Ceramic Micropalaeontology

The analysis of microfossils in archaeological ceramics with special reference to its application in the southern Aegean

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Abbreviations

MA	Million years
BP	Before present
EM	Early Minoan
MM	Middle Minoan
LM	Late Minoan
LO	Last occurrence
FO	First occurrence
FCO	First common occurrence
LCO	Last common occurrence
acme	Period of high abundance
NN	Neogene nannoplankton zones (Martini 1971)
CN	Neogene nannoplanton zones (Okada and Bukry 1980)
DSDP	Deep Sea Drilling Project
ODP	Ocean Drilling Project
PPL	Plane polarised light microscopy
XP	Cross polarised light microscopy
SEM	Scanning electron microscopy
AAS	Atomic absorption spectrophotometry
ICP	Inductively coupled plasma spectrometry
INAA	Instrumental neutron activation analysis
OES	Optical emmision spectrometry
XRD	X-ray diffraction
IGME	Institute of Geology and Mineral Exploration, Athens

10 Fieldwork sampling

10.1 Introduction

In the case studies which are presented in Chapter 11, the raw materials of ceramic manufacture, as interpreted through the analysis of microfossils, have been related to the regional and local geology of the areas in question, in order to determine aspects of provenance and technology. This has been achieved by referring to published geological maps and reports on the geology of Crete and the Mediterranean, as well as the authors own extensive fieldwork observations and the analysis of sediment samples.

Several fieldwork seasons were undertaken, during the summers of 1996, 1997 and 1998 in order to visit specific archaeological sites on Crete and become familiar with the surrounding geology and geomorphology. By way of a field guide, the author referred to the publications of the Utrecht school of micropalaeontology and stratigraphy (e.g. Fortuin 1977) as well as the detailed 1:50 000 geological maps of Crete produced by the Institute of Geology and Mineral Exploration (IGME), Athens.

As the case studies which are presented below rely heavily upon biostratigraphy as a means of determining provenance, it was not necessary to collect large numbers of clay samples for direct comparison with the archaeological ceramics. Instead, the sampling strategy was aimed at establishing or confirming the geological age of specific late Neogene sedimentary deposits in several areas of Crete. This was achieved by collecting relatively small, *in situ* sediment samples which were then interpreted biostratigraphically, with calcareous nannofossils. Calcareous nannofossils were chosen as the tool for biostratigraphy because of the small sample size which is required for their study (Section 5.3), the high level of biostratigraphic resolution which they can achieve in the Cretan late Neogene (Section 5.6), and because they are the principal group of microfossils used for the analysis of archaeological ceramics in this study.

On Crete, fieldwork observations and sampling concentrated on the Messara plain, the southern edge of the Gulf of Mirabello, the south coast and the north-central parts of the island, all of which contained important centres of Bronze Age ceramic production (Figure 10.1). In total, some 250 individual samples were collected, all of which were prepared for the study of calcareous nannofossils, however only a small proportion of these were selected for detailed analysis (Sections 10.2 to 10.4). In addition, extensive fieldwork observations and sampling was carried out on the late Neogene sedimentary succession of Melos in the Cycladic Islands. All of the sediment samples are stored at the University of Sheffield along with extensive notes on the geology of the various study areas.

10.2 South coast of Crete

In this report, what is referred to as the south coast of Crete comprises the area west of Ierapetra, between the villages of Ammoudares and Myrtos (Figure 10.1). This area, which appears to have been an important centre for the production of Early Minoan ceramics (Whitelaw *et al.* 1997), contains the archaeological sites of Myrtos Fournou Korifi (MFK) and Myrtos Pyrgos (MPY), and is characterised by well-exposed,

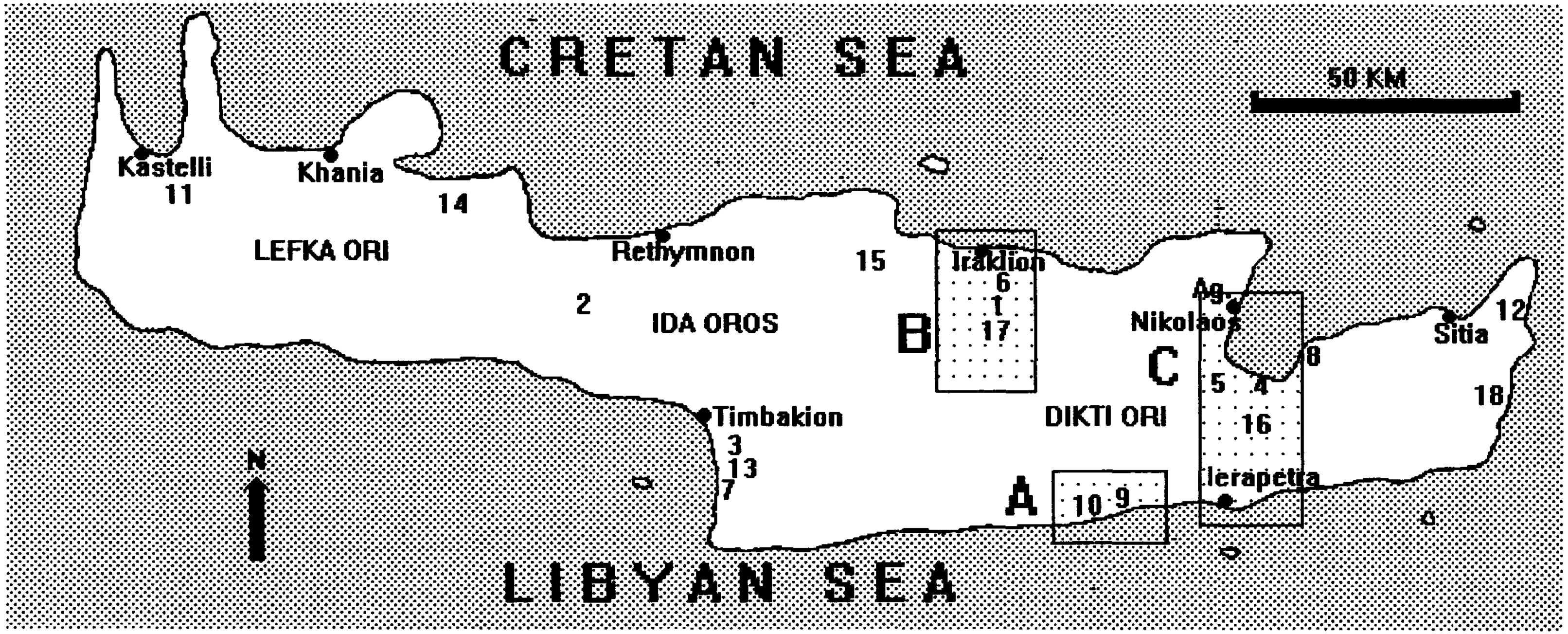


Figure 10.1 The location of the three main areas of Crete in which geological fieldwork was undertaken. A. The south coast of Crete, B. North-Central Crete and C. The Gulf of Mirabello and Isthmus of Ierapetra. The location of the three main Pre Neogene mountain ranges which form the basement of Crete are indicated, as are important archaeological sites: 1 = Archanes, 2 = Armenoi, 3 = Ayia Triada, 4 = Gournia, 5 = Kalo Khorio, 6 = Knossos, 7 = Kommos, 8 = Mochlos, 9 = Myrtos Fourno Korifi, 10 = Myrtos Pyrgos, 11 = Nochia, 12 = Palaikastro, 13 = Phaistos, 14 = Stylos, 15 = Tylissos, 16 = Vasiliki, 17 = Vathypetro, 18 = Zakros.

undulating Neogene topography, backed by the pre-Neogene Dikti mountains (Figure 10.2). Fortuin (1977, 1978) has studied the Neogene and pre-Neogene geology of the south coast area as well as the Ierapetra depression, and the current 1:50 000 IGME Ierapetra sheet is based upon his work. By referring to these publications, as well as first hand field observations, five of Fortuin's Neogene sedimentary deposits were identified as being relevant to the analysis of the microfossiliferous South Coast ceramics (Section 11.2).

In the south coast area of Crete, Fortuin (1977) divided the autochthonous late Neogene sediments into six 'formations' and one 'complex'. Of these, only the Kalamavka, Makrylia, Ammoudares and Myrtos Formations were deemed to be particularly significant for the study of microfossilifeous pottery, as the other two (the Mythoi and Males Formations) are represented in the south coast area by very coarse grained, non-microfossiliferous sandstones and conglomerates which were deposited during the 'post-orogenic' sedimentation which preceded marine deposition on Crete (Section 4.2). However, in the upper Males Formation, there is a small marine succession of sands and marls (Fortuin's 'Parathiri Member'), which occurs in a narrow east-west strip some 3 km from the coast, behind a large olistolith ridge of the Kalamavka Formation (Figure 10.2). The finer-grained, calcareous sediments of the Parathiri Member represent the partial invasion of the sea in this area of Crete during the Middle Miocene (Fortuin 1978), and is therefore directly relevant to the analysis of the microfossiliferous South Coast pottery (Section 11.2).

The overlying Prinia Complex which occurs across a large area, surrounding the village of Anatoli, contains a confusing mixture of lithological units which have been grouped together by Fortuin (1977), due to their uncertain stratigraphic position. This poorly fossiliferous group of sediments can be subdivided into breccias and breccio-conglomerates of reworked pre-Neogene rocks and olistoliths and breccias of metamorphosed limestone. The conglomeratic section of the Prinia complex contains some, partly fossiliferous fine-grained intervals in a few small areas at the eastern end of its occurrence, however these are very small and situated some distance inland from the sites of MFK and MPY.

Allochthonous pre-Neogene olistoliths also occur in the overlying Kalamavka Formation in the south coast area, where they form a high east-west ridge and isolated rocky knolls some 2 km from the coast. An olistolith-free, argillaceous equivalent of this formation can be found close by, covering a strip of land from the Myrtos river in the west to the Kalamavkianos river in the east, as well as an equally large area on the north-eastern flank of the latter. In the area surrounding MFK and MPY, this part of the Kalamavka Formation lies in a depression at the foot of the aforementioned olistolith ridge, and consists of alternating sands and marls. Despite being poorly exposed, *in situ* sediments of this formation were sampled at one small outcrop (Figure 10.2, Sample D).

The three groups of late Neogene sediments which overlie the Kalamavka Formation (Fortuin's Makrylia, Ammoudares and Myrtos Formations), were of principal interest to the study of microfossiliferous South Coast ceramics (Section 11.2), and consequently, the majority of sediment samples which were collected and analysed, originate from these (Figure 10.2). In the south coast area, the Makrylia Formation consists of a large thickness of alternating marls and graded sandstones which are steeply dipping in a southerly direction and cover most of the area between the Kalamavka olistoliths in the north and the coast (Figure 10.2). Travelling inland from the archaeological site of MPY one passes through the whole Makrylia succession, which contains distinct variations on the sand/marl alternation, in terms of grain size, as well as the amount of calcite and degree of lithification. Four samples of clays and clayey marls were chosen for calcareous nannofossil analysis from various positions within the Makrylia succession in order to determine the geological age of this formation in the south coast area (Samples A, R, W and Y).

The Ammoudares Formation is more calcareous than the underlying Makrylia Formation, and whilst it also consists of alternating sandstones and marls or marly clays, the sediments of this formation can be identified by the occurrence of synsedimentary and post-depositional deformation. The homogeneous and laminated marls and sandy limestones of the Ammoudares Formation have an east-north-east to west-south-west trend in the south coast area and form several small hills between the sites of MFK and MPY (Figure 10.2). Samples S, C and ε were taken from this formation.

The youngest group of late Neogene sediments which occur in the south coast area are those belonging to Fortuin's Myrtos Formation. The Myrtos Formation is limited in occurrence to a narrow area between Nea Anatoli and Myrtos, where it occurs as two main lithologies; these are an undisturbed calcareous succession of light-coloured homogeneous and foliated marls and sands, and a geographically more extensive mass of gypsiferous marl breccia, formed during unstable tectonic conditions. The undisturbed Myrtos sediments occur in only three places in the south coast of Crete;

these are the hill of Fournou Korifi (Fortuin's type section for this formation) upon which MFK is situated, a coastal succession near the village of Ammoudares and a small area close to Nea Anatoli. Several samples (B, I and κ) of these white marls were taken from various outcrops on the hill of Fournou Korifi, in order to determine the stratigraphic extent of this formation in the Myrtos area (Figure 10.2).

The sedimentary succession of the south coast of Crete continues after a long hiatus, in the form of coarse-grained Quaternary marine deposits. These poorly-sorted, partially lithified, shelly beds are the remains of marine terraces and can be found in a large area from Nea Anatoli towards Ierapetra (Figure 10.2). This lithology also forms the hard capping of Fournou Korifi upon which MFK is built, where it unconformably overlies the uppermost sediments of the Myrtos Formation. The coarse nature of these Quaternary sediments means that they were not of principal concern to the analysis of microfossiliferous south coast ceramics, however, one sample was collected from a finer horizon in order to establish whether they contain any microfossils, as well as to determine their precise geological date.

The south coast sediment samples which were selected for detailed calcareous nannofossil analysis are listed below, and their location is indicated in Figure 10.2. Descriptions of the calcareous nannofossil assemblages and the biostratigraphic interpretations of all south coast samples are presented in Section AIII.2.

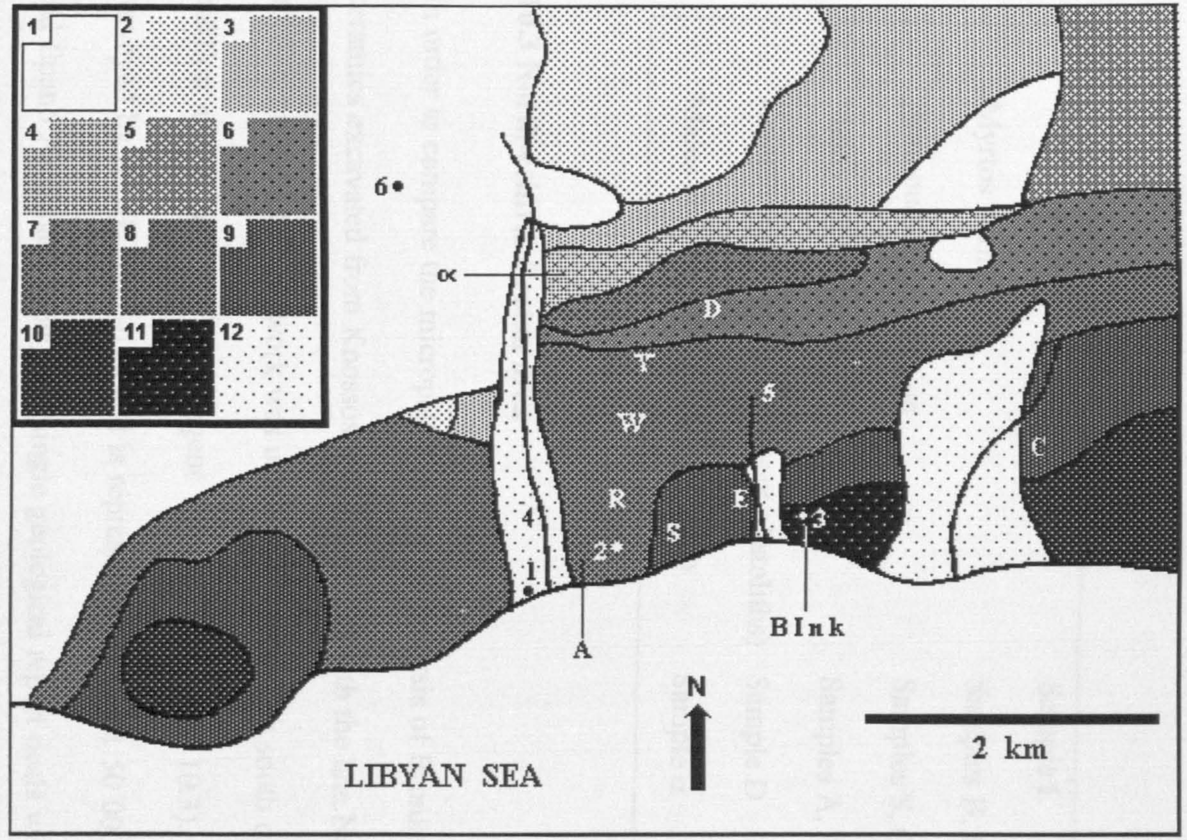


Figure 10.2 Simplified geological map of the Myrtos region of south Crete (based on Fortuin 1977), indicating the location of the sediment samples chosen for calcareous nannofossil analysis. Sites: 1 = modern Myrtos, 2 = MPY, 3 = MFK, 4 = Myrtos river, 5 = ephemeral stream, 6 = Mithi. Key to geology: 1 = Pre Neogene, 2 = Mythoi Fm., 3 = Males Fm. conglomerates and sands, 4 = Parathyri Member, 5 =Prinia Complex, 6 = Kalamavka marls and sands, 7 = Kalamavka olistoliths, 8 = Makrylia Fm., 9 = Ammoudares Fm., 10 = Myrtos Fm. breccia, 11 = Myrtos Fm. marls, 12 = Alluvium. A, α = geological samples.

Quaternary marine terraces	Sample L
Myrtos Formation	Samples B, I and κ
Ammoudares Formation	Samples S, C and ε
Makrylia Formation	Samples A, R, W and Y
Kalamavka Formation (without olistoliths)	Sample D
Males Formation (Parathiri Member)	Sample α

10.3 North-central Cretan area

In order to compare the micropalaeontological analysis of Bronze Age archaeological ceramics excavated from Knossos (Section 11.3), with the late Neogene sediments of north-central Crete, fieldwork was undertaken in the area south of the modern city of Iraklion and around the pre-Neogene Mt. Juktas (Figure 10.3). This area has been surveyed by IGME geologists and is represented by two 1:50 000 maps (the Iraklion and Epano Archanae sheets). No single geological report deals with the late Neogene of north-central Crete in sufficient detail, therefore it was necessary to refer to the numerous descriptions of sedimentary sections, studied by Utrecht geologists in this area, as well as the IGME maps.

The late Neogene sediments of north-central Crete have been subdivided into seven formations which vary in terms of their age, lithology and geographic distribution. In order to visit representative outcrops of all these formations it was necessary to survey an extensive area, many times larger than that for the south coast region of Crete (Section 10.2). However, in doing so it was possible to assess the nature of the

Neogene sediments surrounding several archaeological sites, including Knossos, Archanes, Vathypetro and Juktas, some of which are believed to have contained ceramic workshops (Michaelidis 1993). Approximately 80 sediment samples were collected in total, of which twelve were chosen for calcareous detailed nannofossil analysis from four of the seven formations. The Pleistocene Iraklio Formation was not sampled because of its limited extent within the suburbs of modern Iraklion as well as the lack of suitable outcrop, the Ilias Formation, which occurs as distinct bodies to the west and south-west of Mt. Juktas was also ignored, as it consists of brecciated, unfossiliferous, metamorphosed components of pre-Neogene limestone, and the Viannos Formation which occurs in the southern part of the study area was sampled but not chosen for further analysis because of its non-marine origin.

The Skinias Formation which occurs south-west of Mt. Juktas, close to the archaeological site of Vathypetro consists of well-bedded grey clays with coarser intercalations. Unlike the underlying Viannos Formation, the sediments of the Skinias Formation are of marine origin and its lower boundary with these non-marine clays is hard to define. Two samples (1 and 2) taken from good outcrops of the Skinias Formation were chosen for calcareous nannofossil analysis (Figure 10.3).

A much more varied sedimentary succession is present in the Abelouzos Formation which overlies the Skinias Formation. This formation contains coarse and fine grained sediments of both marine and non-marine origin and occurs in association with the Agia Varvara limestones north of Mt. Juktas, as well as in a small area south of the town of Archanes on the east side of Mt. Juktas (Figure 10.3). Here small sections were found in the form of cuttings which have been made in an attempt to level the undulose agricultural land, and a few samples (9 and 15) of a light coloured chalky marl were taken.

The Late Miocene Agia Varvara Formation of north-central Crete can be divided into two main lithologies, these are a predominantly limestone and a predominantly marly variant, which pass laterally into each other. In the central part of this region, the limestone variant dominates, and occurs in a wide area to the east and north of Mt. Juktas, where it forms high ground separating several river systems flowing north towards the modern town of Iraklion (Figure 10.3). The marly variant is much more restricted in its distribution and contains gypsum bodies near to Profitas Ilias (Figure 10.3). Despite the predominance of limestone in the Agios Varvara Formation, there are many small clayey and marly interbeds as well as coarser-grained sediments such as sandstones and more rarely conglomerates. Many samples were taken from the clayey interbeds, some of which (Samples 18 and 20) have been studied for calcareous nannofossils along with a representative samples of the Agia Varvara marls.

In the relatively flat, northern-most part of north-central Crete, Pliocene sediments of the Finikia Formation occur. These light coloured marls, limestones and clays are, on the whole, rather poorly exposed and often form low-ground between hills of Agia Varvara limestone, for example at Knossos (Figure 10.3). However, several samples from various positions within this formation were collected. In the area south of Knossos, between the towns of Agia Irini and Fortessa, the Finikia Formation occurs as heavily brecciated marls with reworked Agia Varvara limestone and isolated gypsum bodies.

The geological samples from the north-central area of Crete which were selected for detailed calcareous nannofossil analysis are listed below, and their location is indicated in Figure 10.3. A description of the calcareous nannofossil assemblages and the biostratigraphic interpretation of all north-central Cretan sediment samples can be found in Section AIII.3.

Finikia Formation		Samples 6, 10.1, 10.5, 16 and 17.
Agia Varvara Fm:	limestone variation	Samples 18 and 20
	marly variation	Sample 5
Abelouzos Formation	Sample 9, 15	
Skinias Formation		Samples 1 and 2

10.4 The Gulf of Mirabello

During the analysis of ceramics from the Mirabello production group (Section 11.4), it was necessary to compare the calcareous nannofossil biostratigraphic assignments of this pottery with the age of suitable late Neogene sedimentary deposits occurring in the Isthmus of Ierapetra and Gulf of Mirabello region. Of the various geological units in this area, the Makrylia Formation which outcrops close to the archaeological site of Vasiliki, and the Pakhiammos Formation, which occurs in the vicinity of Gournia (Figure 10.4), were chosen as candidates for the source of the calcareous microfossiliferous sediment in the Mirabello samples. In order to establish the geological age and calcareous nannofossil zones in which these deposits were produced, it was necessary to collect field samples of the Pakhiammos Formation on

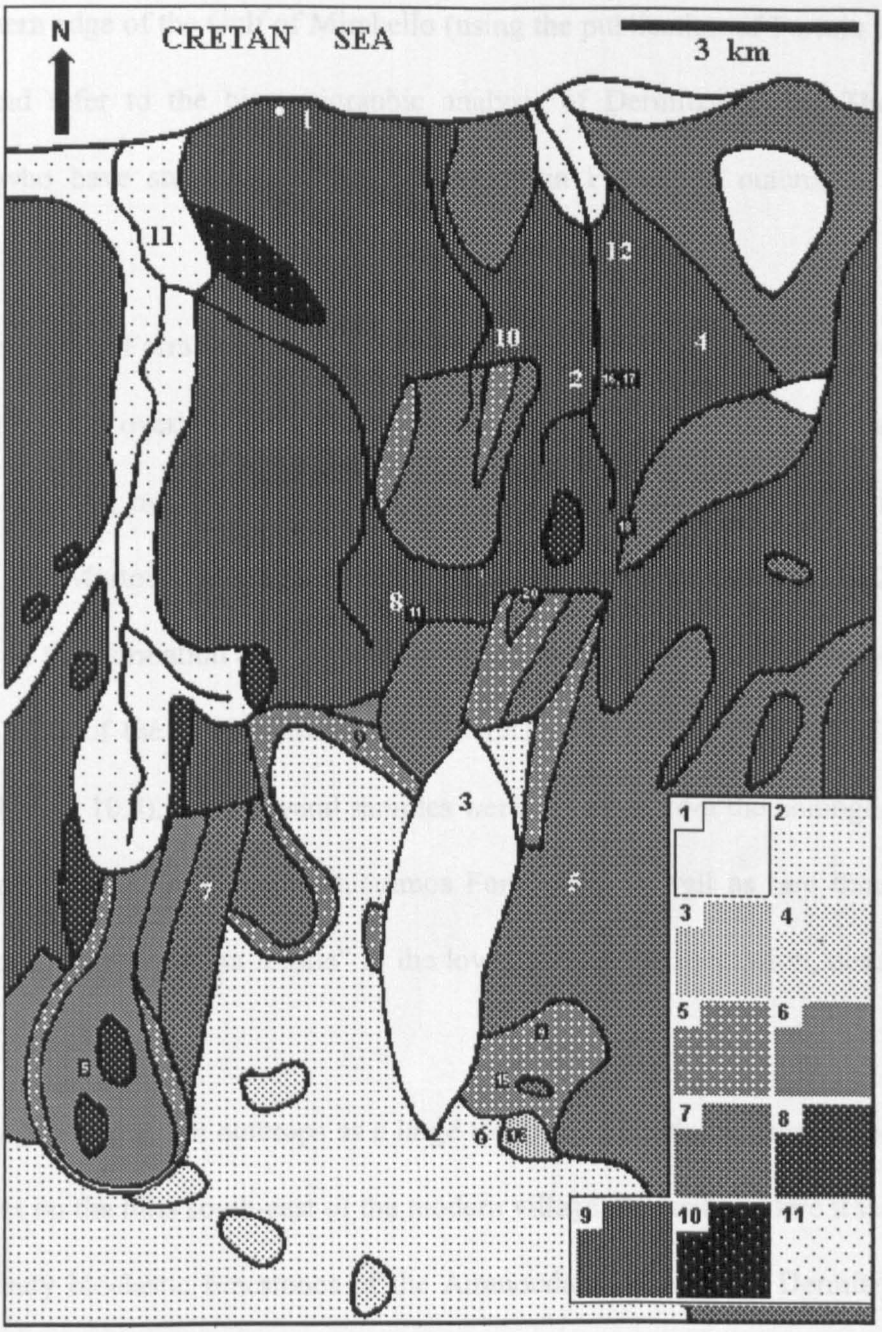


Figure 10.3 Simplified geological map of north-central Crete, (based on the IGME maps of this area), indicating the location of the sediment samples chosen for calcareous nannofossil analysis (numbers in boxes). Sites: 1 = Iraklion, 2 = Knossos, 3 = Juktas, 4 = Kalithea, 5 = Archanes, 6. Vathypetro, 7 = Ag. Sillas, 8 = Vasilies, 9 = Ag. Vlassios, 10 = Fortessa, 11 = rivers and streams. Key to geology: 1 = Pre Neogene, 2 = Viannos Fm., 3 = Skinias Fm., 4 = Ilias Fm., 5 = Abelouzos Fm., 6, 7, 8 = Ag. Varvara marls, limestones and gypsum bodies, 9 = Finikia Fm., 10 = Iraklio Fm., 11 = Alluvium.

the southern edge of the Gulf of Mirabello (using the publication of Fortuin 1977 as a guide) and refer to the biostratigraphic analysis of Dermitzakis and Theodoridis (1984), who have studied the extensive Makrylia Formation outcrop at Vasiliki (Figure 10.4).

The Pakhiammos Formation contains poorly laminated, red-brown, non-marine basal strata which are overlain by a very calcareous succession of limestone and marl breccia, followed by homogenous and laminated marls, which are very similar to those of the Myrtos Formation on the south coast of Crete (Section 10.2). Good outcrops of this formation are limited to a small region close to Pakhiammos, on the southern edge of the Gulf of Mirabello, where Fortuin (1977) established the type section (Figure 10.4). Here, several samples were collected from the homogenous and laminated marls of the upper Pakhiammos Formation, as well as rare thin beds of "green sandy marls without fossils" in the lower part of the succession, described by Fortuin (1977, 119).

The Makrylia Formation outcrops as a large thickness of dark grey marls and graded sandstones on the hills south-east of the modern village of Vasiliki. Here it is overlain by the sandy bioclastic limestones of the Ammoudares Formation. Dermitzakis and Theodoridis (1984) analysed calcareous nannofossils, planktonic foraminifera, bivalves, gastropods, corals and echinoids from several samples of both the Makrylia and Ammoudares Formation at Vasiliki and assigned this section to the early part of the Late Miocene, Tortonian Stage.

The Pakhiammos sediment samples which were selected for detailed calcareous nannofossil analysis are listed below, and their location is indicated on Figure 10.4.

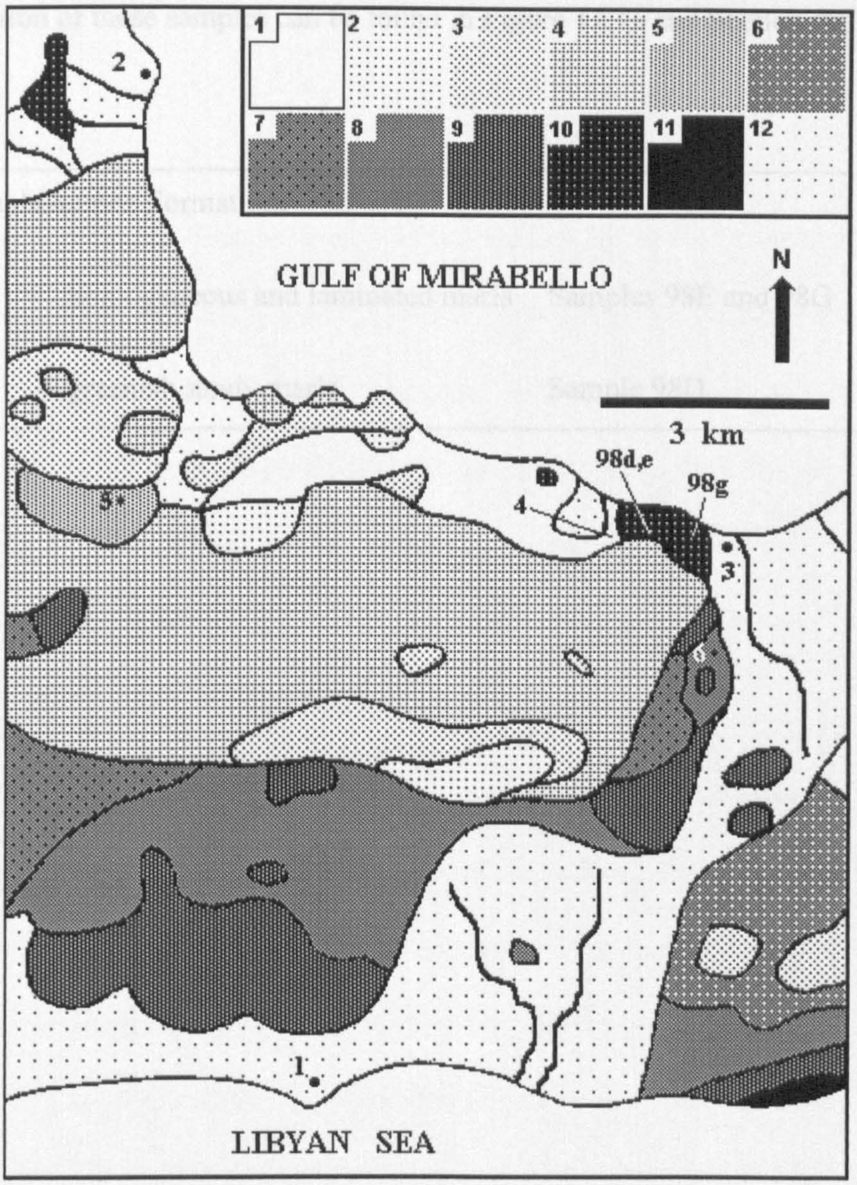


Figure 10.4 Simplified geological map of the Isthmus of Ierapetra and southern edge of the Gulf of Mirabello, Crete (based on Fortuin 1977), indicating the location of the Makrylia **Formation at Vasiliki and the Pakhiammos sediment samples chosen for calcareous nannofossil analysis. Sites: 1 = Ierapetra, 2 = Ag. Nikolaos, 3 = Pakhiammos, 4 = Gournia, 5 = Kalo Chorio, 6 = Vasiliki. Key to geology: 1 = Pre Neogene, 2 = Mithi Fm., 3 = Males Fm., 4 = Prinia Complex, 5 = Prinia marls, 6 = Fothia Fm., 7 = Kalamavka Fm., 8 = Makrylia Fm., 9 = Ammoudares Fm., 10. Pakhiammos Fm., 10. Myrtos Fm., 12. Alluvium.**

A description of the calcareous nannofossil assemblages and the biostratigraphic interpretation of these samples can be found in Figure 11.11 and Section AIII.4.

Pakhiammos Formation:	
homogeneous and laminated marls	Samples 98E and 98G
greenish sandy marls	Sample 98D

11 Case studies

11.1 Introduction

In chapters 5 to 9, we discussed each of the various groups of microfossils which occur in archaeological pottery from Crete and elsewhere in the world, and anticipated how they may be used to classify ceramics and interpret their provenance and technology. In order to demonstrate this methodology, five case studies are presented below. These focus primarily on calcareous microfossils from the Bronze Age archaeological ceramics of Crete, however, for comparison, two case studies are presented from elsewhere in the Mediterranean.

Each of the five examples represent clear archaeological questions, formulated through the results of other more conventional techniques such as the macroscopic study of shape, decoration and fabric, thin section petrography and chemical analysis, in which microfossils are used to microprovenance ceramics by identifying the precise sedimentary deposits utilised in their manufacture (Sections 11.2, 11.3, 11.6), ascertain the mesoprovenance of imported pottery by comparing them to ceramic assemblages of know provenance (Section 11.5) and investigate aspects of ceramic technology (Sections 11.2, 11.3, 11.4).

11.2 Microprovenancing on the south coast

11.2.1 Introduction

In the excavation of the Early Minoan village of Fournou Korifi near Myrtos on the south coast of Crete, Warren (1969) discovered eight clay disks which he interpreted as potters turntables. These were argued to comprise evidence for the existence of a local ceramic production at this site.

Day *et al.* (n.d.) analysed the rich, *in situ* ceramic assemblage of the EM IIB (Period II) occupation phase, preserved in the final destruction horizon at Myrtos Fournou Korifi (MFK) using petrographic and SEM analysis. Some of these analyses have been presented in Whitelaw *et al.* (1997, 266) who, remarking that the eight clay disks do not provide clear evidence for workshops, instead "relied on the information which can be determined directly from the ceramics themselves".

Whitelaw *et al.* (1997) subdivided the EM IIB ceramics from Myrtos into three production groups, originating from two main source areas, on the basis of macroscopic and thin section fabric analysis, construction techniques, finishing and surface decoration. The main fabric distinction between these three groups was originally identified by Warren (1972) however, he interpreted these as originating from different local clay beds, rather than geographically separate areas. The largest proportion (47 %) of the destruction assemblage at MFK belongs to Whitelaw *et al.*'s (1997) 'South Coast' production group and was produced broadly within the Myrtos region. However, some 49 % of the total pottery has been attributed to a source area on the southern edge of the Gulf of Mirabello, between Kalo Chorio and Vasiliki, approximately 20 km from MFK (Whitelaw *et al.* 1997). This imported pottery falls into two main production groups, the 'Mirabello' production group (Section 11.4) and the 'Vasiliki' production group, both of which constitute a similar proportion of the Myrtos assemblage (Figure 11.1).

Day *et al.* (n.d.) subdivided the pottery of the south coast tradition into six groups and several subgroups based on petrology. These fall into three main fabrics which are a non-calcareous clay with angular rock fragments (Groups 1 and 2), and fine (Groups 5 and 6) and coarse variants (Groups 3 and 4) of a medium to highly calcareous, microfossiliferous clay, "tempered with well-rounded water worn sand" (Whitelaw *et al.* 1997, 269). The rounded inclusions of the calcareous fabrics are largely of basaltic and serpentiniferous composition and appear to have derived from the pre-Neogene ophiolites and flysch mélange which occur west of the modern town of Myrtos (Day *et al.* n.d.). Beach sand was sampled from various sites along the south coast between Keratokambos and MFK and it was found that this is compatible with the rounded igneous and metamorphic inclusions of the South Coast pottery.

This beach sand has been added to a calcareous, microfossiliferous base clay which Whitelaw *et al.* (1997, 268) considered to have originated "from a clay deposit inland, at least 3 km west of the settlement". This corresponds with the extensive, fossiliferous Neogene marls of the Makrylia Formation which occur on the west side of the main Myrtos valley (Figure 10.2). However, deposits of this formation and other microfossiliferous Neogene sediments also occur within the vicinity of MFK, and along the coast as far as Ierapetra. Furthermore, Whitelaw *et al.* (1997, 268) have identified similar fabrics in local pottery excavated from the neighbouring site of Myrtos Pyrgos and suggested that "even if pottery was produced at Fournou Korifi, vessels employing similar fabrics and made within the South Coast tradition were also produced at other sites within this broader south coast region". This provenance interpretation of the south coast pottery was therefore on a meso-scale. Through a petrographic interpretation of the base clay and temper used in its construction, the source area of this pottery was identified as the land bordering the coast between MFK and the beginning of the pre-Neogene ophiolites and flysch to the west.

The present case study attempts to further this provenance interpretation by utilising the biostratigraphic information provided by the various microfossils contained within representative samples of South Coast pottery excavated at MFK, MPY, Kalo Chorio (KAC) and Kavousi (KAV), to suggest the precise geological formation from which it may have been procured; this is a micro-scale provenance interpretation. In addition, a comparison has been made between the presence and absence of foraminifera, ostracods and calcareous nannofossils, and Day *et al.*'s (n.d.) petrographic groups of the south coast pottery, in order to evaluate the utility of these microfossils as a means of classifying ceramics (Sections 5.9.2, 6.7.3, 7.7.3).

