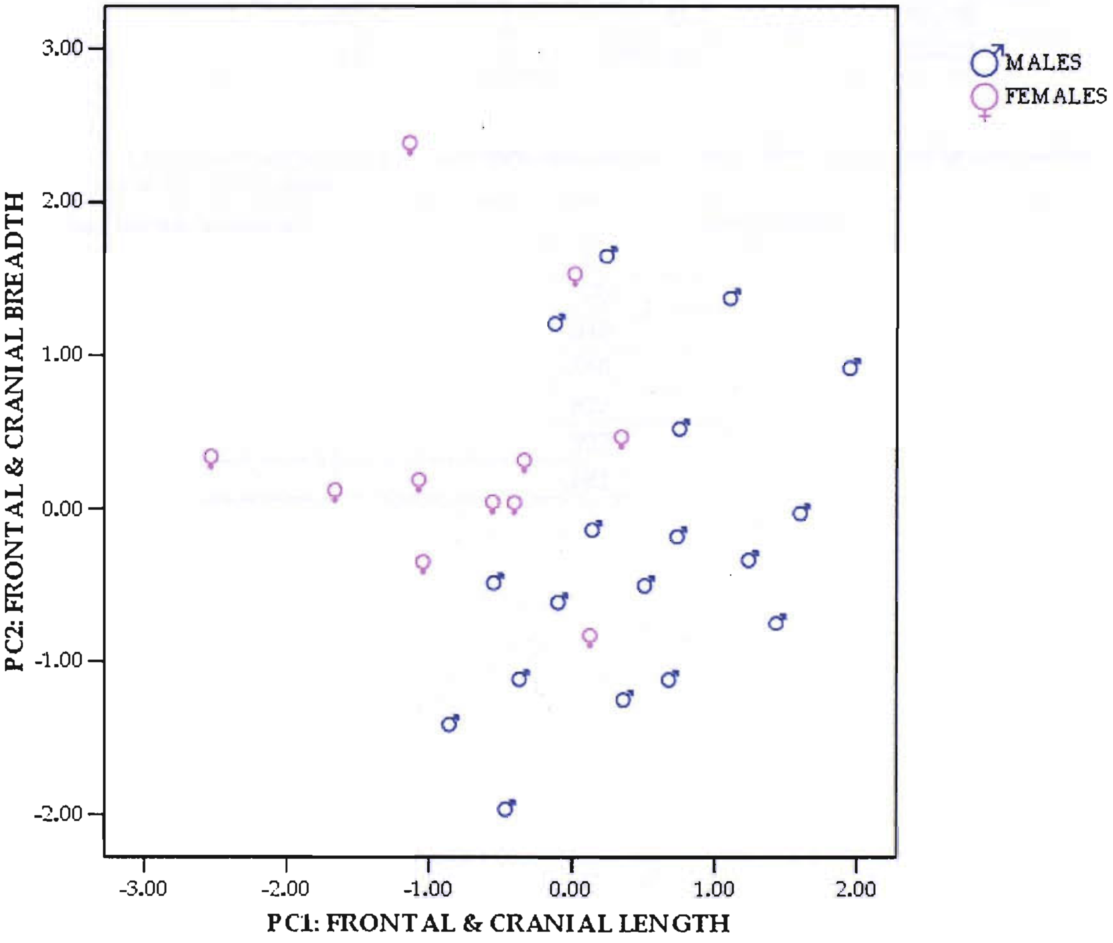
Table 6.1.7 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.003	50.043	50.043
2	1.431	23.854	73.897

Table 6.1.8 Component loadings for PCA of variables describing the cranial length and breadth and the morphology of the frontal bone.

Cranial Metric Variables	Component	
	1	2
GOL	.702	-.600
XCB	.685	.564
FRC	.896	-.208
FRS	.581	.304
FRF	.684	-.511
XFB	.658	.597

Figure 6.1.9 Sexual dimorphism in the Argolid population (samples pooled): PCA results for variables describing the cranial length and breadth and the morphology of the frontal bone.



The tested variables describe the length and breadth of the cranium, and the morphology of the frontal bone (its midline curvature and maximum breadth). Patterning of the data in Figure 6.1.9 suggests that males have longer crania in relation to their breadth than females. This agrees with the results of analysis of the Cranial Index (Figure 6.1.5) in that the female cranium appears to be more rounded than the male cranium (Figure 6.1.9).

Next, sex differences were explored for the height of the cranial vault. The variables tested were GOL, XFB, FRF, VRR, FRC and FRS, and the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape are given in Tables 6.1.9 and 6.1.10 (N=21). Males appear to have crania both longer and higher-vaulted in relation to their frontal breadth and frontal subtense than females (Figure 6.1.10).

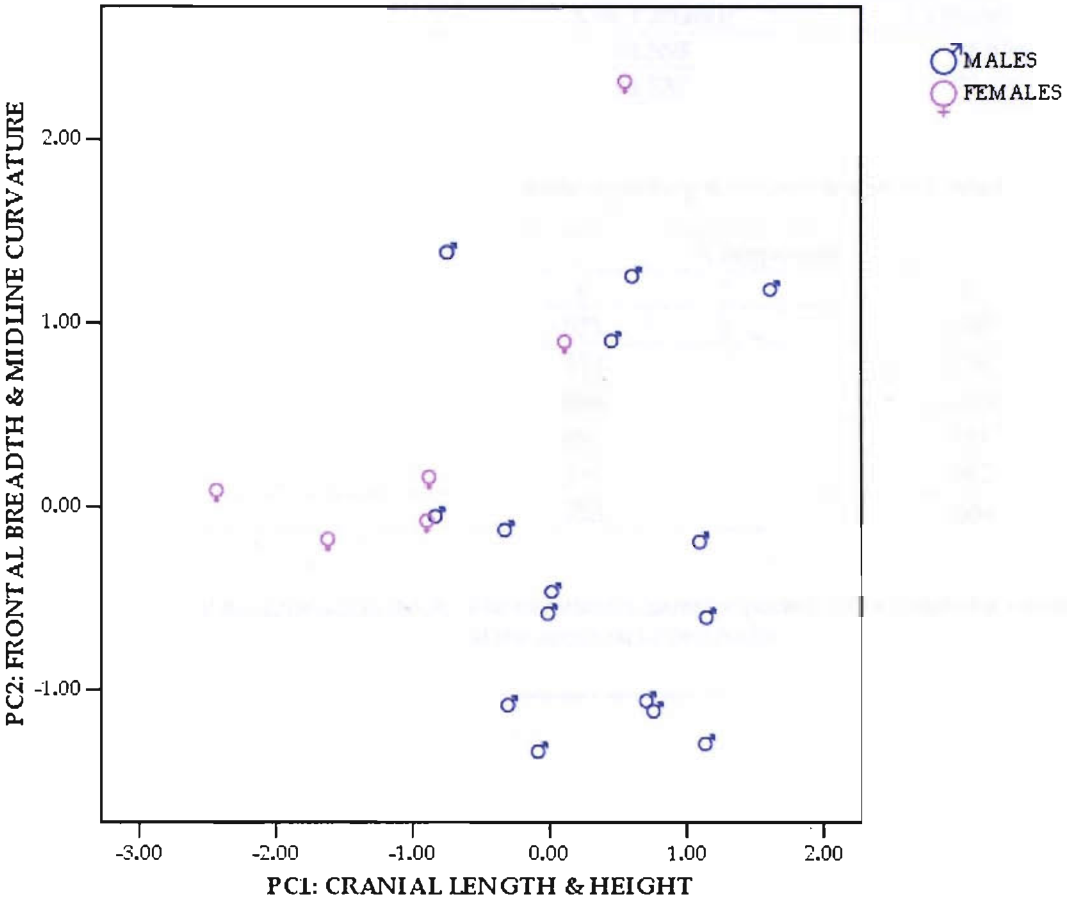
Table 6.1.9 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.462	57.705	57.705
2	1.183	19.718	77.423

Table 6.1.10 Component loadings for PCA of variables describing the cranial length and height, and the morphology of the frontal bone.

Cranial Metric Variables	Component	
	1	2
GOL	.770	-.463
XFB	.540	.662
FRF	.760	-.403
VRR	.823	-.238
FRC	.927	.144
FRS	.681	.540

Figure 6.1.10 Sexual dimorphism in the Argolid population (samples pooled): PCA results for variables describing the cranial length and height and the morphology of the frontal bone.



Sexual dimorphism was further assessed using the protrusion of the upper facial skeleton (measured at the nasion). With the exception of one individual from Lerna (LER 48), the other Argolid individuals form distinct groups according to their skeletally assigned biological sex (Figure 6.1.11). The amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape are given in Tables 6.1.11 and 6.1.12 respectively. Patterning of the data suggests that a male cranium is longer and more protruding in the upper facial region in relation to its breadth than a female cranium.

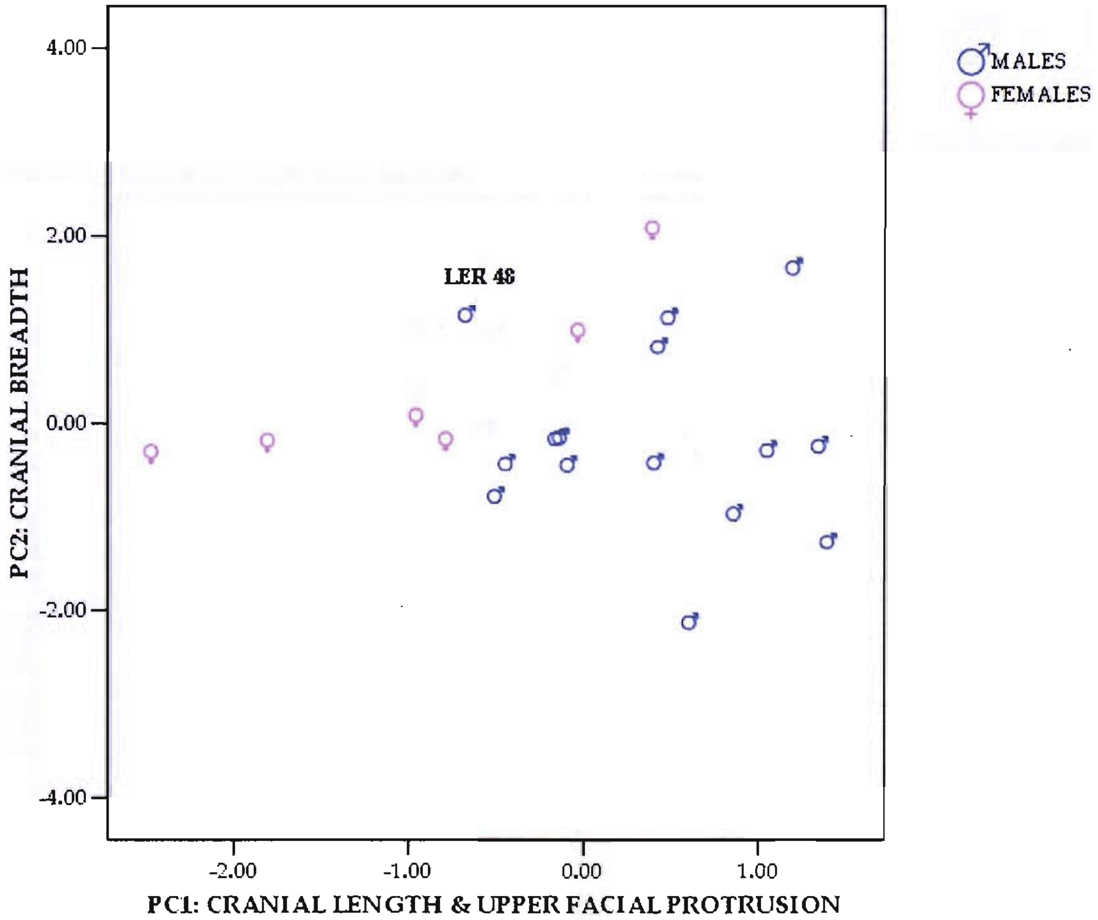
Table 6.1.11 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.273	54.558	54.558
2	1.472	24.537	79.095

Table 6.1.12 Component loadings for PCA of variables describing the cranial length and breadth and the upper facial protrusion.

Cranial Metric Variables	Component	
	1	2
GOL	.831	-.357
XFB	.452	.718
FRF	.806	-.302
FRC	.891	.281
FRS	.643	.582
NAR	.723	-.566

Figure 6.1.11 Sexual dimorphism in the Argolid population (samples pooled): PCA results for variables describing the cranial length and breadth and the upper facial protrusion.



In order to explore further sexual dimorphism in the Argolid population, two additional morphological features of the cranium, the glabella (GLS) and the mastoid process (MDH, MDB), were entered into analysis (Tables 6.1.13 and 6.1.14) (N=30). The morphology of the glabella and mastoid process are widely accepted as very reliable sex indicators (e.g. Buikstra & Ubelaker 1994). The relationship between the two sexes is graphically represented in Figure 6.1.12.

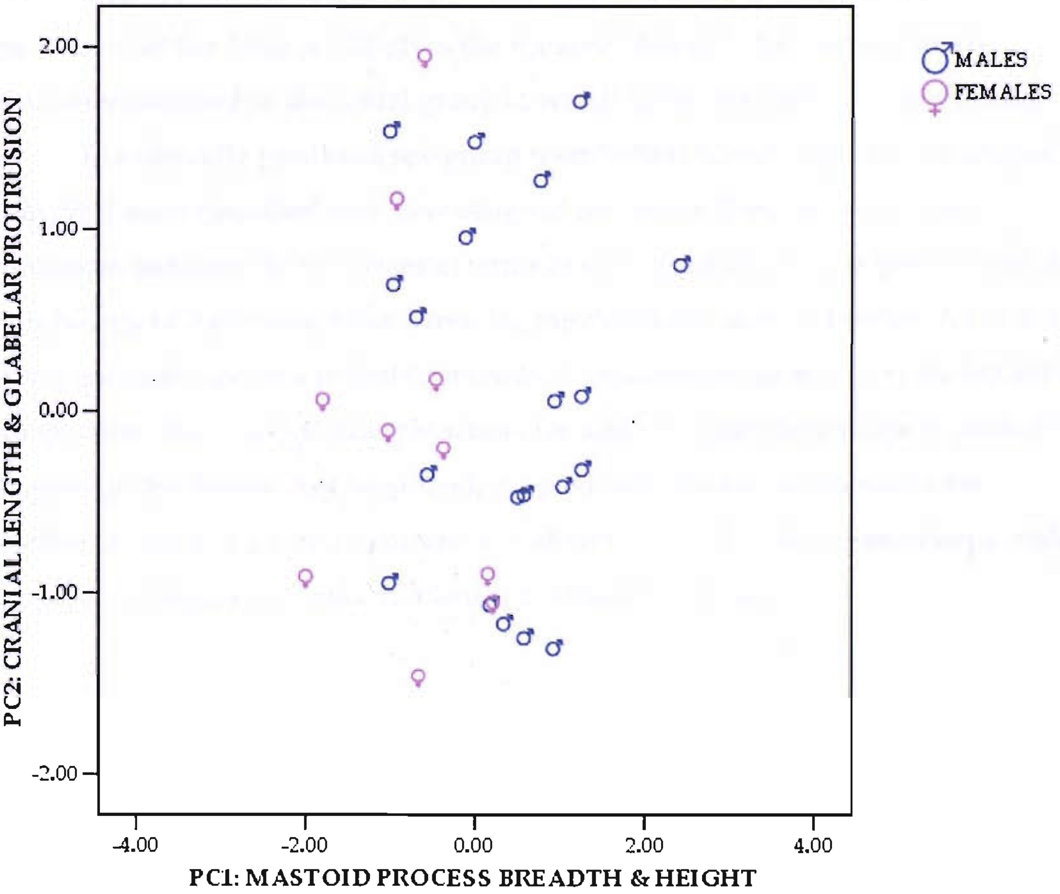
Table 6.1.13 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.079	51.979	51.979
2	1.061	26.524	78.502

Table 6.1.14 Component loadings for PCA of variables describing the cranial length, glabellar protrusion and the mastoid process.

Cranial Metric Variables	Component	
	1	2
GOL	.677	.529
GLS	.683	.519
MDH	.682	-.629
MDB	.831	-.341

Figure 6.1.12 Sexual dimorphism in the Argolid population (samples pooled): PCA results for variables describing the cranial length, glabellar protrusion and the morphology of the mastoid process.



It is clear from the graph that the mastoid process of the male individuals tends to have a greater volume and their glabella to be more prominent than for females. The results of the analysis accord well with the expectation that males and females separate clearly in terms of the morphology of the glabella and the mastoid process.

In order to cross-validate the results of PCA for sexual dimorphism in the Argolid population (12 Apatheia and 22 Lerna individuals), and explore how accurately the two sexes separate in terms of cranial metric morphology, Disciminant Function Analysis (DFA) is applied to variables describing the length and breadth of the cranium, as well as the midline curvature of the frontal bone (GOL, XCB, FRC, FRS, FRF). The variables were selected on the basis of the results of PCA for GOL, XCB, FRC, FRS, FRF and XFB (Figure 6.1.9). DFA aims to assign group membership to the tested individuals using a number of predictors (see section 5.1.2.4.2). Squared Mahalanobis distance is the distance from the values of each case (individual) for the predictor variables to the average of the values for the group to which the case is assigned (i.e. predicted group, Table 6.1.15) (Norušis 2003:300). With the exception of three individuals (A5 24, LER 182 and LER 239), the remaining thirty-one were assigned the correct sex-group membership on the tested variables (Table 6.1.15). The last column of the Table 6.1.15 gives the squared Mahalanobis distance to the population centroid of the actual group to which those misclassified cases belong.

The correctly predicted sex-group membership is very high. Of the original cases, 91% were classified into their assigned sex, hence there are significant differences between the two sexes in terms of the cranial length and breadth and the morphology of the frontal bone. From the misclassified cases, individual A5.24 is a very interesting case of a probably successful trephination operated on the left side frontal bone. The practice of trephination, for which to date there is scarce published evidence in the Bronze Age Mainland, coupled with the sole incidence in the Apatheia sample of a metopic suture on individual A5.24, could be associated with a non-local biological and cultural identity for this individual.

Table 6.1.15 Sexual dimorphism in the Argolid population (samples pooled): Discriminant Function Analysis of variables describing the cranial length and breadth and the morphology of the frontal bone.

INDIVIDUAL	ACTUAL GROUP	PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF ACTUAL GROUP (for the misclassified cases)
A1 z	F	F	.074	
A1 c	M	M	.071	
A3 a	M	M	.004	
A3 b	F	F	.863	
A3 c	F	F	.953	
A5 a	M	M	.069	
A5 14	F	F	.716	
A5 24	**M**	**F(**)**	**.253**	**2.773**
A5 9	F	F	.369	
A5 c	F	F	.006	
A5 5	F	F	.198	
A5 3	M	M	.155	
LER 66	F	F	.259	
LER 3	F	F	5.946	
LER 2	M	M	1.541	
LER 95	M	M	.915	
LER 56	F	F	.384	
LER 52	M	M	.984	
LER 48	M	M	.599	
LER 181	M	M	.893	
LER 189	M	M	2.215	
LER 239	**M**	**F(**)**	**.029**	**5.469**
LER 91	M	M	.017	
LER 97	F	F	.175	
LER 182	**F**	**M(**)**	**.703**	**1.769**
LER 115	M	M	.349	
LER 125	M	M	.154	
LER 132	M	M	.398	
LER 174	M	M	.400	
LER 18	M	M	.043	
LER 50	M	M	.188	
LER 19	M	M	2.581	
LER 40	M	M	.093	
LER 23	M	M	.380	

KEY: M= MALE, F= FEMALE, **= Misclassified case

6.1.1.7 Inter-sample analysis of cranial size and shape of the Argolid population (Lerna and Apatheia samples): One-way ANOVA

Having established the similar pattern of sexual dimorphism in the Lerna and Apatheia samples, the two sexes were pooled in order to maximize the size of the samples (37 and 25 individuals for the Lerna and Apatheia samples respectively), but differentiated by symbols (♂= male, ♀= female) in scatterplots, and by separate boxes in box and whisker plots. Analysis of the cranial morphology tested the hypothesis that the two Argolid samples are biologically distant one from the other, but, when compared with population samples from Crete and Naxos, they should be related more closely with each other than with any of the samples from outside the Argolid (Mainland). My auxiliary hypothesis is that the Lerna sample will show greater intra-population biological variation than the Apatheia one. Both principal and auxiliary hypotheses relating to inter-population biological distance and intra-population biological variation in the Bronze Age Argolid population were formed with reference to population genetic theory. The amount of genetic divergence between populations is a function of the genetic make-up of the parent population, gene flow, genetic drift, mutation and natural selection (Hiorns *et al.* 1969).

Assuming the two Mainland populations share a common ancestor, genetic drift is expected to have been greater for the Apatheia population in comparison to Lerna, due to its smaller size in comparison to the Lerna population, as inferred from material culture studies (Caskey 1957:144; Konsolaki-Yannopoulou 2003), and the comparatively lower rate of gene-flow from an external source (Relethford & Harpending 1994: 259; Relethford *et al.* 1997:445). Genetic drift would have increased the distance between the two Mainland populations (Relethford & Lees 1982) and reduced intra-population genetic diversity for the Apatheia population (Futuyma 1995). Material culture and physical anthropology studies have argued that in the transition from the Early Helladic II to III, new population elements settled at Lerna (Caskey 1960; Angel 1971; Renfrew 1972; Gimbutas 1974, Wiencke 1989:509, Rutter 2001:116). Hence gene-flow into the Lerna population would have increased intra-population variation and its distance to the regional population centroid.

Nevertheless, the relatively similar environmental conditions prevailing in the two regions (Lerna and Apatheia) would not have increased the inter-population biodistance to significant levels. Both settlements are expected to have shared similar climatic and geomorphologic conditions. They are both located in the vicinity of both the sea and a marsh. Similarities in the subsistence strategies of the two population are expected to have resulted in a comparable diet, health status and activity patterns.

In order to investigate the two hypotheses, univariate analysis was applied to the craniometric data to detect which measurements show the greatest variance between the two population samples (Lerna and Apatheia) and achieve some basic understanding of the relationship between the tested samples. Those variables for which analysis shows significant variance between the means of the two samples, should be regarded as the best discriminators between the two Argolid samples.

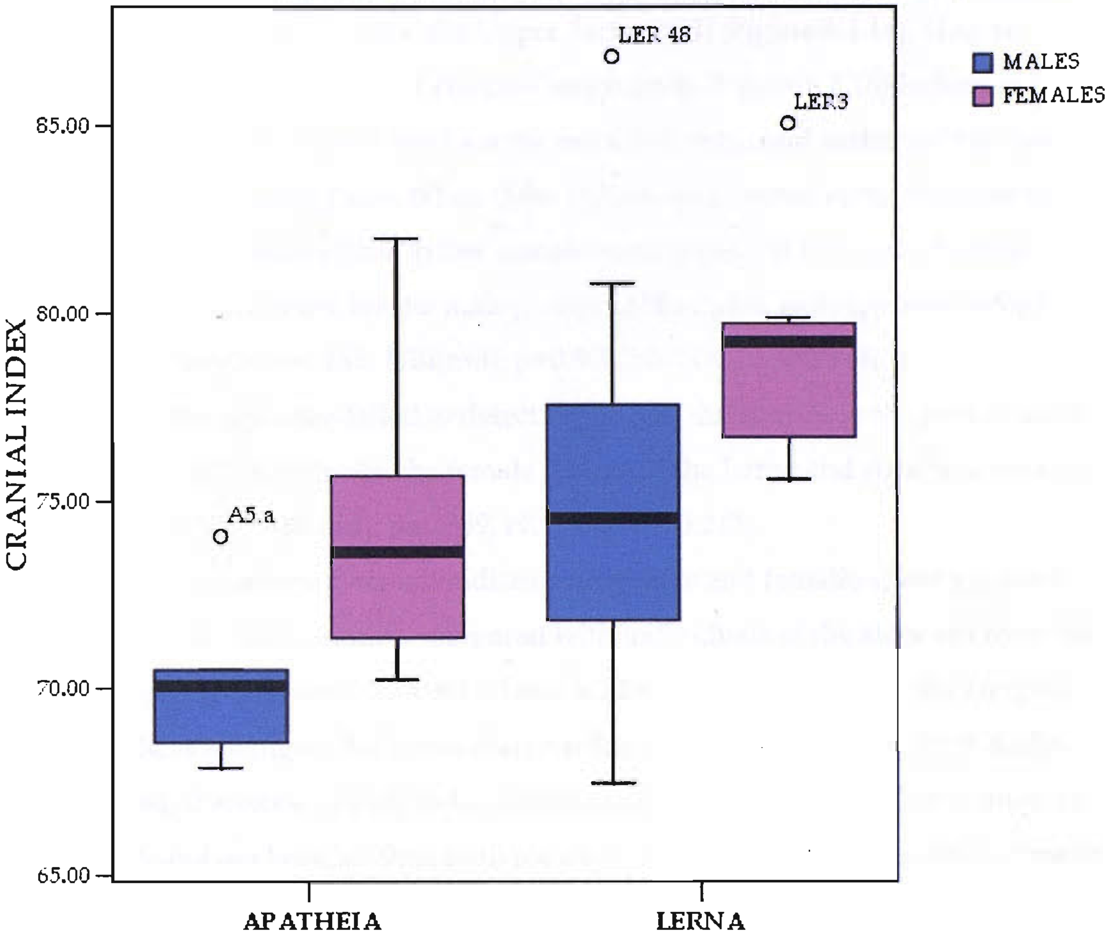
All cranial metric variables were tested for significant differences in the mean values of the two populations using a two independent samples t-test and One-way ANOVA. Since the sum of the sample sizes of the two populations is greater than forty, there is no need to be concerned about the assumptions of normality of the data, when the t-test is applied (Norušis 2003). Analysis showed significant differences ($p<0.05$) in the mean values of the two populations for eight of fifty-seven tested variables: STB ($p=0.004$), AUB ($p=0.009$), MDH ($p=0.028$), FMB ($p=0.001$), NAS ($p=0.023$), FRF ($p=0.017$), OCS ($p=0.018$) (Appendix D, Table 6.9). Inter-population difference in the mean value for SSR is very close to the level of significance ($p=0.052$). These variables describe the cranial breadth, the height of the facial skeleton, the breadth and protrusion of the upper-facial region, the midline curvature of the frontal and occipital bones and the length of the mastoid process. Subspinale radius (SSR) describes the protrusion of the facial skeleton at the subnasal region.

One-way ANOVA was applied to all recorded cranial metric variables separately for the males the females of the Lerna and Apatheia samples. For the males, due to the size difference of the tested groups (23 Lerna males and 14 Apatheia males) and the inequality of the intra-group variances suggested for NOL ($p=0.039$), PAC ($p=0.04$) and OCF ($p=0.027$) by the Levene test (Appendix D, Table 6.10), the inter-group variance was further tested using the more robust tests of variance. Difference between the mean values of the two groups reached significance for the following variables: AUB ($p<0.001$), GLS ($p=0.035$), FRF ($p=0.021$) and NAR ($p=0.04$) (Appendix D, Table 6.11). These variables describe the cranial breadth, the upper facial protrusion and the shape of the midline curvature of the frontal bone. For the females from the Lerna and Apatheia samples, the Levene test showed significant heterogeneity of group variances for BNL (p=0.039), ASB (p=0.023), JUB (p<0.001), WMH (p=0.011), SOS (p=0.048), PAF (p=0.046) and PRR (p=0.005) (Appendix D, Table 6.12). The robust tests of equality of means detected significant inter-group variance for GOL (p=0.003), NOL (p=0.016) and FMB (p=0.029) (Appendix D, Table 6.13). These variables describe the cranial length and the upper facial breadth. Inter-sample differences in the cranial morphology of the Argolid population are further explored using the analysis of Cranial Indices.

6.1.1.8 Inter-sample analysis of cranial size and shape of the Argolid population (Lerna and Apatheia samples): Cranial Indices

Cranial index (CI= 100*XCB/GOL): One-way ANOVA was applied to Cranial Index data separately for males and females from the Lerna and Apatheia samples. This assumes that variance in all tested populations is equal, and this depends largely on the relative equality of the sample sizes. The Lerna male group, however, is considerably larger than the Apatheia one (17 to 5 males respectively). Therefore the Welch and the Brown-Forsythe tests of equality of means were applied to the data. These suggested significant inter-group difference in the mean value for the Cranial Index (p=0.011). Cranial Index data for the female groups from Lerna (7 females) and Apatheia (7 females) were tested using One-way ANOVA and the more robust tests of variance (due to low sample size). These showed significant inter-group difference (One-way ANOVA: p= 0.034, Welch and Brown-Forsythe tests: p=0.035).

Figure 6.1.13 Box and whisker plot of the Cranial Index, Argolid samples, sexes separately.



Plotting of the Cranial Indices shows that the males and females from Apatheia tend to have crania that are long for their breadth compared with individuals of the same sex from Lerna (Figure 6.1.13). Hence, the Lerna crania appear to be more rounded in comparison with these from Apatheia. By plotting males and females separately, the possibility that the relationship between the two samples (in terms of cranial shape) is an artifact of sexual dimorphism and the differential representation of the two sexes in the two samples is rejected, as it is demonstrated that the two samples share a similar pattern of sexual dimorphism and the proportional representation of females (who tend to have a more rounded cranium than males) is higher for the Apatheia sample than for Lerna. Moreover, the inter-quartile range (i.e. the difference between the 25th and 75th percentiles) for the Cranial Index values for the Lerna males on the box and whisker plot (Figure 6.1.13) is suggestive of a greater intra-sample variation for the Lerna males relative to the Apatheia ones.

Upper Facial (md), Height-Breadth (md) and Height-Length (md) Indices: In addition to the Cranial Index, the Upper Facial (md) (Figure 6.1.14), Height-Breadth (md) (Figure 6.1.15) and Height-Length (md) (Figure 6.1.16) Indices were also calculated. The formulae used are the modified ones used earlier in this chapter to explore sexual dimorphism. When these indices were tested using the more robust tests of equality of means (due to low sample size), these did not reject the null hypothesis that the means for the male groups of the Lerna and Apatheia samples are equal (UFI(md): p=0.151, HBI(md): p=0.507, HLI(md): p= 0.148). The Welch and Brown-Forsythe tests also failed to detect significant differences in the mean values for the tested indices between the female groups of the Lerna and Apatheia samples (UFI(md): p=0.277, HBI(md): p=0.389, HLI(md): p= 0.273).

For all three tested cranial indices, Lerna male and females show a greater range of intra-sample variation compared with individuals of the same sex from the Apatheia sample (Figures 6.1.14, 6.1.15 and 6.1.16). Median values for the Height–Length Indices are higher for Lerna than Apatheia. Lerna individuals (both males and females), therefore, appear to have crania that are higher vaulted in relation to their length and are broader than individuals of the same sex from Apatheia. Finally, although the Lerna males appear to have longer faces (greater facial height) in relation to cranial breadth than the Apatheia males, the Lerna females do not differ from these from Apatheia in this respect.

Figure 6.1.14 Box and whisker plot of the Upper Facial (md) Index, Argolid samples, sexes separately.

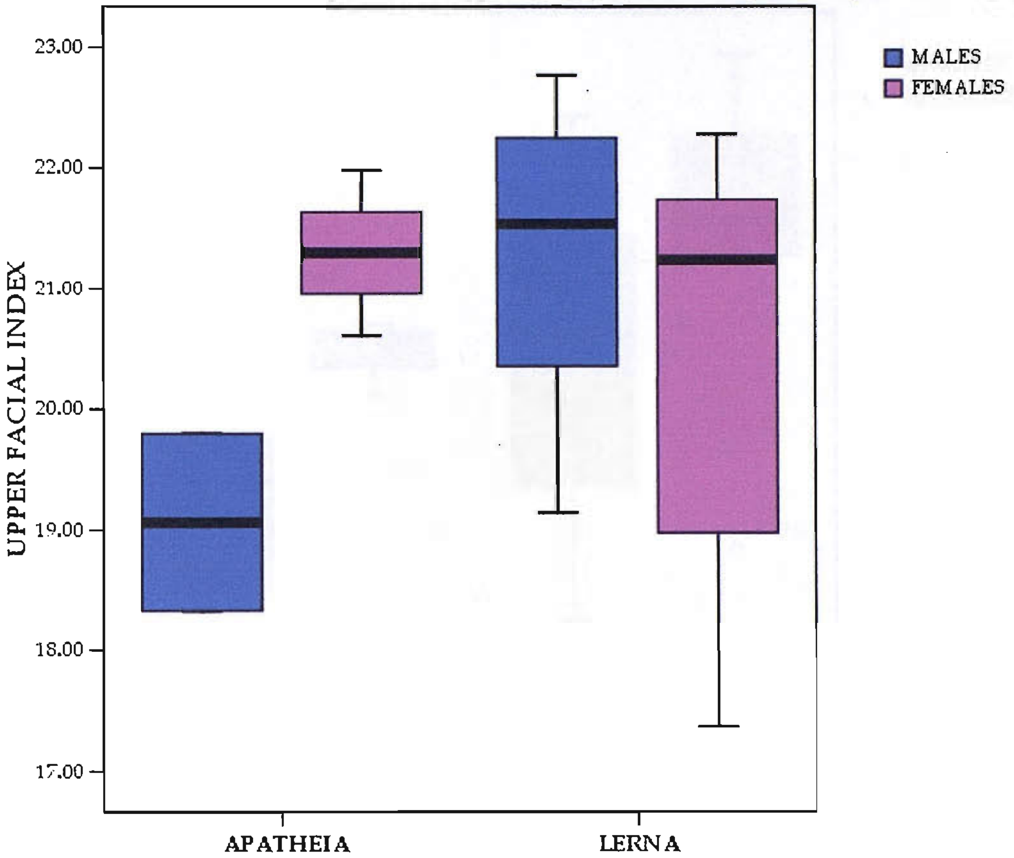


Figure 6.1.15 Box and whisker plot of the Height-Breadth (md) Index, Argolid samples, sexes separately.

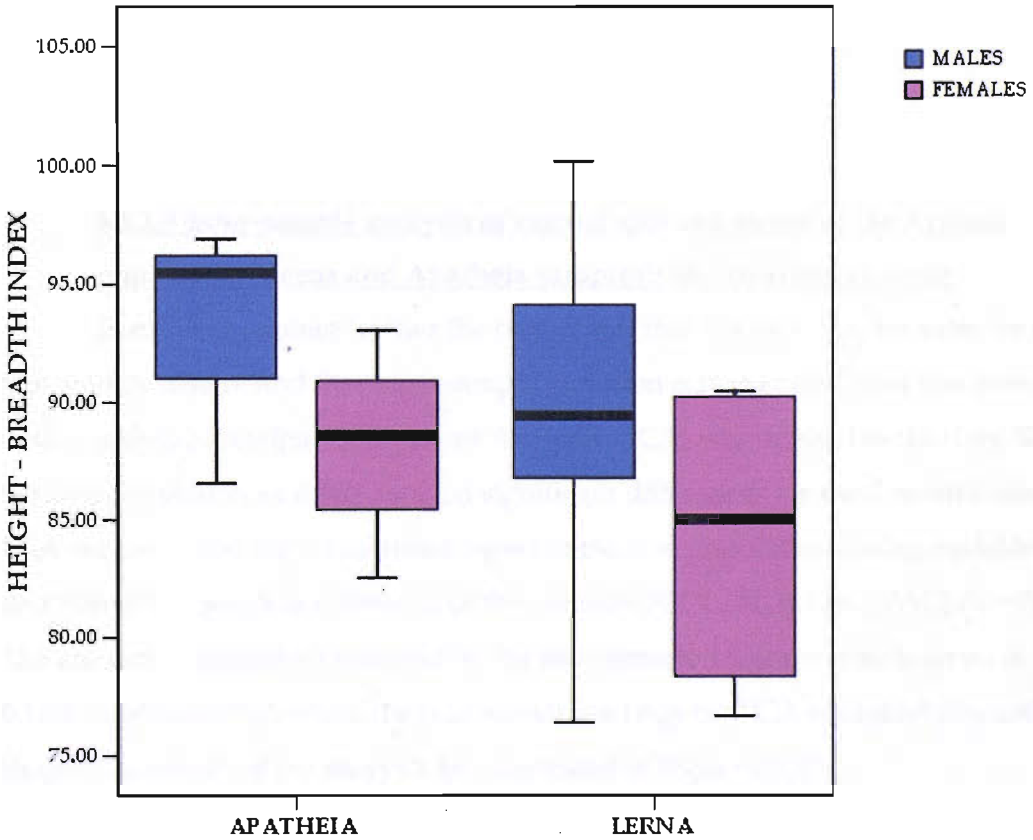
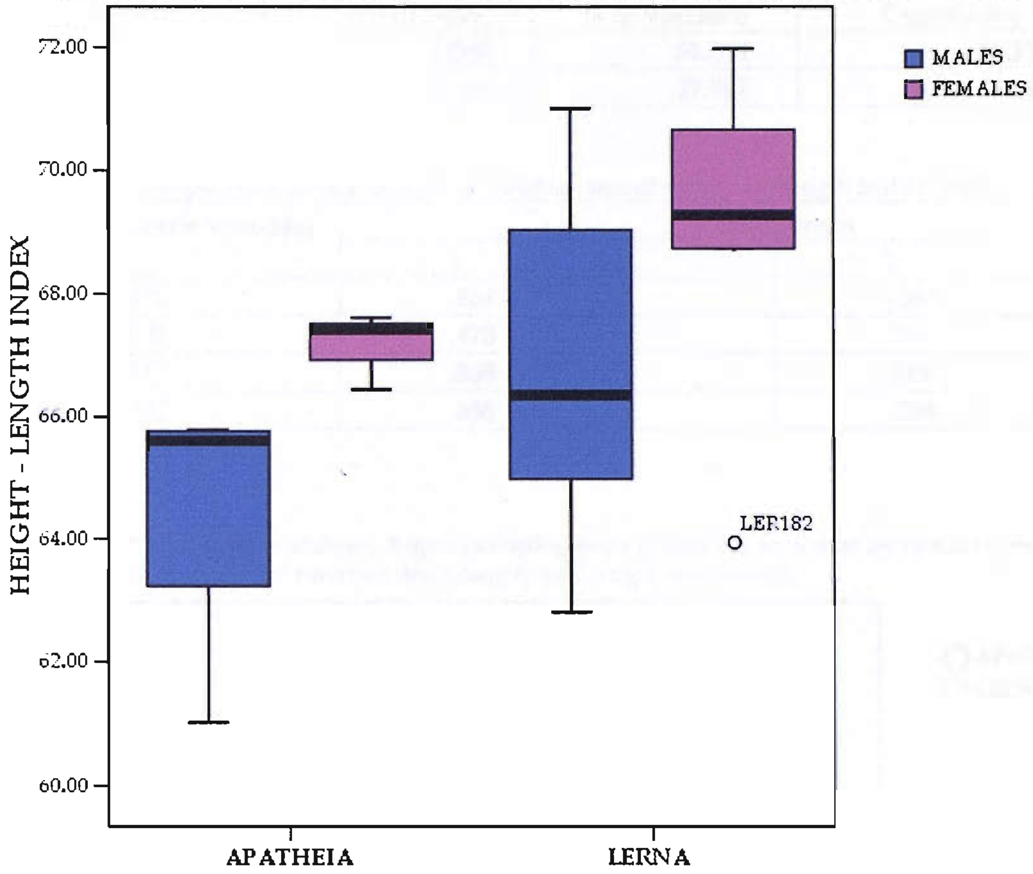


Figure 6.1.16 Box and whisker plot of the Height-Length (md) Index, Argolid samples, sexes separately.



6.1.1.9 Inter-sample analysis of cranial size and shape of the Argolid population (Lerna and Apatheia samples): Multivariate analysis

In order to explore further the hypothesis that the two Argolid samples are biologically distant and that intra-sample variation is higher for Lerna compared with Apatheia, Principal Component Analysis (PCA) was applied to the data. Since the two population samples showed significant differences for the Cranial Index, PCA explored first the relationship between the two populations using variables describing the length and breadth of the cranium (GOL, XCB, FRC, PAC) (N=35). The amount of variance explained by the two extracted components is given in Table 6.1.16. Table 6.1.17 provides the component loadings for PCA of cranial size and shape. The results of the analysis are illustrated in Figure 6.1.17.

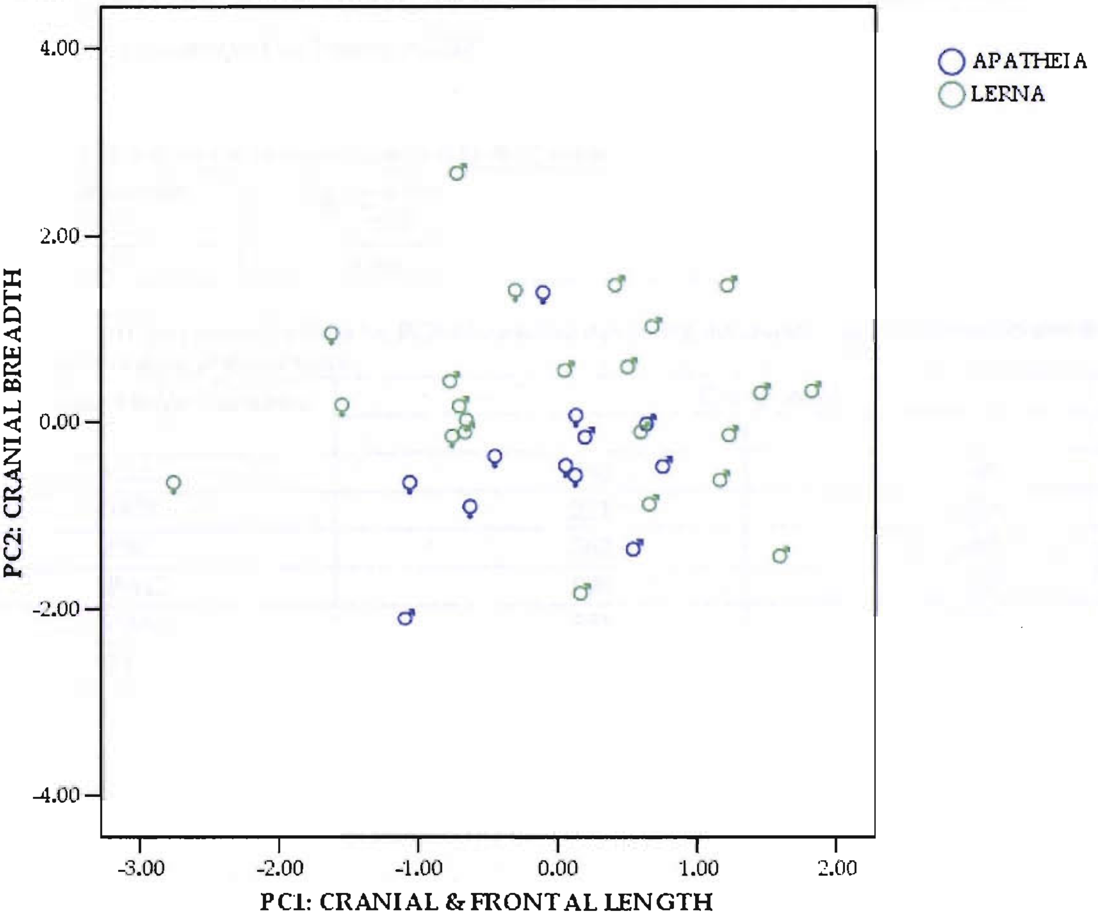
Table 6.1.16 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	2.060	51.511	51.511
2	1.116	27.907	79.418

Table 6.1.17 Component loadings for PCA of variables describing cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.864	-.267
XCB	.478	.765
FRC	.808	.319
PAC	.658	-.598

Figure 6.1.17 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂=male, ♀=female): PCA results for variables describing cranial length and breadth.



Patterning of the data in Figure 6.1.17 suggests a greater range of variation for the tested variables for Lerna in comparison with the Apatheia sample, especially for cranial length. Additionally, Lerna individuals tend to have relatively broader crania in comparison to individuals from Apatheia. By indicating on the graph the sex of the tested individuals for both samples, the possibility that the inter-sample variance for the tested variables results from sexual dimorphism and differences in the representation of males and females in the two samples is assessed and refuted. As was demonstrated earlier in this chapter, females in both the Lerna and Apatheia samples tend to have crania less long for their breadth compared with males from the same sample (section 6.1.1.2). This means that in Figure 6.1.17, the Lerna individuals appear to have crania broader for their length, but this is not the result of the higher representation of females in the Lerna than the Apatheia sample.

Two additional variables (PAS, PAF) were entered into the analysis. These describe the midline curvature of the cranial vault. Table 6.1.18 shows the amount of variance explained by the two extracted components, and Table 6.1.19 the component loadings for PCA of cranial size and shape (N=35). The distribution of the data is illustrated in Figure 6.1.18.

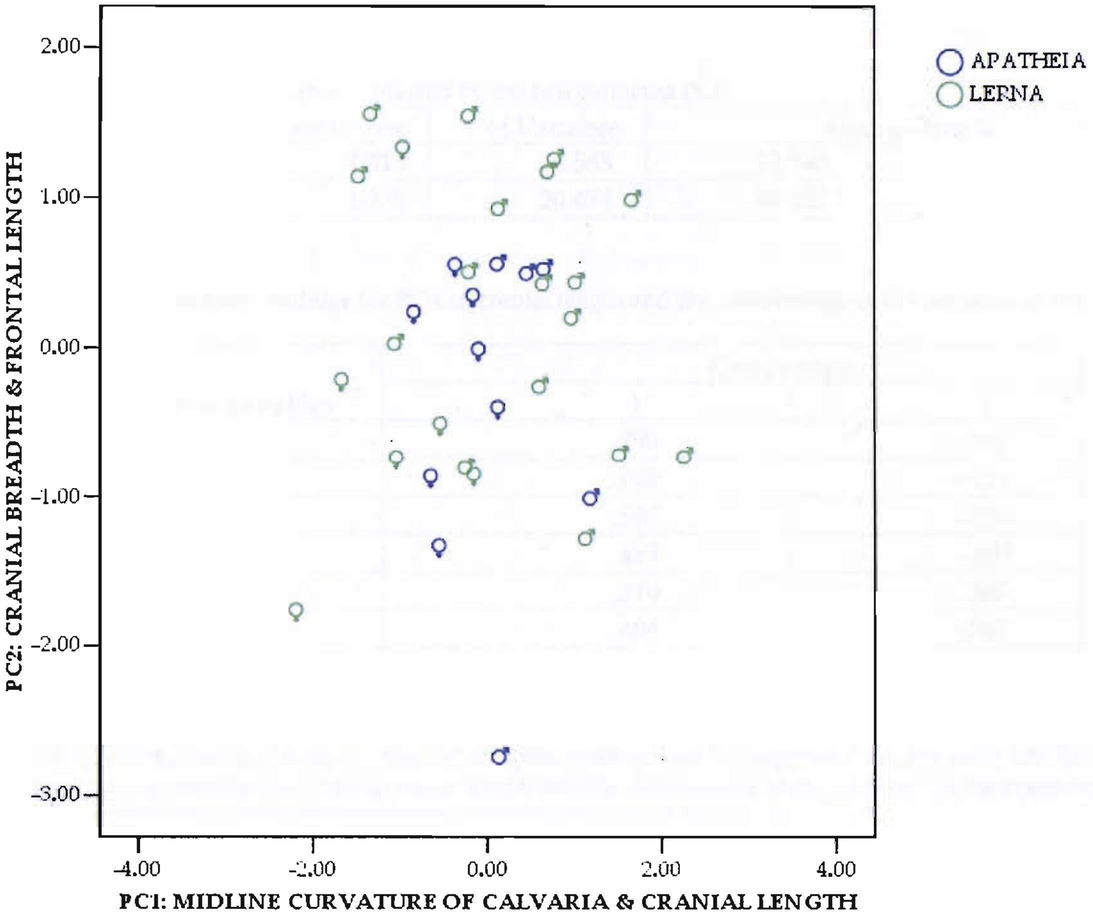
Table 6.1.18 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	2.733	45.549	45.549
2	1.660	27.660	73.209

Table 6.1.19 Component loadings for PCA of variables describing the cranial length and breadth and the midline curvature of the calvaria.

Cranial Metric Variables	Component	
	1	2
GOL	.742	.348
XCB	.211	.679
FRC	.562	.683
PAC	.898	-.327
PAS	.551	-.698
PAF	.843	-.126

Figure 6.1.18 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing cranial length and breadth and the midline curvature of the calvaria.



Patterning of the data in Figure 6.1.18 is very similar to that produced by the results of PCA for GOL, XCB, FRC and PAC in Figure 6.1.17. Nevertheless, with the introduction of variables describing the midline curvature of the calvaria, the span of the intra-population variation of the Lerna sample appears to have reduced. The tendency, however, of Lerna individuals to have crania that are relatively broad for their length in comparison with Apatheia is still distinct.

Prior to data recording, the Lerna and Apatheia crania were visually examined. At that stage, it was observed that the shape of the Lerna cranium is more rounded relative to Apatheia. Apatheia crania appear to be more oblong as a result of the calvaria extending more to the posterior compared with the Lerna crania. In order to assess the statistical value of this observation, PCA was carried out for GOL, PAC, OCC, OCS, OCF and ASB. These variables describe the length and posterior breadth of the cranium, and the posterior midline curvature of the calvaria. The results of the PCA are provided in Tables 6.1.20 and 6.1.21, and graphically represented in Figure 6.1.19 (N=25).

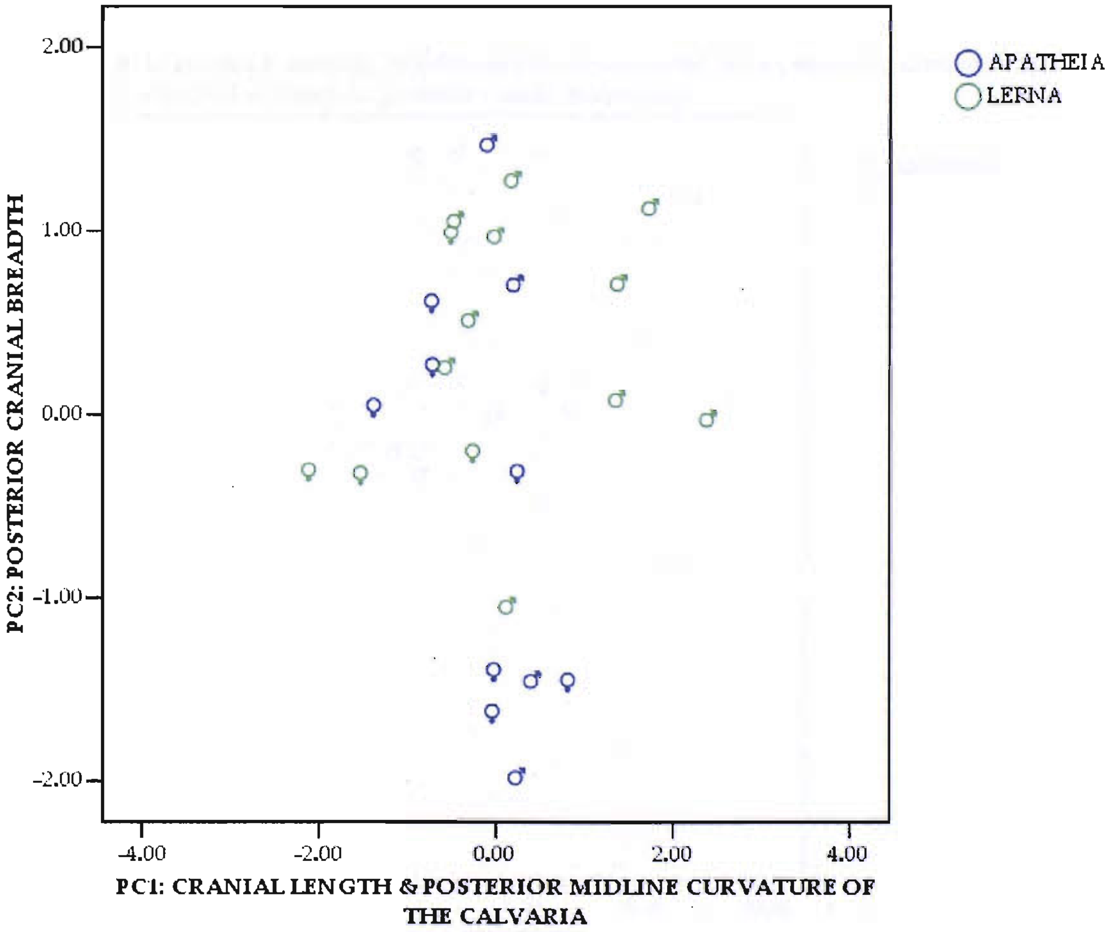
Table 6.1.20 Amount of variance explained by the two extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.014	33.563	33.563
2	1.228	20.474	54.037

Table 6.1.21 Component loadings for PCA of cranial length and the morphology of the posterior of the cranium.

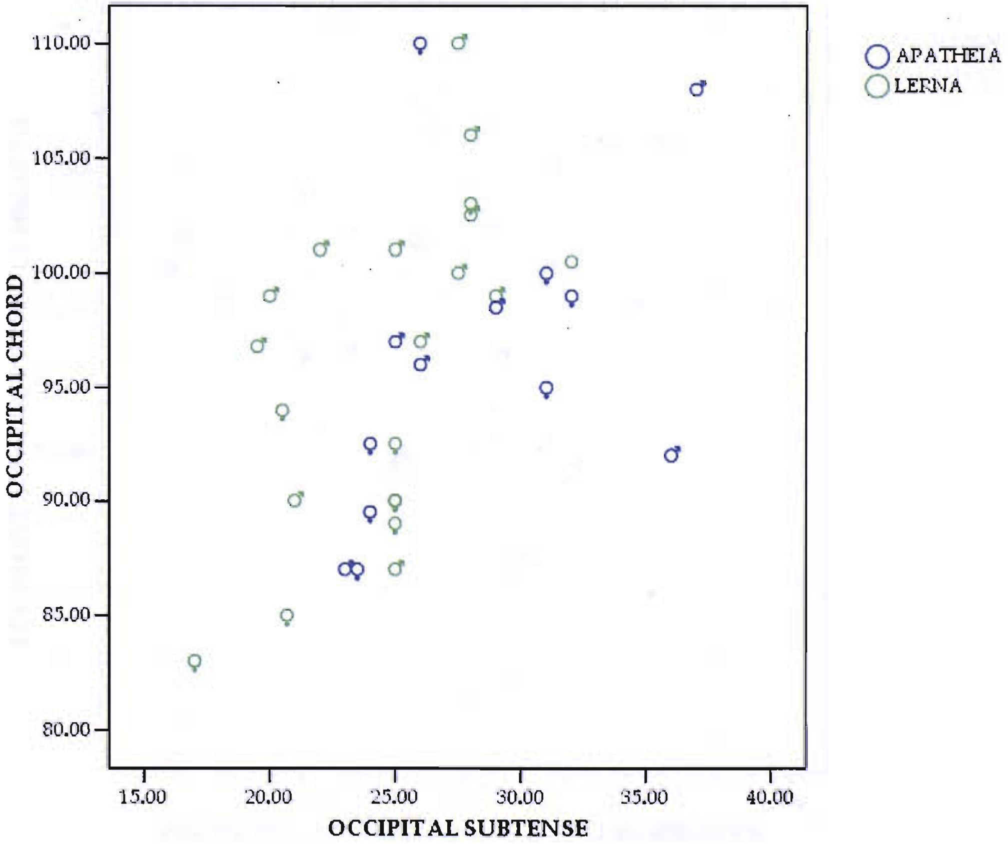
Cranial Metric Variables	Component	
	1	2
GOL	.798	.190
OCC	.700	-.216
OCS	.507	-.556
OCF	.453	-.403
PAC	.510	.305
ASB	.404	.762

Figure 6.1.19 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing cranial length and the morphology of the posterior of the cranium.



In Figure 6.1.19 both males and females of the Lerna sample appear to have a more rounded cranium compared with their counterparts from Apatheia. Although there is some area of overlapping between the two samples on the graph (Figure 6.1.19), the pattern of variation for the tested variables is different for Lerna and Apatheia samples. The Apatheia individuals show greater variation in terms of the posterior cranial breadth, whereas in the Lerna sample greater variation is recorded for variables describing the length and posterior curvature of the cranium. The relationship of the two samples on the morphology of the posterior portion of the calvaria was further explored by plotting the two variables describing the occipital length and the prominence of the occipital bone on the midline (OCC, OCS). Patterning of the data thus conforms well to the initial visual observation of inter-sample differences in the morphology of the occipital bone on the midline (Figure 6.1.20). The Lerna individuals appear to have an occipital bone more vertical for its length in comparison to Apatheia. This difference in the occipital morphology, in combination with the relatively broader and higher vaulted for its length cranium of the Lerna individuals compared with Apatheia, results in the more rounded shape of the Lerna crania relative to these from Apatheia.

Figure 6.1.20 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): Plotting of variables describing the posterior cranial morphology.



The relationship between the two samples was further explored by testing variables that describe the morphology of the upper facial region, namely FMB, XFB, NAR and FRC (Figure 6.1.21) (N=20). Tables 6.1.22 and 6.1.23 show the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape respectively.

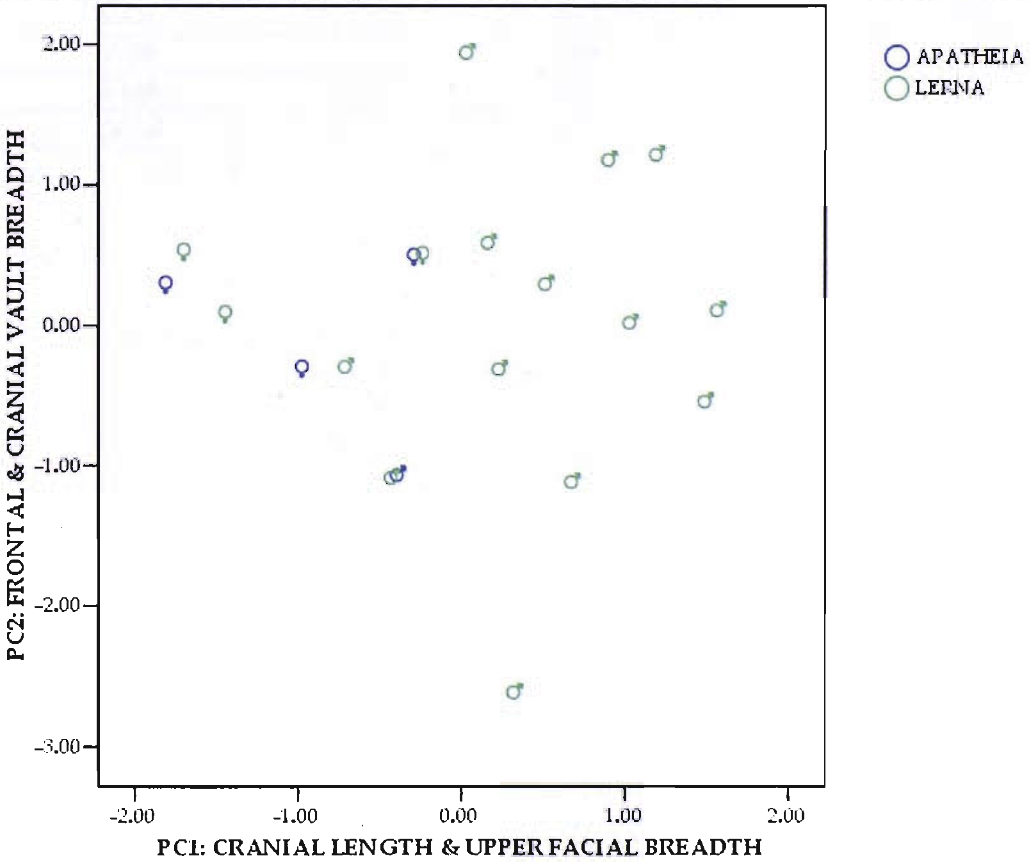
Table 6.1.22 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	3.255	54.257	54.257
2	1.399	23.319	77.576

Table 6.1.23 Component loadings for PCA of variables describing cranial length and breadth and the upper facial morphology.

Cranial Metric Variables	Component	
	1	2
GOL	.766	-.465
FRC	.819	.034
NAR	.701	-.631
XCB	.692	.594
FMB	.749	-.110
XFB	.683	.647

Figure 6.1.21 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing cranial length and breadth, and the upper facial morphology.



What emerges from the graphical representation of the results of PCA in Figure 6.1.21, is a relatively high intra-sample variation for the Lerna sample in terms of the cranial length and breadth and protrusion of the upper facial skeleton. However, due to the very small number of the Apatheia individuals that qualified for the analysis, any interpretation of the relationship between the two Argolid samples in terms of the tested variables is avoided (Figure 6.1.21).

PCA was applied to FMB, NAR, GOL and ASB (N=22) (Tables 6.1.24 and 6.1.25) in order to investigate further the relationship between Lerna and Apatheia on the morphology of the facial skeleton, for which One-way ANOVA suggested significant differences between the two Argolid samples (section 6.1.1.7).

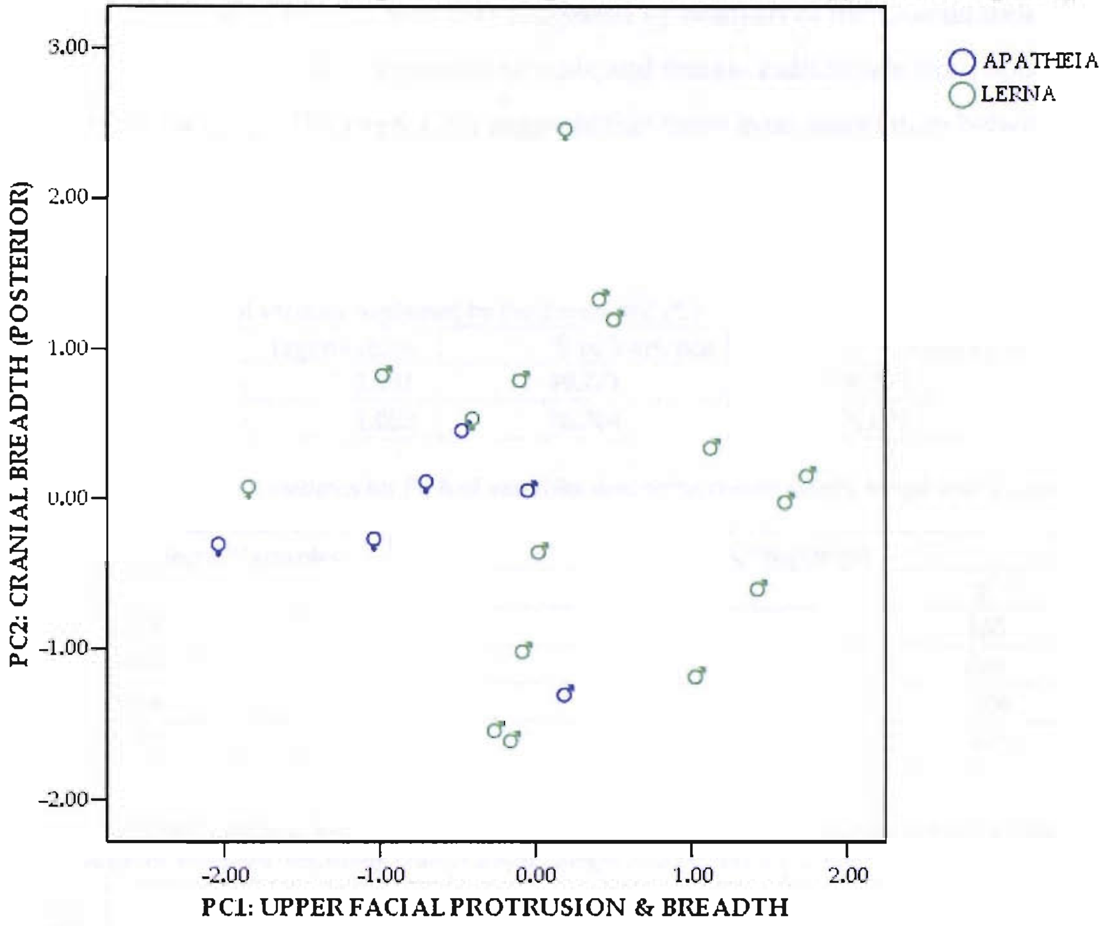
Table 6.1.24 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.592	64.805	64.805
2	.768	19.204	84.009

Table 6.1.25 Component loadings for PCA of variables describing the cranial length and breadth and the upper facial morphology.

Cranial Metric Variables	Component	
	1	2
GOL	.819	-.353
ASB	.600	.784
FMB	.854	-.035
NAR	.912	-.166

Figure 6.1.22 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the cranial length and breadth, and the upper facial morphology.



Patterning of the data in Figure 6.1.22 suggests that the upper facial region of the Lerna crania is both more protruding and broader in comparison with the Apatheia crania. Given the small number of the Apatheia individuals represented in the analysis, this interpretation should be treated with caution. It is also observed that the females in both samples tend to have crania that are less protruding and less broad in the upper facial region compared with males from the same sample, and that inter-sample variance is not due to sex differences in the morphology of the examined cranial region (i.e. the upper facial skeleton) and differences in the relative representation of males and females in the two samples.

The relationships between the two Argolid samples were further explored by analysis of the height of the cranial vault. PCA was applied to GOL, ASB, PAF and VRR and the results are provided in Tables 6.1.26 and 6.1.27 (N=24). Acknowledging the unequal size of the tested samples, patterning of the data suggests a greater variation for the Lerna sample relative to the Apatheia sample (Figure 6.1.23).

Moreover, the Lerna crania tend to be broader for their height and length than these in the Apatheia sample. This was also suggested by analysis of the Cranial Index (Figures 6.1.13 and 6.1.16). Patterning of male and female individuals from both samples on the graph (Figure 6.1.23) suggests that there is no association between inter-sample variance for the tested variables and sexual dimorphism in the two samples.