11.2.2 Micropalaeontological analysis of the South Coast pottery and geological samples

The foraminifera and ostracods of representative samples from all South Coast fabric groups and subgroups were studied in the manner described in Sections 6.7.1 and 7.7.1, using the thin sections produced and analysed by Day *et al.* (n.d.). In addition, calcareous nannofossil smear slides were prepared from subsamples of these sherds

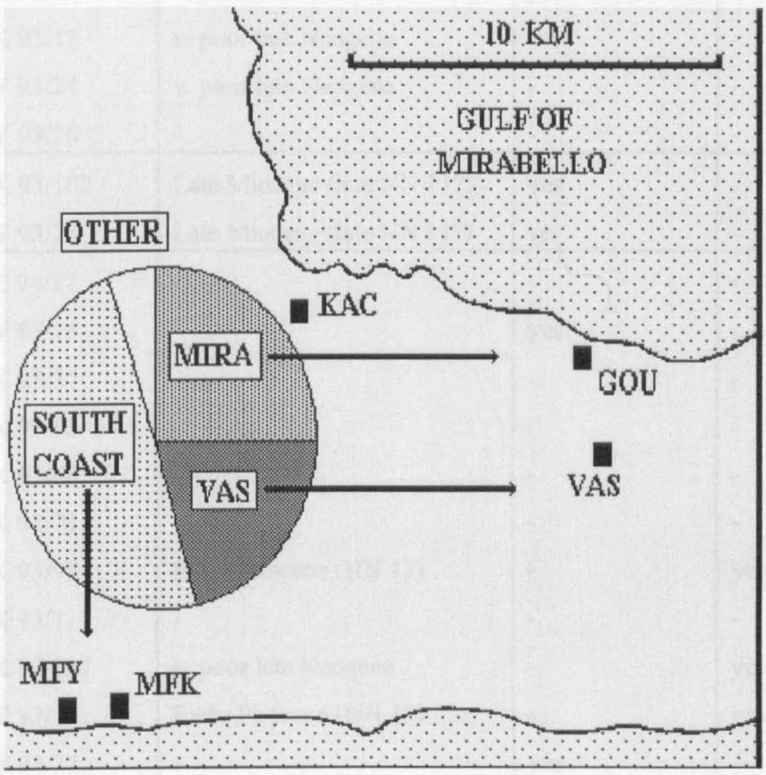


Figure 11.1. The provenance and production groups of 370 vessels in use at MFK at the time of the EM IIB destruction. After Whitelaw *et al.* (1997, 275: Plate CIIa). MFK = Myrtos Fournou Korifi, MPY = Myrtos Pyrgos, VAS = Vasiliki, GOU = Gournia, KAC = Kalo Chorio.

Group	Sample	Calcareous nannofossils	Forams.	Ostracods
SC-1	MFK 93/3	-	yes	-
	MFK 93/6	v. poor late Neogene	yes	-
	MFK 93/12	v. poor late Neogene	-	-
	MPY 93/24	v. poor late Neogene	-	-
	MPY 93/26	-	-	-
SC-2	MFK 93/102	Late Miocene (late NN 11?)	yes	-
	MPY 93/25	Late Miocene (late NN 11?)	yes	-
SC-3A	KAC 94/12	-	-	-
	KAV 93/76	-	yes	-
	MFK 93/37	-	-	-
	MFK 93/58	-	-	-
	MFK 93/68	-	-	-
	MFK 93/71	-	-	-
	MFK 93/99	Early Pliocene (NN 13)	-	yes
	MFK 93/117	-	-	-
	MFK 93/127	v. poor late Neogene	-	yes
	MPY 93/10	Early Pliocene (NN 13)	-	yes
	MPY 93/27	-	yes	-
SC-3B	MFK 93/38	-	-	-
	MFK 93/185	-	-	yes
	MFK 93/197	-	-	yes

Figure 11.2 Part 1. The micropalaeontological analysis of representatives samples from the South Coast ceramic production group of Whitelaw *et al.* (1997), compared to the petrographic groups and subgroups of Day *et al.* (n.d.). (-) = barren. Full descriptions of the foraminiferal and calcareous nannofossil assemblages of all samples can be found in Figure 11.3 and Section AII.2 respectively.

Group	Sample	Calcareous nannofossils	Forams.	Ostracods
SC-3C	MFK 93/28	-	-	-
	MFK 93/69	-	yes	-
	MFK 93/87	-	yes	-
	MPY 93/20	poor late Neogene	yes	yes
	MPY 93/48	v. poor late Neogene	-	-
SC-4	MFK 93/105	Early Pliocene (NN 13)	yes	-
	MFK 93/196	Early Pliocene (NN 12 or 13)	yes	yes
SC-5	MFK 93/55	Late Miocene (late NN 11?)	yes	yes
	MFK 93/129	-	yes	-
	MFK 93/133	-	yes	yes
	MFK 93/142	-	-	yes
	MFK 93/148	-	-	-
	MFK 93/169	-	-	yes
	MFK 93/198	-	yes	yes
	MPY 93/37	-	-	-
	MPY 93/40	-	-	-
SC-6	MFK 93/27	-	-	-
	MFK 93/48	-	yes	yes
	MFK 93/94	-	-	-
	MFK 93/116	v. poor late Neogene	yes	yes
	MFK 93/138	-	-	-

Figure 11.2 Part 2. The micropalaeontological analysis of representatives from the South Coast ceramic production group of Whitelaw *et al.* (1997), compared to the petrographic groups and subgroups of Day *et al.* (n.d.). (-) = barren. Full descriptions of the foraminiferal and calcareous nannofossil assemblages of all samples can be found in Figure 11.3 and Section AII.2 respectively.

MFK 93/3 *Globigerina sp.*

MFK 93/6 *Globigerina sp.*, unidentifiable foraminiferal remains.

MFK 93/12, 93/27, 93/28, 93/37, 93/38 Barren.

MFK 93/48 *Globigerina sp.*

MFK 93/55 Unidentifiable benthic foraminiferal remains.

MFK 93/58, 93/68 Barren.

MFK 93/69 Unidentifiable foraminiferal remains.

MFK 93/71 Barren.

MFK 93/87 *?Globorotalia sp.*, 'microforaminifer' cf. *Globigerina sp.*, unidentifiable foraminiferal remains.

MFK 93/94, 93/99 Barren.

MFK 93/102 *Globigerina sp., Globorotalia sp., ?Orbulina sp.* unidentifiable foraminiferal remains cf. biserial benthic.

MFK 93/105 *Bolivina cf. antiqua, Bolivina cf. spathulatata, Bolivina sp., Bulimina exilis, ?Cibicides sp., Globigerina sp., Globorotalia sp., ?Gyroidina sp., ?Sphaeroidinellopsis sp., Uvigerina proboscidea, Uvigerina sp., Valvulineria complanata, Vulvulina pennatula.*

MFK 93/116 Unidentifiable foraminiferal remains.

MFK 93/117, 93/127 Barren.

MFK 93/129 Unidentifiable biserial foraminifer within calcareous inclusion.

MFK 93/133 *Uvigerina sp.*, unidentifiable foraminiferal remains.

MFK 93/138, 93/142, 93/148, 93/169, 93/185 Barren.

MFK 93/196 *Bolivina cf. subexcavata, Bolivina sp., Cibicides ungerianus, Globigerina sp.*, unidentifiable foraminiferal remains.

MFK 93/197 Barren.

MFK 93/198 *?Bolivina sp., Cibicides sp.*, unidentifiable planktonic foraminiferal remains cf. *Globigerina sp.*

MPY 93/10 Barren.

MPY 93/20 Unidentifiable biserial foraminifer within a clay pellet.

MPY 93/24 Barren.

MPY 93/25 *Globigerina sp.*

MPY 93/26 Barren.

MPY 93/27 Benthic foraminiferal remains cf. *Cibicides sp.*

MPY 93/37, 93/40, 93/48 Barren.

KAC 94/12 Barren.

KAV 93/76 Unidentifiable foraminiferal remains within a chert inclusion.

Figure 11.3 Foraminiferal assemblages in representative thin sections of South Coast pottery. The calcareous nannofossil analysis and petrographic groupings of these samples are presented in Figure 11.2 Parts 1 and 2.

Quaternary marine terraces

<u>Sample L</u> - NN 19E (small *Gephyrocapsa* interval) = late Early Pleistocene.

Myrtos Formation

<u>Sample B</u> -NN 13 (late NN 12-13B) = Early Pliocene (Zanclian).

<u>Sample I</u> -NN 12 or NN 13 (late NN 12-13A or early NN 12-13B) = Early Pliocene (Zanclian).

<u>Sample κ</u> - NN 13 (NN 12-13B) = Early Pliocene (Zanclian).

Ammoudares Formation

<u>Sample S</u> -late NN 11 or NN 12 = Latest Miocene or earliest Pliocene (Messinian or Zanclian).

<u>Sample C</u> -NN 12 (NN 12-13A?) = Latest Miocene or earliest Pliocene (Messinian or Zanclian).

<u>Sample ε</u> -tentatively small *Reticulofenestra* interval (SRI), latest NN 10 or early NN 11 = Late Miocene, tentatively upper Tortonian.

Makrylia Formation

<u>Sample A</u> -late NN 9 = Late Miocene (early Tortonian).

<u>Sample R</u> -tentatively NN 9 = Late Miocene (early Tortonian).

<u>Sample W</u> - Late NN 9 = Late Miocene (early Tortonian).

<u>Sample Y</u> -late NN 8 or NN 9 = Late Miocene (early Tortonian).

Kalamavka Formation (without olistoliths)

<u>Sample D</u> - late NN 6 or early NN 7 = (late Serravalian).

Males Formation (Parathiri member)

<u>Sample α</u> -late NN 6 or early NN 7 = Middle Miocene (late Serravalian).

Figure 11.4 Calcareous nannofossil biostratigraphic assignments of some south Cretan sediment samples. For detailed assemblage descriptions see Section AIII.2.

using the method described in Section 5.3.2. The results of this micropalaeontological analysis are summarised in Figures 11.2 and 11.3, and a full description of the calcareous nannofossil assemblages of all South Coast pottery samples which were analysed, is presented in Section AII.2.

In order to relate the biostratigraphic assignments of the various samples of South Coast pottery to the late Neogene sediments of the production area identified by Whitelaw *et al.* (1997), representative samples of the various geological formations of Fortuin (1977) have been studied for calcareous nannofossils. The results of this analysis are presented in Figure 11.4, and a full description of the Neogene geology of the south coast of Crete, with the location of the sediment samples (Figure 10.2) can be found in Section 10.2.

11.2.3 Discussion

11.2.3.1 Non-calcareous fabrics SC-1 and SC-2

Day *et al.* (n.d.) interpreted their South Coast (SC) fabrics 1 and 2, as low-fired, coarse, non-calcareous clays which have been tempered with sub-angular and sub-rounded volcanic, metamorphic and sedimentary rocks (SC-1), and angular monocrystalline calcite (SC-2). It was therefore surprising to discover various calcareous microfossil specimens in several of the sections which were analysed.

In SC-1, two of the five samples which were analysed contained one or two specimens of the planktonic foraminifer *Globigerina* within the non-calcareous matrix, and three samples contain a low abundance calcareous nannofossils assemblage. The rare and sporadic occurrence of foraminifera and calcareous nannofossils in this non-calcareous fabric group may suggest that these microfossils do not occur *in situ*, but could be a reworked component of the clay.

Both of the samples which were analysed from fabric SC-2 were found to contain foraminifera and calcareous nannofossils. In sample MFK 93/102 isolated planktonic foraminifera occur within the matrix as well as part of several regions of fine grained calcareous clay mixing, whereas section MPY 93/25 contained but a few isolated fragments of the planktonic foraminifer *Globigerina* within the matrix. The generally non-calcareous nature of the micromass in the pottery samples attributed to fabric group SC-2 and the occurrence of identical foraminifera in the two contexts indicates that these microfossils were not a feature of the original clay, but have been incorporated intentionally or unintentionally after its procurement by the addition of small quantities of fine grained calcareous sediment.

The relatively abundant calcareous nannofossil assemblages which were recovered from the two SC-2 samples are likely to have the same origin as the isolated foraminifera, and those which occur within the incomplete calcareous mixing. The analysis of these calcareous nannofossil assemblages indicates that the component of microfossiliferous sediment which has been incorporated within the non-calcareous clay of the two SC-2 samples, is likely to be Late Miocene, tentatively late NN 11 (Messinian) in age.

It is worth noting that the foraminifera, calcareous nannofossils and regions of fine grained microfossiliferous marl which occur in SC-2, are not related to the large, angular monocrystalline calcite inclusions with which Day *et al.* (n.d.) characterise this fabric.

11.2.3.2 Calcareous sand-tempered fabrics SC-3, 4, 5 and 6

Day *et al.*'s (n.d.) fabric groups SC-3, 4, 5 and SC-6 constitute the majority of South Coast pottery, and are characterised by a calcareous Neogene base clay tempered with fine (SC-5 and 6) and coarse (SC-3 and SC-4) beach sand. All of these petrographic groups and their subgroups contain microfossils, however there is a great deal of variation in terms of the occurrence of specific groups of microfossils between and within the groups.

The three subgroups of fabric group SC-3 which are believed to be finer and coarser variants of the same recipe, can be neither grouped nor separated in terms of their microfossil assemblages, which vary between and within each subgroup. Only one sample out of the 11 which were analysed from subgroup SC-3A contains a few foraminifera, three contain ostracods and three contain calcareous nannofossils. Two out of the three sections which were analysed from subgroup SC-3B contain ostracods, but no foraminifera or calcareous nannofossils, and Group SC-3C contains sporadic foraminifera, calcareous nannofossils, with abundant ostracods present in one section.

The sporadic occurrence of foraminifera, ostracods and calcareous nannofossils in subgroups SC-3A, B and C of fabric group SC-3 indicates that the microfossiliferous Neogene marl which Day *et al.* (n.d.) and Whitelaw *et al.* (1997) believe was used as a base clay for this pottery tradition, may have been procured from more than one source. There does not seem to be much continuity within or between the subgroups of SC-3 in terms of the presence or absence of microfossils, although certain samples can be correlated, these are; MFK 93/99 and MPY 93/10 from SC-3A, plus MFK 93/185 and MFK 93/197 from SC-3B. This correlation is discussed in Section 11.2.3.5.

In their detailed ceramic description of group SC-3, Day *et al.* (n.d.) noted the occurrence of few to absent (0-15 %) carbonate rock fragments containing foraminifera and ostracods, in the coarse fraction (> 0.1 mm). No such inclusions were found within the representative SC-3 sections which were analysed in this study, however it is suspected that a highly calcareous, microfossiliferous sediment such as this may have been added to the calcareous clay of the SC-3 fabrics, and was the source of the isolated microfossils in the matrix.

No biostratigraphic information can be interpreted from the thin section analysis of the poor foraminifera and ostracod assemblages of SC-3. However, by analysing the calcareous nannofossils which were liberated from a few sherds, a broad biostratigraphic interpretation of 'late Neogene' can be assigned to samples MPY 93/20 and MPY 93/48 of subgroup SC-3C plus MFK 93/127 of subgroup SC-3A, and a more detailed biostratigraphic interpretation of 'Early Pliocene' can be attributed to MFK 93/99 and MPY 93/10 of SC-3A.

Too few samples from fabric group SC-3 contained dateable calcareous nannofossil assemblages for any definite conclusions to be drawn, however, the scanty results of this analysis confirms that the calcareous base clay (Day *et al.* n.d.) or carbonate rock fragments (this report), in at least some of this pottery, are late Neogene in age. Only two of the 19 SC-3 pottery samples contained calcareous nannofossil assemblages which could be interpreted with any precision; these indicate that Early Pliocene sediments may have been used.

Day *et al.*'s (n.d.) fabric group SC-4 consists of but two pottery samples; the thin sections of these contain abundant foraminifera and calcareous nannofossil assemblages, and one sample (MFK 93/196) contains a single ostracod specimen. Detailed analysis of these microfossil assemblages has indicated further similarity between the two samples. The rich associations of foraminifera in MFK 93/105 and 93/196 bear striking similarities to those described by Jonkers (1984, Section 6.6.3) from the Early Pliocene of Crete, the calcareous nannofossil assemblages of both samples can be assigned to late NN 12 or the early part of zone NN 13, which is equivalent to the early Zanclian (earliest Pliocene) geological stage.

It therefore appears that a component of Early Pliocene microfossiliferous sediment was used in the manufacture of these two samples. The presence in MFK 93/105 and 93/196 of micrite and sparite inclusions containing foraminifera and ostracods, indicates that this may have been in the form of a quantity of calcareous sediment added to a non-microfossiliferous base clay.

It is worth noting that in addition to the close similarity between the composition and geological age of the microfossil assemblages in the two samples of fabric group SC-4, their foraminifera exhibit comparable aspects of preservation, including the common occurrence of benthic and planktonic foraminifera within dark red to black opaque bodies. These are interpreted as being products of the oxidation of organic matter associated with the foraminiferal specimens and have no direct archaeological significance.

The ten samples which were analysed from the fine calcareous sand-tempered fabric group SC-5 exhibit considerable variability in terms of their microfossil assemblages. One sample (MFK 93/55) contains foraminifera, ostracods and calcareous nannofossils, two (MFK 93/133 and MFK 93/198) contain foraminifera and ostracods, MFK 93/129 contains a single foraminifer within a calcareous inclusion, MFK 93/169 contains and abundant ostracod assemblage but no other microfossils, and the remaining four samples are barren. The foraminifera and ostracod assemblages within the six microfossiliferous samples are also rather heterogeneous themselves and therefore very few inferences can be made for this fabric group as a whole, other than that there may have been some variability in the site of procurement of the microfossiliferous sediment which was used in its manufacture. There is almost no correlation between these six samples except for the occurrence of abundant ostracod associations in MFK 93/133, 169 and 198, however this is not supported by the nature of their foraminiferal assemblages. The sporadic occurrence of different groups of microfossils in this fabric group is discussed in Section 11.2.3.5.

Ostracods are the most commonly occurring group of microfossils in SC-5 and although very little biostratigraphic information can interpreted through their analysis in thin section (Section 7.2), they are characteristic of this fabric group and comparatively rare in other Cretan ceramics. The evidence provided by the calcareous nannofossil analysis of the ten SC-5 samples is equally scanty; only one sample (MFK

93/55) contained an *in situ* nannoflora, however, this was poorly-preserved, non-abundant and could only be assigned to the Late Miocene (tentatively late NN 11).

Day *et al.* (n.d.) noted the occurrence of frequent to few (30 - 5%) calcareous inclusions within the coarse fraction (> 0.0625 mm) of SC-5, and speculated that this microfossiliferous fabric has been tempered with fine non plastic inclusions consisting mainly of carbonate rock fragments (limestone). The discovery in sample MFK 93/129 of a foraminifer within one of these micritic inclusions suggests that the carbonate rock temper may have in fact been the source of the isolated ostracods and foraminifera in this fabric group.

SC-6 is a heterogeneous fabric group, containing samples which may be finer versions of SC-3 or coarser versions of SC-5. Only 2 of the 5 samples which were analysed from this group contained microfossils; section MFK 93/48 contained a few planktonic foraminifera and one possible ostracod specimen and MFK 93/116 contained one poorly-preserved foraminifer, a rich ostracod assemblage and a low abundance of calcareous nannofossils. There is no evidence for the addition of calcareous, microfossiliferous temper within the thin sections of this group, and it may be that the microfossils appear *in situ.* The evidence provided by the poor calcareous nannofossil assemblage in MFK 93/116 suggests that the microfossiliferous sediment which was used in the construction of this sherd is likely to be late Neogene in age.

11.2.3.3 Calcareous nannofossil analysis of sediment samples from the south coast of Crete

Although there seems from the results of this analysis to have been some unexpected variation in the nature of the calcareous material used in the construction of the South Coast pottery found at Myrtos Fournou Korifi, some observations can be made. The calcareous nannofossil analysis of the various south central Cretan sediment samples (Section 10.2), has provided relatively detailed biostratigraphic assignments for the late Neogene formations which occur in this region (Figure 11.4). By comparing these with the calcareous nannofossil analysis of the South Coast ceramic samples (Figure 11.2), it is possible to identify two late Neogene formations which may have been utilised for pottery production in this region. These are the Early Pliocene (Zanclian) Myrtos Formation and the Late Miocene (late Tortonian and Messinian) Ammoudares Formation.

The calcareous nannofossil analysis of the South Coast pottery indicates that several samples (MFK 93/99 and MPY 93/10 of SC-3A; MFK 93/105 and MFK 93/196 of SC-4) contain a quantity of calcareous, microfossiliferous, Early Pliocene sediment. This is compatible with the light coloured marls of the Myrtos Formation, which form the hill upon which the site of MFK is situated (Figure 10.2). An equally small number of samples (MFK 93/102 and MPY 93/25 of SC-2; MFK 93/55 of SC-4) contained a component of Late Miocene (late Tortonian or Messinian) sediment which is compatible with the folded grey marls of the Ammoudares Formation. This formation occurs in a narrow east-north-east to west-south-west trending belt across the south coast area, and forms several small hills between the two sites of MFK and

MPY (Figure 10.2). The late Neogene calcareous nannofossil assemblages of samples MFK 93/6, 93/12, 93/24, 93/116, 93/127 and MPY 93/20, 93/48 could not be dated with any precision, and therefore no specific late Neogene formation can be positively identified as being the source of the microfossiliferous sediment in these samples. However, the Ammoudares and Myrtos Formations are strong candidates.

11.2.3.4 The isolation of foraminifera from South Coast pottery sample MFK 93/105

During a pilot study into the possible isolation of three-dimensional foraminifera from samples of archaeological ceramics (Section 6.5), a small quantity of South Coast pottery sherd MFK 93/105 yielded approximately 100 benthic and planktonic foraminifera. Through the identification of the planktonic foraminifera and the application of appropriate zonation schemes (Section 6.6.2.2), it was possible to assign this sample to the Early Pliocene, Zanclian geological stage. This is in agreement with the calcareous nannofossil analysis which is presented in Figure 11.2 Part 2, and confirms the correlation between the pottery of Day *et al.*'s (n.d.) fabric group SC-4 and the Early Pliocene Myrtos Formation, which is suggested in Section 11.2.3.3 above.

In addition, a comparison of the benthic foraminifera which were isolated from this pottery sample with the work of Jonkers (1984), has permitted a rough palaeoenvironmental interpretation of the raw material in fabric group SC-4, of 'normal marine'. This is not of much value archaeologically, however, it demonstrates the level of information which can be attained from the analysis of isolated foraminifera, compared to those assemblages present in ceramic thin sections.

11.2.3.5 Comparison between micropalaeontological analysis and petrographic groups

As outlined in Section 11.2.3, there is a great deal of heterogeneity within the South Coast petrographic groups which are identified by Day *et al.* (n.d.), in terms of the occurrence of different microfossils in thin section. Only fabrics SC-2 and SC-4 form homogeneous micropalaeontological groups, however both of these consist of but a few samples. In the groups and subgroups which contain many samples, e.g. SC-3A and SC-5, there is not a great deal of correlation between the presence/absence of the different groups of microfossils in the individual samples.

The variability in the occurrence of different microfossils in the South Coast fabric groups can be interpreted in several ways. The most extreme interpretation is that the samples which constitute a particular group (e.g. SC-5) have been manufactured from different raw materials and therefore have been incorrectly grouped by Day *et al.* (n.d.). However, it is more likely that the variability in the occurrence of the different groups of microfossils between thin sections of fabric groups SC-1, SC-5, SC-6 and the subgroups of SC-4, is a result of their low but variable abundance in the original sherds, as well as the differential representation produced by thin sectioning. Day *et al.*'s (n.d.) South Coast fabric groups were formed on the basis of numerous criteria, including the nature of the numerous types of non-plastic inclusions and the textural and optical features of the clay matrix. In some of these fabric groups (e.g. SC-5), it is suspected that small quantities of calcareous microfossiliferous sediment have been intentionally or unintentionally incorporated within the clay body. Therefore, variation in the micropalaeontological composition of this material, as well as its distribution within the sherds, combined with the random sample which is captured by the process of thin sectioning, may well explain the variation which has been observed.

Whitelaw *et al.* (1997) have presented broad firing temperature estimates for the three main fabrics in their South Coast production group, based upon the precise determinations of particular samples which were carried out by Day *et al.* (n.d.). These estimations have been made by the observation of clay vitrification structures in the SEM, using the methodology of Tite *et al.* (1982), and are outlined in Figure 11.5. Because the firing temperature estimations presented by Whitelaw *et al.* (1997) are very general, and Day *et al.* (n.d.) only made specific determinations for a few of the samples which are analysed in the present report, it is not possible to interpret the presence/absence of different groups of microfossils with any certainty from this data. Nevertheless, some broad inferences can be made. For example; if the non-calcareous (or low-calcareous) South Coast fabrics were in fact fired below 750 °C, as stated by Whitelaw *et al.* (1997), then the absence of calcareous nannofossils in many of the smear slides which were analysed of group SC-1, may be reflection of their low abundance in the original raw material which was used for the manufacture of this pottery. On the other hand, the poor nature of the calcareous nannofossil assemblages in some samples belonging to SC-3C and the absence of calcareous nannofossils in other members of this subgroup, may be related to their high firing temperature, which has been estimated between 850 and 1050 °C.

In terms of the taxonomic composition and geological age of the microfossil assemblages in the South Coast thin sections and smear slides analysed, none of the samples in each of Day *et al.*'s (n.d.) groups and subgroups were found to be conflicting. Whilst the presence/absence and abundance of particular groups of microfossils varied significantly in many of the fabric groups, similar genera and species of foraminifera were identified, the ostracod assemblages were not dissimilar in appearance, and the calcareous nannofossil assemblages were broadly contemporaneous, where present.

The comparison between the presence/absence and abundance of different types of microfossils in ceramics and the petrographic fabric groupings, which has been outlined above, highlights the difficulties which are involved in the use of the occurrence of microfossils in classifying ceramics (Sections 5.9.2, 6.7.3, 7.7.3, 8.5.1 and 9.5.1). Riley (1983) indicated that the presence/absence of microfossils in thin sections of archaeological ceramics provides independent and an unequivocal criterion for grouping ceramics in his analysis of Late Minoan fine wares from Knossos. However, the results of the present case study suggests that such groupings are likely to have little meaning without a consideration of the whole fabric, as the occurrence of microfossils can vary in thin sections of otherwise identical fabrics. Likewise, classifications of archaeological pottery sherds based upon the exact taxonomic

Whitelaw *et al.* (1997)	Day *et al.* (n.d.)
Non-calcareous fabric:	SC-1: *MFK 93/3* < 750 °C O/R
(neutral atmosphere < 750 °C)	*MFK 93/6* 750-800°C OX
	SC-2: -
Coarse calcareous fabric:	SC-3A: *MFK 93/117* c.1050 °C ORO
(850-1050 °C)	SC-3B: -
	SC-3C: *MFK 93/87* c. 1050 °C ORO
	SC-4: -
Fine calcareous fabric:	SC-5: -
(800-950 °C)	SC-6: *MFK 93/27* 750-800 °C OX

Figure 11.5 General SEM firing temperature and atmosphere estimates of the main fabrics of South Coast pottery presented by Whitelaw *et al.* (1997), based upon the SEM firing determinations of specific samples from precise fabric groups of South Coast pottery made by Day *et al.* (n.d.). OX = oxidation firing, O/R = oxidation and reduction firing, O/R/O = oxidation, reduction, oxidation firing.

composition of their representative microfossil assemblages, such as those constructed in the diatom analysis of Alhonen *et al.* (1980) and De La Fuente and Martinez Macchiavello (1997: Section 2.3.1.2), can be less than helpful, as not all genera and species which occur in the original assemblage are likely to appear in the analysed sample (this is especially true for thin section analysis).

The only sure way of grouping and classifying samples of archaeological ceramics using micropalaeontology is by a biostratigraphic or palaeoenvironmental interpretation of the microfossil assemblages present in archaeological ceramics. In this way it may be possible to demonstrate significant similarities and differences between individual samples in terms of the exact nature of their raw materials, which may be used to confirm or disprove classifications based upon petrography. Such an approach is heavily dependent upon the precision and accuracy of these interpretations, which is itself related to the state of preservation and the groups microfossils which are present in the archaeological pottery.

In the present case study, the analysis of calcareous nannofossils and foraminifera strongly support Day *et al.*'s (n.d.) petrographic groups SC-2 and SC-4, and the microfossil assemblages of SC-1, SC-3A-C, SC-5 and SC-6, do not contain any information with which to disprove these fabric groups and subgroups.

11.2.4 Conclusions

The detailed micropalaeontological analysis of representatives from all of Day *et al.*'s (n.d.) South Coast fabric groups and subgroups has revealed useful information pertaining to the microprovenance and technology of this pottery tradition and has raised other interesting questions which prompts re-assessment.

Both of the non-calcareous, tempered fabric groups (SC-1 and SC-2) were found to contain microfossils. In SC-1 these are interpreted as reworked components of the non-calcareous base clay, whereas the microfossils in SC-2 appear to have originated from the intentional or unintentional addition of small quantities of fine grained Late Miocene marl or limestone to a non-calcareous base clay. This indicates a clear difference between these two fabric groups in terms of their base clay, which was not identified by Day *et al.* (n.d.), in addition to their different tempering materials. The microfossils of SC-2 are considered to have no relation to the large fragments of monocrystalline calcite which characterise this group.

Many of the fine and coarse sand-tempered, calcareous South Coast fabric samples (SC-3 to SC-6), contain identical microfossil assemblages isolated in the matrix and as part of calcareous, usually micritic inclusions. This is interpreted here as evidence for the addition of variable amounts of calcareous Neogene sediment to an already calcareous base clay. The calcareous nannofossil analysis of these samples has indicated that the microfossiliferous raw material which was utilised in the manufacture of the calcareous sand tempered fabrics was latest Miocene and earliest Pliocene in age. This is compatible with the late Tortonian and Messinian Ammoudares Formation which outcrops across the study area and forms several small hills between the sites of MFK and MPY, as well as the Zanclian Myrtos Formation, which has a restricted occurrence within the study area, one of which is hill of Fournou Korifi, upon which the archaeological site of MFK is situated.

With the exception of SC-2 and SC-4, all of the South Coast fabric groups exhibit considerable variability in terms of the presence/absence of different types of microfossils in thin section, and very few samples within each of the groups can be correlated on the basis of their microflora and fauna. This may be a result of the low but variable abundance and uneven distribution of microfossils in the original clay body, combined with the random sample which is captured by the process of thin sectioning, as well as variations in the firing temperature. The biostratigraphic interpretation of calcareous nannofossils in SC-2 and SC-4 strongly support these petrographic groupings, and there is no positive biostratigraphic evidence with which to discount any of Day *et al.*'s (n.d.) other groups.

11.3 Re-addressing the Knossos Dark-Faced Incised Ware problem

11.3.1 Introduction

Some controversy has surrounded the archaeological date and origin of various distinctive pyxides found at several locations within the palace and environs of Knossos, by Evans, Pendlebury and Hood. The pottery consists of several small (complete and fragmentary) pyxides and lids with a distinctive dark-faced and incised decoration, and is referred to as 'Dark Faced Incised Ware' or DFIW (MacGillivray *et al.* 1988).

There are various theories which have been put forward for the origin of the DFIW pyxides. These include the view that they are Cycladic imports or were manufactured under a strong Cycladic influence (Barber 1981; MacGillivray 1984), that they are Neolithic survivors in Middle Minoan levels (Platon 1968; Andreou 1978) or Middle

Minoan imitations of Cycladic imports (Evans *in* MacGillivray *et al.* 1988). In order to solve the controversy surrounding this group of pottery MacGillivray *et al.* (1988) undertook a detailed macroscopic, petrographic and physico-chemical study of the Knossian DFIW and comparable pottery from other sites. This study included micropalaeontological analysis carried out by S. Tsaila from the Institute of Geological and Mineral Exploration (IGME), Athens.

MacGillivray *et al.* (1988) established the consistency of the DFIW group (with the exception of one sample), and proved that it was dissimilar from some comparative Knossian Neolithic and Middle Minoan, Melian and Aeginitan pottery, using macroscopic fabric analysis, stylistic analysis, thin section petrography, INAA and AAS.

The analysis of ceramic thin sections prepared from selected DFIW samples indicated that the raw material which had been used for the manufacture of these pyxides was a microfossiliferous marl. Tsaila (n.d.) identified various genera of foraminifera from the samples (Figure 11.6) which she took to indicate that the DFIW marl was deposited in a deep water environment during the Miocene or Pliocene. Neogene marine marls occur extensively on Crete, Kythira and Karpathos and have a more isolated occurrence within other islands of the southern Aegean, e.g. Melos. MacGillivray *et al.* (1988, 92-93) noted that the Neogene sediments of Melos were deposited in a shallow marine environment so that they could not be the source of the DFIW marls, and stated that "although foraminifera are present in some Bronze Age Theran pottery fabrics, they are usually accompanied by volcanic rocks ... and

<u>Kn 86/1</u> *Globigerina sp.*, biserial planktonic foraminifera of family Heterohelicidae. (Miocene or Pliocene).

<u>Kn 86/2</u> *Globigerina sp.* (Miocene or Pliocene).

<u>Kn 86/3</u> *Globigerina sp.*, biserial planktonic foraminifera of family Heterohelicidae (Miocene or Pliocene).

<u>Kn 86/4</u> *Globigerina sp.*, benthic foraminifera. (Miocene or Pliocene).

<u>Kn 86/5</u> *Globigerina sp.* (Miocene or Pliocene).

<u>Kn 86/7</u> *Globigerina sp.*, benthic foraminifera. (Miocene or Pliocene).

<u>Kn 86/8</u> *Globigerina sp.* (Miocene or Pliocene).

<u>Kn 86/10</u> Planktonic foraminifera. (Miocene or Pliocene).

<u>Kn 86/11</u> *Globigerina sp.* (Miocene or Pliocene).

<u>Kn 86/12</u> *Globigerina sp.*, small benthic foraminifera. (Miocene or Pliocene).

<u>Kn 86/14</u> *Globigerina sp.*, *Globorotalia sp.* (Miocene or Pliocene).

<u>Kn 86/16</u> Planktonic and benthic foraminifera. (Miocene or Pliocene).

<u>Kn 86/17</u> *Globigerina sp.*, *Globorotalia sp.* (Miocene or Pliocene).

<u>Kn 86/18</u> *Globigerina sp.*, biserial planktonic foraminifera of family Heterohelicidae, benthic foraminifera. (Miocene or Pliocene).

<u>Kn 86/19</u> *Globigerina sp.* (Miocene or Pliocene).

Figure 11.6 The DFIW thin section foraminiferal analysis of Tsaila (n.d.), with corresponding geological dates; as utilised in MacGillivray *et al.* (1988).

phyllites". These two facts led them to conclude that the DFIW samples were most likely to have been produced from the Neogene marls of central or eastern Crete.

Although it is highly feasible that the DFIW pottery was produced in central or eastern Crete, this is only a very broad provenance interpretation, as Neogene deposits cover one third of the island. MacGillivray *et al.* (1988) aimed simply to establish the internal homogeneity of the DFIW and determine whether this group of pottery was produced on Crete or in the Cycladic Islands (macroprovenace), however it would be useful to know whereabouts in central or eastern Crete the pottery could have originated (mesoprovenance). Their macro-scale provenance interpretation relied mainly on the broad biostratigraphic determinations of Tsaila (n.d.). Therefore, by seeking a more precise biostratigraphic assignment for the raw material used in the production of the DFIW pottery it may be possible to identify specific geological units or formations within the Neogene sediments of central and eastern Crete, from which the sediments could have been procured.

The following case study re-examines the foraminifera in the original DFIW thin sections and utilises detailed calcareous nannofossil analysis to further the pioneering micropalaeontological work of Tsaila (n.d.). In order to investigate whether the DFIW pyxides are compatible with other pottery fabrics at Knossos and to perhaps investigate their origin, a comparison has made between their microfossil assemblages (Figure 11.7), 26 'soft sandy' and 'soft brown burnished' pottery samples excavated from Early and Middle Minoan levels at Knossos (Figure 11.8), and the calcareous nannofossil analysis of several north-central Cretan sediment samples (Section 10.3 and Figure 11.9).

11.3.2 Micropalaeontological analysis of the DFIW pyxides, comparative pottery from Knossos and north-central Cretan sediment samples

The calcareous nannofossil and foraminiferal analysis of the DFIW and comparative pottery from Knossos was carried out using the methodology which is outlined in Sections 5.10 and 6.7.1. The foraminiferal assemblages of all thin sections are presented in Figures 11.7 to 11.8 with the accompanying biostratigraphic assignments based on the calcareous nannofossil analysis of smear slides. The full calcareous nannofossil assemblage descriptions are presented in Sections AII.3 and AII.4, and the calcareous nannofossil biostratigraphic assignments of the north-central Cretan sediment samples are presented in Figure 11.9. A discussion of the field sampling strategy for these samples is presented in Section 10.3, and full descriptions of their calcareous nannofossil assemblages can be found in Section AIII.3.

11.3.3 Discussion

11.3.3.1 Foraminifera

The DFIW thin sections contain relatively rich planktonic and benthic foraminiferal assemblages. It was not possible to speciate the small globular planktonic foraminiferal specimens, however the genera *Globigerina* and *Globorotalia* have been identified in many sections. Benthic foraminifera are more common than planktonic foraminifera in the DFIW thin sections and can be speciated in many cases. The rich benthic foraminiferal associations of the DFIW pyxides are dominated by members of the genera *Bulimina*, *Bolivina* and *Cibicides*.

Knossos 86/1	*Bulimina exilis, Globigerina sp., Globorotalia sp,* planktonic biserial. (NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/2	*Globigerina sp., Globorotalia sp.* (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/4	*Bolivina sp., Globigerina sp.* (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/5	*Bolivina sp., Globigerina sp.,* biserial microforaminifer. (NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/6	*Bolivina sp., Bulimina sp., ?Cancris auricula, Cibicides sp., Globigerina sp., Planorbulina mediterranensis,* planktonic biserial. (NN 13 ~NN 12 -13B = Early Pliocene, middle Zanclian).
Knossos 86/7	*Bolivina cf. antiqua, Bolivina subexcavata, Cibicides ungerianus, Globigerina sp.* (NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/8	*Globigerina sp.,* unidentifiable benthic foraminiferal remains cf. *Bulimina sp.* (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/9	*Astigerina sp., Bolivina cf. subexcavata, Bulimina cf. exilis, ?Cibicides sp., Globigerina sp. Cibicides lobatulus.* (NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/10	*Bolivina sp., Cibicides sp., Globorotalia sp.* (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/11	*Astigerina planorbis, Bolivina sp., Bulimina exilis, Globigerina sp., Uvigerina sp.* (NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/12	*Bolivina cf. subexcavata, Cibicides sp., Globigerina sp.* (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/13	*Bolivina sp., Globigerina sp.,* biserial microforaminifer. (NN 13 ~late NN 12-13B = Early Pliocene, middle Zanclian).
Knossos 86/14	*Globigerina sp., Globorotalia sp., Bulimina sp., ?Dentalina filiformis.* (NN 13 ~NN 12-13A or B = Early Pliocene, early or middle Zanclian).
Knossos 86/15	Barren.
Knossos 86/16	*Cibicides sp., Globigerina sp.* (NN 12-13B - Early Pliocene, middle Zanclian).
Knossos 86/17	*Globigerina sp., Globorotalia sp.* (NN 13 ~NN 12-13C = Early Pliocene, middle-late Zanclian).

Figure 11.7 New thin section foraminiferal analysis of the DFIW samples and the accompanying calcareous nannofossil biostratigraphic assignments (a full description of the calcareous nannofossil assemblages is presented in Section A2.3).