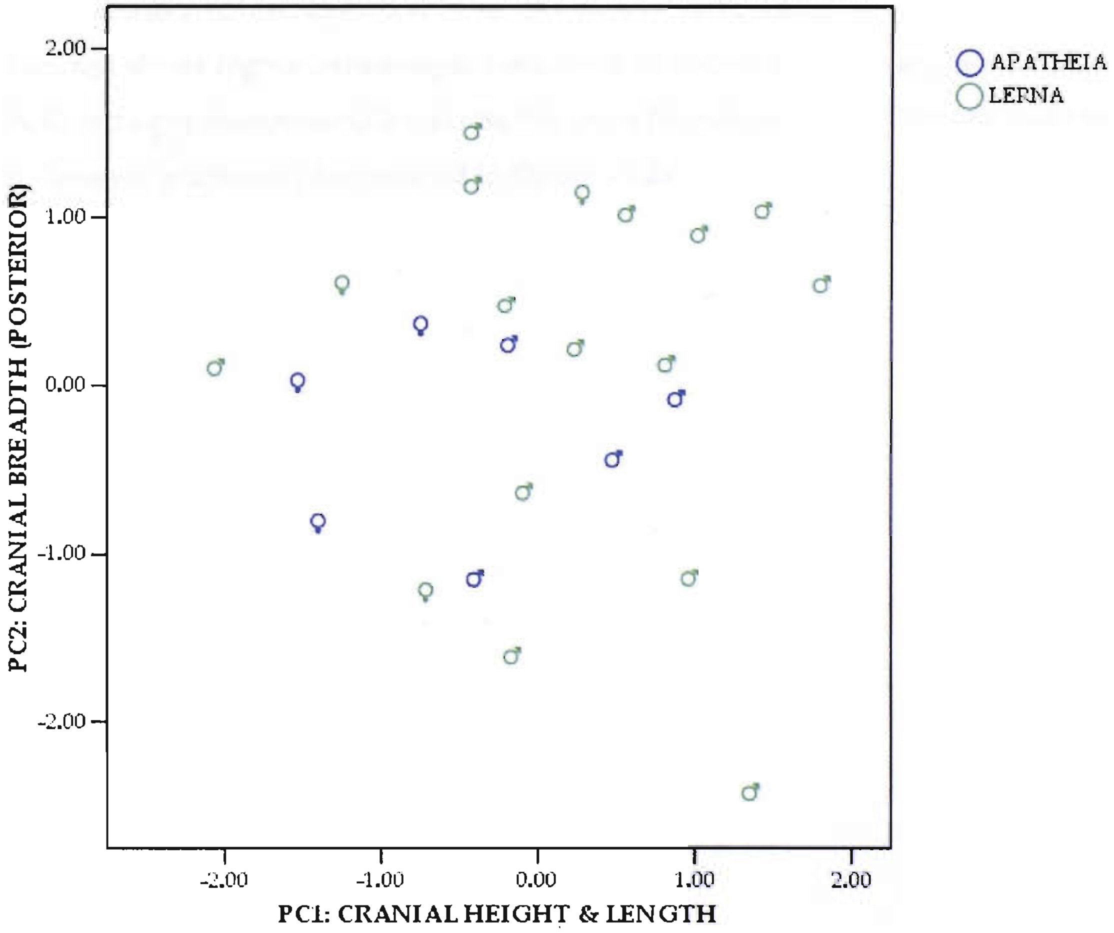
Table 6.1.26 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	1.991	49.771	49.771
2	1.052	26.304	76.075

Table 6.1.27 Component loadings for PCA of variables describing cranial height, length and posterior breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.763	.185
ASB	.333	.869
PAF	.712	-.506
VRR	.889	-.079

Figure 6.1.23 Inter-sample analysis, Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing cranial length, height and posterior breadth.

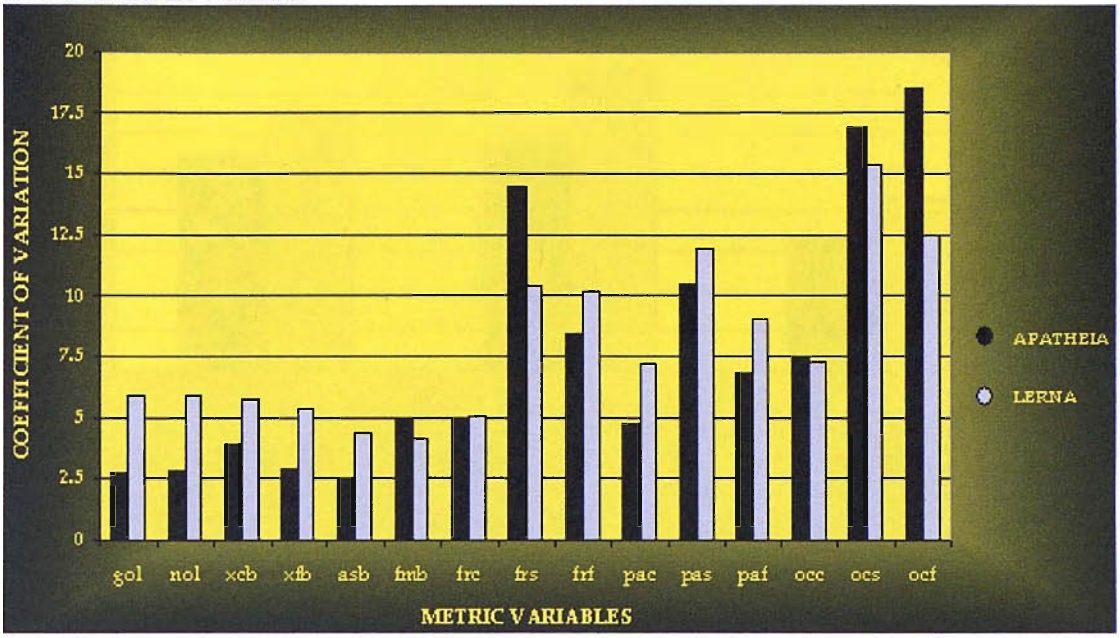


6.1.1.10 Comparative examination of intra-sample variation of the two Argolid samples (Lerna and Apatheia): Coefficient of variation of cranial metric variables

This section investigates the hypothesis that Lerna shows greater intra-sample variation relative to Apatheia in order to explore the possibility of gene-flow from extra-regional source/s. On the basis of neutral models of population genetics that have shown that the intra-population variation is a function of population size, migration rates and mutation rate (Relethford & Harpending 1994), it is likely that a population with higher intra-sample variation compared to its immediately preceding population has admixed with biologically different population elements.

Intra-population variation for Lerna and Apatheia was assessed by calculating the coefficient of variation for the most adequately represented cranial dimensions in the two samples (GOL, NOL, XCB, XFB, ASB, FMB, FRC, FRS, FRF, PAC, PAS, PAF, OCC, OCS, OCF). The coefficient of variation ($v=s*100/\bar{y}$) measures the relative dispersion of the data in relation to the mean (Sokal & Rohlf 1995). The analysed variables describe the cranial length and breadth and the midline morphology of the calvaria. For nine out of the fifteen tested variables, the highest variation was recorded in the Lerna sample. In four cases (FMB, FRS, OCS, OCF), Apatheia shows higher intra-sample variation than Lerna. For two variables (FRC, OCC) intra-population variation is roughly equal for both samples. The results of the analysis are graphically represented in Figure 6.1.24.

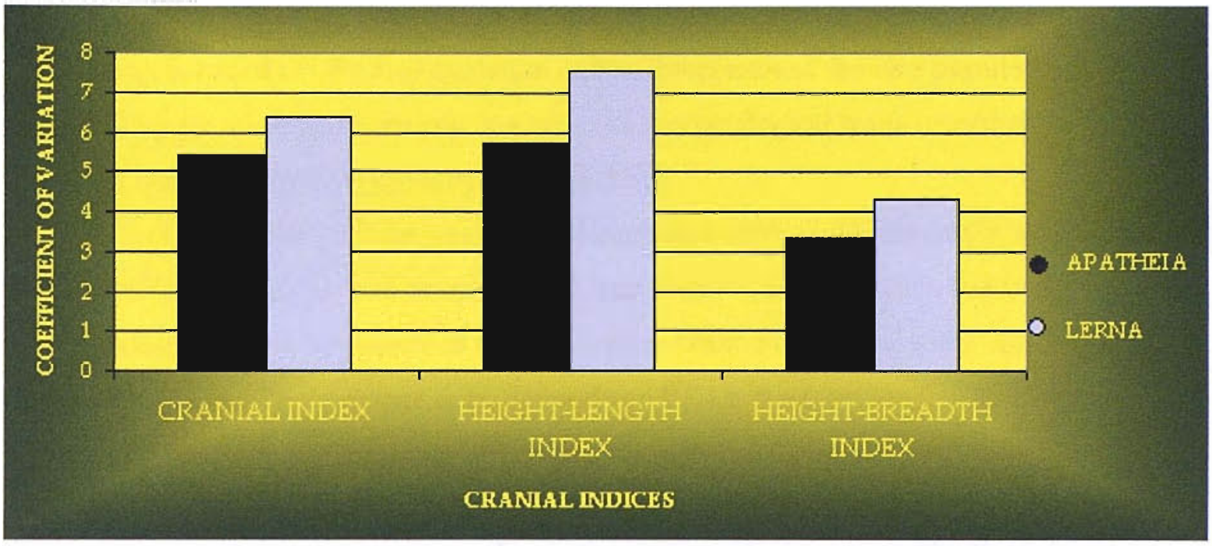
Figure 6.1.24 Inter-sample analysis, Argolid samples, sexes pooled: Coefficient of variation calculated for Cranial Metric Variables.



Sample sizes: **GOL**: APATHEIA (A)=15, LERNA (L)=26, **NOL**: A=15, L=24, **XCB**: A=15, L=27, **XFB**: A=11, L=24, **ASB**:A=16, L=27, **FMB**: A=11, L=26, **FRC**: A=18, L=30, **FRS**: A=18, L=29, **FRF**: A=18, L=29, **PAC**: A=20, L=28, **PAS**: A=20, L=27, **PAF**: A=19, L=27, **OCC**: A=13, L=23 , **OCS**: A=13, L=21 , **OCF**: A=13, L=21.

The coefficient of variation was also calculated for the Cranial, Height-Breadth (md) and Height-Length (md) indices and the results are graphically represented (Figure 6.1.25). Taking into consideration the unequal size of the two samples for the calculated Cranial index (12 cases for Apatheia and 24 for Lerna), the Height-Breadth (md) and Height-Length (md) Indices (7 and 20 cases for the Apatheia and Lerna samples respectively), analysis suggests higher variation for the Lerna sample in variables describing the size and shape of the cranium.

Figure 6.1.25 Inter-sample analysis, Argolid samples, sexes pooled: Coefficient of variation calculated for Cranial Indices.



Sample sizes: **CRANIAL INDEX**: APATHEIA (A)=12, LERNA (L)=24, **HEIGHT-LENGTH (md) INDEX**: A=7, L=20, **HEIGHT-BREADTH (md) INDEX**: A=7, L=20.

6.1.2 Argolid: Cranial Non-metric Morphological Analysis

Mean Measure of Divergence (MMD) analysis of skeletal non-metric morphology is based on the quantification of the divergence of the two populations, expressed by the average frequency of a series of morphological traits recorded on the individuals from both populations (Tyrell 2000).

If t is the number of the non-metrics recorded on the material and x_{ij} is the number of the individuals in a sample n_{ij} of a population i, scored to possess trait j, then an estimate of the frequency of trait j in a population i is derived from this equation: $p_{ij}=x_{ij}/n_{ij}$. The variance of p_{ij} depends on P_{ij}, i.e. the frequency of that trait in the entire population. One simple transformation to stabilize the variance of p_{ij} is the following: $\theta_{ij}=\arcsin(1-2p_{ij})$. Thus the Mean Measure of Divergence between two populations is defined as: $MMMp=\Sigma(\Theta_{1j}-\Theta_{2j})^2/t$ and a sample estimate of it as: $MMMp=\Sigma(\theta_{1j}-\theta_{2j})^2/t-\Sigma(1/n_{1j}+1/n_{2j})/t$ (Tyrell 2000).

The MMD value was standardized by dividing it by the standard deviation. The standard deviation was calculated using the equation given by Green & Suchey (1976), $SD=(1/n_{1j}+1/n_{2j})^2$. If the MMD value is greater than twice its standard deviation, there is significant biological distance between the examined populations (Tyrell 2000). Also, if the standardized MMD value is greater than two then it suggests a significant genetic distance between the studied populations, i.e. they derive from different parent populations (Lloyd-Jones 1997).

The Mean Measure of Divergence analysis is applied here to explore the possibility of significant biological distance between Lerna and Apatheia assessed using the difference in frequency of traits and to assess whether the two population samples share a common ancestor.

Care was taken given the small samples sizes and inequalities in the number of the scorable cases within the two samples. Trait frequencies for which at least one of the tested samples was represented by less than 5 individuals were removed from the MMD analysis, thereby reducing the number of traits analysed. From the one hundred and three non-metric traits that were selected to be recorded (for the bilateral traits, the right and left sides are counted separately, see section 5.1.2.3.2), seventy-eight were used to estimate the MMD for the two Argolid population samples (trait frequencies (%) and number of individuals scored (n) for Lerna and Apatheia samples are given in Appendix E, Table 6.1). The results of the MMD analysis are presented in Table 6.1.28.

Table 6.1.28 MMD analysis' values calculated using 78 Cranial Non-Metric Traits.

POPULATION SAMPLES	MMDp	MMDv	SD	MMDst
APATHEIA - LERNA	0.5417	0.3051	0.0184	16.5458

The value for the MMD analysis is greater than twice its standard deviation; hence it suggests significant biological distance between the two Argolid populations (Tyrell 2000). Additionally, the standardized value for the MMD analysis (MMDst=16.5458) rejects the hypothesis that the Apatheia and Lerna individuals derive from the same parent population.

6.1.3 Argolid: Dental Metric Morphological Analysis

Over the last three decades, studies of population biological distance have demonstrated that tooth size, shape, morphology and number of cusps on a tooth have a sufficiently strong genetic component in their complex etiology which renders them useful variables for assessing population biological relationships and micro-evolutionary trends (see Scott & Turner 1988 for a review of past studies). Because there is no adequate justification for the assumption that side asymmetry in tooth crown dimensions is random (Hillson 2002:77), in the present study, tooth crown measurements were recorded separately for right and left sides (see section 5.1.2.3.1). Analysis explored right and left side differences for the bucco-lingual and mesio-distal crown diameters for all tested samples. On the basis of the results of this analysis, it was decided that right and left sides could legitimately be pooled for investigation of inter-sample distances at the intra- and inter-regional level, thereby increasing sample sizes. GLM univariate hierarchical analysis was applied to explore the interaction between the tested dental metric variables, biological sex- and sample-ascription of the examined individuals, in order to assess whether it is legitimate to pool the two sexes to maximize sample sizes.

Because of poor tooth representation within the skeletal collections studied, dental metric and non-metric morphological analysis is focused on the investigation of the hypothesis that people from the Argolid arrived and settled at Knossos at the end of LMIB. Therefore, the results of the analysis of dental morphology (metric and non-metric) regarding the potential relationship between the Lerna and Apatheia samples are presented and discussed in sections 6.3.3 (dental metric analysis) and 6.3.4 (dental non-metric analysis), exploring the biological relationship between the Argolid and Cretan samples to answer the main archaeological question of this study. This current section (6.1.3) presents and discusses the implications of the results of the analysis of side asymmetry in tooth crown diameters and the interaction between the tested metric variables, sex- and sample-ascription of the examined individuals for the two Argolid samples.

6.1.3.1 Right and Left side asymmetry in tooth crown diameters, Argolid samples: paired t-test

In order to decide whether it is legitimate to pool together right and left side measurements in order to maximise sample sizes, differences between the bucco-lingual and mesio-distal crown diameters of the right and left side within the Lerna and Apatheia samples were explored using the paired t-test (Table 6.1.29). This is preferred to the standard Student's t-test because it makes no assumption regarding the homogeneity of variance and is more efficient in detecting significant side differences (Potter *et al.* 1981).

Four of the eight cases for which side differences in the tested values reached the level of significance ($p<0.05$), showed higher values on the right side and the other four on the left side teeth. The percentage of significantly asymmetrical tooth crown diameters is very low for both the Lerna (19%) and Apatheia (8%) samples. For that reason, and due to the fact that the actual side differences in crown diameters are considered to be small in relation to intra- and inter-observer error and the precision at which dental measurements can be taken (Hillson 2002:78), it was decided that right and left side measurements can be pooled, thereby maximising dental sample sizes.

Table 6.1.29 Side asymmetry in tooth crown diameters of the two Argolid samples, sexes pooled, Paired t-test, p values ($p<0.05$).

Measurements	Skeletal collections			
Maxillary	Apatheia		Lerna	
	p	N	P	N
I1BL			.559	9
I1MD			.103	12
I2BL	.823	2	1.000	12
I2MD			.571	15
CBL			.275	14
CMD			.613	17
PM3BL	.245	4	1.000	13
PM3MD	.449	4	.879	16
PM4BL	.343	4	**.031**	**12**
PM4MD	.111	4	.701	13
M1BL	.588	5	.241	13
M1MD	.426	5	**.004**	**14**
M2BL	**.028**	**2**	.106	14
M2MD	.251	2	**.020**	**15**
M3BL			.810	6
M3MD			**.014**	**5**

Measurements	Skeletal collections			
Mandibular	Apatheia		Lerna	
	p	N	p	N
I1BL	.580	3	.270	3
I1MD	**.040**	**5**	.596	11
I2BL	.560	3	.761	10
I2MD	.062	4	.969	19
CBL	.528	5	.520	12
CMD	.482	6	.627	18
PM3BL	.898	5	.569	18
PM3MD	.266	5	**.023**	18
PM4BL	.070	2	**.044**	**13**
PM4MD	.500	2	.057	14
M1BL	.184	5	.679	5
M1MD	.295	5	.203	6
M2BL	.700	6	.405	12
M2MD	.304	6	.278	17
M3BL	.282	6	.237	6
M3MD	.901	6	.462	7

6.1.3.2 Inter-sample analysis, Argolid samples: GLM Univariate Hierarchical Analysis results for dental measurements

In order to explore the possibility that inter-sample relationships reconstructed using dental metric variables could be an artifact of different sex-composition of the tested population samples, GLM univariate analysis was applied to the data. This analysis explored the relationship between the dental metric variables, population sample- and sex-ascription of the examined Argolid individuals. The results are given in Table 6.1.30. Analysis suggested that biological sex is significant ($p<0.05$) for I1RBL, M3LMD, M1RMD, M3RBL, LCLBL, LCLMD, LCRBL and LCRMD. It is noteworthy that the bucco-lingual and mesio-distal diameters of both right and left mandibular canines are significantly associated with sex. Analysis, thus, accords well with the results of studies of canine morphology that suggest significant sexual dimorphism in the size of the canines (Frayer & Wolpoff 1985).

Differences between Apatheia and Lerna reached significance for I2LBL, CLMD, PM3LBL, PM3LMD, PM4RBL, PM4RMD, M1RMD, LI1LBL, LPM3LMD, LPM4LBL, LM2LMD, LM3LBL, LCRBL and LM2RMD. Analysis also showed that there is significant interaction between biological sex and the tested samples for M1RBL, M3RMD, LM3BL, LM2RBL and LM2RMD. This, however, has no major implications for the calculated inter-sample distances, because this analysis uses mainly only polar teeth (i.e. 1st Incisor, Canine, 3rd Premolar and 1st Molar). Of the polar teeth measurements, GLM univariate hierarchical analysis indicated only a significant interaction between biological sex and the tested samples for M1RBL. This implies that there should be no effect of sex and sample interaction for calculated inter-sample distances for other polar teeth. It is, therefore, unfortunate that this interaction exists, given the relatively large sample size for this dental measurement (n=30).

Table 6.1.30 Inter-sample analysis, Argolid samples (Lerna and Apatheia): GLM Univariate Hierarchical Analysis results for dental measurements, Tests between-subjects effects, F and p values ($p<0.05$).

TOOTH CROWN MEASUREMENT	N	SEX		POPULATION SAMPLE		SEX*POPULATION SAMPLE	
MAXILLA		F	p	F	P	F	p
I1LBL	20	2.183	0.145	0.017	0.897	-	-
I1LMD	21	1.425	2.202	0.042	0.839	-	-
I2LBL	24	2.466	0.111	13.479	**0.001**	0.309	0.584
I2LMD	25	1.25	0.307	0.087	0.769	0.258	0.616
CLBL	29	3.193	0.086	0.302	0.587	0.215	0.646
CLMD	30	3.993	0.056	9.025	**0.005**	0.211	0.649
PM3LBL	34	1.915	0.165	8.062	**0.008**	0.671	0.419
PM3LMD	34	1.652	0.209	6.099	**0.019**	0.274	0.604
PM4LBL	28	0.049	0.951	3.009	0.998	1.479	0.236
PM4LMD	26	0.343	0.713	0.09	0.766	0.623	0.438
M1LBL	32	0.12	0.887	0.285	0.597	2.44	0.129
M1LMD	32	2.999	0.066	0.09	0.765	0.144	0.706
M2LBL	22	0.238	0.79	0.024	0.877	1.169	0.294
M2LMD	24	0.415	0.666	1.956	0.178	2.267	0.148
M3LBL	15	0.199	0.821	0.478	0.503	-	-
M3LMD	14	6.007	**0.019**	0.566	0.468	-	-
I1RBL	14	6.773	**0.024**	51.644	1.783	-	-
I1RMD	17	0.441	0.652	1.977	0.183	-	-
I2RBL	21	2.098	0.155	1.668	0.214	0.679	0.421
I2RMD	24	0.027	0.973	0.485	0.494	0.01	0.919
CRBL	21	0.122	0.885	0.004	0.947	-	-
CRMD	24	3	0.073	1.437	0.245	0.193	0.665
PM3RBL	27	2.676	0.091	1.87	0.185	2.458	0.131
PM3RMD	28	3.125	0.062	3.08	0.092	1.331	0.26
PM4RBL	25	0.033	0.967	5.357	**0.031**	1.306	0.266
PM4RMD	26	0.848	0.442	8.082	**0.009**	0.753	0.395
M1RBL	30	0.387	0.682	0.006	0.938	5.745	**0.024**
M1RMD	31	3.557	**0.043**	7.498	**0.01**	0.715	0.405
M2RBL	26	1.441	0.258	0.004	0.948	3.57	0.072
M2RMD	28	1.297	0.292	1.197	0.285	3.712	0.066
M3RBL	18	7.419	**0.007**	3.9	0.069	1.781	0.204
M3RMD	18	1.786	0.206	1.51	0.24	12.737	**0.003**
MANDIBLE							
LI1LBL	14	0.317	0.735	6.135	**0.035**	0.123	0.733
LI1LMD	24	0.699	0.509	0.002	0.962	0.003	0.956
LI2LBL	24	1.658	0.215	0.045	0.832	-	-
LI2LMD	33	0.189	0.828	0.760	0.39	2.175	0.151
LCLBL	31	4.032	**0.029**	3.617	0.068	0.44	0.512
LCLMD	36	3.983	**0.028**	2.432	0.129	1.456	0.236
LPM3LBL	34	0.575	0.568	1.352	0.254	2.506	0.124
LPM3LMD	34	1.015	0.374	8.188	**0.007**	1.106	0.301
LPM4LBL	30	0.493	0.488	4.75	**0.038**	0.145	0.706
LPM4LMD	31	0.084	0.772	3.745	0.0634	0.089	0.767
LM1LBL	19	0.227	0.64	0.841	0.373	1.203	0.289
LM1LMD	19	1.442	0.248	0.278	0.605	2.123	0.165
LM2LBL	25	2.55	0.125	0.037	0.848	4.485	**0.046**
LM2LMD	28	0.536	0.47	8.401	**0.007**	2.34	0.139
LM3LBL	19	0.221	0.644	6.936	**0.018**	5.241	**0.036**
LM3LMD	20	0.062	0.805	2.243	0.153	0.669	0.425
LI1RBL	13	0.294	0.751	1.297	0.284	-	-

TOOTH CROWN MEASUREMENT	N	SEX		POPULATION SAMPLE		SEX*POPULATION SAMPLE	
		F	p	F	p	F	p
LI1RMD	21	1.596	0.233	0.971	0.338	0.005	0.944
LI2RBL	21	3.158	0.093	2.128	0.162	1.353	0.26
LI2RMD	31	0.208	0.651	2.174	0.151	0.004	0.945
LCRBL	29	11.273	**<0.001**	4.601	**0.042**	0.009	0.924
LCRMD	35	7.043	**0.003**	3.121	0.087	0.928	0.342
LPM3RBL	34	3.536	0.069	0.605	0.442	0.592	0.447
LPM3RMD	36	3.542	0.068	3.402	0.074	1.586	0.216
LPM4RBL	29	0.107	0.898	0.028	0.867	1.032	0.319
LPM4RRMD	29	1.867	0.176	1.706	0.203	1.769	0.195
LM1RBL	27	0.27	0.765	1.407	0.248	1.927	0.178
LM1RMD	28	0.455	0.639	1.105	0.303	3.013	0.095
LM2RBL	30	2.026	0.152	1.006	0.325	10.449	**0.003**
LM2RMD	35	0.916	0.41	0.366	**0.004**	5.003	**0.032**
LM3RBL	23	0.126	0.726	0.001	0.969	2.36	0.14
LM3RMD	23	0.753	0.485	0.071	0.792	2.49	0.998

6.1.4 Argolid: Summary of Cranial Metric and Non-metric and Dental Metric Morphological Analysis

On the basis of the results of cranial metric morphological analysis with regard to sexual dimorphism in the Lerna and Apatheia samples, it was decided to pool the two sexes in order to maximise the sample sizes in the investigation of inter-sample relationships, but to differentiate them (the sexes) by symbols (♂= male, ♀= female) in scatterplots, and by separate boxes in box and whisker plots. Furthermore, on the basis of a similar pattern of sexual dimorphism in the Lerna and Apatheia samples, the two samples were pooled to assess sexual dimorphism in the overall Argolid population.

The results of the analysis of cranial morphology are consistent with both the principal and auxiliary hypotheses that the Lerna and Apatheia samples are biologically distant one from the other, and that Lerna shows higher biological variation relative to Apatheia. The results of the analysis reveal that Lerna individuals have more rounded crania in comparison with Apatheia. This is a result of their crania being relatively broader and higher vaulted for their length (Figures 6.1.13, 6.1.16, 6.1.17), with a more vertical occipital compared with the Apatheia crania (Figure 6.1.20). Additionally, the Lerna crania tend to be broader and more protruding in the upper facial region (Figure 6.1.22). Due to the disproportionate and poor representation of the two samples in analysis of the upper facial region morphology, these results should be treated with caution. The possibility, however, that inter-sample variance is due to sex differences in cranial morphology and differences in the representation of males and females within the two tested samples was assessed and refuted. The very similar environmental conditions for the two sites should have played a very important role in preventing the metric morphological distance between the two populations from reaching statistically significant levels (Appendix A, section A.1).

The results of non-metric morphological analysis of the cranium suggest that there is significant biological distance between the two Argolid samples. It is difficult, however, to explore the hypothesis that it is Lerna, rather than the Apatheia population, that increased its distance to the regional population centroid, due to higher rates of gene flow from extra-regional sources (Relethford & Blangero 1990), because the Bronze Age Argolid population is represented only by these two samples. In this case, the regional population centroid is defined by the two tested samples and the mean distance of these two samples to it (population centroid), is biased by their contribution to its calculation. Therefore, it is biased by their size.

Since non-metric traits have been suggested to be more genetically canalized than metric traits (Hauser & De Stefano 1989), it is legitimate to infer that Lerna and Apatheia populations probably share a rather distant common ancestor. The higher variation within the Lerna sample, in comparison with the Apatheia sample, calculated using variables describing the morphology of the cranium, constitutes strong evidence of gene flow from extra-regional sources. Therefore, it is most probable that it is the Lerna population that increased its distance to the regional population centroid as a result of gene flow from extra-regional sources. However, one additional factor contributing to the higher intra-population variation of the Lerna sample compared to Apatheia could be time-depth (Konigsberg 1987). In terms of absolute chronology, the Lerna sample spans a time period of 500 years, whereas Apatheia spans a narrower period of approximately 325 to 340 years (chronologies taken from Warren & Hankey 1989; Manning & Weninger 1992; Manning 1995).

With regard to the results of the brief analysis of dental metric morphology, presented in section 6.1, it is worth mentioning the agreement of the results of GLM univariate analysis suggesting a significant association between the BL and MD crown diameters of both right and left mandibular canines of the examined Argolid individuals and their biological sex with results of studies of canine sexual dimorphism (Frayer & Wolpoff 1985). Finally, on the basis of the results of the analysis of side asymmetry in tooth crown diameters, it was decided that the percentage of significantly asymmetrical metric variables for the two Argolid samples is low enough to permit pooling of right and left side measurements to maximise sample sizes.

6.2 Crete

Section 6.2 examines the cranial and dental morphology of Bronze Age skeletal collections from Crete. It explores sexual dimorphism in the cranial metric morphology of the Cretan collections (section 6.2.1). It also assesses inter-sample biological distance on the basis of the results of the analysis of cranial non-metric (section 6.2.2), dental metric (section 6.2.3) and non-metric (section 6.2.4) morphology. Inter-sample distance for the Cretan Bronze Age samples is further investigated in section 6.3 (Argolid, Cretan and Naxos samples: Inter-regional Analysis of Skeletal Morphology), where the hypothesis for a Mycenaean migration to Knossos following the LMIB destructions on the island is systematically examined.

6.2.1 Crete: Cranial Metric Morphological Analysis

In this section (6.2.1), I will present the analysis and interpretation of the cranial metric morphology of nine Cretan population samples (i.e. the Palaikastro, Moni Odigitria, Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo, Mavrospelio, Kastelos and Palama samples). These derive mainly from Central Crete and span the entire Bronze Age. The analysis explores the population biovariability at both the intra- and inter-sample level and is devoted to the assessment of sexual dimorphism in the Cretan samples for the reasons outlined at the beginning of the chapter.

6.2.1.1 Sexual dimorphism in the Cretan samples: One-way ANOVA

Palaikastro: Fourteen males and thirteen females from the Palaikastro sample were tested for sexual dimorphism (the sex and age of the analysed individuals is given in Appendix C, Table 6.3). Sex differences in the mean values for the cranial metric variables were tested using One-way ANOVA. Analysis showed GOL ($p<0.001$), NOL ($p<0.001$), FMB ($p=0.041$), GLS ($p=0.001$), FRF ($p=0.007$), PAC ($p<0.001$), PAS ($p=0.017$), PAF ($p<0.001$) and NAR ($p=0.020$) to be significantly sexually dimorphic variables ($p<0.05$) (Appendix D, Table 6.14). These variables describe the cranial length and breadth, the midline curvature of the cranial vault, the upper facial protrusion and the projection of the glabella. The homogeneity of the intra-group variances was explored using the Levene test (Appendix D, Table 6.15). This showed significantly unequal intra-group variances for the two sexes for GOL ($p= 0.045$), NOL ($p= 0.048$) and OCS ($p=0.032$). Therefore, variance for GOL, NOL and OCS was further explored using the Welch and Brown-Forsythe tests (Appendix

D, Table 6.16). The results, however, did not differ significantly from those derived from one-way ANOVA (GOL: p<0.001, NOL: p =0.001, OCS: p=0.932).

Moni Odigitria: The Moni Odigitria sample (13 males and 7 females) was explored for sexual dimorphism (Appendix C, Table 6.4). One-way ANOVA suggested significant sex differences for SOS (p=0.032) and GLS (p=0.012) (Appendix D, Table 6.17). These variables describe the projection of the supra-orbital and glabellar region. Due to the difference in the size of the two sex samples, the Levene test was applied to the data to test for equality of the intra-sex group variances. The Levene test showed significantly unequal intra-group variances for WCB (p <0.001), FMB (p=0.021), GLS (p=0.021) and PAC (p= 0.05) (Appendix D, Table 6.18). Due to the sample size differences between the two sex-groups, and the inequality of the intra-group variances for WCB, FMB, GLS and PAC, the Welch and Brown–Forsythe tests were used to explore further the data for sexual dimorphism (Appendix D, Table 6.19). These showed significant sex differences only for SOS (p=0.039).

Ailias: The Ailias sample was explored for sexual dimorphism. Due to the significant size difference between male and female samples (41 and 22 individuals respectively, Appendix C, Table 6.5), inter-sample variance was tested using the Welch and Brown–Forsythe tests (Appendix D, Table 6.20). The tests suggested significant sex differences for GOL (p=0.000), NOL (p=0.000), BNL (p=0.001), AUB (p= 0.019), ASB (p=0.000), JUB (p=0.018), MDH (p=0.005), MDB (p=0.006), FMB (p=0.011), EKB (p=0.029), GLS (p<0.001), FRC (p=0.006), PAC (p=0.008), PAF (p=0.004), NAR (p=0.019). These variables describe the cranial length and breadth, the frontal breadth and upper facial protrusion, the morphology of the mastoid process and the protrusion of the glabella. The Levene test showed significant inequality of the intra-group variances of the two sex-groups for AUB (p= .041), IML (p= .034), PAS (p=0.035) and SSR (p<0.001) (Appendix D, Table 6.21).

Myrtos Pyrgos: The skeletal remains from both the primary and secondary burials within the tomb were grouped together and sexual dimorphism was explored. Sixteen males and eleven females (Appendix C, Table 6.6) were entered for One-way ANOVA. This showed significant sex differences for GOL (p=0.032), NOL (p=0.019), XFB (p=0.042), STB (p=0.026), FRC (p=0.034), PAC (p=0.012), PAS (p=0.034), NAR (p=0.029) and FMR (p=0.031) (Appendix D, Table 6.22). These variables describe the length and frontal breadth of the cranium, the midline protrusion of the cranial vault and the upper facial protrusion. The Levene test suggested significantly unequal intra-group variances for the two groups for AUB (p=0.029), WCB (p=0.001) and FRC (p<0.001) (Appendix D, Table 6.23). The more robust tests of variance were applied to the data. These failed to show significant sex differences for AUB (p=0.938), WCB (p=0.953) and FRC (p=0.331) (Appendix D, Table 6.24).

Gypsades: The Gypsades sample (13 males and 9 females, Appendix C, Table 6.7) was explored for sexual dimorphism. The Levene test was applied to the data to confirm the equality of intra-group variances of the two sex groups. Results failed to reach significance for any of the tested variables. The variable closest to the significance level is GOL (p=0.052) (Appendix D, Table 6.25). One-way ANOVA, therefore, was applied to the data, and differences between the two sexes reached the level of significance (p<0.05) for the following variables: XCB (p=0.046), XFB (p=0.003), ASB (p=0.037), MDB (p=0.007), GLS (=0.029) (Appendix D, Table 6.26). These variables describe the cranial breadth, the breadth of the mastoid process and the protrusion of the glabella. When the 3 individuals from Upper Gypsades (dating to MMIII) are removed from the analysis to allow for the sexual dimorphism to be explored exclusively in the LMI Lower Gypsades sample (10 males and 9 females), the results are very similar. Sexual dimorphism reached significance for NOL (p=0.008), XFB (p=0.018), MDB (p=0.009), SOS (p=0.009), GLS (p=0.020) (Appendix D, Table 6.27). These variables describe the cranial length and breadth, the breadth of the mastoid process and the projection of the glabella and supra-orbital region of the upper facial skeleton. The Levene test was applied to the data from the Lower Gypsades sample and it detected significant unequal intra-group variances for one variable, GLS (p=0.041) (Appendix D, Table 6.28). Therefore, sexual dimorphism for GLS was further explored using the Welch and Brown-Forsythe tests (p=0.018 for both tests) (Appendix D, Table 6.29).

Sellopoulo: Due to the small size of the Sellopoulo sample (3 males and 3 females, Appendix C, Table 6.8), the Welch and Brown-Forsythe tests were used to assess sexual dimorphism (Appendix D, Table 6.30). Although sexual dimorphism failed to reach significance for any of the tested variables, tests showed the difference between the two sex-groups for OCS to be very close to the significance level (p=0.051). OCS describes the midline protrusion of the occipital bone.

Mavrospelio: A rather small sample of 7 individuals (4 males and 3 females, Appendix C, Table 6.9) was studied. The Levene test showed significant inequality of the intra-group variances of the two sex-groups for GLS (p=0.008), PAS (p=0.012) and VRR (p<0.001) (Appendix D, Table 6.31). Neither the One-way ANOVA, nor the Welch and Brown-Forsythe tests detected any significant inter-group variance for the tested variables (Appendix D, Tables 6.32 and 6.33). This could be the result of the small sample size.

Kastelos: As in the case of the Mavrospelio sample, both One-way ANOVA and the more robust tests of variance applied to the Kastelos sample (2 males and 2 females, Appendix C, Table 6.10) failed to detect significant sex differences in the means of the tested variables (Appendix D, Tables 6.34 and 6.35). The Levene test suggested significantly unequal inter-group variance for XFB, FMB, PAC and PAF (p<0.001) (Appendix D, Table 6.36).

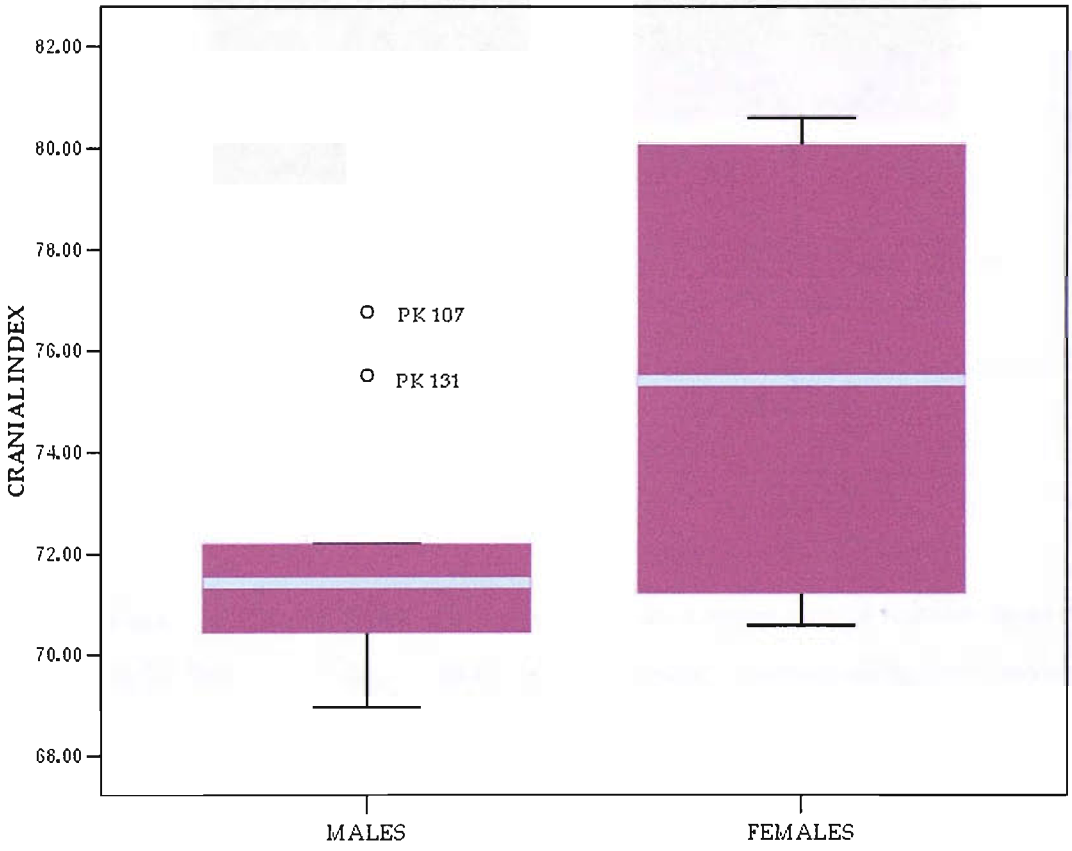
Palama: Data from 6 males and 5 females from the Palama sample were analysed for sexual dimorphism (Appendix C, Table 6.11). One-way ANOVA detected significant sex differences for SOS (p=0.027) (Appendix D, Table 6.37). The Levene test showed that the intra-group variances are significantly unequal for MDH (p=0.007) and OCS (p=0.007) (Appendix D, Table 6.38). Due to low small sample sizes, the more robust tests of variance were applied to the data (Appendix D, Table 6.39). These showed that sexual dimorphism for STB reached significance (p=0.05). Supra-orbital projection (SOS) and Bistephanic Breadth (STB) describe the projection of the supraorbital region and frontal breadth respectively.

6.2.1.2 Sexual dimorphism in the Cretan samples: Cranial Indices

Cranial index (CI= 100*XCB/GOL): The Cranial Index was calculated for the tested Cretan samples in order to explore further sex differences in the cranial shape of the Cretan individuals from each population sample separately.

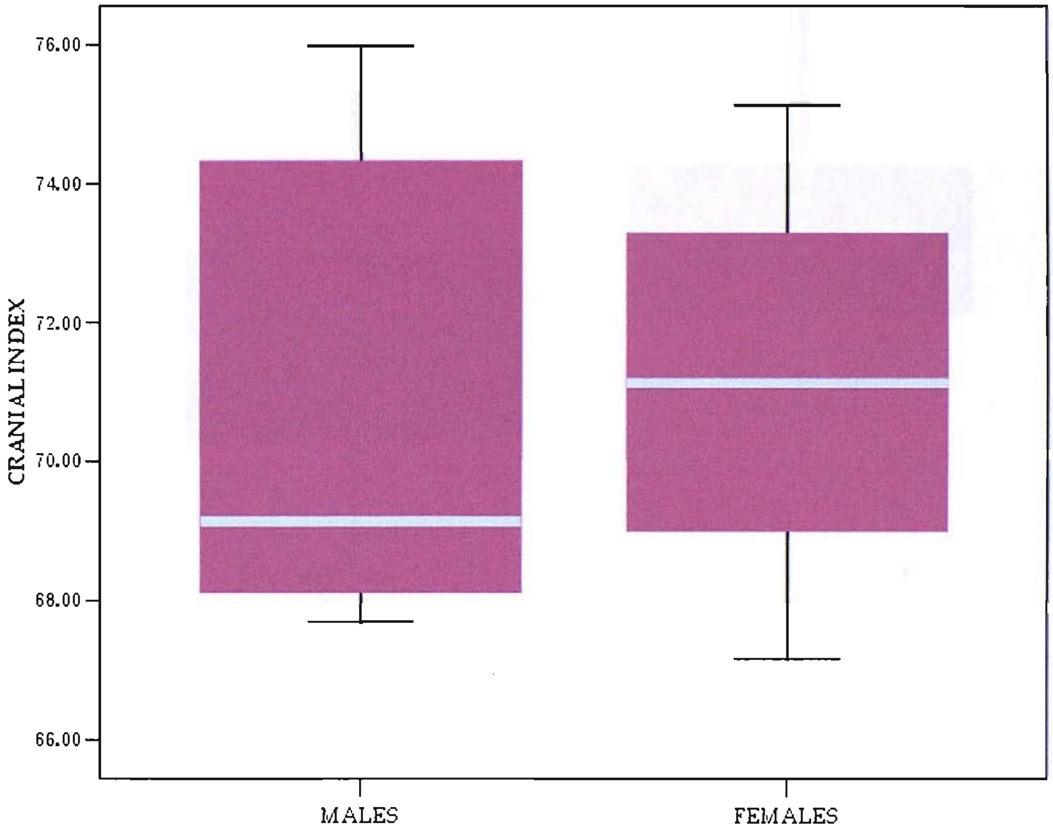
Palaikastro: One-way ANOVA ($p<0.05$) assessed sexual dimorphism in the Cranial Index for the Palaikastro sample (6 females and 11 males) (Figure 6.2.1) and showed that it reached significance ($p=0.037$). The Levene test, however, suggested significant inequality of the intra-group variances and hence, the more robust tests of variance were applied. The Welch and Brown-Forsythe tests did not confirm the results of One-way ANOVA. They failed to show significant sexual dimorphism in the Cranial Index ($p=0.096$). This suggests that differences between the two sex-groups in terms of the Cranial Index most probably result from unequal intra-group variances; the female sample shows higher variance (Figure 6.2.1).

Figure 6.2.1 Box and whisker plot of sexual dimorphism in the Palaikastro sample, Cranial Index.



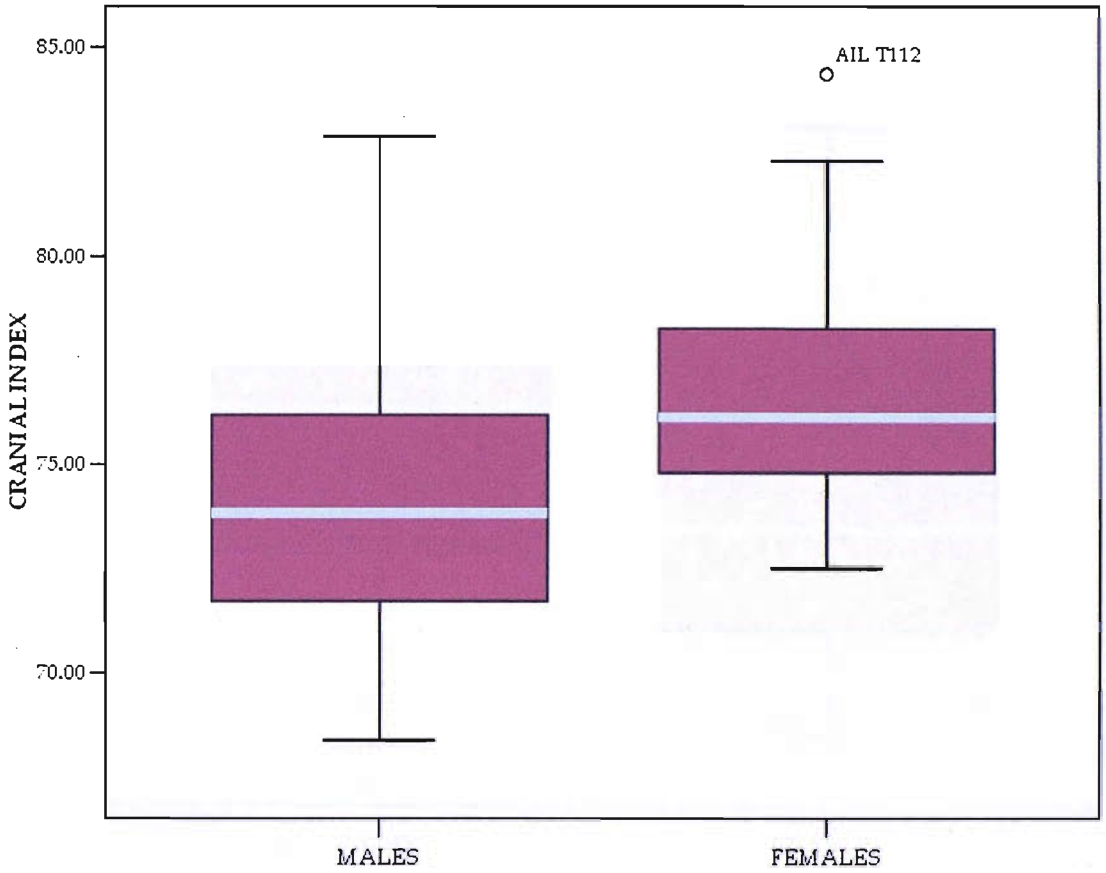
Moni Odigitria: Sex differences in the Cranial Index did not reach statistical significance for the Moni Odigitria sample (5 males and 4 females) (Figure 6.2.2). One-way ANOVA and the more robust tests were applied to the data and the p values were calculated as p=0.972 and p=0.971 respectively. The Levene test detected no statistically significant inequality of the variances of the two tested groups (p=0.327).

Figure 6.2.2 Box and whisker plot of sexual dimorphism in the Moni Odigitria sample, Cranial Index.



Ailias: The Cranial Index was calculated for 24 males and 14 females from the Ailias sample. The intra-group variances were tested for equality using the Levene test. Although this test did not show significant inequality of the intra-group variances (p=0.747), sexual dimorphism in the Ailias sample was tested by One-way ANOVA (p=0.026) and the more robust tests of variance (Welch and Brown-Forsythe tests: p=0.026), due to unequal sample size, and it reached significance for all tests. The distribution of the data is symmetrical for the male individuals, whereas it tends to be positively skewed for the females (Figure 6.2.3). Moreover, males show a greater range of variation for the Cranial Index in comparison to females. This could be related to the greater male sample size.

Figure 6.2.3 Box and whisker plot of sexual dimorphism in the Ailias sample, Cranial Index.

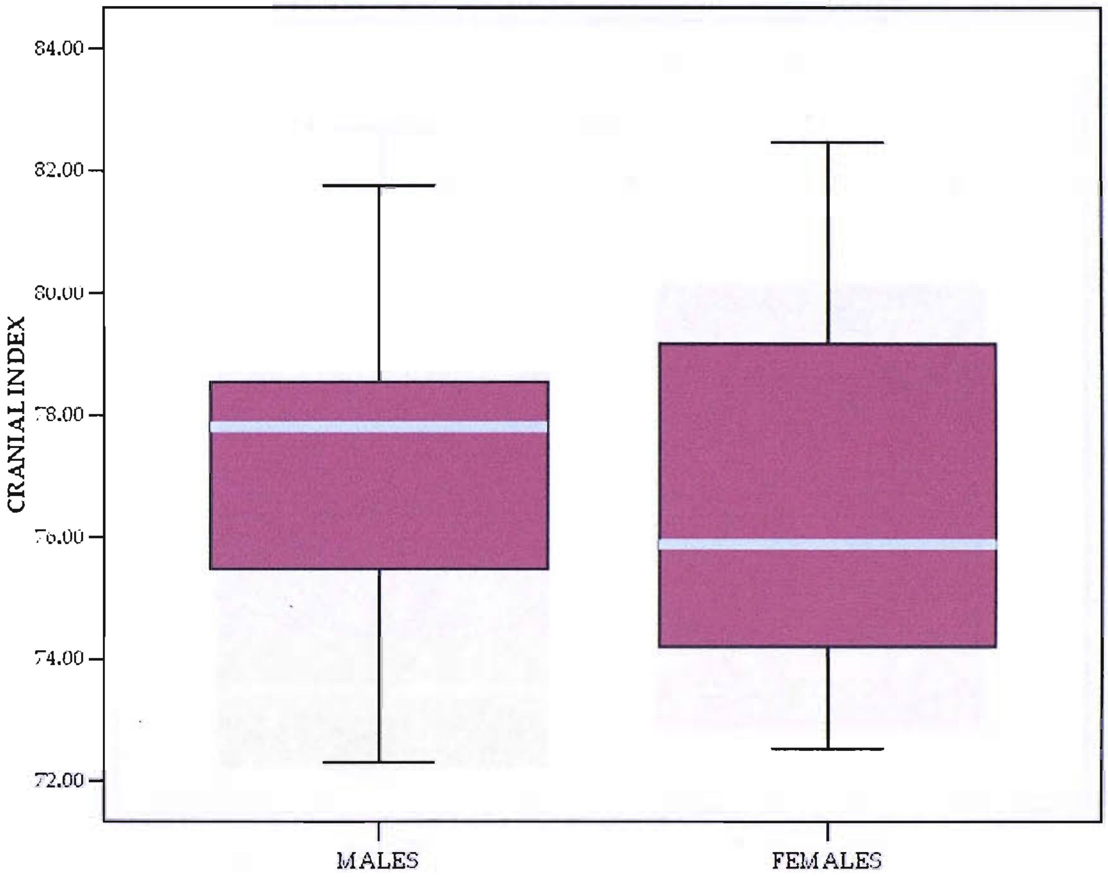


Myrtos Pyrgos: There is a disproportionate representation of the two sexes in the Myrtos Pyrgos sample. The Cranial Index was calculated for 10 males and 2 females and sexual dimorphism failed to reach significance for both One-way ANOVA (p=0.1), and the Welch and Brown-Forsythe tests (p=0.288). The Levene test for the equality of the intra-group variances did no show significant differences between the two sexes (p=0.996).

Gypsades: The Cranial Index was calculated for 6 males and 3 females of the Gypsades sample (Figure 6.2.4). One-way ANOVA failed to show significant sexual dimorphism (p =0.901). Due to the low sample size and sample size difference of the two sex-groups, sex differences were further explored using the more robust tests.

These tests, however, also failed to show significant differences between the two sexes (p=0.920). The Levene test explored the homogeneity of the sex-group variances and failed to show significantly unequal variances (p=0.379).

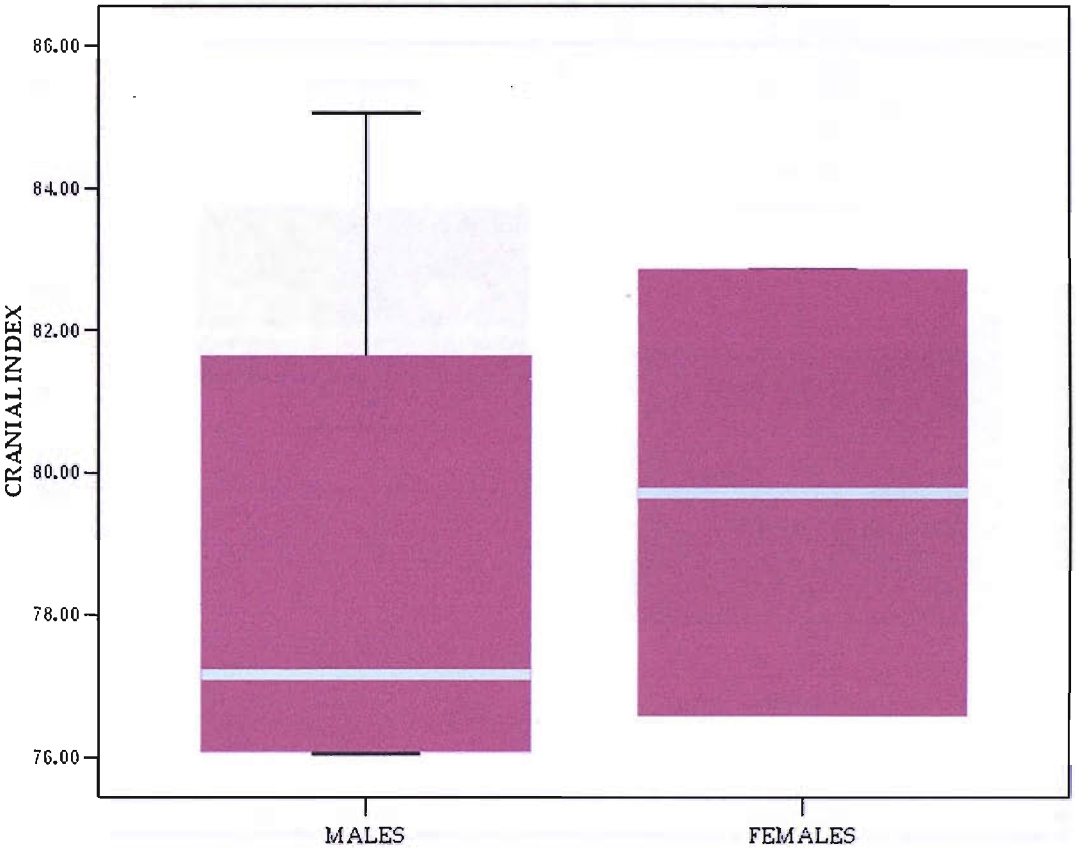
Figure 6.2.4 Box and whisker plot of sexual dimorphism in the Gypsades sample, Cranial Index.



Sellopoulo: In the Sellopoulo sample, the Cranial Index was calculated for 2 males and 2 females. One-way ANOVA showed that there is no significant sexual dimorphism for the Cranial Index (p=0.295). Nevertheless, sex differences were further tested using the more robust tests, due to the significantly heterogeneous inter-group variance (p<0.001) and the small sample size. The Welch and Brown-Forsythe tests failed as well to show significant difference between the two sexes for the Cranial Index (p=0.324).

Mavrospelio: Sexual dimorphism in the Cranial Index did not reach significance for the Mavrospelio sample (4 males and 2 females) (Figure 6.2.5). One-way ANOVA was performed and sex differences were not statistically significant (p=0.828). Due to low sample size, the more robust tests of variance were applied to the data and the results (p=0.841) agree with those derived from One-way ANOVA (p=0.828). The Levene test showed that there is no significant heterogeneity in the inter-sex-group variance for the Cranial index (p=0.989).

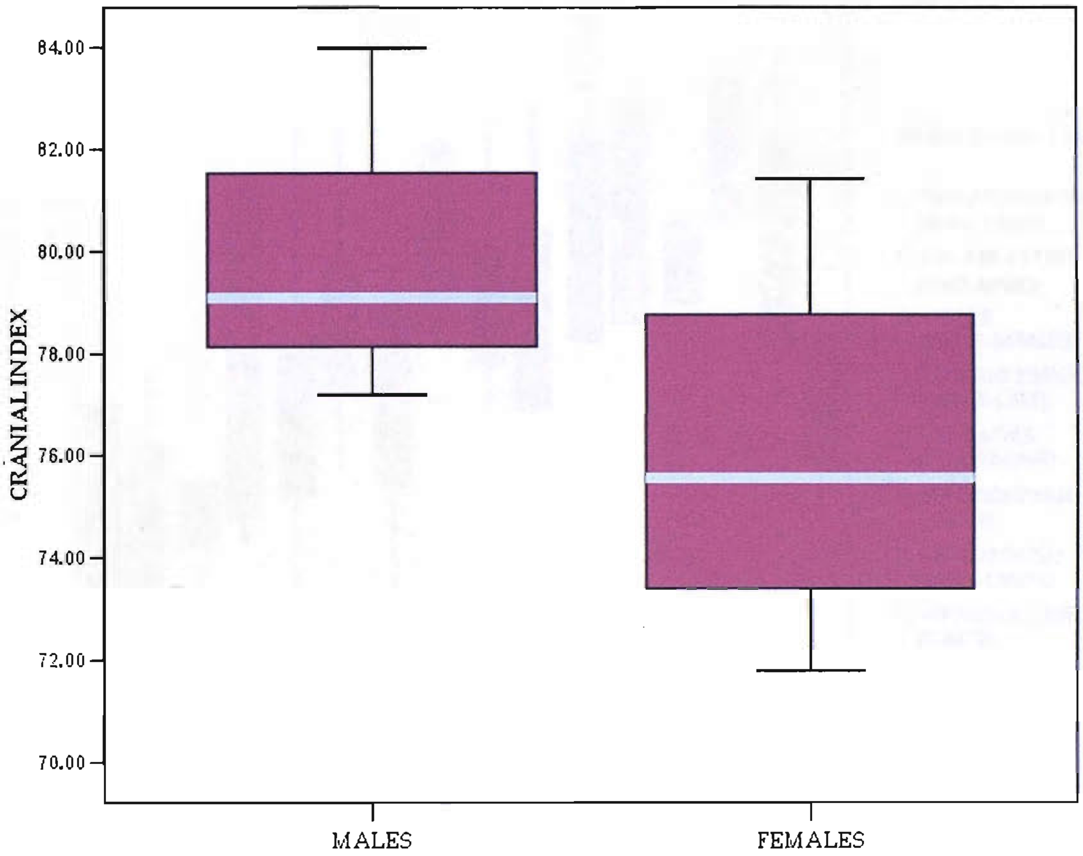
Figure 6.2.5 Box and whisker plot of sexual dimorphism in the Mavrospelio sample, Cranial Index.



Palama: Three males and four females from the Palama sample were tested for sexual dimorphism in the Cranial Index (Figure 6.2.6). Sex differences failed to reach significance both when the One-way ANOVA (p=0.227) and the Welch and Brown-Forsythe tests (p=0.221) were applied to the data. According to the Levene test, intra-group variances were not significantly unequal for the two sex-groups (p=0.957). A note should be made on the reverse patterning of sexual dimorphism in the Cranial Index for the Palama compared with all others apart from the Gypsades sample. The Cranial Index for the male individuals from the Palama cemetery is higher than for females. With the exception of the Gypsades sample, the rounder cranial shape of the Palama males relative to the females is in contrast with the available data from all other skeletal samples from the Argolid and Crete. In the

Gypsades sample, the median for the Cranial Index is higher for the males compared with females, like in the Palama sample. The implications of the relationship between sex and Cranial Index in the Palama sample are discussed later in this section, when Cranial Index data for all Cretan samples are plotted in the same graph (Figure 6.2.7).

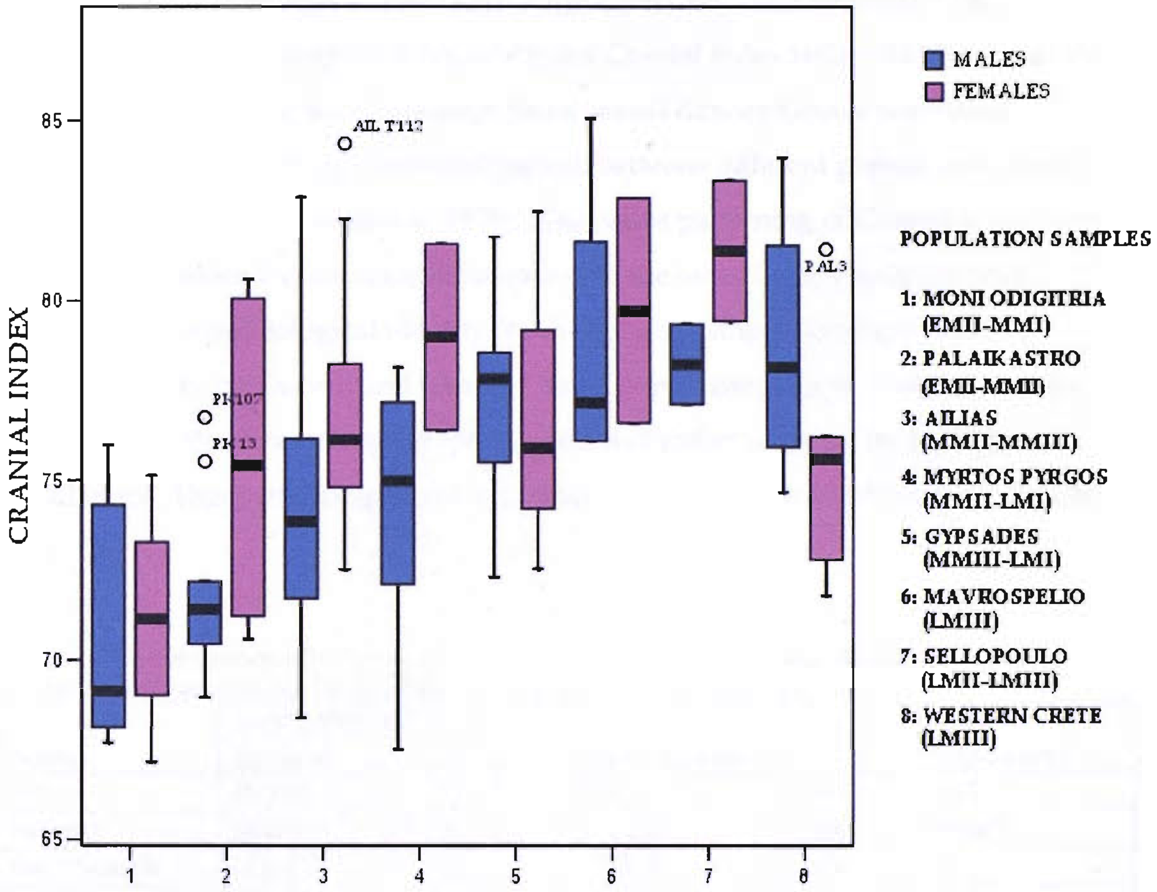
Figure 6.2.6 Box and whisker plot of sexual dimorphism in the Palama sample, Cranial Index.



Kastelos: Sexual dimorphism was not explored for the Kastelos sample, due to very low sample size (2 males and 2 females).

Cranial index: Inter-sample analysis of cranial size and shape of the Bronze Age Cretan population (all samples): In order to explore inter-sample differences/similarities in terms of the cranial size and shape and investigate the patterning of changes in cranial morphology for the Cretan samples over the course of the Bronze Age, the Cranial Index for all Cretan samples was plotted in the same graph (Figure 6.2.7). The two sexes are plotted separately and the samples are arranged in chronological order, from the Early to Late Bronze Age. Because of the low size of the Kastelos sample, the four individuals from that site are grouped with the Palama individuals, also from Western Crete.

Figure 6.2.7 Box and whisker plot of sexual dimorphism in the Cretan population samples, Cranial Index.



Plotting of the Cranial Indices suggests that for the majority of the samples, the females show a higher median value for the Cranial Index than males from the same sample. Therefore, females tend to have a relatively broad cranium for its length in comparison with males. The Western Crete (Palama and Kastelos pooled samples) and Gypsades samples, however, show the opposite relationship between Cranial Index and sex. In both samples, the median Cranial Index is greater for the males than the females. In the Gypsades sample, however, the mean Cranial indices for males and females are very similar (calculated as 76.96 and 77.29 respectively).

The Cranial Index data were tested using GLM Univariate Hierarchical analysis ($p<0.05$). This analysis is applied to test hypotheses about the means of a single dependant variable when cases are classified into groups based on one or more factor variables (Norušis 2003: 477). Here it is used to explore the interaction between the Cranial Index, sample and sex. The results suggest that there are significant differences in Cranial Index between males and females (p=0.015), and between population samples (p<0.001) (Table 6.2.1). There is no significant interaction, however, between sex and sample (p=0.206). This eliminates the possibility that inter-sample differences in the Cranial Index reflect differences in the sex-composition of the tested samples. Since sexual dimorphism is population specific and differs in magnitude and pattern between different populations (Ascadi & Nemeskéri 1970; Richman *et al.* 1979), the reverse patterning of Cranial Index with sex for the Western Cretan sample compared to the other Cretan samples might suggest a different biological identity for the Palama sample (Western Crete) compared with the Eastern and Central Cretan population samples, or that the two sex-groups of the Palama sample are composed of rather different biological populations. This patterning, however, could be an artefact of relatively low sample size.

Table 6.2.1 Sexual dimorphism, Cretan population samples: GLM Univariate Hierarchical Analysis results for the Cranial Index, Tests of Between-Subjects Effects, p values (p<0.05).

Source	Type I Sum of Squares	Df	Mean Square	F	Significance
Sex	75.148	1	75.148	6.142	**.015**
Sample	479.679	9	53.298	4.356	**<0.001**
Sex * Sample	152.921	9	16.991	1.389	.206
Error	1064.433	87	12.235		
Total	608501.930	107			
Corrected Total	1772.180	106			

The second important trend in the data is the very clear gradual increase in Cranial Index over the course of time, as the samples are plotted in chronological order from Early to Late Bronze Age (Figure 6.2.7). The gradual increase in Cranial Index over the Bronze Age could be the result of gene-flow from population/s biologically different from the Early Bronze Age Cretan population and from inter-population biological interactions (admixture) in the succeeding periods.

An additional, though not very strong, interpretation of the pattern of change of the Cranial Index in the course of the Bronze Age is offered by the thermoregulatory model of Beals *et al.* (1984). According to this model, an increasingly higher Cranial Index, resulting from a rounder head shape, reflects an adaptation to cold climates. The rounding of the head shape minimises its surface area, which anticipates heat and maximises the cranial volume, producing heat. This suggests that the gradual increase in the Cranial Index for the Cretan samples could reflect a long-term adaptation from warmer to colder climate. This would imply that either over the course of the Bronze Age the climatic conditions on Crete became colder enough to introduce changes in the cranial morphology (for which there is no substantial evidence), or, that the climatic conditions remained roughly stable and the first inhabitants of Crete originated from comparatively warmer climates, but over time gradually adapted to the local comparatively colder environment of Crete.