Knossos 95/172	(EM IA) *Cibicides sp., Globigerina sp., Globorotalia sp., Planorbulina mediterranensis, Uvigerina pygmea*, biserial "microforaminifer". (NN 9? = Late Miocene, Tortonian)
Knossos 95/187	(MM IA) *Bolivina antiqua, Bolivina spathulatata, Bolivina sp., Bulimina elongata, Bulimina exilis, Globigerina sp., ?Stilostomella adolphina, Uvigerina cf. cylindrica gaudryinoides, Uvigerina sp.* (NN 11-NN 13 = Late Miocene or earliest Pliocene).
Knossos 95/211	(MM IA) *Bulimina cf. elongata, Bulimina cf. exilis., ?Cibicides sp., Globigerina sp., Globorotalia sp., ?Orbulina universa, Uvigerina sp.*, unidentifiable calcareous structure. (Latest Miocene or earliest Pliocene).
Knossos 95/212	(MM IA) *Bulimina exilis., ?Cibicides sp., ?Globigerina sp.*, unidentifiable foraminiferal remains. (Barren).
Knossos 95/214	(MM IA) *Astigerina sp., Bolivina cf. alata, Bolivina spathulatata, Bulimina exilis., Globigerina sp., Uvigerina pygmea.* (Ex. poor late Neogene).
Knossos 95/222	(MM IA) *Bulimina exilis., ?Cibicides sp., Globigerina sp., Globorotalia sp., Uvigerina proboscidea.* (NN 12-13C = Early Pliocene, middle to late Zanclian).
Knossos 95/223	(MM IA) Unidentifiable isolated globular chamber. (late Neogene, Late Miocene or Early Pliocene).
Knossos 95/384	(MM IA) Barren. (Barren).
Knossos 95/387	(MM IA) *Astigerina sp., Bolivina antiqua, Bulimina cf. costata, Bulimina exilis, ?Dentalina filiformis, Globigerina sp.* (Ex. poor late Neogene).
Knossos 95/233	(MM IB) *Bolivina sp., ?Cancris auricula, ?Cibicides sp., Globigerina sp., Globorotalia sp., Uvigerina cf. cylindrica, Uvigerina pygmea.* (Late Neogene ~NN 13 = Early Pliocene).
Knossos 95/234	(MM IB) *Bulimina exilis., Bulimina sp., Globigerina sp., ?Uvigerina sp.* (NN 12-13C = Early Pliocene, middle to late Zanclian).
Knossos 95/235	(MM IB) *Bulimina exilis, ?Cibicides sp., Globigerina sp., Uvigerina sp., ?Uvigerina pygmea.* (Latest Miocene or earliest Pliocene).
Knossos 95/236	(MM IB) *?Globigerina sp.*, unidenitifiable foraminiferal remains. (Ex. poor late Neogene).
Knossos 95/237	(MM IB) *Bolivina sp., Bulimina cf. exilis, Globigerina sp., Globorotalia sp., Nodosaria albatrossi, Uvigerina cf. cylindrica*, biserial "microforaminifer", unidentifiable foraminiferal remains. (Barren).

Figure 11.8 Part 1. Foraminiferal analysis and calcareous nannofossil biostratigraphic assignment of EM IA, MM IA and MM IB pottery from Knossos (a full description of the calcareous nannofossil assemblages is presented in Section A2.4).

Knossos 95/238 (MM IB) *Bulimina sp., Globigerina sp., ?Nodosaria sp., Stilostomella adolphina, Uvigerina sp.* unidentifiable calcareous structure. (Ex. poor late Neogene).

Knossos 95/239 (MM IB) *?Bolivina spathulatata, Bolivina cf. dilatata, Bulimina sp., Globigerina sp., Globorotalia sp.* (NN 12-13C = Early Pliocene, middle to late Zanclian).

Knossos 95/240 (MM IB) *Astigerina sp., Bolivina subexcavata, ?Bolivina sp., Globigerina sp., Globorotalia sp., Uvigerina sp.* (late Neogene, Late Miocene or Early Pliocene).

Knossos 95/246 (MM IB) *Bolivina spathulatata, Bolivina sp., ?Cancris auricula, Globigerina sp., Uvigerina sp.*, unidentifiable calcareous structure. (poor late Neogene, Late Miocene or Early Pliocene).

Knossos 95/250 (MM IB) *Globigerina sp.*, unidentifiable foraminiferal remains. (NN 13 ~NN 12-13B = Early Pliocene, middle Zanclian).

Knossos 95/277 (MM IB) Barren. (Ex. poor late Neogene).

Knossos 95/400 (MM IB) Unidentifiable globular planktonic foraminiferal remains cf. *Globigerina sp.* (NN 12-13B = Early Pliocene, middle Zanclian).

Knossos 95/407 (MM IB) *Globigerina sp., ?Globorotalia sp.* unidentifiable foraminiferal remains. (Ex. poor late Neogene).

Knossos 95/361 (MM IIB) *Bolivina dilatata, ?Cibicides sp., Globigerina sp., Globorotalia sp.*, unidentifiable foraminiferal remains. (late Neogene, Late Miocene or Early Pliocene).

Knossos 95/372 (MM IIB) *Bolivina cf. antiqua, Bolivina sp., Bulimina exilis, Cancris auricula, Globigerina sp, ?Globorotalia sp., Uvigerina cf. bononiensis, Uvigerina cf. cylindrica*, unidentifiable calcareous structure. (Late Neogene, latest Miocene or earliest Pliocene).

Knossos 95/376 (MM IIB) *Bolivina cf. subexcavata, Globigerina sp., Planorbulina mediterranensis, Uvigerina cf. bononiensis.* (NN 12-13B = Early Pliocene, middle Zanclian).

Knossos 95/382 (MM IIB) *Bolivina cf. subexcavata, ?Bulimina sp., ?Cibicides sp., Globigerina sp.*, unidentifiable foraminiferal remains. (Ex. poor late Neogene).

Figure 11.8 Part 2. Foraminiferal analysis and calcareous nannofossil biostratigraphic assignments of MM IB and MM IIB pottery from Knossos (a full description of the calcareous nannofossil assemblages is presented in Section A2.4).

Finikia Formation

Sample 6 -NN 12-13B = Early Pliocene, middle Zanclian.

Sample 10.1 -NN 12-13B = Early Pliocene, middle Zanclian.

Sample 11.4 -NN 12-13B = Early Pliocene, middle Zanclian.

Sample 16 -NN 12-13C = Early Pliocene, middle to late Zanclian.

Sample 17 -NN 12-13 A or B = Early Pliocene, early to middle Zanclian.

Agios Varvara Formation

limestone variation:

Sample 18 -early NN 11 = Late Miocene, late Tortonian.

Sample 20 -NN 11= Late Miocene, late Tortonian.

marly variation:

Sample 5 -upper NN 11 = Late Miocene, Messinian?

Abelouzos Formation

Sample 9 -middle NN 11= Late Miocene, late Tortonian.

Sample 15 -middle NN 11 = Late Miocene, late Tortonian.

Skinias Formation

Sample 1 -late NN 6 or early NN 7 = Middle Miocene, late Serravalian.

Sample 2 -late NN 6 or early NN 7 = Middle Miocene, late Seravallian.

Figure 11.9 Calcareous nannofossil biostratigraphic assignments of some North-central Cretan geological samples. For detailed assemblage descriptions see Section A3.3.

In terms of the foraminiferal genera and species which have been identified in the various thin sections (Tsaila, n.d. and this study), the majority of the DFIW samples form a coherent group. There are variations in terms of the presence/absence and abundance of particular taxa, but these can be attributed to natural variation in the foraminiferal assemblages or sampling variability. Only one sample (Knossos 86/13) cannot be included in this large micropalaeontological group.

Because of the difficulty in identifying the planktonic foraminifera to species level, no precise geological date can be positively assigned to the DFIW samples using this group of microfossils. The broad geological assignment of 'Miocene or Pliocene' which was inferred by Tsaila (n.d.) is considered here to be correct. However, by considering the similarity between the benthic foraminiferal associations in the DFIW thin sections and those described from homogeneous and laminated marls in north-central, and southern Crete by Jonkers (1984, Section 6.6.3), a more precise biostratigraphic assignment of Early Pliocene is suggested.

Several of the small DFIW thin sections contain foraminifera within calcareous inclusions or areas of calcareous clay mixing. In both cases, these foraminifera are very similar to those which occur as isolated inclusions within the clay matrix, indicating that the DFIW pyxides may have been produced by the admixture of two different raw materials; a very calcareous microfossiliferous sediment and a less calcareous or non-calcareous, non-microfossiliferous clay. The isolated calcareous inclusions and calcareous concentration features in some of the samples therefore represent the incomplete mixing of these two components.

11.3.3.2 Calcareous nannofossils

The calcareous nannofossil analysis of smear slides prepared from the original DFIW pyxides (Figure 11.7), confirms the homogeneity of this group and supports the separation of sample Knossos 86/15, which was barren. The smear slides which were prepared from the remaining samples contained reasonably abundant to very abundant, relatively well-preserved calcareous nannofossil assemblages, which could be dated with varying precision to the Early Pliocene calcareous nannofossils zone NN 13 of the Zanclian stage. A subzonal assignment has been attempted for some of the assemblages, according to the biostratigraphic scheme of Driever (1988; Section 5.6.2.2 and Figure 5.23). This appears to indicate some minor variation in terms of the geological date of the calcareous nannofossils in the DFIW pyxides (e.g. Knossos 86/14 and 86/17), however, 13 out of the 16 samples were dated to subzone NN 12-13B (middle Zanclian).

The results of the calcareous nannofossil analysis confirm the suggestion in Section 11.3.3.1, that the calcareous component of the DFIW pyxides is Early Pliocene in age. The existence of some minor variation in terms of the particular subzone to which the individual samples have been ascribed may represent real variability in the site of procurement of the raw material, or inaccuracy in the biostratigraphic interpretation of the calcareous nannofossil assemblages, and is discussed in more detail below.

11.3.3.3 Knossian comparative samples

The Knossian EM and MM samples do not form a homogeneous petrographic or stylistic group and were selected for comparison with the DFIW pottery on the basis of their similar decorative techniques, surface finish and fabric in hand specimen. As a result, they exhibit some variation in terms of their foraminiferal and calcareous nannofossil assemblages. Nevertheless, a great number of these samples contain benthic and planktonic foraminiferal assemblages and Early Pliocene calcareous nannofossil assemblages which are closely comparable to those of the DFIW pyxides. The assemblages of foraminifera in the thin sections of the EM and MM pottery from Knossos are, on the whole, more diverse than those of the DFIW samples. However, this can be attributed to the difference in size between the two groups of thin sections (all of the DFIW thin sections are very small), as can the occurrence of one or two ostracod shells in some of the Knossian samples (9 out of 26). Several of the EM and MM thin sections contain foraminifera within calcareous inclusions, as in the DFIW samples, indicating that this is may be the origin of the foraminifera isolated within the clay matrix.

The calcareous nannofossil assemblages of EM and MM pottery from Knossos, vary considerably in terms of their preservation and abundance, however 23 of the 26 samples can be interpreted biostratigraphically as late Neogene (Late Miocene or Pliocene), eight of these can be assigned to the Early Pliocene, Zanclian calcareous nannofossil zone NN 13, and six can be correlated with one of Driever's (1988) Early Pliocene subzones. As with the DFIW assemblages, there is some variability in terms of the three particular calcareous nannofossil subzones of NN 13 to which the samples can be assigned, however subzone NN 12-13B (middle Zanclian) is again common.

By comparing the foraminiferal and calcareous nannofossil analysis of the two groups of pottery it can be seen that the DFIW pyxides are very similar, in terms of their micropalaeontology, the geological age of their raw materials and the technology used in their production, to some but not all of the MM IA, MM IB and MM IIB samples analysed from Knossos.

11.3.3.4 North-central Cretan geological samples

The calcareous nannofossil analysis of the north-central Cretan sediment samples (Section 10.3 and Figure 11.9) indicates that the Finikia Formation, which covers a wide area south of the modern town of Iraklion, is Early Pliocene in age (Figure 10.3). The sediment samples which were analysed do not represent the full stratigraphic extent of this formation, nevertheless they indicate that it contains strata deposited during the middle Zanclian calcareous nannofossil zone NN 13, including all of Driever's (1988) subzones for this period (NN 12-13A, B and C).

The palace of Knossos stands on highly calcareous white marls of the Finikia Formation, which also occur for several kilometres north and south of this site, in the valley between two areas of high ground formed by hard limestones of the Agia Varvara Formation.

The extensive micropalaeontological analysis of Spaak (1983), Jonkers (1984), Driever (1988) and other Utrecht stratigraphers who have analysed several sections of the Early Pliocene Finikia Formation, has established in far greater detail, the age and geographical extent of this geological unit. The three principal north-central Cretan sections of the Finikia Formation analysed by Driever (1988), which cover the complete stratigraphical extent of this formation, are Kalithea Section 1 (NN 12-13A: base of the Pliocene, to NN 14-15A: late Zanclian), Agios Vlassios (top of NN 12-

13A: just above the base of the Pliocene, to NN 16-17D: early Piacenzian) and Finikia (NN 16-17B: earliest Piacenzian, to NN 16/17D: early Piacenzian). Jonkers (1984) and Spaak (1983) have also studied samples from Kalithea Section 1 plus Kalithea Sections 2 and 3, and the Prassas section, all of which can be placed in the "Kalithea basin" (Jonkers 1984, 13). The total stratigraphical extent of the Finikia Formation in the Kalithea basin, which includes the area around Knossos, is from the base of the Pliocene to the upper part of the *Globorotalia punctictulata* Zone (Spaak, 1983), which is equivalent to calcareous nannofossil subzone NN 16-17B of Driever (1988) or the early part of the Piacenzian. The Kalithea sections are the closest sediments of the Finikia Formation to Knossos (c. 1.5 km) which have been studied in detail and as such are a useful reference point, as very few suitable exposures of these sediments occur in the area immediately surrounding the site. The white marls of the small valley in which the site of Knossos is situated relate to the lower part of the Kalithea Section 1 a short distance away, which corresponds to the 'Kourtes facies' of the Finikia Formation (*Globorotalia margaritae* Zone: upper NN 12-13A and NN 12-13B; Driever 1988). This interpretation agrees lithologically with the nature of the sediments at Knossos (observations in this report), as well as the calcareous nannofossil analysis of field samples which are presented in Figure 11.9. Sample 17, which was collected from a small outcrop of the highly calcareous 'marl breccia' at the foot of the hill upon which the palace is built (Figure 10.3) was assigned to the latter part of subzone NN 12-13A or the early part of NN 12-13B, and the stratigraphically higher sample 16 which came from the homogeneous and laminated 'Finikia facies' sediments on the slopes of the hill of Ailias to the east of the palace at Knossos, was dated to subzone NN 12-13C.

It thus appears that the calcareous 'marl breccia', the Kourtes facies and part of the Finikia facies of the Early Pliocene Finikia Formation occur at and around the site of Knossos. The two samples which were analysed from the upper and lower of these units, as well as a correlation between the Knossos area and the well-studied Kalithea Section 1 a short distance to the north, indicate that these sediments belong to the Early Pliocene (middle Zanclian) subzones NN 12-13 A, B and C of Driever (1988: Figure 5.23).

11.3.3.5 The isolation of foraminifera from Knossos pottery sample Kn 95/187

During the pilot study into the possible isolation of three-dimensional foraminifera from archaeological ceramics, a small quantity of Knossos pottery sample Kn 95/187 yielded numerous benthic and planktonic foraminifera (Section 6.5.4.3). Through the identification of the planktonic foraminifera and the application of appropriate zonation schemes (Section 6.6.2), it was possible tentatively to assign this sample to the Early Pliocene, Zanclian geological stage. This helps to refine the broad biostratigraphic interpretation that was achieved by the calcareous nannofossil analysis of this sample (Figure 10.8 Part 1) and indicates a more definite correlation between this particular sample, the DFIW pottery and the sediments of the Finikia Formation.

In addition, a comparison of the benthic foraminifera which were isolated from this pottery sample with the assemblages described by Jonkers (1984), has indicated that the raw material utilised in the manufacture of this pottery sample was deposited in a poorly-oxygenated environment. This interpretation is not of much value to the present case study, however it demonstrates the level of information which can be attained from the analysis of isolated foraminifera, compared to those assemblages present in ceramic thin sections. The full details of this analysis are presented in Section 6.6.4.

11.3.4 Conclusions

By reassessing the foraminifera which occur in the Knossian DFIW thin sections analysed by Tsaila (n.d.), the results of which are used in MacGillivray *et al.* (1988), the present case study has indicated that all samples, with the exception of Kn 86/15, have a homogeneous micropalaeontological assemblage of benthic and planktonic foraminifera which are very similar to the associations described by Jonkers (1984) from the Pliocene sediments of Crete. This coherency is confirmed by the occurrence of abundant, reasonably well-preserved calcareous nannofossil assemblages in all samples, which can be assigned to the Early Pliocene, Zanclian Stage calcareous nannofossil zone NN 13 (subzone NN 12-13B, and possibly NN 12-13A and C).

The current reassessment of the original DFIW thin sections has revealed the occurrence of calcareous inclusions and the incomplete mixing of a calcareous sediment, both of which contain similar foraminifera to those in the matrix. This has been used to interpret the ceramic technology of this pottery, which appears to have been produced by the admixture of a non-microfossiliferous, non-calcareous clay with a component of highly calcareous, microfossiliferous Early Pliocene sediment, such as a marl or marly limestone.

The foraminiferal and calcareous nannofossil analysis of thin sections and smear slides of comparable EM I, MM IA, MM IB and MM IIB pottery from the site of Knossos in north-central Crete has established that several of these samples can be correlated biostratigraphically and in terms of technology, with the DFIW material, as they contain similar Early Pliocene microfossil assemblages, both within the main clay body and in small isolated calcareous inclusions. It therefore appears that the DFIW and the majority of these EM to MM pottery samples were manufactured with geologically contemporaneous raw materials, using similar technology.

The calcareous nannofossil analysis of sediment samples from the various late Neogene formations of north-central Crete, as well as the interpretation of detailed micropalaeontological studies by Utrecht geologists working in this area, has indicated that if the calcareous raw material used for the production of the DFIW pottery was procured from one of the Neogene formations of central Crete (one of the potential source areas which was suggested by MacGillivray *et al.* 1988), then the Early Pliocene Finikia Formation is the most likely candidate.

The Finikia Formation covers a large area in the northern part of central Crete and is particularly extensive in the region south of the modern town of Iraklion. The archaeological site of Knossos is situated on a fault-bounded strip of Finikia sediments, which forms a north-south trending valley between two elevated regions of hard limestones belonging to the Agia Varvara Formation. The sediments of the Finikia Formation which occur in this area consist of a basal Pliocene 'marl breccia' (earliest Zanclian calcareous nannofossil zone NN 12-13A) which is overlain by the highly calcareous, white marls of the Kourtes facies (middle Zanclian calcareous nannofossil zone NN 12-13B) and the lower part of the homogeneous and laminated marls and marly limestones of the Finikia facies (middle to late Zanclian calcareous nannofossil zone NN 12-13C). As such, this group of sediments are a likely candidate for the source of the highly calcareous microfossiliferous material used in the manufacture of the DFIW and the comparative EM-MM Knossian pottery analysed in this case study.

It is worth noting that the utilisation of Early Pliocene microfossiliferous sediments for the manufacture of ceramics at Knossos has also been suggested by the thin section foraminiferal analysis of Late Minoan fine wares carried out by Riley *et al.* (n.d.: Section 2.3.4.3), and is compatible with the foraminiferal and calcareous nannofossil analysis of range of pottery from the EM I well at Knossos in the present report. The significance of these discoveries are discussed further in Section 12.5.

11.4 Technological and provenance interpretations of ceramics from the Mirabello production group

11.4.1 Introduction

Myer (1979) analysed several samples of the distinctive EM IIB Vasiliki Ware from its type site on the southern edge of the Gulf of Mirabello using petrography. The assemblage of minerals which characterised these thin sections, was also noted by the same author in numerous samples of EM III white-on-dark-ware from the neighbouring sites of Gournia and Mokhlos (Figure 11.1), as well as a single MM I example from Priniatikos Pyrgos (Myer 1984). In addition, large quantities of ceramics belonging to this fabric group, which was termed the 'Mirabello Fabric' by

Day (1991, 99), occurs throughout east Crete in the Neopalatial period (Day 1997), as imports at Myrtos Fournou Korifi on the south coast of Crete during EM IIB (Whitelaw *et al.* 1997), and the island of Pseira in the Gulf of Mirabello (Myer *et al.* 1995).

Myer (1979) incorrectly identified the mineral and composite rock fragments of the Mirabello pottery as weathered metamorphic rocks, and postulated that this material had been partly crushed before being added as temper to a two-part base clay, produced by the mixing of the terra rossa soils of the Isthmus of Ierapetra and white marine clays. In defining this fabric group, Day (1991) instead related its distinctive inclusions to the granitic and dioritic igneous rocks which occur along the southern edge of the Gulf of Mirabello, and used their homogenous grain-size and denuded appearance to postulate that weathered material had been added as temper rather than crushed rock fragments.

Day (1991) defined three different types of Mirabello Fabric at Gournia; his Fabrics 1 and 3, which occurred as jugs or jars at this site, were interpreted as being a mixture of the weathered grano-diorite sand and a grey Neogene clay, whereas the ceramics of the low-fired Cooking Pot Fabric 2 he believed to have been produced from the terra rossa soils of the Isthmus of Ierapetra, which contained many other types of inclusions in addition to the igneous rock fragments, mixed with a quantity of Neogene marls.

Pottery belonging to the Mirabello Fabric has been interpreted as the product of several centres in the north part of the Isthmus of Ierapetra or the southern border of the Gulf of Mirabello (Myer 1984; Day 1991; Myer *et al.* 1995), which were grouped by Whitelaw *et al.* (1997) into the 'Mirabello Tradition' or 'Mirabello production group'.

The meso-scale provenance interpretation of the Mirabello production group which is presented above, represents a good example of how ceramic petrography can be used to relate the mineral inclusions in pottery to geographically isolated occurrences of specific rock types. The petrographic analysis of Mirabello Fabric thin sections also revealed useful information pertaining to the technology of this group of ceramics, including the use of tempered and blended marine clays (Day 1991), which Whitelaw *et al.* (1997, 270) have linked to the "fine grey Upper Miocene clays present in the Isthmus area". However, Myer (1979) and Day (1991) identified more specifically, the Neogene clays occurring in the vicinity Vasiliki and Gournia respectively, as being likely candidates for the source of the calcareous marine component of the Mirabello fabric.

In order to investigate more precisely the geological age and provenance of the marine sediments used in the manufacture of the ceramics belonging to the Mirabello production group, the present case study analyses the microfossils contained within several thin sections and smear slides of the Mirabello Jar (MJ) and Cooking Pot (MCP) Fabrics (equivalent to Fabrics 1 and 3 of Day 1991) excavated from the sites of Myrtos Fournou Korifi, Myrtos Pyrgos and Kalo Chorio. The results of this micropalaeontological analysis are compared to the geological report of Fortuin (1977) which deals with the Isthmus of Ierapetra, as well as with the biostratigraphic interpretation of field samples collected from the Neogene sediments in the source areas identified by Myer (1979) and Day (1991).

Group	Samples	Calcareous nannofossils	Foraminifera	Ostracods
MJ	MFK 93/18	-	-	-
	MFK 93/19	tent. late NN10-mid. NN 11 (late Tortonian).	-	-
	MFK 93/110	-	-	-
	MFK 93/173	ex poor. late Neogene	-	-
	MFK 93/180	poor late Neogene	-	-
	MPY 93/17	-	-	-
MCP	KAC 94/28	-	-	-
	KAC 94/27	-	-	-
	MFK 93/20	v. poor late Neogene	-	-
	MFK 93/17	ex. poor late Neogene	-	-

Figure 11.10 Micropalaeontological analysis of the Mirabello Cooking Pot (MCP) and Mirabello Jar (MJ) Fabric samples. MFK = Myrtos Fournou Korifi, MPY = Myrtos Pyrgos and KAC = Kalo Chorio. (-) = barren.

Pakhiammos Formation homogeneous and laminated marls:

Sample 98E -NN 13 (early NN 12-13B) = Early Pliocene (Zanclian).

Sample 98G - tentatively late NN 12 (late NN 12-13A) = earliest Pliocene (early Zanclian).

Pakhiammos Formation greenish sandy marls:

Sample 98D -late NN 11 or NN 12 = latest Miocene or earliest Pliocene (Messinian or earliest Zanclian).

Makrylia Formation grey clays at Vasiliki (Dermitzakis and Theodoridis 1984).

NN 9 = Late Miocene (lower Tortonian).

Figure 11.11 Calcareous nannofossil biostratigraphic assignments of sediment samples from the southern edge of the Gulf of Mirabello. For detailed assemblage descriptions see Section AIII.4

11.4.2 Micropalaeontological analysis of the Mirabello Fabrics and field samples from the Isthmus of Ierapetra

The calcareous nannofossil and microfossil analysis of the Mirabello pottery is summarised in Figure 11.10 and the full calcareous nannofossil assemblage descriptions of these pottery samples are presented in Section AII.5. The calcareous nannofossil assignments of the Pakhiammos Formation geological samples are presented in Figure 11.11. A discussion of the sampling strategy is presented in Section 10.4 and full descriptions of the calcareous nannofossil assemblages from the various sediment samples can be found in Section AIII.4. No field samples were analysed from Vasiliki in the present report, however the detailed micropalaeontological data of Dermitzakis and Theodoridis (1984) from the Makrylia and Ammoudares Formations in this area are considered.

11.4.3 Discussion

11.4.3.1 Technology

Of the ten Mirabello samples, five contained microfossils and five were barren. Two samples, both belonging to the Mirabello Jar Fabric (MJ), were characterised by a relatively low abundance of reasonably well-preserved late Neogene calcareous nannofossils (Figure 11.10). In addition, the smear slides of one other Mirabello Jar sample and two from the Mirabello Cooking Pot Fabric, contained extremely poor Neogene calcareous nannofossil assemblages, consisting of but a few specimens. None of the ten Mirabello thin sections contained any foraminifera or ostracods in thin section.

The occurrence of calcareous nannofossils in Mirabello Jar samples MFK 93/19, MFK 93/180, and possibly MFK 93/173 indicates that these sherds contain marine sediments, as suggested by Day (1991). Whitelaw *et al.* (1997) have reported that the calcareous Mirabello Fabric samples from Myrtos Fournou Korifi were highly-fired to a temperature of c. 850-1080 °C in an O/R/O atmosphere, which may account for the poor nature of the assemblage in sample MFK 93/173 and absence of calcareous nannofossils in the smear slides of MFK 93/18, MFK 93/110 and MPY 93/17.

The presence of a few Neogene calcareous nannofossil specimens in the smear slides prepared from Mirabello Cooking Pot samples MFK 93/17 and MFK 93/20 may be taken to support the suggestion of Day (1991) that this fabric contains a component of Neogene marine marls, mixed with terra rossa clays. Small numbers of contaminant calcareous nannofossils can be incorporated during smear slide preparation (Section 5.3.2.2), however the specimens in these two slides may have originated from the original raw materials as no Neogene calcareous nannofossils were encountered in the 'control slide' produced during whilst sampling the Mirabello pottery using this method. It is also worth noting that no calcareous nannofossils were found in the smear slides of the other two MCP samples (KAC 94/27 and KAC 94/28) which were prepared at the same time. Samples KAC 94/27 and KAC 94/28 originated from baking plates (Appendix V) and it is therefore possible that they onced contained calcareous nannofossils as MFK 93/17 and MFK 93/20 but were rendered barren as a result of usage.

11.4.3.2 Provenance

The calcareous nannofossil assemblages which were recorded in the smear slides of Mirabello Jar Fabric samples MFK 93/19 and MFK 93/180 are of low abundance and cannot be interpreted biostratigraphically with much precision. The flora of MFK 93/19 is late Neogene in age and may be assigned tentatively to the late Tortonian (late NN 10 to middle NN 11 calcareous nannofossil zones). The calcareous nannofossil assemblage of MFK 93/180, on the other hand can only be assigned to the late Neogene (Late Miocene or Early Pliocene) period.

The broad geological date which has been assigned to MFK 93/180 is of little help in indicating the source of the marine marl which was used in the manufacture of this Mirabello Jar sample, as it covers the complete stratigraphic interval represented by microfossiliferous marine sediments on Crete (Chapter 4, Figure 4.2), including both the Makrylia and Pakhiammos Formations in the Isthmus of Ierapetra (Figure 11.11). However, the more detailed biostratigraphic interpretation which has been possible for MFK 93/19 indicates that the microfossiliferous sediment of this pottery sample may be incompatible with the grey marls of the Makrylia Formation which occur at Vasiliki and the green and white marls of the Pakhiammos Formation between Gournia and Pakhiammos.

Of the other late Neogene marine formations which occur in the Isthmus of Ierapetra and the southern edge of the Gulf of Mirabello, only the Ammoudares Formation is compatible in age with the biostratigraphic assignment of sample MFK 93/19. This formation which was suspected to have been used in the manufacture of some South Coast pottery at Myrtos Fournou Korifi (Section 11.2) occurs in several places close to the village of Vasiliki (Figure 10.4), and is early Tortonian to Messinian in age (Fortuin 1977; Dermitzakis and Theodoridis 1984; the present report, Figure 11.4). The Ammoudares Formation consists of bioclastic sandy limestones, intercalated with highly calcareous slightly sandy marls and as such may also be unsuitable for the manufacture of ceramics, except when mixed with a finer, less calcareous component (observations in the present report). However, there was no evidence in the MJ ceramic thin sections which were analysed in the present report for the admixture of a calcareous microfossiliferous sediment such as the marls of the Ammoudares Formation, with another, less calcareous raw material.

The very low abundance calcareous nannofossil assemblages in Mirabello Cooking Pot samples MFK 93/17 and MFK 93/20 cannot be interpreted biostratigraphically with any precision (Figure 11.10), and therefore it is not possible to identify which of the late Neogene formations of the Isthmus of Ierapetra and the southern edge of the Gulf of Mirabello may represent the source of the microfossiliferous marine sediment used in the manufacture of these ceramics.

11.4.4 Conclusions

In this case study the detailed micropalaeontological analysis of several pottery samples from the east Cretan Mirabello production group supports the technological interpretation of Day (1991) that the pottery belonging to the Mirabello Jar Fabric was produced with tempered Neogene marine clays and the Mirabello Cooking Pot fabric contains a component of marine sediment added to a non-calcareous base clay.

The poor nature of the calcareous nannofossil assemblages in most of the samples (which is suspected to be a result of high firing in the case of the Mirabello Jar samples) meant that it was not possible to biostratigraphically interpret the Neogene marine sediments which were used in their manufacture with any precision. The assemblage in one Mirabello Jar sample (MFK 93/19), could be tentatively assigned to the late Tortonian Stage of the Late Miocene. This suggests that of the various marine formations occurring in the Isthmus of Ierapetra and the southern edge of the Gulf of Mirabello (Fortuin 1977) the sandy calcareous marls and limestones of the Ammoudares Formation are the most contemporaneous.

The fine grey clays of the Makrylia Formation which underlie the Ammoudares Formation at Vasiliki and have been suggested by Myer (1979) to be the source of the marine sediment in the Mirabello pottery, were deposited in the early Tortonian and as such are not compatible with the microfossil assemblage of sample MFK 93/19. Of the marine sediments which occur close to the site of Gournia (suggested by Day 1991 to be the source of the raw materials in his Mirabello Jar Fabric), the marls of the Pakhiammos Formation are closest in age to the calcareous nannofossil assignment of sample MKF 93/19, however these highly calcareous sediments are not suitable as a raw material for ceramic manufacture and are likely to have been deposited at a slightly later date.

Although the sediments of the Ammoudares Formation are of a similar age to the marine sediments of the Mirabello Jar Fabric, they too are unsuitable for pottery production without the addition of finer, non-calcareous raw material. There is no evidence in the thin sections of this pottery for the admixture of calcareous and non-calcareous clays (Day 1991 and the present report), which suggests that the marls of the Ammoudares Formation may not have been used in their manufacture. Nevertheless, it is perhaps unwise to attempt to provenance the raw materials of this pottery using a tentative biostratigraphic assignment of the poor calcareous nannofossil assemblage from a single sample.

The very poor calcareous nannofossil assemblages which were recorded in the smear slides of Mirabello Cooking Pot samples MFK 93/17 and 93/20 cannot be interpreted biostratigraphically with any precision and it is therefore not possible to indicate the provenance of the component of Neogene marine sediment used in their manufacture.

11.5 Comparing shapes: The analysis of ostracod specimens from the Tel Haror inscribed sherd

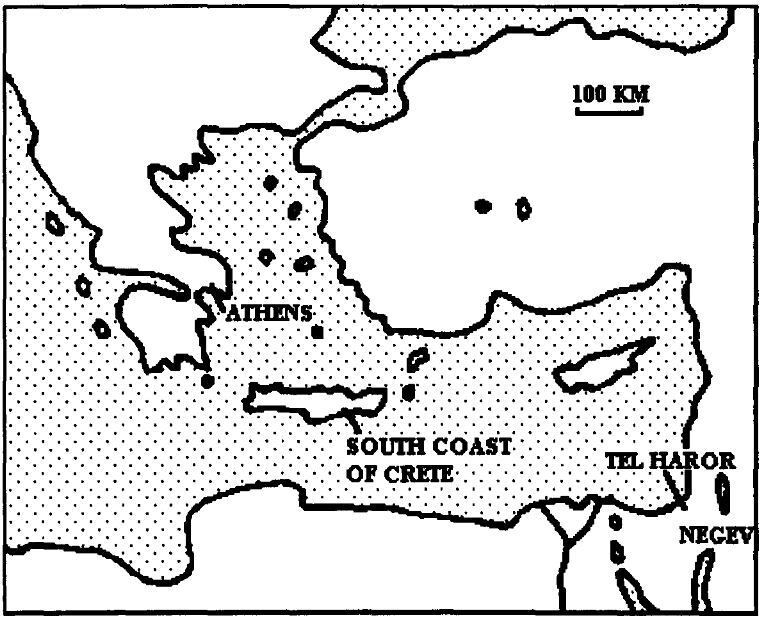
11.5.1 Introduction

During the excavation of a Middle Bronze Age II temple complex at Tel Haror in the western Negev, Israel (Figure 11.12) by Oren (1993), a distinctive sherd was found featuring three inscribed signs. Oren *et al.* (1996) suggested that these were Hieroglyphic or Linear A characters which represent three commodities: 'figs', 'cloth' and a 'bull's head rhyton'. The sherd appears to have originated from a storage jar, and the absence of any accompanying fragments at the site of Tel Haror indicates that it may have been removed from the complete vessel at another location. Oren *et al.*'s (1996) interpretation of the graffito on the 'Tel Haror inscribed sherd', in particular the reference to a bull's head rhyton, indicates that it may have a Cretan origin.

In order to further investigate the origin of this sherd, Oren *et al.* (1996) analysed it petrographically and chemically. By comparing the results of the chemical (neutron activation) analysis of the Tel Haror inscribed sherd with that from a databank of Israeli pottery, they confirmed its non-local origin. Unfortunately, the sherd did not relate chemically to their comparative pottery from Cyprus, mainland Greece, Rhodes or Crete either. The results of the petrology however, indicated that the Tel Haror inscribed sherd, which contained altered igneous rock fragments and a component of calcareous sediment, was not compatible with the local geology of the western Negev, but related well to that of Crete. A comparison of the petrology of the sherd with published groups of Cretan pottery, produced no suitable match.

More recently, this research has been supplemented by Day *et al.* (1999). The latter authors have restudied the Tel Haror thin section (# 20984) of Oren *et al.* (1996) and compared it to an extensive collection of Minoan pottery thin sections from various sites on Crete. The new and more detailed petrographic analysis of Day *et al.* (1999) has revealed that the Tel Haror inscribed sherd is highly compatible in terms of its non-plastics with the pottery of the South Coast production group which was defined by Whitelaw *et al.* (1997: Section 11.2). The ceramics of this group which have been excavated from several Early Minoan archaeological sites including Myrtos Fournou Korifi (MFK) and Myrtos Pyrgos (MPY), are thought to have been produced somewhere along the south coast of Crete (Figure 11.12).

As part of the re-examination of the Tel Haror thin section, the present author has analysed the ostracods and rare foraminifera, and compared these to the specimens contained within ten representative thin sections of South Coast pottery using the



11.12 The location of Tel Haror in the western Negev, Israel and the south coast of Crete.

methodology outlined in Section 7.7.1, in an attempt to confirm or refine the suggestion provided by the new petrographic analysis.

11.5.2 Results

The thin section of the Tel Haror inscribed sherd contains seven complete and fragmentary ostracod specimens (Figure 11.13) and one poorly-preserved foraminifer. The ostracods in this thin section appear as simple, crescentic, micrite and mono-crystalline calcite inclusions, often with inflated extremities. They exhibit no features which can be used for generic or specific identification, as was the case for all specimens which have been observed in thin sections in the present study (Section 7.2). The single foraminifer was also unidentifiable, although it may be possible to conclude that it is a benthic form.

The analysis of the ostracods from the South Coast thin sections was equally unsuccessful. All ten comparative samples contained numerous, unidentifiable ostracods, sometimes with inflated ends, but otherwise featureless. A few of the South Coast samples contained single foraminifera; two of these were globular planktonic specimens belonging to the genus *Globigerina*, and the other was an unidentifiable benthic form.