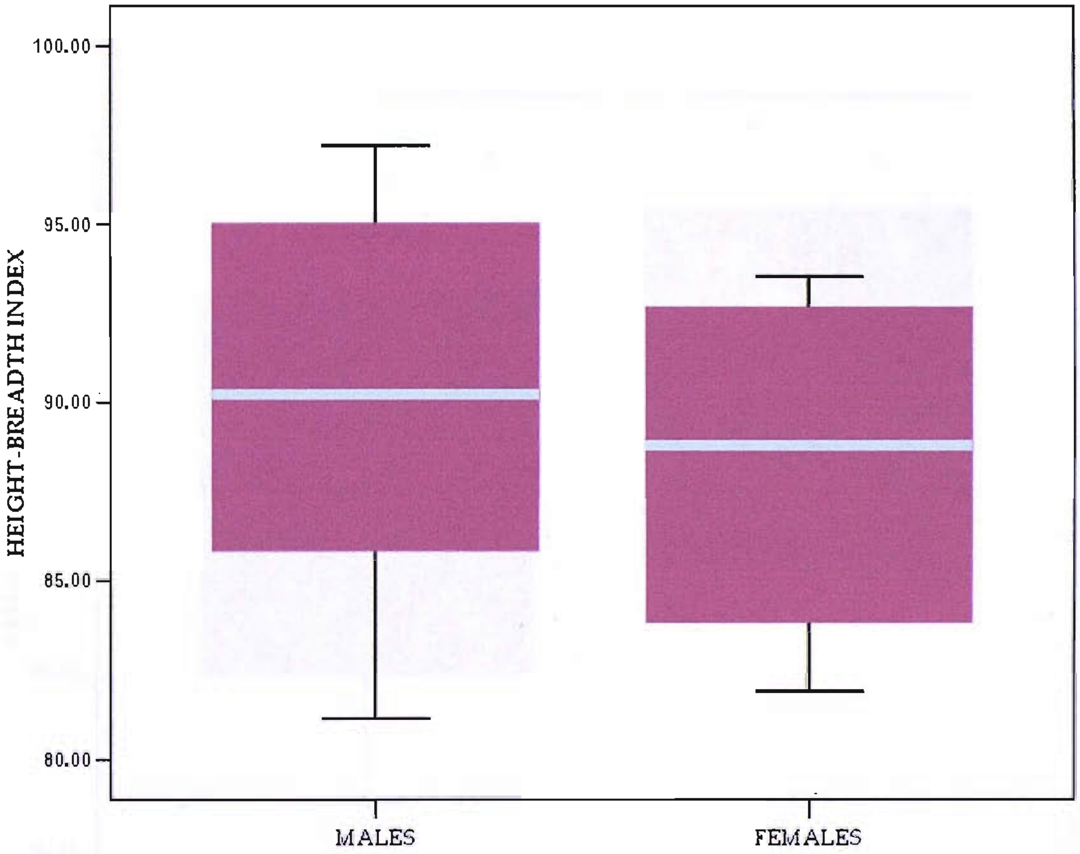
In addition to the Cranial Index, the Upper Facial (UFI =100*NPH/ZYB), the Height-Breadth (HBI=100*BBH/XCB) and the Height-Length (HLI=100*BBH/GOL) Indices were calculated in order to explore further sexual dimorphism in the tested Cretan samples. Due to the relatively poor preservation and incompleteness of the material, the original formulae for these three cranial indices were modified. The new modified indices are the same as those used in the analysis of the skeletal material from the Argolid (sections 6.1.1.2 and 6.1.1.5).

Upper Facial (md) Index (UFI(md) =100*NPH/ZYB): Due to the poor preservation of the upper facial skeleton, the Upper Facial (md) Index was calculated for a small number of cases (less than 10) for all the samples, with the exception of Ailias (11 cases). As a result only the Ailias sample was tested for sexual dimorphism in the Upper Facial (md) Index. For the Ailias sample, 4 females and 7 males were tested. One-way ANOVA ($p<0.05$) was applied to the data and showed that sex differences do not reach significance ($p=0.814$). Although Levene test failed to detect significant inequality of the intra-group variances of the two sexes, the more robust tests of variance were further applied, due to low sample size. The results of Welch and Brown-Forsythe tests ($p = 0.834$) confirm those derived from One-way ANOVA.

Height-Breadth (md) Index (HBI(md^1)= 100*VRR/XCB): In all but one of the tested Cretan samples the Height-Breadth (md) and Height-Length (md) Indices were not found to differ significantly between the two sexes.

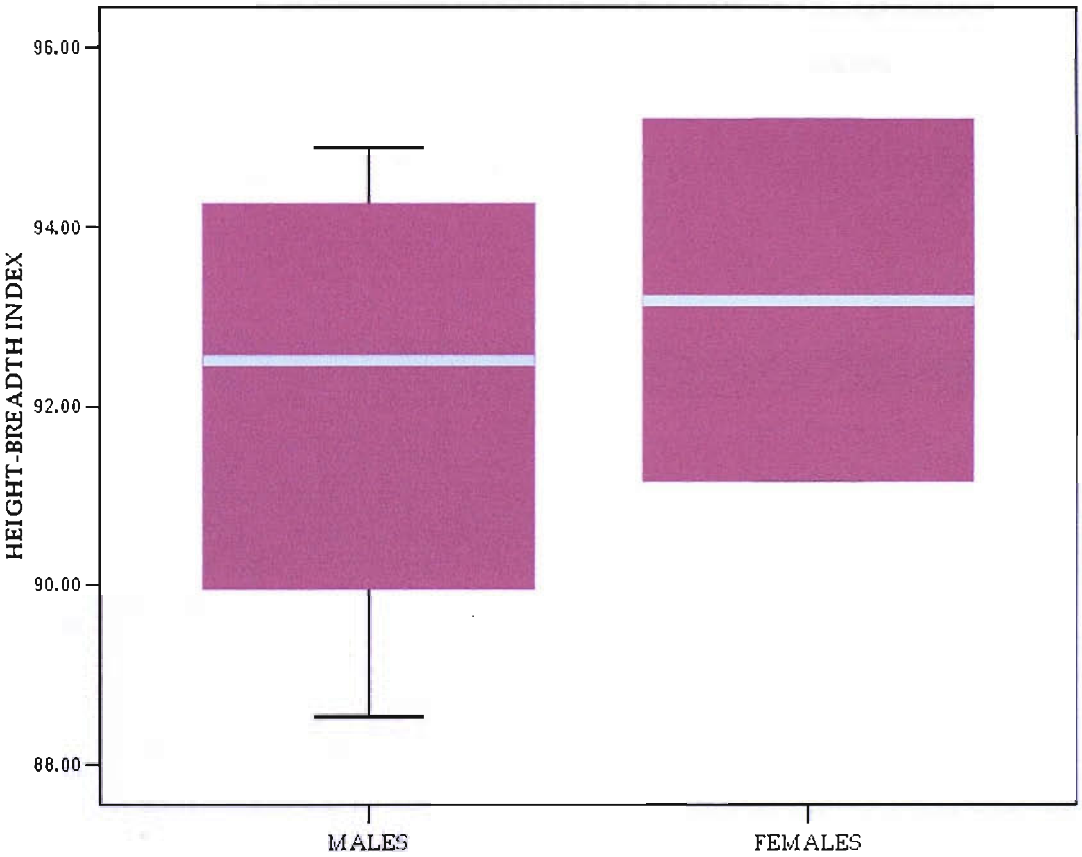
Palaikastro: In the Palaikastro sample (10 males and 4 females), sexual dimorphism in the Height-Breadth index did not reach significance ($p<0.05$), when One-way ANOVA was applied to the data ($p=0.557$) (Figure 6.2.8). Due to the difference in the sample sizes of the male and female groups, the more robust tests of variance were further applied. These also failed to show significant sex differences (p=0.565). According to the Levene test, intra-group variances for the HBI(md) are not significantly unequal (p=0.995).

Figure 6.2.8 Box and whisker plot of sexual dimorphism in the Palaikastro sample, Height-Breadth (md) Index.



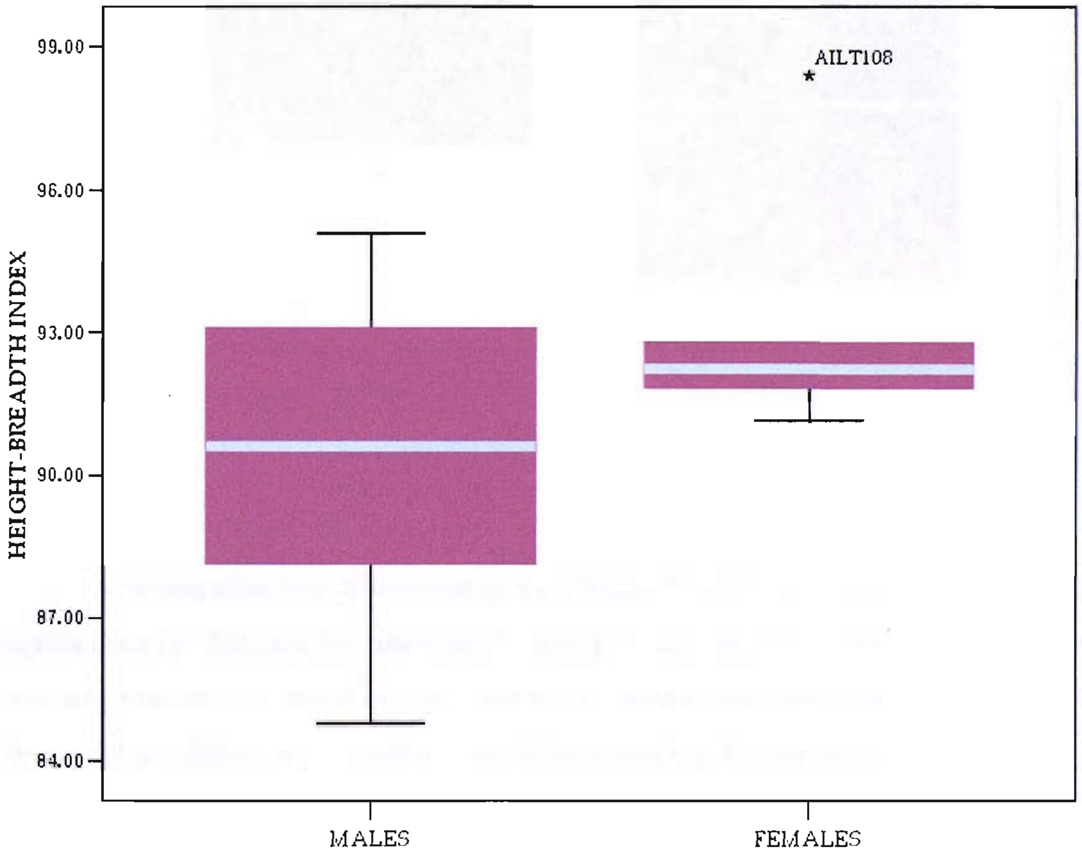
Moni: The Height-Breadth (md) index was calculated for 6 individuals from the Moni sample (4 males and 2 females). Sexual dimorphism did not reach significance ($p<0.05$), either when the data were tested using One-way ANOVA ($p=0.681$) or the more robust tests ($p=0.703$) (Figure 6.2.9). The Levene test failed to detect significant inequality of the intra-group variances of the two sex-groups ($p= 0.893$).

Figure 6.2.9 Box and whisker plot of sexual dimorphism in the Moni sample, Height-Breadth (md) Index.



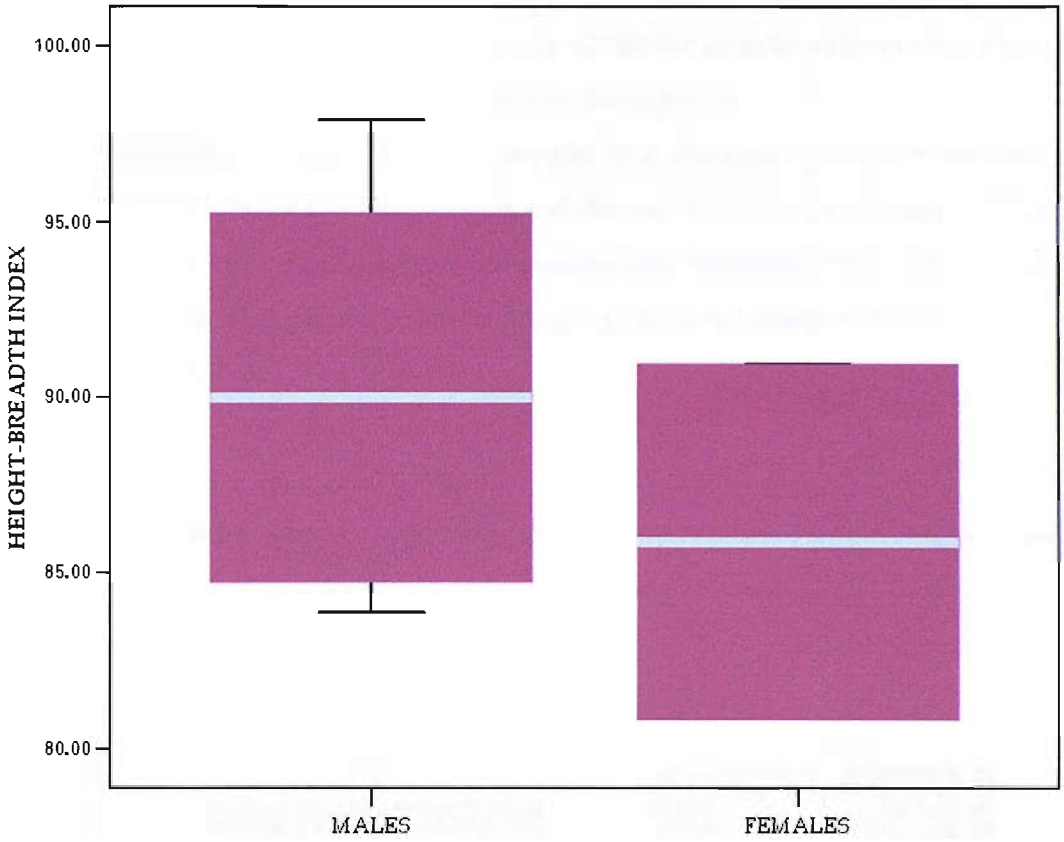
Ailias: In the Ailias sample, the two sexes are disproportionately represented (19 males and 5 females) by the calculated Height-Breadth (md) indices. Therefore, sexual dimorphism in Height-Breadth (md) index was explored using the Welch and Brown-Forsythe tests and failed to reach significance (p=0.106) (Figure 6.2.10). Despite the inequality of the size of the male and female samples, the Levene test did not suggest significantly unequal intra-group variances for the tested variable (p=0.432).

Figure 6.2.10 Box and whisker plot of sexual dimorphism in the Ailias sample, Height-Breadth (md) Index.



Myrtos Pyrgos: Two females and six males from the Myrtos Pyrgos sample were tested for sex differences in the Height-Breadth (md) Index (Figure 6.2.11). Sexual dimorphism did not reach significance (p<0.05) either for the One-way ANOVA (p=0.397) or the Welch and Brown-Forsythe tests of variance (p=0.537). The Levene test did not show significant inequality of the intra-group variances of the two sex-groups (p=0.799).

Figure 6.2.11 Box and whisker plot of sexual dimorphism in the Myrtos Pyrgos sample, Height-Breadth (md) Index.



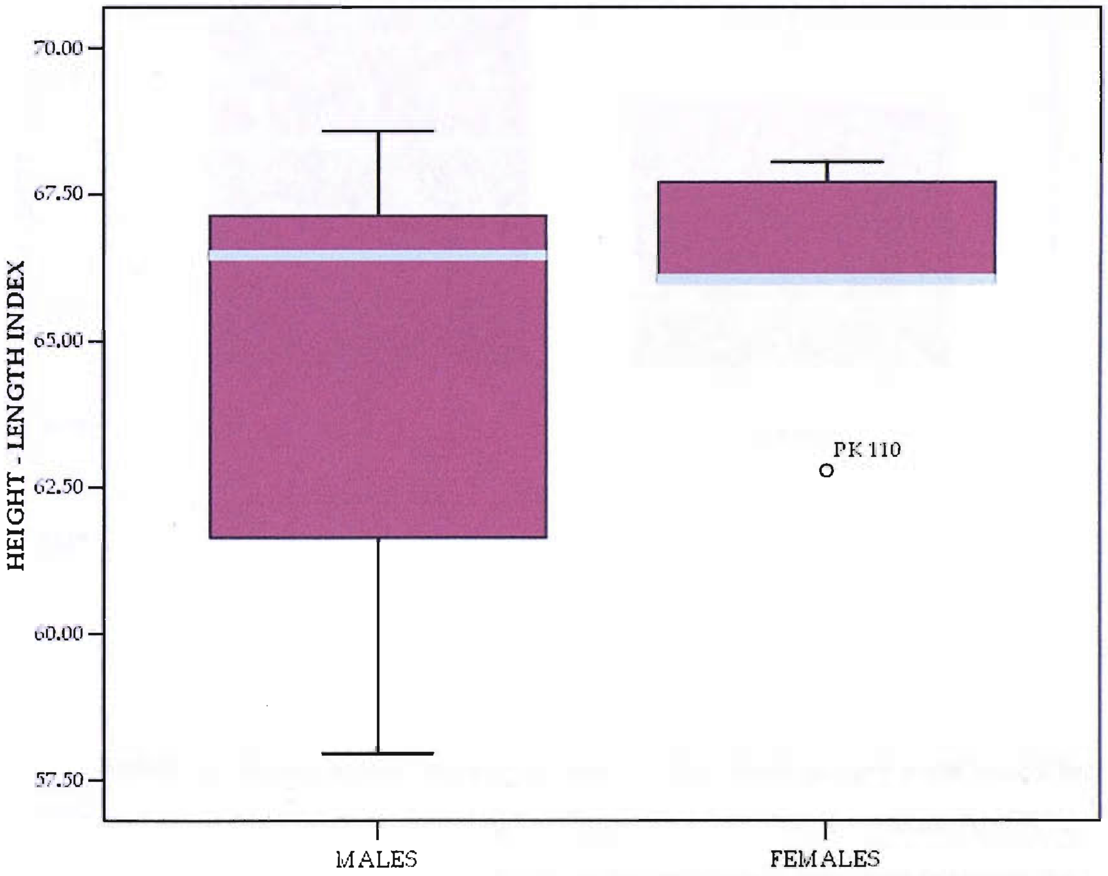
Mavrospelio: Sex differences in the Height-Breadth (md) Index did not reach significance ($p<0.05$) for the Mavrospelio sample (2 males and 2 females). Due to the very low sample size, the Welch and Brown-Forsythe tests were applied to the data. These did not detect any significant sex differences for the tested Index ($p=0.418$).

Sellopoulo, Kastelos, Gypsades and Palama samples: In the Sellopoulo (1 male and 2 females), and Kastelos samples (1 male and 1 female), the Height-Breadth (md) Index was calculated for a considerably small number of individuals. In the Gypsades and Palama samples, the Height-Breadth (md) index was calculated for 3 and 2 males respectively. The low size of the Mavrospelio, Sellopoulo, Kastelos, Gypsades and Palama samples rendered it inappropriate to explore any reliable sex-relationship in terms of the calculated Height-Breadth (md) Indices.

Height-Length (md) Index (HLI(md^1)=100*VRR/GOL): Regarding the Sellopoulo (N=3), Gypsades (N=3), Palama (N=2) and Kastelos (N=0) samples, the Height-Length (md) Index could not be calculated for an adequate number of cases to permit for a reliable assessment of sexual dimorphism.

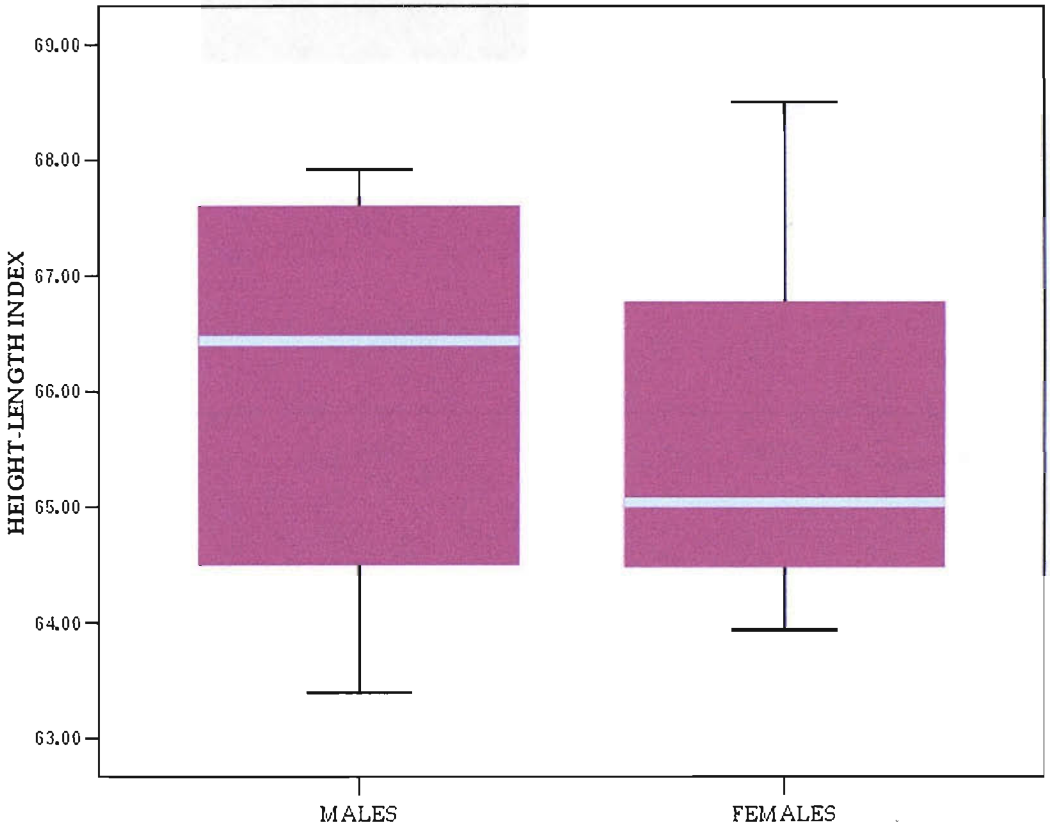
Palaikastro: In the Palaikastro sample, 10 males and 6 females were tested using One-way ANOVA and the Welch and Brown-Forsythe tests (Figure 6.2.12). Neither test detected significant sex differences (p=0.445 and p=0.371 respectively). Additionally, the Levene test failed to detect significantly unequal intra-group variances (p= 0.056).

Figure 6.2.12 Box and whisker plot of sexual dimorphism in the Palaikastro sample, Height-Length (md) Index.



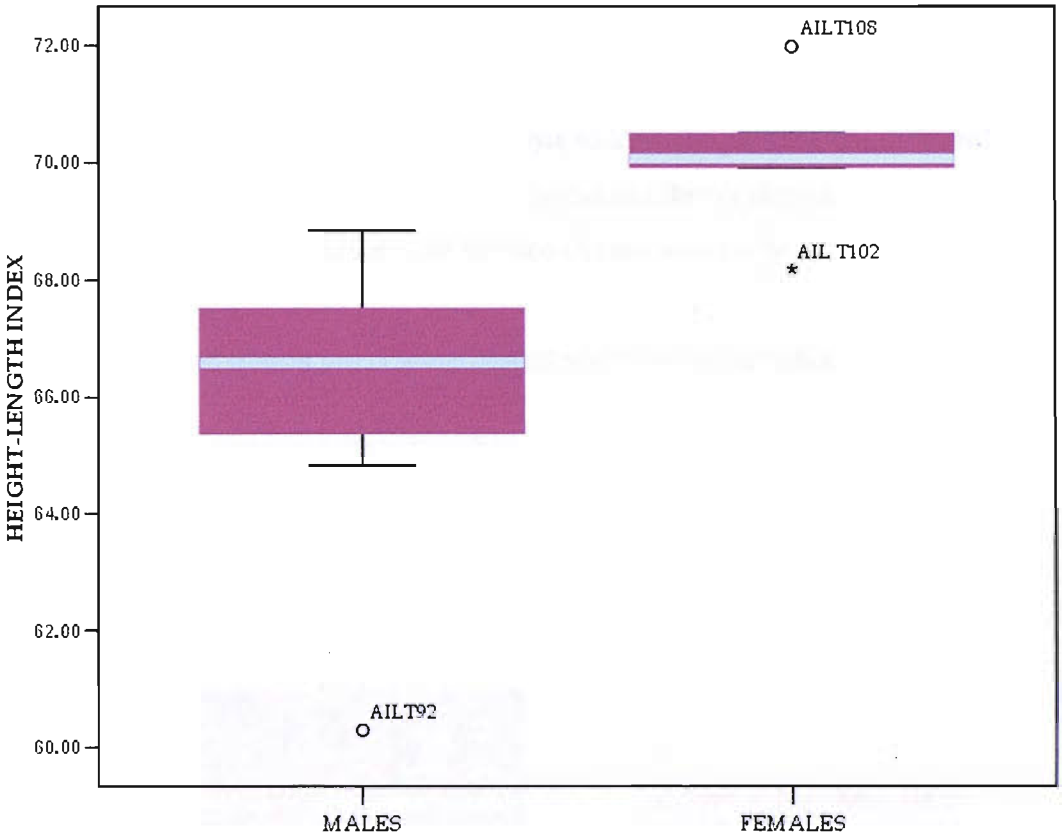
Moni Odigitria: The Height-Length (md) Index was calculated for 4 males and 3 females of the Moni Odigitria sample (Figure 6.2.13). Therefore, sex differences in this variable were explored using the more robust tests of variance. The results suggested insignificant sexual dimorphism (p=0.902). Moreover, the Levene test did not show the intra-group variances to be significantly unequal (p=0.755).

Figure 6.2.13 Box and whisker plot of sexual dimorphism in the Moni Odigitria sample, Height-Length (md) Index.



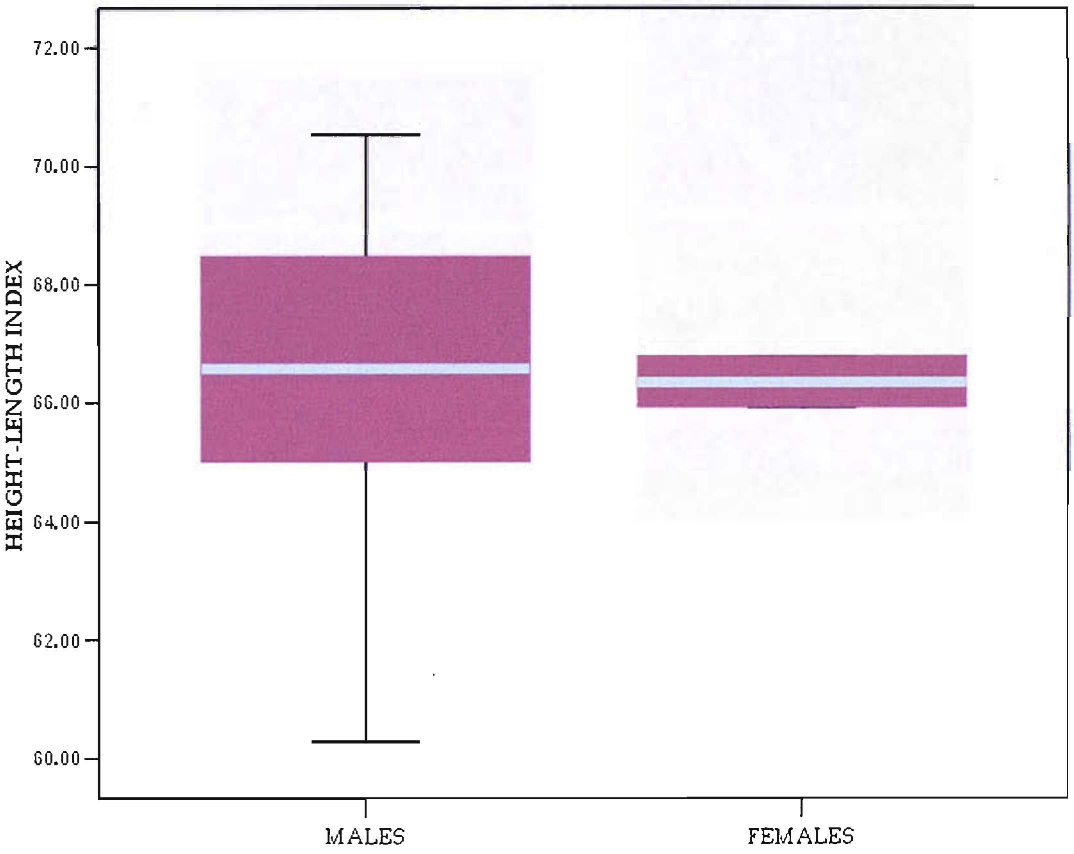
Ailias: Seventeen males and five females of the Ailias sample were tested for sex differences in the Height-Length Index (Figure 6.2.14). Both One-way ANOVA and the more robust tests of variance suggested significant differences between the two sexes for the tested variable (p=0.001 for One-way ANOVA and the Welch and Brown-Forsythe tests). Plotting of the data suggests a cranium that is relatively high for its length for the females in comparison with the males. According to the Levene test, the intra-group variances are not significantly unequal (p=0.511).

Figure 6.2.14 Box and whisker plot of sexual dimorphism in the Ailias sample, Height-Length (md) Index.



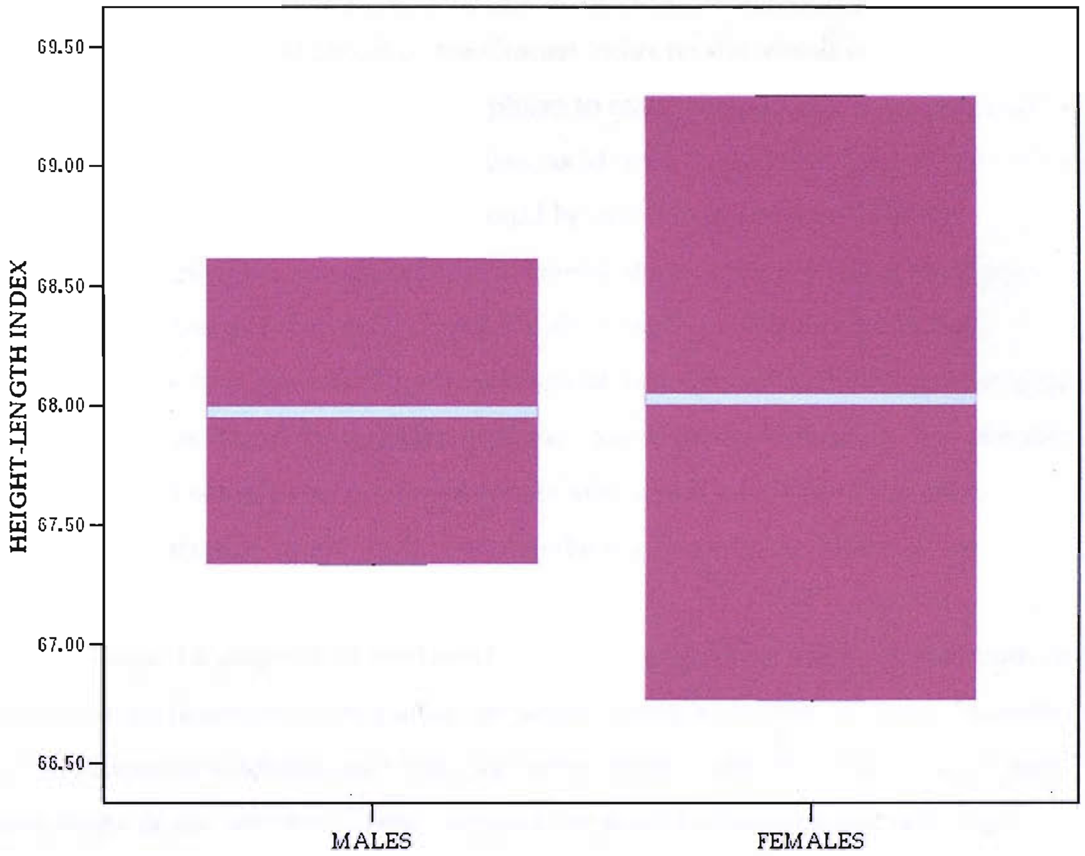
Myrtos Pyrgos: The Height-Length (md) Index was calculated for 6 males and 2 females from the Myrtos Pyrgos sample (Figure 6.2.15). Due to the size difference of the sex-groups, the Levene test was applied to explore the homogeneity of the intra-group variances. This failed to detect significant differences in intra-group variance (p=0.271). Nevertheless, due to low sample size, the more robust tests of variance were applied to the data. These did not detect significant sex differences in the Height-Breadth Index for the Myrtos Pyrgos sample (p=0.943).

Figure 6.2.15 Box and whisker plot of sexual dimorphism in the Myrtos Pyrgos sample, Height-Length (md) Index.



Mavrospelio: Due to low sample size (2 males and 2 females), the Welch and Brown-Forsythe tests were preferred to One-way ANOVA. These failed to show significant sex differences for the Height-Length (md) index in the Mavrospelio sample (p=0.974) (Figure 6.2.16).

Figure 6.2.16 Box and whisker plot of sexual dimorphism in the Mavrospelio sample, Height-Length (md) Index.



6.2.1.3 Summary of the analysis of Sexual dimorphism in the Cretan samples

The majority of the tested Cretan samples (Palaikastro, Ailias, Myrtos Pyrgos, Gypsades) show a very similar pattern of sexual dimorphism in the tested variables. Significant sex differences were recorded for variables describing the length and breadth of the cranium, frontal breadth and protrusion of the upper facial skeleton, morphology of the glabella and mastoid process, shape of the midline curvature of the cranial vault (Appendix D, Tables 6.14, 6.15, 6.19, 6.19, 6.24, 6.26). Sex differences reached significance for not more than two of the tested variables for the Moni (SOS and GLS) and Palama (SOS) samples (Appendix D, Tables 6.16, 6.18, 6.36, 6.38). Tests of variance failed to detect significant sexual dimorphism in the Sellopoulo, Mavrospelio and Kastelos samples for any of the tested variables (Appendix D, Tables 6.29, 6.31, 6.32, 6.33, 6.34). This could be related to low sample sizes.

Sexual dimorphism in the Cranial Index reached significance in two of the eight tested samples, Ailias (One-way ANOVA: p=0.026) and Palaikastro (One-way ANOVA: p=0.037). The more robust tests of variance, however, did not suggest significant sexual dimorphism in the Cranial Index for the Palaikastro sample (p=0.096). The failure of sexual dimorphism to reach significance in the other six samples could result from their low sizes, as Myrtos Pyrgos was the only one of these six samples for which Cranial Index could be calculated for more than ten individuals. Likewise, sex differences in cranial shape explored using the Upper Facial (md), Height-Breadth (md) and Height-Length (md) Indices, reached significance only in one case; significant sexual dimorphism in the Height-Length (md) Index was found for the Ailias sample. Due to low sample sizes, it is possible that the tested samples do not represent accurately the whole range of intra-population variation of the respective population. Thereby the failure of sex differences to reach statistical significance.

Since the majority of the tested Cretan samples share a very similar pattern of sexual dimorphism and it is mainly the smaller samples that show a small number or no significant sex differences for the variables (measurements) describing the size and shape of the cranium, Cretan samples are pooled to investigate further the sexual dimorphism in the Cretan population. Pooling the Cretan samples has the advantage of maximising the sample size for each sex. Hence it helps achieve a better understanding of the sexual dimorphism in the Cretan population and permits its comparison with the sexual dimorphism in the contemporary Argolid population (assessed in sections 6.1.1.4, 6.1.1.5 and 6.1.1.6).

6.2.1.4 Sexual dimorphism in the Cretan population, Early to Late Bronze Age samples pooled: One-way ANOVA

The nine Cretan samples (Palaikastro, Moni Odigitria, Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo, Mavrospelio, Kastelos and Palama samples) were pooled (120 males and 77 females) and the data were tested for significant ($p<0.05$) sex differences in the mean values of the cranial variables using One-way ANOVA (Appendix D, Table 6.40). Analysis indicated the following variables as significantly sexually dimorphic: GOL (p<0.001), NOL (p<0.001), BNL (p=0.003), BBH (p=0.003), XCB (p=0.005), XFB (p=0.001), STB (p= .029), AUB (p=0.002), ASB (p< 0.001), MDH (p<0.001), MDB (p<0.001), ZMB (p=0.046), FMB (p=0.007), WMH (p=0.002), GLS (p<0.001), FRC (p=0.002), FRF (p=0.006), PAC (p=0.001), PAF (p<0.001), OCC (p=0.025), OCS (p=0.023), VRR (p=0.006), NAR (p=0.001), ZOR (p=0.003), FMR (p=0.002), EKR (p=0.014), AVR (p=0.018). These variables describe the length, breadth and height of the cranium, the facial height and upper-facial breadth, the upper-facial and subnasal protrusion, the morphology of the mastoid process and the protrusion of the glabellar region.

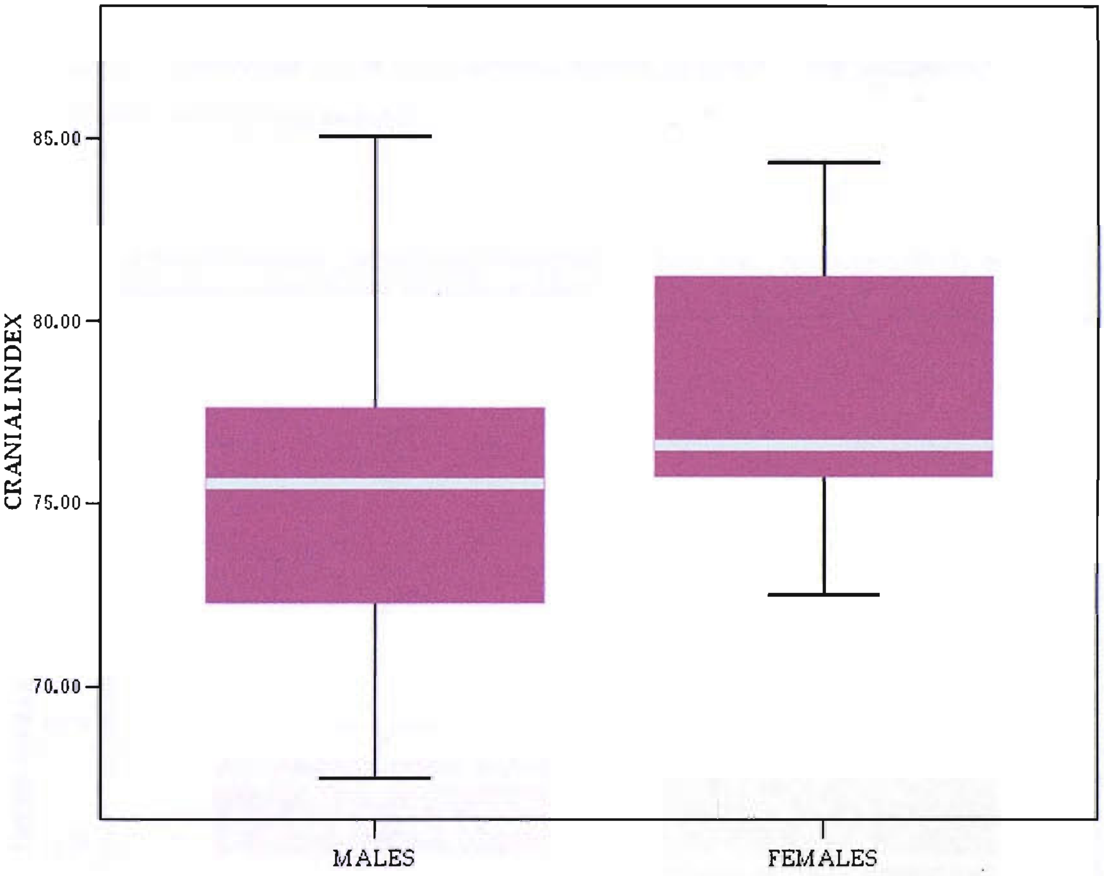
The Levene test explored the equality of intra-group variances for the tested variables and showed significant differences for OBB (p=0.049), ZMB (p=0.001), DKB (p=0.022), IML (p=0.009) and AVR (p=0.050) (Appendix D, Table 6.41). The Welch and Brown-Forsythe tests of variance were applied to the data to explore further the sexual dimorphism for those variables for which the Levene test suggested significant inequality of variances. Sexual dimorphism was significant only for AVR (p=0.005) from the tested variables (OBB, ZMB, DKB, IML and AVR) (Appendix D, Table 6.42).

6.2.1.5 Sexual dimorphism in the Cretan population, Middle and Late Bronze Age samples pooled: Cranial Indices

To allow for comparability of the Argolid and Cretan populations in terms of sexual dimorphism, the Early Bronze Age samples from Crete were removed from the analysis, because there was no data available for the Early Bronze Age population from the Argolid. The two analysed Argolid population samples, Lerna and Apatheia, date to the Middle and Late Bronze Age. Following the removal of the Early Minoan Moni and Palaikastro samples, the Central Crete population is represented by the Middle Minoan Ailias and Late Minoan Gypsades, Mavrospelio and Sellopoulo samples. The Eastern Cretan population is represented by the MMIII-LMI Myrtos Pyrgos sample.

Cranial Index (CI= 100*XCB/GOL): Middle and Late Bronze Age population samples from Central and Eastern Crete were pooled and the Cranial Index was calculated (for 46 males and 23 females) in order to investigate sex differences in the size and shape of the cranium. Plotting the calculated Cranial Indices for the two sexes shows a greater range of intra-sample variation for males in comparison to females (Figure 6.2.17). Nevertheless, the Levene test did not show significantly unequal intra-group variances for the two sex-groups for the Cranial Index (p=0.815).

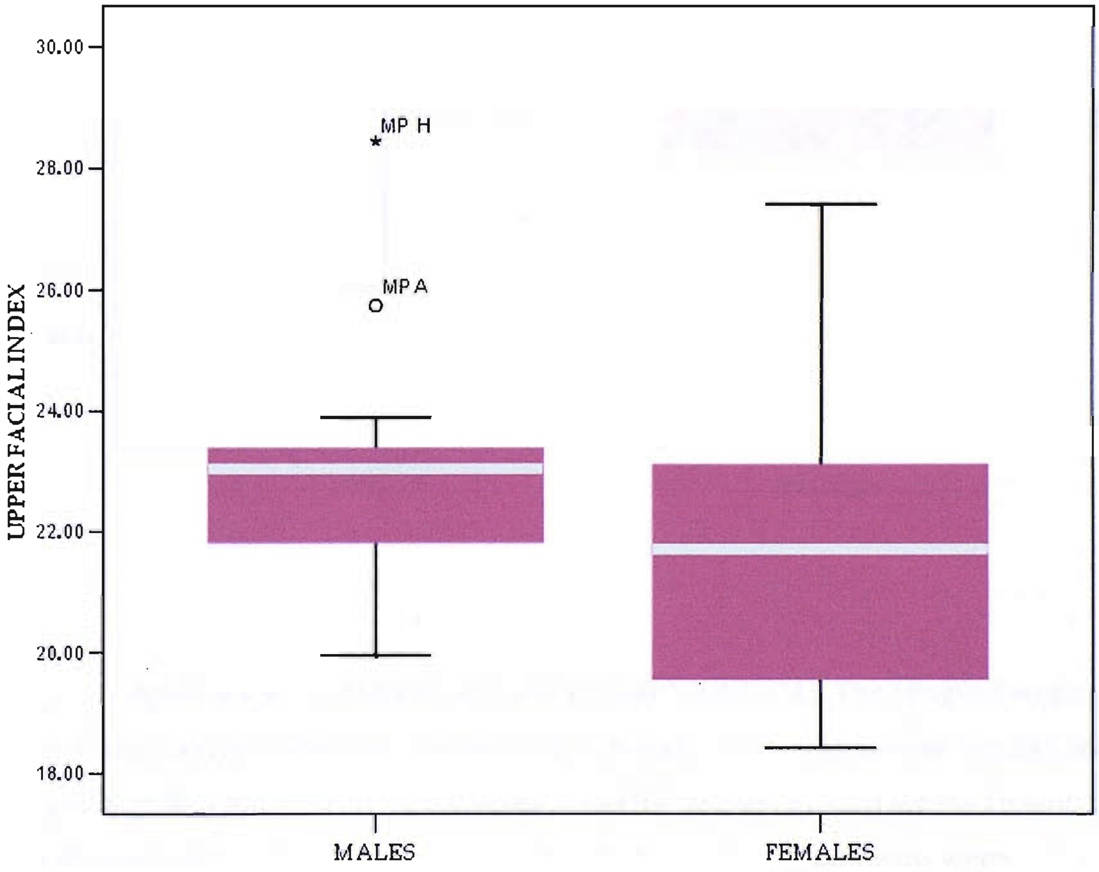
Figure 6.2.17 Box and whisker plot of sexual dimorphism in the Cretan population (Middle and Late Bronze Age samples pooled), Cranial Index.



Sex differences in the size and shape of the cranium were explored by applying One-way ANOVA to the Cranial Index data. Results suggest significant sexual dimorphism for the Cranial Index (p=0.009). Due to the unequal representation of the two sexes in the Cretan population sample (46 males and 23 females), sexual dimorphism in the cranial size and shape was further explored using the more robust tests of variance. Analysis, however, produced the same result as the One-way ANOVA (p=0.009 for both the Welch and Brown-Forsythe tests). Patterning of the data suggests that the females of the Cretan population have a cranium that is broad for its length in comparison with the males (Figure 6.2.17).

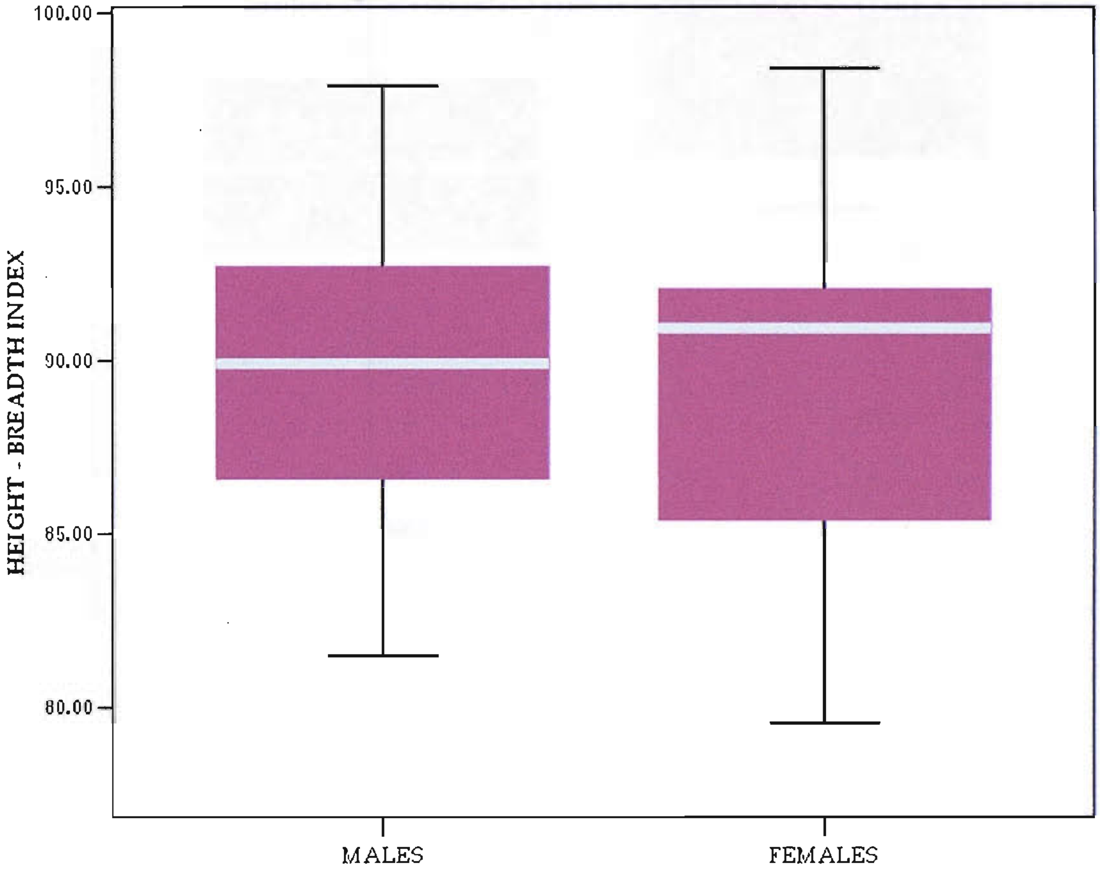
Upper Facial (md) Index (UFI(md) =100*NPH/ZYB): The Upper Facial (md) Index was calculated for 17 males and 8 females from the Cretan population in order to examine sexual dimorphism in this region of the cranium. Sex differences for the Upper Facial (md) Index were explored using the more robust tests of variance, due to the inequality of the size of the two samples. The Welch and Brown-Forsythe tests of variance did not show significant sexual dimorphism for the tested variable (p=0.375). Data distribution in Figure 6.2.18 suggests a greater range of variation for the females in comparison with the males. As in the case of the Cranial Index, inequality of the variances of the male and female samples is not statistically significant (Levene test: p=0.31).

Figure 6.2.18 Box and whisker plot of sexual dimorphism in the Cretan population (Middle and Late Bronze Age samples pooled), Upper Facial (md) Index.



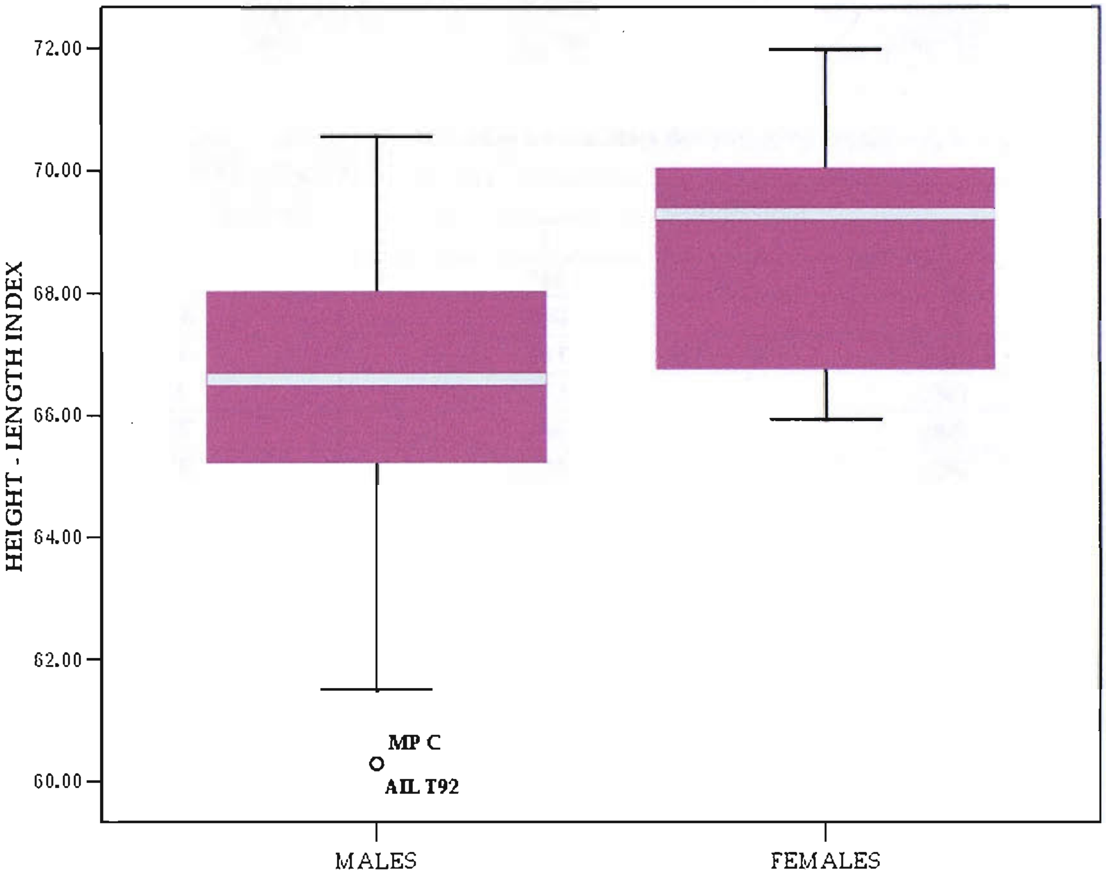
Height-Breadth (md) Index (HBI(md^1)= 100*VRR/XCB): The Height-Breadth Index was calculated for a very unequal number of males and females from the Cretan population (30 males and 11 females) (Figure 6.2.19). Sexual dimorphism, therefore, was explored using the Welch and Brown-Forsythe tests of variance. These failed to detect significant differences between the two sex-groups for the calculated index (p=0.639).

Figure 6.2.19 Box and whisker plot of sexual dimorphism in the Cretan population (Middle and Late Bronze Age samples pooled), Height-Breadth (md) Index.



Height-Length (md) Index (HLI(md^1)=100*VRR/GOL): The Height-Length (md) index was calculated for 29 males and 11 females. Although Levene test did not suggest significant inequality of the variances of the two sex-groups for the Height-Length (md) Index (p=0.939), the more robust tests of equality of means were applied, due to the size differences of the two tested samples. The Welch and Brown-Forsythe tests detected significant differences between the two sexes for the calculated HLI(md) (p=0.005). Patterning of the data in Figure 6.2.20 suggests that the female crania are higher vaulted for their length relative to the male crania.

Figure 6.2.20 Box and whisker plot of sexual dimorphism in the Cretan population (Middle and Late Bronze Age samples pooled), Height-Length (md) Index.



6.2.1.6 Sexual dimorphism in the Cretan population, Early to Late Bronze Age samples pooled: Multivariate analysis

Sexual dimorphism in the Cretan population (samples dating from the Early to Late Bronze Age) was explored further using PCA to allow for the more comprehensive understanding of sex differences in cranial morphology. PCA was applied to variables describing the cranial size and shape and the morphology of the frontal bone (GOL, XCB, XFB, FRC, FRS and FRF). The morphology of the frontal bone and particularly the shape of its midline curvature is regarded to be a reliable sex indicator. Tables 6.2.2 and 6.2.3 show the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape (N=71). A visual examination of the results (Figure 6.2.21) suggests longer crania for the males in comparison with the females (Figure 6.2.21). Males and females, however, do not appear to differentiate in terms of cranial breadth.

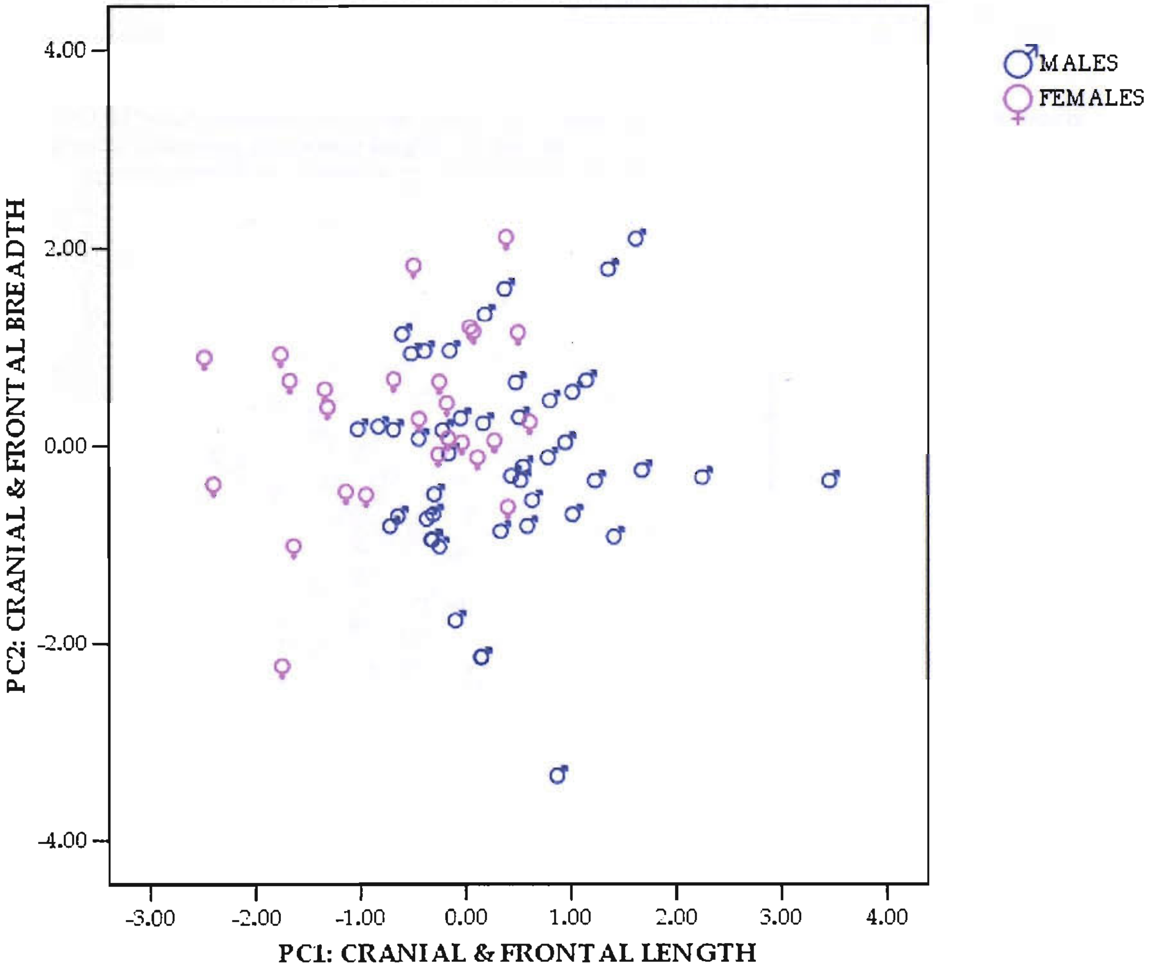
Table 6.2.2 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.736	45.595	45.595
2	1.367	22,789	68.384

Table 6.2.3 Component loadings for PCA results for variables describing the cranial length and breadth, and the frontal midline curvature.

Cranial Metric Variables	Component	
	1	2
GOL	.766	-.423
XCB	.458	.774
XFB	.641	.640
FRC	.873	-.301
FRS	.496	.065
FRF	.721	-.292

Figure 6.2.21 Sexual dimorphism in the Cretan population (EBA to LBA samples pooled): PCA results for variables describing the cranial length and breadth and the frontal midline curvature.



In order to explore sexual dimorphism in the morphology of the posterior cranium, XFB was substituted by ASB in the PCA of the data (N=77). Table 6.2.4 provides the amount of variance explained by the two extracted components and Table 6.2.5 the component loadings for PCA of cranial size and shape. Plotting of the results clearly suggests longer crania for the males in comparison with the females (Figure 6.2.22).

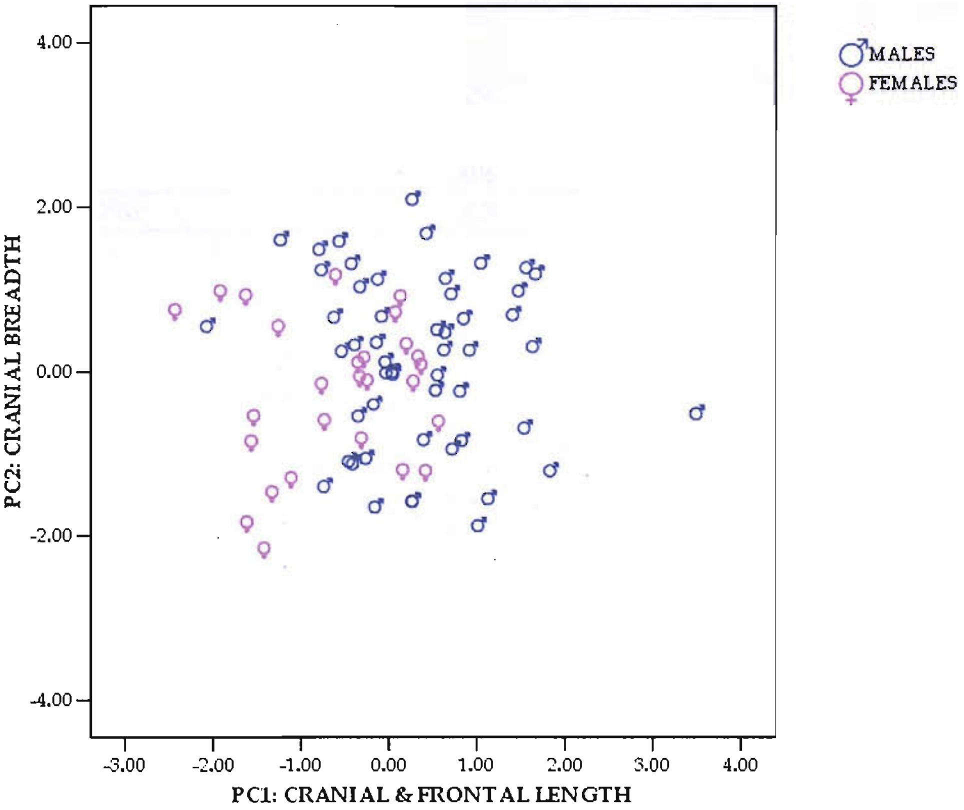
Table 6.2.4 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.863	47.716	47.716
2	1.304	21.739	69.455

Table 6.2.5 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.803	-.162
XCB	.601	.649
FRC	.886	-.279
FRS	.566	-.391
FRF	.678	-.282
ASB	.540	.739

Figure 6.2.22 Sexual dimorphism in the Cretan population (EBA to LBA samples pooled): PCA results for variables describing the cranial length and breadth.



To allow for comparability between the Argolid and Cretan populations in terms of sexual dimorphism, PCA was applied to data from samples dating to the Middle and Late Bronze Age from Central Crete (i.e. the MM Ailias, MMII-LMI Myrtos Pyrgos, MMIII-LMI Gypsades, and the LM Sellopoulo and Mavrospelio samples) and the EM Moni Odigitria and Palaikastro samples were removed from the analysis. Differences between the two sexes were explored using variables describing the length and breadth of the cranium and the morphology of the frontal bone (GOL, XCB, XFB, FRC, FRS, FRF) (Tables 6.2.6 and Table 6.2.7) (N=40). The results are graphically represented (Figure 6.2.23) and males appear to separate from females with the male cranium being longer in relation to its breadth relative to the females.

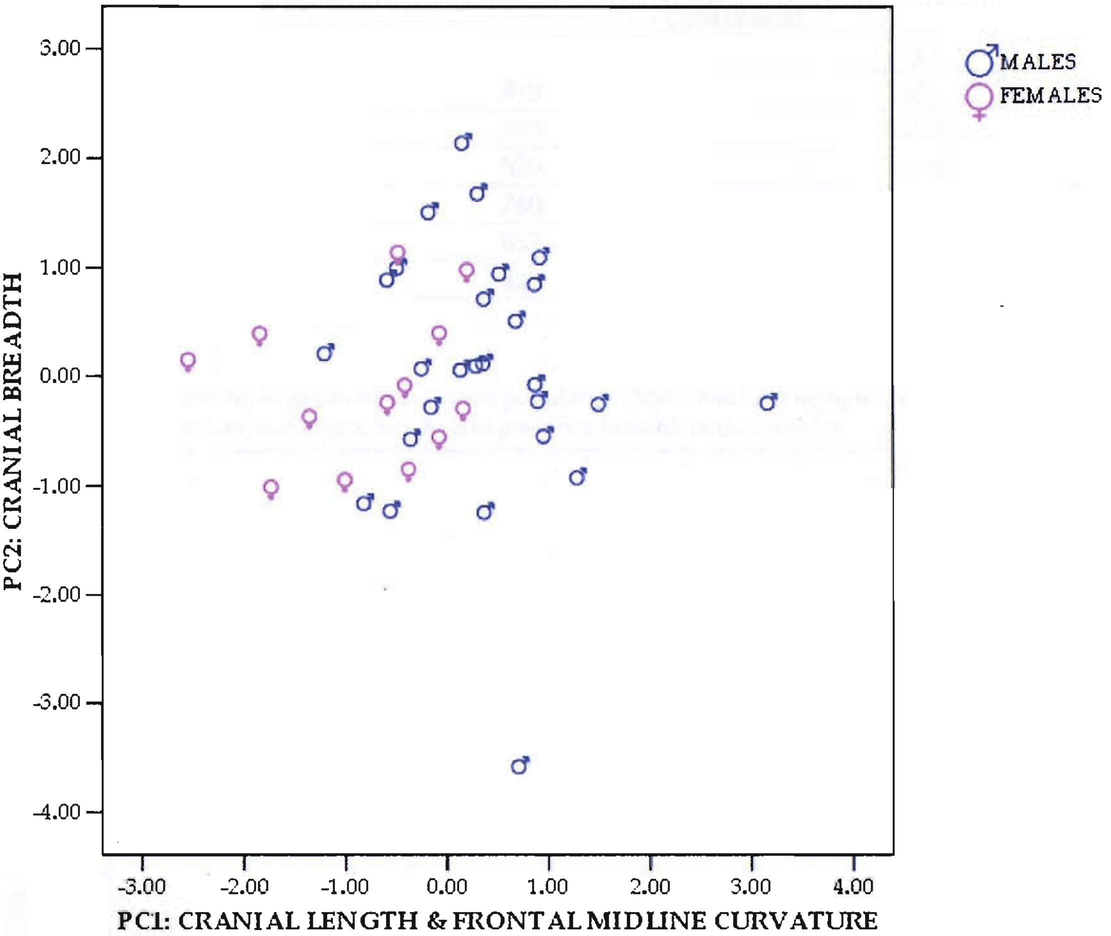
Table 6.2.6 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	2.851	47.511	47.511
2	1.466	24.435	71.946

Table 6.2.7 Component loadings for PCA of variables describing the cranial length and breadth and the morphology of the frontal bone.

Cranial Metric Variables	Component	
	1	2
GOL	.816	-.270
XCB	.344	.816
XFB	.676	.534
FRC	.872	-.326
FRS	.406	-.568
FRF	.828	.113

Figure 6.2.23 Sexual dimorphism in the Cretan population (MBA and LBA samples pooled): PCA results for variables describing the cranial length and breadth and the morphology of the frontal bone.



Sexual dimorphism was explored further by adding cranial height (VRR) to the PCA and the results are tabulated (Tables 6.2.8 and 6.2.9). Cranial Height was entered to the analysis because One-way ANOVA suggested significant sex differences for this measurement in the pooled Cretan samples (see section 6.2.1.4). Allowing for the low size of the female sample (9 females to 26 males), patterning of the data suggests a greater range of intra-population variation for the cranial length and height within the males relative to the females (Figure 6.2.24). The male crania appear to be longer, higher vaulted and relatively broader than these of the females.