By comparing the individual ostracod specimens in the Tel Haror inscribed sherd with those of the ten representative thin sections of South Coast pottery, on a purely morphological basis, i.e. in terms of their size, curvature, shell thickness as well as the appearance of their often inflated dorsal ends, it was possible to infer that the two are not dissimilar. This method of comparison is severely hindered by the random

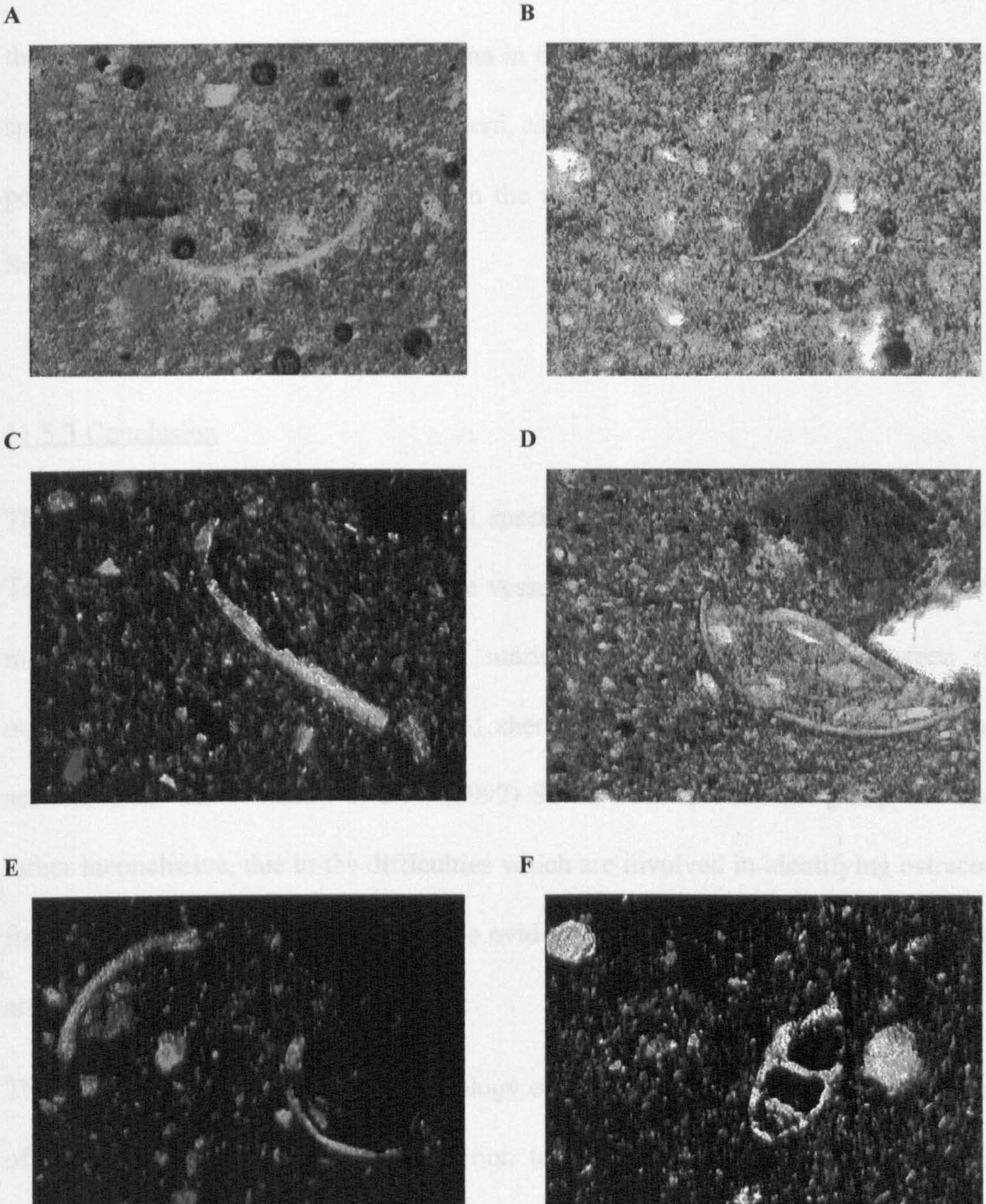


Figure 11.13 Representative ostracod specimens and a single foraminifer in a thin section of the Tel Haror inscribed sherd. A, B and D = PPL, C, E and F = XP. Field of view = 0.5 mm.

representation of the ostracod specimens in thin section, however it was the only approach which was possible in this case. All eleven samples contain a range of shapes, some of which are similar to one another, so that it is not possible to separate them on the basis of their ostracod fauna in thin section. The abundance of ostracod specimens in the Tel Haror inscribed sherd, as calculated by the number of specimens per area of the section, was also within the range which was calculated for the ten South Coast samples.

11.5.3 Conclusion

The detailed analysis of the microfossil specimens which were contained within the Tel Haror thin section indicates that the vessel from which this sherd originated was manufactured using a component of marine marl. A comparison between the microfossils in the Tel Haror inscribed sherd and those contained within ten thin sections from the Whitelaw *et al.*'s (1997) South Coast production group has been rather inconclusive, due to the difficulties which are involved in identifying ostracods from thin sections. However, there is no evidence with which to suggest that the two are dissimilar.

The strong similarity between the petrology of the Tel Haror inscribed sherd and that of the South Coast ceramics, in addition to the presence of broadly comparable ostracod specimens and rare and sporadic foraminifera in both, is sufficient to indicate that the sherd may have been produced on Crete.

11.6 Calcareous nannofossil analysis of ceramics and probable raw materials from an ancient punic kiln site on the island of Mozia (western Sicily)

11.6.1 Introduction

A ceramic workshop dated to the VI-V century B.C. was found at the ancient punic settlement on the island of Mozia, off western Sicily (Figure 11.14). This workshop contained several well-preserved kilns, fired ceramic artefacts and quantities of raw materials. Alaimo *et al.* (1997) have analysed samples of the pottery and probable raw materials using mineralogy, geochemistry as well as macro- and microfossil analysis, and indicated that the two are compatible. The raw materials found at Mozia also proved to be similar to alluvial sediments from the mouth of the Birgi stream, approximately 3 km from Mozia (Figure 11.14).

The correlation between the pottery, probable raw material found near to the kiln and the Birgi alluvium was based upon the occurrence of a homogeneous chemical and mineralogical composition, as well as similar assemblages of benthic foraminifera, ostracods and macrofossil debris in all samples (Figure 11.15). These two facts provide evidence in support of Alaimo *et al.*'s hypothesis, however it was deemed advantageous to discover whether a programme of detailed calcareous nannofossil analysis (the present case study and Quinn *et al.* 1998) could be used to confirm or refine this conclusion.

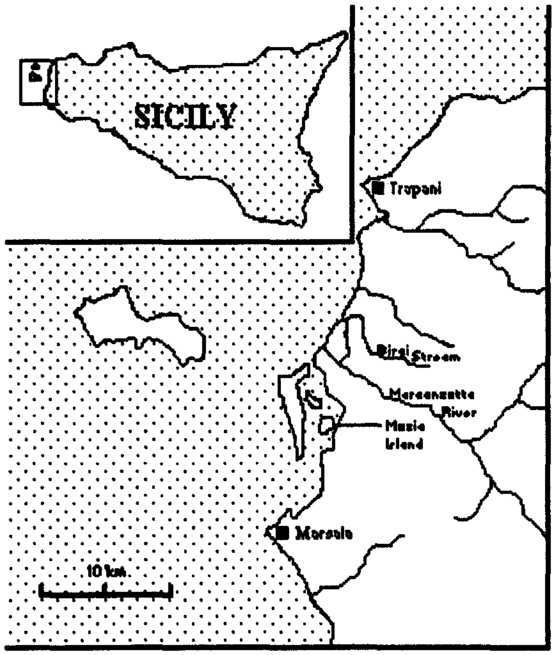


Figure 11.14. The location of Mozia and the Birgi stream in western Sicily.

MK 2 (raw material found near the kiln)

Benthic foraminifera: *Quinqueloculina sp., Triloculina sp., Elphidium crispum, Ammonia sp.*

Ostracods: *Cyprideis sp.*

Macrofossils: *Tricolia sp., Chlamys sp., Lithothamnium sp.*, echinoid spines.

MK 6 (sand temper? found near the kiln)

Benthic foraminifera: *Quinqueloculina sp., Triloculina sp., Elphidium crispum, Ammonia sp.*

Macrofossils: *Tricolia sp., Chlamys sp., Lithothamnium sp.*, echinoid spines.

MK 7 (raw material found near the surface)

Benthic foraminifera: *Quinqueloculina sp., Triloculina sp., Elphidium crispum, Ammonia sp.*

Ostracods: *Cyprideis sp.*

Macrofossils: *Tricolia sp., Chlamys sp., Lithothamnium sp.*, echinoid spines.

MK 12 (fragment of an amphora support)

Benthic foraminifera: *Quinqueloculina sp., Triloculina sp., Elphidium crispum, Ammonia sp.*

Ostracods: *Cyprideis sp.*

Macrofossils: *Tricolia sp., Chlamys sp., Lithothamnium sp.*, echinoid spines.

MK 16 (fragment of a dish)

Benthic foraminifera: *Quinqueloculina sp., Triloculina sp., Elphidium crispum, Ammonia sp.*

Ostracods: *Cyprideis sp.*

Macrofossils: *Tricolia sp., Chlamys sp., Lithothamnium sp.*, echinoid spines.

Mo 3 (alluvium from the Birgi stream)

Benthic foraminifera: *Elphidium crispum,*

Ammonia sp.

Macrofossils: *Tricolia sp., Cerithium sp., Lithothamnium sp.*, echinoid spines.

Figure 11.15. Macro and microfossil analysis of pottery and possible raw materials from an ancient Punic kiln at site Mozia, western Sicily carried out by Alaimo *et al.* (1997).

11.6.2 Methods of calcareous nannofossil analysis

In order to analyse the calcareous nannofossil assemblages contained with the samples of archaeological pottery and probable raw materials from the Mozia kiln, standard nannofossil smear slides were prepared from each sample (Section 5.3.2). Sample MK 6 was extremely sandy and the coarse fraction had to be separated in water; after ten seconds the fine clay fraction which remained suspended, was then pipetted onto a coverslip and allowed to dry. All samples were studied semi-quantitatively according to the method outlined in Section 5.10. The results of this analysis are presented in Figures 11.16 Parts 1-4, Section AII.6, and below.

11.6.3 Results

MK 2 (raw material found near the kiln)

A very abundant, variable, but reasonably well-preserved assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Palaeocene or Early Eocene, Late Eocene to Early Oligocene, Late Oligocene to Early Miocene and Late Neogene.

MK 6 (sand found near the kiln, thought to have been used to temper the pottery)

An abundant, extremely variable, but generally poorly-preserved assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Oligocene or Early Miocene and Late Neogene (Early Pliocene), and possibly the Late Palaeocene or Early Eocene.

Species and approximate range / Sample	MK2	6	7	12	16	Mo3
Arkhangelskiella specillata (Camp. and Maas.)		R			P	
Arkhangelskiella sp. (Cretaceous)						P
Biscutum ellipticum (Jurassic and Cretaceous)	R					
Braarudosphaera cf. regularis (Ber. - Con.)	P					
Calcicalathina oblongata (Val. - Bar.)	P					
Calcidiscus leptoporus (Miocene - Recent)	R	F	R			R
Calculites cf. obscurus (Camp. and Maas.)	F		F		R	R
Calculites sp. (Late Cretaceous)	P					
Ceratolithoides kamptneri (Maas.)	P					
Chiastozygus sp. (Cretaceous and Palaeocene)			P			
Coccolithus formosa (Eocene and Oligocene	P	R			P	R
Coccolithus miopelagicus (Miocene)	P	R	F		R	F
Coccolithus pelagicus (Cenozoic)	A	C	A	P	A	A
Cribrocentrum reticulatum (Late Eocene)	R		P		P	R
Cribrosphaerella ehrenbergii (Alb. - Maas.)		R				
Cruciellipsis cuvillieri (Early Cretaceous)	P					
Cruciplacolithus cribellum (Late Palaeocene - Early Eocene)						
Cyclagelosphaera margerelii (Jurassic and Cretaceous)		P				
Cyclicargolithus abisecta (Late Oligocene)	C	A	C		A	A
Cyclicargolithus floridanus (Eocene - Middle Miocene)			R		F	F
Dictyococcities antarcticus (Miocene)	R	F	F		P	F
Dictyococcities bisecta (Oligocene)	F	C	F		C	F
Dictyococcities productus (Late Miocene - Pliestocene)	C	C	F		F	F
D. productus / Gephyrocapsa (mid Zanclian) transitional specimens						R
Discoaster barbadiensis (Eocene)	R	P	P		P	
Discoaster bellus (Late Miocene)						R
Discoaster cf. druggii (Early Miocene)	P		P			
Discoaster deflandrei (Eocene - Middle Miocene)			R		F	
Discoaster kugleri (Middle Miocene)			P			
Discoaster mohleri (Palaeocene)	R	R	P		R	

Figure 11.16 Part 1. Semi-quantitative calcareous nannofossil analysis of ceramics and probable raw materials from an ancient punic kiln site on the island of Mozia.

Species and approximate range / Sample	MK2	6	7	12	16	Mo3
Discoaster saipanensis (Late Eocene)			P			
Discoaster tanii (Late Eocene and Early Oligocene)			P			
Discoaster tanii nodifer (Late Eocene)			P			
Discoaster variabilis (Middle Miocene - Late Pliocene)					P	
6 rayed indeterminable *Discoaster sp.* (Cenozoic)	R	P		P	R	R
Eiffellithus eximius (Tur. - Camp.)			P			
Ericsonia cava (Palaeocene)	P					
Ericsonia robusta (mid Palaeocene - Early Eocene)	R					
Ericsonia subdisticha (Late Oligocene - Early Oligocene)	R					
Geminlithella sp. (Neogene)		R				R
large *Gephyrocapsa sp.* (Pleistocene - Recent)					P	
small *Gephyrocapsa sp.* (middle Zanclian - Recent)		R				
Helicosphaera carteri (Miocene - Recent)	R		R			
Helicosphaera compacta (Late Eocene and Oligocene)	R					
Helicosphaera euphratis (Late Eocene - Early Miocene)			P			
Helicosphaera gertae (early Miocene)			P			
Helicosphaera intermedia (Oligocene and Miocene)	R	P			R	
Helicosphaera palaeocarteri (Neogene)		P	P		P	
Helicosphaera recta (Late Oligocene and Early Miocene)	P					
Helicosphaera sp. (Cenozoic)		P				
Heliolithus sp. (Palaeocene)					P	
Lucianorhabdus cayeuxii (Sant. - Maas.)			R			
Lucianorhabdus sp. (Late Cretaceous)	P					
Micula decussata (Sant. - Maas.)	R	P	P			
Micula swastica (Camp. and Maas.)			R			
Nannoconus elongatus (Bar. - Camp.)		P				
Nannoconus farinacciae (Tith. - Bar.)					P	
Nannoconus kamptneri (Ber. - Apt.)						P
Nannoconus steinmannii (Tith. - Bar.)			P			
Nannoconus s. minor (Val. - Haut.)						

Figure 11.16 Part 2. Semi-quantitative calcareous nannofossil analysis of ceramics and probable raw materials from an ancient punic kiln site on the island of Mozia.

Species and approximate range/ Sample	MK2	6	7	12	16	Mo3
Nannoconus sp. (Cretaceous)					P	
Polypodorhabdus escaigii (Jurassic)	P					
Pontosphaera multipora (Early Eocene - Pleistocene)	P		R			
Pontosphaera segmenta (Miocene)				P		
Pontosphaera sp. (Late Palaeocene - Recent)		P				
Prediscosphaera majungae (Maas.)			P			
Prediscosphaera stoveri (Camp. and Maas.)			P			
Prinsius sp. (Palaeocene)	R					
Pseudoemiliania lacunosa (Pliocene and Pleistocene)		P				R
Pyrocyclus orangensis (Miocene)	R					R
Quadrum sissinghi (Camp. and Maas.)		P				
Quadrum trifidium (Camp. and Maas.)						R
Quadrum sp. (Tur. - Maas.)	P				P	
Retecapsa angustiforata (Cretaceous)			P			R
Retecapsa sp. (Jurassic and Cretaceous)						R
Reticulofenestra minuta (Early Eocene - Pleistocene)	VA	A	C		F	A
Reticulofenestra minutula (Miocene - Pleistocene)		A	A		A	A
Reticulofenestra pseudoumbilica (Miocene - mid. Pliocene)	C	C	A		A	A
Rhagodiscus asper (Cretaceous)		R				
Sphenolithus anarrhopus (Palaeocene - Early Eocene)	R					
Sphenolithus moriformis (Eocene - Miocene)	P		R		R	F
Sphenolithus neoabies (Late Miocene - middle Pliocene)	P	F	P			
Sphenolithus obtusus (late Eocene)			R			
Sphenolithus predistensus (Late Eocene and Oligocene)			R			
Sphenolithus tribulosus (Early Oligocene)			P			
Sphenolithus sp. (Cenozoic)	F	F	F		F	
?*Speetonia colligata* (Early Cretaceous)						P
Scyphosphaera sp. (Eocene - Recent)					R	
Sollasities sp. (Jurassic and Cretaceous)			P			
Teichorhabdus ethmos (Maastrichtian)			P			

Figure 11.16 Part 3.. Semi-quantitative calcareous nannofossil analysis of ceramics and probable raw materials from an ancient punic kiln site on the island of Mozia.

Species and approximate range/ Sample	MK2	6	7	12	16	Mo3
Thoracosphaera sp. (Mesozoic and Cenozoic)	P		P			
Triquetorhabdulus carinatus (Oligocene - Early Miocene)	P		P			
?*Triquetorhabdulus shetlandensis* (Val. and Haut.)			P			
Watznaueria barnesae (Jurassic and Cretaceous)	R	F	F		P	F
Zeugrhabdotus embergeri (Late Jurassic and Early Cret.)			P			R

Figure 11.16 Part 4. Semi-quantitative calcareous nannofossil analysis of ceramics and probable raw materials from an ancient punic kiln site on the island of Mozia.

MK 7 (raw material found near the surface)

An extremely abundant, variable but reasonably well-preserved assemblage containing calcareous nannofossils which are indicative of the Late Cretaceous, Late Eocene, Early Miocene and late Neogene (Late Miocene or Early Pliocene).

MK 12 (fragment of an amphora support)

An extremely low abundance, very poorly-preserved assemblage which represents contamination or a highly degraded flora.

MK 16 (fragment of a dish)

An abundant, variable, but reasonably poorly-preserved assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Palaeocene, Late Eocene or Early Oligocene, Late Oligocene or Early Miocene, late Neogene and possibly the Pleistocene.

Mo 3 (alluvium from the Birgi stream)

An abundant, variable, but reasonably well-preserved assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Oligocene or Early Miocene, Late Miocene, Early Pliocene and possibly the Late Eocene or Early Oligocene.

11.6.4 Discussion

All of the samples, except MK 12, contained rich calcareous nannofossil assemblages with a variable state of preservation. In all cases the calcareous nannofossil taxa present in the assemblages were of widely varying geological dates ranging from the

Early Cretaceous to the Early Pliocene and possibly the Pleistocene. Whilst certain calcareous nannofossil taxa occur in some samples and not in others, the assemblages are generally very compatible and it is likely that samples MK 2, MK 6, MK 7, MK 12 and Mo 3 have a similar origin.

Sample MK 12 contained an extremely poor calcareous nannofossil assemblage characterised by a very low abundance of badly preserved specimens. It is it possible that this may be an artefact of contamination, which can be unavoidable despite the stringent sampling procedures described in Section 5.3.2. However, it is likely that this poor calcareous nannoflora is the remnants of an assemblage which was compatible with those of the other samples but has been degraded, since Alaimo *et al.* (1997) found no difference between this sample and the other six in their analysis. The firing temperature estimates for the two pottery sherds indicates that samples MK 16 and MK 12 were fired to temperatures of 600 and 700 °C respectively, suggesting that sample MK 12 may have once contained a rich calcareous nannofossil assemblage like sample MK 16, but this was subsequently degraded during the firing process. Calcareous nannofossils are rather sensitive to the process of firing, and under certain conditions they can be totally destroyed (Section 5.4; Quinn 1999).

The similarity of samples MK 2, MK 6, MK 7 and MK 16 to the sample of alluvium collected from Birgi stream indicates that this may be the source of the raw material stored at Mozia and used in the production of some of the pottery. The presence of calcareous nannofossils in the slide of sample MK 6 is surprising as they are not usually preserved in coarse-grained sediments. However, it may be that this sand, which is thought to be the source of the temper used in the pottery from Mozia

(Alaimo *et al.* 1997), could represent the coarse component sieved from Birgi alluvium (in which case sample MK 2 represents the fine fraction) or that it was contaminated with small amounts of Birgi alluvium during its storage in the Punic workshop.

The presence in samples MK 2, MK 6, MK 7 and MK 16 of mixed Mesozoic and Cenozoic calcareous nannofossil assemblages of variable preservation suggests that they have a secondary source which has been produced by the erosion of rocks from a wide stratigraphic interval. This is in agreement with an alluvial origin and the similarity of these samples with Mo 3 confirms the interpretation. The Birgi stream cuts through marine sediments of Early and Late Pleistocene age as well as Holocene alluvium during its short journey from Rilievo to the coast (D'Angelo and Vernuccio 1997). The Chinsia/Marcanzotta/Borrania river system which drains a very large catchment area at the western end of Sicily (Figure 11.14), is channelled throughout its last several kilometres across the plains of the Birgi area. Here, a small distributary branching off the main trunk of this river travels northwards to join the Birgi stream. The drainage basin of this river contains extensive marine sediments of Miocene and Pliocene age as well as smaller sequences of Jurassic, Cretaceous, Eocene and Oligocene marine deposits (D'Angelo and Vernuccio 1997).

11.6.5 Conclusions

The analysis of the calcareous nannofossils in the material from the ceramic workshop at Mozia supplements the interpretations which were made using macro- and microfossil analysis as well as mineralogical and chemical analysis by Alaimo *et al.*

(1997). The samples contained reworked calcareous nannofossils ranging from the Early Cretaceous to the Early Pliocene and possibly the Pleistocene, which is shown to be compatible with a source in the alluvium of the nearby Birgi stream. The calcareous nannofossil analysis has therefore provided important new information concerning the geological date and consequently the nature of the material, which was not achieved by the methods utilised in the previous study.

12 Conclusions

12.1 Introduction

This thesis has reviewed, developed and applied the techniques of a 'ceramic micropalaeontology': the scientific analysis of microscopic fossils occurring in archaeological ceramics. This 'subject', though not at all new, has been studied previously only in a selective manner (Chapter 2), and the preceding sections of this report (Chapters 5, 6, 7, 8, 9) represent the foundations of a more thorough approach. Having discussed each of the many groups of microfossils which occur in archaeological pottery, some of the techniques have been applied to archaeological samples from the Mediterranean. This chapter brings together these various strands and discusses several specific aspects of the subject as a whole, in order to assess the overall potential of micropalaeontology for the analysis of archaeological ceramics.

12.2 The application of micropalaeontology to the analysis of archaeological ceramics

The justification for the micropalaeontological analysis of archaeological ceramics can be demonstrated by the case studies presented in Chapter 11, as well as the work of previous authors which is discussed in Chapter 2. Microfossils are clearly a highly distinctive type of aplastic inclusion where present in archaeological pottery. Through careful taxonomic identification, it has been shown that they can be used to interpret information pertaining to the geological age and palaeoenvironment of the raw materials of ceramic manufacture. This is clearly an additional level of information which cannot be ascertained by the analysis of the other common types of inclusions or by the chemical and mineralogical analysis of the clay micromass itself and which may be utilised to classify archaeological ceramics. In certain circumstances it may enable the identification of the precise sources of raw materials as well as the technology used in their manufacture.

12.2.1 Description and classification

Within the scientific analysis of ceramics, description, classification, provenance and technology are all interrelated (Riley 1982). In particular, the processes of description and the formation of groups (i.e. classification) are essential to the determination of technological aspects of ceramic production, as well as the identification of potential sources of raw materials (Whitbread 1995, 376-377) and therefore should be the first step in all types of pottery analysis. The recording of selected attributes of individual samples provides the criteria with which to group and separate them (Bishop *et al.* 1982), and the classifications which are produced should reflect both the composition of the raw materials and the technology used in their production (Whitbread 1987, 68).

The microfossil assemblages in archaeological ceramics contain various levels of information which can be used to characterise individual samples, including: the presence or absence of specific groups of microfossils, the component of the ceramic in which they occur, their state of preservation and, more specifically, their taxonomic composition and the geological date and palaeoenvironment of which they are indicative. By recording these characteristics it is possible to construct detailed micropalaeontological descriptions of archaeological ceramics, such as those presented in Appendix II and Figures 11.3, 11.7 and 11.8 of the present report. The level of information contained within these assemblage descriptions and the way in which they are interpreted in terms of biostratigraphy and palaeoenvironment has a direct affect on the precision and accuracy of the provenance and technological interpretations which can be based upon them.

In previous micropalaeontological analyses of archaeological ceramics (Chapter 2), there are several examples in which the presence/absence, abundance or preservation of microfossils have been used independently of other compositional data to form less than meaningful classifications (e.g. Jansma 1977 and Troja *et al.* 1996). As illustrated by the analysis of ceramics from the South Coast production group at Myrtos Fournou Korifi, Crete (Section 11.2), there may be significant variability in terms of the presence/absence of different groups of microfossils in thin sections of petrographically identical pottery. This can be related to real variation in the composition of microfossiliferous ceramics, but may also be an artefact of preservation or a consequence of differential representation (Section 11.2.3.5). Likewise, minor taxonomic differences between the detailed microfossil assemblage descriptions of archaeological ceramics, have also been used to group and separate archaeological pottery samples (e.g. De Le Fuente and Martinez Macchiavello 1997; Alhonen *et al.* 1980), however these classifications are also subject to variations of preservation and representitivity, in addition to having little compositional meaning.

A better approach is to utilise all of the many different levels of information contained within the microfossil assemblages of archaeological ceramics. This involves the integration of biostratigraphic and palaeoenvironmental interpretations of host material with a consideration of the rest of the ceramic fabric, in thin section, in order to form meaningful groups. In this way it may be possible to identify samples affected by high firing or post-depositional alteration, as well as those thin sections in which specific groups of microfossils are poorly represented.

The interpretations of geological date or palaeoenvironment which can be ascertained by the detailed analysis of microfossil assemblages in archaeological ceramics are very useful as a means of grouping samples, or for examining variability within classifications based upon other criteria such as typology and ceramic petrography (Section 11.2.3.5). This is because such information is highly contextual, relating as it does to the geological nature of the raw materials used in ceramic manufacture. Of course it is not always possible to interpret this type of information from the microfossil assemblages in archaeological ceramics. This is because they can be poorly-preserved and may occur in low abundance, or be difficult to identify, as is the case with ostracods in thin section (Section 7.2). Nevertheless, as illustrated by the analysis of the Tel Haror Inscribed Sherd (Section 11.5 and Day *et al.* 1999), simple comparisons between various samples can be made on the basis of the overall appearance of their microfossil assemblages within the confines of a well-structured archaeological question.

11.2.2 Provenance

Provenance and the identification of sources of raw material has long been considered the major aim of ceramic analysis, including petrography (Day 1991, 64) and micropalaeontology (Battarbee 1988, 638). The main approach has been to relate the composition of ceramics (as determined by their description and classification) to the geological characteristics of a region.

Whilst the presence of specific groups of microfossils may be used to provenance ceramics in cases where geographically isolated occurrences of compatible sediments can be identified (e.g. Whitbread 1995, 331 and Stilborg 1997, 229), it is usually necessary to utilise the biostratigraphic and palaeoenvironmental interpretation of detailed microfossil assemblage descriptions to indicate the possible sources of raw materials used in ceramic production. However, the homogeneity of the surface geology over vast regions (e.g. north-west Europe) and the repetition of similar geological units (e.g. Crete and the Aegean) means that it may not be possible to use this micropalaeontological information alone to determine provenance.

The value of micropalaeontology in provenance analyses of ceramics is in the location of geologically compatible sediments within specific areas, identified through ceramic petrography and other archaeological evidence, as illustrated by the case studies presented in Sections 10.3, 10.4 and 10.7. The scale upon which these provenance interpretations can be made depends on several factors such as the size of the region, the diversity of its geology and the precision with which the microfossil assemblages can be interpreted. Biostratigraphic and palaeoenvironmental analyses of microfossils in ceramics are not well-suited to the determination of macro-scale provenance, due to the cosmopolitan distribution of planktonic microfossils and the occurrence of sediments deposited under similar geological conditions in geographically separate areas, although this is possible in some cases (e.g. Riley *et al.*'s interpretation of Late Bronze Age stirrup-jars from the house of the House of the Wine Merchant at Mycenae).

Often it may only be possible to distinguish between the local and non-local pottery occurring at a specific archaeological site (Jansma 1977), on the basis of its similarities and differences with the geology of the surrounding area (Battarbee 1988). This approach has been demonstrated by the analysis of diatoms in archaeological ceramics from north-west Europe. If it is not possible to make detailed taxonomic identifications and geological interpretations of the microfossil assemblages contained within archaeological ceramics, provenance may still be inferred by comparing the nature of the microfossils and petrography of the samples with ceramics of known origin, as illustrated by the analysis of ostracods from the Tel Haror Inscribed sherd (Section 11.5). Similarly, aspects of ceramic technology, as determined in thin section, may be correlated with that of other groups of pottery which are suspected to have originated from a specific area (Whitbread 1995, 374). Micropalaeontology has a role to play in this process, where specimens occur within temper or clay mixing; as in the correlation (in Section 11.3) of the Dark Faced Incised Ware pyxides with comparable ceramics excavated from the site of Knossos.

In all studies of ceramic provenance determination, knowledge of the local and regional geology is essential (Bishop *et al.* 1982). However, as maps and geological reports do not always contain sufficient detail, it is necessary to undertake raw material prospection and analyse those properties of sediment samples which are relevant to the specific project (Day 1991, 64). In the case studies which are outlined in Chapter 11 of the present report, field samples have been analysed for calcareous nannofossils and compared to the assemblage descriptions and biostratigraphic interpretations of the archaeological ceramics.

11.2.3 Technology

Technological studies address the human interactions with raw materials and are a major concern to ceramic analysis, both as a means of interpreting the behaviour of ancient potters as well as a tool in provenance determination (Whitbread 1995, 374). The main topics which are addressed in technological analyses of archaeological ceramics are the manipulation of raw materials: including clay mixing and tempering, the techniques of forming and the conditions of firing. Ceramic petrography is particularly well-suited to the determination of these factors, however the precise conditions of temperature and atmosphere during the firing of ceramics can be established more successfully by SEM or XRD analysis.

As demonstrated by the experimental work in this report, the behaviour of microfossils during firing is not easily quantifiable (Sections 5.4, 6.4 and 9.4). Combined with the range of other processes which affect the preservation of microfossil specimens in archaeological ceramics (Chapter 3), this means that their application to the precise determination of firing conditions is limited. Organic microfossils, which undergo easily observable physical changes with increasing temperatures in geological contexts, have the greatest potential in this respect, however there are difficulties associated with the application of these properties in archaeological ceramics (Section 9.4). Nevertheless, within the subject of firing technology, the eventual destruction of microfossils at high temperatures may be utilised, if somewhat crudely, to make simple inferences about the 'degree' of firing in ceramics (e.g. Davis 1951; Jansma 1977).

The main potential of microfossils within the subject of ceramic technology lies in the investigation of the nature and origin of clay mixing and temper in archaeological pottery. In this respect microfossils have been used to identify the mixing of two clays containing different groups of microfossils (Stilborg 1997, 230), the blending of calcareous microfossiliferous sediment with a non-calcareous base clay (Section 11.3 of the present report) and the addition of organic temper (Ayyad *et al.* 1991 and Hunt 1996). It is essential, when investigating aspects of technology in this way to analyse thin sections of archaeological ceramics, in order to support the presence of the suspected features, as microfossil specimens can be re-sedimented by natural processes and incorporated into the ceramic body during it's preparation.

11.2.4 Other aspects of pottery production and ancient societies

It may be possible to utilise microfossils in archaeological ceramics to interpret other types of information about ancient societies, including the decision making processes of potters, the seasonality of ceramic production and even information concerning agriculture. The subject of clay choice can be approached from several perspectives, including the preference of one clay over another, the utilisation of several different clay sources by sedentary potters and the changes in clay choice which take place over time. These questions have been addressed by some previous analyses of diatoms in archaeological ceramics (e.g. Jansma 1981 and Maktiskainen and Alhonen 1984), and represent a progression from the identification of potential clay sources and the technology utilised in the manufacture of archaeological pottery, towards an understanding of the ecology of ceramic production (Matson 1965) and the adaptation of populations to changing resources (Arnold 1985, 236). In making the leap from compositional and technological analyses of ceramics to the inference of more complex processes in ancient societies, it is often useful to consider ethnographic data on pottery production and to have an awareness of the factors which affect the production of pottery manufacture in the past and present.

The seasonality of pottery production and the investigation of agriculture are two potential applications of the palynological investigation of archaeological ceramics, and concern the identification of allochthonous pollen and spores in archaeological ceramics and the reconstruction of the vegetation surrounding the site of ancient ceramic production. As illustrated in Chapter 2, contaminant microfossils in archaeological ceramics can originate from many sources, however these two examples represent promising areas of new research as suggested by the work of Ayyad *et al.* (1991) on un-fired mudbricks from Egypt.

12.3 The application of specific groups of microfossils to the analysis of archaeological ceramics

Of the various types of microfossils some are more applicable to the analysis of archaeological ceramics in certain situations than others. The suitability of specific groups of microfossils for the analysis of a particular sample or group of archaeological ceramics depends upon several factors which include: its occurrence in the pottery being analysed, the inherent advantages and disadvantages of this type of microfossil in the study of ceramic micropalaeontology, the local and regional geology, the archaeological question being addressed, the nature and quantity of material which is available for analysis and the resources open to the analyst. These factors are discussed below with emphasis on the determination of ceramic provenance.

12.3.1 The occurrence of specific microfossil groups in the ceramics being analysed

Not all archaeological ceramics contain microfossils. Those which do usually possess representatives of one or two, and less commonly three or more, types of microfossils. The groups of microfossils which are present in archaeological ceramics usually determine the type of approach which can be taken, and the success of micropalaeontology in provenance analysis. For example, at the Neolithic site of Aartswould in the Netherlands, Holocene diatoms were the main group of microfossils occurring in the archaeological ceramics studied by Jansma (1984) and, as a result of the broad palaeoenviromental information which he was able to extract from the analysis of these microfossils, it was only possible to determine between local and non-local pottery at this site. On the other hand, in the analysis of pottery from the Early Minoan 'South Coast' production group at Myrtos Fournou Korifi, Crete in Section 11.2 of the present report, the detailed biostratigraphic information inferred from the assemblages of calcareous nannofossils has led to the identification of specific geological formations as candidates for the source of raw materials utilised in the manufacture of this pottery.

The groups of microfossils which occur in archaeological ceramics are determined by several factors, including the nature of the sedimentary deposits which were utilised by potters in antiquity, the technology of the ceramics (e.g. degree of firing) and other processes which can alter the microfossil assemblages in archaeological pottery (Chapter 2), as well as the representitivity of thin sections, where this is the method of analysis.

There may be substantial variation in terms of the occurrence and composition of microfossils within different ceramics, even in those which have been manufactured with similar raw materials (Section 11.2.3.5). This calls for a flexible approach in which the most useful type of information must be extracted from the most suitable group of microfossils occurring in each sample.

12.3.2 Inherent advantages and disadvantages of specific groups of microfossils for the study of ceramic micropalaeontology

The advantages and disadvantages of the various groups of microfossils in the analysis of archaeological ceramics are outlined in Figure 12.1. These are related to the success with which they can be identified taxonomically in thin sections of archaeological ceramics, their behaviour during firing and susceptibility to post-depositional alteration, as well as the precision with which they can be used to determine the geological age and palaeoenvironment of their host sediment. Calcareous nannofossils are deemed to be the most suitable group of microfossils for

Group of microfossils	Advantages	Disadvantages	Analyses
Planktonic foraminifera	- precise biostratigraphy. - abundant in calcareous marine sediments. - can survive a relatively high degree of firing.	- only present in marine sediments. - not well suited to the analysis of palaeoenvironment. - not readily identifiable to genus or species level in thin section, except during specific geological periods (e.g. Late Cretaceous) and must be isolated from ceramics for detailed analysis. - susceptible to dissolution by acidic conditions during usage and the burial of ceramics.	* Riley (1983). * MacGillivray *et al.* (1988). * Troja *et al.* (1996). ~ Stilborg (1997). * Riley *et al.* (n.d.). * Tsaila (n.d.). * this report.
Benthic foraminifera	- well-suited to the analysis of palaeoenvironment. - relatively distinctive in thin section and can be identified to genus level in many cases. - abundant in calcareous marine sediments. - can survive a relatively high degree of firing.	- only present in marine sediments. - imprecise biostratigraphy. - not readily identifiable to species level in thin section and must be isolated from ceramics for detailed analysis. - susceptible to dissolution by acidic conditions during usage and the burial of ceramics.	- Davis (1951). * Riley (1983). * MacGillivray *et al.* (1988). * Troja *et al.* (1996). * Riley *et al.* (n.d.). * Tsaila (n.d.). * this report.

Figure 12.1 Part 1. The advantages and disadvantage of the main groups of microfossils for the study of ceramic micropalaeontology, plus all previous and new analyses of each group of microfossils in archaeological ceramics. Those preceded by an (*) are important contributions to the subject, and those preceded by a (~) are less detailed analyses or a review of previous work.

Group of microfossils	Advantages	Disadvantages	Analyses
Ostracods	- relatively precise biostratigraphy and well-suited to the analysis of palaeoenvironment. - present in marine, non-marine and brackish sediments. - can survive a relatively high degree of firing.	- are virtually unidentifiable to any level in thin section and must be isolated from ceramics for detailed analysis. - less abundant than foraminifera and other calcareous microfossils and can therefore have a sporadic distribution in ceramics. - biostratigraphy can be imprecise in some environments (e.g. non-marine). - susceptible to dissolution by acidic conditions during usage and the burial of ceramics.	* Day *et al.* (1999). ~ Riley *et al.* (n.d.). * this report.
Calcareous nannofossils	- very precise biostratigraphy. - can be speciated in ceramic thin sections and may be isolated in great numbers from a small scraping. - abundant in calcareous marine sediments and can occur in great numbers in ceramics.	- only present in marine sediments. - not well-suited to the analysis of palaeoenvironment. - susceptible to contamination in antiquity and after excavation. - can be destroyed by high firing. - susceptible to dissolution by acidic conditions during usage and the burial of ceramics.	* Troja *et al.* (1996). * Quinn *et al.* (1998). * Quinn (1999). * Burnett and Young (n.d.). * this report.

Figure 12.1 Part 2. The advantages and disadvantage of the main groups of microfossils for the study of ceramic micropalaeontology, plus all previous and new analyses of each group of microfossils in archaeological ceramics. Those preceded by an (*) are important contributions to the subject, and those preceded by a (~) are less detailed analyses or a review of previous work.

Group of microfossils	Advantages	Disadvantages	Analyses
<u>Diatoms</u>	- relatively precise biostratigraphy in marine environments and well-suited to the analysis of palaeoenvironment. - present in marine, non-marine and brackish sediments. - can survive a relatively high degree of firing. - resistant to dissolution by acidic conditions during usage and the burial of ceramics.	- are obscured by the clay matrix in ceramic thin sections and must be isolated from ceramics to be studied in detail. - biostratigraphy can be imprecise in some environments (e.g. non-marine). - are generally less abundant in marine sediments than calcareous microfossils. ~ Battarbee (1988). * Stilborg (1997). * De La Fuente and Martinez Macchiavello (1997).	* Edgren (1966; 1970). * Foged (1968). * Jansma (1977, 1981, 1982, 1990). * Alhonen *et al.* (1980). * Håkansson (1982; 1997). * Matiskainen, and Alhonen (1984). * Gibson (1983a and b). * Håkansson and Hulthén (1986, 1988)
<u>Radiolaria</u>	- precise biostratigraphy. - resistant to dissolution by acidic conditions during usage and the burial of ceramics.	- are obscured by the clay matrix in ceramic thin sections and must be isolated using acids to be studied in detail.	~ Whitbread (1995).

Figure 12.1 Part 3. The advantages and disadvantage of the main groups of microfossils for the study of ceramic micropalaeontology, plus all previous and new analyses of each group of microfossils in archaeological ceramics. Those preceded by an (*) are important contributions to the subject, and those preceded by a (~) are less detailed analyses or a review of previous work.