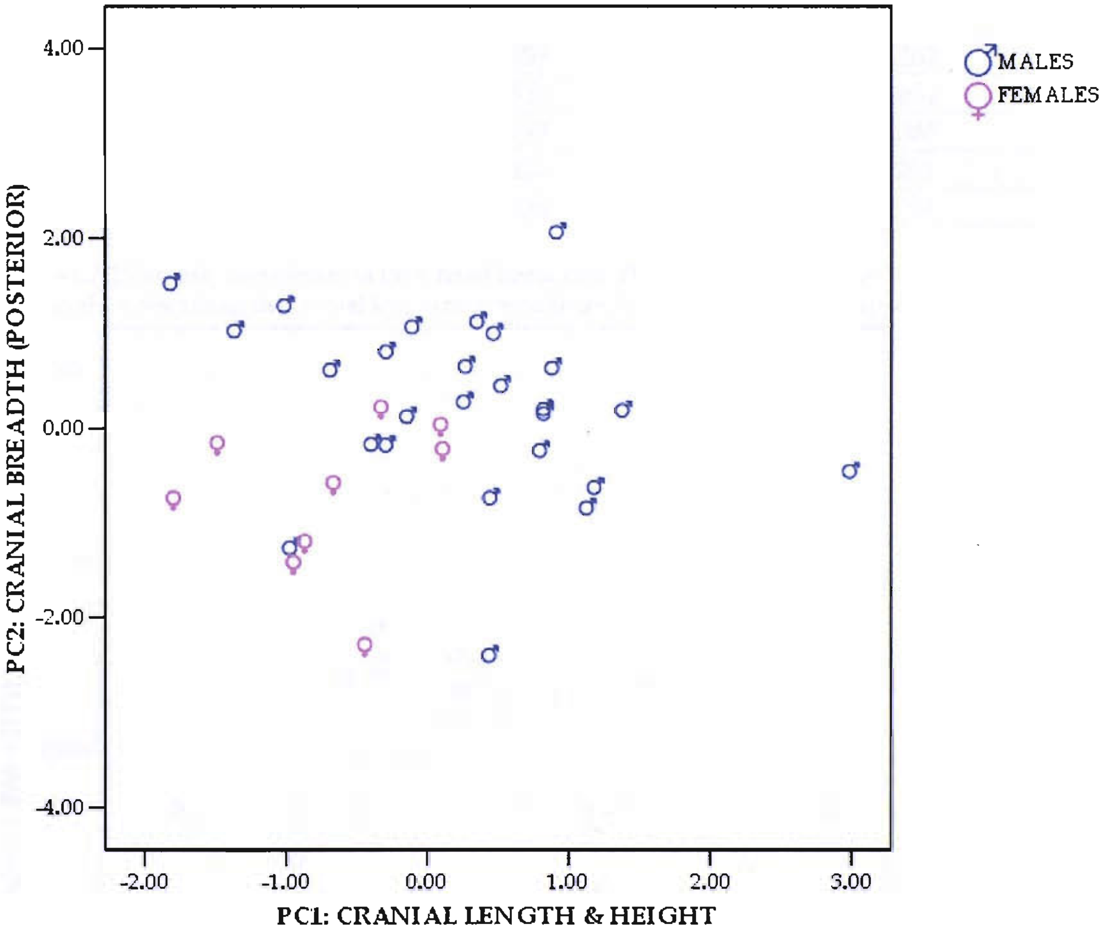
Table 6.2.8 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.253	54.212	54.212
2	1.273	21.223	75.436

Table 6.2.9 Component loadings for PCA of variables describing the length, height and posterior breadth of the cranium.

Cranial Metric Variables	Component	
	1	2
GOL	.818	.321
FRC	.903	-.214
FRS	.529	-.634
FRF	.760	-.311
VRR	.855	.209
ASB	.423	.763

Figure 6.2.24 Sexual dimorphism in the Cretan population (MBA and LBA samples pooled): PCA results for variables describing the length, height and posterior breadth of the cranium.



NAR, which describes the protrusion of the upper facial skeleton and was shown by One-way ANOVA (section 6.2.1.4) to differ significantly between the two sexes, was added to the analysis and the results are presented in Tables 6.2.10 and 6.2.11 (N=37). Given the disproportionate representation of the two sexes in the analysed sample (10 females to 27 males), the results show that the male cranium is longer and more protruding in the upper-facial region and generally broader than that of the females (Figure 6.2.25).

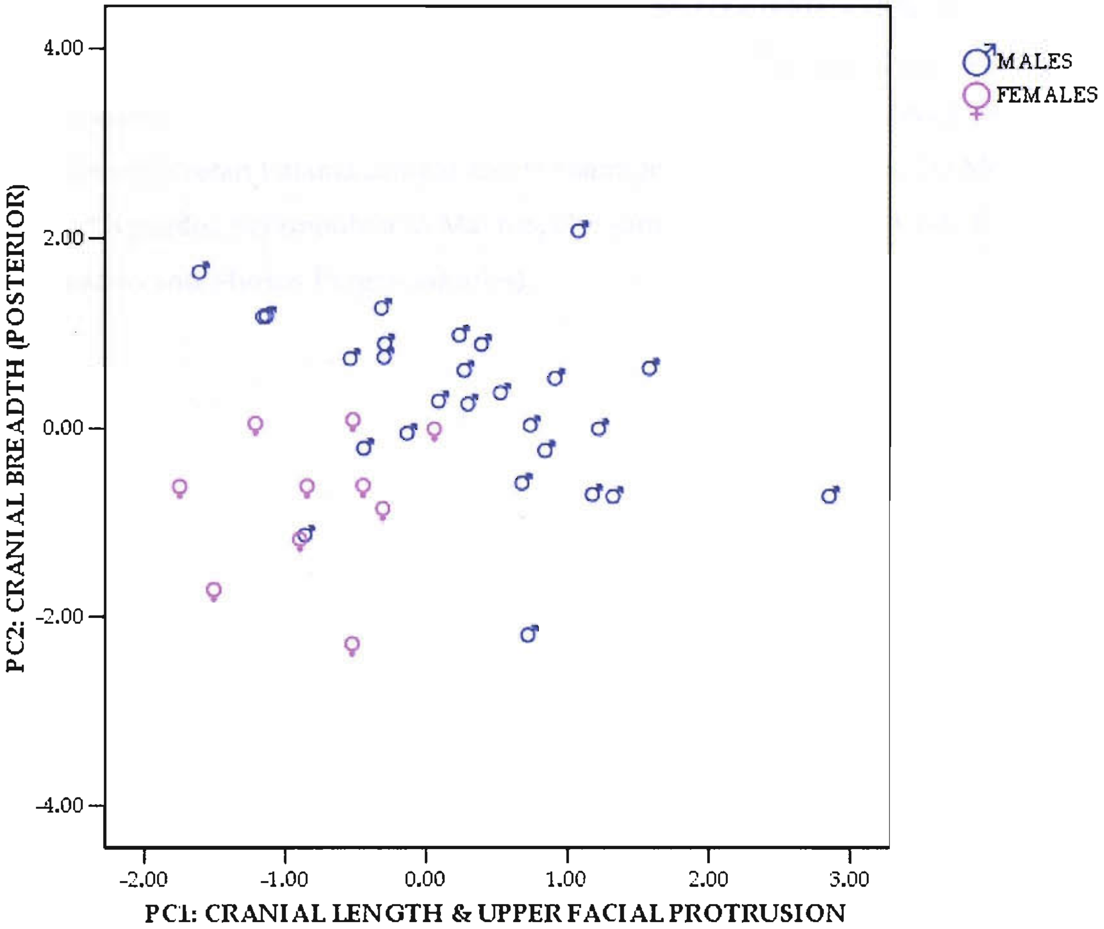
Table 6.2.10 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	3.159	52.652	52.652
2	1.332	22.204	74.856

Table 6.2.11 Component loadings for PCA of variables describing the cranial length and breadth and the protrusion of the upper facial skeleton.

Cranial Metric Variables	Component	
	1	2
GOL	.853	.308
FRC	.853	-.262
FRS	.520	-.632
FRF	.719	-.367
NAR	.851	.263
ASB	.438	.751

Figure 6.2.25 Sexual dimorphism in the Cretan population (MBA and LBA samples pooled): PCA results for variables describing the cranial length and breadth and the protrusion of the upper facial skeleton.



6.2.2 Crete: Cranial Non-metric Morphological Analysis

Mean Measure of Divergence analysis is used here to measure the genetic distance between the Bronze Age Cretan skeletal collections in order to investigate the hypothesis that the Eastern, Central and Western Cretan populations share a common ancestor.

The principles of this analysis have been outlined in section 6.1.2. Care was taken given the low size of the samples and inequalities in the number of the scorable cases in the tested samples. Trait frequencies for which at least one of the tested samples was represented by less than 5 individuals were removed from the MMD analysis, thus reducing the number of traits analysed (trait frequencies (%) and number of individuals scored (n) for all tested Cretan samples are given in Appendix E, Tables 6.2 and 6.3). The results of MMD analysis are presented in Table 6.2.12. The results of the analysis are very interesting. The standardised values of the Mean Measure of Divergence analysis in Table 6.2.12 suggest that the following pairs of population samples share a common ancestor (MMDst <2): Moni - Palaikastro, Moni - Ailias, Ailias - Mavrospelio, Myrtos Pyrgos - Gypsades, Myrtos Pyrgos - Mavrospelio, Gypsades - Mavrospelio and Gypsades - Sellopoulo. These samples span Eastern and Central Crete. The results also show significant distance between the Western Cretan Palama sample and the samples from Central (i.e. the Moni, Ailias, Gypsades, Sellopoulo and Mavrospelio samples) and Eastern Crete (i.e. the Palaikastro and Myrtos Pyrgos samples).

Table 6.2.12 Inter-population distance, Cretan samples, sexes pooled: MMD analysis results for cranial non-metrics.

POPULATION SAMPLES	Number of traits tested	MMDv	SD	MMDst
Moni - Palaikastro	71	0.0504	0.059841	**0.8429**
Moni - Ailias	42	0.005974	0.003681	**1.6229**
Moni - Myrtos Pyrgos	71	0.0700	0.023466	2.9851
Moni - Gypsades	42	0.6088	0.040391	15.0730
Moni - Sellopoulo	42	0.2758	0.017178	16.0564
Moni - Palama	36	-0.00486	0.006234	-0.78028
Palaikastro - Myrtos Pyrgos	71	0.3962	0.043438	9.1213
Palaikastro - Palama	35	0.066097	0.005821	11.3547
Ailias - Myrtos Pyrgos	43	0.1054	0.001879	56.1238
Ailias - Gypsades	43	0.1842	0.033995	5.4192
Ailias - Sellopoulo	44	0.0667	0.016469	4.0535
Ailias - Mavrospelio	34	0.012233	0.006413	**1.9074**
Ailias - Palama	45	0.067364	0.003867	17.4201
Myrtos Pyrgos - Mavrospelio	57	0.02907	0.023736	**1.2247**
Myrtos Pyrgos - Palama	45	0.122916	0.004242	28.9746
Gypsades - Palaikastro	42	0.114269	0.055264	**2.067674**
Gypsades - Mavrospelio	40	0.0609	0.068377	**0.8914**
Gypsades - Sellopoulo	50	0.09133	0.088154	**1.036**
Gypsades - Myrtos Pyrgos	43	0.026985	0.034659	**0.7785**
Gypsades - Palama	18	0.072576	0.00182	32.8718
Sellopoulo -Mavrospelio	54	0.2816	0.095597	2.9464
Sellopoulo - Palama	14	-0.18735	0.002588	-75.3786
Palama - Mavrospelio	24	-0.06109	0.004083	-14.9605

6.2.3 Crete: Dental Metric Morphological Analysis

Inter-sample relationships at the regional level (the island of Crete) were also explored in terms of dental morphology. As mentioned in section 6.1.3, biodistance studies have clearly demonstrated that tooth size, shape, morphology and number of cusps have a strong genetic component in their complex etiology, and hence the analysis of dental morphology is efficacious for assessment of population biological relationships and micro-evolutionary trends (see Scott & Turner 1988 for a review of past studies).

Due to the poor representation of the studied skeletal collections by tooth specimens, dental metric and non-metric morphological analysis is focused on the investigation of the hypothesis that people from the Argolid settled at Knossos following the LMIB destructions on Crete. In this section, analysis of dental metric morphology explores the relationship between Bronze Age samples from Eastern, Central and Western Crete. It focuses on three successive Bronze Age samples from Knossos for evidence of continuity or discontinuity in the biological history of the Bronze Age Knossos population that provide negative and positive evidence respectively for the arrival and admixture of biologically different population elements.

Inter-sample distance was measured using the results of the analysis of tooth crown bucco-lingual and mesio-distal diameters. In order to control, however, for the unequal impact of dental enamel wear on the two tooth crown diameters (Hillson *et al.* 2005) and its possible distorting effect on the reconstructed inter-sample distances, analysis was applied to the bucco-lingual diameter data only. In addition to the analysis of tooth crown measurements, both the Crown Index (100 x BL/MD) and the Robustness Index (or Crown Area: MD X BL) were calculated. If the bucco-lingual and mesio-distal tooth crown diameters are not affected by dental wear asymmetrically enough to distort inter-sample distances, I expect the analysis of the Robustness Index to detect temporal trends in the distance between populations of the same region, introduced by changes in the diet and food processing in the course of the Bronze Age, for reasons outlined in Chapter 5 (section 5.1.2.4.2). Although this is not the prime objective of this research, it is worth investigating it as it opens up an avenue for future research. Regarding inter-population distance in dental metric morphology, selection pressures between the Argolid and Crete are not expected to have been sufficiently different to introduce detectable consistent inter-population crown size differences between the Argolid and Cretan populations (see Appendix A, section A.1). According to the principal assumption of this study that the Cretan and Argolid populations are biologically distant, shape (hence the Crown Index) rather than size differences in the tooth crown are anticipated to discriminate more clearly between the tested Argolid and Cretan population samples (Kieser 1990).

6.2.3.1 Right and Left side asymmetry in tooth crown diameters, Cretan samples: paired t-test

In order to decide whether it is legitimate to pool together measurements from the right and left sides for the purpose of maximizing sample sizes, differences between the bucco-lingual and mesio-distal crown diameters of the right and left side within each sample were explored using the paired t-test (Table 6.2.13).

In 12 out of the 20 cases, for which side differences in the tested values reached the level of significance ($p<0.05$), higher values were recorded on the right side. The percentage of significantly asymmetrical tooth crown diameters is very high for the Palama sample (54%) (Table 6.2.13). This could be related to the low size of the Palama sample. However, the percentage of significantly asymmetrical tooth crown diameters is low for all other tested population samples (i.e. the Ailias, Myrtos Pyrgos, Gypsades, and Sellopoulo samples). For this reason and because the actual side differences in crown diameters are considered to be small in relation to intra- and inter-observer error and the precision at which dental measurements can be taken (Hillson 2002:78), right and left side measurements were pooled in order to maximise sample sizes and Hierarchical Cluster Analysis was applied in order to measure inter-sample biological distance. Inter-sample distances, however, were also measured from variables entered to analysis separately for right and left sides, in order to ensure that pooling together data from the two sides does not affect the integrity of the reconstructed distances (i.e. reduction of intra-sample variation).

Table 6.2.13 Side asymmetry in tooth crown diameters of the Cretan samples, sexes pooled, Paired t-test, p values (p<0.05).

Measurements	**Skeletal collections**									
Maxillary	Ailias		Myrtos Pyrgos		Gypsades		Sellopoulo		Palama	
	p	N	p	N	p	N	p	N	p	N
I1BL			.774	3	.500	2				
I1MD			.423	3	.500	2			<0.001	2
I2BL			.187	4					<0.001	2
I2MD			.519	4	.795	2			<0.001	2
CBL	**.035**	**4**	.394	6	.716	3				
CMD	.061	4	.227	7	.128	3				
PM3BL	.930	2	.063	7	.278	4	1.000	2	**.011**	4
PM3MD	.205	2	.948	9	.223	4	1.000	2	**.030**	3
PM4BL	.844	2	**.027**	**9**	.423	4	.683	3	.316	3
PM4MD	.438	3	.321	9	.671	4	.269	3	.603	3
M1BL			.445	6	.264	5	.804	4	.175	4
M1MD	.129	3	.195	6	**.011**	**6**	.343	4	.077	4
M2BL	.134	4	.677	11	.126	4	.721	3	.311	3
M2MD	**.044**	**4**	**.024**	**11**	.200	4	**.007**	**3**	0.451	3
M3BL			.177	2						
M3MD			.319	2						
Mandibular										
I1BL							.057	3	**.001**	5
I1MD			.500	2	.789	3	.833	3	<0.001	6
I2BL							.423	3		
I2MD			.626	2	.358	4	.560	3	.322	5
CBL			1.000	2	.272	2	.073	3	.146	3
CMD			.679	3	.678	3	.339	4	**.008**	4
PM3BL			.884	5	1.000	3	.258	2	.149	3
PM3MD			.595	6	.840	3	.809	4	.083	3
PM4BL			.226	3	.174	6	.067	3	<0.001	2
PM4MD			.511	3	.576	4	.060	4	<0.001	2
M1BL			.168	6	.926	5	.497	6	**.013**	4
M1MD			**.042**	**6**	.611	5	.062	5	.731	4
M2BL			.675	7	.368	4	.615	5	<0.001	2
M2MD			.730	7	**.039**	**6**	.757	5	<0.001	2
M3BL			.777	4						
M3MD			.530	5						
Variables significantly different between R & L sides (%)	22		10		8		4.5		54	

6.2.3.2 Inter-sample analysis, Cretan samples: GLM Univariate Hierarchical Analysis results for dental measurements

In order to explore the relationship between the dental metric variables, population sample- and sex-ascription of the examined individuals, GLM univariate analysis was applied to the data. This was undertaken in order to explore the possibility that inter-sample relationships reconstructed using these variables could be an artefact of the different sex-composition of the tested population samples. The results are given in Table 6.2.14. Analysis detected a significant ($p<0.05$) impact of biological sex on I1RMD, PM4LBL, PM4RMD, M3RBL, M3RMD, LCLBL, LCLMD, LCRBL and LCRBL for the Cretan samples (Table 6.2.14). As noted for the two Argolid samples, bucco-lingual and mesio-distal diameters of both right and left mandibular canines are significantly associated with biological sex. Thus the results of the analysis agree with studies of canine sexual dimorphism that suggest significant tooth crown size differences between males and females (Frayer & Wolpoff 1985).

Inter-sample differences for the Cretan samples reached significance for I1LMD, I1RMD, M2RBL, M3RBL, LCLBL, LCLMD and LPM3LBL. Analysis also showed that there is significant interaction between biological sex and the tested samples, which has an effect on inter-sample variation for I2LMD and LPM3MD. This, however, has no major implications for the calculated inter-sample distances, because analysis uses the polar teeth (i.e. 1st Incisor, Canine, 3rd Premolar and 1st Molar). LPM3MD, describing the crown morphology of the 3rd Premolar (a polar tooth), for which analysis suggested significant interaction between biological sex and the tested samples, differs significantly neither between the two sexes, nor between the tested samples (Table 6.2.14).

Table 6.2.14 Inter-sample analysis, Cretan samples (Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo, Palama): GLM Univariate Hierarchical Analysis results for dental measurements, Tests between-subjects effects, F and p values ($p<0.05$).

TOOTH CROWN MEASUREMENT	N	SEX		POPULATION SAMPLE		SEX*POPULATION SAMPLE	
MAXILLA		F	P	F	P	F	p
I1LBL	16	0.016	0.9	0.106	0.977	1.111	0.319
I1LMD	17	2.942	0.117	9.964	**0.001**	2.915	0.118
I2LBL	18	2.926	0.121	0.411	0.796	0.661	0.596
I2LMD	20	1.693	0.219	2.607	0.093	3.695	**0.046**
CLBL	21	2.729	0.124	0.129	0.968	0.324	0.807
CLMD	23	3.629	0.079	1.44	0.276	1.029	0.428
PM3LBL	24	0.477	0.501	0.408	0.799	0.321	0.858
PM3LMD	24	2.344	0.148	1.995	0.15	0.694	0.608
PM4LBL	21	5.001	**0.045**	1.214	0.355	0.3	0.824
PM4LMD	24	0.557	0.466	1.107	0.389	0.283	0.836
M1LBL	29	3.52	0.076	0.139	0.965	0.723	0.586
M1LMD	30	3.107	0.093	2.493	0.075	0.697	0.602
M2LBL	23	0.000	0.987	1.797	0.189	2.315	0.112
M2LMD	24	0.002	0.961	1.062	0.411	1.31	0.313
M3LBL	10	0.132	0.75	0.248	0.889	0.562	0.639
M3LMD	10	0.632	0.509	0.263	0.88	0.903	0.525
I1RBL	9	2.829	0.191	1.628	0.349	2.082	0.244
I1RMD	9	12.806	**0.037**	22.079	**0.015**	0.05	0.837
I2RBL	17	2	0.19	1.663	0.241	0.007	0.992
I2RMD	16	0.047	0.832	2.59	0.117	0.61	0.566
CRBL	19	4.439	0.064	1.432	0.299	2.568	0.11
CRMD	21	2.264	0.16	0.958	0.467	0.469	0.757
PM3RBL	32	0.951	0.339	0.801	0.537	0.397	0.807
PM3RMD	34	0.537	0.47	1.214	0.33	0.404	0.803
PM4RBL	26	1.363	0.259	0.561	0.693	0.136	0.966
PM4RMD	28	4.44	**0.049**	1.290	0.321	0.615	0.656
M1RBL	28	2.646	0.121	0.577	0.682	0.614	0.657
M1RMD	32	0.636	0.433	0.984	0.436	1.428	0.257
M2RBL	30	0.718	0.406	3.274	**0.032**	0.616	0.655
M2RMD	29	0.043	0.837	2.467	0.079	0.894	0.486
M3RBL	14	16.038	**0.007**	5.858	**0.028**	3.978	0.079
M3RMD	14	17.058	**0.006**	2.475	0.154	1.529	0.29
MANDIBLE							
LI1LBL	9	3.816	0.108	0.52	0.623	-	-
LI1LMD	13	0.274	0.616	1.29	0.35	0.499	0.5
LI2LBL	11	0.022	0.885	0.416	0.748	0.215	0.661
LI2LMD	21	0.058	0.813	1.811	0.191	0.211	0.886
LCLBL	29	8.876	**0.007**	3.347	**0.029**	0.224	0.878
LCLMD	30	5.52	**0.028**	3.216	**0.033**	0.319	0.811
LPM3LBL	27	3.347	0.083	3.773	**0.021**	1.067	0.387
LPM3LMD	28	0.158	0.695	1.726	0.185	1.005	0.411
LPM4LBL	24	0.695	0.417	0.787	0.551	0.99	0.423
LPM4LMD	25	0.099	0.756	0.701	0.601	1.617	0.224
LM1LBL	29	0.084	0.773	1.045	0.408	1.793	0.18
LM1LMD	28	0.44	0.515	1.498	0.242	1.319	0.297
LM2LBL	28	0.038	0.846	0.783	0.549	0.852	0.482
LM2LMD	29	1.209	0.284	1.618	0.208	2.324	0.105
LM3LBL	17	1.634	0.229	0.597	0.63	1.838	0.208
LM3LMD	19	3.592	0.995	0.371	0.775	0.476	0.631
LI1RBL	11	3.05	0.141	0.538	0.676	1.228	0.318
LI1RMD	19	0.837	0.379	0.517	0.724	0.952	0.415

TOOTH CROWN MEASUREMENT	N	SEX		POPULATION SAMPLE		SEX*POPULATION SAMPLE	
		F	P	F	P	F	p
LI2RBL	14	2.073	0.199	0.328	0.849	0.129	0.881
LI2RMD	20	1.584	0.232	1.808	0.192	3.399	0.067
LCRBL	19	6.492	**0.027**	0.73	0.589	1.587	0.247
LCRMD	21	8.844	**0.01**	2.377	0.105	2.702	0.104
LPM3RBL	22	2.304	0.152	1.106	0.394	1.481	0.265
LPM3RMD	27	1.236	0.280	3.664	0.023	4.318	**0.018**
LPM4RBL	23	1.06	0.32	2.806	0.066	0.206	0.89
LPM4RRMD	24	1.208	0.288	0.518	0.723	0.954	0.439
LM1RBL	30	0	1	0.396	0.809	0.538	0.661
LM1RMD	30	0.04	0.842	0.151	0.96	0.299	0.825
LM2RBL	29	0.259	0.616	0.953	0.454	0.356	0.785
LM2RMD	32	0.47	0.499	1.054	0.401	0.929	0.442
LM3RBL	19	0.308	0.589	0.571	0.689	0.868	0.446
LM3RMD	19	0.000	0.992	0.77	0.566	0.117	0.89

6.2.3.3 Intra-regional analysis of dental morphology, Cretan samples: Box and whisker plots of measurements

All dental metric variables were plotted separately for each tested samples (i.e. the Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo and Palama samples) to allow some basic understanding of inter-sample relationships in terms of dental metric morphology (Appendix D, Figures 1 to 96). On the graphs males and females from each sample are plotted separately. Teeth with no associated alveolar bone (i.e. loose teeth) that could not be sexed were also plotted separately for each sample. Numbers of individuals represented by the plotted variables are given for each tested sample. For practical reasons sample sizes are not given for the variables tested by analyses undertaken in this chapter and the reader is referred to Appendix D, Figures 1 to 96, for this information. Metric data are first plotted separately for right and left sides and then, on the basis of the results of the analysis of side asymmetry (section 6.2.3.1), are pooled to maximize sample sizes. Patterning of the data on the graphs does not suggest a broader range of intra-sample variation for the mesio-distal compared to the bucco-lingual tooth crown diameter. This is unexpected given that the two crown diameters are asymmetrically affected by dental wear and that normally the mesio-distal diameter is strongly affected, whereas the bucco-lingual is only affected when the crown has been severely worn (Hillson *et al.* 2005). This could be attributed to a combination of factors, e.g. this study does not use the unworn to slightly worn dentitions of children, dental wear is not severe for the recorded

Bronze Age Aegean samples, or, the measuring methodology employed by this study (see section 5.1.2.3.1).

6.2.3.4 Intra-regional analysis of dental morphology, Cretan samples: One-way ANOVA

In order to explore inter-sample relationships for the Bronze Age Cretan samples (i.e. the Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo and Palama samples), One-way ANOVA was applied to tooth crown dimensions. Males, females, and individuals for whom sex could not be determined were tested separately. Analysis suggested significant differences ($p<0.05$) between the tested male groups for the following variables: I1LMD ($p=0.024$), I2LMD ($p=0.038$), LPM3LBL ($p=0.041$), LM2LMD ($p=0.015$), LPM3RMD ($p=0.038$) (Appendix D, Table 6.43). Analysis of inter-sample differences for the females reached significance for I1LMD ($p=0.014$) and I1RMD ($p=0.041$) (Appendix D, Table 6.44). Finally, inter-sample differences for individuals of unknown sex were found to be significant for PM4LMD ($p=0.024$), PM3RBL ($p=0.013$), and M1RMD ($p=0.004$) (Appendix D, Table 6.45). Inter-sample differences in tooth crown diameters were further explored using the more robust tests of equality of means, due to the unequal size of the tested samples. The Welch and Brown-Forsythe tests failed to detect any statistically significant inter-sample difference for the tested variables for the male groups (Appendix D, Table 6.46), or groups of individuals of unknown sex (Appendix D, Table 6.47). They showed, however, significant differences between the tested female groups for I1LMD ($p=0.02$), and LPM4LBL (Welch: $p=0.007$) (Appendix D, Table 6.48). The I1LMD tooth crown diameter was measured only for the Gypsades and Palama females. The Gypsades females show lower values than the Palama females (see Appendix D, Figure 2). Concerning inter-sample differences in LPM4LBL, the Gypsades and Palama females show lower values than the Myrtos Pyrgos and Sellopoulo females (see Appendix D, Figure 41).

6.2.3.5 Intra-regional analysis of dental morphology, Cretan samples: Hierarchical cluster analysis of mean dental measurements, R and L sides pooled

Although the application of multivariate statistical analysis to many dental crown diameters is considered to be the most accurate means of reconstruction of inter-population relationships (Hillson 2002), analysis here is performed using a rather small number of variables. This was dictated by the very small number of cases represented by the complete set of recorded variables. Right and left side tooth crown measurements (bucco-lingual and mesio-distal diameters) were pooled in order to maximize sample sizes. Before applying Hierarchical Cluster Analysis to measurements from the polar teeth of each tooth class, namely 1st incisor (I1), canine (C), 3rd premolar (PM3) and 1st molar (M1), from both the maxilla and mandible, GLM univariate hierarchical cluster analysis was applied to the pooled right and left measurements of the BL and MD diameters of the polar teeth (Table 6.2.15). Although analysis demonstrated that both the biological sex (I1MD, LCBL, LCMD and LPM3BL) and the population sample (M1MD, LCBL, LCMD and LPM3MD) with which individuals are associated have a significant effect on the tested measurements, there is no significant association between biological sex and population sample. This analysis thus rejects the possibility that inter-sample differences in the tested variables are an artefact of differences in the representation of the two sexes in the tested samples.

Table 6.2.15 Inter-sample analysis, Cretan samples (Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo, Palama): GLM Univariate Hierarchical Analysis results for dental measurements, polar teeth, R and L sides pooled. Tests between-subjects effects, F and p values ($p<0.05$).

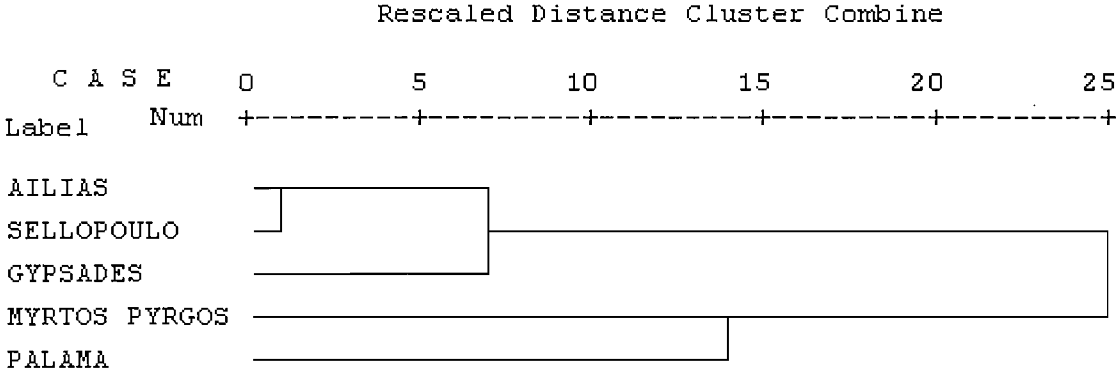
TOOTH CROWN MEASUREMENT	N	SEX		POPULATION SAMPLE		SEX*POPULATION SAMPLE	
		F	P	F	P	F	P
I1BL	17	0.025	0.875	0.076	0.987	1.341	0.273
I1MD	20	7.058	**0.02**	10.006	0.008	1.983	1.801
CBL	26	2.945	0.105	0.7197	0.59	1.844	0.169
CMD	29	2.206	0.153	1.181	0.35	0.71	0.594
PM3BL	39	1.019	0.321	1.038	0.404	0.305	0.872
PM3MD	41	1.541	0.223	1.875	0.139	0.379	0.821
M1BL	37	3.291	0.08	0.114	0.976	0.159	0.956
M1MD	41	1.217	0.278	2.805	**0.042**	1.573	0.206
LI1BL	11	3.653	0.114	0.513	0.73	1.546	0.268
LI1MD	19	0.806	0.388	0.624	0.654	1.151	0.351
LCBL	37	13.177	**0.001**	3.018	**0.034**	0.877	0.464
LCMD	36	8.1	**0.008**	3.462	**0.02**	0.425	0.736
LPM3BL	37	7.456	**0.01**	2.61	0.056	1.464	0.245
LPM3MD	40	1.941	0.173	4.122	**0.008**	2.772	0.058
LM1BL	39	0.162	0.689	0.306	0.871	0.111	0.952
LM1MD	39	0.702	0.408	0.703	0.595	0.259	0.854

Confinement of the Hierarchical Cluster Analysis to polar teeth from each tooth class was employed because dental measurements have been considered less effective than cranial measurements in discriminating between populations, partially due to inter-correlation of crown diameters and subsequent duplication in discriminatory power of one by the other (Harris & Rathbun 1991). Moreover, side asymmetry is less pronounced for the polar teeth of each tooth class (Butler 1939), and hence pooling right and left sides is even more applicable. Polar teeth are considered to represent more accurately the underlying genotype than the more lateral teeth of the respective tooth class (Dahlberg 1945). The variables describing the crown morphology of the upper and lower first incisors (I1BL, I1MD, LI1BL, LI1MD), were removed from analysis, due to the susceptibility of the measurement of the mesio-distal crown diameter of the 1st Incisor to dental wear. Hierarchical Cluster Analysis was applied to the mean data and the calculated Squared Euclidean distances between the tested Cretan samples (i.e. the Ailias, Myrtos Pyrgos, Gypsades, Sellopoulo and Palama samples) are tabulated (Table 6.2.16) and visually represented (Figure 6.2.26).

Table 6.2.16 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for mean dental measurements, Polar teeth (excluding 1st Incisor), R and L sides pooled, Squared Euclidean Distances between the tested samples.

Samples	**Squared Euclidean Distance**				
	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	PALAMA
AILIAS	.000	1.843	.923	.684	1.904
MYRTOS PYRGOS	1.843	.000	1.738	2.033	1.311
GYPSADES	.923	1.738	.000	1.022	2.538
SELLOPOULO	.684	2.033	1.022	.000	1.200
PALAMA	1.904	1.311	2.538	1.200	.000

Figure 6.2.26 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements, Polar teeth (excluding 1st incisor), R and L sides pooled, Dendrogram using Average Linkage (Between Groups).



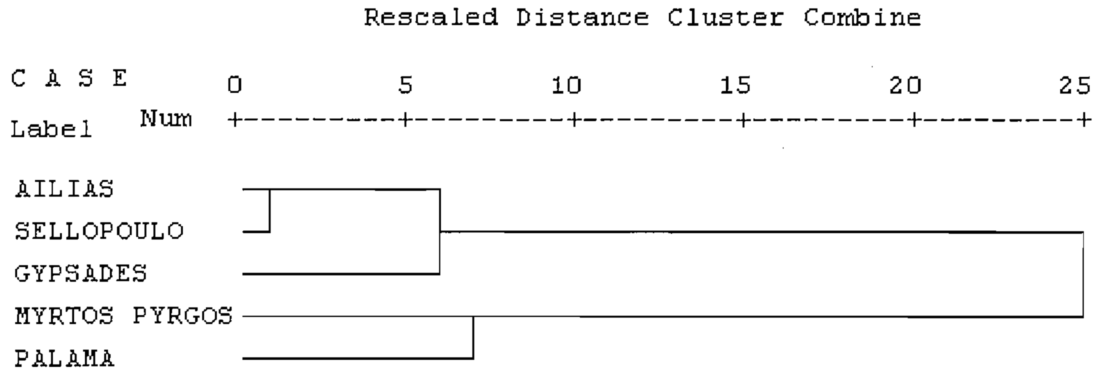
Reading the dendrogram (Figure 6.2.26) from left to right, the vertical lines show the clusters and the position of the line on the scale indicates the distance at which clusters are joined. On the dendrogram (Figure 6.2.26) the tested Cretan samples are arranged in two main clusters. The first consists of the Ailias, Sellopoulo and Gypsades samples and the second of the Myrtos Pyrgos and Palama samples. This clustering agrees with the geographical distances between the tested samples. The Middle Minoan Ailias and the LMI Gypsades and LMII-III Sellopoulo samples, which cluster together, derive from cemeteries located less than 2km apart from each other, in the Knossos district (North-central Crete). The Middle Minoan Myrtos Pyrgos sample derives from the border between South-central and Eastern Crete. The Palama sample from the Western part of Crete appears to be clearly separated from the three Knossos population samples.

In order to control for the impact of dental wear on the mesio-distal tooth crown diameter and its distorting effect on inter-sample distances reconstructed using this measurement, Hierarchical Cluster Analysis was applied to mean bucco-lingual polar tooth crown diameters only (Table 6.2.17, Figure 6.2.27). Clustering of the samples on the dendrogram (Figure 6.2.27) is in agreement with results using both bucco-lingual and mesio-distal tooth crown diameters (Figure 6.2.26). This result provides supportive evidence for the suggestion made earlier in section 6.2.3.3, on the basis of equal ranges of variation for mesio-distal and bucco-lingual tooth crown diameters, that, in this study, the mesio-distal diameter is not significantly affected by dental wear (6.2.3.3). Also, although tooth size that is described by bucco-lingual tooth crown diameter, is asserted to have been exposed to natural selective forces (Brace *et al.* 1991), in the present study, it may reflect more than that, i.e. the genetic make-up of the parent population, gene flow, genetic drift.

Table 6.2.17 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for mean dental measurements, Bucco-lingual diameter only, Polar teeth, R and L sides pooled, Squared Euclidean Distances between the tested samples.

Samples	**Squared Euclidean Distance**				
	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	PALAMA
AILIAS	.000	1.154	.294	.198	.534
MYRTOS PYRGOS	1.154	.000	1.391	1.272	.382
GYPSADES	.294	1.391	.000	.446	.693
SELLOPOULO	.198	1.272	.446	.000	.590
PALAMA	.534	.382	.693	.590	.000

Figure 6.2.27 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements, Bucco-lingual crown diameter only, Polar teeth, R and L sides pooled, Dendrogram using Average Linkage (Between Groups).



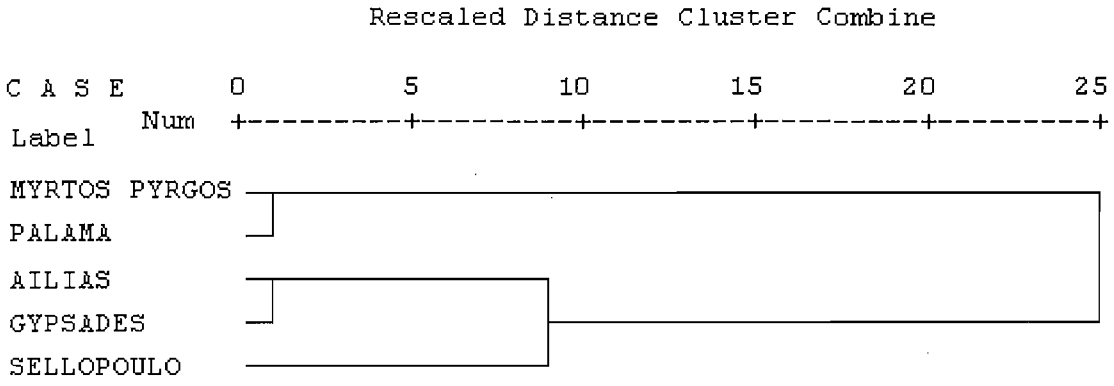
Although the results of GLM univariate hierarchical analysis of MD and BL diameters of polar teeth, right and left sides pooled, did not show for any of the tested variables a significant interaction between the biological sex and the population sample with which the tested individuals are associated (Table 6.2.15), it was decided to calculate inter-sample distances separately for males and females using bucco-lingual diameters of polar teeth only, in order to verify that there are no differences in inter-sample distances calculated for male and female groups separately. Due to low sample sizes, there were not enough female groups to perform cluster analysis (from the Cretan samples only the female groups from Palama and Gypsades had values for all tested variables).

The results of Hierarchical Cluster analysis of male groups for bucco-lingual crown diameters of polar teeth are given in Table 6.2.18 and Figure 6.2.28. Inter-sample distances, measured from the results of the analysis of bucco-lingual diameters of polar teeth of male individuals only, are in agreement with distances measured when samples were entered into analysis with sexes pooled (Figure 6.2.27). Also, they are in agreement with distances measured from the analysis of both bucco-lingual and mesio-distal crown diameters (Figure 6.2.26). The three successive Bronze Age samples from Knossos in Central Crete (i.e. the Ailias, Gypsades and Sellopoulo samples) cluster together and are distant from the Myrtos Pyrgos and Palama samples from Eastern and Western Crete respectively (Figure 6.2.28).

Table 6.2.18 Inter-sample distance, Cretan samples, males: Hierarchical Cluster Analysis results for mean dental measurements, Bucco-lingual diameter only, Polar teeth, R and L sides pooled, Squared Euclidean Distances between the tested samples.

Samples	Squared Euclidean Distance				
	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	PALAMA
AILIAS	.000	1.444	.320	.466	2.174
MYRTOS PYRGOS	1.444	.000	2.423	.751	.271
GYPSADES	.320	2.423	.000	1.194	3.224
SELLOPOULO	.466	.751	1.194	.000	1.137
PALAMA	2.174	.271	3.224	1.137	.000

Figure 6.2.28 Inter-sample distance, Cretan samples, males: Hierarchical Cluster Analysis results for dental measurements, Bucco-lingual crown diameter only, Polar teeth, R and L sides pooled, Dendrogram using Average Linkage (Between Groups).



6.2.3.6 Intra-regional analysis of dental morphology, Cretan samples, sexes pooled: Hierarchical Cluster Analysis of Dental Indices

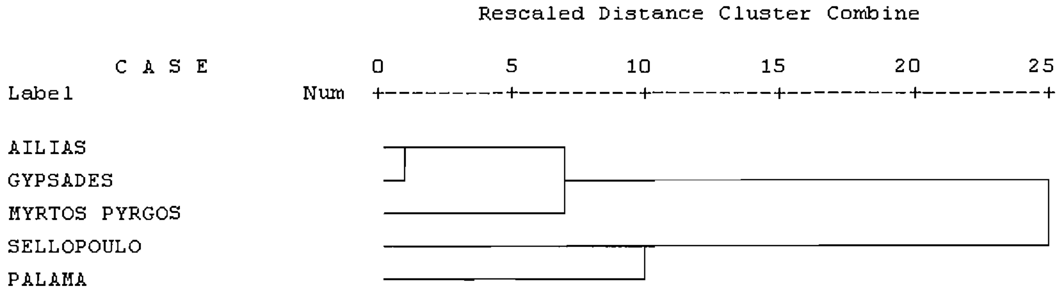
Robustness Index or Crown Area: As the tooth Crown Area is suggested to reflect temporal trends in intra-population variation, relationships between Cretan samples spanning the Bronze Age Crete were investigated using Hierarchical Cluster Analysis of the Robustness Index calculated for the right upper and lower teeth.

Inter-sample distances were measured using Hierarchical Cluster Analysis of the mean Robustness Index of the right side upper polar teeth for each tooth class, i.e. I1, C, PM3 and M1 (Table 6.2.19, Figure 6.2.29). (For sample size (N) see Appendix D, Table 6.49).

Table 6.2.19 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness indices of the R side Upper Polar teeth, Squared Euclidean Distances between the tested samples.

Samples	Squared Euclidean Distance				
	AILIAS	SELLOPOULO	GYPSADES	MYRTOS PYRGOS	PALAMA
AILIAS	.000	108.748	40.264	60.164	234.801
SELLOPOULO	108.748	.000	138.382	111.078	85.034
GYPSADES	40.264	138.382	.000	83.619	250.397
MYRTOS PYRGOS	60.164	111.078	83.619	.000	98.059
PALAMA	234.801	85.034	250.397	98.059	.000

Figure 6.2.29 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness indices of the R side Upper Polar teeth, Dendrogram using Average Linkage (Between Groups).



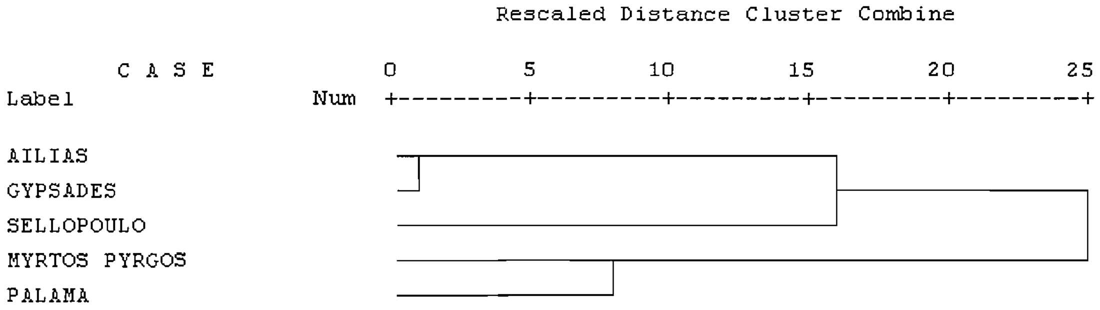
In Figure 6.2.29, the tested samples are grouped into two separate clusters. The first consists of MM Ailias, MMII-LMI Myrtos Pyrgos and the LMI Gypsades samples, whereas the second is composed of the LMII-III Sellopoulo and LMIII Palama samples. Thus inter-sample distances reconstructed from analysis of the Robustness Index of the upper right polar teeth accord well with the dating of the samples.

Hierarchical Cluster Analysis was applied to the Robustness Indices of both maxillary and mandibular right side polar teeth (I1, C, PM3, M1). The 1st incisor was removed from the analysis, due to the susceptibility of its mesio-lateral tooth crown diameter to dental wear (Table 6.2.20 and Figure 6.2.30) (For N see Appendix D, Table 6.49).

Table 6.2.20 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness indices of the R side Upper and Lower Polar teeth (excluding 1st Incisor), Squared Euclidean Distances between the tested samples.

Samples	**Squared Euclidean Distance**				
	AILIAS	SELLOPOULO	GYPSADES	MYRTOS PYRGOS	PALAMA
AILIAS	.000	160.424	50.993	171.171	331.139
SELLOPOULO	160.424	.000	182.436	225.710	157.978
GYPSADES	50.993	182.436	.000	231.528	382.880
MYRTOS PYRGOS	171.171	225.710	231.528	.000	110.417
PALAMA	331.139	157.978	382.880	110.417	.000

Figure 6.2.30 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness indices of the R side Upper and Lower Polar teeth (excluding 1st Incisor), Dendrogram using Average Linkage (Between Groups).

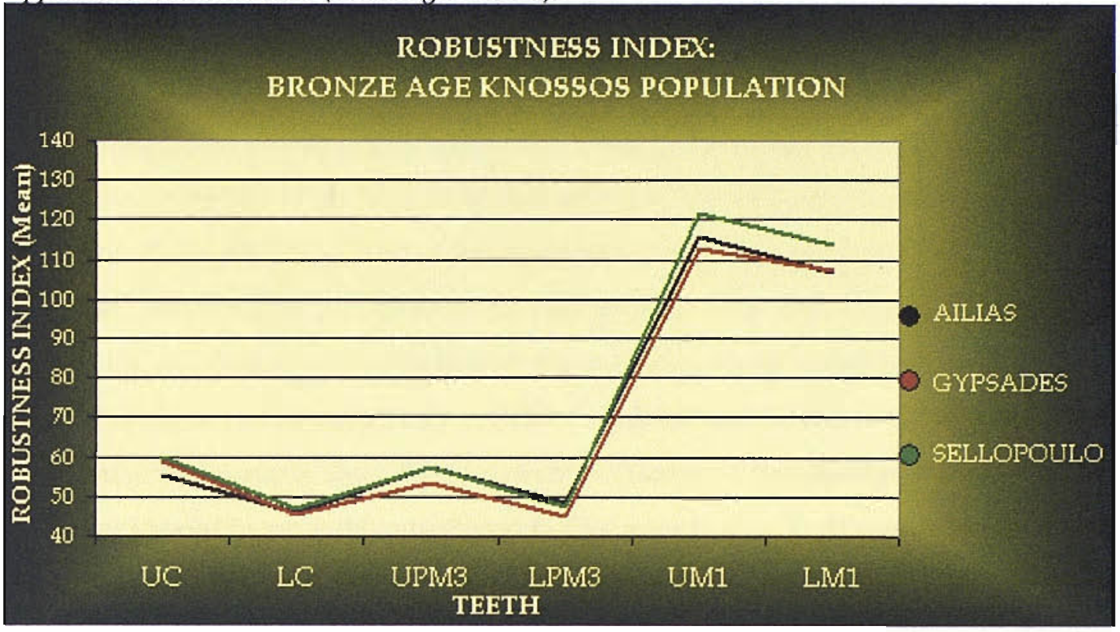


The results of the analysis indicate that the tested samples are arranged in two distinct clusters (Figure 6.2.30). In the first, MM Ailias and its immediate successor in the district of Knossos, the LMI Gypsades sample, cluster in close proximity. The later LMII-III Sellopoulo, also from Knossos, is the third sample grouped in this cluster. In the second cluster, MMII-LMI Myrtos Pyrgos from South-Eastern Crete and LMIII Palama from Western Crete group together. Patterning of the relationships between the Bronze Age samples from the district of Knossos represented by the first cluster of the dendrogram (Figure 6.2.30), is noteworthy, because inter-sample distances accord well with the time-relationship between the samples.

The Knossos samples were further compared to explore the nature of the change in the size of the tooth crown of the Knossos district population through the

Bronze Age. The calculated mean robustness indices for the polar teeth from the samples from the Knossos district are graphically represented (Figure 6.2.31).

Figure 6.2.31 Inter-sample analysis, Knossos samples, sexes pooled: Robustness Index for the R side Upper and Lower Polar teeth (excluding 1st incisor).



Patterning of the data in Figure 6.2.31 shows an increase in the size of the tooth crown for the later compared with the earlier population samples from the district. The values for the mean robustness index of the upper and lower canines, upper 3rd premolar and both upper and lower 1st molars are higher for the LMII-III Sellopoulo relative to the earlier Ailias and Gypsades samples. This probably should be attributed to improved diet, as the possibility that gene-flow accounts for the increase in the size of the tooth crown for the later populations from Knossos is invalidated by the results of the cranial metric and non-metric morphological analyses (discussed earlier in this chapter) which suggested continuity in the biological history of the Knossos population from the Middle to Late Bronze Age. The two analyses falsified the hypothesis for the arrival and settlement of biologically different individuals at Knossos following the LMIB destructions. Even if there was some gene-flow from the Argolid to Knossos, it did not have a strong impact on the skeletal morphology of the Knossos population.

6.2.4 Crete: Dental Non-metric Morphological Analysis

Inter-population genetic distance was measured by applying Mean Measure of Divergence analysis to dental non-metric traits. Twelve and eleven non-metric traits were scored for the upper and lower dentition respectively (Appendix B, Table 5.6). Right and left sides were scored separately for reasons outlined in Chapter 5, section 5.1.2.3.2. Nevertheless, the actual number of traits entered into the analysis was smaller. It was hampered by the small number of individuals for which scoring of traits was feasible. Trait frequencies for which at least one of the tested samples consisted of less than five individuals were not entered into analysis (Table 6.2.21). However, when negative values for the MMDst were recorded, inter-sample distances were measured by entering to the analysis all trait frequencies available, even those recorded in samples of less than 5 individuals. Negative values are regarded as an anomaly since the two samples cannot be less divergent than zero, and, they should be probably attributed to low sample size. Trait frequencies and sample size for all tested samples are given in Appendix E, Tables 6.4, 6.5, 6.6 and 6.7.

Table 6.2.21 Inter-population distances, Cretan samples, sexes pooled: MMD analysis results for Dental Non-metrics.

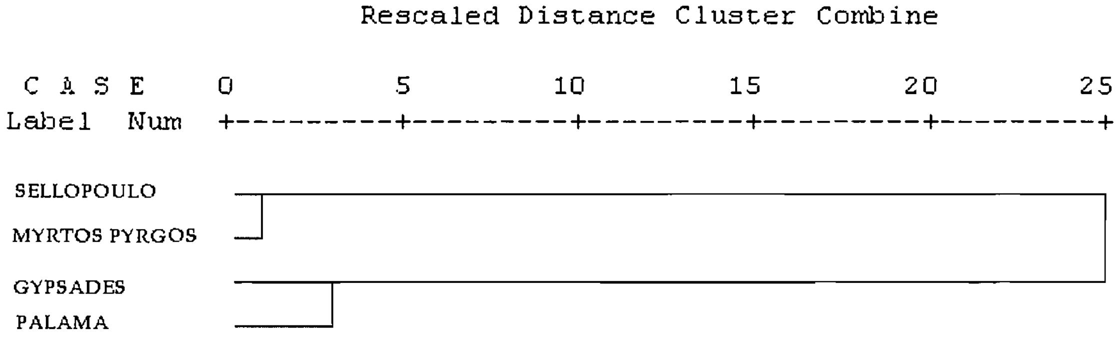
Population Samples	Number of traits tested	MMDv	SD	MMDst
Myrtos Pyrgos - Gypsades	33	-0.04282	0.003768	-11.3617
	46	-0.09024	0.012238	-7.3741
Myrtos Pyrgos - Sellopoulo	20	0.03334	0.002416	13.79765
Gypsades - Sellopoulo	20	-0.05439	0.003761	-14.464
	46	0.059558	0.029504	**2.018643**
Sellopoulo - Palama	46	0.122984	0.002741	3.405807
	12	-0.04689	0.03611	-17.1112
Gypsades - Palama	46	-0.02226	0.023227	-0.95856
	18	-0.03892	0.003767	-10.3323
Palama - Myrtos Pyrgos	46	-0.04551	0.014751	-3.0854246
	22	-0.13022	0.003476	-37.4649

Hierarchical Cluster Analysis was applied to the values of Mean Measure of Divergence analysis of dental non-metric traits in order to assess the distances between the Cretan samples (Table 6.2.22). Inter-sample distances are visually represented in Figure 6.2.32.

Table 6.2.22 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the values of MMD analysis of Dental Non-metrics, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance			
Samples	GYPSADES	SELLOPOULO	MYRTOS PYRGOS	PALAMA
GYPSADES	.000	.012	.020	.011
SELLOPOULO	.012	.000	.009	.031
MYRTOS PYRGOS	.020	.009	.000	.040
PALAMA	.011	.031	.040	.000

Figure 6.2.32 Inter-sample distance, Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the values of MMD analysis of Dental Non-metrics, Dendrogram using Average Linkage (Between Groups).



The analysis produced two main clusters (Figure 6.2.32). The MMII-LMI Myrtos Pyrgos and LMII-III Sellopoulo samples are grouped together in one, and LMI Gypsades and LMIII Palama are grouped together in the other. Patterning of the data does not confirm the prediction that the smallest value for inter-population biological distance (as measured from the frequencies of dental non-metrics) should be found between the LMI Gypsades and LMII-III Sellopoulo samples from Knossos. The Late Minoan Gypsades and Sellopoulo individuals were expected to show higher genetic relatedness than with any of the other tested samples from South-Eastern (Myrtos Pyrgos) and Western Crete (Palama). However, the actual distance between the Sellopoulo and Gypsades samples is not considerably greater than that between each one of them separately and its pair in the cluster (Myrtos Pyrgos for Sellopoulo and Palama for Gypsades) (see Table 6.2.22). It is mainly the distance between the Palama sample on one hand, and Sellopoulo and Myrtos Pyrgos samples on the other, which causes the Gypsades and Sellopoulo samples to group in two distinct clusters (Table 6.2.22).

The calculated standardized values for the Mean Measure of Divergence Analysis (MMDst) confirm the hypothesis that Gypsades and Sellopoulo individuals share a common ancestor (MMDst = 2.018643). When the relationships between the Palama sample and the other Cretan samples are examined using the calculated MMDst, negative values are predominant. This anomaly probably should be attributed to the rather small number of cases of the Palama sample entered into analysis, in combination with the small number of traits for which inter-sample distances are calculated.

6.2.5 Crete: Summary of Cranial and Dental Metric and Non-metric Morphological Analysis

Analysis of cranial metric morphology suggested a very similar pattern of sexual dimorphism for the majority of the tested Cretan samples (i.e. the Palaikastro, Ailias, Myrtos Pyrgos and Gypsades samples). With regard to the other Cretan samples for which sex differences failed to reach statistical significance for more than one (Palama sample), or two (Moni sample) variables, or that did not show any significantly sexually dimorphic variables (i.e. the Sellopoulo, Mavrospelio and Kastellos samples), it is possible that low sample size accounts for this result.

Noteworthy is the reverse patterning of the relationship between sex and Cranial Index for the Western Cretan sample relative to the other Cretan samples (Figure 6.2.7). Western Cretan males appear to have a higher Cranial Index than the females, and hence a more rounded cranial shape. Moreover, the Western Cretan females have crania that are less rounded than their contemporaries from Central Crete (i.e. the Sellopoulo and Mavrospelio females). Given the low sample size, and because the magnitude and pattern of sexual dimorphism are population specific (Ascadi & Nemeskéri 1970), the reverse patterning of the sex-Cranial Index relationship for the Western Cretan sample, relative to the other Cretan samples, and the relationship of the Western Cretan females with their contemporaries from Central Crete in terms of cranial shape, could potentially reflect biological distance between the Late Minoan population samples from Western and Central Crete.

The results of the analyses of cranial non-metric, dental metric and non-metric morphology also suggest significant distance between the Palama sample from Western Crete and the samples from Central and Eastern Crete. Mean Measure of Divergence Analysis results for cranial and dental non-metrics suggest that the Palama sample does not share a common ancestor with any of the other tested Cretan samples (Tables 6.2.12 and 6.2.21). Cranial non-metric analysis further suggests a close biological relationship shared between the Central and Eastern Crete population samples spanning the entire Bronze Age (Table 6.2.12). In particular the three successive Bronze Age samples from Knossos (i.e. the Ailias, Gypsades and Sellopoulo samples), dating from the period before the alleged Mycenaean migration to that following it, appear to share a common ancestor (Table 6.2.12). Analysis of dental metric (Figures 6.2.26, 6.2.27, 6.2.28, 6.2.30) and non-metric (Table 6.2.21) morphology provided additional evidence of biological relatedness for the Ailias, Gypsades and Sellopoulo samples.

Finally, noteworthy is the patterning of the Cranial Index data for the Cretan Bronze Age samples (Figure 6.2.7). The gradual increase in the Cranial Index over time results from greater rounding of the cranial shape of the later compared with earlier Cretan samples, and most probably reflects gene flow into the Early Bronze Age Cretan population from biologically different population/s and admixture in the succeeding periods.

6.3 Argolid, Cretan and Naxos samples: Inter-regional Analysis of Skeletal Morphology

This section explores the inter-population biological relationships between the Argolid, Cretan and Naxos samples using cranial and dental metric and non-metric morphological analysis in order to address specific archaeological questions of population movement from the Argolid to Crete and Naxos. Due to the poor preservation and incompleteness of the Bronze Age skeletal material from Naxos (see section 5.1.1.2), the analysed sample in this study (1 male and 1 female) could neither be assessed for sexual dimorphism in cranial metric morphology nor assessed in terms of cranial non-metric, and dental metric and non-metric morphology. In section 6.3.1, the two crania from Naxos are used to explore very briefly the hypothesis for the settlement of new population elements (from the Argolid) on Naxos at the LHIIIB-C. The two archaeological hypotheses tested in this section are outlined bellow.

Archaeological Hypothesis A: The first archaeological hypothesis to be tested is that, at the end of LMIB, people from the Mainland arrived at Knossos. It has been postulated that their arrival took the form of a military invasion and political domination of the site. Therefore, it is most probably the highly-ranked individuals, surrounded by their warrior aristocracy, who settled at Knossos and were interred into the "warrior" graves after they died (Sakelarakis 1972; Popham *et al.* 1974; Kanta 1980; Hood 1985; Doxey 1987: 301; Driessen 1990: 125; Popham 1994: 93).

Proof statements: In order to confirm this hypothesis, the following conditions need to be met:

First, the biological history of the Bronze Age Knossos population is disrupted at the end of the LMIB. Discontinuity in the biological history is manifested in two ways:

1. The inter-population distance of the successive Bronze Age Central Crete population samples increases between the samples dating immediately prior and following the suggested migration at the end of LMIB (this is the distance between Gypsades on one hand, and Sellopoulo and Mavrospelio samples on the other). This is examined in section 6.3.1.1.1.

2. The intra-population variation increases for the samples postdating the LMIB destructions compared with earlier population samples, due to the arrival of biologically different individuals from the Argolid. This is examined in section 6.3.1.1.2.

Second, the distance between the populations from the Argolid and Knossos district decreases for the samples postdating the destructions when compared with earlier samples. This is tested by assessing the distance between the Apatheia (Mainland), and the Sellopoulo and Mavrospelio samples (Knossos district). This is examined in section 6.3.1.1.3.

Archaeological Hypothesis B: The second archaeological hypothesis, briefly tested here using cranial morphological metric data, argues that following the LHIIIB-C destructions and the collapse of the palatial system on the Mainland, Mycenaean kings and/or their aristocracy sought refuge in the Cyclades. At death, they were interred into the rich LCIII tombs at Aplomata and Kamini cemeteries at the Chora of Naxos (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

Proof Statement: In order to confirm this hypothesis the individuals from the examined Naxos tombs should be biologically related to their contemporaries from the Argolid. Due to the small number and poor preservation of the available for study human skeletal material from the LCIII Aplomata and Kamini tombs, the biological relationship of Naxos individuals with their contemporaries from the Argolid and Crete is assessed by applying discriminant function analysis to the cranial morphology. This is examined in section 6.3.1.2.

6.3.1 Argolid, Cretan and Naxos samples: Inter-regional Analysis of Cranial Metric Morphology

6.3.1.1 Testing the archaeological hypothesis for a Mycenaean migration to Knossos following the destructions at the end of LMIB

Before testing the hypothesis, the results of the analysis of sexual dimorphism in the Argolid and Central Cretan Middle and Late Bronze Age populations are briefly reviewed to justify pooling of sexes in order to maximize sample sizes.

The pattern and magnitude of sexual dimorphism in the Argolid and Central Cretan Middle and Late Bronze Age populations, explored in sections 6.1.1.4, 6.1.1.5, 6.1.1.6 and 6.2.1.4, 6.2. 1.5, 6.2.1.6 respectively, are suggested to be very similar for the two populations. Male crania in both populations appear to be longer, higher vaulted and more protruding in the upper facial region compared with female crania (Figures 6.1.5, 6.1.7, 6.1.10, 6.1.11, 6.1.12, 6.2.17, 6.2.23, 6.2.24 and 6.2.25). In terms of cranial breadth, however, on the basis of the results of PCA, the Argolid males do not appear to separate from females, whereas Cretan male crania tend to be broader than the female ones (Figure 6.2.24 and 6.2.25). In agreement with the PCA results are those derived from plotting the calculated Height-Breadth (md) indices for the two populations. Patterning of the values for the Height-Breadth (md) Index suggests a less sexually dimorphic cranial shape in terms of the relationship between height and breadth dimensions for the Cretan relative to the Argolid population (Figures 6.1.7 and 6.2.19). On the contrary, sexual dimorphism in Cranial Index (although it suggests for both Cretan (Figure 6.2.17) and Argolid (Figure 6.1.5) females a cranium that is broader for its length compared with males), reached statistical significance for the Cretan population (p=0.009), but not for the Argolid (p=0.095 and p=0.086 for the One-way ANOVA and the more robust tests of equality of means respectively).

In order to maximize sample sizes in inter-regional analysis of cranial metric morphology, the two sexes were pooled, but differentiated by symbols (♂= male, ♀=female) in scatterplots, and separate boxes in box and whisker plots, due to sexual dimorphism in the tested samples of the Argolid and Cretan populations.

6.3.1.1.1 Bronze Age Central Cretan population samples: Inter-sample distance

This section investigates the biological history of the Central Crete population from the Early to Late Bronze Age by assessing fluctuations in the biological distance between succeeding populations, mainly at the Knossos district. Analysis of the skeletal morphology focuses on the relationship between the Gypsades on one hand, and the Sellopoulo and Mavrospelio samples from Knossos on the other. The LMI Gypsades sample antedates the suggested migration, whereas the LMII-III Sellopoulo and LMIII Mavrospelio samples postdate it. Material culture studies suggest that the Sellopoulo and Mavrospelio cemeteries include burials of Mainlanders (Hood 1985; Popham 1994, Rehak & Younger 2001:444; Alberti 2004b).

In the graphs in this section, Early Bronze Age samples are depicted in blue, Middle Bronze Age in green and Late Bronze Age samples in red colours (LBA samples are differentiated by the shades of red used for the marker). On the graphs, males and females in each sample are indicated by ♂ and ♀ respectively, in order to assess and exclude the possibility that the inter-sample variance is due to sexual dimorphism and differences in the representation of the two sexes in the tested samples. The relationship between the two Early Bronze Age samples, from Eastern and Central Crete, namely the Palaikastro and Moni Odigitria samples, was explored by analysis of GOL, XCB, XFB, FRC and PAC. These variables describe the cranial length and the maximum cranial and frontal breadth. Tables 6.3.1 and 6.3.2 show the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape respectively (N=22). The results were plotted and the patterning of the cases suggests a very similar cranial shape for the individuals from the two contemporary but geographically distinct population samples (Moni and Palaikastro) (Figure 6.3.1).

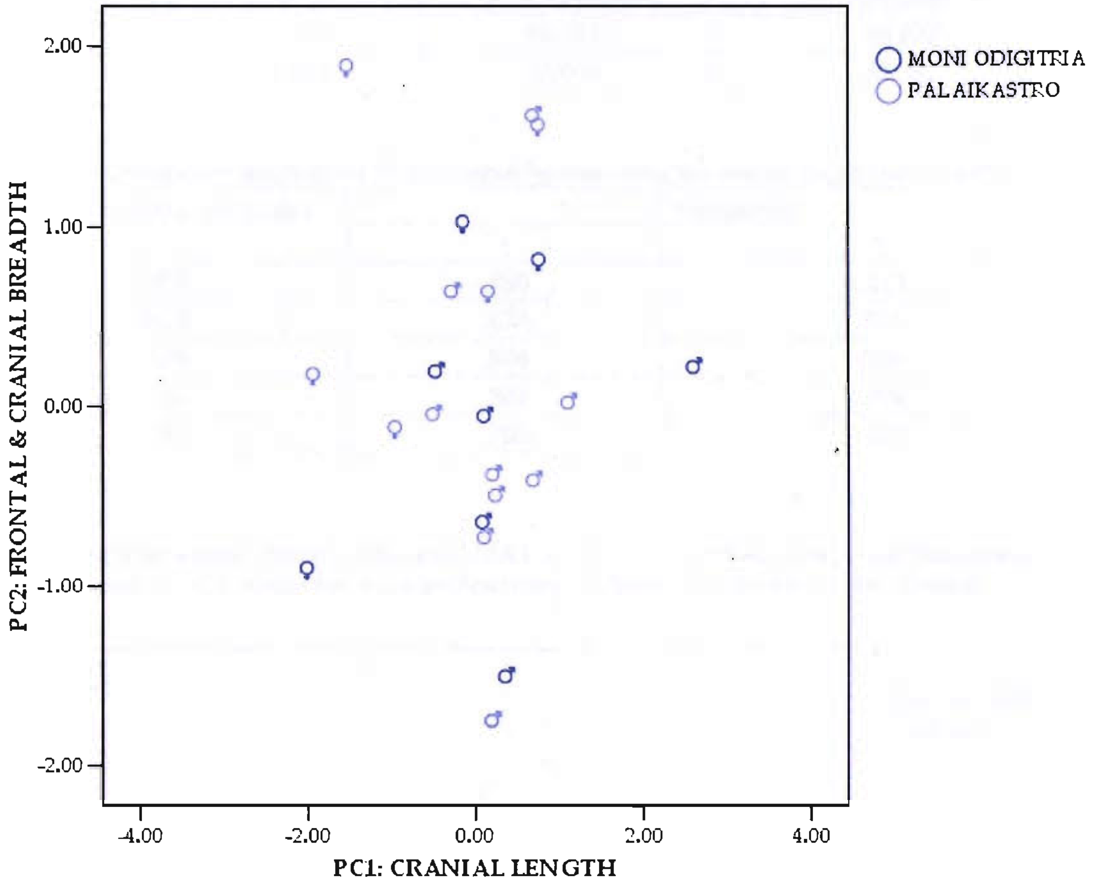
Table 6.3.1 Amount of variance explained by the 2 extracted PCs.