Group of microfossils	Advantages	Disadvantages	Analyses
Dinoflagellate cysts	- precise biostratigraphy. - resistant to dissolution by acidic conditions during usage and the burial of ceramics.	- only present in marine sediments. - not well-suited to the analysis of palaeoenvironment. - are obscured by the clay matrix in ceramic thin sections and must be isolated from ceramics using highly dangerous acids to be studied in detail. - are destroyed by oxidation firing at relatively low-temperatures.	* Hunt (1996).
Pollen and spores	- relatively precise biostratigraphy. - present in marine and non-marine sediments. - resistant to dissolution by acidic conditions during usage and the burial of ceramics.	- not readily applicable to the analysis of palaeoenvironment. - are obscured by the clay matrix in ceramic thin sections and must be isolated from ceramics using highly dangerous acids to be studied in detail. - are destroyed by oxidation firing at medium and high temperatures.	* Hunt (n.d.). ~ Matiskainen, and Alhonen (1984). ~ Tsaila (n.d.).

Figure 12.1 Part 4. The advantages and disadvantage of the main groups of microfossils for the study of ceramic micropalaeontology, plus all previous and new analyses of each group of microfossils in archaeological ceramics. Those preceded by an (*) are important contributions to the subject, and those preceded by a (~) are less detailed analyses or a review of previous work.

the analysis of archaeological ceramics in the present report and have been used to identify the specific sources of raw materials used in ceramic manufacture (Sections 11.2 and 11.6), as a result of their ease of study and biostratigraphic potential.

12.3.3 The local geology

If more than one group of microfossils occur in the archaeological ceramics being analysed, a consideration of the surrounding geology is essential in determining which group will be most applicable to the determination of provenance. For example, if the local geology comprises microfossiliferous sediments formed during a short geological period under several different depositional conditions (e.g. the Holocene sediments of the Netherlands), then it may be necessary to analyse those groups of microfossils which will give a good indication of palaeoenvironment (i.e. diatoms or ostracods). Whereas if the local or regional geology contains a large stratigraphic interval of microfossiliferous sediments which were deposited in broadly similar environments (e.g. the late Neogene marine sediments of Crete), then it is advisable to concentrate on those groups of microfossils, which are most useful for biostratigraphy (i.e. foraminifera, calcareous nannofossils and dinoflagellate cysts).

Other factors which must be considered here are the availability of relevant micropalaeontological literature and the precision of local biostratigraphic zonations for specific microfossil groups.

12.3.4 The archaeological question

The type of question which is asked of micropalaeontology has a direct bearing on the suitability of the different groups of microfossils which occur in ceramics. More often than not the scientific analysis of ceramics is concerned with provenance, however, it is also possible to address questions pertaining to ceramic technology and clay choice in which case certain groups of microfossils may be more applicable than others. In the case of archaeological provenance, those microfossil groups which give a precise indication of the geological age or palaeoenvironment of their host sediment are most applicable, as this information can be used to locate potential sources of raw materials (Section 11.2 and Section 11.3: calcareous nannofossils; Jansma 1990: diatoms). On the other hand, if the question posed of micropalaeontology is ceramic technology, then other groups of microfossils, less well-suited to the determination of provenance, may be the most readily applicable. This is illustrated by the use of non-fossil pollen grains in archaeological ceramics to indicate the addition of organic temper in the work of Hunt (1996).

12.3.5 The artefact and resources

The methods of analysing the various types of microfossils which occur in archaeological ceramics vary considerably. For example, benthic foraminifera and calcareous nannofossils can be identified taxonomically in ceramic thin section, whereas diatoms, radiolaria and organic microfossils must be isolated from archaeological ceramics using complex laboratory procedures. As a result, the format of the study material (i.e. ready-made thin sections or original artefacts) and its quantity (where actual sherds are available), as well as the resources available to the analyst (laboratory equipment, chemicals, light and scanning electron microscopes) are likely to have a large influence on the group(s) of microfossils which are analysed in each case. These two factors are extremely important, as large quantities of archaeological pottery are not always available for destruction and most analysis is constrained by cost.

12.4 The relationship between micropalaeontology and ceramic petrography

Ceramic micropalaeontology, as outlined in this report, is a fusion of traditional micropalaeontological techniques with aspects of the scientific study of ceramics, including ceramic petrography. Ceramic petrography itself is a relatively recent term for a youthful subject which combines aspects of several more established techniques (mineralogy, petrography and soil micromorphology) and therefore it is very important to consider how ceramic micropalaeontology fits into this framework as well as the scientific analysis of ceramics in general.

Traditionally, ceramic petrologists have classified the microfossil specimens which occur in archaeological ceramics alongside mineral grains and rock fragments, as a type of aplastic inclusion. In their detailed petrographic descriptions of fabric groups, most analysts simply record the abundance of microfossils relative to the other components of the particular fraction in which they occur, or less frequently, indicate their size, state of preservation and the broad group of microfossils to which they belong (see discussion of Riley 1981 and Whitbread 1995 in Section 2.2). However, as indicated in the present report, this simple treatment of microfossils fails to make use of important compositional information pertaining to the geological age and palaeoenvironment of the raw materials used in the manufacture of ceramics. The detailed microfossil assemblage descriptions of archaeological ceramics which are necessary to interpret this information are not routine procedure in petrographic analysis, rather this has been the subject of infrequent detailed micropalaeontological work (Section 2.3). The reason for the simple treatment of microfossils in ceramic petrography is, of course, the extremely specialised nature of micropalaeontology.

The subject of micropalaeontology has long been separate from the rest of palaeontology, perhaps because of the necessity for the use of a microscope, and certainly as a consequence of the intense growth of the former which resulted from its connection with oil exploration. The explosion which occurred within micropalaeontology as a result of the discovery and application of its precise biostratigraphic and correlative potential, served to isolate the subject from many other related disciplines, such as palaeobiology, and has had a detrimental effect on the subject (Lipps 1981). The very nature of this highly specialised subject serves to isolate its practitioners “in a blanket of systematics, biostratigraphies, and terminologies, and as a result discourages outsiders with other viewpoints or contributions from utilising its fine fossil record” (Lipps, 1981, p. 167). However, the rapid growth of micropalaeontology, especially in the later part of this century has also resulted in intense specialisation *within* the subject, so that many micropalaeontologists mainly concentrate on a single group of microfossils from a specific geological period .

It is therefore hardly surprising that there has been very little routine application of micropalaeontology in the scientific analysis of archaeological ceramics. The subject is perhaps too specialised and rapidly changing to be adopted by archaeological scientists. In addition, most micropalaeontologists themselves have been too busy describing new taxa, refining biostratigraphies and concentrating on geological problems within their chosen group of fossils and part of the geological column to cross disciplinary boundaries and address archaeological questions.

Unfortunately, micropalaeontology may always remain relatively inaccessible, even to those archaeologists with a general geological background and experience in ceramic petrography. It is not that it would be impossible for archaeological scientists to obtain the basic skills which would allow them to analyse microfossils, but rather that the time involved would be too great, and the knowledge of what to study and how to study it requires some experience. For a micropalaeontologist to apply his or her knowledge to the study of ceramics, on the other hand, is a little easier. Many micropalaeontologists are trained in other aspects of geology, including mineralogy, igneous, sedimentary and metamorphic petrography, as well as sedimentology and field geology, so that adapting to the scientific analysis of ceramics would be a matter of applying these fundamental skills in a slightly different manner. It is of course important not to underestimate the differences between the study of ceramics and that of geological materials, which is exemplified by the limited interpretations of some micropalaeontological analyses of archaeological pottery (e.g. Jansma 1977; Troja *et al.* 1996).

In general, very few micropalaeontologists are prepared to cross disciplines in this way, so that the detailed analysis of microfossils in archaeological ceramics has taken place so far by way of infrequent collaborations between scientists from the two subjects. This approach can work, as indicated by the promising results of previous analyses such as Riley *et al.* (n.d.) however it does not serve to *integrate* micropalaeontological analysis within the study of ceramics.

Without individual cross disciplinary investigations into their occurrence and utility for the analysis of ancient pottery, microfossils in ceramics may continue to be paid little attention. However, archaeological scientists can be made aware of the information which may be retrieved from an evaluation of this type of inclusion, e.g. how to recognise the main groups of microfossils, what environments they are indicative of, how and how not to use them in classifying ceramics. This task and indeed the future of ceramic micropalaeontology belongs to the micropalaeontologists rather than archaeologists, and it is the former who should be accountable for providing information and examples useful to scientists from other disciplines that encounter microfossils.

In order that collaborations between archaeologists and micropalaeontologists are successful, the former must "provide samples and information that will maximise the utility of the analytical data" and the latter should "not be kept in the dark about archaeological problems, objectives, and provisional findings" (Bishop *et al.* 1982, 278). In effect, both should understand each others assumptions and interpretations (Riley 1982).

12.5 Ceramic production, distribution and the potential of ceramic micropalaeontology in the Crete and the Mediterranean

12.5.1 Introduction

In the five case studies which are presented in Chapter 11, micropalaeontology has been used to address several questions pertaining to the provenance and technology of archaeological ceramics from the Aegean and elsewhere in the Mediterranean. It is now necessary for us to consider this information in terms of the overall potential which micropalaeontology has to offer the scientific analysis of ceramics in this region and the way in which it can be used to further the interpretations based upon more conventional techniques.

12.5.2 Macroprovenance - Crete versus the rest of the Aegean and Mediterranean

As a result of the repetition of contemporaneous geological units and the cosmopolitan distribution of microfossils within the Aegean and the Mediterranean, micropalaeontology alone has little potential for the determination of macro-scale provenance in this area. In favourable circumstances, micropalaeontology can be used to discriminate between two or more geographically isolated potential source areas of ceramic production identified on the basis of archaeological evidence or other compositional techniques. This is illustrated by Riley *et al.*'s (n.d.) analysis of foraminifera in Late Bronze Age wheel-made decorated ware from Trebisacce (Section 2.3.2.3). In this study, the biostratigraphic interpretation of foraminifera in thin section and its comparison with the distribution of geologically contemporaneous sediments was used to indicate that the ceramics were not compatible with a Cretan origin as suggested by their high technological quality, fine decoration and clear Aegean motifs, but may have been locally produced. Likewise, simple comparisons of ostracod specimens in thin sections of archaeological ceramics have been used to address very specific macro scale provenance questions formulated by pottery typology and petrography in the present report (Section 11.5; Day *et al.* 1999). In essence, the potential of micropalaeontology for the determination of ceramic macroprovenance in the Mediterranean lies in its application, alongside other information which narrows the geographical range of the study.

12.5.3 Meso- and microprovenance - provenance within Crete and the identification of specific sources of raw materials within suspected production areas

Within Crete, early provenance interpretations sought to distinguish between the pottery originating from different broad regions, e.g. Jones' three chemical composition zones (1986, 460-461). More recently, the application of thin section petrography to ceramic analysis in this area has refined the scale with which pottery can be provenanced (Day 1988; 1995b) by identifying smaller production areas (e.g. Whitelaw *et al.*'s (1997) three geographically isolated ceramic traditions occurring in the EM IIB assemblage of Myrtos Fournou Korifi; Figure 11.1). On Crete, micropalaeontology is much less suited to the determination of these zones or production areas than chemistry and petrography, due to the occurrence of similar stratigraphic intervals of microfossiliferous late Neogene marine strata in the various sedimentary basins which exist within the block-faulted pre-Neogene backbone of the island (Chapter 4). As a result of the differential tectonic movement of this basement during the Middle to Late Miocene and Early Pliocene, some differences do exist between the autochthonous geological successions in various regions of Crete, however, these are mainly in the form of palaeoenvironment and as such are not well-suited to the biostratigraphic approach to ceramic provenance which has been outlined in the present report.

To exemplify this point it is necessary to compare the micropalaeontological analysis of pottery from the Early Minoan 'South Coast' pottery production group excavated from Myrtos Fournou Korifi (Section 11.2) with that of the contemporaneous Dark Faced Incised Ware pyxides from Knossos in north-central Crete. The biostratigraphic interpretation of foraminiferal and calcareous nannofossil assemblages in individual samples from these two groups of pottery indicated that they were manufactured with a component of calcareous Early Pliocene marine sediment. However, on the basis of this information alone it is not possible to distinguish between the provenance of these two groups of pottery, as comparable microfossiliferous Early Pliocene marine sediments occur in both areas, as well as numerous other parts of Crete. Such separation *was* possible with other techniques of analysis.

The value of micropalaeontology as a provenance tool for archaeological ceramic analysis on Crete lies in its application to micro-scale problems, such as the identification of the specific geological deposits, utilised within a general area (e.g. a pottery production centre) which has been identified by other techniques of analysis. Turning again to the South Coast pottery from Myrtos Fournou Korifi (Section 11.2), the detailed analysis of micropalaeontological assemblages within the framework of Whitelaw *et al.*'s (1997) petrographic interpretation has permitted the identification of the exact geological formations used in the manufacture of some of these ceramics. In this way, micropalaeontology has the potential to refine the scale of ceramic provenance interpretation on Crete beyond that which is capable using chemistry and petrography alone (i.e. zones or production centres) and suggest the exact choice of raw materials made by ancient potters.

12.5.4 Clay choice and technology of Minoan pottery production

In the Myrtos Fournou Korifi case study described above and presented in Section 11.2, the microprovenance interpretation afforded by the biostratigraphic information of calcareous microfossil assemblages has indicated that the potters working at or close to this site are likely to have utilised at least two sources of raw materials occurring in the local area, including the microfossiliferous marine sediments of the Ammoudares and Myrtos Formations. Similarly, in the analysis of the Dark Faced Incised Ware pyxides from Knossos (Section 11.3), the calcareous microfossil assemblages of this pottery are geologically contemporaneous with marine deposits occurring in close proximity to their site of excavation (i.e. the calcareous marls of the Finikia Formation). The utilisation of local sources of raw materials which is suggested by the Myrtos example (Section 11.2) is very significant as it agrees with the ethnographic observations of Arnold (1976) and the view of ancient ceramic production presented by other workers such as Bishop *et al.* (1982, 277), who stated that "the bulky materials used in fabricating pottery- the clay and temper -are not likely to have been obtained from a distant location in preindustrial societies", in addition to the analysis of siliceous microfossils from Neolithic pottery in north-west Europe (Jansma 1977).

In both of these examples, the microfossil assemblages in some of the ceramics which were analysed could be linked biostratigraphically with highly calcareous marine deposits of Early Pliocene age. However, direct field observations in Day (1989, 142) and the present report indicates that this material is not well-suited to the production of ceramics as it "works poorly and sometimes breaks up on experimental firing". Day's (1989) opinion that these sediments of the Knossos area may not have been utilised by ancient potters working in this area also conflicts with the micropalaeontological analysis of archaeological ceramics from the site by Riley *et al.* (n.d.), who discovered Early Pliocene foraminiferal associations in thin sections of fine wares from LM IA to LM IIIB and linked these with specific exposures in the neighbourhood of Iraklion.

Nevertheless, the interpretation of ceramic technology which has been afforded by the analysis of microfossils in Knossian ceramic thin sections in the present report (Section 11.3), indicates that the Early Pliocene material in the north-central Cretan area, as well as that occurring in the vicinity of Myrtos Fournou Korifi (the Myrtos Formation) may have been used as a raw material for ceramic manufacture, by their admixture with a less calcareous base clay. Neither Day (1989) or Riley *et al.* (n.d.) considered this possibility, which is indicated by the occurrence of comparable microfossil assemblages within the clay micromass, highly calcareous inclusions and areas of incomplete clay mixing. The practise of tempering a non-calcareous clay with calcareous sediment, which accounts for the conflicting interpretations of Day (1989) and Riley *et al.* (n.d.) has also been indicated by the petrographic analysis of pottery from the Gulf of Mirabello (Day 1991) and its subsequent micropalaeontological analysis in the present report (Section 11.4), as well as some vessels from the EMI Well at Knossos (Day pers. comm.).

12.6 Scope for further study

This thesis has detailed the potentials and limitations of micropalaeontology as a tool for the investigation of the provenance and technology of archaeological ceramics, and as such provides a clear foundation for further research. Several notes of caution have been sounded regarding the limitations; but positive ways of approaching them have also been highlighted. The various case studies which are presented illustrate the very positive role which micropalaeontology can fulfil, alongside other more conventional techniques of compositional analysis, in presenting a picture of ceramic production and distribution in the Bronze Age and later archaeological periods of the Aegean. In addition, there is good reason to be optimistic also about the role of micropalaeontological analyses of archaeological ceramics in other areas of the world, where indeed there is often a longer-lived tradition of such work.

It emerges from this critical review that a flexibility in the types of microfossils studied, the approach taken, and the method of application of these techniques is necessary. The key to success appears to be clear communication and the full integration of both personal expertise and sets of data.

Further applications of micro and nannopalaeontology to major archaeological assemblages from Crete, which have been studied in full in terms of typology, chemistry, mineralogy and microstructure, have already commenced. Although the demands for the successful application of micropalaeontological techniques to archaeological ceramics are not insubstantial, we may look forward with optimism to a more routine application of the techniques developed in this thesis for application in the archaeology of the Mediterranean.

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Appendix I Review of calcareous nannofossil taxa

AI.1 Introduction

The following section reviews the range, biometry and variations in abundance, of several calcareous nannofossil taxa including *Calcidiscus, Coccolithus, Geminilithella, Gephyrocapsa, Helicosphaera, Pontosphaera, Pseudoemiliania, Reticulofenestra, Rhabdosphaera, Scyphosphaera, Sphenolithus* and *Umbilicosphaera.* This has been achieved by utilising available literature on Neogene Mediterranean calcareous nannofossils, and important studies from extra-Mediterranean areas, in order to determine how they may used as a means of supplementing the more conventional marker species for this period.

AI.2 *Calcidiscus* Kamptner 1950

The two members of the genus *Calcidiscus* which occur in the late Neogene are differentiated primarily by size. *Calcidiscus leptoporus* (Murray and Blackman 1898) Loeblich and Tappan (1978) is the smaller and *Calcidiscus macintyrei* (Bukry and Bramlette 1969) Loeblich and Tappan (1978) is the larger. Both species have first occurrences (FOs) within the Early Miocene zone NN 4 (Theodoridis, 1984). Forinanciarri *et al.* (1990) assigned *C. macintyrei* a FO in the middle Miocene zone NN 7 of the western tropical Indian Ocean, however, this may be due to a different size definition used for the species, or a consequence of the strong diachroneity of its FO at various locations in the Indian Ocean (Knappertsbuch 1989).

Both species are consistent components of calcareous nannofossil assemblages throughout the late Neogene until the latest Pliocene to earliest Pleistocene, when the larger variety (*C.macintyrei*) becomes extinct, leaving *C. leptoporus*, which continues until the present day. The LO of *C. macintyrei* is the only useful stratigraphic datum provided by the genus *Calcidiscus* in the late Neogene. However, its position varies due to the "different taxonomic concepts used by various authors" Rio *et al.* (1990, 526). Janin (1981), Driever (1988), Rio *et al.* (1990) and Young (1991) all defined *C. macintyrei* as those specimens of *Calcidiscus* which are >10μm in size, whereas Forinacciari *et al.* (1990) and Gartner (1992) restricted *C. macintyrei* to coccoliths >11μm, and Raffi and Rio (1979) used an even larger size definition of 13-14μm. Despite these differences, the LO of *Calcidiscus macintyrei* can be consistently placed slightly above the Plio-Pleistocene boundary. It is an isochronous event occurring over widely separate geographical areas (Backman and Shackleton 1983), and can be used to approximate the Plio-Pleistocene boundary where discoasters are rare (Bizon and Müller 1977; Müller 1978). The extinction of *C. macintyrei* is isochronous across the Mediterranean (Bizon and Müller 1977), but may be less reliable as a marker in on-land sections "owing to reworking and its irregular distribution" Raffi and Rio (1979, 141). In the Plio-Pleistocene Mediterranean zonation scheme of Driever (1988), which is utilised in the present report, the LO of *Calcidiscus macintyrei* (>10 μm), based upon 10,000 specimen counts, defines horizon m1, which subdivides subzones NN 19A and NN 19B in the Early Pleistocene (Figure 5.23).

Theodoridis (1984) working in the Mediterranean, identified a third species of Calcidiscus; *Calcidiscus premacintyrei* (syn. *Calcidiscus leptoporus centrovallis* Stradner and Fuchs 1980) Perch-Nielsen (1985b). This "moderate to large elliptical form with a large elliptical centre whose rim can be focused clearly" (Gartner 1992, 330) is considered to be a useful biostratigraphic marker and Theodoridis established its Mediterranean range as mid NN 4 (*Helicosphaera obliqua* subzone) to mid NN 6 (*Helicosphaera orientialis* subzone). Despite being defined on purely qualitative criteria *Calcidiscus premacintyrei* is a useful datum in Miocene biostratigraphy.

More elaborate subdivisions of the genus *Calcidiscus* have been proposed, based upon the number of elements in the distal shield and the ratio between the size of the central opening and the distal shield, in addition to overall size (e.g. Janin 1981; Perch-Nielsen 1985ba). However, these schemes are impractical for use in the light microscope and the ranges of the different 'varieties' or 'subspecies' are poorly defined.

AI.3 *Coccolithus* Schwarz (1894)

Another member of the family Coccolithaceae which is present consistently in late Neogene calcareous nannofossil assemblages from the Mediterranean, and the samples of archaeological ceramics which are analysed in the present report, is the type genus *Coccolithus*.

Originally represented by one long-ranging species in the Neogene (*Coccolithus pelagicus*), this genus has since been morphometrically subdivided into three or more species, including *Coccolithus miopelagicus* (Bukry 1971), *Coccolithus pliopelagicus* (Wise 1973) and *Coccolithus pelagicus* s.s. (Wallich 1877) Schiller (1930). Although tentative ranges have been assigned to these different 'species' (Gartner 1992; Perch-Nielsen 1985bb), few have been utilised in published Neogene biostratigraphic schemes from any part of the world, and are likely to be "somewhat artificial ... and might be better thought of as populations or races" Gartner (1992, 325).

Backman (1980), using biometric data from the north Atlantic ocean rejected *Coccolithus pliopelagicus*, which cannot be distinguished from *C. pelagicus s.s.*, but retained the label *C. miopelagicus* for very large specimens of *Coccolithus* (>13μm). *Coccolithus miopelagicus* is the only Neogene 'species' of *Coccolithus* which has been used for biostratigraphy, having a sporadic range from the base of the Miocene or earlier, to somewhere in the Mid-Late Miocene (Perch-Nielsen 1985b). Gartner (1992) defined the last common occurrence of *Coccolithus miopelagicus* as occurring at 10.4 MA (NN 8) at DSDP site 608 in the north Atlantic. This is in general agreement with the data of Peleo-Alampay (1995) who assigned *C. miopelagicus* a LO of between 10.6 and 10.8 MA (late NN 7 and NN 8) in low-latitudes, as well as with that of Ellis (1979) working in the eastern Mediterranean, who implied a LO in zone NN 8 or above (deciphered from the description of zonal assemblages).

Other events in the Neogene record of *Coccolithus* which may well be useful for biostratigraphy, are the occurrence of Pliocene forms "with a small bridge across the central opening which is aligned with the minor axis" Backman (1980, 11), and the drastic decrease in abundance of *Coccolithus pelagicus* close to the LOs of *Calcidiscus macintyrei* and *Discoaster brouweri* around the Plio-Pleistocene boundary, as reported by Raffi and Rio (1979) and Müller (1990) from the western Mediterranean.

As with other highly variable Neogene coccolith groups, such as the reticulofenestrids (Section AI.8), the overall size, central opening diameter and degree of roundness or ellipticity of *Coccolithus* may be strongly affected by ecological conditions (Baumann 1995), so that a large range of morphologies may exist between the somewhat arbitrarily defined end members. This intraspecific variation may explain the rare occurrence of round *Coccolithus* specimens, labelled as *Coccolithus formosus* (Kamptner 1963) Wise 1973, in some samples from this report (Appendix 2), which would otherwise be attributed to reworking from the Palaeogene.

AI.4 *Geminilithella* Backman (1980) and *Umbilicosphaera* Lohman (1902)

AI.4.1 *Geminilithella*

The small, round, dark specimens of this genus can easily be overlooked under the light microscope, especially in XP, however, they are present consistently, in low numbers, throughout much of the Neogene. The two Neogene species of *Geminilithella*; *Geminilithella rotula* (Kamptner 1956) Backman (1980) and *Geminilithella jafari* (Müller 1974) Backman (1980) have Mediterranean FOs in late NN 2 and NN 3 respectively, according to Theodoridis (1984), who used the FO of the former as a datum in the lower part of his Mediterranean Miocene zonation.

The upper extent of the species' ranges are however less well established as the genus *Geminilithella* evolves into the *Umbilicosphaera sibogae* group of coccoliths somewhere in the Late Pliocene or Early Quaternary. *Geminilithella rotula* may have a LO in the latest Zanclian (Müller 1978, Mediterranean DSDP leg 42A) or earliest Piacenzian (Backman 1980, north Atlantic DSDP site 116) and *G. jafari* appears to range through the Neogene to the present day (Müller 1978). Therefore, the disappearance of *Geminilithella rotula* at somewhere around the Early/Late Pliocene boundary as well as the almost synchronous appearance of both species of *Geminilithella* in late NN 2 or NN 3, may be useful for biostratigraphy where they are recorded.

AI.4.2 *Umbilicosphaera*

Umbilicosphaera is another small, dark, member of the Coccolithaceae family which ranges throughout much of the Neogene. The species of this genus are not dealt with in any detail by biostratigraphers of the Mediterranean Neogene, but rather lumped together as *Umbilicosphaera sibogae* (Weber-van Bosse 1901) Gaarder (1970) (syn. *Umbilicosphaera mirabilis* Lohmann 1902), with a range beginning somewhere in the Miocene and continuing until the Recent (Müller 1978; 1990; Ellis 1979). However, several other species and a subspecies of the generotype *Umbilicosphaera sibogae*, have been proposed by various authors, based upon the ellipticity of the coccoliths and the central opening. Perch-Nielsen (1985b) indicated tentative ranges for these.

Because of the lack of information on the ranges of the various *Umbilicosphaera* species in the Mediterranean and its low abundance and sporadic occurrence in the samples of archaeological ceramics which are analysed in the present report, this genus is not here considered to be very useful for biostratigraphy and all specimens are grouped together as *Umbilicosphaera spp.* (Appendix II).

AI.5 *Gephyrocapsa* Kamptner (1943)

Some years ago it was believed that 'reticulofenestrid' coccoliths with a distinct bridge (*Gephyrocapsa*), were restricted to Pleistocene and Holocene sediments (Raffi and Rio 1979; Perch-Nielsen 1985b). However, very small representatives of this genus, which can be easily overlooked with the light microscope, appear in the Pliocene. All specimens of *Gephyrocapsa* which occur before the FO of *Gephyrocapsa carribeanica* (Early Pleistocene) are small, and despite some variation in overall size, the size of the central opening and the angle of the cross-bar (Rio 1982), they are all included in 'small *Gephyrocapsa sp.*'. In Gartner's (1977) subdivision of the Gephyrocapsids for the light microscope, his 'small gephyrocapsae' group is restricted to all specimens < 3.5μm in diameter; this definition has been followed by subsequent authors such as Rio (1982), Raffi and Rio (1979), Rio *et al.* (1990) and Young (1991). Nevertheless, as most Pliocene members of the genus fall within this size range, the subdivision is not required until the arrival of larger Gephyrocapsids, in the Pleistocene.

The first occurrence of the genus *Gephyrocapsa* (i.e. FO small *Gephyrocapsa sp.*) is thought to have taken place somewhere in the Lower Pliocene (Zanclian), however, its exact position is not often agreed upon. The earliest recorded occurrence of Gephyrocapsids in the Mediterranean, is in the Late Miocene of the Cappella Montei section in southern Italy where Bonci and Radrizzani (1992), claimed to have discovered a few small reticulofenestrids with a marked bridge, in the upper part of their section (early NN 12). Whilst Miocene occurrences of small-sized *Gephyrocapsa* specimens are also reported by Jiang and Gartner (1984) and Pujos (1985), from the

Middle Miocene of the southern Atlantic and central equatorial Pacific respectively, the observations of Bonci and Radrizzani (1992) are not in agreement with other Mediterranean studies, and as such they may be the result of sample contamination. In the Mediterranean Pliocene, small Gephyrocapsids are reported to appear in zone NN 13 (Dermitzakis and Theodoridis, 1978: Koufonisi Island, Crete; Müller, 1978: DSDP site 378, Aegean sea; Driever, 1988: Crete and Sicily; Frydas, 1990: S.W. Peleponnese; Müller, 1990: ODP site 654A, Tyrrhenian sea), NN 14 (Pirini Radriziani and Valleri, 1977: Tyrrhenian sea; Lohman and Ellis, 1981: eastern Mediterranean), NN 15 (Rio, 1982: Mediterranean DSDP material), and as late as NN 18 (Raffi and Rio, 1979: DSDP site 132, Tyrrhenian sea).

The evolution of *Gephyrocapsa* from *Dictyococcites* may be a gradational event (sensu Young *et al.* 1994), and is not isochronous between the open-ocean and the Mediterranean. However, it appears that small gephyrocapsids first occur in the Mediterranean, somewhere in the middle Zanclian, and as such this event, though gradational, may be useful for Lower Pliocene biostratigraphy, in the absence of *Ceratolithus rugosus*, *Amaurolithus spp.* and *Discoaster asymmetricus,* which are used in the standard zonations. In his quantitative study of Pliocene calcareous nannofossils from Crete and Sicily, Driever (1988) used the first rare occurrence of *Gephyrocapsa* in 200 counts of 'reticulofenestrid coccoliths' to define horizon n2, which divides subzones NN 12-13B and NN 12-13C of his Pliocene biostratigraphic scheme (Figure 5.23). Gephyrocapsids then increase in abundance through NN 12-13C, and become common to abundant by subzone NN 14-15A, after which larger specimens (up to 4 μm) may appear, and are present until early NN 16-17B, when they become less abundant before a short acme in NN 16-17D, the beginning of which (horizon n7) defines the base of this zone. This detailed, quantitative approach to the study of gephyrocapsids in the Pliocene has revealed several other useful events in the size and/or abundance of the genus as well as providing an overall pattern for the late Neogene history of small gephyrocapsids, which can be used as a semi-quantitative means of confirming age assignments made using other taxa.

Below horizon n2 (NN 12-13B/C boundary) Driever (1988) indicated that Gephyrocapsids may have already been present in the Mediterranean Pliocene, but only for a short period (c. 0.1 MA) and in very low numbers (not scoring in his 200 specimen counts). In this interval before the true appearance of the genus (i.e. in the late part of subzone NN 12-13B), Driever (1988, 163) reported that "a thickening of the collar which is reminiscent of the cross-bar of gephyrocapsids" is a feature of some very small reticulofenestrids. These specimens may represent transitional or primitive forms in the evolution of *Gephyrocapsa* from small *Dictyococcites* (*Dictyococcites productus*) and have also been seen by Müller (1978) at DSDP site 378 in the Aegean sea and Gartner (1992) at DSDP site 608 in the North Atlantic, as well as in the present report. As such, these *D. productus*/small *Gephyrocapsa sp.* transitional specimens where present, are a useful marker for Lower Pliocene biostratigraphy, when applied in association with other evidence.

AI.6 *Helicosphaera* Kamptner (1954)

The various species of *Helicosphaera* and their ranges in the Lower to Middle Miocene of the Mediterranean have been well established and utilised as subzonal markers by Theodoridis (1984), in his Mediterranean Miocene zonation. In the latest

Miocene and most of the Pliocene, however, helicosphaeras are much more evolutionary conservative, and only a few species represent the genus.

The long-ranging, extant species *Helicosphaera carteri* (Wallich 1877) Kamptner (1954), has been subdivided by Theodoridis (1984), into several sub-species; *Helicosphaera carteri carteri*; *Helicosphaera carteri burkei*; *Helicosphaera carteri wallichi*. However, the stratigraphic distribution of these are not well established and he considers them to be present throughout the entire range of the *H. carteri* group (Early Miocene to Recent). Theodoridis named the member of this group which possesses two small pores, offset from the central area, *Helicosphaera palaeocarteri* but in his systematic description of *H. palaeocarteri* he commented that it "ranges throughout the Miocene and most of the Pliocene" (1984, 131), in which case it may perhaps be better classified as another subspecies of *Helicosphaera carteri.*

The distinctive Oligocene and Miocene helicolith, *Helicosphaera intermedia* Martini (1965), which has a large low-angle sigmoidal bar, has been found to occur consistently in the Mediterranean, as high as the *Discoaster hamatus* subzone (early NN 9) by Theodoridis (1984). In addition, this author found rare specimens occurring as high as late NN 11 (*Calcidiscus leptoporus* zone) in Sicily. A latest Miocene Mediterranean occurrence for *Helicosphaera intermedia* has also been reported by Negri (pers. comm.), however, de Kaenel (pers. comm.) working on the western Mediterranean ODP Site 161, found the species in the Early Pliocene until about 4.07 Ma (NN 15).

Some authors, including Aubry (1990) and Perch-Nielsen (1985b) have identified a second Late Miocene helicosphaera with an optically discontinuous bridge;

Helicosphaera rhomba Bukry (1971), which is distinguished from *H. intermedia* by having a larger, non-sigmoid bar. The discrepancies between the ranges of *Helicosphaera intermedia* given by various authors may be due to the confusion between this species and *Helicosphaera rhomba* (Denne pers. comm.). In the present study all late Neogene helicosphaeras with an optically discontinuous, diagonal bridge are referred to as *Helicosphaera intermedia* and have been found in both Late Miocene and Early Pliocene geological samples.

The most biostratigraphically important *Helicosphaera* species in the Pleistocene of the Mediterranean is *Helicosphaera sellii* Bukry and Bramlette (1969). This species' LO is a "strong stratigraphic signal" (Rio *et al.*, 1990, 526), occurring in the early part of zone NN 19, between the LO of *Calcidiscus macintyrei* and the temporary disappearance of large (> 4 μm) Gephyrocapsids (i.e. the beginning of the acme of small *Gephyrocapsa*). This was dated by Gartner (1977) as 1.2 MA. The FO of this species, however, is not so well agreed upon. Perch-Nielsen (1985b) indicated that *H. sellii* originates in the Mid to Late Miocene at about 10 MA; this is supported by the observations of Haq (1973). However, Rio *et al.* (1990) found *H. sellii* to be absent until the Early Pliocene, near the boundary of zones NN 12 and NN 13, and close to the last common occurrence of *Amaurolithus spp.* in the Tyhrrenian sea, where they used it as a marker. This late appearance of *H. sellii* is considered to be a migration event by Rio *et al.* (1990) and occurs at the same time in the nearby on-land section of Cappo Rosello, Sicily. The question is, whether *H. sellii* also appears at a similar time in the eastern Mediterranean (i.e. whether the migration seen by Rio *et al.* (1990) in the Early Pliocene of the western Mediterranean is a migration within the Mediterranean, or from the open-ocean to the Mediterranean). In the range charts and assemblage descriptions of Bukry (1973), Müller (1978) and Ellis (1979) there appears to be no evidence for a Miocene occurrence of *H. sellii* in the Mediterranean. Theodoridis (1984) in his reassessment of the genus *Helicosphaera* stated that *H. sellii* is present from the Late Miocene. However, he did not specify from which zone this species ranges, or indicate its occurrence in his Miocene range charts. By analysing his data from the Late Miocene sections of Kastelli, Skouloudhiana, Kastelli and Vasiliki, it is possible to see that Theordoridis (1984) did not record this species on Crete. In which case it may be possible that *H. sellii* did not occur in the Mediterranean Miocene, but migrated into this area at sometime during the Pliocene, perhaps at about the same time as the disappearance of *Amaurolithus spp.*, as suggested by Rio *et al.* (1990). In this case it may be possible to use the presence of this species in conjunction with other evidence, to indicate a Pliocene date for samples. If *Helicosphaera sellii* was absent in the Mediterranean Miocene, and migrated from the open-ocean in the Early Pliocene, then its FO in the eastern Mediterranean may be in NN 13 or later, assuming that the migration was from west to east.

AI.7 *Pseudoemiliania lacunosa* (Kamptner, 1963) Gartner (1969)

Round and elliptical reticulofenestrid coccoliths which have slits between the elements of their outer cycles are placed in the genus *Pseudoemiliania*. There exists continuing nomenclatural controversy regarding the taxonomy of these coccoliths. The main arguments have centred around whether reticulofenestrids with slits should be attributed to variation within the genus *Reticulofenestra* (Young 1990), the genus

Emiliania (Bukry 1973; Ellis 1979; Driever 1988) or retained in a separate genus *Pseudoemiliania* (Schmidt 1973; Dermitzakis and Theodoridis 1978; Müller 1978; Raffi and Rio 1979; Backman 1980; Rio *et al.* 1990; Negri *et al.* 1991; Young 1991; Young *et al.* 1994).

Another point of contention, is whether or not such specimens should be subdivided into two species; one to include larger, circular forms with many slits (*Emiliania annula* Bukry 1973 syn. *Reticulofenestra lacunosa lacunosa* Young 1990) and the other encompassing the smaller, elliptical forms with less slits (*Emiliania ovata* Bukry 1973 syn. *Reticulofenestra lacunosa ovata* Young 1990). In the present report, the view of Backman (1980) and others has been adopted; that all late Neogene reticulofenestrid coccoliths with slits (but not 'I' or 'T'-shaped elements as in *Emiliania*) in their outer shields, whether large, small, round or elliptical should be included in the taxonomic concept of *Pseudoemiliania lacunosa.*

The FO of *Pseudoemiliania lacunosa* is not particularly well established in the Mediterranean, perhaps due to the ease with which early representatives of this species can be confused with medium sized reticulofenestrids (*Reticulofenestra minutula*) Rio *et al.* (1990). One of the earliest reports of this species in the Mediterranean is by Schmidt (1973), working on land sections from the southern Aegean. He recorded the FO of *P. lacunosa* in his *Discoaster surculus* interval zone (NN 16). Bukry (1973) studied material from DSDP leg 13 and recorded the first reticulofenestrids with slits in the *Discoaster pentaradiatus* subzone (NN 17). He also noted that they increase in abundance through the overlying *Calcidiscus macintyrei* subzone (NN 18). Ellis (1979), in his eastern Mediterranean calcareous nannofossil zonation scheme, indicated a similar range for *P. lacunosa* (NN 16-NN 19/20), whereas Müller (1978), Raffi and Rio (1979) and Rio *et al.* (1990) reported that its FO takes place just below the LO of *Reticulofenestra pseudoumbilica*, in the western Mediterranean.