Cranial Metric Variables	Eigenvalues	% of Variance	Cumulative %
1	2.607	52.143	52.143
2	1.412	28.234	80.377

Table 6.3.2 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.855	-.414
XCB	.632	.596
XFB	.688	.635
FRC	.832	-.092
PAC	.558	-.688

Figure 6.3.1 Inter-sample distance, EBA Cretan samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



PCA was applied to GOL, XCB, XFB, FRC and PAC in order to explore the relationship between the Moni and Ailias samples. The Palaikastro sample was removed from the analysis. Both the Moni and Ailias samples derive from the Central part of Crete, but they date to the Early and Middle Bronze Age respectively. Tables 6.3.3 and 6.3.4 show the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape respectively (N=29). Patterning of the data in Figure 6.3.2 suggests a greater range of variation for the cranial breadth for the Ailias sample relative to the Moni sample. In the interpretation of the greater intra-population variation of the Ailias sample, however, one should not disregard the size difference of the two tested samples (21 and 8 individuals from Ailias and Moni respectively). The lower intra-sample variation for Moni could result from the low size of the sample. Moreover, the Ailias males and females appear to have a cranium that is relatively broad for its length when compared with the Moni males and females respectively.

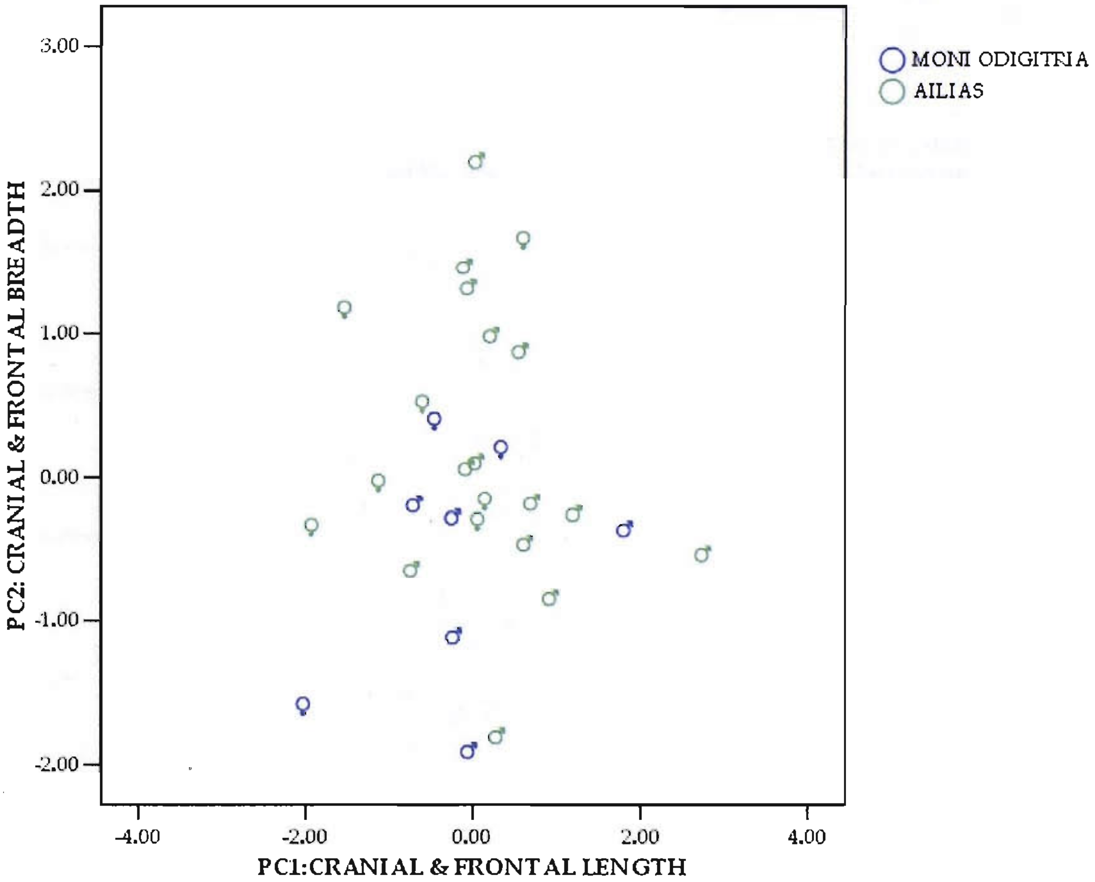
Table 6.3.3 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.004	60.077	60.077
2	1.204	24.084	84.161

Table 6.3.4 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.860	-.413
XCB	.633	.714
XFB	.806	.509
FRC	.847	-.206
PAC	.705	-.472

Figure 6.3.2 Inter-sample distance, EBA and MBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



The two Early Minoan Moni and Palaikastro samples and the Middle Minoan Ailias were analysed by applying PCA to GOL, XCB, XFB, FRC and PAC and the results are graphically represented (Table 6.3.5, Table 6.3.6, Figure 6.3.3) (N=42). Patterning of the data suggests that the Ailias male and female crania tend to be broad for their length, and hence more rounded in comparison with the crania of the two earlier samples.

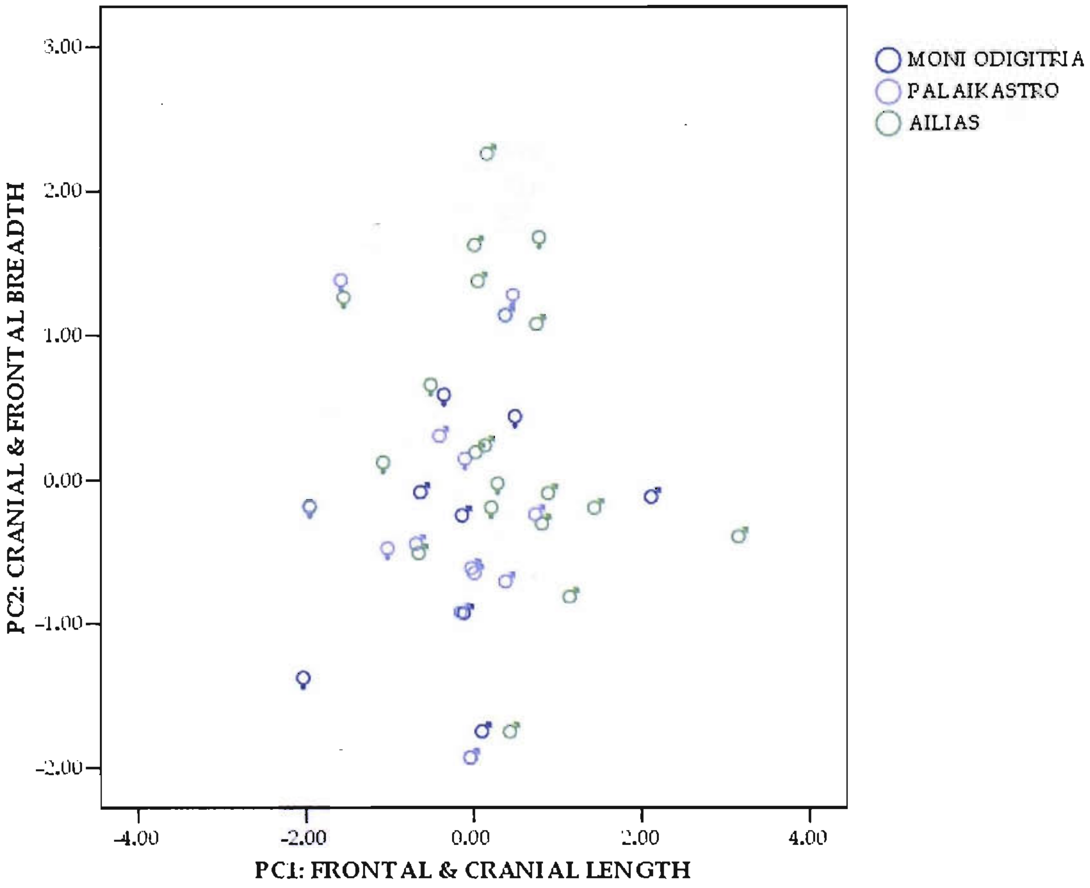
Table 6.3.5 Amount of variance explained by the 2 extracted PCs.

Cranial Metric Variables	Eigenvalues	% of Variance	Cumulative %
1	2.803	56.065	56.065
2	1.335	26.693	82.758

Table 6.3.6 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.836	-.443
XCB	.636	.676
XFB	.733	.593
FRC	.844	-.145
PAC	.671	-.556

Figure 6.3.3 Inter-sample distance, EBA and MBA Cretan samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



In order to focus the assessment of inter-population distances on Central Crete, the later LMI sample from the Gypsades cemetery (Knossos district) was introduced to analysis and the EBA Palaikastro (Eastern Crete) was removed. PCA was applied to GOL, XCB, XFB, FRC and PAC. Table 6.3.7 shows the amount of variance explained by the two extracted components and Table 6.3.8 the component loadings for PCA of cranial size and shape (N=34). Despite the low sample size from LMI Gypsades, plotting of the data shows clearly that the Gypsades male and female individuals tend to have crania that are broad for their length when compared with individuals of the same sex from Ailias, and even more so when compared with the Moni sample (Figure 6.3.4).

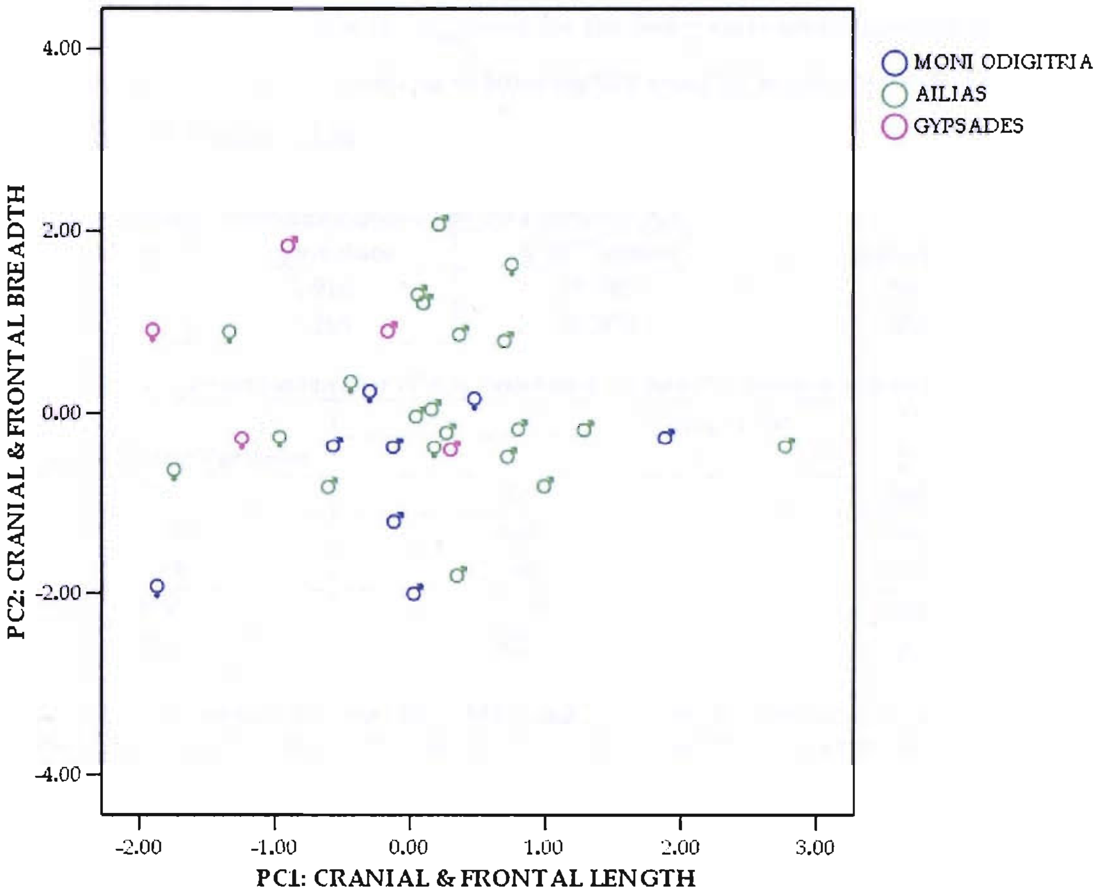
Table 6.3.7 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.014	60.288	60.288
2	1.230	24.606	84.894

Table 6.3.8 Component loadings for PCA of variables describing the cranial length and breadth.

	Component	
Cranial Metric Variables	1	2
GOL	.879	-.394
XCB	.632	.709
FRC	.846	-.216
PAC	.721	-.478
XFB	.779	.546

Figure 6.3.4 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



The Mavrospelio and Sellopoulo samples, also from the Knossos district, were introduced to the analysis (Figures 6.3.5 and 6.3.6). In studies of the material culture, these samples are suggested to be comprised of individuals from the Argolid. The Sellopoulo sample dates to the LMII-III and the Mavrospelio sample to the LMIII.

All three Late Minoan samples from Knossos (i.e. the Gypsades, Mavrospelio and Sellopoulo samples) are depicted in red colour on the graphs and are differentiated by the shades of red used for the markers (Figures 6.3.5 and 6.3.6). Inter-sample relationships are assessed using the same set of variables as for the previous tests (GOL, XCB, XFB, FRC and PAC) (Tables 6.3.9, 6.3.10, 6.3.11 and 6.3.12). These tests showed that the individuals from later samples tend to have a more rounded cranial shape relative to the earlier ones. Given the relatively low sample size (N=40), plotting of the PCA results in Figure 6.3.5 suggests that the Mavrospelio male and female individuals tend to have a cranium that is rather broad for its length when compared with individuals of the same sex from Ailias and Moni. Likewise, a more rounded cranial shape is suggested for the Sellopoulo and Gypsades males and females relative to their counterparts from earlier samples in the region (Central Crete) (N=43) (Figure 6.3.6).

Table 6.3.9 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.910	58.201	58.201
2	1.265	25.292	83.493

Table 6.3.10 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.870	-.394
XCB	.581	.740
XFB	.760	.536
PAC	.717	-.498
FRC	.852	-.161

Figure 6.3.5 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.

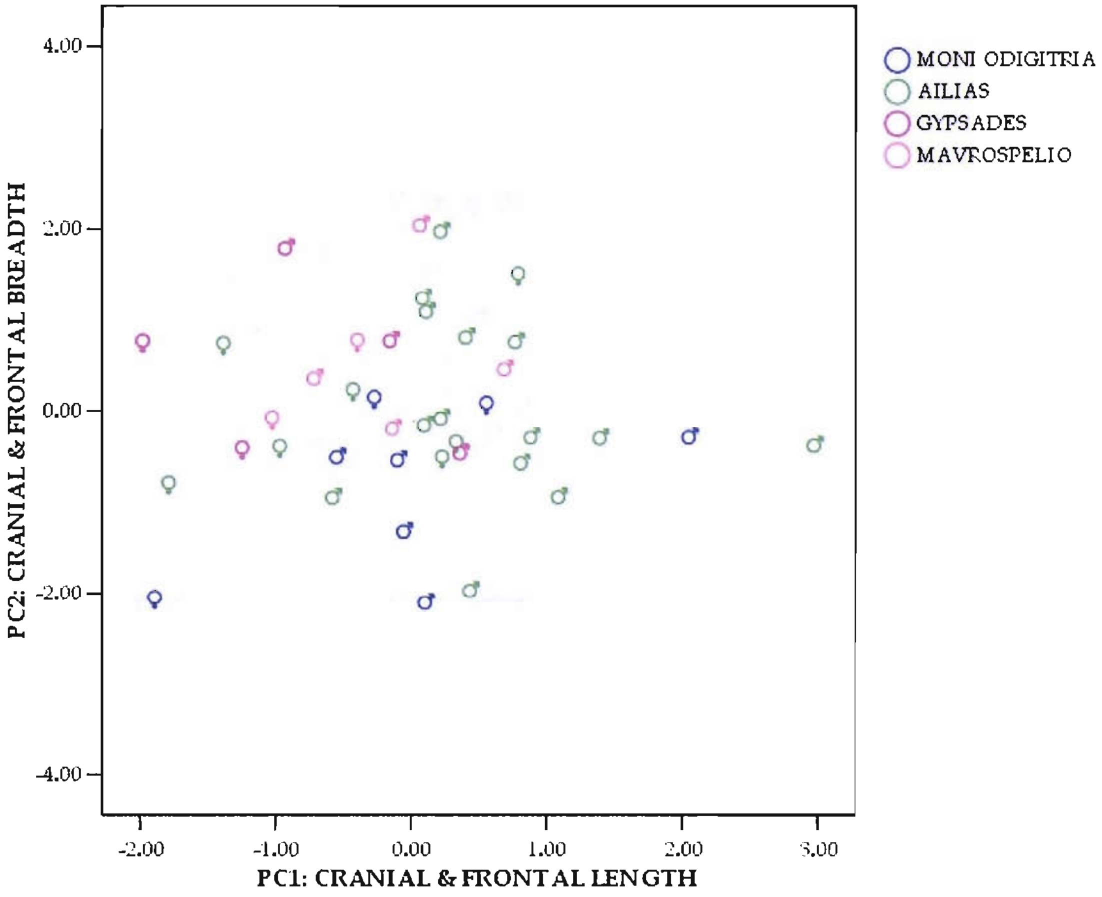


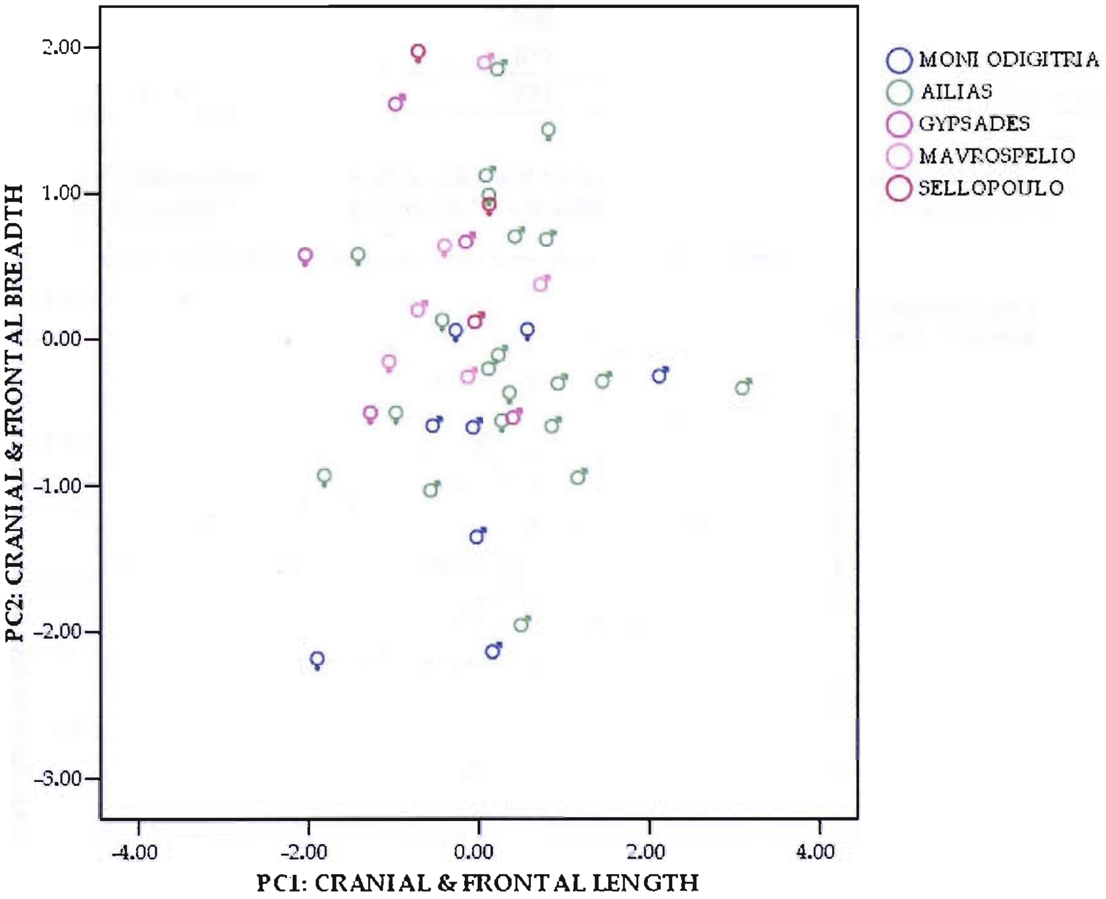
Table 6.3.11 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.765	55.301	55.301
2	1.367	27.336	82.638

Table 6.3.12 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.866	-.400
XCB	.558	.746
XFB	.696	.614
FRC	.836	-.167
PAC	.721	-.496

Figure 6.3.6 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



Graphical representation of the results of PCA applied to variables describing the length and breadth of the cranium (Figure 6.3.6) suggests a very similar morphology for the three Late Minoan samples from Knossos. In order to better understand the pattern of changes in the cranial morphology of the Central Crete population in the course of the Bronze Age, the three Late Minoan samples from the district of Knossos were pooled and the results of PCA are graphically represented (Figure 6.3.7). PCA analysis was applied to the same set of variables used in the previous analysis (GOL, FRC, PAC, XCB, XFB) (N=43) (Tables 6.3.13 and 6.3.14).

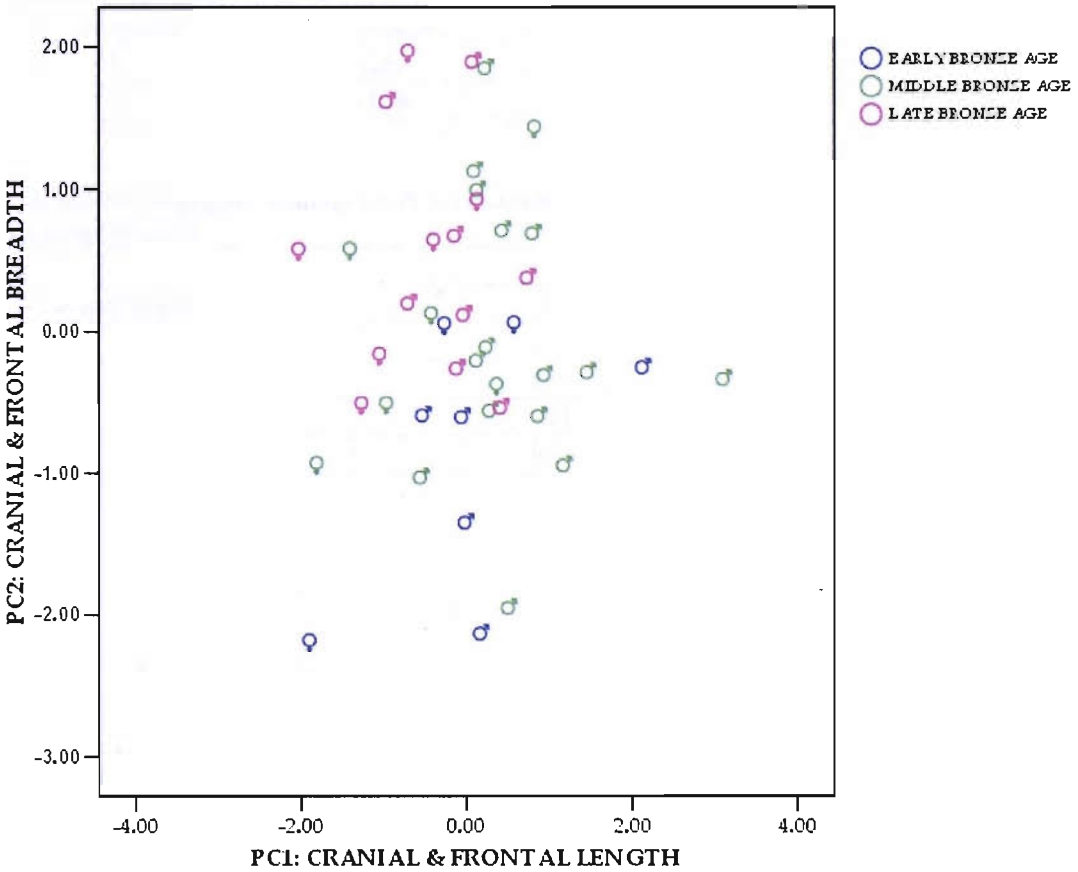
Table 6.3.13 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.765	55.301	55.301
2	1.367	27.336	82.638

Table 6.3.14 Component loadings for PCA of variables describing length and breadth of the cranium.

Cranial Metric Variables	Component	
	1	2
GOL	.866	-.400
XCB	.558	.746
XFB	.696	.614
FRC	.836	-.167
PAC	.721	-.496

Figure 6.3.7 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



Patterning of the data in Figure 6.3.7 suggests a rounder cranial shape for males and females of the later Central Crete samples when compared with individuals of the same sex from earlier periods. Changes in the cranial morphology of the Central Crete population in the course of the Bronze Age were investigated further by adding NAR (N=24) to the analysis (Tables 6.3.15 and 6.3.16). NAR describes the protrusion of the upper facial skeleton. In Figure 6.3.8, the male individuals from Ailias (MBA) appear to have crania that are relatively more protruding and longer for their breadth when compared with both earlier and later male samples from the region. The same relationship is observed for females from Middle and Late Bronze Age samples (no females from the Early Bronze Age Moni sample qualified for this analysis). On the other hand, males and females from the three Late Bronze Age samples appear to have crania that are broad for their length and upper facial protrusion relative to individuals of the same sex from samples predating them. The present interpretations, however, should be treated with caution due to the low size of the tested samples.

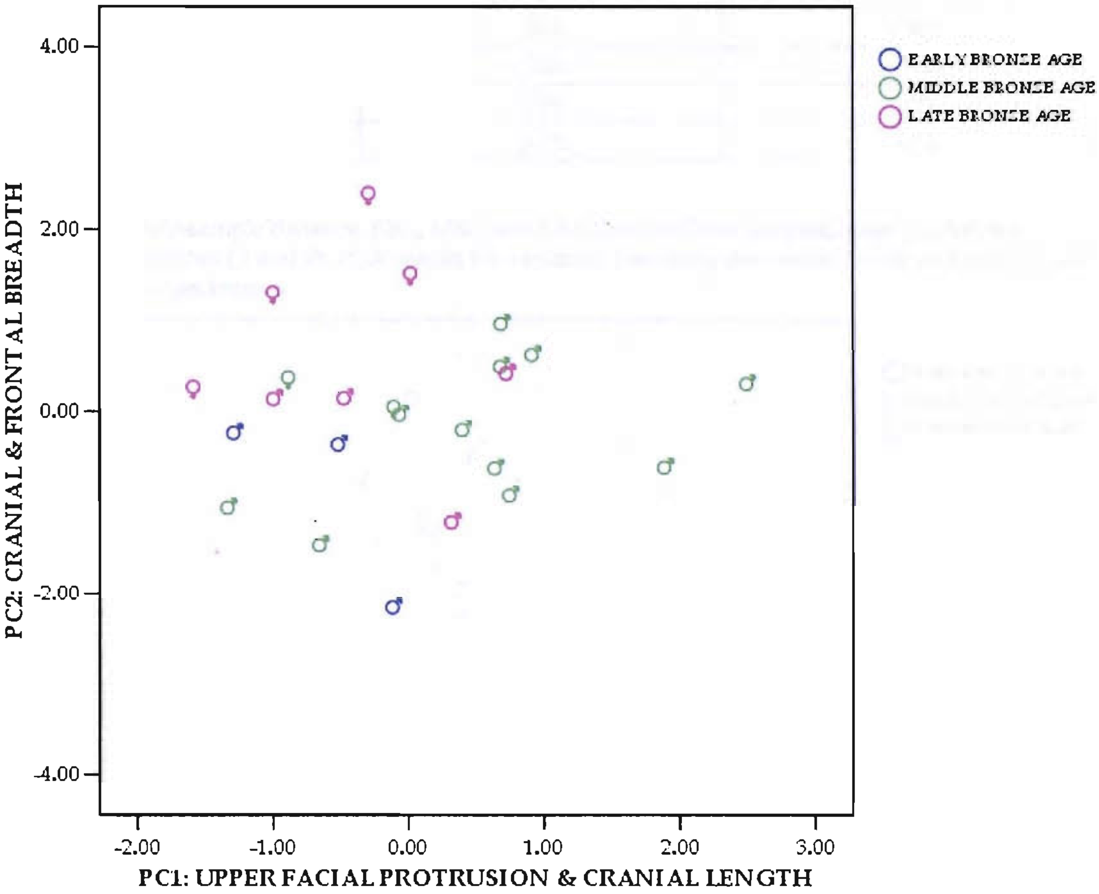
Table 6.3.15 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.263	56.582	56.582
2	1.068	26.691	83.274

Table. 6.3.16 Component loadings for PCA of variables describing the upper facial protrusion, cranial length and breadth.

Cranial Metric Variables	Component	
	1	2
GOL	.767	-.539
XCB	.669	.576
XFB	.724	.521
NAR	.839	-.416

Figure 6.3.8 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the upper facial protrusion, the length and breadth of the cranium.



In order to investigate inter-sample relationships in terms of the morphology of the posterior cranium, the breadth of the posterior part of the cranium (ASB) substituted for the breadth of the frontal bone (XFB) in the analysis and the results of the PCA are given in Tables 6.3.17 and 6.3.18 (N=32). The separation of the three samples on the results of the present analysis of cranial morphology is clearer than previously (see Figure 6.3.8). Patterning of the data suggests a cranium that is broad for its length and upper facial protrusion for the Late Bronze Age individuals from Knossos in comparison with the earlier Moni (South-central Crete) and the immediately preceding MM Ailias, also from the Knossos district (Figure 6.3.9).

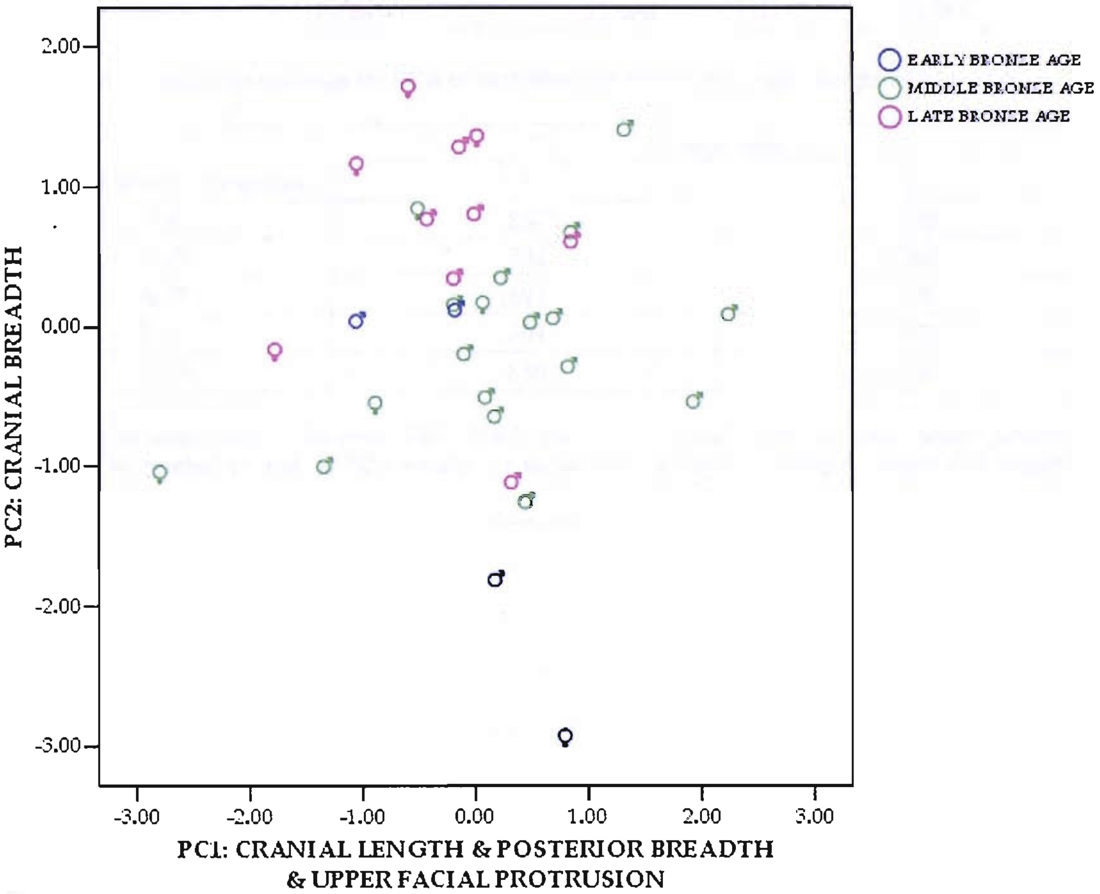
Table 6.3.17 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.399	59.968	59.968
2	1.021	25.514	85.482

Table 6.3.18 Component loadings for PCA of variables describing cranial length and breadth and the upper facial protrusion.

Cranial Metric Variables	Component	
	1	2
GOL	.848	-.383
NAR	.763	-.558
ASB	.799	.403
XCB	.678	.632

Figure 6.3.9 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the cranial length and breadth and the upper facial protrusion.



Changes in the cranial morphology of Central Crete population samples in the course of the Bronze Age were monitored further using variables describing the height and posterior breadth of the cranium (VRR, ASB) (Tables 6.3.19 and 6.3.20) (N=37). The graphically represented results agree well with those derived from the analysis of variables describing cranial length and breadth and upper facial morphology (Figure 6.3.10). The Late Bronze Age individuals from Knossos appear to have a cranium that is broad for its length and height in comparison with Middle and Early Bronze Age Central Crete individuals. The crania of Late Bronze Age males and females tend to be more rounded than the crania of their predecessors of the same sex from the region, as suggested earlier in this chapter by the patterning of the Cranial Index data for these samples (Figure 6.2.7).

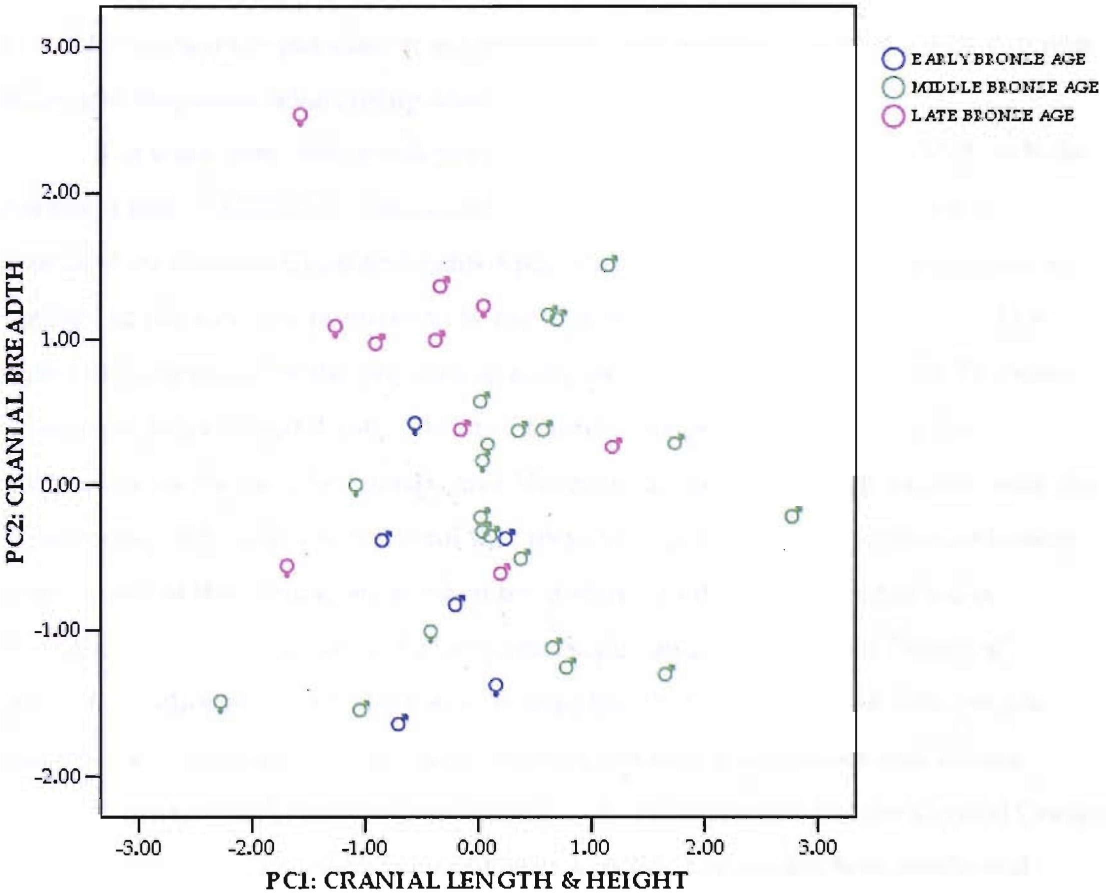
Table 6.3.19 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.781	55.624	55.624
2	1.198	23.960	79.584

Table 6.3.20 Component loadings for PCA of variables describing the length, height and breadth of the cranium.

Cranial Metric variables	Component	
	1	2
GOL	.857	-.310
VRR	.824	-.262
ASB	.691	.598
PAF	.701	-.492
XCB	.630	.658

Figure 6.3.10 Inter-sample distance, EBA, MBA and LBA Central Crete samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length, height and breadth of the cranium.



6.3.1.1.2 Intra-population variation of Bronze Age Cretan population samples: Fluctuations in the distance of succeeding populations from the regional (Central Cretan) population centroid

Fluctuations in the intra-population variation over the course of time resulting from differential amounts of gene flow from an extra-regional source can be detected by assessing changes (increase and/or decrease) in the mean distance of the examined populations to the regional centroid. The Relethford & Blangero (1990) model of intra-group heterogeneity detects differential amounts of gene flow (immigration) from an extra-regional source. Its application is demonstrated to be particularly useful in studies of the correlations between cultural processes and fluctuations in population structure using skeletal morphological data (Steadman 1998). This model is a modification of the Harpending & Ward (1982) model of population heterogeneity based on allele frequencies. According to population genetic theory, if all populations within a region exchange migrants from an external source at an equal rate, the relationship between the average intra-population variation and genetic distance of each population to the regional population centroid (the average heterozygosity of all subpopulations) should be linear (null hypothesis). When one population increases the rate of genetic exchange with external populations, its intra-population heterogeneity will increase due to the influx of new genes and the linear relationship will be violated.

If at some time, either following the destructions at the end of LMIB or in the transition from LMIIIA1-2 (Niemeier 1982, 1985; Hallager 1988; Catling 1989: 7), Mainlanders invaded Crete and gained political control of Knossos, then the mean distance of the Knossos population to the regional population centroid would be expected to increase for the population samples post-dating these events. Therefore, an increase in the mean distance to the Central Crete population centroid is anticipated for the later Sellopoulo and Mavrospelio samples in comparison with the earlier ones. Although it is doubtful that there was an active Mainland colonisation of the island at this period, increase in the distance to the regional centroid is expected for the samples derived from cemeteries with the so-called "warrior" graves (i.e. Sellopoulo and Mavrospelio samples) that are associated with people from the Argolid relative to samples preceding them (i.e. Gypsades and Ailias).

Mean squared Mahalanobis distance (D^2) to the centroid of the Central Cretan population was calculated for Moni Odigitria, Ailias, Gypsades, Sellopoulo and

Mavrospelio samples. Distances were calculated for GOL, XCB, VRR, PAC, PAS and PAS and the results are shown in Table 6.3.21. These variables describe the cranial length, breadth, and height and the midline curvature of the calvaria. Variables were selected in order to provide a good description of the cranial shape and with concern not to reduce sample sizes (by introducing to the analysis rare variables in the tested samples).

On the basis of the population samples' distances (mean squared Mahalanobis distance) to the regional centroid, measured using analysis of cranial length, breadth and height, the Moni Odigitria sample is the most distant of the tested Central Cretan samples to the regional population centroid.

Table 6.3.21 Mean Squared Mahalanobis Distance of population samples to the Central Cretan population centroid.

Skeletal Sample	**Mean Squared Mahalanobis Distance to the Bronze Age Central Cretan Population Centroid**
Moni Odigitria	**2.1879**
Ailias	0.8161
Gypsades	**1.1732**
Sellopoulo	0.6257
Mavrospelio	0.7518
Mean distance to population centroid	1.0391

The greater distance of the Moni Odigitria sample to the regional population centroid accords well with the geographical distance of Moni Odigitria to the Knossos region (from where all other tested samples derive). Also, it is in agreement with the interpretation proposed for the pattern of changes in the Cranial Index of the Bronze Age Central Crete population that implicates gene flow from populations biologically different from the Early Bronze Age Cretan population and population admixture in the succeeding periods (section 6.2.1.2). The later Central Cretan populations (i.e. Gypsades, Sellopoulo, Mavrospelio samples) are morphologically more similar to each other and to the MM Ailias than to the EM Moni Odigitria sample (Figures 6.3.6, 6.3.7, 6.3.8, 6.3.9 and 6.3.10), and because the proportional representation of the Middle and Late Minoan samples in the Bronze Age Central Cretan population sample is higher than that of the EM Moni sample, their contribution to the determination of the regional centroid is also greater. Hence Moni shows the highest value for the mean squared Mahalanobis distance (D^2).

However, the distance (D^2) of the Moni sample to the regional centroid could reflect more than higher amounts of gene flow from an extra-regional source. Although biodistance studies that apply the model of intra-population heterogeneity assume a zero environmental deviation for succeeding populations within the same geographical region (Williams-Blangero & Blangero 1989), the possibility of a long-term adaptation of the first inhabitants of Crete to comparatively colder climatic conditions than those prevailing in their place of origin could be argued on the basis of the patterning of the Cranial Index for the Bronze Age Central Crete samples over time (Figure 6.2.7). In this line of reasoning, the greater distance to the regional population centroid of the Moni relative to other Central Cretan samples could reflect adaptation of the first inhabitants of Crete to comparatively colder climatic conditions than those at their place of origin. The interpretation of the distance of the Moni sample to the regional population centroid implicating gene flow from population/s biologically different from the EBA Cretan population appears, however, to be more valid.

In order to confine the framework of the analysis to the region of Knossos, the Moni Odigitria sample was removed from the data set. The population distances were explored for GOL, XCB, FRC, PAS, PAC and PAF, and the results are given in Table 6.3.22.

Table 6.3.22 Mean Squared Mahalanobis Distance of population samples to the Knossos population centroid.

Skeletal Sample	**Mean Squared Mahalanobis Distance to the Bronze Age Knossos Population Centroid**
Ailias	**1.1728**
Gypsades	0.5192
Sellopoulo	0.6694
Mavrospelio	0.8210
Mean distance to population centroid	0.9748

The results of the two analyses of the population distances to the regional centroid of the Central Crete and Knossos populations respectively (Tables 6.3.21 and 6.3.22) failed to show a clear increase of the distance (mean squared Mahalanobis distance) of the samples from the cemeteries with the so-called "warrior" graves (Sellopoulo and Mavrospelio) to either the Central Crete or Knossos population centroids compared with that (distance) of the samples preceding the LMIB destructions (Ailias and Gypsades). This suggests that the tested samples do not represent populations biologically different from the regional one.

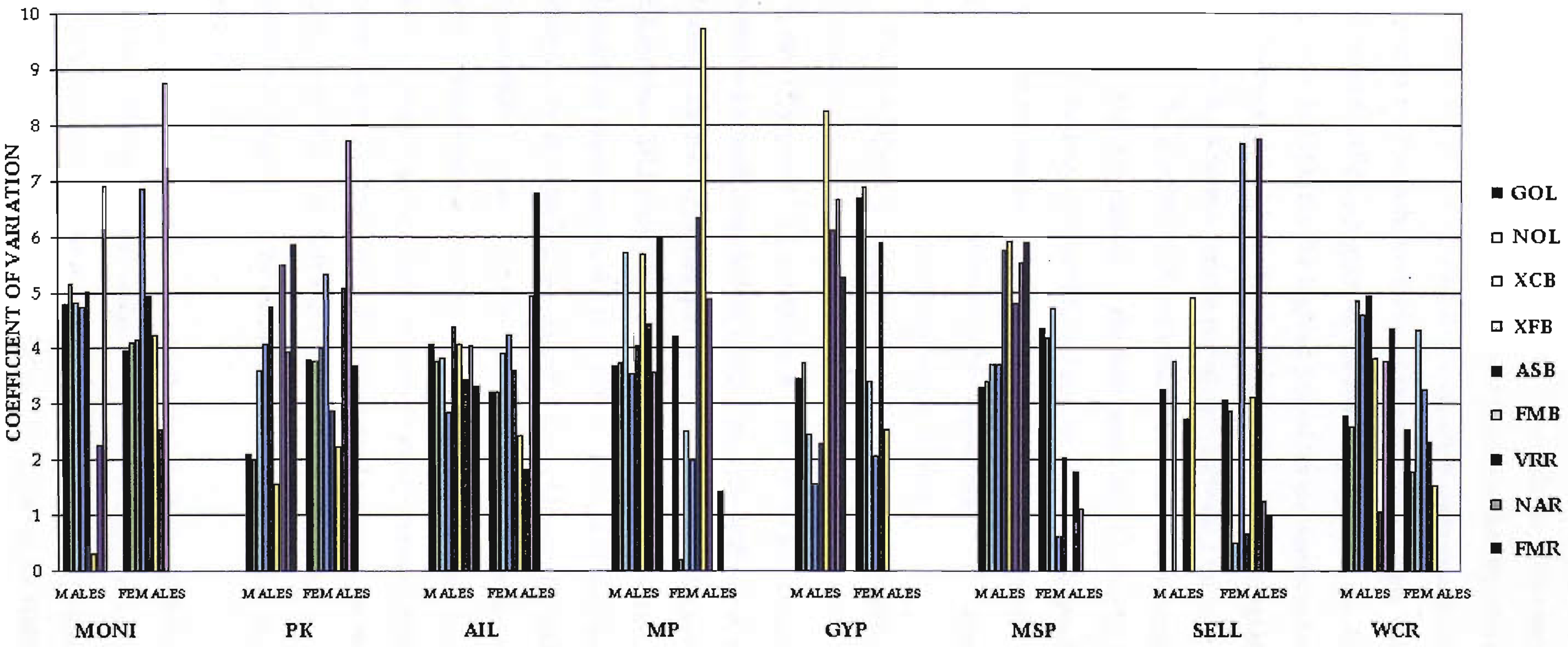
Changes in the range of the intra-population variation of the Cretan population over the course of the Bronze Age were monitored further by calculating the coefficient of variation for the most frequently recorded craniometric variables in the tested samples (GOL, NOL, XCB, XFB, ASB, FMB, VRR, NAR, FMR). The tested variables describe the length, breadth and height of the cranium, and the protrusion of the upper facial skeleton and the results are graphically represented (Figure 6.3.11).

If the hypothesis that following the LMIB destructions on Crete, biologically different individuals from the Argolid settled at Knossos and were interred into the tombs of the Sellopoulo and Mavrospelio cemeteries is true, then the intra-population variation of the Knossos population is expected to be higher for the Sellopoulo and Mavrospelio samples in comparison with the Gypsades and Ailias samples. The Ailias and Gypsades samples precede the suggested migration, whereas the first two postdate it.

The coefficient of variation ($v=s*100/\bar{y}$) was calculated for the tested cranial variables and the results are graphically represented in Figure 6.3.11. Males and females are plotted separately for each sample, in order to explore fluctuations in intra-population variation of the Knossos Middle to Late Bronze Age population separately for males and females. Due to low sample size, the coefficient of variation could not be calculated for the Moni males and females for FMR, the Myrtos Pyrgos females for NAR, the Gypsades females for VRR, NAR, FMR, the Mavrospelio females for FMB and FMR, the Sellopoulo males for XFB, NOL, VRR, NAR, and FMR, and the Western Cretan females for VRR, NAR, and FMR.

Of the nine tested variables, intra-population variation of the Knossos male population increased only for three variables (XFB, ASB, FMR), in the period postdating the suggested migration. For the other six variables, intra-sample

Figure 6.3.11 Intra-population variation of Cretan samples: Coefficient of variation for cranial metric variables.



PK=Palaikastro, AIL= Ailias, MP= Myrtos Pyrgos, GYP= Gypsades, MSP= Mavrospelio, SELL= Sellopoulo, WCR= Western Crete.

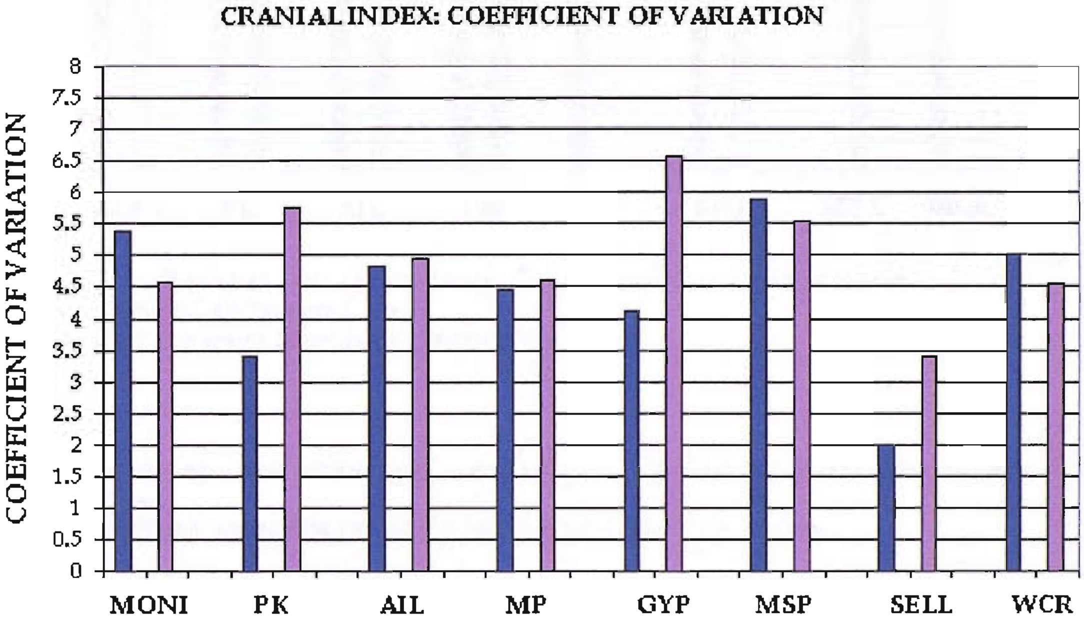
variation was lower for both the Mavrospelio and Sellopoulo males compared with the Gypsades and Ailias male groups. Although the intra-sample variation for ASB was higher for the Mavrospelio males than the earlier Knossos male groups, the Sellopoulo male group showed lower variation compared to the Ailias and Gypsades male groups for the same variable. Moreover, intra-sample variation for maximum frontal breadth (XFB) is higher for the Mavrospelio than the Ailias and Gypsades male groups, but it is not the highest scored for the samples from Central Crete.

Following the LMIB destructions and suggested migration, intra-population variation for the Knossos female population increased for four of the nine tested variables, i.e. XCB, XFB, FMB and VRR. For all these four variables, it is either the Mavrospelio (for 3 variables) or the Sellopoulo (for 1 variable) female groups, which show higher intra-sample variation than the Ailias and Gypsades female groups. Although the intra-sample variation for the bifrontal breadth (FMB) is higher for the Sellopoulo females than the Ailias and Gypsades ones, it is lower than that for the Moni females, who also derive from Central Crete.

The coefficient of variation was further calculated for the Cranial, Height–Breadth (md) and Height–Length (md) indices and the results are graphically represented (Figures 6.3.12, 6.3.13 and 6.3.14). Males and females from each sample are plotted separately. Due to low sample size, the coefficient of variation could not be calculated for the Gypsades and Western Cretan females and the Sellopoulo males for HBI(md) and HLI(md). The calculated coefficients of variation for the tested variables fail to show a clear increase in the variation of the Knossos male population following the destructions at the end of the Late Minoan IB. Although the intra-sample variation for the Cranial Index that describes the size and the shape of the cranium is higher for the Mavrospelio male group compared with the Ailias and Gypsades male groups, the Sellopoulo male group appears to be very homogeneous in Cranial Index compared with the other tested samples. On the other hand, intra-sample variation for HBI(md) and HLI(md) is lower for the Mavrospelio male group than for its predecessors in the district of Knossos (i.e. the Ailias and Gypsades male groups).

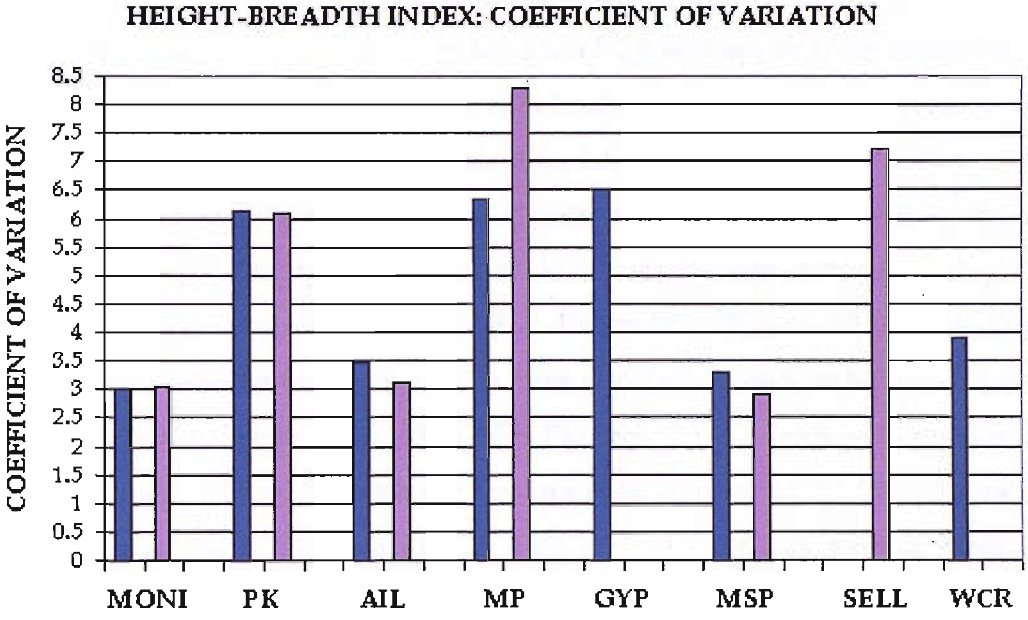
Although the intra-sample variation of the Sellopoulo female group for HBI(md) and HLI(md) is higher than that of the Ailias female group, it is lower (for HBI(md)) and very similar (for HLI(md)) to that of the Gypsades male group. Moreover, the variation of the Sellopoulo female group for HBI(md) is not the highest scored for the tested Cretan female groups. Intra-sample variation for HBI(md) is higher for the Myrtos Pyrgos female group from South-eastern Crete. Finally, intra-sample variation for the cranial index (CI) is lower for both the Mavrospelio and Sellopoulo female groups compared with their predecessor in the district of Knossos (i.e. the Gypsades female group).

Figure 6.3.12 Intra-population variation of Cretan samples: Coefficient of variation for the Cranial Index.



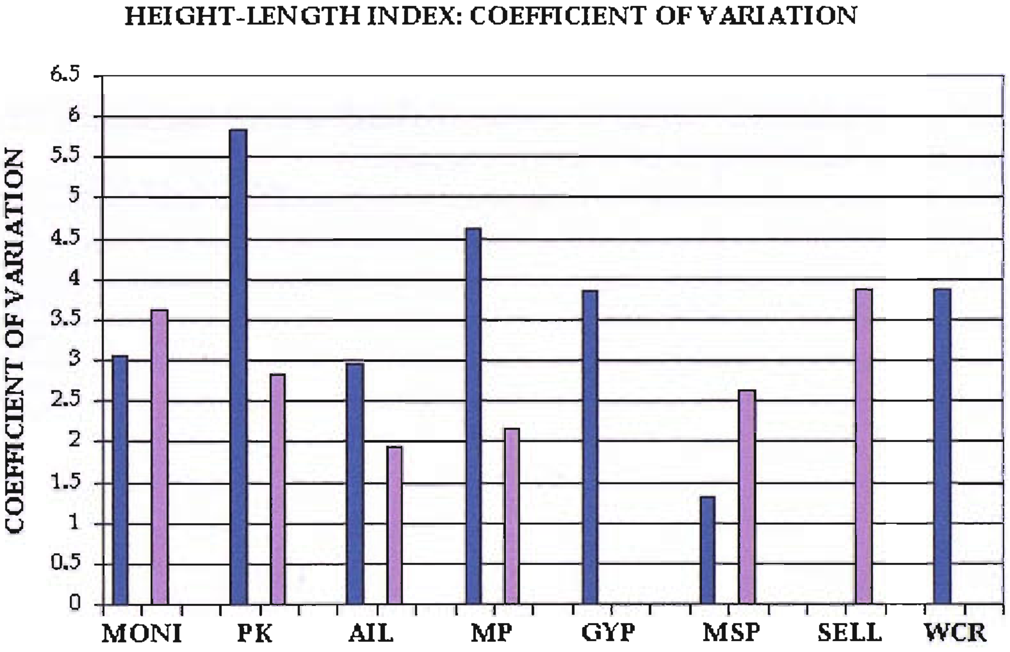
PK=Palaikastro, AIL= Ailias, MP= Myrtos Pyrgos, GYP= Gypsades, MSP= Mavrospelio, SELL= Sellopoulo, WCR= Western Crete.
Key to colours on the graph: blue=males, pink=females.

Figure 6.3.13 Intra-population variation of Cretan samples: Coefficient of variation for the Height-Breadth (md) Index.



PK=Palaikastro, AIL= Ailias, MP= Myrtos Pyrgos, GYP= Gypsades, MSP= Mavrospelio, SELL= Sellopoulo, WCR= Western Crete.
Key to colours on the graph: blue=males, pink=females.

Figure 6.3.14 Intra-population variation of Cretan samples: Coefficient of variation for the Height-Length (md) Index.



PK=Palaikastro, AIL= Ailias, MP= Myrtos Pyrgos, GYP= Gypsades, MSP= Mavrospelio, SELL= Sellopoulo, WCR= Western Crete.
Key to colours on the graph: blue=males, pink=females.

6.3.1.1.3 Fluctuations in the biological distance between the Argolid and Central Crete populations in the course of the Bronze Age

Late Minoan – Late Helladic samples: PCA was applied to explore the relationship (relatedness vs. divergence) between the Late Bronze Age samples from the Knossos district (Gypsades, Mavrospelio, Sellopoulo) and the Argolid (Apatheia Galatas). The individual from Episkopi also derives from Central Crete; Episkopi is situated less than 15km from Knossos. All four Central Crete samples are depicted in blue colour on the graphs (Figures 6.3.15, 6.3.16 and 6.3.17) and differentiated by the shade of blue used for the markers. The inter-population relationship was assessed using the same variables (GOL, XCB, XFB, FRC and PAC), which were analysed to explore the relationship between the Cretan samples (section 6.3.1.1.1). The results of the analysis are plotted in Figure 6.3.15. Tables 6.3.23 and 6.3.24 provide the amount of variance explained by the two extracted components and the component loadings for PCA of cranial size and shape respectively (N=24).

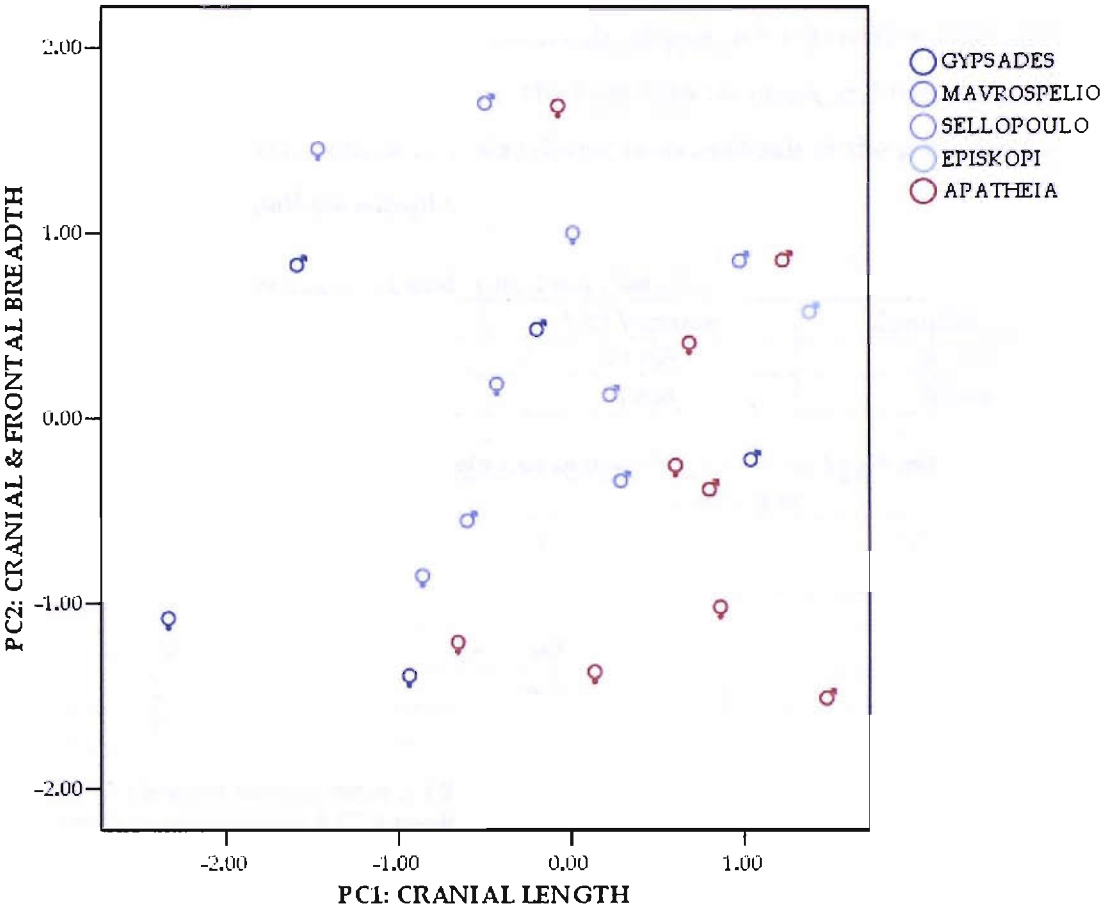
Table 6.3.23 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.183	43.657	43.657
2	1.674	33.487	76.371

Table 6.3.24 Component loadings for PCA of variables describing the cranial length and breadth.

	Component	
Cranial Metric Variables	1	2
GOL	.937	-.001
XCB	-.027	.904
XFB	.102	.883
FRC	.786	.157
PAC	.822	-.229

Figure 6.3. 15 Inter-population distance, LBA Central Crete and Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



Plotting of the data shows a distinct separation between the Late Minoan Knossos samples and the Late Helladic Apatheia. The individuals from Apatheia (with the exception of Individual A5. C) appear to have crania that are narrow for their length in comparison with their contemporaries from Crete. In Figure 6.3.15, the representation of the two sexes in the tested samples excludes the possibility that the difference in cranial morphology between the Cretan and Argolid samples is due to sexual dimorphism and differences in the representation of males and females in the tested samples. Concerning the brief overlap of the Late Minoan and Late Helladic samples, from the two males that group with the Apatheia individuals, one is from Knossos and antedates the LMIB destructions and the hypothesised Mycenaean migration, and the other one is from Episkopi. Hence patterning of the data shows a distinct separation of the LMII-III Knossos individuals from their contemporaries from Apatheia (Mainland).

XFB was substituted by ASB in the PCA (Figure 6.3.16) and the results are given in Tables 6.3.25 and 6.3.26 (N=27). ASB describes the posterior breadth of the cranium. Graphical representation of the results (Figure 6.3.16) confirms the results of the previous analysis (Figure 6.3.15). The Late Minoan males and females from Knossos appear to have rounder crania relative to individuals of the same sex from the Late Helladic Apatheia sample.

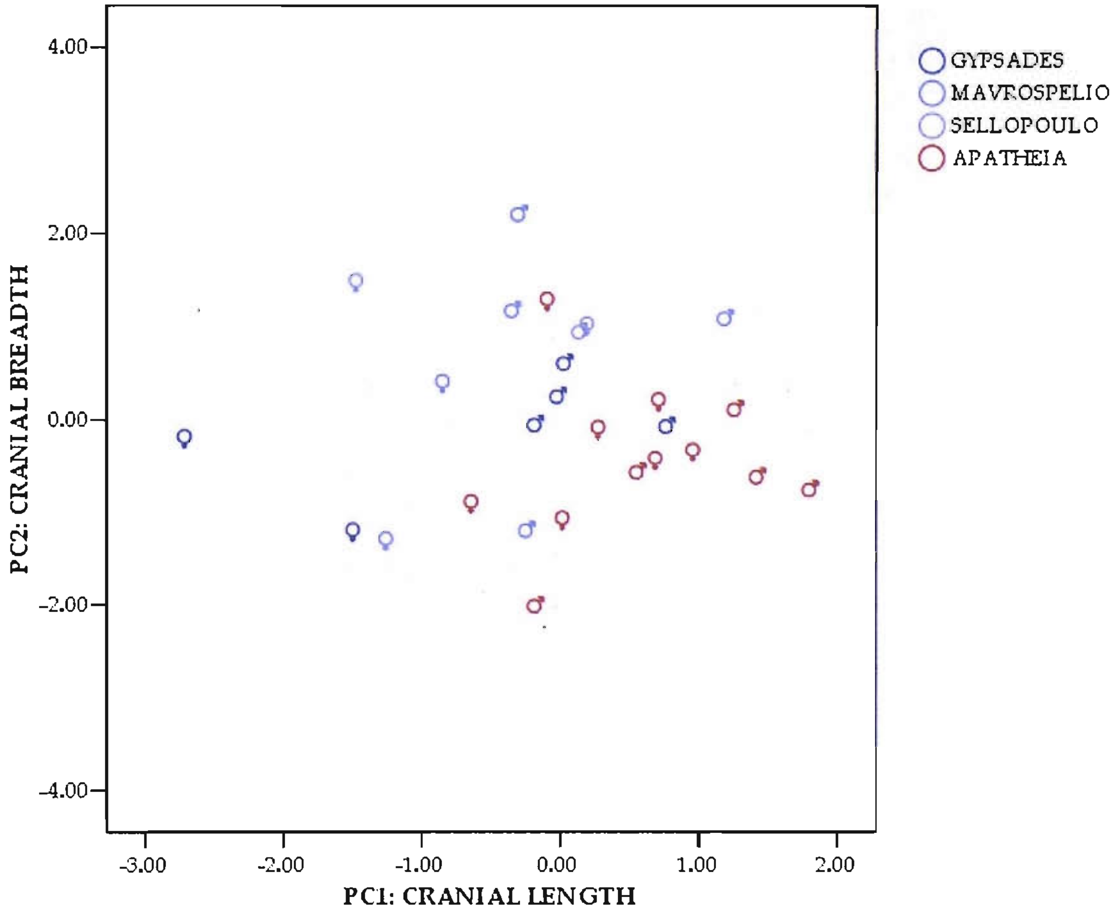
Table 6.3.25 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	1.958	39.165	39.165
2	1.583	31.653	70.818

Table 6.3.26 Component loadings for PCA of variables describing the cranial length and breadth.