There may well be some inter-Mediterranean diachroneity in the FO of *P. lacunosa*, as this species has been found in the eastern Mediterranean "far below the extinction of large forms of *Reticulofenestra pseudoumbilica*" in NN 13 by Dermitzakis and Theodoridis (1978, 639): Koufonisi island, in NN 14 by Müller (1978): DSDP sites 378 and 378A (Aegean sea), and as low as the earliest part of NN 13 by Driever (1988) in Cretan sections. The latter author documented the quantitative distribution of *Pseudoemiliania lacunosa* specimens (which he grouped together as *Emiliania ovata*), throughout the Pliocene and revealed that their first rare occurrence (in counts of 200 reticulofenestrid coccoliths), takes place at the boundary between nannofossil zones NN 12 and NN 13 (horizon n1: NN 12-13A/B boundary). These coccoliths then increase in abundance at n2 (NN 12-13 B/C boundary; mid NN 13), close to the first rare occurrence of small *Gephyrocapsa sp.* and the size increase of *R. pseudoumbilica.*

Driever (1988) also documented the appearance of elliptical morphotypes of this species, occurring in NN 14-15B; a trend which is continued in the Pleistocene (Young 1991) prior to the extinction of *Pseudoemiliania lacunosa* at around 0.5MA. This event is commonly used to define the boundary between nannofossil zones NN 19 and NN 20. In the present report the FO of *P. lacunosa* in zone NN 13 has been used for biostratigraphy, however it was not possible to utilise the changes in the shape and relative abundance of this species which Driever (1988) outlines, due to its low abundance in the calcareous nannofossil assemblages.

AI.8 'Reticulofenestrid' coccoliths

AI.8.1 Introduction

The late Neogene representatives of the coccolith family Noelaerabdaceae (Jerkovic 1970): *Reticulofenestra* Hay *et al.* (1966), *Dictyococcites* Black (1967); *Gephyrocapsa* Kamptner (1943); *Pseudoemiliania* Gartner (1969) and *Emiliania* Hay and Mohler *in* Hay *et al.* (1967) are often informally referred to as the 'reticulofenestrid' coccoliths (Young 1989; Young *et al.* 1997). These coccoliths dominate calcareous nannofloras from the Late Miocene to the Pleistocene of the Mediterranean, as well as being the most common component of the nannofossil assemblages in the archaeological ceramics which are analysed in the present report (Appendix II). Their continuous 'background' occurrence in the late Neogene, which can be likened to that of the family Watznaueriaceae during the Upper Jurassic and Cretaceous, is the result of a high abundance in the original nannoflora and their resistance to diagenesis (Young 1990).

The late Neogene reticulofenestrid coccoliths exhibit a large variation in diameter, size of the central opening, size of the collar cycle, overall shape (i.e. degree of roundness), the development of a bridge or bar across the central area, as well as the number of slits between the elements of the outer cycles. This 'plexus' has been subdivided into numerous genera and species (see Gallagher 1989 or Pujos 1987 for a review) which are often poorly defined, synonymous and extremely confusing to the

Species name	Shape	Central area	Overall size
Reticulofenestra minuta	elliptical	open	up to 3.5 μm
Reticulofenestra minutula	elliptical	open	3.5-5 μm
Reticulofenestra pseudoumbilica	elliptical	open	> 5 μm
Reticulofenestra p. rotaria	circular	large open	5-7 μm
Dictyococcites productus	elliptical	closed	up to 4.5 μm
Dictyococcites antarcticus	elliptical	closed or pore	> 4.5 μm

Figure AI.1 Key to 'reticulofenestrid' coccoliths without a cross bridge or slits identified in late Neogene assemblages in the present report.

light microscope user. The presence of a cross-bar or slits in the outer cycle of reticulofenestrid coccoliths are the characteristics which define the species of *Gephyrocapsa* and *Pseudoemiliania/Emiliania* respectively; both of which are biostratigraphically useful in the Lower Pliocene, and are not discussed in this section but dealt with elsewhere (Sections AI.5 and AI.7).

The various genera and species of late Neogene reticulofenestrids without a cross-bar or slits (i.e. the species of *Reticulofenestra*, *Dictyococcites* and their various synonyms), have been defined somewhat arbitrarily using quantitative parameters (overall size and size of the central opening) as well as subjective, qualitative means (degree of roundness, central area pore or slit) by many authors such as Backman (1980), Flores (1985), Young (1990), Gartner (1992) and Takayama (1993).

There has been much debate over the validity of these subdivisions of late Neogene reticulofenestrid coccoliths, and whether the so-called species, subspecies and variants represent actual genotypic variation, ecological control or a combination of the two (Young 1990). Regardless of how one chooses to subdivide these coccoliths or the validity of such classifications, it is possible to identify correlatable changes in the average size of the plexus, variations in the overall and relative size and abundance of different populations, and the occurrence of characteristic morphotypes, all of which can be used for biostratigraphy.

In the analysis of smear-slides from archaeological ceramics in the present study, all reticulofenestrid coccoliths occurring in the '100-specimen counts' were measured, as were any significant specimens which were encountered during further searching. However, it was necessary to express these results as different species in the relative abundance descriptions (Appendix II). For this purpose, the reticulofenestrids were subdivided using a scheme which bears similarities to that of Backman (1980), Flores (1985) and Gartner (1992); Figure AI.1.

AI.8.2 Reticulofenestrids in the Upper Miocene

AI.8.2.1 The 'small *Reticulofenestra* interval', 'small *Reticulofenestra* event' or '*Reticulofenestra pseudoumbilica* paracme'.

The most important event in the Upper Miocene record of reticulofenestrid coccoliths is the temporary disappearance or 'paracme' (sensu Driever 1981), of large specimens with an open central area (*Reticulofenestra pseudoumbilica* Gartner, 1967). During this interval, which occurs in the late Tortonian, the reticulofenestrid population is dominated by coccoliths with a small overall size: *Reticulofenestra minuta* Roth (1970) and *Reticulofenestra minutula* Gartner (1967) Haq and Berggren (1978).

The 'small *Reticulofenestra* interval' (SRI), was defined by Young (1990, 76) from DSDP cores in the Indian Ocean, as a period of the Late Miocene in which a "dramatic decrease in the maximum, minimum and modal size" occurred "with coccoliths over 5 μm long virtually disappearing". By reassessing the work of previous authors, Young (1990) found evidence for the occurrence of an SRI in the Late Miocene of the N.E. Atlantic (Backman 1980), S. Atlantic (Haq 1980) and central Pacific (Pujos 1985; 1987). Subsequent work by other authors has revealed the occurrence of such an interval elsewhere, e.g. Gartner 1992: N. Atlantic and Takayama 1993: Ontong Java Plateaux. In fact, the onset of the *Reticulofenestra pseudoumbilica* paracme or the 'small *Reticulofenestra* event' appears to be globally synchronous, occurring quite suddenly (over less than 100,000 years) at around 8MA (Mock and Bralower 1993). However, its duration varies between different areas, and the reappearance of large specimens in NN 11 is gradualistic process which may not be very useful for biostratigraphy (Young *et al.* 1994).

The size definition for the SRI is usually 5 μm (the lower size limit for *Reticulofenestra pseudoumbilica* sensu Backman 1980; Flores 1985). However, the disappearance of large reticulofenestrids can be more precisely defined if a size definition of 7 μm is employed (Rio *et al.* 1990; Takayama 1993).

Unfortunately there does not appear to be any published data on the quantitative distribution of Late Miocene reticulofenestrids from the Mediterranean, so it is not possible to say whether the SRI occurs here or not. However, given the 'global' nature of this event as well as the adequate marine connections which existed between the Mediterranean sea and the Indian and N. Atlantic oceans at the time, the SRI is likely to occur here too.

AI.8.2.2 *Reticulofenestra pseudoumbilica var. rotaria* (Theodoridis 1984) Young, 1990

The occurrence of roughly circular, medium to large-sized reticulofenestrid coccoliths with a reasonably large central opening, was reported by Theodoridis (1984) in middle NN 11 (uppermost Tortonian and lower Messinian) of the Mediterranean, as well as elsewhere. Theodoridis (1984) erected the name *Reticulofenestra rotaria* for this form, and used its short range to define the upper and lower boundaries of the '*R.*

rotaria total range zone' in his 'Mediterranean Miocene' and 'Integrated Miocene' zonations.

Young (1990) also observed these circular reticulofenestrid coccoliths in the Upper Miocene of several Indian ocean DSDP cores, but at a slightly lower level, confined within the upper half of zone NN 11. He emended the taxonomy of Theodoridis (1984), attributing the specimens to variation within the population of large reticulofenestrids (*Reticulofenestra pseudoumbilica*), supported by the range of intermediate, nearly-circular forms which were also present.

Since its erection in 1984, this distinctive species or variety of the genus *Reticulofenestra* has rarely been reported (Young *et al.* 1994). However, the occurrence of *Reticulofenestra pseudoumbilica rotaria* in the extensive Mediterranean analysis of Theodoridis (1984) and its subsequent identification by Flores *et al.* (1992) in ODP cores from the Tyhrrenian sea makes it a potentially useful marker in this area. *Reticulofenestra pseudoumbilica rotaria* has been identified in some of the assemblages which are analysed in the present report, and has been used in conjunction with other taxa to indicate Theodoridis' (1984) Late Miocene zone of the same name.

AI.8.3 Reticulofenestrids in the Pliocene

AI.8.3.1 Last occurrence of *Dictyococcites antarcticus,* size increase in *Reticulofenestra pseudoumbilica* and variations in the relative abundance of *Reticulofenestra minuta* and *R. minutula.*

Large (>5 μm) reticulofenestrid coccoliths with a closed central area or a very small pore (*Dictyococcites antarcticus* Haq 1976), increased in abundance thorough the latest Miocene and earliest Pliocene in the Mediterranean. This response is attributed to a decrease in the temperature of surface waters (Flores *et al.* 1992). *D. antarcticus* was more abundant than large reticulofenestrids with an open central area (*Reticulofenestra pseudoumbilica*) by the earliest Zanclian nannofossil zone NN 12. However, at the end of this zone *Dictyococcites antarcticus* exhibited a sharp decrease in absolute abundance, and in relation to *R. pseudoumbilica*, which became more common.

This temperature-controlled change in the dominance of the two forms of large reticulofenestrid coccoliths from the Mediterranean, has been quantified by Driever (1988). He maintained that by counting 30 large (> 5 μm) reticulofenestrids it is possible to locate Pliocene samples in relation to the event, which he uses as a marker (n1) in his subzonal Pliocene biostratigraphic scheme (Section 5.7.2.2: Figure 5.23). *Dictyococcites antarcticus* virtually disappears extinct at this horizon and does not reappear in the Mediterranean Pliocene. However, it may be present in low numbers for some time within the earliest part of zone NN 13, as indicated in the frequency charts of Driever (1988) and the assemblage descriptions of Frydas (1990) from the S.W. Peleponnese, Greece.

Some 0.5 MA after the virtual disappearance of *Dictyococcites antarcticus* there is an increase in the size of the large reticulofenestrid population (*Reticulofenestra pseudoumbilica*). This takes place at approximately the same time as the FO of *Gephyrocapsa spp.* and has been recorded in the Indian Ocean by Young (1990), as well as at various sites in the Mediterranean by Driever (1988). The latter author measured the average size range of these coccoliths above (7.5-9.6 µm) and below (5.8-8.1 µm) the event and presented a simple method of counting 30 specimens, which can be used to locate Early Pliocene samples in relation to the change, which defines the boundary (n2) between subzones NN 12-13B and NN 12-13C in his Mediterranean Pliocene zonation.

Driever (1988) also established the relative abundance of the smaller reticulofenestrids (*Reticulofenestra minuta* and *R. minutula*) in the Pliocene of the Mediterranean. The various changes in the relative abundance of these two species as well as the size increase of *R. pseudoumbilica* have been used in the present report as means of confirming the position of Pliocene samples as indicated by more conventional markers.

AI.8.3.2 Last occurrence of *Reticulofenestra pseudoumbilica*

The most important biostratigraphic event in the Pliocene record of reticulofenestrid coccoliths is the extinction of *Reticulofenestra pseudoumbilica,* which occurs at the boundary between nannofossil zones NN 15 and NN 16. This event has been used in nearly all Cenozoic biostratigraphic schemes, to orientate samples relative to the Zanclian/Piacenzian (Lower/Upper Pliocene) boundary. However, there are problems associated with its application in on-land sections and discrepancies in the size definition used by various authors to locate this event.

Using a size definition of >5 µm (i.e. the lower size limit of *Reticulofenestra pseudoumbilica*) can be difficult, as specimens of 5-6 µm in length have been found to occur in early Piacenzian sediments (Raffi and Rio 1979; Backman and Shackleton 1983; Driever, 1988). Therefore, it is more convenient to use a size definition of 7 μm (Young *et al.* 1994) or 7-9 μm (Rio *et al.* 1990). In on-land sections *Reticulofenestra pseudoumbilica* can be reworked (Rio *et al.* 1990), and it is therefore necessary to be aware of any visible signs of reworking in samples and use alternative markers. These include the first common occurrence (FCO) of *Discoaster tamalis* (Driever 1981; Rio *et al.* 1990), the appearance of elliptical morphotypes of *Pseudoemiliania lacunosa* (Driever 1988) or the LO of *Sphenolithus spp.,* although the latter can also be affected by reworking on land sections of the Mediterranean (Raffi and Rio 1979).

AI.9 *Rhabdosphaera* Haeckel (1894)

Rhabdosphaera is the type genus of the family Rhabdosphaeraceae (Lemmermann 1908). The genus *Rhabdosphaera* contains many species, mostly from the Palaeogene, but a few from the Neogene, which can be distinguished primarily by the shape of their central processes in lateral view.

The two Neogene species of this genus; *Rhabdosphaera procera* (Martini 1969) and *Rhabdosphaera claviger* (Murray and Blackman 1898), are relatively small forms with short, simple stems. *Rhabdosphaera procera* has a process with straight, parallel to slightly converging sides, and a distinct central canal, whereas *R. claviger* has a gradually diverging, club-shaped stem (Perch-Nielsen 1985b). *Rhabdosphaera procera* is thought to have appeared in the Late Miocene zone NN 8 (Jafar 1975) and may have given rise to *R. claviger* in the Early Pliocene (Perch-Nielsen 1985b), which continues to the present day.

In the literature on Mediterranean Neogene calcareous nannofossils, little attention is given to the genus *Rhabdosphaera* and, as a result, the ranges of its two principal species are not well-defined. Theodoridis (1984) did not subdivide *Rhabdosphaera* at the species level, but instead, assigned a range encompassing the whole of the Miocene to his '*Rhabdosphaera sp.*', which may be equivalent to *R. procera*. This conflicts with the view of Perch-Nielsen (1985b, 517) who stated that *R. procera* appears "after a long interval where rhabdoliths are hardly ever found".

The FO of *Rhabdosphaera claviger* in the Mediterranean is a little more certain, and appears to have taken place somewhere in the Early Pliocene (Zanclian) according to Bukry 1973 (NN 12C); Müller 1978 (NN 13); Frydas 1990; (NN 13). However, Ellis (1979) working in the eastern Mediterranean, indicated that *Rhabdosphaera procera* occurs in the Pliocene and Pleistocene, from zone NN 12 upwards. Because of the similarity between this range and that of *R. claviger*, it appears that she may have used a different species concept. Nevertheless, the FO of *Rhabdosphaera* specimens with a short club-shaped central process in late NN 12 or NN 13 may well be used as a supplementary marker for the Mediterranean Pliocene biostratigraphy.

AI.10 *Scyphosphaera* Lohmann (1902) and *Pontosphaera* Lohmann (1902)

AI.10.1 *Scyphosphaera*

Fossil lopadoliths assigned to the extant genus *Scyphosphaera* are a significant component in many of the archaeological pottery samples which were analysed in the present report. Coccoliths of this genus are characterised by a cribrilith (*Pontosphaera*) basal plate with an inflated, distally-expanded margin that shows an extreme range of morphologies from barrel-shaped to elongate tubular (Aubry 1990). More than 50 species of *Scyphosphaera* have been proposed based upon the shape of the wall in side view under plane-polarised light or cross-polarised light, with the long axis of the lopadolith at 45° to the nicols (Perch-Nielsen 1985b).

In his re-examination of Kamptner's (1955) lopadoliths from Rotti (Indonesia), Jafar (1975) commented upon the striking polymorphism and morphological variation in this genus. This is well illustrated well by the two extant forms *Scyphosphaera apsteinii* Lohmann (1902) and *Scyphosphaera apsteinii cf. dilatata* Gaarder (1970), which contain both cribriliths and lopadoliths (as an equatorial ring). In addition, both taxa exhibit variation in the size and shape of the lopadolith coccoliths within a single coccosphere. For this reason, the evolutionary relationships proposed by Rade (1975) for *Scyphosphaera* species are to be treated with caution, as it appears that individual cells have the ability to produce a whole range of shapes intermediate between the so-called species.

Despite the large number of taxa proposed for this genus, the overall knowledge of the group is limited (Aubry 1990). This is mainly due to the sporadic distribution of *Scyphosphaera* world-wide, which is a consequence of their apparent preference for warm, shallow water. *Scyphosphaera* lopadoliths have a geological record from the Eocene to Recent, featuring periods of high diversity (e.g. Middle Miocene) and low diversity (Oligocene; during which there is a gap in the geological record of the genus). This pattern is likely to be a consequence of regional environmental fluctuations, as suggested by Rade (1975) who attributes the absence of

Scyphosphaera in the Oligocene of eastern Australia to the deterioration of the climate in the S.W. Pacific at this time.

The ranges of individual *Scyphosphaera* species are, on the whole, poorly defined, due to the rare occurrence of lopadolith-rich assemblages, and only a couple of taxa have been used for biostratigraphy. The limited knowledge of the stratigraphic distribution of this genus is illustrated by Perch-Nielsen's (1985b) 'D.I.Y.' chart of scyphosphaeras in which she presented the 50 or so species with their type levels, and encouraged workers to complete the diagram for themselves. Many lopadolith taxa are extremely long ranging, for example *Scyphosphaera apstienii* (Lower Eocene-Recent) and others which have poorly defined ranges may also turn out to be equally conservative, as our knowledge of this group expands.

Nevertheless it is possible to use the presence of certain forms as markers in some areas (such as the Mediterranean) where their stratigraphic distribution is restricted. For example, Hay and Schmidt *in* Hay *et al.* (1967) used the LO of the vase-shaped species *Scyphosphaera amphora* Deflandre (1942) to define the top of their '*S. amphora* zone' in the Upper Miocene to Lower Pliocene of Italy. Ellis (1979), working in the eastern Mediterranean located the FO of *Scyphosphaera globulata* Bukry and Percival (1971) and possibly *Scyphosphaera pulcherrima* Deflandre (1942) as mid NN 11, where she used them to mark the top of the *Discoaster quinqueramus* subzone of Bukry (1973, 1975), in the absence of *Amaurolithus primus.*

More recently, Siesser (1998) presented a thorough review of the structure, taxonomy, biostratigraphy and phylogeny of the genus *Scyphosphaera*, based upon all previous studies, as well as new onshore and offshore data from many parts of the world. This compilation contains the most up to date account of the geographic and stratigraphic distribution of *Scyphosphaera* species. By analysing Siesser's (1998) species descriptions and range charts, it is possible to identify four taxa which have a limited stratigraphic distribution within the Mediterranean, and may be useful for biostratigraphy. The datums provided by these are: the appearance of *Scyphosphaera gladstonensis* Rade (1975) and *Scyphosphaera pacifica* Rade (1975) near the NN 11/NN 12 boundary (late Messinian); the disappearance of *Scyphosphaera ventriosa* Martini (1968) at the NN 14/15 boundary (Early Pliocene); and the disappearance of *Scyphosphaera kamptneri* Müller (1974) and *Scyposphaera pulcherrima* Deflandre (1942) at the NN 18/19 boundary (Late Pliocene).

In addition to the species of *Scyphosphaera* which are listed above, the overall abundance of this genus in late Neogene sediments from the Mediterranean, may well be useful in orientating samples with respect to the Miocene/Pliocene boundary. Müller (1978, 749) reported that scyphosphaeras are "either rare or entirely absent in Miocene cores of the Mediterranean" and Bukry (1973), Müller (1978) and Frydas (1990) have found that lopadoliths are common in the Early Pliocene (NN 12 and NN 13) zones. The frequent occurrence of scyphosphaeras in the earliest Pliocene appears to be related to an influx of warm water into the Mediterranean at this time, which also produced a high abundance of *Discoaster* species (Müller 1978). This phenomenon, which has also been noted in the present report and may be used, in addition to the common occurrence of scyphosphaeras in NN 15 and NN 16 (Müller 1978; 1990), to aid biostratigraphic assignments in the Pliocene.

AI.10.2 *Pontosphaera*

Cribriliths of the genus *Pontosphaera* are a consistent component of the calcareous nannofossil assemblages which have been analysed from archaeological ceramics in the present report (Appendix II). In these assemblages, the two most commonly occurring species of *Pontosphaera* are *Pontosphaera multipora* (Kamptner 1948) Roth (1970) and *Pontosphaera japonica* (Takayama, 1967) Nishida (1971). The taxonomy of these two cribriliths is rather confused (see Aubry 1990 for list of synonyms), however, both appear to range throughout the late Neogene in the Mediterranean (Müller 1978). In the present report, late Neogene cribriliths with a relatively thick margin and many very fine pores which cannot be recognised clearly in the light microscope, are referred to the species *P. japonica*, and those which possess fewer, coarser pores are assigned to *P. multipora*.

A species of *Pontosphaera* which occurs more sporadically in the calcareous nannofossil assemblages of this report, is *Pontosphaera jonesi* (Boudreaux and Hay 1969) Backman (1980). This species is characterised by having a rugged, non-perforate basal plate of coarse granules, and has a deep suture flanked by irregular, bifurcate sutures (Aubry 1990). *P. jonesi*, which bears similarities to the Jurassic discolith *Crepidolithus crassus* (Deflandre *in* Deflandre and Fert, 1954) Nöel (1965), has been reported by Backman (1980) from the Pliocene of DSDP site 116, N.E Atlantic Ocean, and by Boudreaux and Hay (1969) from the Late Pliocene and Pleistocene of the Caribbean.

The absence of *P. jonesi* in the Miocene of DSDP site 116, as indicated by Backman (1980) may suggest that this species did not evolve until the Pliocene. *P. jonesi* was not identified in any of the analyses of Mediterranean calcareous nannofossils which have been considered in the present report, therefore this possibility cannot be confirmed. However, Varol, working on land sections from the Mut Basin of southern Turkey, figured cribriliths which fit the description of *P. jonesi* above (1985, Plate 1, Figs. 26 and 28). Varol (1985) attributed these specimens to the Palaeogene species *Pontosphaera segmenta* Bukry and Percival (1971) Varol (1985), and recorded them in all of his sections (Burdigalian to Serravalian, NN 2-NN 7). The occurrence of such specimens in the Early and Middle Miocene of the Mediterranean, indicates that this type of heavily calcified cribrilith may well have a long range and as such, is not of any use for late Neogene biostratigraphy. All overgrown *Pontosphaera* cribriliths fitting the description of *Pontosphaera jonesi* are labelled as *Pontosphaera sp.* in the calcareous nannofossil assemblages in Appendcies II and III of the present report.

AI.11 *Sphenolithus* Deflandre (1952)

AI.11.1 Introduction

Within the late Neogene, seven species of *Sphenolithus* have been described by various authors (*Sphenolithus abies, Sphenolithus compactus, Sphenolithus grandis, Sphenolithus moriformis, Sphenolithus neoabies, Sphenolithus quadrispinatus* and *Sphenolithus verensis*) for which Perch-Nielsen (1985b: Fig 96, 518) has proposed tentative evolutionary relationships. In this later part of the 'iterative evolution' in sphenoliths (Aubry, 1989), six of these seven species have essentially the same general shape, i.e. "Morphotype 4" of Roth *et al.* (1971, 1101), or "short-fat" (Towe, 1979, 557). They are distinguished by their overall size as well as the shape of the proximal shield or 'column' and the extent to which the lateral elements are extended distally to form a pseudo-apical spine.

The small size and high relief of sphenoliths hinders the clear illustration of their structural details in the light microscope (Roth *et al.* 1971), so that the identification of some species can be difficult, especially in poorly preserved assemblages (Perch-Nielsen 1985b). However, it is of interest to the present study (in which sphenoliths can be one of the more common nannofossils), to ascertain which species of *Sphenolithus* can be positively identified, and whether their reported geological ranges can be utilised in order to date samples in the absence of conventional biostratigraphic markers.

AI.11.2 *Sphenolithus moriformis* (Brönnimann & Stradner 1960) Bramlette & Wilcoxon (1967)

Sphenolithus moriformis is the longest ranging species of the genus (Bramlette and Wilcoxon 1967) and can be likened to the species *Discoaster deflandrei* in that it evolves in the Early Eocene, is very common in the early Neogene and forms the root stock for the evolution of several late Neogene forms. *S. moriformis* has the characteristic "beehive" profile (Roth *et al.* 1971, 1105) of which all but one of the late Neogene species are variants. This shape is formed by the combination of a slightly flaring proximal shield (Aubry 1989) and a bulbous distal shield, produced by an extension of the distal-most lateral elements (Bramlette and Wilcoxon 1967). Workers such as Roth *et al.* (1971) and Aubry (1989) have included values for the number of elements and cycles in the proximal and distal shields of *S. moriformis* in their descriptions, however, these characteristics are not of use to the light microscope user.

The overall size of sphenoliths can be measured in the light microscope and is an important characteristic for distinguishing between the various late Neogene species. In the original description of *S. moriformis*, Bramlette and Wilcoxon (1967) figured specimens which are approximately 7-8 µm long. However, Backman (1980) in a quantitative study of Neogene sphenoliths from the North Atlantic found no specimens of this size, but noted that *S. moriformis* could be distinguished from the smaller *S. neoabies* by its larger size (although he did not quantify this in any way). Aubry (1989, 159) listed the size of *S. moriformis* as "about 5µm" whereas Perch-Nielsen (1985b) simply stated that it is smaller than the 10-18µm *Sphenolithus grandis*, and Roth *et al.* (1971) comment that its size is variable.

S. moriformis is a long ranging form which is reported from the Early Eocene (where it evolves from *Sphenolithus primus*), to the Late Miocene. The FO of this species is not of interest to this discussion, however its LO which takes place somewhere in the Middle or Late Miocene, may be of use. It is commonly stated in the literature that *S. moriformis* disappears through its gradual evolution into *Sphenolithus abies* (Section AI.11.3). Bramlette and Wilcoxon (1967, 124) claimed that this takes place through the Miocene to produce "*S. abies* of the Late Miocene and Pliocene" and that "variations and the gradual change in populations ... made it impractical to differentiate the two species within the Miocene part of the Cipero section". Other authors have attributed a more specific date to the LO of *S. moriformis*, e.g. NN 8 (Theodoridis 1984) and NN 9 (Perch-Nielsen 1985b). However, by considering the loose taxonomic description of this species as well as the various different ages which have been proposed for its uppermost range and the FO of *S. abies* (Section AI.11.3), it is clear that there is little agreement as to when the evolution took place, or whether it was synchronous in different areas, which is unlikely, given that the change was gradualistic. As a result of this uncertainty, the LO of *S. moriformis* is not utilised in any biostratigraphic schemes for the Neogene of any part of the world despite the species' cosmopolitan distribution and regular occurrence in calcareous nannofossil assemblages.

In the Mediterranean Neogene, *S. moriformis* has been recorded up to the *D. kugleri* zone (NN 7) by Ellis (1979) and the *E. bollii* zone (early NN 8) by Theodoridis (1984). However, the specimens of *S. moriformis* figured by the latter author clearly exhibit features characteristic of *S. abies* (Section AI.9.11.3), i.e. a flared column and a pseudo-spinose distal shield.

AI.11.3 *Sphenolithus abies* Deflandre in Deflandre & Fert (1954)

Sphenolithus abies is generally thought to have evolved somewhere in the Miocene from *S. moriformis* through the extension of the most distal 'lateral' elements parallel to the median axis of the sphenolith, to form a loosely fused, apical spine (Roth *et al.* 1971). This (pseudo) spine is not to be confused with the apical spine of other sphenoliths, such as *Sphenolithus radians* and *Sphenolithus heteromorphous*, as it is a prolongation of the lateral elements in the absence of a separate apical structure. Other features of *S. abies* include a flared proximal column (more flared than that of *S. moriformis*, but less than that of *Sphenolithus verensis*) and a strongly arched base

(Aubry, 1989). The overall shape is therefore more conical than the beehive profile of *S. moriformis* (Perch-Nielsen 1985b), so that *S. abies* could be placed in either the 'short-fat' or 'long-thin' groups of Towe (1979, 557).

S. abies is usually quoted as being smaller than *S. moriformis*, but can be up to about 8μm in length (observations in the present report). Despite a considerable overlap between the two species' size ranges, *S. abies* has a smaller minimum size (approximately 2 μm: observations in the present report), as tiny *S. moriformis* shaped specimens are likely to be identified as *Sphenolithus compactus*. Despite this overlap in size between the two species, differentiating between well-formed, blunt-ended, conical *S. abies* specimens and the broad beehive shape of *S. moriformis* is simple. However, a whole range of interspecific morphotypes occur, in which the pseudo-apical spine and flared, arched base are developed to varying degrees. The difficulty that Bramlette and Wilcoxon (1967) had in differentiating between the two species in a Miocene section from Trinidad reflects the problem of inter-specific individuals and is supported by the observations of Roth *et al.* (1971). Towe (1979), who considers *S. abies* as an invalid species concept due to its morphological gradation with *S. moriformis* invites the reader to compare the Pliocene *S. abies* of Roth *et al.* (1971: Pl 5, Fig 8) and the Miocene *S. moriformis* of Perch-Nielsen (1972: Pl 16, Fig 5) in support of his claim. To this may be added the *S. moriformis* of Theodoridis (1984: Pl. 8, Figs 1-3) which appears to be morphologically intermediate, between the two species.

As mentioned above, the evolution of *S. abies* is not well established. There is almost general agreement between authors that *S. abies* developed from *S. moriformis*. Less certain however, is the date during which the evolution took place. Perch-Nielsen (1985b) and Martini and Worsley (1971) considered the FO of *S. abies* to occur in zone NN 9, however, others such as Aubry (1984), Ellis (1979) and Theodoridis (1984) have this species ranging from NN 4, NN 7 and NN 2/3 respectively. The uncertainty surrounding the FO of *S. abies*, as well as its gradation with *S. moriformis* explains why it is not often used as a biostratigraphic marker.

The LO of *S. abies*, *S. neoabies* and the genus *Sphenolithus* itself are useful data events which appear to take place close to the Lower/Upper Pliocene boundary (NN 15/16), near the extinction of large specimens of *Reticulofenestra pseudoumbilica*. A rough date of NN 15/16 is often quoted for the LO of both species, however, it appears that the extinction of *S. abies* takes place within NN 15 (Ellis, 1979; Schmidt, 1973); and *Sphenolithus neoabies* disappears at or just above the boundary. Therefore the LO of *S. abies* may well be used in the absence of, or to supplement the LO of *R. pseudoumbilica* to approximate the Lower/Upper Pliocene (NN 15/16) boundary, or as a means of finely dating samples from near the boundary, in conjunction with other markers.

AI.11.4 *Sphenolithus neoabies* Bukry and Bramlette (1969)

Sphenolithus neoabies was described by Bukry and Bramlette (1969) as lacking the prominent apical spine, typical of most species of the genus (morphotypes 1-3 of Roth *et al.* 1971), but instead, having a slightly extended distal shield (not as well developed as *S. abies*, but more so than the round-topped *S. moriformis*). It appears to also differ from these two closely related species by its small size (Backman, 1980).

Additional characteristics of this species which have been defined by other authors are the presence of a flared proximal column (Aubry 1989), combined with a flat base, to produce a 'triangular outline' at 45° to the crossed nicols (Perch-Nielsen 1985b).

S. neoabies, therefore, shares features common to both *S. moriformis* and *S. abies*, with which it may occur, and size appears to be the main discriminating factor, given the range of intermediate forms which exist between these two species in the late Neogene. Backman (1980) used size to discriminate between *S. neoabies* and *S. moriformis* in a quantitative study of samples from the Mid-Late Miocene of the North Atlantic, but a considerable range was found, and the appearance of *S. neoabies* was detected by a 30% mean size reduction from late Middle Miocene to Late Miocene, a method of identification which can not be applied to single samples.

The FO of *S. neoabies*, which was considered to take place near the NN 11/12 boundary by Perch-Nielsen (1985b), is not well defined. In Backman's study the 30% mean size reduction in hemispherical sphenoliths which is thought to herald the evolution of *S. neoabies,* takes place in early Late Miocene. However, in the Mediterranean, Ellis (1979) recorded *S. neoabies* in his *Discoaster kugleri* subzone (Middle Miocene, NN 7) and Aubry (1989, 159), stated that the FO of *S. neoabies* is "poorly defined within the Early Miocene" (approximately NN 4).

The LO of *S. neoabies* occurs at or above the Zanclian/Piacenzian boundary after the disappearance of *Sphenolithus abies* (Perch-Nielsen 1985b). In NN 15, prior to its last occurrence *S. neoabies* occurs in greater abundance than *S. abies*. This acme ends in mid NN 15 and is used to define the top of the *S. neoabies* zone of Ellis (1979), close to the point at which *S. abies* becomes extinct and *S. neoabies* continues in low numbers. Some authors such as Ellis (1979) and Schmidt (1973), place the LO of *S. neoabies* at the NN 15/16 boundary, however others consider this to have occurred some time after the Early/Late Pliocene boundary, for example in NN 16 (Perch-Nielsen 1985b).

Thus, despite minor discrepancies, there appears to be a general agreement as to the position of *S. neoabies* LO, so that it may be used with caution to approximate the Early/Late Pliocene (NN 15/16) boundary.

AI.11.5 *Sphenolithus compactus* Backman (1980)

Backman (1980) erected the species *Sphenolithus compactus* to include small sphenoliths with a straight or slightly flaring proximal column and a rounded 'mushroom-like' distal profile, which he found in Early to Late Miocene samples at DSDP Site 116 in the North Atlantic. Subsequent description by other authors are identical, and it appears that this tiny species can be differentiated from its nearest relatives by the more spiny distal shield and obtusely flaring column in *S. neoabies*; and the larger size of *S. moriformis*. Distinguishing between *S. neoabies* and *S. compactus* in this way may not be easy, as a great deal of expertise and good eyesight is surely needed in order to determine whether a 2 μm calcareous nannofossil specimen has flaring or slightly flaring base and a rounded or slightly triangular distal end. Backman (1980) commented that *S. moriformis* has a more spiny distal column and a more obtuse ring of basal spines than *S. compactus*, which are the two features used to distinguish *S. compactus* from *S. neoabies*. Therefore, the fact that *S. moriformis* is "considerably larger" (Backman 1980, 45) has priority in the specific determination of hemispherical sphenoliths. Backman (1980, 60) described *S. compactus* as "usually not exceeding 2-3 µm in height", and the smallest measurement given for *S. moriformis* in the literature is 5 µm (Aubry 1989), which indicates that there is no overlap between the size ranges of these two species. However, the problem remains of what to call hemispherical sphenoliths between 3 & 5 µm in length.

The FO of *S. compactus* occurs somewhere in the earliest Miocene and the species is thought to range into the Late Miocene (Backman 1980; Perch-Nielsen 1985b; Aubry 1989). However, the date at which it actually becomes extinct, or evolves into *S. neoabies* (as suggested by Perch-Nielsen 1985b) is not well defined. If the afore mentioned evolutionary process did take place, then it can be likened to the that of *S. abies* from *S. moriformis*, in which the main morphological changes were an extension of the distal elements to form a pseudo-apical spine and subsequent flaring of the proximal column, to producing a more conical shape. If this is the case then the evolution of *S. neoabies* from *S. compactus* may have also been a gradualistic process, which took place over some time, and is therefore of little use for biostratigraphy.

AI.11.6 *Sphenolithus verensis* Backman (1978)

Sphenolithus verensis is a rarely identified conical sphenolith which is very similar to *S. abies* and is reported to have a restricted range from Late Miocene to Early Pliocene. This species, which was described by Backman (1978) from the Neogene of the Vera Basin, S.E. Spain, is characterised by a broadly flaring proximal column made of long straight elements, a strongly arched base, a crude pseudo-spine formed of loosely-fused elements and a rugged outline. *S. verensis* differs from *S. abies* by "its broader base and more irregular (spiny) outline; and in being not as bright under crossed nicols" (Aubry 1989, 169). To this, one could add that the pseudo spine of *S. verensis* is broader and less tapered than that of *S. abies*. Despite these several differences it may be difficult to discriminate between the two species, given the range of morphological variation that is present in sphenolith populations and the subjective nature of the criteria used. Backman (1978, 112) himself commented that "In the light microscope *S. verensis* can be confused with *S. abies*".

In the literature, *S. verensis* is recorded as having a larger maximum size (9μm) than *S. abies*. However, nowhere is this mentioned as being a means of identification (perhaps due to the overlap in the two sizes), and observations in the present report indicate that *S. abies* can reach a size of approximately 9 μm in length.

Despite its close similarities to *S. abies*, *S. verensis* is reported to occur in a restricted interval of the Late Miocene to Early Pliocene (Backman 1978), which Perch-Nielsen (1985b) indicates more specifically as late NN 10-early NN 13. If correct, this means that the occurrence of this morphotype may be useful for dating sediments which straddle the Miocene/Pliocene boundary. However, the failure of other authors to identify *S. verensis* and its absence in all Mediterranean Neogene zonations indicates that it may only be found very rarely or is difficult to identify. Nevertheless, in the presence of other Late Miocene/Early Pliocene species, the occurrence of *S. verensis* may be a useful additional marker.

AI.11.7 *Sphenolithus grandis* Haq and Berggren (1978)

Sphenolithus grandis is one of the more distinctive species of late Neogene sphenoliths due to its large size (10-19 μm). The overall shape of this species is most similar to that of *S. moriformis* in that it is roughly equidimensional, it has a slightly flaring proximal column, and a broadly rounded distal end. However, the two species can easily be distinguished as *S. grandis* is larger, has disjointed radiating spinose elements and its extinction pattern differs from *S. moriformis*. Although an upper size range is not quoted for *S. moriformis* and in their original description, Bramlette and Wilcoxon (1967) stated that the its size varies greatly. *S. moriformis* is usually less than 10 μm (observations in the present study), in which case *S. grandis* may be identified by size alone.

Haq and Berggren (1978) commented that *S. grandis* occurs in rare numbers in the Mid-Late Miocene of the Rio Grande Rise, but they did not specify when it appears or disappears. However, Perch-Nielsen (1985b), perhaps through the interpretation of Haq and Berggren's original data, indicated that *S. grandis* may have evolved from *S. moriformis*, and has a sporadic range from NN 7 to NN 11. *S. grandis*, perhaps due to its rare occurrence in nannofossil assemblages (observations in the present report) and poorly defined FO and LO has not been utilised in any biostratigraphic schemes for the Mediterranean Neogene. Being so large and robust, *S. grandis*, like *S. moriformis*, may be reworked and incorporated into younger sediments. However, if reworking is not suspected, then the ease with which it can be distinguished from all other late Neogene sphenoliths and its relatively short range means that the presence of *S. grandis* may be a useful marker to supplement other biostratigraphic data.

AI.11.8 *Sphenolithus quadrispinatus* Perch-Nielsen (1980)

Another highly distinctive late Neogene sphenolith is *Sphenolithus quadrispinatus*, which has a restricted range, but is rarely identified and not utilised in any biostratigraphic schemes for the Mediterranean. Unique among all other late Neogene species of *Sphenolithus*, it possesses four long, gently tapering distal spines which are developed by the extension of the lateral elements. The body has a straight-sided column which sits beneath one of two tiers of blocky lateral elements, from which the spines radiate at 45°. These delicate spines which set this species aside from other sphenoliths are rarely preserved, and it is conceivable that a specimen of *S. quadrispinatus* which has lost all four spines could be misidentified as a *S. compactus* or *S. moriformis*. Nevertheless, given that Perch-Nielsen (1980) documented a restricted range within zone NN 10 for this distinctive species, it may be an extremely useful stratigraphic marker where present, despite the fact that it is not utilised in the Neogene biostratigraphic schemes of the Mediterranean.

AI.11.9 Discussion and conclusions

Given the similarity between many of the late Neogene sphenolith species and their controversial and often overlapping ranges (Perch-Nielsen 1985b), very few can be

	S. morif.	*S. abies.*	*S. neo.*	*S. comp.*	*S. veren.*	*S. grand.*	*S. quad.*
Proximal Shield:	straight to flared	flared	slightly flared	straight	very flared	straight to flared	straight
Base:	flat to arched	arched	flat to arched?	flat	very arched	flat? to arched	flat
Distal Shield:	domed	pseudo-spine	triang-ular	domed	broad ps.-spine	domed	4 thin spines
Outline:	distinct	distinct	distinct	distinct	ragged	ragged	distinct
Length: (μm)	5-9	2-8	2-5?	2-5?	?-9	10-18	appx 12

Figure AI.2 Characteristics of the late Neogene '*S. moriformis*' group of sphenoliths and *S. quadrispinatus*.(ps. -spine = pseudo-spine.)

Flared column	*S. compactus* **NO**	*S. morif.* & *S. grandis*	*S. neoabies*	*S. abies*	*S. verensis* **YES**
Arched base	*S. compactus* **NO**	*S. neoabies*	*S. morif.* & *S. grandis*	*S. abies*	*S. verensis* **YES**
Extended distal shield	*S. compactus* **NO**	*S. morif.* & *S. grandis*	*S. neoabies*	*S. verensis*	*S. abies* **YES**
Size	*S. compactus* **SMALL**	*S. neoabies*	*S. abies*	*S. morif.* & *S. verensis*	*S. grandis* **LARGE**

Figure AI.3 The progressive development of a flared proximal column, arched base, extended distal shield and overall length in the late Neogene '*S. moriformis*' plexus of sphenoliths. The six species are arranged from left to right in order of the degree to which they exhibit the above features.

used for biostratigraphy in the Mediterranean. Backman (1980, 45) commented that "it may be difficult to make differentiations between *S. moriformis*, *S. abies* and *S. neoabies*" due to their concurrence in Late Miocene samples along with intermediate forms. Perch-Nielsen (1985b) added *S. compactus* to this group, and it would perhaps be wise to include *S. verensis*, which is another modification of the basic structure (morphotype 4 of Roth *et al.* 1971), which characterises these late Neogene sphenoliths. From the subtle differences which are used to differentiate between these 'species' and the presence of interspecific variation, it is tempting to agree with the view of Towe (1979) that the genus *Sphenolithus* is over-divided, and that what have been described as different species are in fact variation within a single population. Determining what is and is not a species in nannopalaeontology can be difficult, especially considering the discrepancies between the use of this term in the study of living coccolithophores and that of calcareous nannofossils. It is perhaps unwise to be as pessimistic as Towe (1979), who suggested that only two species of *Sphenolithus* should be retained (*S. moriformis* and *S. radians*), however, a revision of the '*Sphenolithus moriformis* group' is clearly required, the results of which may improve the use of this plexus in late Neogene stratigraphy.

For the purpose of the present report, only two late Neogene sphenolith datums are of use. These are; the LO of *S. abies* (NN 15) and the LO of *S. neoabies* (early NN 16). Yet, even these must be applied with caution as Driever (1988), who combined both species under the heading of *Sphenolithus spp.*, noted that sphenoliths are present discontinuously in low numbers above their 'subtop' in NN 16 (which defines the upper boundary of his NN 16/17 A subzone). In addition, the high abundance (acme) of *S. neoabies* and the presence of *S. grandis*, *S. quadrispinatus* and *S. verensis* may be used to supplement other biostratigraphic information.

AI.12 Biostratigraphy of Neogene calcareous nannofossil taxa recorded in geological and archaeological assemblages

AI.12.1 Introduction

The following section outlines the currently accepted ranges and events in the record of the various Neogene calcareous nannofossil taxa which have been recorded in the archaeological and geological samples analysed in the present report. This summary, which is based upon numerous sources, complements the calcareous nannofossil assemblage descriptions and their biostratigraphic interpretations (Appendices II and III). Detailed discussions of the majority of the taxa which are listed below can be found in Sections AI.1 to A1.11.

AI.12.2 Abbreviations

FO = First occurrence	LO = Last occurrence
FCO = First common occurrence	LCO = Last common occurrence
extant = Species still living	acme = Period of high abundance

? = Some uncertainty, species may range above or below this level.

AI.12.3 Taxa

Amaurolithus spp.:	FO Late Miocene (Tortonian) NN11, LO Early Pliocene (Zanclian) NN14/NN15.
Amaurolithus delicatus:	FO Late Miocene (Tortonian) NN11, LO Early Pliocene (Zanclian) NN14/NN15.
Amaurolithus primus:	FO Late Miocene (Tortonian) NN11, LO Early Pliocene (Zanclian) NN13.
Amaurolithus tricorniculatus:	FO Late Miocene (Messinian) NN11, LO Early Pliocene (Zanclian) NN12/NN13.
Braarudosphaera bigelowii:	FO Cretaceous, extant.
Calcidiscus leptoporus:	FO Early Miocene (Burdigalian) NN4, extant.
Calcisidcus macintyrei:	FO Early Miocene (Burdigalian) NN4, LO (>10μm) Early Pleistocene NN19.
Ceratolithus acutus:	FO Early Pliocene (Zanclian) NN12, LO Early Pliocene (Zanclian) NN13?
Ceratolithus rugosus:	FO Early Pliocene (Zanclian) NN12/NN13, LO Early Pleistocene.
Coccolithus formosus:	Spherical forms of *Coccolithus pelagicus* identified in this report, range undefined, may be extant.
Coccolithus miopelagicus:	FO Late Oligocene or Early Miocene?, LO Late Miocene (Tortonian) NN7.

Coccolithus pelagicus: FO Palaeogene, extant, may have bridge aligned with short axis of central opening in the Pliocene, decrease in abundance close to the Pliocene/Pleistocene boundary.

Coronocyclus nitescens: FO Eocene, LO Middle Miocene (Serravalian) NN6/NN7.

Cyclicargolithus floridanus: FO Late Eocene?, LO Middle Miocene (Serravalian) NN6/NN7.

Daktylethra punctulata: Range undefined.

Dictyococcites antarcticus: Early Miocene (Aquitanian) NN1?, earliest Pliocene (early Zanclian) NN12 abundance > *Reticulofenestra pseudoumbilica*, LCO Early Pliocene (Zanclian) NN12/NN13.

Dictyococcites productus: FO undefined, extant.

Dictyococcities productus/small *Gephyrocapsa sp.* transitional specimens: Occur in Early Miocene (Zanclian) NN13 prior to FO of small *Gephyrocapsa sp.*

Discoaster asymmetricus: Present in low abundance from Upper Miocene, FCO (start of acme) Early Pliocene (Zanclian) NN13/NN14, end of acme Late Pliocene (Piacenzian) mid NN16, LCO shortly afterwards, present in low numbers until LO *Discoaster brouweri*.

Discoaster bollii: FO Middle Miocene (Serravalian) NN7/NN8, LO Late Miocene (Tortonian) NN9.

Discoaster brouweri: FO Late Miocene (Tortonian) NN9, present in low abundance in the Early Pliocene (Zanclian) until NN13/14, LO Late Pliocene (Piacenzian) NN18/NN19.

Discoaster deflandrei: FO Eocene, LCO Middle Miocene (Serravalian) NN7, present in low abundance until Late Miocene (Tortonian) NN9.

Discoaster exilis: FO Middle Miocene (Langhian) NN4, LO Late Miocene (Tortonian) NN9.

Discoaster pansus: Present in low abundance in Middle Miocene (Serravalian) NN7, FCO Late Miocene (Tortonian) NN9, LO Late Miocene (Messinian) NN11.

Discoaster pentaradiatus: FO Late Miocene (Tortonian) NN10, present in low abundance from Early Pliocene (Zanclian) NN15 until Late Pliocene (Piacenzian) NN16, acme late NN16 and NN17 (LCO NN17/NN18), present in low abundance during NN18.

Discoaster surculus: FO Late Miocene (Tortonian) NN11, LCO Late Pliocene (Piacenzian) NN17/NN18, present in low abundance during NN18.

Discoaster tamalis: Present in low abundance in the Late Miocene, FCO (start of acme) Early Pliocene (Zanclian) NN14/NN15, end of acme Late Pliocene (Piacenzian) mid NN16, LCO shortly afterwards, present in low abundance until LO *Discoaster brouweri*.

Discoaster variabilis: FO Middle Miocene (Serravalian) NN5?, LCO Early Pliocene (Zanclian) late NN13, present in low abundance in Late Pliocene (Piacenzian).

Geminilithella spp.: FO Early Miocene (Burdigalian) NN2, LO undefined.

small *Gephyrocapsa sp.*: FO specimens <3.5μm Early Pliocene (Zanclian) NN13, larger specimens (up to 4μm) occur in NN14, NN15 and Late Pliocene (Piacenzian) early NN16, acme mid NN16, extant.

Hayaster perplexus: FO Late Oligocene, extant.

Helicosphaera carteri: FO base of Miocene, extant.

Helicosphaera intermedia: FO Oligocene, LCO Late Miocene (Tortonian) NN9, present in low abundance in latest Miocene (NN11) and possibly Early Pliocene (Piacenzian).

Helicosphaera pacifica: FO Middle Miocene (Serravalian) NN7?, LO Late Miocene (Tortonian or Messinian) NN11?

Helicosphaera palaeocarteri: FO base of Miocene, extant?

Helicosphaera pavimentum: FO Pleistocene?, extant.

Helicosphaera sellii: FO Early Pliocene (Zanclian) NN12/13?, LO Pleistocene NN19.

Helicosphaera stalis: FO Middle Miocene (Serravalian) NN6, LO Late Miocene (Messinian) NN11.

Holodiscolithus macroporus: Range undefined.

Holodiscolithus solidus: Range undefined.

Lithostromation perdurum: Range undefined.

Pontosphaera japonica: Ranges throughout the Neogene.

Pontosphaera multipora: Ranges throughout the Neogene.

Pseudoemiliania lacunosa: Present in low abundance from Early Pliocene (Zanclian) NN12/NN13, FCO mid NN13, subcircular specimens appear in NN15, LO Pleistocene NN19/20.

Reticulofenestra minuta: FO Early Eocene, Early Pliocene (Zanclian) NN12 and NN13 abundance > *Reticulofenestra minutula*, LO Pleistocene.

Reticulofenestra minutula: FO Early Miocene?, Early Pliocene (Zanclian) NN12 and NN13 abundance < *Reticulofenestra minuta*, LO Pleistocene.

Reticulofenestra pseudoumbilica: FO (specimens >7 μm) Middle Miocene (Serravalian) NN6, temporary disappearance of large specimens (>7 μm) Late Miocene (Tortonian) NN10-mid NN11 'small *Reticulofenestra* interval', earliest

Pliocene (early Zanclian) NN12 abundance <

Dictyococcities antarcticus, mid NN13 size increase

(5.8-8.1μm to 7.5-9.6 μm), LO (specimens >7 μm)

Early/Late Pliocene (Zanclian/Piacenzian) NN15/NN16.

Reticulofenestra pseudoumbilica var. rotaria: Restricted range in Late Miocene (latest Tortonian and earliest Messinian) mid NN11.

Rhabdosphaera procera: FO Late Miocene (Tortonian) NN8?, LO Early Pliocene (Zanclian) NN15?

Scyphosphaera amphora: FO Middle Miocene (Serravalian) NN6, LO Late Pliocene (Piacenzian) or Pleistocene.

Scyphosphaera apsteinii: FO Early Eocene, extant.

Scyphosphaera canescens: FO Late Miocene (Tortonian) NN9, LO Late Pliocene (Piacenzian).

Scyphosphaera globulosa: FO Late Miocene (Tortonian) NN9, LO Pleistocene.

Scyphosphaera lagena: FO Late Miocene (Tortonian) NN9?, LO Late Pliocene (Piacenzian).

Scyphosphaera piriformis: FO Middle Miocene (Serravalian) NN6?, LO Pleistocene.

Scyphosphaera pulcherrima: FO Middle Miocene (Langhian), LO Pleistocene.

Sphenolithus spp.: LO (*Sphenolithus abies* and *Sphenolithus neoabies*) Late Pliocene (earliest Piacenzian) early NN16.

Sphenolithus grandis: FO Middle Miocene (Serravalian) NN7?, LO Late Miocene (Tortonian) NN11?

Sphenolithus moriformis: FO Early Eocene, LO Middle or Late Miocene (Serravalian or Tortonian) NN7-NN9.

Sphenolithus quadrispinatus: Restricted range within Late Miocene (Tortonian) NN10?

Sphenolithus verensis: FO Late Miocene (Tortonian) NN10? LO Early Pliocene (Zanclian) NN13?

Syracosphaera fragilis: FO Middle Miocene (Serravalian) NN6, LO Late Miocene (Tortonian) NN10?

Tetralithoides symeonedesi: Early Miocene (Burdigalian) NN3, LO Late Miocene (Tortonian) NN9.

Thoracosphaera sp.: FO Jurassic, extant.

Triquetorhabdulus rugosus: FO Middle Miocene (Serravalian) NN6, LO Early Pliocene (Zanclian) NN12.

Umbilicosphaera sp.: FO Middle Miocene (Serravalian), extant.

Appendix II Calcareous nannofossil assemblages from smear slides of archaeological ceramics

AII.1 Explanation of the assemblage descriptions

AII.1.1 Overall abundance and preservation

Rough qualitative estimates of the overall abundance and state of preservation of the calcareous nannofossil assemblage are presented, in order to highlight those samples which were particularly rich or poor in calcareous nannofossils, as well as those in which the calcareous nannofossil assemblages were very well-preserved or badly preserved.

AII.1.2 Relative abundance of calcareous nannofossil species

The abundance of the various calcareous nannofossil taxa relative to the whole assemblage is indicated, using the semi-quantitative key below. The various categories are based upon a count of 100 calcareous nannofossil specimens (Section 5.10.2), which was carried out for most samples. The label 'present' refers to those taxa which were encountered after the 100-specimen count.

Extremely abundant (EX): >40% of total nannofossil assemblage

Very abundant (VA): 21-40%

Abundant (A): 11-20%

Common (C): 6-10%

Few (F): 2-5%

Rare (R): <2%

Present (P): species which did not score in relative abundance counts

AII.1.3 The average diameter of *Reticulofenestra pseudoumbilica* and the relationship between *Reticulofenestra pseudoumbilica* and *Dictyococcites antarcticus*

In order to locate Early Pliocene samples in relation to the size increase of the species *Reticulofenestra pseudoumbilica* and the change in the dominance of large 'reticulofenestrid' coccoliths from *Dictyococcites antarcticus* to *Reticulofenestra pseudoumbilica* (Section AI.8.3), an indication of the average size of *R. pseudoumbilica* and the relationship between this species and *D. antarcticus* is presented.

AII.1.4 Pliocene *Discoaster* relative abundance counts

In those samples which contained sufficiently abundant Pliocene *Discoaster* assemblages, a count was made of the various species, in accordance with the work of Driever (1981, Section 5.6.2). These counts, which were carried out separate from the 100-specimen counts, were used to locate samples in relation to various *Discoaster* acme and paracme zones of Driever (1988, Section 5.6.2.2).

AII.1.4 Barren and extremely low abundant samples

Those samples which contained no calcareous nannofossil specimens are labelled 'barren'. In several samples only a few calcareous nannofossil specimens were encountered; these are labelled 'extremely low abundance'. In such cases it was very difficult to determine whether the poor assemblage was due to contamination, a result of firing, post-depositional alteration or other processes which can reduce the abundance and diversity of calcareous nannofossil assemblages in archaeological ceramics (Chapter 3), or simply due to a low abundance in the original clay.

AII.1.5 Reworking

Reworked specimens were encountered in the floras of some pottery samples, these are underlined in the assemblage descriptions.

AII.1.6 Biostratigraphic assignment

A biostratigraphic assignment, relative to the standard calcareous nannofossil zonation of Martini (1971) and/or the Mediterranean zonations of Theodoridis (1984) and Driever (1988), is given for all samples except those which were barren or contained a very poor assemblage. This is accompanied by the corresponding geological Age and Stage.

AII.2 Pottery from the South Coast production group (Section 11.2)

KAC 94/12.

Barren.

KAV 93/76.

Barren.

MFK 93/3.

Barren.

MFK 93/6.

Extremely low abundance. Tentatively late Neogene.

MFK 93/12.

Extremely low abundance. Tentatively late Neogene.

MFK 93/27.

Barren.

MFK 93/28.

Barren.

MFK 93/37.

Barren.

MFK 93/38.

Barren.

MFK 93/48.

Barren.

MFK 93/55.

Low abundance, poor to very poorly preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (F), *Coccolithus pelagicus* (EX), *Cyclicargolithus abisectus* <11μm (F), *Dictyococcites antarcticus* (A), *D. productus* (R), *D. cf. surculus* (R), six-rayed indet. *Discoaster sp.* (F), *Helicosphaera carteri* (F), *Helicosphaera sp.* (C), *R. minutula* (C), *R. pseudoumbilica* (C), *Sphenolithus spp.* (C).

Biostratigraphic assignment: Late Miocene, tentatively late NN 11 or NN 12 (Messinian).

MFK 93/58.

Barren.

MFK 93/68.

Barren.

MFK 93/69.

Barren.

MFK 93/71.

Barren.

MFK 93/87.

Barren.

MFK 93/94.

Barren.

MFK 93/99.

Very low abundance, reasonably well-preserved.

Assemblage: *Coccolithus pelagicus, Dictyococcites productus,* small *Gephyrocapsa sp., Reticulofenestra minuta, R. minutula, Sphenolithus spp.* (including one *S. cf. quadrispinatus*).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13-15.

MFK 93/102.

Low abundance, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus miopelagicus* (R), *C. pelagicus* (A), *Cyclicargolithus abisectus* <11μm (C), *Cyclicargolithus floridanus* (F), *Dictyococcites antarcticus* (A), *D. productus* (A), *Discoaster barbadiensis* (P), *D. pentaradiatus* (R), *Helicosphaera carteri* (F), *Pontosphaera japonica* (R), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (F), *R. minutula* (C), *R. pseudoumbilica* (A), *Sphenolithus spp.* (C).

Biostratigraphic assignment: Late Miocene, NN 10 or late NN 11 (mid Tortonian or Messinian).

MFK 93/105.

Reasonably abundant, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus* (A), *C. macintyrei* (P), *Cocccolithus pelagicus* (VA), *Cyclicargolithus abisectus* <11μm (P), *Dictyococcites antarcticus* (F), *D. productus* (F), *Discoaster cf. variabilis* (P), six-rayed indet. *Discoaster sp.* (F), *Geminilithella spp.* (P), *Helicosphaera carteri* (A), *H. sellii* (P), *Helicosphaera sp.* (F), *Pontosphaera japonica* (P), *P. multipora* (P), *Pontosphaera sp.* (R), ?*Pseudoemiliania lacunosa* (R), *Reticulofenestra minutula* (F), *R. pseudoumbilica* (A, average size = 7.3μm, abundance > *D. antarcticus*), *Sphenolithus spp.* (A), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), tentatively early NN 13 (NN 12-13 B).

MFK 93/116.

Extremely low abundance.

MFK 93/117.

Barren.

MFK 93/127.

Extremely low abundance. Tentatively late Neogene.

MFK 93/129.

Barren.

MFK 93/133.

Barren.

MFK 93/138.

Barren.

MFK 93/142.

Barren.

MFK 93/148.

Barren.

MFK 93/169.

Barren.

MFK 93/185.

Barren.

MFK 93/196.

Very abundant, variable but reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (C), *Cribrocentrum reticulatum* (P), *Cyclicargolithus abisectus* <11μm (F), *Dictyococcites antarcticus* (A), *D. productus* (A), *Discoaster brouweri* (R), *Geminilithella spp.* (R), *Helicosphaera euphratis* (P), *H. palaeocarteri* (R), *H. sellii* (R), *Helicosphaera sp.* (R), *Reticulofenestra minuta* (VA), *R. minutula* (F), *R. pseudoumbilica* (A, average size = 7.8μm, abundance < *D. antarcticus*), *Sphenolithus spp.* (F), *Triquetorhabulus cf. carinatus* (R).

Biostratigraphic assignment: Latest Miocene or earliest Pliocene, tentatively late NN 11 to early NN 13 (Messinian or early Zanclian).

MFK 93/197.

Barren.

MFK 93/198.

Barren.

MPY 93/10.

Reasonably low abundance, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (A), *Coccolithus pelagicus* (C), ?*D. antarcticus* (R), *Dictyococcites productus* (A), *Discoaster variabilis* (F), *Helicosphaera carteri* (F), *H. cf. euphratis* (R), *Neocrepidolithus sp.* (R), *Pontosphaera multipora* (F), ?*Pseudoemiliania lacunosa* (R), *R. minuta* (C), *R. minutula* (C), *R. pseudoumbilica* (abundance > *D. antarcticus*) (F), *Sphenolithus spp.* (A).

Biostratigraphic assignment: Early Pliocene (Zanclian), tentatively early NN 13 (NN 12-13 B).

MPY 93/20.

Very low abundance, reasonably well-preserved.

Assemblage: *Coccolithus pelagicus, Dictyococcites productus, Geminilithella spp., Sphenolithus spp.*

Biostratigraphic assignment: Late Neogene.

MPY 93/24.

Extremely low abundance. Tentatively late Neogene.

MPY 93/25.

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calicidiscus leptoporus* (F), *Coccolithus formosus* (F), *C miopelagicus* (P), *C. pelagicus* (C), *Cribrocentrum reticulatum* (P), *Cyclagelosphaera abisectus* <11μm (F), *Dictyococcites antarcticus* (A), *D. productus* (A), *Geminilithella sp.* (R), *Helicosphaera carteri* (F), *H. intermedia* (P), *Helicosphaera cf. pacifica* (R), *Pontosphaera japonica* (R), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (A), *Sphenolithus spp.* (F).

Biostratigraphic assignment: Late Miocene, tentatively late NN 11 (Messinian).

MPY 93/26.

Barren.

MPY 93/27.

Barren.

MPY 93/37.

Barren.

MPY 93/40.

Barren.

MPY 93/48.

Extremely low abundance. Tentatively late Neogene.

AII.3 Knossos Dark Faced Incised Ware ceramics (Section 11.3)

Kn 86/1.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (F), *Discoaster brouweri* (P), *D. cf. deflandrei* (R), *D. pentaradiatus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (A), *Helicosphaera carteri* (F), *H. intermedia* (P), *H. palaeocarteri* (P), *Pontosphaera japonica* (R), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (R, average size =

6.9 μm, abundance > *D. antarcticus*), *Scyphosphaera piriformis* (P), *Sphenolithus spp.* (F, including *Sphenolithus verensis*), *Umbilicosphaera sp.* (F).

Biostratigraphic assignment: Early Pliocene, (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/2.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *C. macintyrei* (P), *Coccolithus pelagicus* (F), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *Discoaster brouweri* (R), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (R), *Geminilithella sp.* (F), *H. intermedia* (P), *Pontosphaera japonica* (P), *Pontosphaera sp.* (R), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (R), *Sphenolithus spp.* (F), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (F).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/4.

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Dictyococcites antarcticus* (R), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (P), *Discoaster brouweri* (P), *D. pentaradiatus* (P), *D. pansus* (P), *D. variabilis* (R), six-rayed indet. *Discoaster sp.* (C), *Geminilithella sp.* (P), *Helicosphaera carteri* (R), *H. intermedia* (P), *H. palaeocarteri* (P), *Pontosphaera japonica* (R), *P. multipora* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (A), *R. minutula* (C), *Scyphosphaera globulosa* (R), *S. pulcherrima* (P), *Sphenolithus spp.* (C), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/5.

Very abundant, reasonably well-preserved.

Assemblage: *Amaurolithus sp.* (P), *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Ceratolithus acutus* (P), *Coccolithus. pelagicus* (P), *C. miopelagicus* (P), ?*Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (F), *Discoaster brouweri* (P), *D. pentaradiatus* (P), *D. variabilis* (R), six-rayed indet. *Discoaster sp.* (R), *Geminilithella sp.* (F), *Helicosphaera carteri* (P), *H. intermedia* (P), *H. palaeocarteri* (P), *Pontosphaera japonica* (P), *P. multipora* (P), *Pseudoemiliania lacunosa* (R), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (R, average size = 6.7 μm, abundance > *D. antarcticus*), *Scyphosphaera globulosa* (P), *S. pulcherrima* (P), *Sphenolithus spp.* (C), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/6.

Abundant, reasonably well-preserved.

Assemblage: *Amaurolithus primus* (P), *Calcidiscus leptoporus* (R), *C. macintyrei* (R), *Coccolithus. pelagicus* (R), *Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *Discoaster brouweri* (P), *D. cf. deflandrei* (P), *D. pentaradiatus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (C), *Helicosphaera carteri* (R), *H. palaeocarteri*

(R), *Pontosphaera japonica* (P), *P. multipora* (R), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (P, average size = 6.8 µm, abundance > *D. antarcticus*), *Sphenolithus spp.* (F, including *Sphenolithus verensis*), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/7.

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Coccolithus pelagicus* (R), *Cyclicargolithus abisectus* (P), *Dictyococcites antarcticus* (R), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (P), six-rayed indet. *Discoaster sp.* (P), small *Gephyrocapsa sp.* (P), *Helicosphaera carteri* (F), *P. multipora* (P), *Reticulofenestra minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (F, average size = 6.72 µm, abundance > *D. antarcticus*), *Scyphosphaera globulosa* (P), *Sphenolithus spp.* (C, including *Sphenolithus verensis*), *Thoracosphaera sp.* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/8.

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Ceratolithus acutus* (P), *Coccolithus pelagicus* (R), ?*Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *Discoaster brouweri* (P), *D. pentaradiatus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (R), *Geminilithella* *sp.* (R), *Helicosphaera carteri* (F), *H. euphratis* (P), *Micrantholithus sp.* (P), *Pontosphaera sp.* (R), *Reticulofenestra minuta* (A), *R. minutula* (F), *R. pseudoumbilica* (R, abundance > *D. antarcticus*), *Scyphosphaera pulcherrima* (P), *Sphenolithus spp.* (F), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (F).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/9.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *Discoaster pentaradiatus* (P), *D. pansus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (P), *Helicosphaera carteri* (F), *H. intermedia* (P), *H. palaeocarteri* (P), *Pontosphaera japonica* (R), *Pontosphaera sp.* (R), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (A), *R. minutula* (F), *R. pseudoumbilica* (P, average size = 6.7 μm, abundance>*D. antarcticus*), *Scyphosphaera apsteinii* (P), *Sphenolithus spp.* (F), *Thoracosphaera sp.* (R), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/10.

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus formosus* (P), *C. pelagicus* (R), *Dictyococcites antarcticus* (R), *D. productus* (VA), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (F), six-rayed indet. *Discoaster sp.* (P), *H. intermedia* (P), *H. palaeocarteri* (P), *Pontosphaera japonica* (P), *P. multipora* (P), *Reticulofenestra* *minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (P), *Sphenolithus spp.* (A, including *Sphenolithus verensis*), *Thoracosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/11.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus. pelagicus* (R), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (F), *D. pentaradiatus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (F), *Geminilithella sp.* (F), *Helicosphaera carteri* (F), *H. intermedia* (R), *H. palaeocarteri* (P), *H. cf. sellii* (P), *Pontosphaera japonica* (P), *P. multipora* (R), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (VA), *R. minutula* (A), *Sphenolithus spp.* (F), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/12.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (F), *Coccolithus pelagicus* (P), Cyclicargolithus abisectus (P), *Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *D. pentaradiatus* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (F), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *Pontosphaera japonica* (R), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (A), *R. minutula* (F), *R. pseudoumbilica* (P, abundance > *D. antarcticus*), *Sphenolithus spp.* (C), *Syracosphaera cf. fragilis* (R), *Thoracosphaera sp.* (F), *Umbilicosphaera sp.* (F).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13B).

Kn 86/13.

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus. pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (F), *Discoaster brouweri* (P), *D. pentaradiatus* (R), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (C), *Helicosphaera carteri* (P), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (VA), *R. minutula* (C), *R. pseudoumbilica* (R, abundance > *D. antarcticus*), *Scyphosphaera canescens* (P), *S. piriformis* (P), *Sphenolithus spp.* (F), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (F).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13, (tentatively late subzone NN 12-13B).

Kn 86/14.

Reasonably abundant, poorly preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Coccolithus. pelagicus* (R), *Dictyococcites antarcticus* (F), *D. productus* (EX), six-rayed indet. *Discoaster sp.* (P), ?small *Gephyrocapsa sp.* (R), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *Pontosphaera japonica* (P), ?*Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (R, abundance < *D. antarcticus*), *Sphenolithus spp.* (A, including *Sphenolithus verensis*).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13 B).

Kn 86/15.

Barren.

Kn 86/16.

Abundant, reasonably well-preserved.

Assemblage: *C. macintyrei* (P), *Coccolithus formosus* (P), *C. pelagicus* (P), *D. productus* (EX), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (P), *Discoaster brouweri* (P), *D. cf. deflandrei* (P), *D. pentaradiatus* (P), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (P), *Helicosphaera carteri* (R), *H. cf. euphratis* (P), *H. intermedia* (P), *H. palaeocarteri* (P), *H. sellii* (R), *Pontosphaera japonica* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (A), *R. minutula* (F), *R. pseudoumbilica* (P), *Sphenolithus spp.* (F, including *Sphenolithus verensis*), *Thoracosphaera sp.* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (subzone NN 12-13B).

Kn 86/17.

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (R), *C. macintyrei* (P), *Ceratolithus cf. acutus* (P), *Coccolithus pelagicus* (R), *Cyclicargolithus floridanus* (R), *Dictyococcites antarcticus* (R), *D. productus* (C), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (P), *Discoaster brouweri* (F), *D. pentaradiatus* (F), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (R), *Geminilithella sp.* (R), *Helicosphaera carteri* (F), *H. sellii* (P), indet. holococcolith (R), *Pontosphaera japonica* (P), *P. multipora* (P), *Pseudoemiliania lacunosa* (F), *Reticulofenestra minuta* (VA), *R. minutula* (VA), *R. pseudoumbilica* (R, average size = 8.97 µm, abundance > *D. antarcticus*), *Sphenolithus verensis* (R), *Sphenolithus spp.* (F), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (tentatively subzone NN 12-13C).

AII.4 Knossian Early and Middle Minoan pottery (Section 11.3)

Kn 95/172.

Low abundance, poorly preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (F), *Dictyococcites antarcticus* (R), *D. productus* (R), *Discoaster bollii* (R), *D. cf. exilis* (R), indet. *Discoaster sp.* (R), *Helicosphaera carteri* (F), *Reticulofenestra minuta* (F), *R. minutula* (F), *R. pseudoumbilica* (A), *Sphenolithus spp.* (EX).

Biostratigraphic assignment: Late Miocene, tentatively NN 9 (Early Tortonian).

Kn 95/187.

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus, Coccolithus pelagicus, Dictyococcites antarcticus, D. productus, Discoaster pentaradiatus, D. variabilis, Helicosphaera carteri, H. sellii, Reticulofenestra minuta, R. minutula, Sphenolithus spp* (including *Sphenolithus verensis*).

Biostratigraphic assignment: Late Neogene, tentatively NN 11 to NN 13 (late Tortonian to early Zanclian).

Kn 95/211.

Reasonably abundant, variable preservation.

Assemblage: *Calcidiscus leptoporus* (A), *Coccolithus formosus* (F), *C. pelagicus* (F), *Cyclicargolithus abisectus* <11μm (R), *Dictyococcites productus* (A), *Discoaster brouweri* (R), *D. pentaradiatus* (R), *D. cf. variabilis* (R), six-rayed indet. *Discoaster* *spp.* (R), *Helicosphaera carteri* (F), *H. cf. mediterranea* (R), *H. palaeocarteri* (P), *Helicosphaera sp.* (F), *Pontosphaera multipora* (R), *Reticulofenestra minuta* (A), *R. minutula* (F), *R. pseudoumbilica* (F), *Sphenolithus spp.* (VA), *Tetralithoides symeonedesii* (P).

Biostratigraphic assignment: Latest Miocene or earliest Pliocene..

Kn 95/212.

Barren.

Kn 95/213.

Barren.

Kn 94/214.

Extremely low abundance. Tentatively late Neogene.

Kn 95/222.

Reasonably abundant, well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (VA), *Discoaster brouweri* (P), *D. pentaradiatus* (P), *D. surculus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P): (*D. brouweri* 25%, *D. pentaradiatus* 29%, *D. surculus* 4%, *D. variabilis* 12.5%, six-rayed indet. *Discoaster sp.* 29%: out of a 25 specimen count), *Geminilithella sp.* (F), small *Gephyrocapsa spp.* (A), *Hayaster perplexus* (P), *Helicosphaera carteri* (R), *H. palaeocarteri* (P), *H. sellii* (R), *Helicosphaera sp.* (R), *Pontosphaera japonica* (R), *P. multipora* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (VA), *R. minutula* (C), *R. pseudoumbilica* (F, abundance > *D. antarcticus*), *Rhabdosphaera procera* (P), *Scyphosphaera lagena* (P), *Sphenolithus spp.* (R), *Syracosphaera cf. fragilis* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), late NN 13 (subzone NN 12-13C).

Kn 95/223.

Reasonably abundant, variable preservation.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus formosus* (F), *C. pelagicus* (VA), *Cyclicargolithus abisectus* (F), *Dictyococcites antarcticus* (F), *D. productus* (C), *Geminilithella sp.* (R), *Helicosphaera carteri* (R), *H. palaeocarteri* (R), *Reticulofenestra minuta* (A), *R. minutula* (A), *R. pseudoumbilica* (F), *Sphenolithus spp.* (A).

Biostratigraphic assignment: Late Neogene, Late Miocene or Early Pliocene.

Kn 95/233.

Reasonably abundant, well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (VA), *D. asymmetricus* (P), *D. pentaradiatus* (R), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), *Helicosphaera carteri* (P), *H. palaeocarteri* (P), *Reticulofenestra minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (R), *Rhabdosphaera procera* (P), *Sphenolithus spp.* (A), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Late Neogene, tentatively Early Pliocene (Zanclian), zone NN 13.

Kn 95/234.

Reasonably abundant, variable but generally well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Coccolithus pelagicus* (F), *Cyclicargolithus cf. floridanus* (P), ?*Dictyococcites antarcticus* (R), *D. productus* (C), *Discoaster brouweri* (R), *Discoaster cf. variabilis* (P), five-rayed indet. *Discoaster sp.* (R), six-rayed indet. *Discoaster sp.* (R), ?*Ericsonia sp.* (P), small *Gephyrocapsa sp.* (VA), *Helicosphaera carteri* (F), *Helicosphaera sp.* (R), *H. sellii* (P), *Helicosphaera sp.* (R), *Holodiscolithus macroporus* (F), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (VA), *R. minutula* (C), *R.. pseudoumbilica* (P, size = 8-10 μm), *Sphenolithus spp.* (A).

Biostratigraphic assignment: Early Pliocene (Zanclian), latest NN 13 (subzone NN 12-13C).

Kn 95/235.

Reasonably abundant, poor preservation.

Assemblage: *Calcidiscus leptoporus* (A), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Dictyococcites antarcticus* (P), *D. productus* (C), *Discoaster cf. asymmetricus* (P), *D. brouweri* (F), six-rayed indet. *Discoaster sp.*(P), *D. pentaradiatus* (P), *D. cf. surculus* (R), *Helicosphaera carteri* (P), *H. cf. mediterranea* (P), *H. palaeocarteri* (P), *H. cf. sellii* (P), *Helicosphaera sp.* (P), *Pontosphaera japonica* (R), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (EX), *R. minutula* (C), *R. pseudoumbilica* (C) (average size = 7.5 μm, abundance > *D. antarcticus*), *Rhabdosphaera procera* (P), *Scyphosphaera sp.* (P), *Sphenolithus spp.* (A, including *Sphenolithus cf. verensis*).

Biostratigraphic assignment: Late Neogene, NN 11-NN 13, Late Miocene or Early Pliocene.

Kn 95/236.

Extremely low abundance. Tentatively late Neogene.

Kn 95/237.

Low abundance, poor preservation.

Assemblage: *Calcidiscus leptoporus* (VA), *Coccolithus pelagicus* (R), *D. cf. antarcticus* (F), *Discoaster brouweri* (F), *D. pentaradiatus* (P), six-rayed indet. *Discoaster sp.* (VA), *Helicosphaera carteri* (C), *H. palaeocarteri* (R), *Reticulofenestra minutula* (C), *R. pseudoumbilica* (A, average size = 6.9 μm, abundance > *D. antarcticus*), *Sphenolithus spp.* (A).

Biostratigraphic assignment: Late Neogene, tentatively latest Miocene or earliest Pliocene).

Kn 95/238.

Extremely low abundance.

Kn 95/239.

Reasonably abundant, variable preservation.

Assemblage: *Braarudosphaera bigelowii* (P), *Calcidiscus leptoporus* (C), *C. macintyrei* (P), *Coccolithus pelagicus* (R), Cribrocentrum reticulatum (P), Cyclicargolithus abisectus <11μm (R), *Dictyococcites antarcticus* (R), *D. productus* (C), *Discoaster asymmetricus* (P), *D. brouweri* (F), *D. pentaradiatus* (P), *D. cf. surculus* (P), *D. cf. variabilis* (P), six-rayed indet. *Discoaster sp.* (F), *Geminilithella sp.* (R), small *Gephyrocapsa sp.* (F), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *H. sellii* (P), *Helicosphaera sp.* (F), *Holodiscolithus macroporus* (P), *Pontosphaera japonica* (P), *P. multipora* (P), *Reticulofenestra minuta* (EX), *R. minutula* (C), *R. pseudoumbilica* (F, average size = 8.4 μm, abundance > *D. antarcticus*), *Rhabdosphaera procera* (P), *Sphenolithus spp.* (A), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), tentatively NN 13 (early NN 12-13C).