Cranial Metric Variables	Component 1	Component 2
GOL	.918	-.187
XCB	.040	.857
ASB	.467	.706
FRC	.630	.256
PAC	.707	-.499

Figure 6.3.16 Inter-population distance, LBA Central Crete and Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



Two more samples were introduced to the analysis. The Palama and Kastelos samples derive from Western Crete and are depicted in green colour (dark green for the Palama sample and light green for the Kastelos sample) on the graph (Figure 6.3.17). Inter-population relationships were assessed through the PCA of GOL, XCB, XFB, FRC and PAC, and the results are given in Tables 6.3.27 and 6.3.28 (N=31). Figure 6.3.17 illustrates the relationship between the Late Minoan and Late Helladic samples reconstructed using variables describing the length and breadth of the cranium.

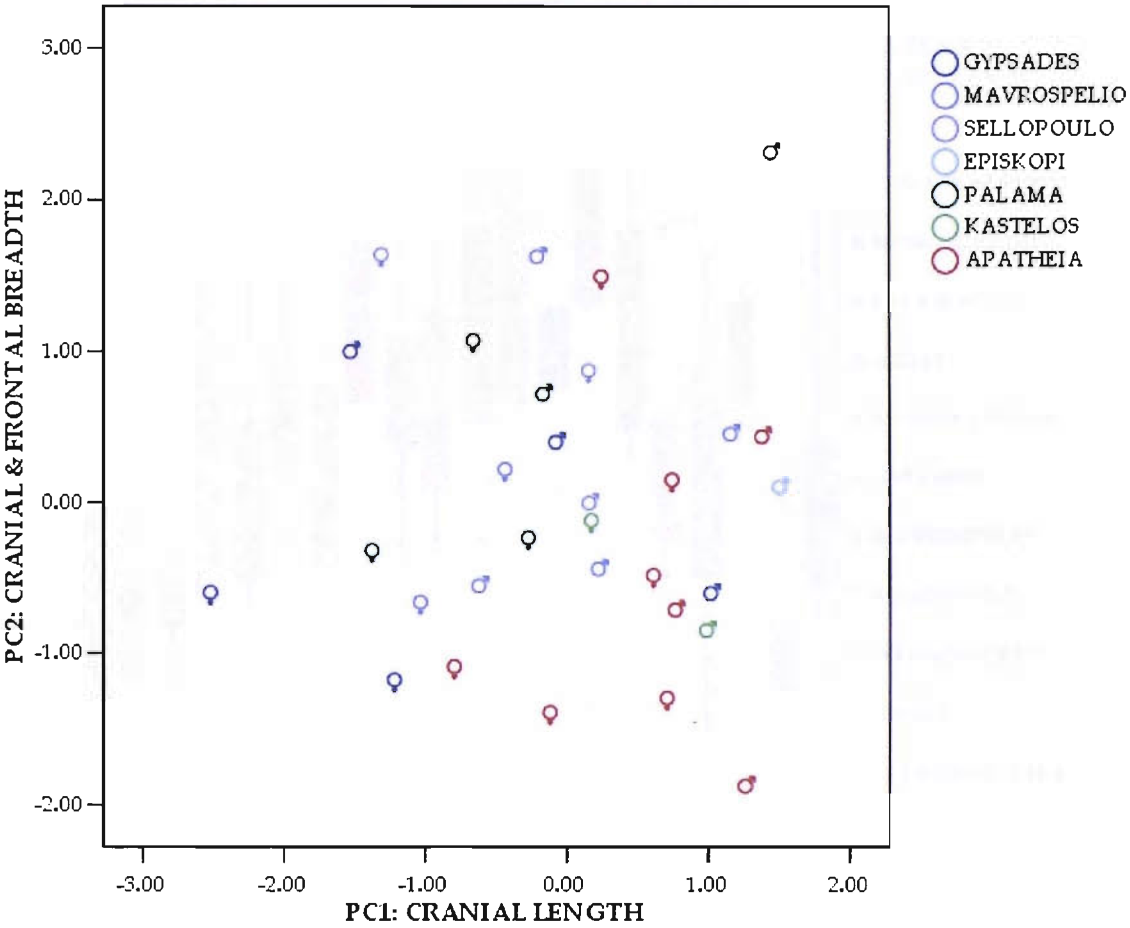
Table 6.3.27 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	2.141	42.824	42.824
2	1.681	33.611	76.435

Table 6.3.28 Component loadings for PCA of variables describing the length and breadth of the cranium.

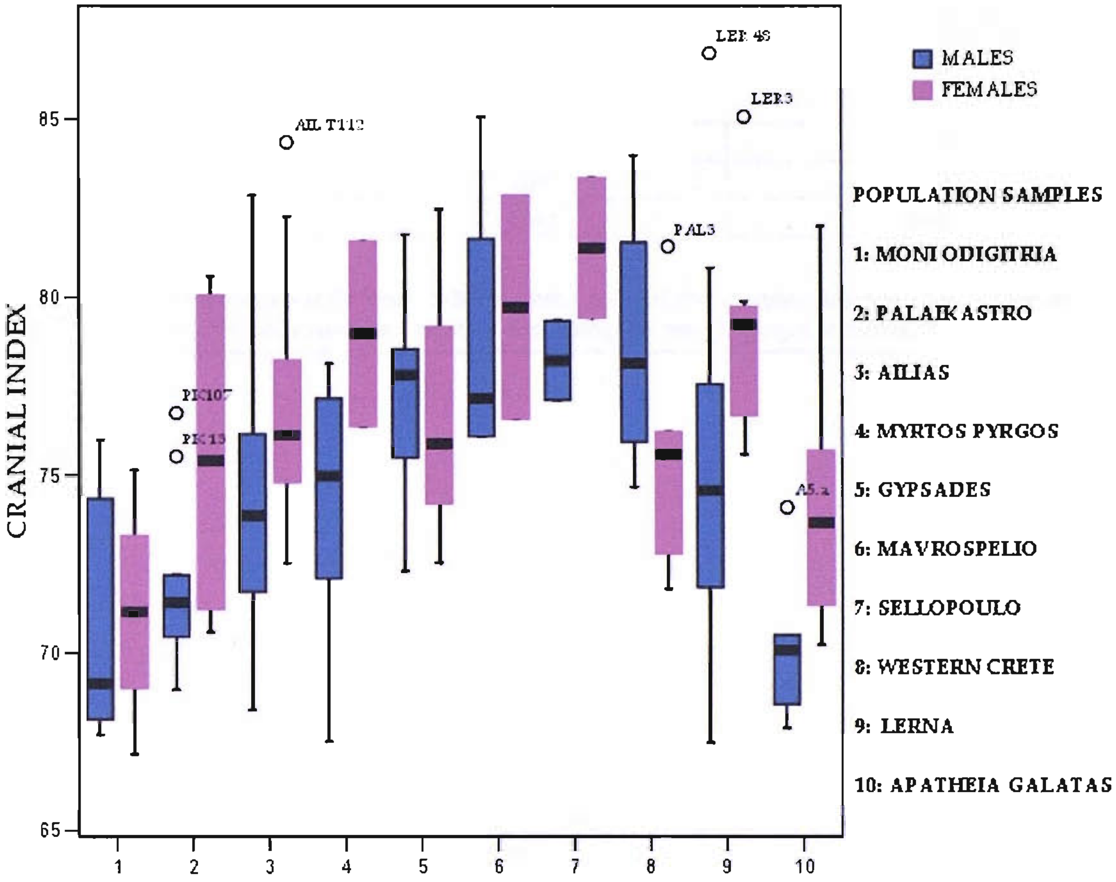
Cranial Metric Variables	Component	
	1	2
GOL	.890	-.227
XCB	.245	.888
XFB	.221	.867
FRC	.795	.030
PAC	.780	-.297

Figure 6.3.17 Inter-population distance, LBA Central and Western Crete and Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



Plotting of the results shows a clear clustering of the Palama individuals with their contemporaries from Central Crete. When compared with males and females from the Apatheia sample, the LBA Cretans of the same sex appear to have crania that are broad for their length, resulting in a more rounded shape. This is also clearly demonstrated when the Cranial Index is plotted for the tested samples (Figure 6.3.18).

Figure 6.3.18 Box and whisker plot of Cranial Index, Bronze Age population samples from Crete and the Argolid.



Middle Minoan Ailias – Middle Helladic Lerna: The relationship between the two Middle Bronze Age collections from the Argolid and Knossos district was explored using PCA (Figure 6.3.19). PCA was applied to GOL, XCB, VRR, FRC and PAC and the results are provided in Tables 6.3.29 and 6.3.30 (N=38). The tested variables describe cranial length, breadth and height.

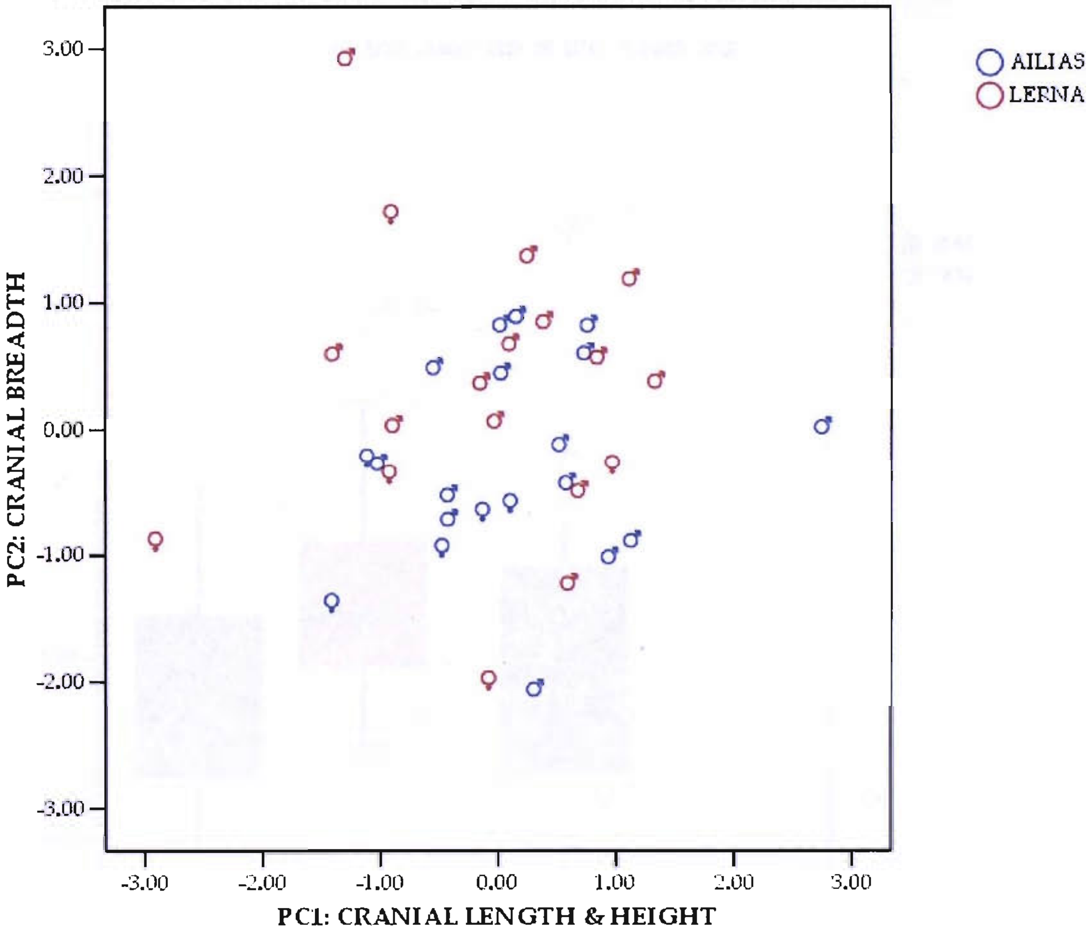
Table 6.3.29 Amount of variance explained by the 2 extracted PCs.

Components	Eigenvalues	% of Variance	Cumulative %
1	3.014	60.277	60.277
2	1.056	21.124	81.401

Table 6.3.30 Component loadings for PCA of variables describing the length, height and breadth of the cranium.

Cranial Metric Variables	Component	
	1	2
GOL	.887	-.050
XCB	.590	.710
FRC	.835	.340
PAC	.699	-.589
VRR	.832	-.296

Figure 6.3.19 Inter-population distance, MBA Knossos and Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length, height and breadth of the cranium.

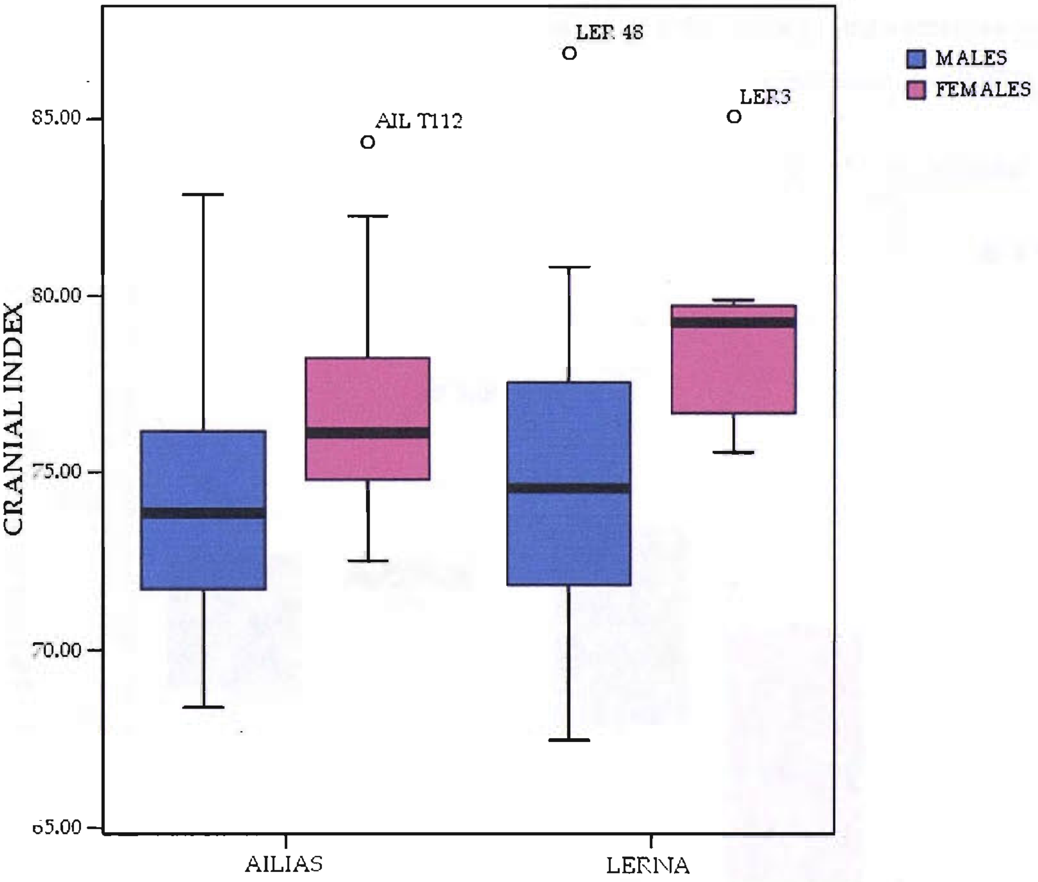


PCA results were plotted in Figure 6.3.19 and the patterning of the data fails to show any distinct separation between the two Middle Bronze age populations. Male individuals in both samples tend to have broader, longer and higher-vaulted crania than the females. Females in both the Ailias and Lerna samples are underrepresented. There is a slight tendency, however, for the Lerna crania to be relatively broad for their length and height in comparison with the Ailias specimens.

Lerna and Ailias samples do not show the distinct separation observed between their descendents of the Late Bronze Age (Figures 6.3.15, 6.3.16 and 6.3.17).

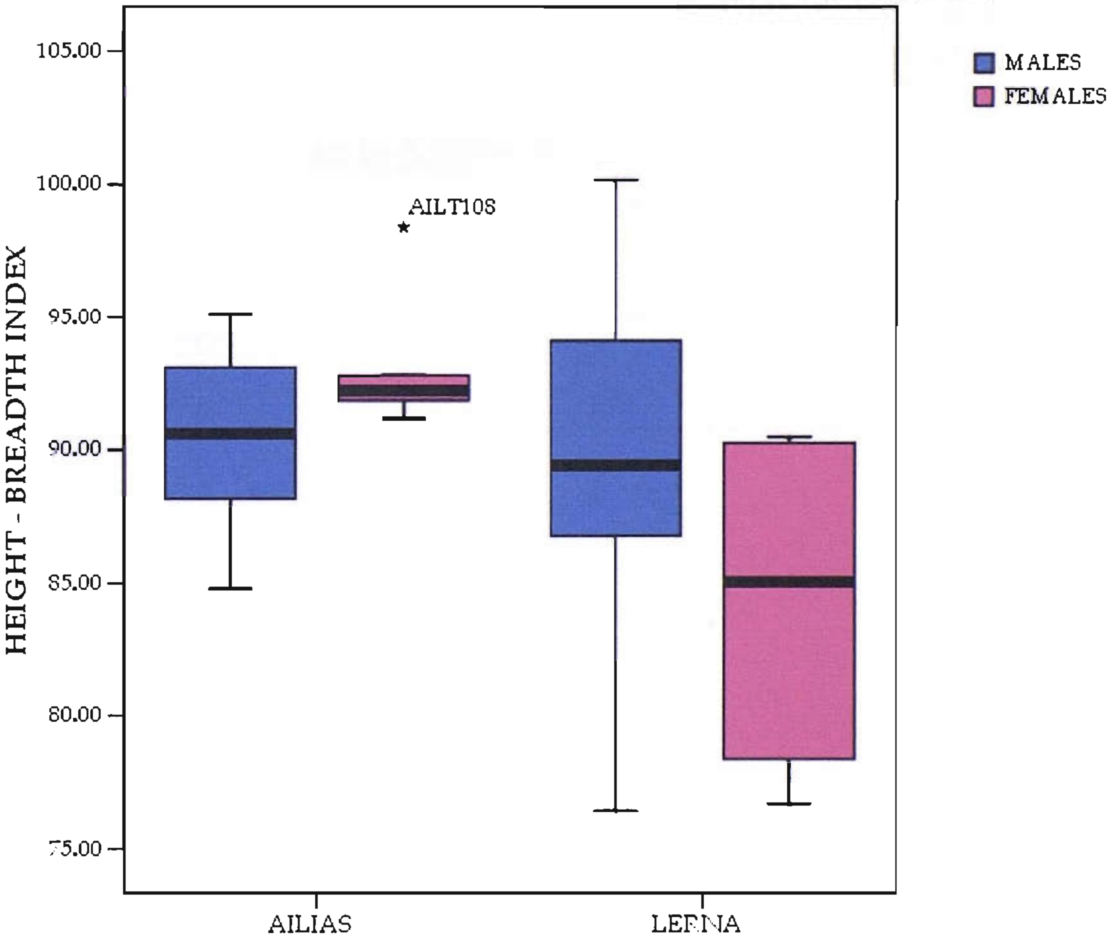
In order to understand better the relationship between the Ailias and Lerna samples in terms of the size and shape of the cranium, the Cranial Index calculated for the two samples was plotted (Figure 6.3.20). One-way ANOVA did not detect significant difference between the means of the two samples. Male and female groups were tested separately and the results for One-way ANOVA are p=0.625 and p=0.232 respectively. Plotting of the data suggests a very similar cranial shape for the two samples. As was observed in Figure 6.3.19, the Lerna female cranium tends to be slightly more rounded than the cranium of the Ailias females.

Figure 6.3.20 Box and whisker plot of the Cranial Index, Ailias and Lerna samples.



One-way ANOVA was applied to the calculated Height-Breadth (md) Indices for the two Middle Bronze Age samples; males and females were tested separately. Analysis failed to detect significant variance for the HBI(md) means between the male groups of the Ailias and Lerna samples (p=0.889). Due to low sample sizes and the inequality of intra-group variances for the HBI(md), as suggested by the Levene test (p=0.009), the variance between the female groups of the Ailias and Lerna samples was tested using the more robust tests of variance (p=0.076 for both the Welch and Brown-Forsythe tests). Plotting of the data in Figure 6.3.21 suggests that the Ailias females tend to have a cranium that is high for its breadth in comparison with that of the Lerna females. Although the males from the Ailias sample also tend to have crania that are slightly higher for their breadth than the Lerna males, inter-sample difference is not as clear as for the females from the same samples. The pattern of sexual dimorphism in Height - Breadth (md) Index is different between the two samples. In the Ailias sample, the females tend to have a cranium that is slightly high for its breadth relative to the males. By contrast, the Lerna males appear to have crania that are high for their breadth compared with the females. Also, the Lerna male and female groups show a greater range of variation for the calculated values. The Levene test confirmed the inequality of the intra-group variances for the Height-Breadth Index for the females (p=0.009), but not for the males (p=0.053).

Figure 6.3.21 Box and whisker plot of the Height-Breadth (md) Index, Ailias and Lerna samples.



The MMII-LMI Myrtos Pyrgos sample (Eastern Crete), which is roughly contemporary with the Ailias and Lerna samples, was entered into analysis, in order to investigate further the relationship between Middle Bronze Age samples from Crete (Central and Eastern) and the Argolid. PCA explored the inter-population relationships using GOL, XCB, XFB, FRC and PAC and the results are provided in Tables 6.3.31 and 6.3.32 (N=51). Graphical representation of the results in Figure 6.3.22 confirms the similarity of the cranial morphology of the Ailias and Lerna individuals that was suggested by the results presented earlier (Figures 6.3.19, 6.3.20 and 6.3.21). Myrtos Pyrgos falls within the range of variation of the Ailias and Lerna samples; it appears to be less variable than Ailias and Lerna. This probably should be attributed to the low size of the tested Myrtos Pyrgos sample and the low representation of the females within it.

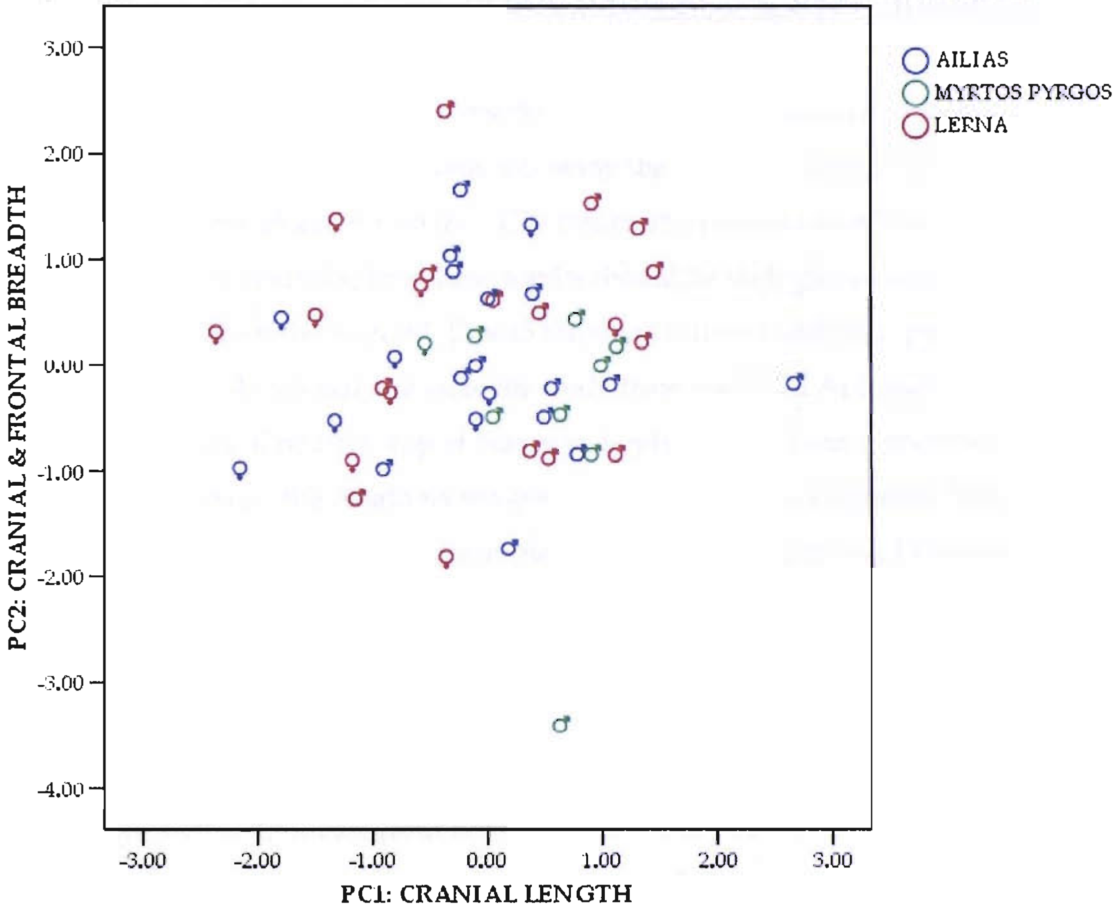
Table 6.3.31 Amount of variance explained by the 2 extracted PCs.

Component	Eigenvalues	% of Variance	Cumulative %
1	2.569	51.385	51.385
2	1.422	28.443	79.829

Table 6.3.32 Component loadings for PCA of variables describing the length and breadth of the cranium.

Cranial Metric Variables	Component	
	1	2
GOL	.834	-.428
XCB	.486	.777
XFB	.644	.647
FRC	.835	-.139
PAC	.725	-.444

Figure 6.3.22 Inter-population distance, MBA Cretan and Argolid samples, sexes pooled but separated by symbol (♂ and ♀): PCA results for variables describing the length and breadth of the cranium.



6.3.1.2 Testing the hypothesis for a Mycenaean high status migration to the Chora of Naxos following the destructions at the end of LHIIIB on the Greek Mainland

In order to confirm the hypothesis that high status individuals from the Argolid settled at the Chora of Naxos following the LHIIIB-C destructions on the Mainland and were interred into the LCIII tombs at Aplomata and Kamini cemeteries, the individuals from these tombs should be biologically related to their contemporaries from the Argolid. Due to the small number and poor preservation of the human skeletal material available for study from the LCIII Aplomata and Kamini tombs, the biological relationship of Naxos individuals with their contemporaries from the Argolid (i.e. the Apatheia sample) and Crete (i.e. the Gypsades, Sellopoulo, Mavrospelio, Kastelos and Palama samples) is assessed by applying Discriminant Function Analysis (DFA) to the cranial morphology.

DFA investigates group membership for the tested cases (i.e. individuals) using selected variables. It was applied to variables describing the cranial length, breadth and the morphology of the midline curvature of the calvaria so as to assess whether the two individuals from Naxos grouped with members of the Argolid sample on the basis of cranial metric morphology. The two individuals from Naxos, a female from Tomb B in the Aplomata cemetery and a male from the Kamini cemetery, who qualified for this analysis were entered into the analysis as members of the Apatheia sample from the Argolid (i.e. actual group, Tables 6.3.34 and 6.3.36), in order to test the hypothesis that they represent Argolid refugees. If the hypothesis is true, the actual and predicted group membership for the two individuals from Naxos will be the same.

DFA was undertaken separately for females and males. It was applied first to GOL, FRC, PAC, PAS, PAF, OCC, OCS, OCF data recorded from females (Table 6.3.33). Analysed cranial metric variables were selected on the basis of the completeness and preservation of the tested Naxos cranium and in order to provide the best possible description of cranial shape. The correctly predicted group membership is high. Of the original cases (female individuals), 92% were classified into their actual group, i.e. all but the Aplomata female. The female individual from Tomb B in the Aplomata cemetery was assigned membership to the Cretan female group and not to the Argolid (Apatheia) one as hypothesized (Table 6.3.34). The last column of Table 6.3.34 gives the squared Mahalanobis distance of the Aplomata female to the centroid of the Argolid female group (D^2=2.478). On the basis of the results of the analysis (Table 6.3.34), the hypothesis that the examined individual from Naxos (APLB) derived from the Argolid population is rejected.

Table 6.3.33 Classification Function Coefficients, DFA of variables describing the cranial length and the morphology of the midline curvature of the calvaria.

CRANIAL METRIC VARIABLES	CLUSTER	
	1	2
GOL	-3.016	-3.022
FRC	10.274	10.372
PAC	19.177	18.355
PAS	24.219	21.759
PAF	-14.159	-13.099
OCC	-.301	.136
OCS	23.109	21.151
OCF	8.522	8.050
(Constant)	-1829.565	-1709.846

Table 6.3.34 Inter-population distance, LBA Argolid, Cretan and Naxos samples, females: Discriminant Function Analysis of variables describing the cranial length and the morphology of the midline curvature of the calvaria.

INDIVIDUAL	ACTUAL GROUP	PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF ACTUAL GROUP (for the misclassified cases)
A1.z	1	1	1.199	
A3.b	1	1	.257	
A3.c	1	1	.646	
A5.14	1	1	2.931	
A5.9	1	1	.060	
A5.c	1	1	1.548	
A5.5	1	1	.056	
LGI.D	2	2	.058	
SEL4.2	2	2	.825	
SEL2.N	2	2	.279	
APL.B	**1**	**2(**)**	**1.556**	**2.478**
MSP7	2	2	.031	
MSP8	2	2	.633	

KEY: 1=ARGOLID, 2=CRETE, ** =Misclassified case.

On the other hand, the male from the Kamini tomb appears to be closely related to the Argolid (Apatheia) male group in terms of the examined aspects of cranial morphology; DFA was applied to XCB, XFB, FRC, FRS, FRF data recorded from males (Table 6.3.35). Of the analysed cases (male individuals), 80% were correctly classified; the correctly predicted group membership is lower than in the previous analysis (Table 6.3.36). For those cases that were misclassified, the last column of Table 6.3.36 gives the squared Mahalanobis distance to the population centroid of the actual group a case belongs.

Table 6.3.35 Classification Function Coefficients, DFA of variables describing the cranial breadth and the morphology of the frontal bone.

CRANIAL METRIC VARIABLES	CLUSTER	
	1	2
XCB	2.155	2.597
XFB	6.202	5.936
FRC	4.563	4.546
FRS	-.079	-.379
FRF	-4.162	-4.543
(Constant)	-669.991	-670.922

Table 6.3.36 Inter-population distance, LBA Argolid, Cretan and Naxos samples, males: Discriminant Function Analysis of variables describing the cranial breadth and the morphology of the frontal bone.

INDIVIDUAL	ACTUAL GROUP	PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF ACTUAL GROUP (for the misclassified cases)
A3.a	1	1	.003	
A5.a	1	1	.430	
A5.3	1	1	.267	
LGI.21	**2**	**1(**)**	**.568**	**1.217**
LGI.F5.1	2	2	.118	
GXVIII.VII	2	2	.315	
SEL1.SEB.1	2	2	.433	
KAMINI	1	1	.037	
KAS6	**2**	**1(**)**	**.009**	**3.100**
PALI	2	2	.000	
PAL.15C	2	2	.196	
MSP5	**2**	**1(**)**	**.384**	**1.530**
MSP4	2	2	.760	
MSP2	2	2	4.419	
MSP1	2	2	.174	

KEY: 1=ARGOLID, 2=CRETE, ** =Misclassified case.

6.3.2 Argolid and Cretan samples: Inter-regional Analysis of Cranial Non-metric Morphology

At the inter-regional level, the Mean Measure of Divergence analysis is used to measure the genetic distance between the Cretan and the two Argolid samples.

The principles of this analysis have been outlined in section 6.1.2. Care was taken given the low size of the samples and the inequality of the number of the scorable cases in the tested samples. Trait frequencies for which at least one of the tested samples was represented by less than 5 individuals, were removed from the MMD analysis, thus reducing the number of traits analysed (trait frequencies (%) and number of individuals scored (n) for all tested Argolid and Cretan samples are given in Appendix E, Tables 6.1, 6.2 and 6.3). The results of MMD analysis are presented in Table 6.3.37.

At the inter-regional level, the significant biological distance (MMDst higher than 2) between the two Early Minoan samples (Moni and Palaikastro) on the one hand, and the Middle Minoan Lerna sample on the other, discredits the possibility for the early Cretans to have derived from Argolid (Mainland) founder populations. Concerning the main archaeological hypothesis examined in this thesis, if the tombs in the Sellopoulo and Mavrospelio cemeteries belonged to people from the Argolid, who arrived at Crete in the LMII or LMIIIA2, then these individuals cannot share a common ancestor with the Gypsades sample, and are biologically related to the Apatheia individuals. However, the results of MMD analysis suggest the converse; the Sellopoulo and Mavrospelio samples share a common ancestor with the Gypsades sample and not with the Apatheia sample (see Table 6.3.38). Thus, on the basis of the results of MMD analysis of cranial non-metrics, the tested hypothesis is rejected.

Table 6.3.37 Inter-population distance, Cretan and Argolid samples, sexes pooled: MMD analysis results for cranial non-metrics.

POPULATION SAMPLES	Number of traits tested	MMDv	SD	MMDst
Moni - Palaikastro	71	0.0504	0.059841	**0.8429**
Moni - Ailias	42	0.005974	0.003681	**1.6229**
Moni - Myrtos Pyrgos	71	0.0700	0.023466	2.9851
Moni - Gypsades	42	0.6088	0.040391	15.0730
Moni - Sellopoulo	42	0.2758	0.017178	16.0564
Moni - Palama	36	-0.00486	0.006234	-0.78028
Moni - Lerna	59	1.6434	0.011585	141.8561
Moni - Apatheia	42	0.154776	0.005626	27.5091
Palaikastro - Myrtos Pyrgos	71	0.3962	0.043438	9.1213
Palaikastro - Palama	35	0.066097	0.005821	11.3547
Palaikastro - Lerna	59	1.5646	0.021335	73.3381
Palaikastro - Apatheia	42	0.194285	0.014379	13.5119
Ailias - Myrtos Pyrgos	43	0.1054	0.001879	56.1238
Ailias - Gypsades	43	0.1842	0.033995	5.4192
Ailias - Sellopoulo	44	0.0667	0.016469	4.0535
Ailias - Mavrospelio	34	0.012233	0.006413	**1.9074**
Ailias - Palama	45	0.067364	0.003867	17.4201
Ailias - Apatheia	43	0.2835	0.003134	90.4736
Myrtos Pyrgos - Mavrospelio	57	0.02907	0.023736	**1.2247**
Myrtos Pyrgos - Palama	45	0.122916	0.004242	28.9746
Myrtos Pyrgos - Lerna	60	1.5980	0.006523	244.9875
Myrtos Pyrgos - Apatheia	43	0.1441	0.00333	43.2946
Gypsades - Palaikastro	42	0.114269	0.055264	**2.067674**
Gypsades - Mavrospelio	40	0.0609	0.068377	**0.8914**
Gypsades - Sellopoulo	50	0.09133	0.088154	**1.036**
Gypsades - Myrtos Pyrgos	43	0.026985	0.034659	**0.7785**
Gypsades - Palama	18	0.072576	0.00182	32.8718
Gypsades - Apatheia	57	0.1544	0.0369992	4.8185
Gypsades - Lerna	43	0.79057	0.032657	24.208
Sellopoulo -Mavrospelio	54	0.2816	0.095597	2.9464
Sellopoulo - Palama	14	-0.18735	0.002588	-75.3786
Sellopoulo - Apatheia	57	0.4548	0.0412137	11.0373
Sellopoulo - Lerna	43	0.416617	0.012646	32.9439
Mavrospelio - Apatheia	34	0.328247	0.009381	34.9913
Mavrospelio - Lerna	56	2.2873	0.03947	57.9516
Palama - Mavrospelio	24	-0.06109	0.004083	-14.9605
Palama - Lerna	41	0.849075	0.003204	265.0358
Palama - Apatheia	36	0.071206	0.003888	18.3131
Apatheia - Lerna	60	0.025	0.006034	16.9864

Table 6.3.38 Inter-population distance, Cretan and Argolid samples, sexes pooled: MMD analysis of cranial non-metrics, Standardized values.

SAMPLES	MONI	PALAIKASTRO	AILIAS	MYRTOS PYRGOS	GYPSADES	MAVROSPELIO	SELLOPOULO	PALAMA	LERNA	APATHEIA
MONI	0									
PALAIKASTRO	**0.8429**	0								
AILIAS	**1.6229**	-5.5226	0							
MYRTOS PYRGOS	2.9851	9.1213	56.1238	0						
GYPSADES	15.073	**2.0676**	5.4192	**0.7785**	0					
MAVROSPELIO	2.1634	7.7815	**1.9074**	**1.2247**	**0.8914**	0				
SELLOPOULO	16.0564	9.4895	4.0535	3.5384	**1.036**	3.6444	0			
PALAMA	-0.78028	11.35473	17.4201	28.97469	32.87183	-14.9605	-75.3786	0		
LERNA	141.8561	73.3381	704.982	244.9875	24.208	57.9516	32.9439	265.0358	0	
APATHEIA	27.5091	13.5119	90.4736	43.2946	4.8185	34.9913	11.0373	18.31317	16.5457	0

MMDst values in bold suggest a common ancestry for the tested population samples.

6.3.3 Argolid and Cretan samples: Inter-regional Analysis of Dental Metric Morphology

This section investigates the relationship between the Argolid and Cretan samples in terms of dental metric morphology.

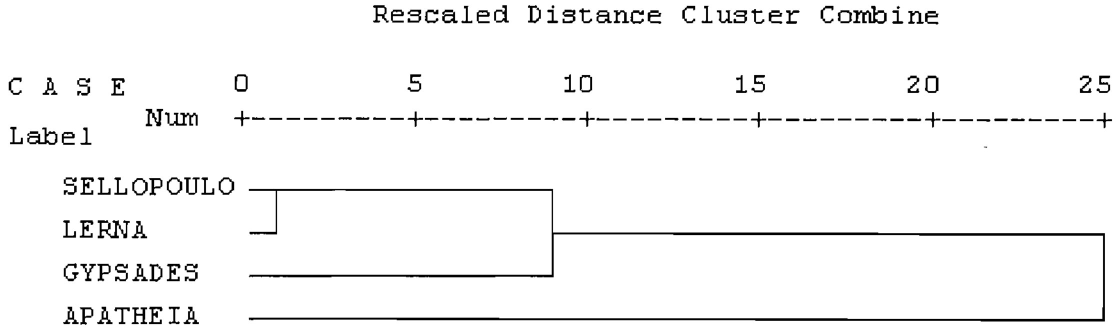
6.3.3.1 Inter-regional analysis of dental morphology, Argolid and Cretan samples: Hierarchical Cluster Analysis of mean dental measurements

In order to explore further inter-sample differences in dental metric morphology and measure inter-sample biological distance at the inter-regional level, Hierarchical Cluster Analysis was applied to all (mean) dental metric variables recorded. The inter-regional analysis of dental morphology focuses on the investigation of the hypothesis that people from the Argolid arrived and settled at Knossos at the end of LMIB. Therefore, the Palama sample from Western Crete was removed from the analysis to allow for the investigation of inter-sample biological distance to focus on Central Crete and the Argolid. The calculated Squared Euclidean distances between the tested samples are given in Table 6.3.39 and the results of the analysis are visually represented in Figure 6.3.23.

Table 6.3.39 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for all mean dental measurements, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance			
Samples	GYPSADES	SELLOPOULO	LERNA	APATHEIA
GYPSADES	.000	12.571	17.136	27.193
SELLOPOULO	12.571	.000	9.579	28.353
LERNA	17.136	9.579	.000	21.810
APATHEIA	27.193	28.353	21.810	.000

Figure 6.3.23 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for all mean dental measurements, Dendrogram using Average Linkage (Between Groups).



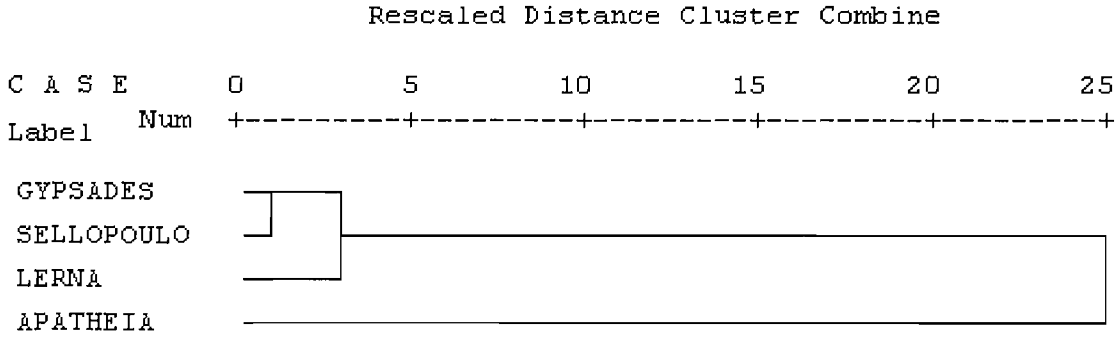
On the dendrogram (Figure 6.3.23), Sellopoulo clusters closer to Gypsades (also in the Knossos district) than to its contemporary sample from the Argolid (i.e. the Apatheia sample). The Apatheia sample forms a distinct cluster and appears to separate very clearly from the two Knossos and Lerna samples. Hence patterning of the data refutes the hypothesis for an Argolid origin of the individuals interred into the Sellopoulo tombs. A second interesting point in the patterning of the data in Figure 6.3.23 is the relationship of Lerna with the Cretan samples on the basis of the tested variables. The Middle Bronze Age Lerna sample would be expected to cluster with the Late Bronze Age Apatheia sample due to their geographical proximity within the Argolid region. In contrast, Lerna clusters closely to the Cretan samples and distantly from Apatheia.

Because the measurement of the mesio-distal tooth crown diameter has been shown to be affected by dental wear more than that of the bucco-lingual diameter (Hillson *et al.* 2005), mesio-distal tooth crown diameters were removed from the analysis and the results are given in Table 6.3.40 and Figure 6.3.24.

Table 6.3.40 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for all mean dental measurements, Bucco-lingual tooth crown diameter only, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance			
Samples	GYPSADES	SELLOPOULO	LERNA	APATHEIA
GYPSADES	.000	5.033	7.055	21.904
SELLOPOULO	5.033	.000	5.580	22.765
LERNA	7.055	5.580	.000	16.120
APATHEIA	21.904	22.765	16.120	.000

Figure 6.3.24 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for all mean dental measurements, Bucco-lingual tooth crown diameter only, Dendrogram using Average Linkage (Between Groups).



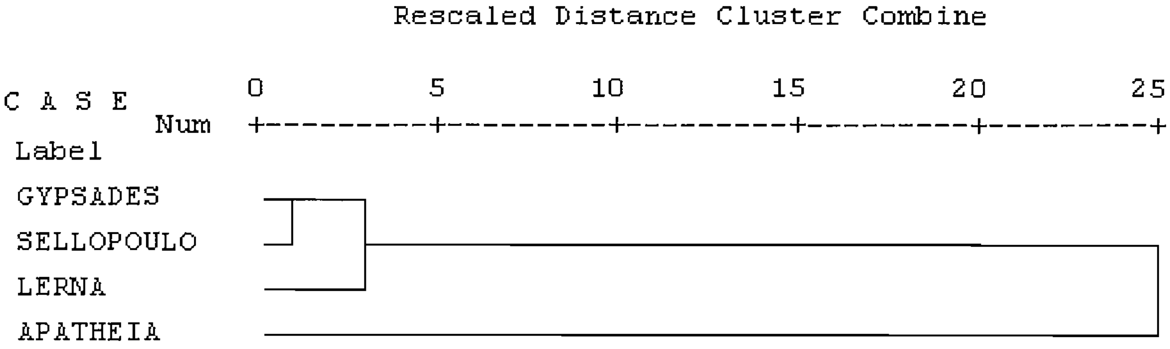
On the dendrogram (Figure 6.3.24), the tested samples are grouped in two clusters. The two successive Bronze Age samples from Knossos (i.e. the Gypsades and Sellopoulo samples) cluster closely together and at marked distance from the Late Bronze Age Argolid sample (Apatheia). As in Figure 6.3.23, the Lerna sample clusters closer to the two Knossos samples than to the Apatheia sample (also from the Argolid). Clustering of the samples in Figures 6.3.23 and 6.3.24 suggests a great biological distance between Apatheia and the other three tested samples.

When Hierarchical Cluster Analysis is applied to bucco-lingual crown diameters of polar teeth only (Table 6.3.41, Figure 6.3.25), the calculated inter-sample distances are very similar to those measured using all the recorded dental metric variables (Figure 6.3.24).

Table 6.3.41 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for mean dental measurements, Bucco-lingual tooth crown diameter only, Polar teeth, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance			
Samples	GYPSADES	SELLOPOULO	LERNA	APATHEIA
GYPSADES	.000	1.127	2.480	14.434
SELLOPOULO	1.127	.000	2.732	18.710
LERNA	2.480	2.732	.000	12.276
APATHEIA	14.434	18.710	12.276	.000

Figure 6.3.25 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for mean dental measurements, Bucco-lingual tooth crown diameter only, Polar teeth, Dendrogram using Average Linkage (Between Groups).

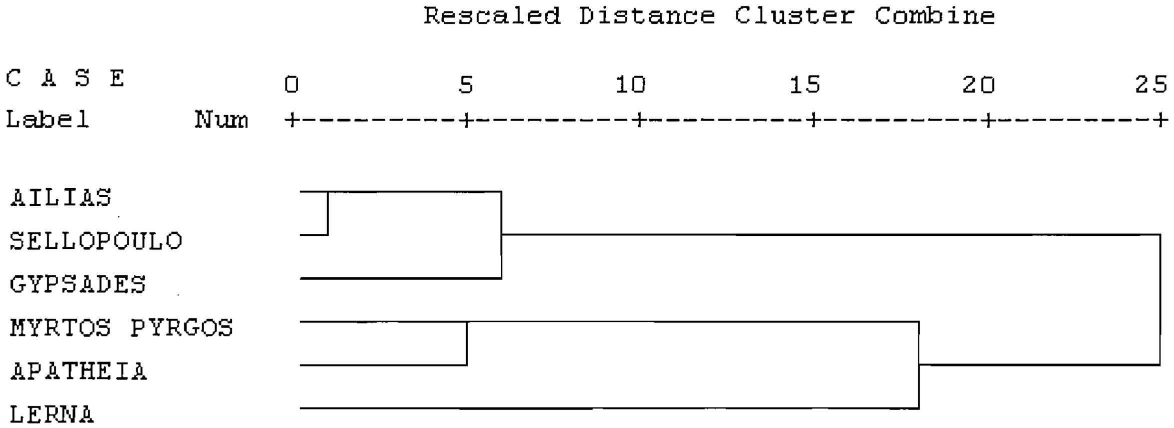


In order to investigate further the patterning of inter-sample distances, Hierarchical Cluster Analysis was applied to the bucco-lingual and mesio-distal diameters (right and left sides pooled to maximize sample size) of the upper and lower polar teeth. The 1st Incisor was removed from the analysis due to the susceptibility of its MD crown diameter to dental attrition. The calculated inter-sample distances are given in Table 6.3.42 and they are graphically represented in Figure 6.3.26.

Table 6.3.42 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth (excluding 1st Incisor), R and L sides pooled, Squared Euclidean Distance between the tested samples.

Samples	**Squared Euclidean Distance**					
	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	LERNA	APATHEIA
AILIAS	.000	1.843	.923	.684	1.864	2.432
MYRTOS PYRGOS	1.843	.000	1.738	2.033	1.275	.924
GYPSADES	.923	1.738	.000	1.022	2.690	2.168
SELLOPOULO	.684	2.033	1.022	.000	1.164	2.005
LERNA	1.864	1.275	2.690	1.164	.000	1.956
APATHEIA	2.432	.924	2.168	2.005	1.956	.000

Figure 6.3.26 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth (excluding 1st Incisor), R and L sides pooled, Dendrogram using Average Linkage (Between Groups).



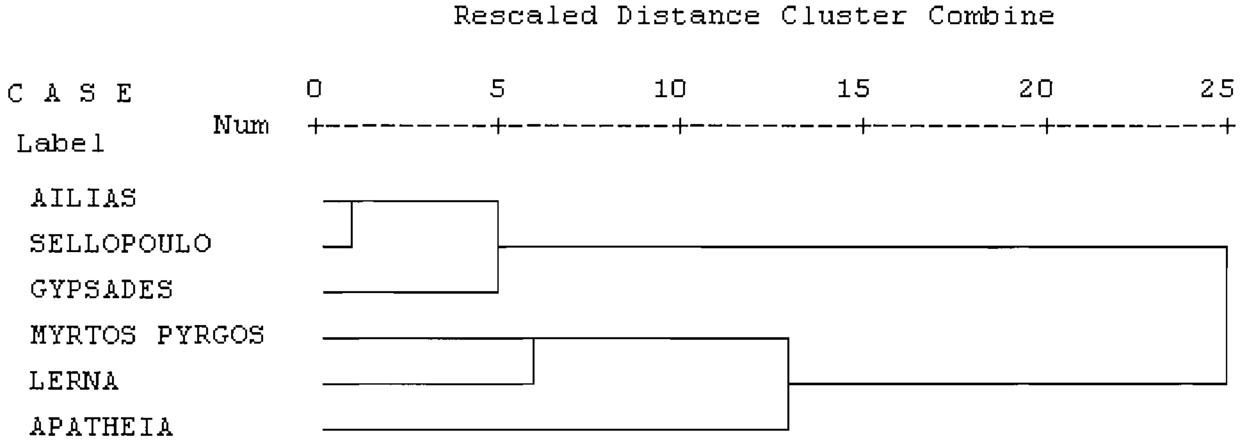
Patterning of inter-sample distances in Figure 6.3.26 suggests a very close biological relationship shared by the three successive Knossos samples (i.e. the Ailias, Sellopoulo and Gypsades samples) and a great biological distance between these and the two Argolid samples (Lerna and Apatheia).

Clustering of the samples in Figure 6.3.26 is very similar to that on the dendrogram produced using the results of the analysis of bucco-lingual crown diameters of polar teeth only when right and left side measurements were pooled (Figure 6.3.27). For reasons related to dental wear, mesio-distal tooth crown diameters were removed from the analysis and inter-sample distances were calculated merely from the bucco-lingual diameters (Table 6.3.43, Figure 6.3.27). The very similar results of the two analyses (Figures 6.3.26 and 6.3.27) suggest no major distorting effect on the calculated inter-sample distances by the unequal impact of dental wear on bucco-lingual and mesio-distal tooth crown diameters.

Table 6.3.43 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth, R and L sides pooled, Bucco-lingual crown diameter only, Squared Euclidean Distance between the tested samples.

Samples	**Squared Euclidean Distance**					
	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	LERNA	APATHEIA
AILIAS	.000	1.154	.294	.198	.974	1.365
MYRTOS PYRGOS	1.154	.000	1.391	1.272	.418	.506
GYPSADES	.294	1.391	.000	.446	1.178	1.502
SELLOPOULO	.198	1.272	.446	.000	.904	1.096
LERNA	.974	.418	1.178	.904	.000	.874
APATHEIA	1.365	.506	1.502	1.096	.874	.000

Figure 6.3.27 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth, R and L sides pooled, Bucco-lingual crown diameter only, Dendrogram using Average Linkage (Between Groups).

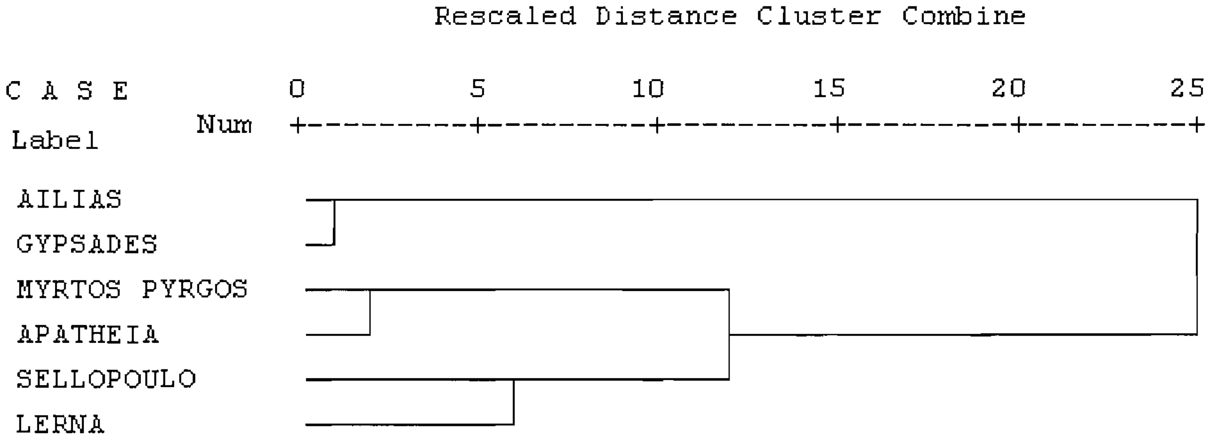


When inter-sample distances from Hierarchical Cluster Analysis results for bucco-lingual crown diameters of polar teeth were calculated separately for males and females, cluster analysis could not be performed for the female groups, because only two (i.e. the Gypsades and Lerna female groups) had values for all tested variables. Hierarchical cluster analysis results for males are provided in Table 6.3.44 and Figure 6.3.28.

Table 6.3.44 Inter-sample distance, Argolid and Cretan samples, males: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth, R and L sides pooled, Bucco-lingual crown diameter, Squared Euclidean Distance between the tested samples.

	Squared Euclidean Distance					
Samples	AILIAS	MYRTOS PYRGOS	GYPSADES	SELLOPOULO	LERNA	APATHEIA
AILIAS	.000	1.444	.320	.466	1.793	1.731
MYRTOS PYRGOS	1.444	.000	2.423	.751	.602	.423
GYPSADES	.320	2.423	.000	1.194	2.928	2.589
SELLOPOULO	.466	.751	1.194	.000	.679	1.400
LERNA	1.793	.602	2.928	.679	.000	1.349
APATHEIA	1.731	.423	2.589	1.400	1.349	.000

Figure 6.3.28 Inter-sample distance, Argolid and Cretan samples, males: Hierarchical Cluster Analysis results for dental measurements from the Upper and Lower Polar teeth, R and L sides pooled, Bucco-lingual crown diameter only, Dendrogram using Average Linkage (Between Groups).



Although on the dendrogram (Figure 6.3.28) the Sellopoulo sample clusters at distance from the other two Knossos samples (Ailias and Gypsades), it does not cluster with its contemporary sample from the Argolid (Apatheia), either. Moreover, on the basis of the values for the calculated Squared Euclidean distance (Table 6.3.44), the Sellopoulo sample is more closely related to the other three Cretan samples (Ailias, Gypsades and Myrtos Pyrgos), than to the Apatheia sample. Finally, these results should be interpreted cautiously given the low sample size. This is exacerbated by entering males, females and individuals of unknown sex separately into analysis.

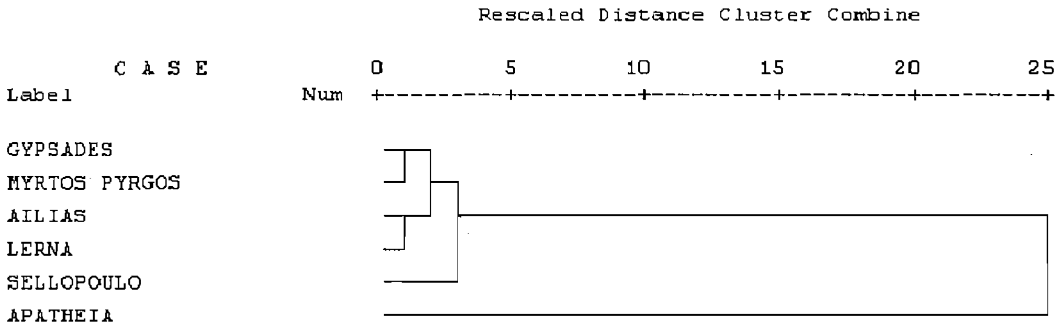
6.3.3.2 Inter-regional analysis of dental morphology, Argolid and Cretan samples, sexes pooled: Hierarchical cluster analysis of mean Dental Indices

Crown Index: Crown indices were calculated for the polar teeth of each tooth class for both the maxilla and mandible. Hierarchical Cluster Analysis was applied first to the Crown Indices of the upper polar teeth and the calculated Squared Euclidean Distances are tabulated (Table 6.3.45) (For N see Appendix D, Table 6.50). Inter-sample distances on the tested variables are visually represented in Figure 6.3.29. On the dendrogram (Figure 6.3.29), the Ailias, Gypsades and Sellopoulo samples cluster separately from the LHIII Apatheia sample from the Argolid. Furthermore, Lerna clusters closer to Ailias and Sellopoulo samples from Knossos than to Apatheia.

Table 6.3.45 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the Upper Polar teeth (R and L sides pooled), Squared Euclidean Distances between the tested samples.

Samples	Squared Euclidean Distance					
	AILIAS	SELLOPOULO	GYPSADES	APATHEIA	LERNA	MYRTOS PYRGOS
AILIAS	.000	172.064	74.543	1013.335	41.833	76.159
SELLOPOULO	172.064	.000	132.878	1746.034	58.604	224.777
GYPSADES	74.543	132.878	.000	1376.688	93.385	14.912
APATHEIA	1013.335	1746.034	1376.688	.000	1344.665	1197.101
LERNA	41.833	58.604	93.385	1344.665	.000	141.209
MYRTOS PYRGOS	76.159	224.777	14.912	1197.101	141.209	.000

Figure 6.3.29 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the Upper Polar teeth (R and L sides pooled), Dendrogram using Average Linkage (Between Groups).



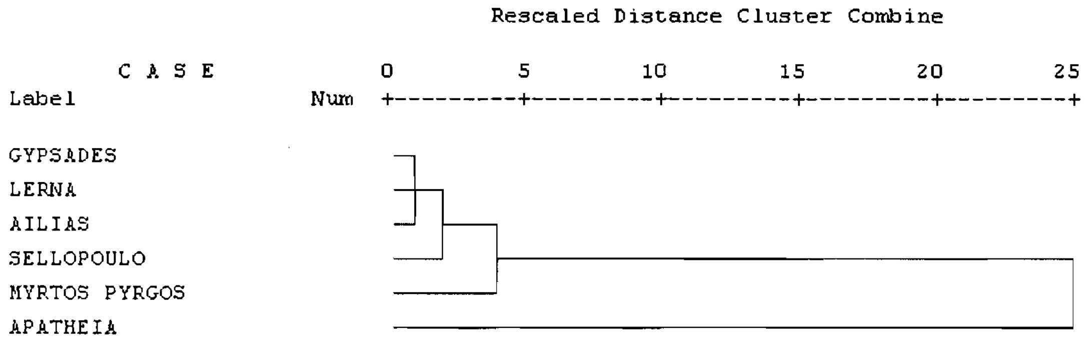
The Crown Indices of lower polar teeth were entered to the analysis and inter-sample Squared Euclidean Distances were calculated for the Crown Indices of both upper and lower polar teeth (For N see Appendix D, 6.50). The results are given in Table 6.3.46 and Figure 6.3.30.

Table 6.3.46 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the Upper and Lower Polar teeth (R and L sides pooled), Squared Euclidean Distances between the tested samples.

Samples	**Squared Euclidean Distance**					
	AILIAS	SELLOPOULO	GYPSADES	APATHEIA	LERNA	MYRTOS PYRGOS
AILIAS	.000	201.501	205.113	1126.296	136.253	239.949
SELLOPOULO	201.501	.000	239.029	1827.224	146.310	328.590
GYPSADES	205.113	239.029	.000	1469.214	118.668	239.605
APATHEIA	1126.296	1827.224	1469.214	.000	1504.350	1272.930
LERNA	136.253	146.310	118.668	1504.350	.000	422.910
MYRTOS PYRGOS	239.949	328.590	239.605	1272.930	422.910	.000

This is a dissimilarity matrix

Figure 6.3.30 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the Upper and Lower Polar teeth (R and L sides pooled), Dendrogram using Average Linkage (Between Groups).



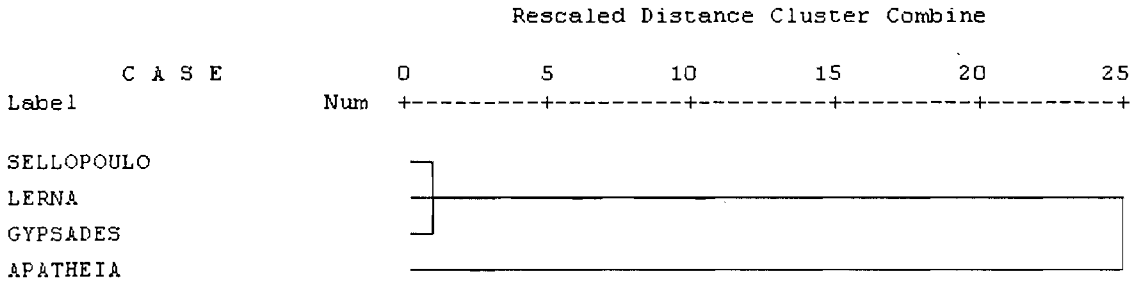
Clustering of the samples in Figures 6.3.29 and 6.3.30 using the results of the analysis of the shape of the tooth crown suggests a very close biological relationship shared by Gypsades, Ailias, Sellopoulo, Myrtos Pyrgos and Lerna on one hand, and a great biological distance between the Cretan samples and Apatheia on the other.

Inter-sample relationships are further explored by entering into the analysis the right and left side Crown Indices as separate variables (For N see Appendix D, Table 6.51). The Ailias and Myrtos Pyrgos samples are not represented by all tested variables (i.e. Crown Indices of I1R and LI1L for Ailias and Crown Index of LI1R for Myrtos Pyrgos) and therefore, did not qualify for this analysis. The results of the Hierarchical Cluster Analysis are given in Table 6.3.47 and are graphically represented in Figure 6.3.31. On the dendrogram (Figure 6.3.31), the Apatheia sample clusters at distance from its two roughly contemporary samples from Knossos (Gypsades and Sellopoulo) and the Lerna sample from the Argolid.

Table 6.3.47 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the R and L side Upper and Lower Polar teeth, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance			
Samples	SELLOPOULO	GYPSADES	APATHEIA	LERNA
SELLOPOULO	.000	556.758	6671.597	356.061
GYPSADES	556.758	.000	5348.372	357.483
APATHEIA GALATAS	6671.597	5348.372	.000	5990.087
LERNA	356.061	357.483	5990.087	.000

Figure 6.3.31 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the R and L side Upper and Lower Polar teeth, Dendrogram using Average Linkage (Between Groups).



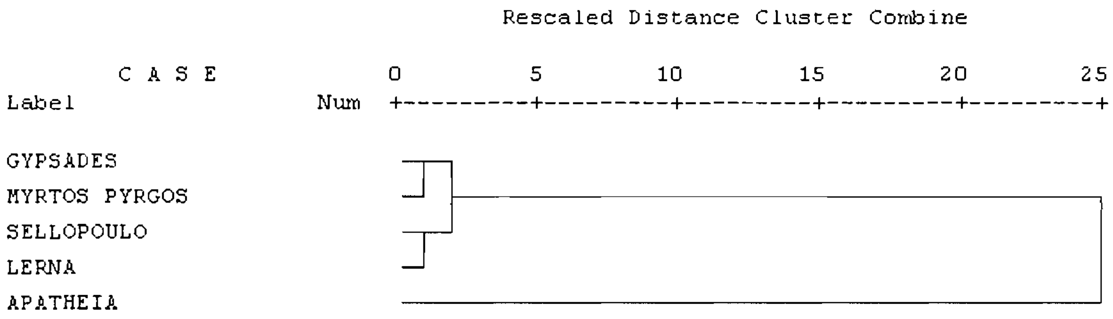
The Crown Index for the 1st incisor was removed from the analysis due to the susceptibility of its MD tooth crown diameter to dental wear, and inter-sample distances were calculated for the Crown Indices of all other polar teeth from both the upper and lower dentition. Right and left sides were introduced separately to the analysis and the results are given in Table 6.3.48 and Figure 6.3.32 (For N see Appendix D, Table 6.51).

Table 6.3.48 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the R and L side Upper and Lower Polar teeth (excluding 1st Incisor), Squared Euclidean Distances between the tested samples.

Samples	Squared Euclidean Distance				
	SELLOPOULO	GYPSADES	APATHEIA	LERNA	MYRTOS PYRGOS
SELLOPOULO	.000	436.930	6667.845	206.017	580.705
GYPSADES	436.930	.000	5237.495	355.743	125.124
APATHEIA GALATAS	6667.845	5237.495	.000	5851.317	5435.151
LERNA	206.017	355.743	5851.317	.000	425.520
MYRTOS PYRGOS	580.705	125.124	5435.151	425.520	.000

This is a dissimilarity matrix

Figure 6.3.32 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Crown Indices of the R and L side Upper and Lower Polar teeth (excluding 1st Incisor), Dendrogram using Average Linkage (Between Groups).



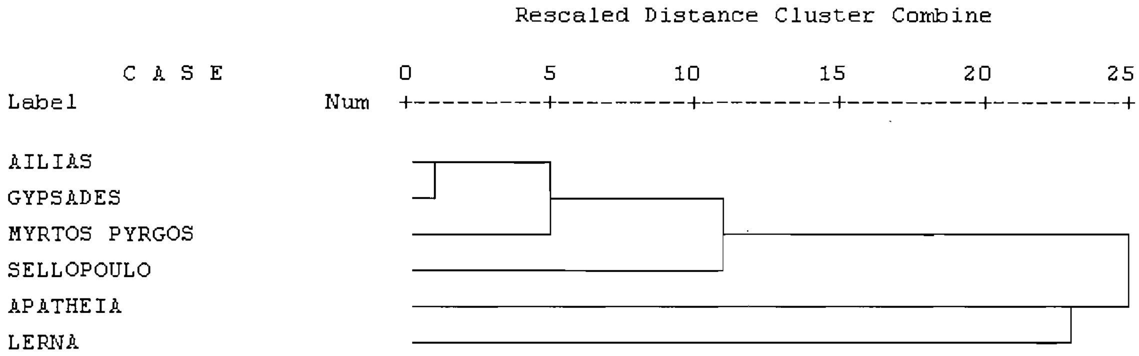
In Figure 6.3.32, Apatheia is clearly separated from the other tested samples on the results of the analysis of the shape of the crown of all maxillary and mandibular polar teeth except the 1st Incisor.

Robustness Index or Crown area: The Robustness Index was calculated for the upper and lower teeth of the tested population samples (i.e. Ailias, Gypsades, Sellopoulo, Myrtos Pyrgos, Lerna and Apatheia samples) and inter-sample biological relationships were investigated using hierarchical cluster analysis. The results of the analysis of the Robustness Index of the upper polar teeth (right and left sides pooled) are presented in Table 6.3.49 (For N see Appendix D, Table 6.52). Figure 6.3.33 shows the clustering of the samples on the basis of the tested variables.

Table 6.3.49 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness Indices of the Upper Polar teeth (R and L sides pooled), Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance					
Samples	AILIAS	SELLOPOULO	GYPSADES	APATHEIA	LERNA	MYRTOS PYRGOS
AILIAS	.000	108.748	40.264	181.624	224.437	60.164
SELLOPOULO	108.748	.000	138.382	382.792	178.674	111.078
GYPSADES	40.264	138.382	.000	247.001	337.903	83.619
APATHEIA	181.624	382.792	247.001	.000	206.492	163.185
LERNA	224.437	178.674	337.903	206.492	.000	107.327
MYRTOS PYRGOS	60.164	111.078	83.619	163.185	107.327	.000

Figure 6.3.33 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness Indices of the Upper Polar teeth (R and L sides pooled), Dendrogram using Average Linkage (Between Groups).



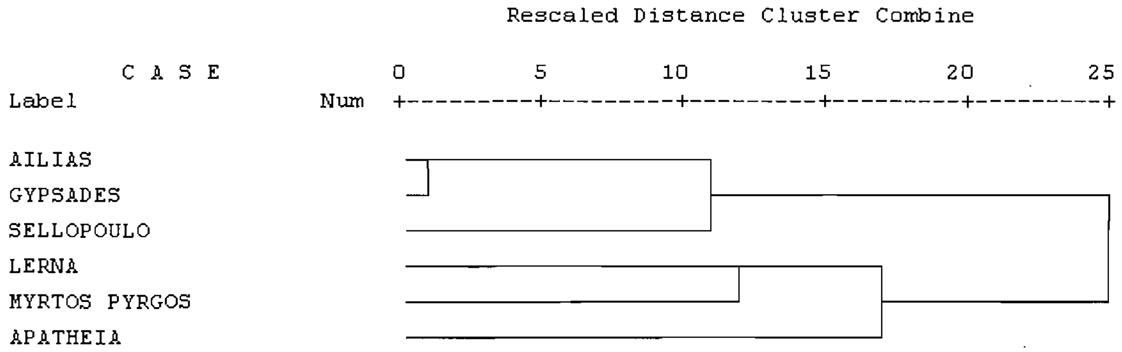
Clustering of the samples in Figure 6.3.33 accords very well with their geographical distribution. The Apatheia and Lerna samples from the Mainland cluster together and at clear distance from the Cretan samples. Furthermore, the patterning of inter-sample relationships in the first cluster (Cretan samples) is in agreement with the dating of the samples. LMI Gypsades succeeded MM Ailias in the district of Knossos. From the other two Cretan samples, the MMII-LMI Myrtos Pyrgos (Eastern Crete) clusters closer to Ailias and Gypsades than does the LMII-III Sellopoulo (Knossos).

Hierarchical cluster analysis was applied to the mean Robustness Index of upper and lower polar teeth from each tooth class (For N see Appendix D, Table 6.52). The 1st incisor was removed from the analysis, for reasons related to dental attrition. The results are tabulated (Table 6.3.50) and graphically represented (Figure 6.3.34).

Table 6.3.50 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness Indices of Upper and Lower Polar teeth (excluding 1st Incisor), R and L sides pooled, Squared Euclidean Distances between the tested samples.

	Squared Euclidean Distance					
Samples	AILIAS	SELLOPOULO	GYPSADES	APATHEIA	LERNA	MYRTOS PYRGOS
AILIAS	.000	160.424	50.993	371.575	341.489	171.171
SELLOPOULO	160.424	.000	182.436	502.738	219.121	225.710
GYPSADES	50.993	182.436	.000	451.117	477.880	231.528
APATHEIA	371.575	502.738	451.117	.000	274.939	195.530
LERNA	341.489	219.121	477.880	274.939	.000	177.039
MYRTOS PYRGOS	171.171	225.710	231.528	195.530	177.039	.000

Figure 6.3.34 Inter-sample distance, Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the Robustness Indices of Upper and Lower Polar teeth (excluding 1st Incisor) (R and L sides pooled), Dendrogram using Average Linkage (Between Groups).



In Figure 6.3.34, the samples form two clusters. One comprises the Ailias, Gypsades and Sellopoulo samples, and the other comprises the Lerna, Myrtos Pyrgos and Apatheia samples. The results of the present analysis of tooth crown size (described by the Robustness Index) confirm the biological relatedness of the three Knossos samples (Ailias, Gypsades and Sellopoulo) and their biological distance from those from the Argolid samples (Lerna and Apatheia).

Finally, a note should be made on the overall agreement of inter-sample distances reconstructed using the results of the analysis of both bucco-lingual and mesio-distal crown diameters, bucco-lingual tooth crown diameters only, and the Crown and Robustness Index data. This finding suggests two things. First, the impact of dental wear on tooth crown morphology appears not to have been unequal enough for the bucco-lingual and mesio-distal tooth crown diameters to distort inter-sample distances measured by entering both diameters into analysis. Second, although tooth size, as described by bucco-lingual tooth crown diameter, is asserted to have been exposed to natural selective forces (Brace *et al.* 1991), in the present study it may reflect more than that, i.e. the genetic make-up of the parent population, gene flow, and/or genetic drift.

6.3.4 Argolid and Cretan samples: Inter-regional Analysis of Dental Non-metric Morphology

Inter-population genetic distance was measured by applying Mean Measure of Divergence analysis to dental non-metric traits. Twelve and eleven non-metric traits were scored on the upper and lower dentition respectively (Appendix B, Table 5.6). Right and left sides were scored separately for reasons outlined in Chapter 5, section 5.1.2.3.2. Information on the impact of low sample size on the actual number of traits entered to the analysis and the meaning of negative values for MMDst and how they were treated in the current analysis is provided in section 6.2.4 (Crete: Dental Non-metric Morphological Analysis). The results of the analysis are given in table 6.3.51. Trait frequencies and sample size for all tested samples are given in Appendix E, Tables 6.4, 6.5, 6.6 and 6.7.

Table 6.3.51 Inter-population distances, Argolid and Cretan samples, sexes pooled: MMD analysis results for Dental Non-metrics.

Population Samples	Number of traits tested	MMDv	SD	MMDst
Myrtos Pyrgos – Lerna	28	0.067644	0.001355	49.90637
Myrtos Pyrgos – Apatheia	36	0.182079	0.003431	53.06755
Myrtos Pyrgos – Gypsades	33	-0.04282	0.003768	-11.3617
	46	-0.09024	0.012238	-7.3741
Myrtos Pyrgos – Sellopoulo	20	0.03334	0.002416	13.79765
Gypsades – Sellopoulo	20	-0.05439	0.003761	-14.464
	46	0.059558	0.029504	2.018643
Gypsades – Apatheia	28	0.063586	0.003403	18.68549
Gypsades – Lerna	34	0.034974	0.004172	8.383902
Sellopoulo - Lerna	20	-0.068948	0.002475	-27.85352
Sellopoulo – Apatheia	20	0.053369	0.003153	16.92898
Palama – Sellopoulo	46	0.122984	0.002741	3.405807
	12	-0.04689	0.03611	-17.1112
Palama – Gypsades	46	-0.02226	0.023227	-0.95856
	18	-0.03892	0.003767	-10.3323
Palama – Myrtos Pyrgos	46	-0.04551	0.014751	-3.0854246
	22	-0.13022	0.003476	-37.4649
Palama – Lerna	46	0.047799	0.01315	3.634801
	22	-0.04131	0.002814	-14.6807
Palama - Apatheia	46	-0.09073	0.017931	-5.56209
	19	-0.05946	0.003356	-17.7189
Apatheia – Lerna	36	0.261777	0.003108	84.23716

Hierarchical cluster analysis was applied to explore the distances between the samples from Central Crete and the Argolid dating from the period before the suggested migration (i.e. the Myrtos Pyrgos, Gypsades and Lerna samples) to the period following it (i.e. the Sellopoulo and Apatheia samples). Squared Euclidean distances were calculated using the Mean Measure of Divergence values (Table 6.3.52) and the results are visually represented (Figure 6.3.35).

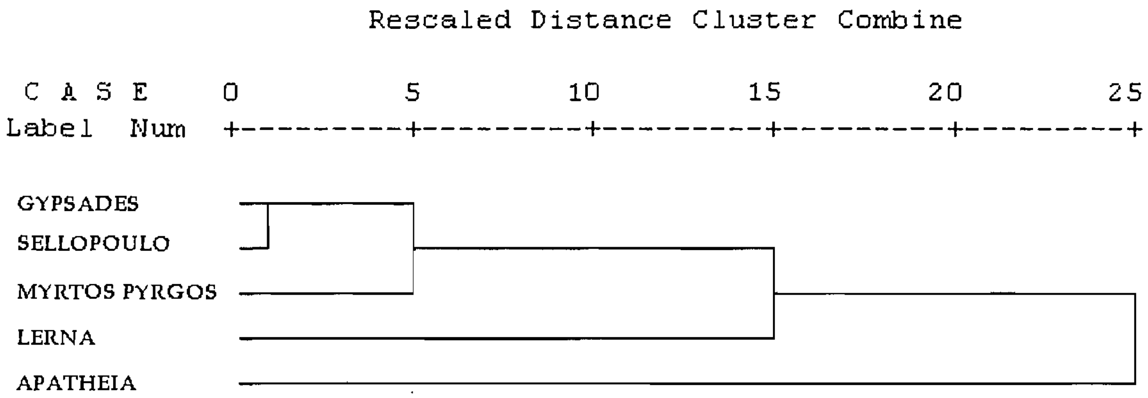
Samples are grouped into two main clusters (Figure 6.3.35). The first consists of three sub-clusters. In this one, the Sellopoulo and Gypsades samples cluster in close proximity. The Myrtos Pyrgos sample clusters at a relatively small distance from the Sellopoulo and Gypsades samples, and slightly more distantly from the Lerna sample. Lerna and Myrtos Pyrgos are contemporary samples from the Argolid and Crete respectively. The Apatheia sample (Argolid) dating to the LHIII is in marked distance from the Cretan samples.

On the basis of the results of the Mean Measure of Divergence analysis of dental non-metric traits, the distance between the population samples from Central Crete and the Argolid does not decrease from the Middle Bronze Age to the period post-dating the LMIB destructions and subsequent cultural upheaval. Therefore, the hypothesis for the migration and settlement of individuals from the Argolid to Knossos following the destructions is rejected.

Table 6.3.52 Inter-sample distance, MBA and LBA Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the values of MMD analysis of Dental Non-metrics, Squared Euclidean Distances between the tested samples.

Samples	**Squared Euclidean Distance**				
	LERNA	APATHEIA	GYPSADES	SELLOPOULO	MYRTOS PYRGOS
LERNA	.000	.097	.053	.057	.027
APATHEIA	.097	.000	.070	.042	.078
GYPSADES	.053	.070	.000	.012	.025
SELLOPOULO	.057	.042	.012	.000	.019
MYRTOS PYRGOS	.027	.078	.025	.019	.000

Figure 6.3.35 Inter-sample distances, MBA and LBA Argolid and Cretan samples, sexes pooled: Hierarchical Cluster Analysis results for the values of MMD analysis of Dental Non-metrics, Dendrogram using Avarage Linkage (Between Groups).



6.3.5 Argolid and Cretan samples: Summary of Inter-regional Analysis of Cranial and Dental Metric and Non-metric Morphology

On the basis of the results of the analysis of sexual dimorphism in the Argolid and Cretan samples (sections 6.1.1.1, 6.1.1.2, 6.1.1.3, 6.2.1.1 and 6.2.1.2), the two sexes were pooled in order to maximize sample size in the investigation of inter-sample biological relationships at the intra- and inter-regional level, but they (sexes) were differentiated by symbols (♂= male, ♀= female) in scatter plots, and separate boxes in box and whisker plots.

Analysis of the cranial morphology investigated the two hypotheses tested in sections 6.3.1.1 and 6.3.1.2 for Mycenaean migration to Knossos and Naxos at the end of the LMIB and at LHIIIB-C respectively. Concerning the first hypothesis, analysis provided negative evidence for discontinuity in the biological history of the Knossos population at the end of the LMIB due to the arrival and settlement of biologically different individuals from the Argolid. The results of PCA suggest a very similar cranial shape for the three successive Knossos samples, dating immediately prior to (LMI Gypsades sample) and following the suggested migration (LMII-III Sellopoulo and LMIII Mavrospelio samples) (Figures 6.3.5 and 6.3.6). In agreement with the results of the analysis of cranial metrics are those derived from cranial non-metric morphology. These suggest that the three Late Minoan populations from Knossos (Gypsades, Sellopoulo and Mavrospelio) share a common ancestor (Tables 6.3.37 and 6.3.38). This is unexpected if the tombs in the Sellopoulo and Mavrospelio cemeteries belong to individuals from the Argolid who settled at Knossos in the LMII or LMIIIA2.

Analysis of dental metric and non-metric morphology also showed that the three successive Bronze Age Knossos population samples (i.e. the MM Ailias, LMI Gypsades and LMII-III Sellopoulo samples) share a close biological relationship (Figures 6.3.23, 6.3.24, 6.3.25, 6.3.26, 6.3.27, 6.3.30, 6.3.31, 6.3.32, 6.3.33, 6.3.34 and 6.3.35). On the basis of the results of dental non-metric analysis (Table 6.3.51), a common ancestor is suggested for the Gypsades and Sellopoulo samples (dating immediately prior to and following the alleged Mycenaean migration).

Additionally, cranial metric analysis failed to provide evidence of an increase in the intra-population variation for the Cretan samples post-dating the LMIB destructions resulting from the settlement at Knossos of biologically different individuals from the Argolid (Tables 6.3.21 and 6.3.22, Figures 6.3.11, 6.3.12, 6.3.13

and 6.3.14). Finally, analysis of cranial (Figures 6.3.15, 6.3.16 and 6.3.17) and dental (Figures 6.3.23, 6.3.24, 6.3.25, 6.3.26, 6.3.27, 6.3.29, 6.3.30, 6.3.31, 6.3.32, 6.3.33 and 6.3.34) metric morphology demonstrated that inter-sample distance did not decrease between the Argolid and Cretan samples dating from the LMII onwards. It showed that there is a distinct separation between the LHII-III Apatheia sample from the Argolid and the LMI-III samples from Knossos (i.e. the Gypsades, Sellopoulo and Mavrospelio samples). The possibility that the separation between the Apatheia and Knossos samples in terms of cranial metric morphology is the result of sexual dimorphism and differences in the representation of the two sexes in the tested samples was checked and refuted.

Although the Middle Bronze Age Lerna sample from the Argolid does not appear to separate clearly from the Cretan samples in terms of cranial (Figures 6.3.19, 6.3.20, 6.3.22) and dental metric morphology (6.3.23, 6.3.24, 6.3.25, 6.3.29, 6.3.30, 6.3.31, 6.3.32), non-metric morphological analysis of both the cranium (Tables 6.3.37 and 6.3.38) and teeth (Table 6.3.51, Figure 6.3.35) showed all tested Cretan samples to be biologically distant from both Argolid samples (i.e. Lerna and Apatheia). Significant biological distance between the two Argolid samples is suggested by the results of cranial and dental non-metric analysis (Tables 6.3.37, 6.3.38 and 6.3.51, Figure 6.3.35).

With regard to inter-sample distances reconstructed using the results of the analysis of dental metric morphology, a note should be made on the agreement of inter-sample distances measured from the analysis of both bucco-lingual and mesio-distal tooth crown diameters and those measured from bucco-lingual diameters only (see Figures 6.2.23, 6.3.24, 6.3.25, 6.3.26 and 6.3.27), and also inter-sample distances measured from Crown and Robustness Index data (Figures 6.3.30, 6.3.31, 6.3.32, 6.3.33 and 6.3.34). Restriction of analysis to bucco-lingual tooth crown diameters was undertaken in order to control for the unequal impact of dental wear on the two diameters of the tooth crown (Hillson *et al.* 2005).

The agreement of the results probably suggests that the impact of dental wear on tooth crown morphology was not unequal enough for the bucco-lingual and mesio-distal tooth crown diameters to distort inter-sample distances measured by entering to the analysis both diameters. This could be attributed to a combination of factors: the unworn to slightly worn juvenile dentitions are not used in this study, dental wear is not severe for the recorded Bronze Age Aegean skeletal collections, and the measuring methodology employed by this study (see section 5.1.2.3.1). Also, although tooth size, as described by bucco-lingual tooth crown diameter, is asserted to have been exposed to natural selective forces (Brace *et al.* 1991), in the present study it may reflect more than that, i.e. the genetic make-up of the parent population, gene flow, genetic drift. Because of the overall agreement of inter-sample distances measured from bucco-lingual and mesio-distal tooth crown diameters, bucco-lingual diameters only, and Crown and Robustness Index data, in order to exclude any possibility the reconstructed inter-sample distances reflecting the unequal impact of dental wear on the two recorded tooth crown diameters, the discussion of dental metric morphological analysis results in Chapter 8 uses only the analysis of bucco-lingual tooth crown diameters.

Hence the results of cranial and dental morphological analysis are consistent with the principal assumption of the study that the Bronze Age populations from the Argolid and Crete were biologically distant enough to allow for the assessment of fluctuations in their biological relationship introduced by inter-regional population movement and biological interactions. Finally, acknowledging the low sample size, on the basis of the results of cranial and dental morphological analysis the hypothesis for the settlement of Mycenaeans at Knossos at the end of the LMIB can be rejected.

With regard to the second hypothesis for the settlement of Mycenaeans on Naxos, the results of the cranial metric analysis are not clear. The hypothesis was tested by analysing males and females separately. Unfortunately, only two individuals from the Aplomata and Kamini cemeteries at the Chora of Naxos qualified for the analysis. Although the results of the analysis for the Aplomata female are not consistent with the tested hypothesis, those for the Kamini male are consistent with it. Strontium isotope ratio analysis was undertaken to shed more light on this matter.

CHAPTER 7

RESULTS OF STRONTIUM ISOTOPE RATIO ANALYSIS

($^{87}Sr/^{86}Sr$)

In this chapter, the results of the strontium isotope ratio (SIR) analysis of bone and dental enamel samples from selected individuals from the studied collections are presented. SIR analysis complements the morphological analysis of the skeleton and it was performed in order to detect the presence of non-local individuals within the indigenous population. It explores two specific questions of population migration within the Bronze Age South Aegean context. These concern the arrival and settlement of individuals from the Argolid first, at Knossos on Crete following the destructions at the end of the Late Minoan IB, and second, on the island of Naxos at the end of LHIIIB. A common element in both hypotheses is that the population movement did not involve the whole body of the society, but a particular stratum of it; the aristocracy. Analysis also explores the hypothesis formulated on the basis of material culture evidence that the pit caves in the Palama cemetery in Western Crete belong to an ethnically different group living among the indigenous Late Bronze Age Cretan population at Chania. Finally, it sets the scene for exploring population movement within the island of Crete and migration from outside the island into other than Knossos sites by analysing samples from all morphologically studied skeletal collections, where possible. Moreover, the application of SIR analysis in the present study endeavours to explore the potential of this analysis for a similar broader future research project.

7.1 Results of Strontium Isotope Ratio Analysis

The choice of the samples for the SIR analysis is outlined in section 5.2.3. The results of the analysis are presented in four sections. Sections 7.1.1 and 7.1.3 investigate the hypotheses for the presence of Mycenaeans among the people buried in cemeteries at Knossos and the Chora of Naxos respectively. Sections 7.1.2 and 7.1.4 present the results of the analysis of samples from more skeletal collections from Crete (including the Palama collection) and Naxos respectively. A description, provenance and the SIR values for all analysed human and non-human samples are provided in Appendix F, Table 7.1.

7.1.1 Hypothesis A for population movement from the Argolid to Knossos (Crete)

The first hypothesis tested here is that at the end of the LMIB, people from the Argolid (Mainland) invaded and settled at Knossos on Crete. Settlement involved high status individuals and their warrior aristocracy. They politically dominated Knossos and they were interred into the so-called "warrior" graves after they died (Sakelarakis 1972; Popham *et al.* 1974; Kanta 1980; Hood 1985; Doxey 1987: 301; Driessen 1990: 125; Popham 1994: 93).

In order to confirm this hypothesis, SIR measured in the dental enamel of individuals interred into the "warrior" graves should be different from the biologically available strontium at the site of Knossos, due to the geology of the two regions (Argolid and Knossos) being different (Higgins & Higgins 1996). On the other hand, the SIR values for these individuals should be congruent with the biologically available strontium at Mycenae in the Argolid. If, however, the hypothesis is false and the tested individuals are locals, then the SIR values for the analysed individuals will fall within the range for the local biologically available SIR at the Knossos district and outside that for Mycenae. Moreover, SIR values measured for the individuals that were interred into the "warrior" graves should be similar to SIRs measured from other individuals from the Knossos district for which a local origin is assumed.

In the district of Knossos, "warrior" graves have been excavated at the Late Minoan cemeteries of Zapher Papoura, Ayios Ioannis, Mavrospelio and Sellopoulo (Popham 1994). Due to the absence of teeth from the first three collections, sampling for measuring the strontium isotope ratio was confined to the Sellopoulo collection. SIR was measured for 8 individuals from the tombs of the Sellopoulo cemetery. For two of the tested individuals (SELI, VII and SELI, III), the ratio was measured from dental enamel and bone samples, whereas for the other 6 individuals measurements were taken from dental samples alone (for the choice of samples see section 5.2.3).

SIR was measured in samples from individuals from the Gypsades and Ailias cemeteries also from the Knossos district (in less than 2 km distance), who are assumed to represent the local population, in order to compare their SIRs with those measured from the Sellopoulo individuals. SIR was measured in samples from 9 individuals of the Gypsades cemetery. Eight individuals from Gypsades are represented merely by samples of dental enamel, whereas for one individual the ratio was measured in both enamel and bone samples. Eight more individuals from the Ailias cemetery were sampled (dental enamel) for the present analysis.

7.1.1.1 Biologically available strontium isotope ratio at the Knossos district and Mycenae

Knossos district: In order to determine the biologically available strontium at the region of Knossos and distinguish between local and non-local individuals, SIR was measured in archaeological and modern animal teeth, as well as in shell samples from modern snails, in addition to measurements taken from archaeological human bone samples (see Chapter 5, section 5.2.2) (Table 7.1).

The mean SIR measured in dental enamel from 3 archaeological animals (2 sheep/goats and 1 pig) is 0.708884 ± 0.000177, and the range for ± 2 s.d. is 0.708530 to 0.709238. Very similar to the mean SIRs for archaeological animal teeth is the mean for the SIR measured in shell samples from four modern snails collected from the same district. This was calculated as 0.708985 ± 0.000031 and the range for ± 2 s.d. is 0.708923 to 0.709047. The value for the ratio (0.708957 ± 0.000011) measured in tooth enamel from a modern rabbit from the village of Asites close to Knossos (less than 10 km distance), accords well with the values derived for the first two controls. The three human bone samples from Knossos (two from the Sellopoulo and one from the Gypsades skeletal collections) gave a mean of 0.709022 ± 0.000022, and the range for ± 2 s.d. is 0.708978 to 0.709066. Individuals from the Knossos district are determined as locals or non-locals using the archaeological animal dental enamel criterion, because it determined a wider range for the local biologically available strontium, compared to the ranges determined from archaeological human bone and modern snails.

Mycenae: The biologically available SIR at Mycenae was determined from shell samples from four modern snails. One was collected from inside the acropolis, two from the area surrounding the fortifications (≤ 500m), and the last at 2km distance from it. The mean value for the SIR measured in the shell of the snails is 0.708267 ± 0.000043 and the range for ± 2 s.d. is 0.708181 to 0.708353.

Table 7.1 SIR values for samples used to determine the biologically available SIR at Knossos and Mycenae; archaeological animal dental enamel, modern snail shell, dental enamel from one modern rabbit and human bone.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
LGI, Balk A-B (ANH)	M1	0.708989
KN A (ANH)	M1	0.708985
SELI A (ANH)	M1	0.708679
SELI, VII (AH)	Femur	0.709000
SELI, III (AH)	Tibia	0.709044
LGI, LARNAX (AH)	Femur	0.709022
KN1 SN	Shell	0.708991
KN2 SN	Shell	0.709026
KN3 SN	Shell	0.708974
KN4 SN	Shell	0.708952
AAS (R)	M1	0.708957
MYC1 SN	Shell	0.708262
MYC2 SN	Shell	0.708254
MYC3 SN	Shell	0.708226
MYC4 SN	Shell	0.708328

Key: LGI=Gypsades, KN=Knossos, SEL=Sellopoulo, AAS=Ano Asites, MYC=Mycenae, ANH=Archaeological Non-Human, AH=Archaeological Human, SN=Snail, R=Rabbit, M1=1st Molar.

7.1.1.2 Knossos district population samples

Ailias: Eight individuals from the tombs of Ailias were sampled for SIR analysis (Table 7.2). The mean ratio for the dental enamel was calculated as 0.709064 ± 0.000099 and the range of SIR values is between 0.708970 and 0.709227. The enamel values for the Ailias sample are very homogeneous; intra-sample variation is low (s.d.=0.000099) compared to other Cretan and Naxos samples (see later in this chapter). All SIR values for the Ailias sample fall within the reconstructed range for the biologically available SIR at the district of Knossos (0.708530 to 0.709238), determined from archaeological animal tooth enamel samples.

Table 7.2 SIR values for Ailias individuals, dental enamel.

Individual	Element Analysed	Strontium Isotope Ratio (value)
AIL 102	M1	0.708999
AIL 2	M1	0.708970
AIL 6	M1	0.709000
AIL 90	M1	0.709014
AIL 15	M1	0.709042
AIL 1	M1	0.709212
AIL 103	M1	0.709050
AIL 98	M1	0.709227

Key: M1=1st Molar.

Gypsades: For the Gypsades sample, the mean SIR in dental enamel was calculated as 0.709037 ± 0.000025 and the range of SIR values is between 0.708997 and 0.709085 (Table 7.3). The range of SIR values is very narrow for the Gypsades sample and it accords very well with the reconstructed local biologically available SIR at the district of Knossos (0.708530 to 0.709238).

Table 7.3 SIR values for Gypsades individuals, dental enamel and bone.

Individual	Element Analysed	Strontium Isotope Ratio (value)
GYPXVIII, III	M1	0.709053
GYPXVIII, II	M1	0.709021
GYPXVIII, III	M1	0.709029
GYPXVIII, VII	M1	0.709025
GYPXVIII, VI	M1	0.709058
LGI, F	M2	0.708997
LGI, F5	PM4	0.709035
LGI, E6	M1	0.709085
LGI, Larnax	M1	0.709033
LGI, Larnax	Femur	0.709022

Key: PM4=4th Premolar, M1=1st Molar, M2=2nd Molar.

Sellopoulo: The mean ratio for the tested Sellopoulo teeth was calculated as 0.708902 ± 0.000154 (Table 7.4). Intra-sample variation for the Sellopoulo sample (s.d.=0.000154) is higher compared to Gypsades (s.d.=0.000025) and Ailias (s.d.=0.000099). Although the ratio measured in the tooth enamel of individual SEL I, IV (0.708604 ± 0.000013) causes the Sellopoulo intra-sample variation to increase, the range of SIR values for Sellopoulo is, however, between 0.708604 and 0.709062 and falls within the reconstructed range for the local at Knossos biologically available SIR (0.708530 to 0.709238), determined from animal dental enamel (Figure 7.1). Therefore, on the basis of the results of SIR analysis the hypothesis for the presence of non-locals among the tested Sellopoulo individuals is rejected.

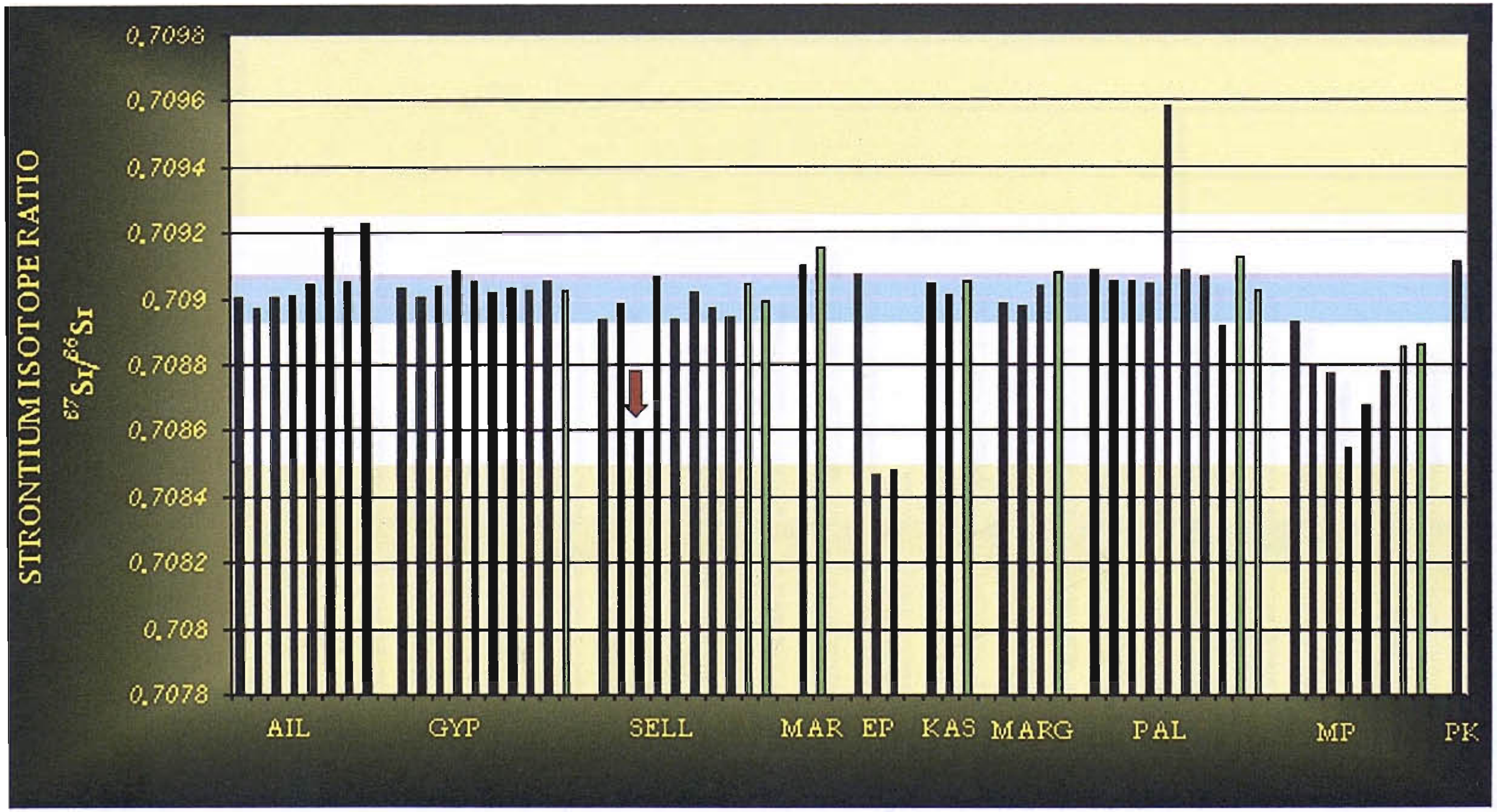
Table 7.4 SIR values for Sellopoulo individuals, dental enamel and bone.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
SEL4, 3	M1	0.708943
SELI, IV	M1	0.708604
SELI, IV	M1	0.708984
SELI, II	M1	0.709062
SELI, III NE	M1	0.708934
SELII, N.BOTHROS	M1	0.709016
SELI, III	M1	0.708967
SELI, III	Tibia	0.709044
SELI, VII	M1	0.708933
SELI, VII	Femur	0.709000

Key: M1=1st Molar.

Additional negative evidence for the presence of Mycenaeans amongst the individuals buried in the Sellopoulo cemetery derives from the local biologically available SIR at the site of Mycenae (Figure 7.2). Because all SIR values for the analysed Sellopoulo individuals fall outside the range for the local at Mycenae biologically available SIR (calculated as 0.708181 to 0.708353), the hypothesis for the presence of Mycenaeans interred into the Sellopoulo tombs is rejected.

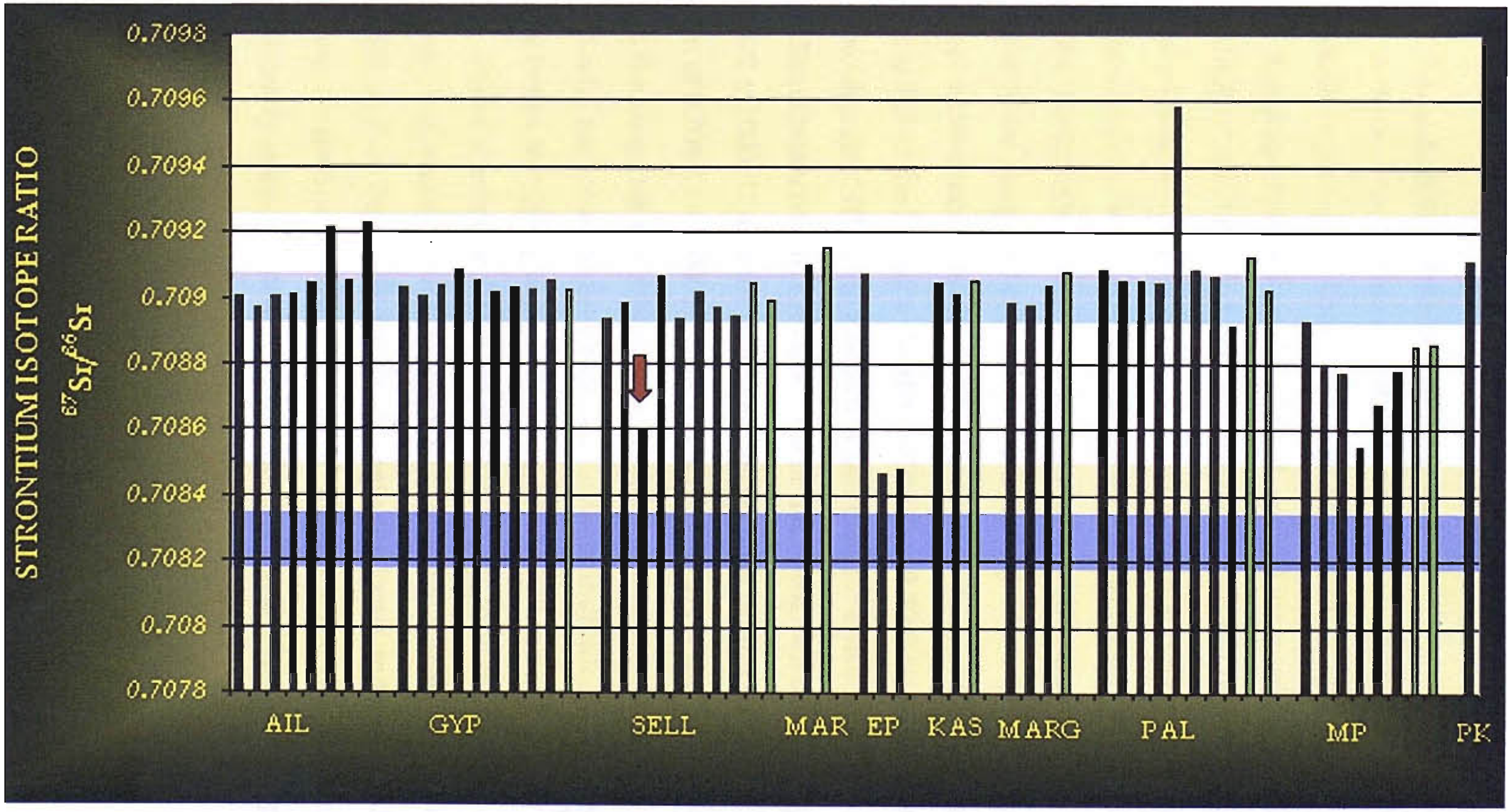
Figure 7.1 Strontium isotope ratios measured in dental enamel and bones from individuals from Crete.



AIL=Ailias, GYP=Gypsades, SELL=Sellopoulo, MAR=Maroulas, EP=Episkopi, KAS=Kastelos, MARG=Margarites, PAL=Palama, MP=Myrtos Pyrgos, PK=Palaikastro.

Key to colours on the graph: BARS: black= dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone, light blue=snail shells, white=archaeological animal teeth. ARROW (red): points to individual SELI, IV.

Figure 7.2 Strontium isotope ratios measured in dental enamel and bones from individuals from Crete.



AIL=Ailias, GYP=Gypsades, SELL=Sellopoulo, MAR=Maroulas, EP= Episkopi, KAS=Kastelos, MARG=Margarites, PAL=Palama, MP=Myrtos Pyrgos, PK=Palaikastro.

Key to colors on the graph: BARS: black=dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone, white=archaeological animal teeth, light blue=modern snail shells, blue=modern snail shells from Mycenae (Mainland), ARROW (red): points to individual SELI, IV.

7.1.2 Cretan skeletal collections from outside the Knossos district

In order to investigate population migration within the island of Crete and migration from outside the island into other than Knossos Cretan sites, sampling was undertaken from as many sites as possible throughout Crete. These had previously been morphologically analysed for the purposes of this thesis.

7.1.2.1 Central Crete population samples

In total, four dental enamel and one bone samples were analysed for SIR from individuals from Central Crete (Episkopi and Maroulas samples).

Episkopi Tomb: Samples of tooth enamel were analysed from three individuals (Table 7.5). No bone samples were analysed from the Episkopi tomb for reasons relating to the very low size of the sample and the very poor completeness of the available skeletal material. The mean ratio in the tooth enamel was calculated as 0.708673 ± 0.000345. Intra-sample variation for SIR values (s.d.=0.000345) is higher than that of the samples from the Knossos district. Mean ratio in tooth enamel for the Episkopi individuals falls within the reconstructed range for the biologically available SIR at the Knossos district (0.708530 to 0.709238). A similar range for the local biologically SIR to the Knossos is assumed for Episkopi, which is situated at less than 15km distance from Knossos. One of the Episkopi individuals gave a ratio of 0.709072 ± 0.000013 and the other two individuals produced very similar ratios, with a mean of 0.708474 ± 0.000010. The value (0.709072) for the first individual falls within the range for the biologically available strontium at Knossos. The mean value for the ratio measured in the other two Episkopi individuals (0.708474) falls very closely below the lower limit of that range (0.708530 to 0.709238).

In the absence of direct information for the local biologically available SIR at Episkopi, it is invalid to accept one or the other two values as representative of the local SIR, and on that basis distinguish between locals and non-locals. Based, however, on the SIR data available from Knossos in the vicinity to Episkopi, it could be tentatively suggested that the three Episkopi individuals do not provide adequate evidence to identify non-locals among them.

Table 7.5 SIR values for Episkopi individuals, dental enamel.

Individual	Element Analysed	Strontium Isotope Ratio (value)
EPIS 1	M1	0.709072
EPIS 2	M1	0.708467
EPIS 3	M1	0.708482

Key: M1=1st Molar.

Maroulas: One individual from the tombs at the Maroulas cemetery was analysed for SIR (Table 7.6). SIRs were measured in both bone and dental enamel of the individual and were found to be 0.709151 ± 0.000013 and 0.709097 ± 0.000011 respectively. Confinement of the analysis to one individual was dictated by the small number of individuals recovered from the tombs at the cemetery (three in total), as well as the poor preservation and recovery of human teeth, which were only present for two out of the three individuals. Therefore, the primary aim of the analysis of the samples from the Maroulas individual was to measure the local biologically available strontium at this settlement located at the western border of Central Crete in order to be able to monitor intra-island population movement, rather than to determine whether the examined individual was local at the site or not. The SIRs measured in dental enamel and bone from the individual MLS2 from Maroulas, however, are very similar to the mean SIR for dental enamel samples from Ailias (0.709064), Gypsades (0.709037) and Sellopoulo (0.708902). Hence it is very difficult to detect the movement of people between these four sites on Central Crete (Maroulas, Ailias, Gypsades and Sellopoulo).

Table 7.6 SIR values for Maroulas individual, dental enamel and bone samples.

Individual	Element Analysed	Strontium Isotope Ratio (value)
MLS2, 1	M1	0.709097
MLS2, 1	Femur	0.709151

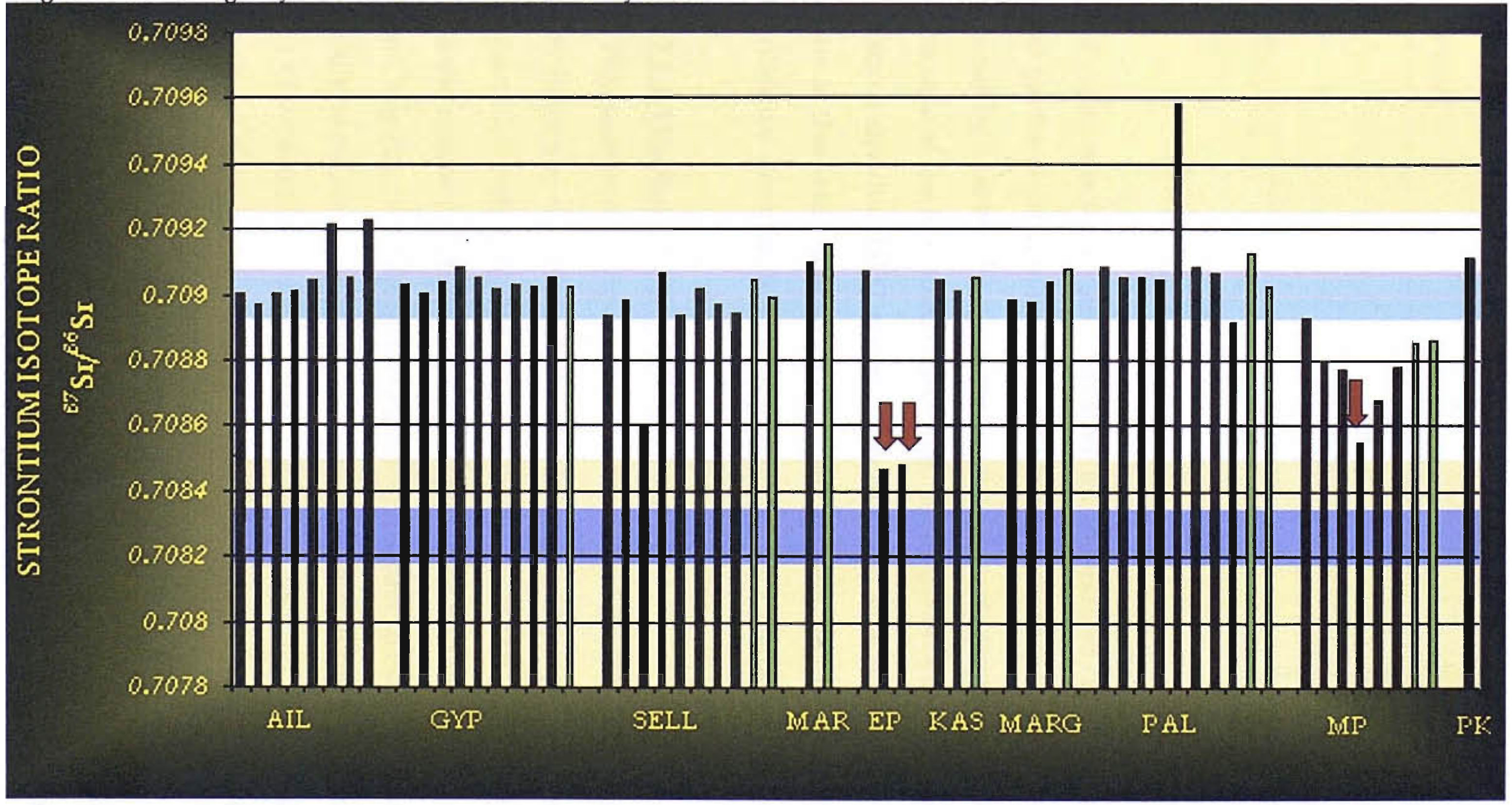
Key: M1=1st Molar.

7.1.2.2 Eastern Crete population samples

In total, seven dental enamel and two bone samples were analysed for SIR from individuals from Eastern Crete (Myrtos Pyrgos and Palaikastro samples).

Myrtos Pyrgos: Seven individuals from Myrtos Pyrgos (South-Eastern Crete) were sampled for the strontium isotope ratio analysis (Table 7.7). Individual MP A is represented by both tooth enamel and bone samples. The local biologically available strontium was determined using two bone samples from the latest burials inside the burial chamber (individuals MP A and MP E). The mean SIR was estimated as 0.708858 ± 0.000003 and the range for ± 2 s.d. is 0.708852 to 0.708864. The mean ratio for the enamel samples is 0.708749 ± 0.000129 and the range of SIR values for Myrtos Pyrgos is between 0.708545 and 0.708931. The mean ratio for the enamel samples (0.708749) falls very closely below the reconstructed range for the biologically available strontium at Myrtos Pyrgos (0.708852 to 0.708864), determined from human bone samples. The SIR measured in the tooth enamel from individual MP A causes the mean ratio in enamel samples from Myrtos Pyrgos individuals to fall below the reconstructed range of local biologically available strontium. The SIR for individual MP A was measured in tooth enamel and bone at 0.708545 and 0.708860 respectively. The discrepancy of the two ratio values is most probably suggestive of a non-local origin for individual MP A. If indeed this individual changed residence some time following the first years of his life, he need not have come from outside the island. The value for the SIR measured in the tooth enamel from individual MP A (0.708545) falls within the reconstructed range for the biologically available strontium at Knossos (0.708530 to 0.709238). Also, it is very similar to the ratio values produced by the analysis of enamel samples from two of the three analysed Episkopi individuals (EPIS 2=0.708467 and EPIS 3=0.708482) (Figure 7.3).

Figure 7.3 Strontium isotope ratios measured in dental enamel and bones from individuals from Crete: Individual MP A in relation to EPIS 2 and EPIS 3 individuals and the ranges for local biologically available SIR at Knossos and Mycenae.



AIL=Ailias, GYP=Gypsades, SELL=Sellopoulo, MAR=Maroulas, EP=Episkopi, KAS=Kastelos, MARG=Margarites, PAL=Palama, MP=Myrtos Pyrgos, PK=Palaikastro.

Key to colors on the graph: BARS: black=dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone from Knossos, white=archaeological animal teeth from Knossos, light blue=modern snail shells from Knossos, blue=modern snail shells from Mycenae (Mainland). ARROWS (red): point to individuals EPIS 2, EPIS 3 and MP A. Figure 7.3 Strontium isotope ratios measured in dental enamel and bones from individuals from Crete: Individual MP A in relation to EPIS 2 and EPIS 3 individuals and the ranges for local biologically available SIR at Knossos and Mycenae.

Table 7.7 SIR values for Myrtos Pyrgos individuals, dental enamel and bone samples.

Individual	Element Analysed	Strontium Isotope Ratio (value)
MP 25B	M1	0.708792
MP H	M1	0.708781
MP 25A	M1	0.708773
MP 5	M1	0.708931
MP D (2nd individual)	M1	0.708675
MP A	M1	0.708545
MP A	Femur	0.708860
MP E	Femur	0.708856

Key: M1=1st Molar.

Palaikastro: Only one tooth from the Palaikastro cranial collection was analysed for the strontium isotope ratio, because there were only two individuals represented by 4 teeth. The value for the ratio was measured as 0.709112 ± 0.000014. As in the case of the Maroulas individual, SIR analysis of dental enamel from the Palaikastro individual D131 aimed to measure the local biologically available strontium at this settlement located at Eastern Crete, on the condition that this was a local individual (in order to be able to monitor intra-island population movement).

7.1.2.3 Western Crete population samples

This section investigates the hypothesis that the pit caves of the Palama cemetery belong to an "ethnically" different group of people living among the indigenous Cretan population at Chania (Hallager & McGeorge 1992). It also presents the results of SIR analysis of samples from two more collections from Western Crete (i.e. Margarites and Kastelos) in order to establish the local biologically available SIR at sites in the Western part of the island, and explore the presence of non-locals among the tested individuals from the two sites. In total, there were analysed thirteen dental enamel and four bone samples from the Western Crete collections.

Palama: The hypothesis for the presence of non-locals at the Palama cemetery was advanced by Hallager (Hallager & McGeorge 1992). She admitted, however, to the lack of positive evidence for this hypothesis from the associated with the burials material culture. The only exception are two silver signet rings from Tomb 8, which are suggested to have been produced outside the Aegean, probably in Cyprus or the Levant. Based on the present data, however, the context of the two signet rings does not agree in chronological terms, with an origin from either of the two suggested sources. McGeorge (Hallager & McGeorge 1992) compared skull measurements taken from three females from pit caves in the Palama cemetery with other Aegean and Eastern Mediterranean population samples and suggested with some reservation, that the results of her analysis do not exclude the possibility that non-locals (non-Cretans) are present among the individuals interred into the pit caves. It should be noted, however, that comparison of the cranial morphology of these three Late Minoan females with samples very distant in time (i.e. Neolithic to Roman), is methodologically invalid. It does not control for microevolutionary changes introduced to cranial morphology in the course of time.

To explore the hypothesis for the non-local origin of the individuals entered into the pit caves, the SIR was measured in samples from 4 individuals from these graves. In order to confirm this hypothesis, SIR measured in the dental enamel of these individuals (interred into pit caves) should be different from the local biologically available SIR, and from SIRs measured in samples from other individuals of the Palama collection for which a non-local origin has not been suggested.

In total, Strontium isotope ratios were measured for eight individuals from the Palama Cemetery (Table 7.8). Two of these (PAL16, 2 and PAL3) are represented by both dental enamel and bone, whereas the other six are represented merely by dental enamel samples. The local biologically available strontium is determined using the mean ratio for the human bone. This was calculated as 0.709075 ± 0.000148 and the range for ± 2 s.d. is 0.708926 to 0.709222. The mean ratio measured in human tooth enamel is 0.709110 ± 0.000199 and the range of SIR values for Palama individuals is between 0.708916 and 0.709585.

Out of the four Palama individuals examined for a non-local SIR signature (i.e. individuals suggested to represent a different "ethnic" group on the basis of material culture evidence), only individual PAL15 A gave a discrepant result. Ratio was measured as 0.709585 ± 0.000013 in the dental enamel of this individual. Individual PAL15 A causes intra-sample variation for the Palama sample to increase (s.d. = 0.000199). If we remove this individual from the analysis, the range of SIR values is reduced (0.708916 to 0.709086) and agrees very well with the reconstructed range for the biologically available strontium at the district of Chania (0.708926 to 0.709222), determined from human bone samples. However, SIR ratio measured in dental enamel from the second individual (PAL15 C) recovered from the same tomb (0.709086 ± 0.000008) conforms very well to the local biologically available strontium (0.708926 to 0.709222). The value for individual PAL15 A (0.709585) does not have a parallel with any of the 59 analysed human samples from Crete. It exceeds by 0.000543 and 0.00051 the mean ratios measured in the dental enamel (0.709042 ± 0.000058) and bone (0.709075 ± 0.000148) of other individuals from the Palama cemetery respectively. It clusters, however, very closely to the mean ratios measured in skeletal material from Naxos (presented in sections 7.1.3 and 7.1.4). Despite the absence of values for the strontium isotope ratio from other South Aegean islands apart from Naxos, it is not invalid to suggest for individual PAL15 A, a probable origin from Naxos or another South Aegean island of similar geology.

Table 7.8 SIR values for Palama individuals, dental enamel and bone samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
PAL15 A	M1	0.709585
PAL16, 1	M1	0.709062
PAL NI	M1	0.709085
PAL15 C	M1	0.709086
PAL8, 2	M1	0.709052
PAL10, 2	M1	0.709044
PAL16, 2	M1	0.708916
PAL16, 2	Femur	0.709022
PAL3	M1	0.709051
PAL3	Femur	0.709127

Key: M1=1st Molar.

Margarites: Due to factors associated with the recovery of the skeletal material from the tholos tomb at Margarites it was not possible to safely reconstruct individuals from the commingled skeletal remains. Strontium isotope ratio was measured in one human bone and three teeth (Table 7.9). The value for the bone is 0.709080 ± 0.000011. The mean ratio for the three dental enamel samples was calculated as 0.708999 ± 0.000033. Intra-sample variation for the Margarites sample is low (s.d. = 0.000033). The range of SIR values for Margarites is between 0.708975 and 0.709037, and it conforms very well with the value for the local biologically available SIR, determined from the human bone sample (0.709080 ± 0.000011).

Table 7.9 SIR values for Margarites individuals, dental enamel and bone samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
MRG 1	M1	0.708986
MRG 2	M1	0.708975
MRG 3	M1	0.709037
MRG 4	Femur	0.709080

Key: M1=1st Molar.

Kastelos: Samples from two individuals from the Kastelos skeletal collection, one (KAS P) represented by both bone and dental enamel and the other merely by dental enamel (KAS 2), were analysed to measure SIR (Table 7.10). SIR in the bone sample was measured as 0.709054 ± 0.000011. The mean ratio for dental enamel is 0.709027 ± 0.000020 and it agrees with the SIR measured in bone from individual KAS P.

Table 7.10 SIR values for Kastelos individuals, dental enamel and bone samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
KAS 2	M1	0.709042
KAS P	M1	0.709013
KAS P	Femur	0.709054

Key: M1=1st Molar.

Due to the geographical proximity of Margarites and Kastelos (less than 15km distance), the 2 samples were pooled together to maximize sample size. The mean SIR in human bone is 0.709067 ± 0.000018 and the range for ± 2 s.d. is 0.709031 to 0.709103. The mean ratio for dental enamel is 0.709010 ± 0.000034. The range of SIR values for the two pooled samples is between 0.708975 and 0.709042, and is narrow compared to other Cretan samples.

Therefore, results failed to confirm the hypothesis for the presence of non-locals among the tested Margarites and Kastelos individuals.

7.1.3 Hypothesis B for population movement from the Argolid to Naxos

Material culture studies suggest that at the end of LHIIIB, kings and/or other high status individuals from the Argolid arrived as refugees at the island of Naxos (Kondoleon 1958, 1959; Kardara 1977; Barber 1987). These were buried in the Aplomata and Kamini cemeteries at the Chora of Naxos, in the west side of the island, within 1km distance from each other. Their burials are conspicuous due to the opulence and symbolic connotations of the material culture associated with their interments.

In order to confirm this hypothesis, the SIR measured in the dental enamel of individuals buried in the so-called "Mycenaean" aristocrat tombs should be different from: a. the ratio measured in the other individuals from the cemetery with no associated evidence for a non-local origin, and b. the local biologically available SIR determined from the results of the analysis of archaeological animal teeth and human bone. On the other hand, the SIR values for these individuals should be congruent with the reconstructed range for the biologically available SIR at Mycenae in the Argolid.

7.1.3.1 Biologically available strontium isotope ratio at the Chora of Naxos

Because the cemeteries of Aplomata and Kamini at the Chora of Naxos are in close proximity one to the other (less than 1km distance) and were probably used by the same community, the biologically available SIR at the Chora of Naxos was determined using samples from both cemeteries (Table 7.11). Dental enamel samples from two animals (VAS C, VAS P) recovered from the interior of the Vasalaki tomb (Aplomata) were analysed to establish the local biologically available SIR. These gave two discrepant values. The SIR measured in the tooth enamel from the cattle is 0.709495 ± 0.000010, and from the pig is 0.710039 ± 0.000011. The mean SIR for the two animals was calculated as 0.709767 ± 0.000384 and the range for ± 2 s.d. is 0.708999 to 0.710535. In addition to the information provided by the analysis of the archaeological animal teeth, bone samples from three humans from the Aplomata and Kamini collections were analysed in order to establish the local biologically available SIR. The mean human bone ratio for Aplomata and Kamini skeletal collections is calculated as 0.709550 ± 0.000127 and the range for ± 2 s.d. is 0.709296 to 0.709804.

Table 7.11 SIR values for samples used to determine the biologically available SIR at the Chora of Naxos; archaeological animal dental enamel and human bone samples.

Individual	Element Analysed	Strontium Isotope Ratio (value)
VAS C (ANH)	M3	0.709495
VAS P (ANH)	M1	0.710039
VAS 3A (AH)	Femur	0.709680
VAS 0282 (AH)	Femur	0.709427
KAM A1 (AH)	Tibia	0.709543

Key: ANH=Archaeological Non-Human, AH: Archaeological Human, M1=1st Molar, M3: 3rd Molar.

The range for the biologically available strontium isotope ratio at the Chora of Naxos determined from the two animal dental enamel samples (0.708999 to 0.710535) is wider than that determined from human bone (0.709296 to 0.709804), and it is the widest one measured in this research. There is a small overlap between the two ranges for the biologically available SIR at the district of Knossos on Crete (0.708530 to 0.709238) and the Chora of Naxos (0.708999 to 0.710535) at 0.708999 to 0.709238. Both ranges are determined from animal tooth enamel samples. The overlap of the two ranges does not have an impact on the investigation of the two principal hypotheses of population movement tested in this study, because they do not implicate population movement between Crete and Naxos.

7.1.3.2 Aplomata Cemetery

Aplomata Late Bronze Age Cemetery: SIR was measured in dental enamel samples from four individuals from Tomb I, Tomb B and the Tomb at the Vasalakis plot, in the LMIII cemetery at Aplomata (Table 7.12). Bone samples from two individuals from the Vasalakis plot were also analysed to measure the SIR. Because the Vasalakis skeletal material is commingled, it cannot be said with certainty that the dental enamel and bone samples from individuals labeled in the Table 7.12 as VAS 0282 and VAS 3A represent the same individual.

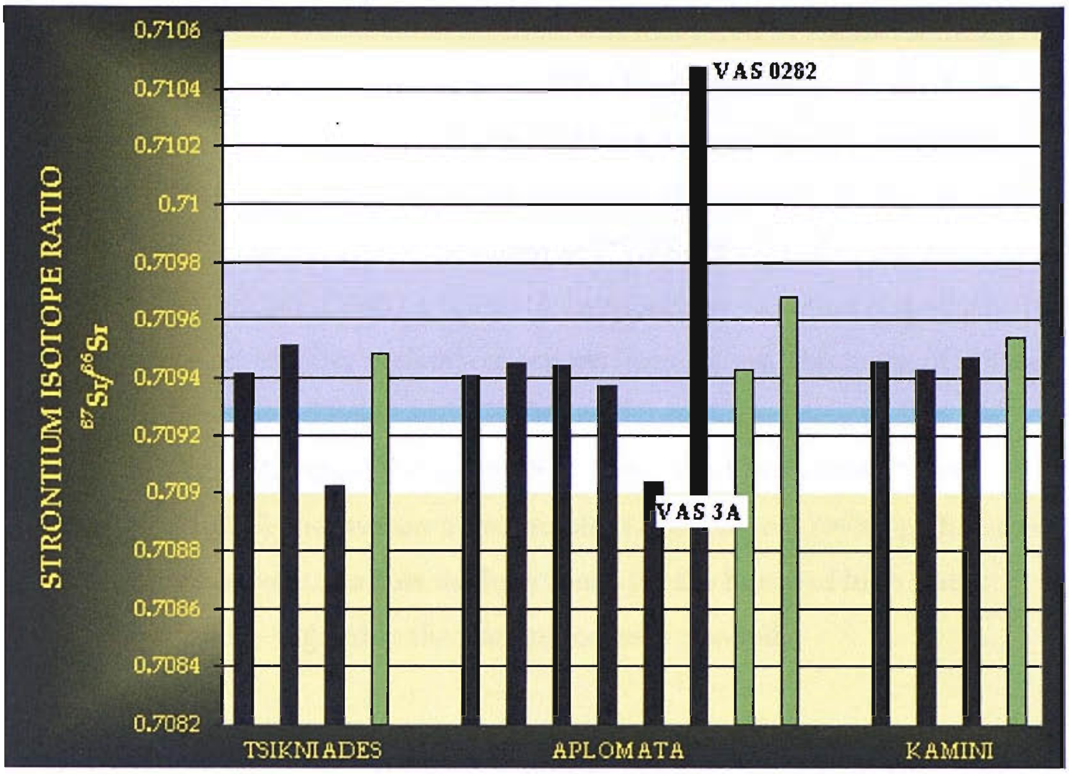
Table 7.12 SIR values for the Aplomata individuals (Late Bronze Age), dental enamel and bone samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
APLI C	M1	0.709372
APLB	M1	0.709440
VAS 3A	M1	0.709038
VAS 3A	Femur	0.709680
VAS 0282	M1	0.710474
VAS 0282	Femur	0.709427

Key: M1=1st Molar.

The mean SIR in the dental enamel of the Late Bronze Age individuals from the Aplomata cemetery was calculated as 0.709581 ± 0.00062. Intra-sample variation (s.d. = 0.00062) is the highest measured in this study. Although the mean ratio for dental enamel conforms well to the range for the local biologically available SIR determined from human bone values, the range of SIR values for Late Bronze Age Aplomata is between 0.709038 and 0.710474 and it is wider than the range for the local biologically available strontium determined from human bone (0.709296 to 0.709804). Ratios in the dental enamel of individuals APLI C and APLB were measured as 0.709372 ± 0.000011 and 0.709440 respectively, and fit within the range of 0.709296 to 0.709804 (local biologically available SIR determined from human bone). Dental samples from the other two individuals from the Vasalakis Tomb, however, produced values (0.710474 and 0.709038) that fall clearly outside the range for local biologically available SIR, determined from human bone values. The values for the two individuals from the Vasalakis Tomb are labeled on the graph (Figure 7.4). However, both values fall within the range for the local biologically available SIR determined from animal dental enamel samples (0.708999 to 0.710535) (Figure 7.4). Hence using the animal dental enamel criterion (0.708999 to 0.710535) all four individuals from LCIII Aplomata tombs are determined to be locals. Additional evidence against the presence of Mycenaeans amongst individuals buried in the LCIII Aplomata cemetery derives from the biologically available SIR at the site of Mycenae determined from modern snail shell samples (0.708181 to 0.708353). SIR values measured in enamel samples from the four tested LCIII Aplomata individuals fall clearly outside this range. Thus on the results of the present analysis the hypothesis for the presence of non-locals in the LCIII Aplomata cemetery is rejected.

Figure 7.4 Strontium isotope ratio measured in dental enamel and bones from individuals from Naxos.



Key to colors on the graph: BARS: black=dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone (Aplomata and Kamini), white=archaeological animal dental enamel (Aplomata), light blue=archaeological snail shells from Tsikniades.

Aplomata Early Cycladic graves: The mean ratio for dental enamel samples from two Early Bronze Age individuals from Aplomata was found to be 0.709429 ± 0.000032 and accords very well with the local biologically available ratio determined from animal teeth (0.708999 to 0.710535) and human bone (0.709296 to 0.709804) (Table 7.13). Because Early and Late Bronze Age individuals from Aplomata had access to the same local biologically available SIR, they were pooled together and the mean ratio in dental enamel from the Aplomata individuals was calculated as 0.709530 ± 0.000487.

Table 7.13 SIR values for Aplomata individuals (Early Bronze Age), dental enamel samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
APL K	M1	0.709406
APL XXIII	M1	0.709452

Key: M1=1st Molar.

7.1.3.3 Kamini Cemetery

In the Kamini skeletal collection, SIR was measured in enamel samples from three individuals (KAM 3, KAM 3B, KAM K3). One bone sample (KAM A1) from the same collection was also analysed, but it could not be established whether it belongs to one of the three Kamini individuals that were analysed using enamel samples (Table 7.14). SIR in the bone was measured as 0.709543 ± 0.000011. The mean ratio in teeth was calculated as 0.709451 ± 0.000018. Intra-sample variation (s.d.=0.000018) is very low compared to other skeletal collections from Naxos. The range of SIR values for Kamini is between 0.709431 and 0.709467 and it conforms very well to the reconstructed local biologically available SIR determined from animal tooth enamel (0.708999 to 0.710535) and human bone samples (0.709296 to 0.709804). Therefore, on the results of the present analysis the hypothesis for the burial of high status individuals from the Argolid in the Kamini tombs is rejected.

Table 7.14 SIR values for the Kamini individuals, dental enamel and bone samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
KAM 3	M2	0.709457
KAM 3B	M1	0.709467
KAM K3	M1	0.709431
KAM A1	Tibia	0.709543

Key: M1=1st Molar, M2=2nd Molar.

7.1.3.4 Grotta population: Early and Late Bronze Age Aplomata and Kamini samples pooled

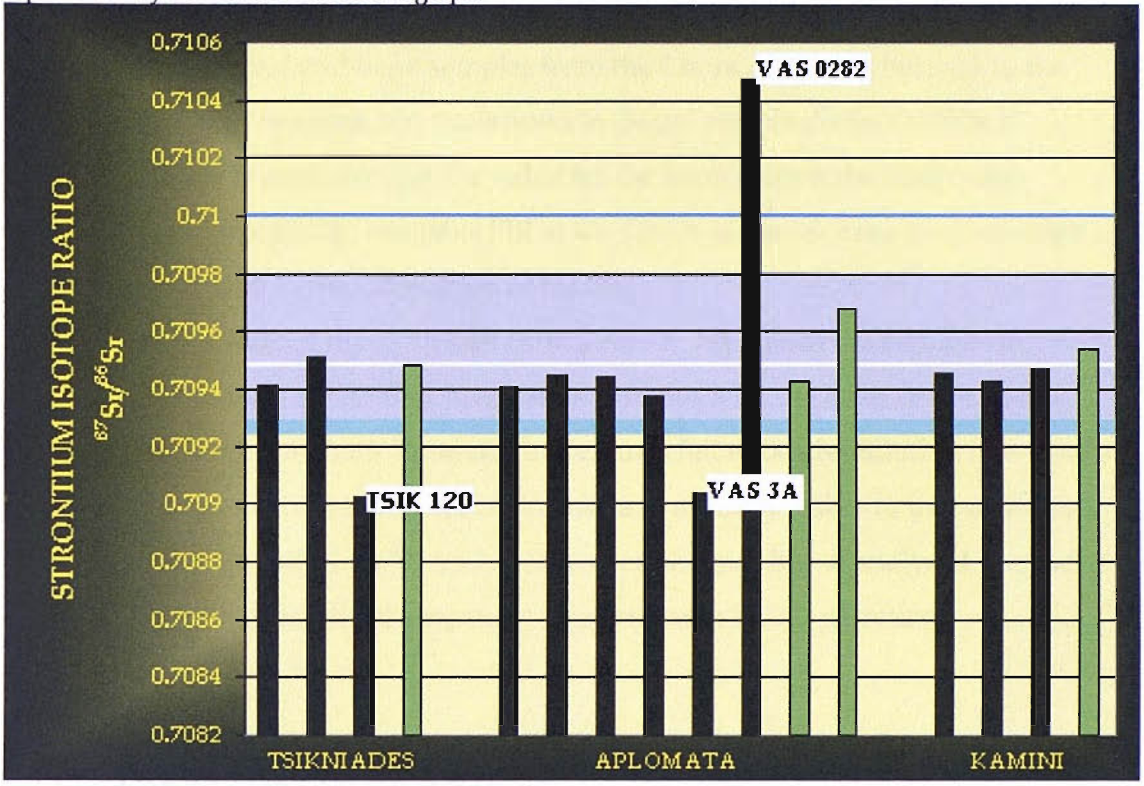
If the analysed individuals from the Early and Late Bronze Age Aplomata cemeteries and the Late Bronze Age Kamini tombs are pooled together, the mean SIRs for the dental enamel and bone are 0.709504 ± 0.000387 and 0.70955 ± 0.000127 respectively. Pooling together these samples is legitimate, since it has been suggested that the Bronze Age population of the settlement of Grotta (Chora of Naxos) used both cemeteries (Hadjianastasiou 1996).

On the results of SIR analysis (section 7.1.3.2) the two individuals from Tombs B and I of the Aplomata cemetery failed to be identified as non-locals. The SIR values measured in enamel from these two individuals fall within both ranges for the biologically available SIR at the Chora of Naxos, determined from animal dental enamel and human bone. Although the two individuals from the Vasalakis tomb (Aplomata cemetery) that were tested using enamel samples, they were identified as locals using the animal dental enamel criterion, they gave SIR values that are divergent from both the mean human dental (0.709504 ± 0.000387) and bone ratios (0.70955 ± 0.000127) for the Grotta population. SIR values for individuals VAS 0282 and VAS 3A are higher (0.710474) and lower (0.709038 ± 0.000016) respectively compared to the means for the Grotta population.

The high SIR (0.710474 ± 0.000017), measured in individual VAS 0282 was not encountered in any of the other analysed human collections from the island of Naxos and Crete. However, the number of human samples analysed from Naxos for SIR is rather low (N=16). Due to the small number of samples analysed (total of 20 samples of human and animal tissue), and the lack of previous research in this context, interpretations are tentative. There is, however, some useful information in the study of Pe-Piper & Piper (2002) of the igneous rocks of Greece. The Chora of Naxos is underlain by granite (Higgins & Higgins 1996: 179). According to Pe-Piper & Piper (2002) SIR ranges from 0.709 to 0.715 in granites of the central Cyclades. Although the degree of precision of the reported measurements is lower than desired for the purposes of the present study, it is important to establish that a ratio of 0.715 is common in the examined region. Thus the value for the SIR for individual VAS 0282 falls within the suggested range for granites from the central Cyclades. Unfortunately, no further precise information is available concerning the specific Cycladic islands where the higher SIR values occur (*ibid.*). Moreover, the data for the pig from Vasalakis Tomb (0.710039 ± 0.000011) renders as highly improbable the proposition that the first residence of individual VAS 0282 was at a great distance from where he was disposed of (Figure 7.5). As mentioned in Chapter 5, section 5.2.2, teeth from pigs are particularly good for controls because pigs are suggested to have a diet comparable to that of the humans and to be rather immobile.

The low SIR (0.709038 ± 0.000016) measured in individual VAS 3A falls nicely within the reconstructed range for the biologically available SIR at the Knossos district determined from archaeological animal dental samples (0.708530 to 0.709238). A similar value (0.709024 ± 0.000011) was recorded for the dental enamel of one of the individuals entered into Tomb 120 of the Early Bronze Age cemetery at Tsikniades in central Naxos (see later section 7.1.4). The value for the individual TSIK 120 is labeled on the graph (Figure 7.5).

Figure 7.5 Strontium isotope ratio measured in dental enamel and bones from individuals from Naxos. SIR ratios for the two animal dental enamel samples from the Vasalakis tomb (Aplomata) are represented by horizontal lines on the graph.



Key to colors on the graph: BARS: black=dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone (Aplomata and Kamini), light blue=archaeological snail shells from Tsikniades. HORIZONTAL LINES (ratio): blue=archaeological pig from Vasalakis tomb, white=archaeological cow from Vasalakis tomb.

Due to the paucity of systematic information concerning the local biologically available SIR from other sites on the island of Naxos and sites in the broader Aegean region, interpretations concerning the SIR values for the two individuals from the Vasalakis tomb are tentative. The results of the SIR analysis of dental enamel from the two animals from the Vasalakis tomb (0.710039 ± 0.000011 and 0.709495 ± 0.000010), snail shell samples from the Early Bronze Age cemetery at Tsikniades (mean SIR=0.70927), and the available geological information (Higgins & Higgins 1996; Pe-Piper & Piper 2002) suggest a great variation in local SIR on the island of Naxos. The geological composition of the Chora of Naxos changes from Pleistocene conglomerates to Oligocene-Miocene sandstone, marl, and granite (Higgins & Higgins 1996: 179) within a radius of 1km. Therefore, in the light of the SIR value from the pig in the Vasalakis tomb and the available geological information, individual VAS 0282 (SIR=0.710474 ± 0.000017) failed to be identified as non-local. If the bone that gave a ratio of 0.709680 ± 0.000027 (which is higher than the means for human dental enamel and bone samples from the Chora of Naxos) belongs to the same individual as the high ratio measured in dental enamel (SIR=0.710474 ± 0.000017), then it is probable that the value for the bone reflects the long-term assimilation of biologically available SIR at the Chora of Naxos from a wider range of geologies compared to the early years of his life.

Interpretation of the SIR value from VAS 3A, for whom the isotope ratio was measured as 0.709038 ± 0.000016, is tentative. Although on the basis of the animal dental enamel criterion, both Vasalakis individuals fail to be identified as non-locals, none of the controls from the Chora of Naxos gave a similar value to that measured in the enamel from individual VAS 3A. However, the number of analysed samples is small. This result highlights the need for more research in this direction.

7.1.4 Tsikniades cemetery, Central Naxos

From the 3 individuals tested, one was represented by both bone and enamel samples (TSIK 114), whereas the other two (TSIK 120 and TSIK 121), merely by dental enamel (Table 7.15). SIR was measured in shell samples from 2 snails recovered from the interior of the tombs in great numbers. SIR analysis gave very similar values for the two snail samples and their mean is calculated as 0.70927. The human bone ratio was measured as 0.709487 ± 0.000014 and the range for 2 s.d. is 0.709473 to 0.709501. The mean ratio for the three teeth was calculated as 0.709316 ± 0.000258. The mean ratio for dental enamel falls below, but is very close to the range for the human bone. It is the value for the individual from Tomb 120 (0.709024 ± 0.000011) that causes the mean SIR to drop. If we remove this individual from the analysis, the mean ratio for dental enamel from Tsikniades is calculated as 0.709463 ± 0.000072 and is congruent with the value measured in human bone.

Taking the small number of analysed samples into consideration, the value for the individual from Tomb T120 is discrepant from those typical for individuals buried in the Tsikniades cemetery. Like the case of individual VAS 3A, this result stresses the need for further research in order to securely establish the biologically available SIR at as many Aegean sites as possible.

Table 7.15 SIR values for the Tsikniades individuals, dental enamel and bone samples, and for two archaeological snail shell samples.

Individual	**Element Analysed**	**Strontium Isotope Ratio (value)**
TSIK1 SN	Shell	0.709279
TSIK2 SN	Shell	0.709261
TSIK 120	M1	0.709024
TSIK 121	M1	0.709514
TSIK114	M1	0.709412
TSIK 114	Femur	0.709487

Key: SN=Snail, M1=1st Molar.

7.2 Discriminant Function Analysis of SIR Data and Discussion of SIR Analysis Results

This section discusses the results of the SIR analysis in relation to the examined hypotheses for population movement in the Bronze Age South Aegean. Also, in this section Discriminant Function Analysis is applied to the Strontium Isotope Ratios in order to explore predicted group membership for the analysed individuals and whether any of these would be classified to a different skeletal collection from that it belongs to on the basis of the tested values.

7.2.1 Crete

7.2.1.1 Hypothesis A for population movement from the Argolid to Knossos

On the basis of the results of the SIR analysis (section 7.1.1), the hypothesis for the presence of Mycenaeans among the individuals deposited in the Sellopoulo tombs is rejected. The mean ratio for the examined Sellopoulo individuals falls within the reconstructed range for the biologically available SIR at the district of Knossos determined from archaeological animal dental enamel (Figure 7.1). Additionally, the data for the biologically available SIR at Mycenae exclude the possibility that the SELI, V individual, who scored the lowest in the sample value for SIR, could originate from Mycenae (Figure 7.2). Last, Discriminant Function Analysis was applied to the data for the reasons outlined above and the results are given in Table 7.16. None of the examined Sellopoulo individuals was assigned an origin from outside the island (see Table 7.16). Two of the three misclassified Sellopoulo cases (SELI, II and SELI, IIIb) were assigned membership to the group of Western Cretan skeletal collections, with which the Knossos group shares very similar SIRs. The third one was SELI, V and he was misclassified to the Episkopi sample. It should be noted that none of the Knossos individuals was classified as Mycenaean.

7.2.1.2 Population movement within the island of Crete

The results of the SIR analysis demonstrate that it is very difficult to monitor the movement of population elements between sites in northern Crete. The reconstructed ranges for the local biologically available SIR are very similar for the examined skeletal collections that span the northern part of the island from west to east. Indicative of the very similar ratios for the northern Cretan skeletal collections are the results of DFA applied to all measured ratios (Table 7.16). Twenty-four of the twenty-eight misclassified cases involved individuals from Crete. Twenty-two out of the twenty-four misclassified Cretan individuals were assigned membership to another northern Cretan collection/ group of collections from that which they belong to. Incorrect assignment of group membership results from the very similar ratios between the Northern Cretan collections involved. In the majority of the cases, misclassification involved cases between the Knossos and Western Cretan collections.

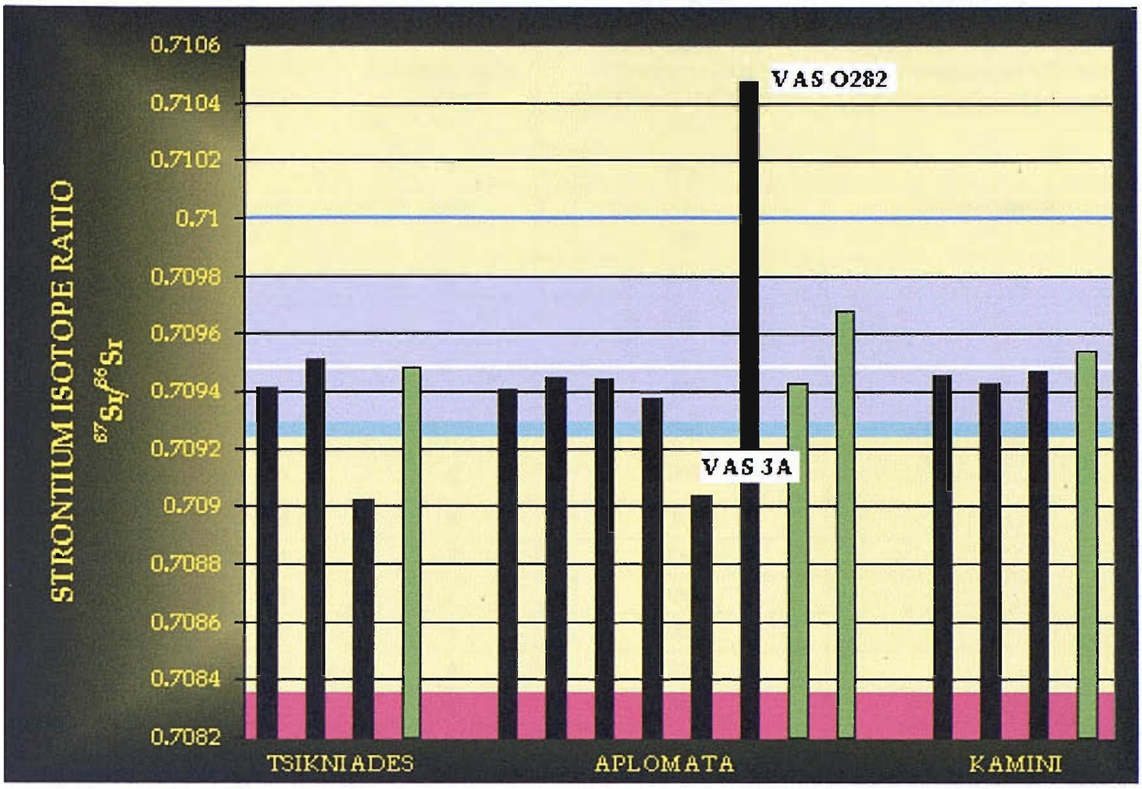
Further research is needed, however, especially in the southern part and the interior of the island, in order to establish the local biologically available SIR. This need has been underlined by the three SIRs recorded in enamel samples from Episkopi and the enamel sample from individual MP A from the Myrtos Pyrgos collection. SIR measured in individual MP A gave different values for dental enamel (0.708545) and bone samples (0.708860). The SIR in the enamel of MP A is very similar to the SIR values measured in the enamel from two of the three tested individuals from Episkopi (0.708467 and 0.708462). The SIR for individual MP A (0.708545) falls within the range of biologically available strontium at Knossos (0.708530 to 0.709238) and it is not very discrepant from the mean ratio measured in human bone samples from Myrtos Pyrgos (0.708858). Therefore, it is highly probable that it represents intra-island population movement. On the basis of the results of the Discriminant Function analysis of SIRs, individual MPA was misclassified to the Episkopi collection (Central Crete) (Table 7.16). Clear evidence for residential change, however, is provided for the principal interment in Tomb 15 in the Palama cemetery. The results of the present analysis tentatively suggest that the individual PAL15 A could have originated from Naxos or another Aegean site of similar geology. This interpretation is supported by the results of Discriminant Function Analysis. On the basis of these results, the individual PAL15 A was assigned membership to the group of Naxos population samples.

7.2.2 Naxos: Hypothesis B for population movement from the Argolid to Naxos

On the results of the present analysis, the range of SIR values measured in dental enamel from individuals from Naxos (0.709024 to 0.710474) is wider than on Crete (0.708467 to 0.709585). The high intra-island variation in SIRs does not need to reflect exclusively population movement and the arrival of population elements from outside the island as is indicated by the variation in the values for the archaeological animal tissue analysed to control for the local biologically available SIR. The range of SIR values for two animal teeth and two snail shells is between 0.709261 and 0.710039. As was advised for Crete, further research is needed in order to reconstruct accurately the entire range of local variation for the biologically available SIR on the island.

Based on present data, the hypothesis for the presence of Mycenaean individuals among those interred into the Late Cycladic tombs of the Aplomata and Kamini cemeteries is rejected. Strontium isotope ratio values measured in teeth from these individuals are congruent with the reconstructed range for the biologically available SIR at the Chora of Naxos, determined from animal dental enamel samples. The ratios (0.709038 and 0.710474) measured in dental enamel from the two individuals from the Vasalakis tomb are, however, very divergent from the mean ratio measured in human enamel (0.709504) and bone samples (0.70955) from the Chora of Naxos. Interpretations are tentative due to the paucity of information on the local biologically available SIR on the entire island and the high intra-island variation for the biologically available SIR, demonstrated by the results of the analysis of the control samples. Nevertheless, on the basis of the SIR measured in the enamel from the Vasalakis pig and the available geological information, individual VAS 0282 failed to be identified as non-local. Ratios measured in the snail shell samples taken from the Tsikniades collection and evidence for high variation in local biologically available SIR on the island (discussed in section 7.1.3.3) suggest that the original residence of individual VAS 3A should be sought first inside the island. If, however, we look for his origins outside the island, northern Crete is a strong candidate. The SIR for VAS 3A agrees with the mean ratios measured in human bone, animal enamel, and snail shell samples from western and central Crete (see sections 7.1.1, 7.1.2.1 and 7.1.2.3). Discriminant Function Analysis of SIRs assigned to the individual VAS 3A membership to the Western Cretan group of population samples (Table 7.16). Even if the two Vasalakis individuals originated from outside the island, they did not come from Mycenae, according to the local at Mycenae biologically available SIR determined from modern snail shell (0.708181 to 0.708353) (Figure 7.6).

Figure 7.6 Strontium isotope ratios measured in dental enamel and bones from individuals from Naxos.



Key to colors on the graph: BARS: black=dental enamel, green=bone. HORIZONTAL BANDS (show confidence limits at mean ratio ± 2 s.d): grey=human bone (Aplomata and Kamini), light blue=archaeological snail shells from Tsikniades, red=modern snail shells from Mycenae (Mainland). HORIZONTAL LINES (ratio): blue=archaeological pig from Vasalakis tomb, white=archaeological cow from Vasalakis tomb.

Table 7.16 Discriminant Function Analysis of SIRs, all analysed samples.

INDIVIDUAL	ACTUAL GROUP	PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF PREDICTED GROUP	SQUARED MAHALANOBIS DISTANCE TO CENTROID OF 2nd HIGHEST GROUP (for the misclassified cases)
TSIK 114	8	8	.150	
TSIK 121	8	8	.024	
TSIK 120	**8**	**1(**)**	**.020**	**.064 (Group 4)**
TSIK 114	8	8	.000	
APL K	8	8	.176	
APL XXIII	8	8	.031	
APLB	8	8	.057	
APLI	8	8	.360	
VAS 3A	**8**	**4(**)**	**.032**	**.046 (Group 1)**
VAS 0282 (BONE)	8	8	.095	
VAS 3A (BONE)	8	8	1.076	
VAS 0282	8	8	27.652	
KAM A1	8	8	.095	
KAM 3B	8	8	.009	
KAM 3	8	8	.022	
KAMK3	8	8	.082	
SELI.VII	1	1	.118	
LGI Larnax	1	1	.036	
SEL4, 3	1	1	.084	
SELI, IV	**1**	**2(**)**	**.137**	**.842 (Group 5)**
GYPXVIII, III	**1**	**4(**)**	**.010**	**.087 (Group 1)**
LGI, F	1	1	.000	
GYPXVIII, II	1	1	.016	
GYPXVIII, III	1	1	.028	
SELI, IV	1	1	.005	
SELI, II	**1**	**4(**)**	**.003**	**.071 (Group 6)**
LGI, F5	**1**	**4(**)**	**.038**	**.040 (Group 1)**
SELI, III.NE	1	1	.114	
LGI, Larnax (BONE)	1	1	.017	
SELI, IIIb	**1**	**4(**)**	**.022**	**.061 (Group 1)**
SELI, VII (BONE)	1	1	.000	
GYPXVIII, VII	1	1	.021	
LGI, E6	**1**	**4(**)**	**.005**	**.021 (Group 6)**
SELII, N. Bothros	1	1	.010	
SELI.III	1	1	.026	
MLS2, 1	**3**	**6(**)**	**.006**	**.018 (Group 4)**
KAS 2	4	4	.025	
KAS P	**4**	**1(**)**	**.007**	**.097 (Group 4)**
MRG 1	**4**	**1(**)**	**.004**	**.207 (Group 4)**
MRG 2	**4**	**1(**)**	**.014**	**.264 (Group 4)**
MRG 3	4	4	.034	
PAL15 A	**4**	**8(**)**	**.283**	**6.007 (Group 3)**
MLS2, 1 (BONE)	3	3	.021	
KAS P (BONE)	4	4	.009	
GYPXVIII,VI	**1**	**4(**)**	**.005**	**.082 (Group 6)**

PAL16, 1	4	4	.003	
PAL16, 2	4	1(**)	.188	.549 (Group 5)
PAL NI	4	4	.005	
PAL15 C	4	4	.006	
PAL8, 2	4	4	.011	
PAL10, 2	4	4	.022	
PAL3	4	4	.012	
PAL3 (BONE)	4	3(**)	.000	.006 (Group 6)
PAL16, 2 (BONE)	4	1(**)	.017	.070 (Group 4)
MRG 4 (BONE)	4	4	.002	
AIL 102	1	1	.000	
AIL 2	1	1	.021	
AIL 6	1	1	.000	
AIL 90	1	1	.008	
AIL 15	1	4(**)	.025	.056 (Group 1)
AIL 1	1	3(**)	.219	.283 (Group 6)
AIL 103	1	4(**)	.013	.078 (Group 1)
AIL 98	1	3(**)	.300	.374 (Group 6)
MP 25B	5	5	.007	
MP A	5	2(**)	.468	1.516 (Group 5)
MP H	5	5	.001	
MP 25A	5	5	.000	
MP 5	5	1(**)	.125	.559 (Group 4)
MP D (2nd individual)	5	2(**)	.000	.292 (Group 5)
EPIS 1	2	4(**)	.000	.045 (Group 6)
EPIS 2	2	7(**)	1.125	1.207 (Group 2)
EPIS 3	2	2	1.038	
PK D131	6	6	.000	
MP E (BONE)	5	5	.178	
MPA (BONE)	5	5	.196	
VAS C	8	8	.003	
VAS P	8	8	8.678	
TSIK1 SN	8	3(**)	.679	.788 (Group 6)
TSIK2 SN	8	3(**)	.530	.627 (Group 6)
KN1 SN	1	1	.001	
KN2 SN	1	1	.023	
KN3 SN	1	1	.016	
KN4 SN	1	1	.059	
MYC1 SN	7	7	.001	
MYC 2SN	7	7	.005	
MYC 3SN	7	7	.049	
MYC 4SN	7	7	.103	
AAS (R)	1	1	.046	
KN A (ANH)	1	1	.004	
LGI, BALK A-B (ANH)	1	1	.002	
SELI A (ANH)	1	2(**)	.001	.269 (Group 5)

**=Misclassified case

Key to Group Numbers: 1=Knossos, 2=Episkopi, 3=Maroulas, 4=Western Crete (Palama, Kastelos, Margarites), 5=Myrtos Pyrgos, 6=Palaikastro, 7=Mainland, 8=Naxos

CHAPTER 8

DISCUSSION AND CONCLUSIONS

This concluding chapter reconstructs certain debated aspects of the bio-cultural history of the Bronze Age South Aegean population, outlined earlier in this work, by bringing together complementing lines of archaeological evidence. On one hand, there is material culture evidence and the associated interpretations. On the other hand, there is evidence for the biological history of the populations who are associated with that material culture, which has been studied in this thesis through morphological skeletal analysis and strontium isotope ratio analysis. Discussion and interpretation of the results of the study is organized at the intra- and inter-regional level of analysis. The chapter closes with the conclusions concerning the two principal archaeological questions investigated in the thesis and recommendations for future work.

8.1 Intra-regional Level of Analysis

This section discusses the reconstructed inter-sample biological relationships at the regional level (i.e. the Argolid and Crete).

8.1.1 Argolid

8.1.1.1 Biological Distance between the Lerna and Apatheia skeletal collections

The results of morphological skeletal analysis of the two collections from the Argolid are consistent with the hypothesis that the two populations are distant. Middle Helladic Lerna individuals have a more rounded cranial shape compared with Late Helladic Apatheia. Lerna crania are comparatively broader and higher vaulted for their length, and their occipital is less protruding in the posterior direction (more vertical). By plotting the two sexes separately for each sample, the possibility that inter-sample variance is due to sexual dimorphism and differences in the representation of the two sexes in the tested samples was checked and refuted. Concerning sexual dimorphism, despite the similarity in its overall pattern in the two samples, sex differences in cranial morphology are more pronounced for the individuals from Lerna relative to those from Apatheia. Since sex–variation is one form of intra-population variation, inter-sample differences in sex dimorphism add to the picture of population biological divergence between Lerna and Apatheia

Analysis of dental metric morphology failed to provide clear confirmation for the biological relatedness of these two Argolid samples. In terms of dental metric morphology, Lerna appears to be more closely related to the Cretan samples than to Apatheia when right and left side measurements were entered to the analysis as separate variables (Figures 6.3.24 and 6.3.25). The two Argolid samples, however, group together and at clear distance from the three Late Minoan samples from Knossos when right and left side measurements were pooled to maximize sample sizes (Figure 6.3.27).

Given the geographical proximity of the two sites within the Argolid region, a common ancestor is hypothesised for the two populations. However, although non-metric traits are suggested to be more genetically canalized than the metric ones (Hauser & De Stefano 1989), the results of the analysis of cranial and dental non-metric traits are not consistent with the tested hypothesis that Lerna and Apatheia populations share a common ancestor. These suggest that the probable common ancestor shared by the two populations may be rather distant. The distant common ancestor, in combination with the operation of micro-evolutionary forces (e.g. gene-flow, genetic drift) on the respective populations, may have caused their biological distance to increase over the course of time.

8.1.1.2 Etiology of Inter-sample Distance: Which of the two samples represents most accurately the regional (Argolid) Bronze Age population?

Limitations on the interpretative power of the results of the analysis of skeletal material from the Argolid derive largely from the unavailability of better preserved and more complete collections from the Bronze Age Argolid. There is a lack of diachronic representation of the studied Lerna and Apatheia populations by skeletal material spanning the entire Bronze Age. As a result, it is impossible to monitor diachronically fluctuations in the biological history of either the Apatheia or Lerna populations through the Bronze Age. Therefore, reconstruction of the biological history of the Argolid population during the Middle and Late Bronze Age is tentative, and the interpretation of the biological relationship between Apatheia and Lerna is not without problems.

Since it was impossible to monitor the shaping of the biological history of either of the two studied skeletal collections over the course of the Bronze Age through fluctuations in intra-population variation, and because in the present analysis the overall Argolid population is represented only by these two samples, it cannot be inferred securely from the present data which of the two populations (represented by the Apatheia and Lerna samples) received extra-regional gene flow, hence increasing its intra-sample variation and thus its distance to the regional population centroid (Relethford & Blangero 1990). From the data available, the MH Lerna sample exhibits higher intra-sample variation for cranial metric morphology relative to Apatheia. The two principal genetic factors that could account for this are gene-flow into the Lerna population from biologically divergent sources and/or higher genetic drift for the Apatheia population. It should be noted, however, that the higher intra-sample variation of the Lerna sample needs not convey information about the genetic make-up of the two populations (or at least not exclusively), but could also result from sample size issues and the greater time-depth of the Lerna sample (Konigsberg 1987).

As the shaping of intra-population variation through the Bronze Age cannot be monitored for either of the two populations, we cannot say with absolute certainty that the Lerna population increased its intra-population variation in the Middle Helladic period. Nevertheless, whilst acknowledging the possibility of limitations in the representative power of the tested skeletal collections for the overall populations from which they derive (i.e. archaeological bias, see section 5.1.1.1), expected to be higher for Apatheia than for the Lerna sample, the high intra-population variation of Lerna constitutes strong evidence for gene flow from extra-regional sources. It conforms well to the hypothesis formulated using material culture data that proposes the arrival of new population elements at the EHIII and during the Middle Helladic (Caskey 1960; Wiencke 1989:509; Rutter 2001:116). In his study of the skeletal morphology of the Lerna population, Angel (1971) arrived at the same conclusion and even proposed specific origins for the new people. If this is true, then the Apatheia sample represents more accurately the regional (Argolid) biological population than Lerna.

With regard to the alleged arrival of new population elements at Lerna in the EHIII and MH period, application of strontium isotope ratio analysis was expected to shed more light on this hypothesis due to the great efficacy of this research method at detecting the presence of non-locals within the local (skeletal) population at a site. The Greek Archaeological Service, however, rejected two formal requests for a sampling permit, and so SIR analysis could not be undertaken.

8.1.2 Crete

Compared with the Argolid, the biological history of the Bronze Age Cretan population was more reliably reconstructed. The size and number of tested samples was larger, and these spanned the entire Bronze Age. The related archaeological questions were more systematically explored. This section discusses the results of the analysis of skeletal morphology that was undertaken here to test specific bioarchaeological hypotheses formulated largely from material culture evidence.

8.1.2.1 Biological Distance between Bronze Age Cretan samples

The principal hypothesis is that the Early Bronze Age populations of Western, Central and Eastern Crete derive from the same parent population. In the course of the Bronze Age, the biological distance between the Cretan populations increased. Increase in the inter-population distance resulted mainly from differential gene flow into the Cretan populations from sources outside the island and the operation of genetic drift. The auxiliary hypothesis is that the impact of the genetic drift was greater on the Western Crete population, and that the Central and Eastern Crete populations are closely related but distant to the Western Crete population. The auxiliary hypothesis was formulated on the basis of interpretations of the material culture of the respective populations suggesting comparatively less contactsand socio-cultural interactions between Western Crete on the one hand, and Central and Eastern Crete on the other. Inter-regional gene flow is expected not to have been regular enough to counter the effects of genetic drift and preserve inter-population biological homogeneity. Unfortunately, due to the very similar ranges of values for the biologically available SIR between sites along the northern part of the Crete, the results of strontium isotope ratio analysis cannot be used to detect population movement (a prerequisite for gene flow) between different regions of northern Crete.

In order to confirm the principal hypothesis, the biological distance between the Western (Palama and Kastelos samples), Central (Moni Odigitria, Ailias, Gypsades, Sellopoulo and Mavrospelio samples) and Eastern (Palaikastro and

Myrtos Pyrgos samples) populations needs to increase from the Early Bronze Age onwards. In this study, however, although the Central and Eastern Crete populations are represented by Early Bronze Age skeletal collections, both Western Crete skeletal collections analysed date to the Late Bronze Age. There was, therefore, no diachronic representation of the Western Cretan population by skeletal collections spanning the entire Bronze Age. Consequently, fluctuations in inter-population distance over the course of the Bronze Age could not be monitored between the analysed samples from Western Crete on the one hand and Central and Eastern Crete on the other.

Positive evidence for the biological relatedness of the Early Bronze Age populations from Eastern and Central Crete was provided by the metric and non-metric analysis of the cranial morphology. Principal component analysis was applied to variables describing the cranial length and breadth. The patterning of the cases in Figure 6.3.1 suggests a very similar cranial shape for the individuals from Moni Odigitria and Palaikastro. These two cemeteries, although roughly contemporary, are situated in the south-central and the easternmost part of the island, respectively.

In agreement with the results of metric analysis are those derived from the non-metric analysis of the cranial morphology. Mean Measure of Divergence analysis of cranial non-metrics suggests that the two populations (i.e. Moni Odigitria and Palaikastro) share a common ancestor (Table 6.2.12). Given the low sample sizes, and despite the considerable geographical distance between Moni Odigitria and Palaikastro, the Early Bronze Age samples from the two sites appear to be very closely related both in terms of cranial metric and non-metric morphology. The results, therefore, of cranial morphological analysis for the two Early Bronze Age samples from Central and Eastern Crete are consistent with the principal hypothesis that the Early Bronze Age Central and Eastern Crete populations derive from the same parent population. Unfortunately, due to the very poor representation of both the Moni Odigitria and Palaikastro samples by tooth specimens, their biological relationship could not be explored in terms of dental morphology.

Non-metric analysis of cranial morphology suggested that, apart from the Moni and Palaikastro samples, the following pairs of samples share a common ancestor: Moni-Ailias, Ailias-Mavrospelio, Gypsades-Sellopoulo, Gypsades-Mavrospelio, Gypsades-Myrtos Pyrgos, Myrtos Pyrgos-Mavrospelio (Table 6.2.12). The Early Minoan Moni and Palaikastro are the two earliest samples analysed in the present study. The Middle Minoan Ailias, LMI Gypsades, LMII-III Sellopoulo and

LMIII Mavrospelio samples derive from the district of Knossos. Finally, the MMII-LMI Myrtos Pyrgos is located in South-eastern Crete. The results of cranial non-metric analysis, therefore, suggest a close biological relationship shared between the Central and Eastern Crete population samples spanning the Bronze Age.

Metric and non-metric analysis of dental morphology provided supporting evidence for the biological relatedness of the successive Knossos population samples (i.e. the Ailias, Gypsades, Sellopoulo and Mavrospelio samples) suggested by the analysis of cranial non-metric morphology (Table 6.2.12). On the basis of the analysis of bucco-lingual tooth crown diameters, the Ailias, Gypsades and Sellopoulo samples cluster together and at distance from the roughly contemporary samples from Eastern and Western Crete (the Myrtos Pyrgos and Palama samples respectively) (Figures 6.2.27 and 6.2.28). Moreover, acknowledging the low sample size, of all examined pairs of samples, the Mean Measure of Divergence analysis of dental non-metrics suggested a shared common ancestry only for the Gypsades and Sellopoulo samples (Table 6.2.21).

In terms of dental metric morphology, the MMII-LMI Myrtos Pyrgos sample from South-eastern Crete clusters in close proximity to the Palama sample from Western Crete and at distance from the three contemporary and later Knossos samples (i.e. the Ailias, Gypsades and Sellopoulo samples) (Figures 6.2.27, 6.2.28 and 6.3.27). Dental non-metric and cranial metric analysis suggested a close biological relationship between the Myrtos Pyrgos sample and the Sellopoulo (Figure 6.2.32) and Ailias (Figure 6.3.22) samples from Knossos. Cranial non-metric analysis suggested a common ancestry shared between the Myrtos Pyrgos, Gypsades and Mavrospelio population samples (Table 6.2.12). Low sample size could be implicated in the discrepancy between the results of dental metric analysis on the one hand, and dental non-metric, and cranial metric and non-metric analysis on the other with regard to the relationship between the Myrtos Pyrgos and Knossos samples.

Unfortunately, the shaping of the inter-population distance on Crete over the course of the Bronze Age could not be monitored between the Western Cretan population on the one hand, and the Central and Eastern populations on the other, as Early and Middle Bronze Age samples from Western Crete were not available for analysis. The results of the cranial metric and non-metric morphological analysis are consistent with the auxiliary hypothesis that the Central and Eastern Crete populations, although closely related to each other, are distant to the Western Crete population. Mean Measure of Divergence analysis of cranial (Table 6.2.12) and dental non-metrics (Table 6.2.21) did not suggest a common ancestor shared between the Palama sample from Western Crete and any of the other Cretan samples.

The Western Crete samples (Palama and Kastelos) show the opposite relationship between sex and Cranial Index from other Cretan (with the exception of the Gypsades sample; mean Cranial Indices are very similar for the Gypsades males and females). Western Crete males appear to have a higher Cranial Index than the females, hence a more rounded cranial shape. Moreover, the cranium of Western Crete females is less rounded relative to their contemporaries from Central Crete (the Mavrospelio and Sellopoulo females). Given that the magnitude and pattern of sexual dimorphism are population specific (Ascadi & Nemeskéri 1970), the different patterning of the relationship between sex and Cranial Index in samples from Western Crete and the relationship of the Western Cretan females to their contemporaries from Central Crete in terms of the cranial shape may reflect biological distance between the Late Minoan Western and Central Crete samples.

On the basis of the results of dental metric morphological analysis (Figures 6.2.27 and 6.2.28), the Palama sample clusters close to the Myrtos Pyrgos sample from Eastern Crete and at distance from the three Knossos samples from Central Crete. However, the results and associated interpretations of the analysis of cranial and dental metric and non-metric traits should be treated with caution, due to low sample size and the possibility that the analysed Palama and Kastelos individuals may not accurately represent the entire range of intra-population variation for the Western Cretan population from which they derive.

8.1.2.2 Etiology of Inter-sample Distance: What does the distance between the Palama sample and the other tested Cretan samples actually mean?

The results of cranial and dental metric and non-metric analysis are consistent with my auxiliary hypothesis that the Central and Eastern Crete populations are closely related to each other, but distantly related to the Western Crete population. Should the Early Bronze populations of Western, Central and Eastern Crete derive from the same parent population, their Late Bronze Age descendants may have become distant because inter-regional gene-flow through of the Bronze Age was not regular enough to counter the effect of genetic drift upon the Western Crete population. Concerning the possibility that population movement (gene flow) into the Palama population resulted in great biological distance between this and the Central and Eastern population samples, strontium isotope ratio analysis suggested a non-local origin for only one (PAL15 A) of the eight Palama individuals examined.

The limitations of the interpretative power of the results of this study with regard to the tested principal and auxiliary hypotheses for inter-population relationships on the island of Crete need brief consideration. First, due to the lack of diachronic representation of the Bronze Age Western Crete population, although analysis of cranial and dental non-metric morphology did not suggest a common ancestor with any of the other Cretan samples for the Late Bronze Age Palama sample, the possibility that the Early Bronze Age Western Crete population derived from the same parent population as the populations of Central and Eastern Crete cannot be rejected. Second, the possibility that the low Palama sample size may have affected its representative power for the Late Bronze Age Western Cretan population should to be borne in mind.

8.1.2.3 Cranial Index data and the Biological History of the Bronze Age Central Crete Population

With regard to the question of the origins of the first inhabitants of Crete, the patterning of the Cranial Index data from the Bronze Age collections is interesting (Figure 6.2.7). The gradual increase of the Cranial Index (rounder cranial shape) of the population from Central Crete through time is striking. The greater rounding of the cranial shape for the later, compared with earlier, populations from Central Crete (as suggested by the Cranial Index data), is also demonstrated by the results of PCA of variables describing the length, breadth (Figure 6.3.7) and height of the cranium

(Figure 6.3.10). This could be the result of gene flow from populations biologically different from the Early Bronze Age Cretan population and from inter-population biological interactions (admixture) in the succeeding periods. Alternatively, following the thermoregulatory model of Beals *et al.* (1984), the increasingly higher Cranial Index, resulting from the rounder cranial shape, could reflect an adaptation to cold climates. The more rounded shape of the cranium minimizes its surface area that radiates heat and maximizes the cranial volume that produces heat. Hence, the gradual increase of the Cranial Index of the Central Crete population in the course of the Bronze Age could reflect a long-term adaptation of the Cretan population from a comparatively warmer climate (at the place of origin of the first inhabitants of Crete) to the local colder one on Crete. It is not legitimate to suggest that the increase of the Cranial index and the rounder cranial shape of the later Bronze Age Central Cretans resulted from changes in the climatic conditions (lowering of temperatures) in the Aegean. Climate change on Crete in the course of the Bronze Age is not expected to have been sufficient to introduce such an identifiable impact on the cranial morphology. Although it should not be altogether rejected that the gradual increase in the Cranial Index for the samples from Central Crete over the course of time could reflect a long-term adaptation of the first inhabitants of the island from comparatively warmer to colder climatic conditions, it most probably reflects gene flow into the Early Bronze Age population from extra-regional sources. Finally, patterning of the Cranial Index data (Figure 6.2.7) also indicates no significant disruption of the biological history of the Bronze Age Central Cretan population.

8.2 Inter-regional Level of Analysis

8.2.1 Biological relationship between the Argolid and Cretan population samples

This section discusses the results of the skeletal morphological analysis in relation to the validity of the principal assumption of the study. According to this assumption, the Argolid and Cretan Bronze Age populations were biologically distant enough in order to allow for the monitoring of fluctuations (relatedness vs. divergence) in their biological relationship due to inter-regional population movement and biological interactions.

Analysis showed that the pattern and magnitude of sexual dimorphism are similar for the Argolid and Central Crete Middle and Late Bronze Age populations. Male crania in both populations appear to be longer, higher vaulted and more protruding in the upper facial region relative to female crania (Figures 6.1.5, 6.1.7, 6.1.10, 6.1.11, 6.1.12, 6.2.17, 6.2.23, 6.2.24 and 6.2.25). In terms of cranial breadth, however, the Argolid males do not appear to separate from females, whereas Cretan male crania tend to be broader than those of the females (Figures 6.2.24 and 6.2.25). The calculated Height-Breadth (md) Index also suggests a less sexually dimorphic cranial shape in terms of the relationship between height and breadth dimensions for the Cretan compared with the Argolid population (Figures 6.1.7 and 6.2.19). Moreover, sexual dimorphism reached statistical significance only for the Cretan pooled samples for the Cranial and Height-Length (md) indices. Therefore, despite the overall similarity between the Argolid and Cretan populations in terms of the pattern and magnitude of sexual dimorphism in cranial morphology, the two measures (sexual dimorphism in cranial breadth and statistical significance of sex-differences for the CI and HLI(md)) for which sexual dimorphism is different for the two populations, could be interpreted as confirmation of the observation that inter-population variation in the magnitude and pattern of sex differences can be used to determine successfully the geographical origin of a skeletal sample (Frayer & Wolpoff 1985).

PCA of variables that describe the length and breadth of the cranium demonstrated a distinct separation between the LH Apatheia individuals and roughly contemporary samples from Central Crete (i.e. Gypsades, Mavrospelio, Sellopoulo and Episkopi) (Figures 6.3.15 and 6.3.16). By plotting the two sexes separately for each sample, the possibility that the observed inter-sample variance in the tested variables resulted from sexual dimorphism and differences in the representation of the two sexes in the tested samples was checked and refuted. On the other hand, the Middle Bronze Age samples from the Argolid and Crete appear to be morphologically similar when inter-sample relationships are explored using PCA of the same set of variables (Figures 6.3.19 and 6.3.22).

Remarkable is the difference between the Argolid and Crete in terms of the pattern of change in the Cranial Index in the course of the Bronze Age. Plotting of the calculated Cranial Indices shows a gradual increase of the Cranial Index for the later relative to the earlier population samples from Crete (Figure 6.2.7). The opposite, however, is observed for the Argolid population. The Cranial Index is lower for the LH Apatheia Galatas compared with the MH Lerna sample (Figure 6.1.13). In agreement with the results of the PCA, the Cranial Index for the MH Lerna sample is very similar to that of the contemporary Ailias and Myrtos Pyrgos samples from Knossos and South-eastern Crete respectively. Late Helladic Apatheia, however, is distant from roughly contemporary Cretan samples (i.e. Gypsades, Mavrospelio and Sellopoulo) in terms of the Cranial Index (Figure 6.3.18).

It should be noted, however, that, in this study the Argolid Bronze Age population is represented merely by the Apatheia and Lerna samples. Moreover, on the basis of cranial and dental morphological analysis, it was suggested that the Lerna population probably received gene-flow from extra regional sources, increased its intra-population variation and thus it distance to the regional (Argolid) population centroid (Relethford & Blangero 1990) (section 8.1.1).Therefore, it cannot be securely inferred from the data that the pattern of change in the Cranial Index in the course of the Bronze Age suggested for the Argolid population by the Lerna and Apatheia samples is representative of the overall Argolid population.

The results of Mean Measure of Divergence analysis of cranial non-metrics are not consistent with the hypothesis that either Lerna or Apatheia samples from the Argolid share a common ancestor with any of the Cretan samples (Table 6.3. 38).

In agreement with the results of the analysis of cranial metric and non-metric morphology are those derived from the analysis of dental morphology. Although Apatheia appears to separate clearly from the Cretan samples in terms of both metric and non-metric dental morphology, Lerna clusters with the Cretan samples and at distance from the Apatheia sample when inter-sample distance was measured by applying Hierarchical Cluster analysis to bucco-lingual diameters of both the complete dentition (Figure 6.3.24) and polar teeth only (Figure 6.3.25). In both analyses, right and left side measurements were entered into the analysis as separate variables. When right and left measurements were pooled to maximize sample size, Lerna appears to be closely related to Apatheia and distant from all but Myrtos Pyrgos Cretan samples for bucco-lingual diameters of polar teeth (Figure 6.3.27).

The results of Mean Measure of Divergence analysis of dental non-metrics are not consistent with the hypothesis that Lerna and Apatheia share a common ancestor with any of the tested Cretan samples (Table 6.3.51). Hierarchical Cluster Analysis applied to the MMD values, although it suggested a great biological distance between the Apatheia and the Cretan samples, it showed Lerna clustering closer to the Cretan samples than to Apatheia (Table 6.3.52, Figure 6.3.35). However, despite clustering with the Cretan samples, Lerna does not appear to share a close biological relationship with them (Table 6.3.52).

The results of both metric and non-metric morphological analysis of the skeletal morphology are consistent with the principal assumption of the study that the Argolid and Central Crete populations are biologically distant enough to detect population movement and biological interaction between the two regions. It is acknowledged, however, that although the Middle to Late Bronze Age Knossos (Central Crete) population is more adequately represented by tested samples, the Argolid is represented by only two samples (the Middle Bronze Age Lerna and the Late Bronze Age Apatheia). Moreover, on the basis of the results of the cranial and dental morphological analysis, these are suggested to be biologically distant. It cannot, therefore, be securely inferred from the data which sample (Lerna or Apatheia) is more representative of the overall Argolid population (section 8.1.1). Nevertheless, concerning the principal assumption of the study that the Argolid and Central Crete populations are biologically distant enough to detect population movement and biological interaction between them, more important than establishing which of the two samples is more representative of the Argolid population is that the Central Crete samples (i.e. the Moni, Ailias, Gypsades, Sellopoulo and Mavrospelio samples) are closely related to each other, and distant from both the Lerna and Apatheia samples from the Argolid for the vast majority of the examined aspects of the skeletal morphology.

The clustering of Lerna with Cretan samples for some of the analyses supports the tentative interpretation of the biological relationship between Lerna and Apatheia (outlined in section 8.1.1). According to that interpretation, Lerna most probably received new population elements and diversified from the regional (Argolid) biological population. However, the present evidence is not adequate to attribute the morphological relatedness between Lerna and the Cretan samples to actual direct biological interaction between these sites. It is more probable that their relationship is more indirect. Lerna may have received gene flow from population sources that have also contributed to the genetic make-up of the Cretan population.

8.2.2 Testing of Archaeological Hypotheses

Skeletal morphological and strontium isotope ratio analysis in this thesis investigated and provided negative evidence for both archaeological hypotheses for a Mycenaean presence at Knossos and on Naxos following the LMIB and LHIIIB-C destructions and cultural discontinuity on Crete and the Mainland respectively.

8.2.2.1 Settlement of people from the Argolid (Mainland) at Knossos following the destructions at the end of LMIB

The principal archaeological hypothesis tested in this study concerns the settlement and political take-over of Knossos by Mycenaeans from the Argolid following widespread destructions on Crete at the end of the LMIB. These Mycenaean rulers and their warrior aristocracy are suggested to have been interred into the so-called "warrior graves" (Sakellarakis 1972; Kanta 1980; Driessen & MacDonald 1984: 66; Hood 1985; Doxey 1987: 301; Driessen 1990: 125; Rehak & Younger 2001).

Proof statements were formulated and tested in order to explore this hypothesis. Analysis of the skeletal morphology focused on the relationship between Gypsades on one hand, and Sellopoulo and Mavrospelio samples from Knossos on the other. The MMIII-LMI Gypsades sample antedates the suggested migration whereas LMII-III Sellopoulo and LMIII Mavrospelio samples postdate it. Material culture studies suggest that the Sellopoulo and Mavrospelio cemeteries include burials ("warrior graves" or "burials with bronzes") of individuals from the Mainland who settled at Knossos (Popham 1974, 1994; Driessen & MacDonald 1984: 66; Hood 1985; Doxey 1987: 301; Rehak & Younger 2001: 444; Alberti 2004).

Continuity in the Biological History of the Bronze Age Knossos population:

Analysis of the cranial morphology did not provide evidence for the disruption of the biological history of the Knossos population at the end of the LMIB that would have resulted from the settlement and admixture of biologically different individuals from the Argolid. The biological distance between the successive Central Crete samples did not increase between the samples dating immediately prior to (Gypsades) and following (Sellopoulo and Mavrospelio) the suggested migration. PCA of variables describing the cranial length, breadth and height, and the protrusion of the upper facial skeleton, explored the relationship between the Central Crete (principally Knossos) population samples spanning the Bronze Age for evidence of discontinuity that are consistent with the arrival and admixture of biologically different individuals. The results demonstrated a gradual rounding of the cranial shape through the Bronze Age resulting from the increase of the breadth of the cranium, and a very similar cranial morphology for all three Late Minoan samples from Knossos (i.e. Gypsades, Sellopoulo and Mavrospelio samples) (Figures 6.3.7, 6.3.8, 6.3.9 and 6.3.10). The continuity of the biological history of the Bronze Age Central Crete population is exemplified by the patterning of the Cranial Index data. This shows a clear gradual increase of the Cranial Index, resulting from the rounding of the cranial shape, in the course of the Bronze Age (Figure 6.2.7).

Fluctuations in intra-population variation (employed as evidence of gene-flow from biologically different populations) were assessed by calculating the mean squared Mahalanobis distance of each Central Crete sample to the regional population centroid. Distances to the Central Crete population centroid were calculated for the Moni Odigitria, Ailias, Gypsades and Sellopoulo samples from variables describing cranial length, breadth and height, and the midline curvature of the calvaria (Tables 6.3.21 and 6.3.22). The results are not consistent with the hypothesis for an increase in the distance of the Sellopoulo and Mavrospelio samples to the Central Crete population centroid relative to the earlier Gypsades and Ailias samples (also from the Knossos district) resulting from the influx of biologically different population elements. Also, the calculated coefficients of variation for the Cretan samples for cranial metric variables and the Cranial, Height-Breadth (md) and Height-Length (md) indices are inconsistent with the hypothesis for an increase in the intra-population variation for the samples post-dating the suggested migration (i.e. Sellopoulo and Mavrospelio) compared with the Ailias and Gypsades samples antedating it (Figures 6.3.11, 6.3.12, 6.3.13 and 6.3.14).

Cranial non-metric morphological analysis agrees with the results of cranial metric analysis. The results of Mean Measure of Divergence analysis suggest that the Gypsades sample shares a common ancestor with the Mavrospelio and Sellopoulo samples. This would not be expected if the Mavrospelio and Sellopoulo burials were of people from the Argolid (Table 6.3.38). Moreover, the results of the dental non-metric analysis suggest a strong biological relationship between the LMI Gypsades and LMII-III Sellopoulo samples from Knossos (no teeth were available from Mavrospelio) (Table 6.3.51, Figure 6.3.35), and a high biological distance between the Knossos samples on the one hand, and both the Lerna and especially the Apatheia samples on the other (Table 6.3.52, Figure 6.3.35). Likewise, the dental metric analysis provided additional evidence of biological relatedness for the Ailias, Gypsades and Sellopoulo samples from Knossos. When inter-sample relationships on Crete were explored using bucco-lingual tooth crown diameters, the three Knossos samples clustered together and at distance from the two samples from Eastern (Myrtos Pyrgos) and Western (Palama) Crete (Figures 6.2.27 and 6.2.28).

Therefore, the results of both metric and non-metric analysis of cranial and dental morphology are not consistent with the hypothesis for the disruption of the biological history of the Knossos population, at the end of the LMIB, resulting from the arrival of biologically different individuals. Having demonstrated the Argolid and Cretan samples to be biologically distant enough to detect population movement and biological interaction between the two regions (section 8.2.1), finding no discontinuity in the biological history of the Knossos population by examining samples dating from the period before to that following the suggested Mycenaean migration constitutes strong evidence against the tested hypothesis. More important than the low size of the Sellopoulo and particularly the Mavrospelio samples, is that the analysed material derives from burials that material culture studies associate with Mainlanders. Concerning the validity of the examined hypothesis, it is important to show that the people interred into the Sellopoulo and Mavrospelio tombs are not biologically distant from their predecessors in the region. The biological relatedness between the Middle to Late Bronze Age Knossos samples is a consistent finding throughout the various analyses undertaken to investigate inter-population relationships in terms of cranial and dental morphology.

Biological distance between the LBA Argolid and Cretan samples:

PCA of variables describing the cranial length and breadth did not provide evidence for decrease in the biological distance between the Argolid and Knossos samples from the Middle to the Late Bronze Age due to arrival of people from the Argolid and genetic admixture with the indigenous Knossos population following the end of the LMIB. The Late Helladic Apatheia individuals separate clearly from their contemporaries at Knossos (i.e. Gypsades, Sellopoulo, Mavrospelio samples) (Figures 6.3.15 and 6.3.16). The possibility that inter-sample variance is the result of sexual dimorphism and differences in the representation of the two sexes in the Argolid and Knossos samples was checked and refuted by using different symbols for males and females in scatterplots. By contrast, their predecessors from Lerna and Ailias appear to be similar in terms of cranial metric morphology (cranial length, breadth and height) (Figure 6.3.19). The two samples, however, show the reverse patterning of sexual dimorphism in Height-Breadth (md) Index (Figure 6.3.21). The results of cranial non-metric analysis are not consistent with the hypothesis that the Argolid samples share a common ancestor with any of the tested Cretan samples (Table 6.3.38).

The results of the dental metric analysis suggested significant distance between the two Late Minoan Knossos samples (i.e. the Gypsades and Sellopoulo samples) and the Late Helladic Apatheia sample from the Argolid (Figures 6.3.24, 6.3.25 and 6.3.27) as derived from bucco-lingual tooth crown diameters. Moreover, on the calculated distances (Squared Euclidean distance) using the values of the Mean Measure of Divergence analysis of the dental non-metrics, the Gypsades and Sellopoulo samples appear to be biologically related to each other but distant from the two Argolid samples (Tables 6.3.51, 6.3.52, Figure 6.3.35).

The possibility that low sample sizes may have impacted on the distinct separation between the Late Bronze Age Apatheia and Knossos samples is acknowledged. Samples of very low size may represent only a portion of the entire range of the variation of the population from which they derive. This thesis, however, analysed skeletal material from all the tombs of the Apatheia cemetery. Moreover, the Late Bronze Age Knossos samples appear to be also distant from the other Argolid sample (Lerna) in terms of both cranial and dental non-metric (Tables 6.3.38, 6.3.51, Figure 6.3.35) and dental metric morphology (Figure 6.3.27).

Finally, even if low sample size has impacted to some extent on the representative power of the examined samples for the population from which they derive, the strontium isotope ratio analysis results are in agreement with those obtained from morphological skeletal analysis. Strontium isotope ratio (SIR) analysis is affected very little by skeletal preservation and completeness. All eight individuals from the Sellopoulo tombs analysed for SIR were shown to be born locally. Thus the results of SIR are not consistent with the hypothesis for the presence of people from Mycenae among those interred into the so-called "warrior graves" at the Sellopoulo cemetery (as well as among all the other examined Middle and Late Minoan Knossos individuals).

8.2.2.2 Settlement of people from the Argolid (Mainland) at the Chora of Naxos following the destructions of LHIIIB-C on the Mainland

The second archaeological hypothesis of Mycenaean migration explored in this thesis concerns the settlement of Mycenaean high status individuals at Naxos, following the destructions and collapse of the palatial system on the Greek Mainland at the end of the Late Helladic IIIB. Material culture studies suggest that the LCIII burials at the Aplomata and Kamini cemeteries belong to high status individuals from the Mainland (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

Analysis of the skeletal morphology was undertaken to explore the biological relationship of the people buried in the Aplomata and Kamini cemeteries with their roughly contemporary population samples from the Argolid and Crete. Analysis was confined to two individuals for reasons related to poor preservation and completeness of the skeletal collections available for analysis from the tombs in question. Of the two examined individuals from Naxos, the male from the Kamini cemetery appears to be similar to the Apatheia sample in terms of the analysed aspects of cranial morphology (Table 6.3.36). On the other hand, the female from the Aplomata cemetery appears to be morphologically very distant from the Apatheia individuals (Table 6.3.34).

Due to the low size of the morphologically examined sample from the Aplomata and Kamini cemeteries, greater emphasis was placed upon the results of SIR analysis. As mentioned above (section 8.2.2.1), SIR analysis is little affected by the poor preservation and completeness of the skeletal material. SIR analysis of dental samples from the two individuals that were morphologically examined suggested a local origin for them. Thus, the hypothesis that these two individuals originated from outside Naxos was rejected (Figures 7.4, 7.5 and 7.6, Appendix F, Table 7.1). Dental enamel samples were analysed from three more individuals from the LCIII Aplomata and two more individuals from LCIII Kamini cemeteries to test the hypothesis for a Mycenaean migration to Naxos following the LHIIIB-C destructions on the Mainland. Despite the low sample size, with regard to the validity or invalidity of the examined hypothesis, it is very important that the SIR analysis was applied to samples from individuals from those tombs that material culture studies associated with high-status Mycenaeans from the Argolid. Analysis provided negative evidence for the presence of Mycenaeans among the individuals analysed. Therefore, the SIR results are not consistent with the hypothesis that the LCIII burials at the Aplomata and Kamini cemeteries belong to high status Mycenaeans from the Argolid (Figure 7.6).

8.2.2.3 Non-local origin of the individuals interred into the pit caves in the Palama Cemetery (Western Crete)

The hypothesis advanced by Hallager (Hallager & McGeorge 1992) that the pit caves in the Palama Cemetery at Chania belong to an "ethnically" different population group was explored by sampling four individuals interred into these graves for SIR. Analysis suggested a local origin for all but the male individual PAL15 A. Individual PAL15 A was identified as non-local. Due to close similarity between the SIR measured in a sample from his dental enamel and the local biologically available SIR at the Chora of Naxos, a probable origin from Naxos or another Aegean island of similar geology could be proposed for this individual.

8.3 Concluding Remarks

This thesis has contributed significantly to the more complex reconstruction of Aegean Bronze Age bio-cultural history by bringing together complementary lines of archaeological evidence. It has demonstrated successfully how greatly archaeological research benefits from both the application of morphological analysis of human skeletal material and strontium isotope ratio analysis in order to investigate questions of population movement and residential change. Strontium isotope ratio analysis, in particular, is very efficient even when the completeness and preservation of the available skeletal material is poor.

Analysis of skeletal morphology and strontium isotope ratio explored two widely debated archaeological questions of cultural discontinuity in Aegean Prehistory by testing their predominant interpretations. Both the results of morphological analysis and strontium isotope ratio analysis of the present research are not consistent with these. The first interpretation concerns the LMIB destructions and subsequent cultural upheaval on Crete. It argues that, at the end of LMIB, people from the Argolid (Mainland) arrived and settled at Knossos. Settlement involved a Mycenaean ruling class which politically dominated Knossos, and their warrior aristocracy. These Argolid warriors were interred into the so-called "warrior graves" following their death (Sakellarakis 1972; Kanta 1980; Driessen & MacDonald 1984: 66; Hood 1985; Doxey 1987: 301; Driessen 1990: 125; Rehak & Younger 2001). In the district of Knossos, "warrior" graves have been excavated at Sellopoulo, Mavrospelio, Ayios Ioannis and Zapher Papoura cemeteries (Popham 1994). The second interpretation suggested that, following the LHIIIB-C destructions and the demise of the palatial system in the Mainland, Mycenaean kings and/or their aristocracy sought refuge in the Cyclades. Interments made in the LCIII tombs at the Aplomata and Kamini cemeteries at the Chora of Naxos have been associated with these Mycenaean expatriates on the basis of finds of royal and ritual connotations associated with the dead (Kondoleon 1958, 1959; Kardara 1977; Barber 1987).

Acknowledging the low sample sizes, the results of the morphological skeletal analysis are not consistent with the hypothesis for a disruption to the biological history of the Bronze Age Knossos population following the LMIB destructions on Crete. Moreover, results showed no decrease in the biological distance between the Argolid and Knossos population samples in the Late Bronze Age relative to the Middle Bronze Age that might have resulted from the settlement of Mainlanders at Knossos and their biological interactions with the local population. Moreover, the results of the strontium isotope ratio analysis suggested a local origin for the tested Sellopoulo individuals from the "warrior graves" and tombs of Mycenaean architecture. Thus, the strontium isotope ratio analysis results are not consistent with the hypothesis that the Sellopoulo (Knossos) tombs belong to Mycenaeans from the Argolid, who, at the time, politically dominated Knossos. They are also inconsistent with the hypothesis that the Aplomata and Kamini (Chora of Naxos) tombs belong to Mycenaeans.

One of the constituent elements of the hypothesis for a Mycenaean presence at Knossos is the occurrence in the site of "warrior graves" and tombs of Mycenaean architecture. On the basis of their architecture, artefacts associated with the dead, and mortuary practices, these graves have been interpreted as belonging to a Mycenaean community that settled at Knossos following the LMIB destructions (Popham 1994: 93-4; Driessen & MacDonald 1984: 66; Doxey 1987: 303; Driessen 1990: 124-5; Rehak & Younger 2001:444). By showing that the analysed individuals from the Sellopoulo tombs are locals, on the basis of the results of SIR analysis, and that they are biologically related to the Bronze Age Knossos regional population, on the basis of the skeletal morphology, I have demonstrated that the equation of the novel cultural features (i.e. funerary architecture, burial assemblages and mortuary practices) on Crete during this period, with the settlement (long-term physical presence) of the people suggested to have been the first to create them is over-simplistic. Therefore, the results of the thesis suggest that the theory of a Mycenaean conquest of Crete and political domination of Knossos, based on the interpretation of "warrior graves" and tombs of Mycenaean architecture as burials of a Mycenaean ruling class and their warrior aristocracy, is problematic and needs revisiting. If Mycenaeans are not buried in the Sellopoulo tombs, where should one look for them?

Moreover, the 'abrupt' nature of innovations in funerary architecture, burial assemblages and associated ideologies, together with other novel material culture features and practices dated to the period immediately succeeding the LMIB destructions and assigned a common etiology (i.e. Mycenaean invasion of Crete and political domination of Knossos), is largely exaggerated by archaeological bias. How can there be a valid argument for a major rupture in funerary tradition at the end of LMIB when so little is known about the burials during the LMI period? Discontinuity in the burial practices of the Late Bronze Age Cretan society becomes less clear-cut in the light of the finds from excavations in Poros-Herakleion (5km from Knossos) (Driessen 1990:125). The archaeological picture is further obscured by the plundering of a very high portion of the Late Bronze Age tombs at Knossos (Alberti 2004: 131). In this line of reasoning, Niemeier (1985:226) and Killian-Dirlmeier (1985) argued for the local origin of both the "warrior graves" and the single-chamber tombs with dromos (the so-called chamber tomb of Mycenaean architecture). It is interesting to note that the single-chamber tomb that was attributed to the Mycenaean invaders did not go out of use following the destruction of the palace and the end of the alleged Mycenaean political domination of Knossos. Likewise, the Linear B writing system that is suggested to have been introduced by the Mycenaean ruling elite survived its demise (*ibid.*).

The results of this study are compatible with more recent archaeological hypotheses for the destructions and cultural upheaval that emphasize factors internal to the Cretan society and social unrest (see discussion in Driessen & Macdonald 1997). There can be very little doubt that the LMIB destructions on Crete are of anthropogenic origin. Evidence of this comes from the awareness of the LMIB people of an imminent danger and the abandonment of the settlement before its destruction, the dearth of human skeletal remains from destruction layers, absence of continuity in reoccupation of burnt sites, hidden weapons and sings of plundering (Driessen & MacDonald 1997:109).

What appears to be the targeted destruction of administrative centres in the depleted sites, most probably conveys information about the identity and the motives of those responsible for the destructions and cultural upheaval. Rehak & Younger (2001) attribute the selective destruction of administrative centres and elite objects to the revolution of the lower class against the ruling elite and their authority. In the context of social unrest and competition, I agree with Driessen (2002) and Hamilakis (2002b), who argue for a horizontal rather than vertical hierarchical organization of the pre-LMIB Cretan societies and factional competition respectively. I see the LMIB destructions and cultural disruption on Crete as being the result of social revolution, caused when the mechanisms of temporal persistence of the "Minoan" civilization failed to circumvent its dissolution, which in turn was triggered by the enhancement of minor perturbations in its internal structure and external context (Bintliff 1994). These perturbations can be associated possibly with what Driessen & MacDonald (1997:112) describe as the psychological and economic consequences of the pre-eruption LMIA earthquake and the actual volcanic eruption, and/or the consequences of the intensification of the power of Knossos over the entire island (Manning 1994).

In the framework of interpretation agreed here, emphasising factors internal to the Cretan society, social unrest and social competition, as responsible for the destructions and cultural discontinuity, the introduction of novel features considered to be Mycenaean in origin (Treuil *et al.* 1996; Rehak & Younger 2001), is attributed to the new political leaders. The new leaders, who were successful in the social competition, adopted a new symbolic system in order to justify the political change and legitimise their power (Schallin 1993) or even because they were affiliated with the Mycenaean world. This system, however, was already known to the Cretans through inter-regional contacts dating back to the Early Bronze Age. These contacts that were responsible for stylistic and ideological interactions between the two regions, could have taken the form in the LMIA of a Mycenaean aid in agricultural products to a depleted Crete from the earthquake and the eruption of the Theran volcano (Driessen & MacDonald 1997: 114).

In the absence of evidence for the burial of Mycenaeans in the LCIII Aplomata and Kamini cemeteries on Naxos, the burial practices and the material culture associated with the interments in the two Naxian cemeteries, most probably represent, as in the case of Crete, the adoption by local political leaders of a foreign (Mycenaean) symbolic system. This system was conceived at the time as superior to the local one, in the context of competitive emulation and power negotiation (Schallin 1993). On Naxos, however, introduction of novel material culture and practices was not preceded by evidence for social unrest and rebellion (as in the case of Crete). Thereby the results of this study confirm that it is problematic to equate certain forms of material culture with certain people and infer population movement, hence biological history, from material culture history, as suggested by Binford (1965) and Renfrew (1972, 1978).

In the future, the author endeavours to use the present study as the stepping-stone to explore further these and other archaeological questions highlighted by this research. With regard to the main archaeological question explored in the thesis, I have already started increasing the database (i.e. metric and non-metric morphological and strontium isotope ratio data) by studying skeletal collections from the Argolid (Grave Circle A at Mycenae) and Knossos (KSP chamber tombs and Sellopoulo shaft grave) that were previously inaccessible. Morphological skeletal analysis in this study used all the available material from Knossos dating to the period following the suggested migration that qualified for the analysis. However, had the archaeological law active at the time been different, and the funding resources permitted it, more individuals from the Sellopoulo skeletal collection could have been analysed to measure the strontium isotope ratio. A more comprehensive reconstruction of the Cretan socio-political context dating from the LMIB onwards is expected to be achieved through more systematic analysis of both the material culture and biological history of the Mainland and Knossos populations from the end of the MBA onwards. In this context, the future endeavours will include analysis of skeletal material from the Poros cemetery, where the two types of chamber tomb (i.e. the local - Cretan and the non-local - Mainland one) are present, and material from new excavations.

Finally, the thesis demonstrated the benefits of archaeological research into cultural discontinuity and population movement from using strontium isotope ratio analysis and highlighted the need for further research in the Aegean to characterize the 'local' biologically available SIR ($^{87}Sr/^{86}Sr$) signature at different sites within this region. Thus it will be possible to produce the first map of biologically available SIR values in the Aegean that can then be used to accurately distinguish between locals and non-locals at the examined sites and detect the probable geographical origin of individuals identified as non-locals.