Kn 95/240.

Very low abundance, reasonably well-preserved.

Assemblage: *Dictyococcites productus,* indet. *Discoaster sp., Reticulofenestra minuta, R. minutula.*

Biostratigraphic assignment: Late Neogene.

Kn 95/246.

Very low abundance, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus, Dictyococcites productus, Discoaster brouweri,* six-rayed indet. *Discoaster sp., Helicosphaera carteri, Reticulofenestra minuta, R. minutula, Sphenolithus spp.*

Biostratigraphic assignment: Late Neogene.

Kn 95/250.

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus pelagicus* (F), *Dictyococcites antarcticus* (F), *D. productus* (VA), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (R), small *Gephyrocapsa sp.* (F), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *H. sellii* (F), *Pontosphaera multipora* (R), *Reticulofenestra minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (F), *Sphenolithus spp.* (F).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (late NN 12-13B).

Kn 95/277.

Extremely low abundance.

Kn 95/361.

Reasonably low abundance, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus* (A), *C. macintyrei* (F), *Coccolithus pelagicus* (A), *Dictyococcites antarcticus* (F), *D. productus* (F), *Discoaster brouweri* (R), *D. pentaradiatus* (R), six-rayed indet. *Discoaster sp.* (F), *Helicosphaera carteri* (C), *Helicosphaera sp.* (F), *Pontosphaera japonica* (F), *Pontosphaera multipora* (F), *Pontosphaera sp.* (R), *Reticulofenestra minuta* (F), *R. minutula* (R), *R. pseudoumbilica* (C), *Sphenolithus spp.* (VA).

Biostratigraphic assignment: Late Neogene, Late Miocene or Early Pliocene (NN 10 to NN 13).

Kn 95/372.

Reasonably abundant, well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (F), *Dictyococcites antarcticus* (P), *D. productus* (A), *Discoaster pentaradiatus* (R), *D. cf. variabilis* (P), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *Helicosphaera sellii* (P), *Helicosphaera sp.* (F), *Pontosphaera multipora* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (EX), *R. minutula* (F), *R. pseudoumbilica* (R), *Sphenolithus spp.* (A), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Late Neogene, latest Miocene or earliest Pliocene.

Kn 95/376.

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (R), *Coccolithus pelagicus* (C), *Dictyococcites antarcticus* (F), *D. productus* (VA), *Discoaster pentaradiatus* (P), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (P), small *Gephyrocapsa sp.* (R), *Helicosphaera intermedia* (P), *H. palaeocarteri* (R), *Helicosphaera sp.* (F), *Pontosphaera japonica* (P), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (VA), *R. minutula* (F), *R. pseudoumbilica* (C, average size = 7.1 μm, abundance > *D. antarcticus*), *Sphenolithus spp.* (C).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13 B).

Kn 95/382.

Extremely low abundance. Tentatively late Neogene.

Kn 95/387.

Extremely low abundance. Tentatively late Neogene.

Kn 95/400.

Reasonably abundance. Tentatively late Neogene.

Assemblage: *Calcidiscus leptoporus* (F), *Coccolithus formosus* (P), *C. pelagicus* (R), *Dictyococcites antarcticus* (R), *D. productus* (VA), *D. productus*/small *Gephyrocapsa sp.* transitional specimens (R), *Geminilithella sp.* (F), small *Gephyrocapsa sp.* (F), *Helicosphaera carteri* (F), ?*Pseudoemiliania lacunosa* (R), *Reticulofenestra minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (F, average size = 7.5μm, abundance > *D. antarcticus*), *Sphenolithus spp.* (C).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13 B).

Kn 95/407.

Extremely low abundance.

AII.5 Pottery from the 'Mirabello tradition' (Section 11.4)

KAC 94/28.

Barren.

KAC 94/27.

Barren.

MFK 93/17.

Extremely low abundance.

MFK 93/19.

Low abundance, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Dictyococcites productus* (C), six-rayed indet. *Discoaster sp.* (R), *Geminilithella sp.* (R), *Helicosphaera carteri* (F), *Helicosphaera sp.* (F), *Reticulofenestra minuta* (VA), *R. minutula* (VA), *Sphenolithus spp.* (F, including one *Sphenolithus verensis*).

Biostratigraphic assignment: Late Neogene (Late Miocene or Early Pliocene), NN 11-NN 13, tentatively Small *Reticulofenestra* interval (late NN 10 - mid NN 11).

MFK 93/20.

Extremely low abundance. Tentatively late Neogene.

MFK 93/110.

Barren.

MFK 93/173.

Extremely low abundance.

MFK 93/180.

Very low abundance, reasonably well-preserved.

Assemblage: *Coccolithus pelagicus, Dictyococcites productus, Helicosphaera carteri, Reticulofenestra minuta, R. minutula, R. pseudoumbilica.*

Biostratigraphic assignment: Late Neogene (Late Miocene or Early Pliocene).

MPY 93/17.

Extremely low abundance.

MPY 93/18.

Barren.

AII.6 Punic ceramics and possible raw materials from Mozia (Section 11.6)

MK 2.

Very abundant, variable but generally well-preserved.

Assemblage: *Braarudosphaera cf. regularis* (P), *Biscutum ellipticum* (R), *Calcicalathina oblongata* (P), *Calcidiscus leptoporus* (R), *Caliculities cf. obscurus* (F), *Caliculities sp.* (P), *Ceratolithoides kamptneri* (P), *Coccolithus formosus* (P), *C. miopelagicus* (P), *C. pelagicus* (A), *Cribrocentrum reticulatum* (R), *Cruciellipsus cuvillieri* (P), *Cruciplacolithus cribellum* (R), *Cyclicargolithus abisectus* (C), *Dictyococcites antarcticus* (R), *D. bisectus* (F), *D. productus* (C), *Discoaster barbadiensis* (R), *D. deflandrei* (P), *D. cf. druggii* (P), *D. mohleri* (R), six-rayed indet. *Discoaster sp.* (R), *Ericsonia cava* (P), *E. robusta* (R), *E. subdisticha* (R), *Helicosphaera carteri* (R), *H. compacta* (R), *H. intermedia* (R), *H. recta* (P), *Lucianorhabdus sp.* (P), *Micula decussata* (R), *Podorhabdus sp.* (R), *Polypodorhabdus escagii* (P), *Pontosphaera multipora* (P), *Prinsius sp.* (R), *Pyrocyclus orangensis* (R), *Quadrum sp.* (P), unidentifiable member of the family Retecapsaceae (P), *Reticulofenestra minuta* (VA), *R. pseudoumbilica* (C), *Sollasities sp.* (R), *Sphenolithus anarrhopus* (R), *S. moriformis* (P), *S. neoabies* (P), *Sphenolithus* *sp.* (F), *Thoracosphaera sp.* (P), *Triqetorhabdulus carinatus* (P), *Watznaueria barnesae* (R).

Biostratigraphic assignment: A mixed assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Palaeocene or Early Eocene, Late Eocene to Early Oligocene, Late Oligocene to Early Miocene and late Neogene (Late Miocene?).

MK 6.

Abundant, extremely variable but generally poorly-preserved.

Assemblage: *Arkhangelskiella specillata* (R), *Calcidiscus leptoporus* (F), *Coccolithus formosus* (R), *C. miopelagicus* (R), *C. pelagicus* (C), *Cribrosphaerella ehrenbergii* (R), *Cyclagelosphaera margerelii* (P), *Cyclicargolithus abisectus* (A), *Dictyococcites antarcticus* (F), *D. bisectus* (C), *D. productus* (C), *Discoaster barbadiensis* (P), *D. mohleri* (R), six-rayed indet. *Discoaster sp.* (P), *Geminilithella sp.* (R), small *Gephyrocapsa sp.* (R), *Helicosphaera intermedia* (P), *H. palaeocarteri* (P), *Helicosphaera sp.* (P), *Micula decussata* (P), *Nannoconus elongatus* (P), *N. steinmannii minor* (P), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Quadrum sissinghii* (P), *Reticulofenstra minuta* (A), *R. minutula* (A), *R. pseudoumbilica* (C), *Rhagodiscus cf. asper* (R), *Sphenolithus neoabies* (F), *Sphenolithus sp.* (F), *Watznaueria barnesae* (F).

Biostratigraphic assignment: A mixed assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Oligocene or Early Miocene and Late Neogene (Early Pliocene?), and possibly the Late Palaeocene or Early Eocene.

MK 7.

Extremely abundant, variable but reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (R), *Caliculities cf. obscurus* (F), *Chiastozygus sp.* (P), *Coccolithus miopelagicus* (F), *C. pelagicus* (A), *Cribrocentrum reticulatum* (P), *Cyclicargolithus abisectus* (C), *C. floridanus* (R), *Dictyococcites antarcticus* (F), *D. bisectus* (F), *D. productus* (F), *Discoaster barbadiensis* (P), *D. deflandrei* (R), *D. cf. druggii* (P), *D. cf. kugleri* (P), *D. mohleri* (P), *D. saipanensis* (P), *D. tanii* (R), *D. tanii nodifer* (P), *Eiffellithus eximius* (P), *Helicosphaera carteri* (R), *H. euphratis* (P), *H. gertae* (P), *H. palaeocarteri* (P), *Lucianorhabdus cayeuxii* (R), *Micula decussata* (P), *Micula swastica* (R), *Nannoconus cf. steinmannii* (P), *Pontosphaera multipora* (R), *Prediscosphaera majungae* (P), *P. cf. stoveri* (P), *Retecapsa angustiforata* (P), *Reticulofenstra minuta* (C), *R. minutula* (A), *R. pseudoumbilica* (A), *R. umbilica* (R), *Sollasities sp.* (P), *Sphenolithus obtusus* (R), *S. predistensis* (R), *S. moriformis* (R), *S. neoabies* (P), *S. tribulosus* (P), *Sphenolithus sp.* (F), *Teichorhabdus ethmus* (P), *Thoracosphaera sp.* (P), ?*Triqetorhabdulus shetlandensis* (P), *Watznaueria barnesae* (F), *Zeugrhabdotus embergeri* (P).

Biostratigraphic assignment: A mixed assemblage containing calcareous nannofossils which are indicative of the Late Cretaceous, Late Eocene, Early Miocene and late Neogene (Late Miocene or Early Pliocene).

MK 12.

Extremely low abundant, very poorly-preserved. May be contamination or highly degraded assemblage.

Assemblage: *Coccolithus pelagicus,* indet. *Discoaster sp.*, *Pontosphaera sp.*

MK 16.

Abundant, variable but reasonably poorly-preserved.

Assemblage: *Arkhangelskiella specillata* (P), *Calcidiscus leptoporus* (R), *Caliculities cf. obscurus* (R), *Coccoltihus formosus* (P), *C. miopelagicus* (R), *C. pelagicus* (A), *Cribrocentrum reticulatum* (P), *Cyclicargolithus abisectus* (A), *C. floridanus* (F), *Dictyococcites antarcticus* (P), *D. productus* (F), *D. bisectus* (C), *Discoaster barbadiensis* (P), *D. deflandrei* (F), *D. mohleri* (R), *D. variabilis* (P), six-rayed indet. *Discoaster sp.* (R), large *Gephyrocapsa sp.* (P), *Helicosphaera palaeocarteri* (P), *H. intermedia* (R), *Heliolithus sp.* (P), *Nannoconus cf. farinacciae* (P), *Nannoconus sp.* (P), *Podorhabdus sp.* (P), *Quadrum sp.* (P), *Reticulofenstra minuta* (F), *R. minutula* (A), *R. pseudoumbilica* (A), *Scyphosphaera sp.* (R), *Sphenolithus moriformis* (P), *Sphenolithus sp.* (F), *Watznaueria barnesae* (P).

Biostratigraphic assignment: A mixed assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Palaeocene, Late Eocene or Early Oligocene, Late Oligocene or Early Miocene, late Neogene (Late Miocene?) and possibly the Pleistocene.

Mo 3.

Reasonably abundant, variable but reasonably well-preserved.

Assemblage: *Arkhangelskiella sp.* (P), *Calcidiscus leptoporus* (R), *Caliculities cf. obscurus* (R), *Coccolithus formosus* (R), *C. miopelagicus* (F), *C. pelagicus* (A), *Cribrocentrum reticulatum* (R), *Cyclicargolithus abisectus* (A), *C. floridanus* (F), Dictyococcites antarcticus (F), D. bisectus (F), D. productus (F), possible D. productus/small Gephyrocapsa sp. transitional specimens (R), Discoaster cf. bellus (R), six-rayed indet. Discoaster sp. (R), Geminilithella sp. (R), Nannoconus cf. kamptneri (P), ?Pseudoemiliania lacunosa (R), Pyrocyclus orangensis (R), ?Quadrum trifidium (R), Retecapsa cf. angustiforata (R), Retecapsa sp. (R), Reticulofenestra minuta (A), R. minutula (A), R. pseudoumbilica (A), ?Speetonia colligata (P), Sphenolithus moriformis (F), Watznaueria barnesae (F), Zeugrhabdotus embergeri (R).

Biostratigraphic assignment: A mixed assemblage containing calcareous nannofossils which are indicative of the Early Cretaceous, Late Cretaceous, Late Oligocene or Early Miocene, late Neogene (Early Pliocene?) and possibly the Late Eocene or Early Oligocene.

Appendix III Calcareous nannofossil analysis of geological samples from the Neogene of Crete

AIII.1 Explanation of the assemblage descriptions

The calcareous nannofossil assemblages of the geological field samples from the Neogene of Crete are presented in terms of the relative abundance of their various taxa; as in the description of the calcareous nannofossil assemblages from archaeological ceramics (Section AII.1).

AII.2 Field samples from the south coast of Crete

Sample α (Parathiri member of the Males Formation)

Low abundance, poor preservation.

Assemblage: *Coccolithus formosus* (F), *C. miopelagicus* (C), *C. pelagicus* (A), *Cribrocentrum reticulatum* (R), *Cyclicargolithus abisectus* <11μm (A), *Cyclicargolithus abisectus* >11μm (R), *C. floridanus* (F), *Dictyococcities antarcticus* (A), *D. productus* (F), *D. mohleri* (P), indet. six-rayed *Discoaster sp.* (F), indet. holococcolith (R), *Reticulofenestra minuta* (F), *R. minutula* (C), *R. pseudoumbilica* (C, including specimens >7μm), *Sphenolithus spp.* (C, including *Sphenolithus moriformis*, R and *Sphenolithus cf. conicus*, R).

Biostratigraphic assignment: Middle Miocene (late Serravalian), late NN 6 or early NN7.

Sample D (Kalamavka Formation)

Reasonably abundant, poorly preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Coccolithus miopelagicus* (R), *C. pelagicus* (F), ?*Coronocyclus nitescens* (P), *Cyclicargolithus abisectus* <11μm (F), *Cyclicargolithus floridanus* (R), *Dictyococcities antarcticus* (C), *D. cf. bisectus* (P), *D. productus* (F), indet. six-rayed *Discoaster sp.* (R), *Helicosphaera carteri* (R), *Pontosphaera multipora* (F), *Reticulofenestra minuta* (F), *R. minutula* (VA), *R. pseudoumbilica* (EX, including specimens >7μm), *Sphenolithus spp.* (R, including *Sphenolithus moriformis* R).

Biostratigraphic assignment: Middle Miocene (late Serravalian), tentatively late NN 6 or early NN 7.

Sample A (Makrylia Formation)

Abundant, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (F), *Cribrocentrum reticulatum* (P), *Dictyococcities antarcticus* (F), *D. productus* (A), *Discoaster brouweri* (R), *D. deflandrei* (P), *D. cf. mohleri* (P), indet. six-rayed *Discoaster sp.* (P), *Geminlithella sp.* (C), *Helicosphaera carteri* (F), *H. intermedia* (R), *Helicosphaera palaeocarteri* (P), *Helicosphaera sp.* (F), *Pontosphaera japonica* (P), *P. multipora* (R), *Pontosphaera sp.* (R), *Reticulofenestra minuta* (F), *R. minutula* (F), *R. pseudoumbilica* (P, including specimens >7μm), *Rhabdosphaera sp.* (P), *Sphenolithus spp.* (EX), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Late Miocene (early Tortonian), late NN 9.

Sample R (Makrylia Formation)

Very abundant, reasonably poor preservation.

Assemblage: *Braarudosphaera bigelowii* (R), *Calcidiscus leptoporus* (P), *C. macintyrei* (P), *Coccolithus pelagicus* (F), *Cyclicargolithus abisectus* <11μm (P), *Dictyococcities antarcticus* (F), *D. productus* (A), *Geminlithella sp.* (VA), *Helicosphaera carteri* (C), *H. intermedia* (P), *H. palaeocarteri* (R), *Helicosphaera sp.* (P), *Pontosphaera japonica* (F), *P. multipora* (P), *Pontosphaera sp.* (F), *Reticulofenestra minuta* (VA), *R. minutula* (F), *R. pseudoumbilica* (R), *Scyphosphaera amphora* (P), *Sphenolithus spp.* (A), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Late Miocene, tentatively NN 9 (early Tortonian).

Sample Y (Makrylia Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus miopelagicus* (P), *C. pelagicus* (C), *Dictyococcities antarcticus* (VA), *D. productus* (VA), indet. six-rayed *Discoaster sp.* (P), *Helicosphaera carteri* (F), *Helicosphaera intermedia* (P), *H. stalis* (P), *Pontosphaera japonica* (P), *P. multipora* (F), *Reticulofenestra minuta* (F), *R. minutula* (C), *R. pseudoumbilica* (A), *Sphenolithus spp.* (C), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Late Miocene, tentatively NN 8, (early Tortonian).

Sample W (Makrylia Formation)

Reasonably abundant, reasonably well-preserved.

Assemblage: *Braarudosphaera bigelowii* (P), *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus pelagicus* (C), *Dictyococcities antarcticus* (C), *D. productus* (A), *Discoaster brouweri* (R), *D. cf. deflandrei* (F), *D. exilis* (F), *D. mohleri*

(P), *D. cf. variabilis* (R), *D. pansus* (P), *Geminlithella sp.* (F), *Helicosphaera carteri* (A), *H. intermedia* (P), *H. palaeocarteri* (P), *H. stalis* (R), *Lithostromation perdurum* (P), *Pontosphaera japonica* (P), *P. multipora* (R), *Reticulofenestra minuta* (C), *R. minutula* (F), *R. pseudoumbilica* >7μm (P), *Sphenolithus spp.* (VA, including *Sphenolithus grandis*, P), *Syracosphaera cf. fragilis* (F), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Late Miocene (early Tortonian), late NN 9.

Sample S (Ammoudares Formation)

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (A), *Dictyococcities antarcticus* (F), *D. productus* (A), *D. pansus* (R), indet. six-rayed *Discoaster sp.* (R), *Geminlithella sp.* (R), *Helicosphaera carteri* (F), *H. euphratis* (P), *Helicosphaera sp.* (R), *Holodiscolithus macroporus* (P), *H. solidus* (P), *Pontosphaera japonica* (P), *P. multipora* (R), *Pontosphaera sp.* (R), *Reticulofenestra minuta* (C), *R. minutula* (F), *R. pseudoumbilica* (F, including specimens >7μm), *Scyphosphaera globulosa* (P), *Sphenolithus spp.* (VA).

Biostratigraphic assignment: Latest Miocene or earliest Pliocene (Messinian or Zanclian), late NN 11 or NN 12.

Sample C (Ammoudares Formation)

Very high abundance, variable preservation.

Assemblage: *Calcidiscus leptoporus* (VA), *C. macintyrei* (R), *Coccolithus pelagicus* (P), *Dictyococcities antarcticus* (P), *D. productus* (VA), *Discoaster cf. variabilis* (P), indet. six-rayed *Discoaster sp.* (C), *Geminlithella sp.* (P), possible small *Gephyrocapsa/Dictyococcities productus* transitional specimens (R), *Helicosphaera carteri* (P), *Pontosphaera japonica* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta*

(A), *R. minutula* (A), *Scyphosphaera apsteinii* (P), *S pulcherrima* (P), *Scyphosphaera spp.* (R), *Sphenolithus spp.* (R), *Triquetorhabdulus rugosus* (R).

Biostratigraphic assignment: Late Miocene or Early Pliocene (Messinian or Zanclian), NN 12 (tentatively NN 12-13A).

Sample ε (Ammoudares Formation)

Reasonably abundant, reasonably poor preservation.

Assemblage: *Dictyococcities antarcticus* (F), *D. productus* (F), *Geminlithella sp.* (F), *Helicosphaera carteri* (F), *Reticulofenestra minuta* (C), *R. minutula* (F), *Sphenolithus spp.* (EX) *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Late Miocene, tentatively in the 'small *Reticulofenestra* interval'(latest NN 10 or early NN 11) upper Tortonian.

Sample B (Myrtos Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *Coccolithus pelagicus* (R), *Dictyococcities productus* (VA), *Discoaster brouweri* (P), indet. six-rayed *Discoaster sp.* (P), small *Gephyrocapsa sp.* (R), *Helicosphaera carteri* (R), *Helicosphaera sp.* (R), *Reticulofenestra minuta* (EX), *R. minutula* (F), *R. pseudoumbilica* (F), *Scyphosphaera sp.* (R), *Sphenolithus spp.* (C).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (late NN 12-13B).

Sample I (Myrtos Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (R), *C. macintyrei* (P), *Dictyococcities antarcticus* (P), *D. productus* (VA), *Geminlithella sp.* (R), ?*Gephyrocapsa* >3.5μm (P), possible small *Gephyrocapsa/D. productus* transitional specimen (R), *Helicosphaera sellii* (R), *Pontosphaera japonica* (P), *P. multipora* (P), *Pontosphaera sp.* (R), ?*Pseudoemiliania lacunosa* (R), *Reticulofenestra minuta* (VA), *R. minutula* (VA), *R. pseudoumbilica* (P), *Sphenolithus spp.* (P), *Umbilicosphaera spp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 12 or NN 13 (late NN 12-13A or early NN 12-13B).

Sample κ (Myrtos Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *C. macintyrei* (R), *Coccolithus pelagicus* (P), *Dictyococcities antarcticus* (P), *D. productus* (F), *Discoaster asymmetricus* (P), *D. brouweri* (P), *D. cf. hamatus* (P), *D. tamalis* (P), indet. six-rayed *Discoaster spp.* (P), small *Gephyrocapsa spp.* (F), *Helicosphaera carteri* (P), *H. palaeocarteri* (R), *H. sellii* (F), *Pontosphaera japonica* (P), *Reticulofenestra minuta* (EX), *R. minutula* (F), *R. pseudoumbilica* (R, average size = 7.72 μm, abundance > *D. antarcticus*), *Sphenolithus spp.* (R, including *Sphenolithus verensis* P), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13B).

Sample L (Quaternary marine terraces).

Reasonably abundant, well-preserved.

Assemblage: *Calcidiscus leptoporus* (P), *C. macintyrei* (P), *D. productus* (A), small *Gephyrocapsa sp.* (VA), *Helicosphaera carteri* (P), *Helicosphaera cf. pavimentum* (C), *Reticulofenestra minuta* (VA), *R. minutula* (P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Late Early Pleistocene, NN 19E (small *Gephyrocapsa* interval).

AIII.3 North-central Cretan field samples

Sample 1 (Skinias Formation)

Reasonably abundant, reasonably well-preserved.

Assemblage: *Coccolithus formosus* (F), *C. pelagicus* (A), *Cribrocentrum reticulatum* (P), *Cyclicargolithus abisectus* <11 µm (F), *C. floridanus* (A), *Dictyococcities antarcticus* (A), *D. bisectus* (C), indet. six-rayed *Discoaster sp.* (P), indet. rosette *Discoaster sp.* (P), *Geminlithella sp.* (F), *Quadrum sp.* (R), *Reticulofenestra minuta* (F), *R. minutula* (A), *R. pseudoumbilica* >7µm (C), *Sphenolithus spp.* (A, including *Sphenolithus obtusus* R), *Tetralithus pyramidus* (P).

Biostratigraphic assignment: Middle Miocene (late Serravalian), late NN 6 or early NN 7.

Sample 2 (Skinias Formation)

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calculities cf. obscurus* (R), *Coccolithus formosus* (R), *C. miopelagicus* (P), *C. pelagicus* (A), *Cribrocentrum reticulatum* (P), *Cyclicargolithus abisectus* <11 µm (P), *C. floridanus* (VA), *Dictyococcities antarcticus* (C), *D. bisectus* (C), *D. productus* (C), *Discoaster deflandrei* (P), *D. mohleri* (P), *Geminlithella sp.* (R), *Micula decussata* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (F), *R. minutula* (F), *R. pseudoumbilica* (F, including specimens >7µm), *R. cf. umbilica* (P), *Sphenolithus spp.* (VA, including *Sphenolithus editus* P), *Watznaueria barnesae* (R).

Biostratigraphic assignment: Middle Miocene (late Serravalian), late NN 6 or early NN 7.

Sample 9 (Abelouzos Formation)

Abundant, well-preserved.

Assemblage: *Amaurolithus sp.* (P), *Calcidiscus leptoporus* (R), *Coccolithus pelagicus* (P), *Dictyococcities antarcticus* (P), *D. productus* (A), *Discoaster pentaradiatus* (P), indet. six-rayed *Discoaster sp.* (P), *Geminlithella sp.* (VA), *Helicosphaera carteri* (R), *H. intermedia* (P), *Pontosphaera japonica* (P), *Reticulofenestra minuta* (VA), *R. minutula* (C), *R. pseudoumbilica* ≤7μm (P), *Rhabdosphaera sp.* (P), *Sphenolithus sp.* (VA, including *Sphenolithus verensis*, P), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Late Miocene (late Tortonian), uppermost 'small *Reticulofenestra* interval' (mid NN 11).

Sample 15 (Abelouzos Formation)

Abundant, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus* (R), ?*Coccolithus miopelagicus* (P), *Coccolithus pelagicus* (F), *Cribrocentrum reticulatum* (P), *Cyclagelosphaera deflandrei* (P), *Cyclicargolithus abisectus* <11 μm (R), *Dictyococcities antarcticus* (R), *D. productus* (VA), *Geminlithella sp.* (C), *Helicosphaera carteri* (F), *Nannoconus sp.* (R), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (C), *R. minutula* (F), *Reticulofenestra pseudoumbilica* ≥7μm (F), *R. pseudoumbilica var. rotaria* (P), *Sphenolithus sp.* (VA), *Umbilicosphaera sp.* (F), *Watznaueria barnesae* (P).

Biostratigraphic assignment: Late Miocene (late Tortonian), '*Reticulofenestra pseudoumbilica var. rotaria* zone' (middle NN 11).

Sample 18 (Agia Varvara Formation limestones)

Reasonably abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (R), *Coccolithus pelagicus* (P), *Calculities cf. obscurus* (P), *Dictyococcities antarcticus* (P), *D. productus* (A), indet. six-rayed

Discoaster sp. (P), *Helicosphaera carteri* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (EX), *R. minutula* (R), *R. pseudoumbilica* ≤7μm (P), *Sphenolithus spp.* (A, including *Sphenolithus verensis,* P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Late Miocene, tentatively 'small *Reticulofenestra* interval' (early NN 11) late Tortonian.

Sample 20 (Agia Varvara Formation limestones)

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (VA), *Coccolithus pelagicus* (P), *Dictyococcities antarcticus* (R), *D. productus* (EX), *Helicosphaera carteri* (C), *H. intermedia* (P), *Pontosphaera japonica* (P), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (A), *R. minutula* (C).

Biostratigraphic assignment: Late Miocene (late Tortonian), 'small *Reticulofenestra* interval' (NN 11).

Sample 5 (Agia Varvara Formation marls)

Reasonably abundant, poor preservation.

Assemblage: Calculities cf. obscurus (P), Chiasmolithus sp. (R), *Coccolithus formosus* (F), *C. pelagicus* (VA), Cribrocentrum reticulatum (R), Cyclicargolithus abisectus (F), *Dictyococcities antarcticus* (A), *D. productus* (C), *Helicosphaera intermedia* (R), Micula decussata (R), *P. multipora* (R), *Reticulofenestra minuta* (A), *R. minutula* (C), *R. pseudoumbilica* (C, including specimens >7 μm, abundance < *D. antarcticus*), *Sphenolithus spp.* (A), Watznaueria barnesae (R).

Biostratigraphic assignment: Late Miocene, tentatively Messinian (upper NN 11).

Sample 6 (Finikia Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Daktylethra punctulata* (P), *Dictyococcities antarcticus* (R), *D. productus* (VA), *Dictyococcities productus*/small *Gephyrocapsa* transitional specimens (F), *Discoaster brouweri* (P), *D. pentaradiatus* (R), indet. six-rayed *Discoaster sp.* (P), *Geminlithella sp.* (R), *Helicosphaera carteri* (F), *Pontosphaera japonica* (P), *P. multipora* (P), *Reticulofenestra minuta* (VA), *R. minutula* (F), *R. pseudoumbilica* (A, average size = 7.6μm, abundance > *D. antarcticus*), *Scyphosphaera globulosa* (P), *Scyphosphaera sp.* (P), *Sphenolithus spp.* (P), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13B).

Sample 11.1 (Finikia Formation)

Very abundant, well-preserved.

Assemblage: *Braarudosphaera bigelowii* (P), *Calcidiscus leptoporus* (P), *C. macintyrei* (R), *Coccolithus pelagicus* (R), *Dictyococcities antarcticus* (P), *D. productus* (A), *Dictyococcities productus*/small *Gephyrocapsa* transitional specimens (P), *Discoaster asymmetricus* (P), *D. brouweri* (P), *D. pentaradiatus* (R), *D. surculus* (P), *D. tamalis* (P), *D. variabilis* (P), indet. six-rayed *Discoaster sp.* (P): (*D. asymmetricus* 11%, *D, brouweri* 27%, *D. pentaradiatus* 25%, *D. surculus* 13%, *D. tamalis* 13%, *D. variabilis* 8.3%: out of a 50 Discoaster count), *Geminlithella sp.* (F), *Helicosphaera carteri* (R), *H. sellii* (F), *Holodiscolithus macroporus* (P), *Pontosphaera japonica* (P), *P. multipora* (R), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (EX), *R. minutula* (A), *R. pseudoumbilica* (F, average size = 6.9μm, abundance > *D. antarcticus*), *Rhabdosphaera sp.* (P), *Scyphosphaera apsteinii* (P), *Scyphosphaera sp.* (P), *Sphenolithus spp.* (P), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13B).

Sample 11.5 (Finikia Formation)

Abundant, well-preserved.

Assemblage: *Amaurolithus delicatus* (P), *A. tricorniculatus* (P), *Calcidiscus leptoporus* (P), *Dictyococcities antarcticus* (P), *D. productus* (VA), *Dictyococcities productus*/small *Gephyrocapsa* transitional specimens (F), *Discoaster asymmetricus* (P), *D. brouweri* (R), *D. surculus* (P), *D. pentaradiatus* (P), *D. pentaradiatus* (P), *D. variabilis* (P), *D. pansus* (P): (*D. asymmetricus* 2%, *D. brouweri* 20%, *D. pentaradiatus* 52%, *D. pentaradiatus* 2%, *D. surculus* 8%, *D. variabilis* 8%- out of a 50 Discoaster count), *Geminlithella sp.* (F), small *Gephyrocapsa sp.* (R), *Holodiscolithus macroporus* (P), *Pontosphaera japonica* (R), *P. multipora* (P), *Reticulofenestra minuta* (EX), *R. minutula* (C), *R. pseudoumbilica* (C, average size = 6.88μm, abundance > *D. antarcticus*), *Rhabdosphaera sp.* (P), *Scyphosphaera globulata* (P), *Scyphosphaera pulcherrima* (P), *Sphenolithus spp.* (R), *Syracosphaera cf. fragilis* (P), *Umbilicosphaera sp.* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13B).

Sample 17 (Finikia Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *C. macintyrei* (P), *Coccolithus pelagicus* (P), *Dictyococcities antarcticus* (R), *D. productus* (EX), *D.* productus/small *Gephyrocapsa sp.* transitional specimens (F), *Discoaster brouweri* (R), *D. pentaradiatus* (P), indet. six-rayed *Discoaster sp.* (P), *Geminlithella sp.* (F), *Helicosphaera carteri* (F), *Pontosphaera japonica* (P), *Pontosphaera sp.* (P), *Pseudoemiliania lacunosa* (P), *Reticulofenestra minuta* (EX), *R. minutula* (C), *R. pseudoumbilica* (R, average size =

6.8 µm, abundance < *D. antarcticus*) *Sphenolithus spp.* (F, including *S. verensis*, P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13A or B).

Sample 16 (Finikia Formation)

Very abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (F), *Ceratolithus rugosos* (P), *Dictyococcities antarcticus* (F), *D. productus* (VA), *Dictyococcities productus*/small *Gephyrocapsa* transitional specimens (P), *Discoaster pansus* (P), indet. six-rayed *Discoaster sp.* (P), *Geminlithella sp.* (A), small *Gephyrocapsa sp.* (P), *Helicosphaera carteri* (R), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (VA), *R. minutula* (A), *R. pseudoumbilica* (F, average size = 9.5µm, abundance > *D. antarcticus*), *Scyphosphaera apsteinii* (P), *S. pulcherrima* (P), *Scyphosphaera sp.* (P), *Sphenolithus spp.* (F), *Syracosphaera cf. fragilis* (R), *Umbilicosphaera sp.* (F), *Watznaueria barnesae* (P).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (NN 12-13C).

AIII.4 Field samples from the Gulf of Mirabello and Isthmus of Ierapetra

Sample 98D (basal Pakhiammos Formation)

Low abundance, reasonably poor preservation.

Assemblage: *Calcidiscus leptoporus* (R), *Caliculities sp.* (R), *Coccolithus formosus* (F), *C. pelagicus* (VA), *Cyclicargolithus abisectus* <11µm (C), *C. floridanus* (F), *Dictyococcities antarcticus* (A), *D. bisectus* (F), *D. productus* (C), indet. six-rayed *Discoaster sp.* (R), *Reticulofenestra minuta* (R), *R. minutula* (F), *R. pseudoumbilica*

(A, average size = 6.6µm, abundance < *D. antarcticus*), *Sphenolithus spp.* (A), Watznaueria barnesae (F).

Biostratigraphic assignment: Late Neogene, tentatively Messinian or earliest Zanclian (late NN 11 or NN 12)..

Sample 98E (laminated marls of upper Pakhiammos Formation)

Abundant, well-preserved.

Assemblage: *Amaurolithus delicatus* (P), *Calcidiscus leptoporus* (R), Chiasmolithus sp. (P), *Coccolithus formosus* (R), *C. pelagicus* (R), Cyclicargolithus abisectus <11 µm (P), *Dictyococcities antarcticus* (F), *D. productus* (C), *Discoaster brouweri* (P), *D. pentaradiatus* (P), *D. surculus* (P), *D. variabilis* (P), indet. six-rayed *Discoaster sp.* (R): (*D. brouweri* 35%, *D. pentaradiatus* 33%, *D. surculus* 7%, *D. variabilis* 9%, indet. six-rayed *Discoaster sp.* 15%: out of 50 Discoaster count), *Helicosphaera carteri* (F), *H. palaeocarteri* (P), *Pontosphaera multipora* (P), *Reticulofenestra minuta* (EX), *R. minutula* (C), *R. pseudoumbilica* (VA, average = 6.8 µm, abundance > *D. antarcticus*), *Sphenolithus spp.* (F), *Thoracosphaera sp.* (P), *Umbilicosphaera sp.* (R).

Biostratigraphic assignment: Early Pliocene (Zanclian), NN 13 (early NN 12-13B).

Sample 98G (homogeneous marls of upper Pakhiammos Formation)

Abundant, reasonably well-preserved.

Assemblage: *Calcidiscus leptoporus* (C), *C. macintyrei* (P), *C. pelagicus* (F), *D. antarcticus* (A), *D. productus* (VA), indet. six-rayed *Discoaster sp.* (R), *Helicosphaera carteri* (F), *Pontosphaera sp.* (P), *Reticulofenestra minuta* (VA), *R. minutula* (F), *R. pseudoumbilica* (F, average size = 8.0 µm, abundance < *D.*

antarcticus), *Sphenolithus spp.* (R), *Syracosphaera cf. fragilis* (P), *Thoracosphaera sp.*(P), *Umbilicosphaera sp.* (R).

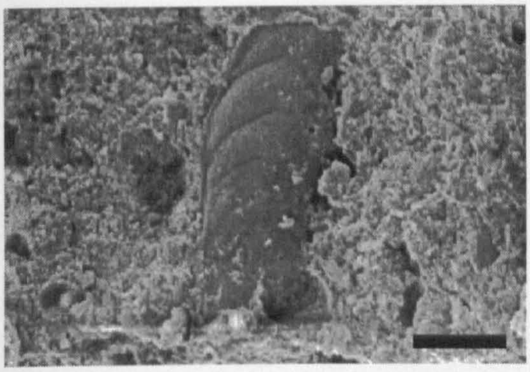
Biostratigraphic assignment: Late Neogene, tentatively late NN 12 (late NN 12-13A), earliest Zanclian.

Appendix IV The observation of microfossiliferous archaeological ceramics with the Scanning Electron Microscope

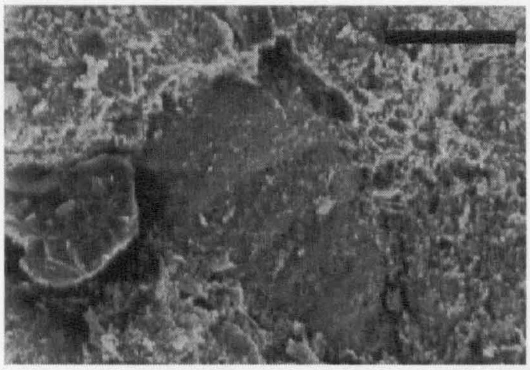
In the preeceeding chapters of this report, we have commented on the occurrence of various groups of microfossils in thin sections, smear slides and strew slides of archaeological ceramics from the Mediterannean and elsewhere in the world. Another method of studying archaeological ceramics, is with the scanning electron microscope, however, very few authors have observed microfossils from pottery in this way. Brissaud and Houdayer (1986) noted the presence of sponge spiccules in archaeological pottery sherds from Mali with the SEM, and used the clustering of these siliceous structures which they observed, to infer a tempering tradition along the interior delta of the river Niger. The only other study which mentions the analysis of microfossils from archaeological ceramics with the SEM, is Håkansson and Hulthén (1988). These authors commented that the digested residues of archaeological ceramics which are the outcome of the floatation method (Section 8.4.1), can be prepared for examination by light or electron microscopy, but in their analysis of Sweedish Neolithic pottery, concentrated only on the former.

Where they occur in archaeological ceramics, microfossil specimens should be visible on the exterior surfaces or the break of a sherd. In the present report, subsamples of archaeological ceramics were scrutinised with the binocular microscope prior to the isolation of foraminifera and ostracods (Sections 6.5 and 7.5). It was possible to observe several specimens of these two groups of microfossils, embedded in the matrix and protruding from the broken edges of the sherds, as well as some flat

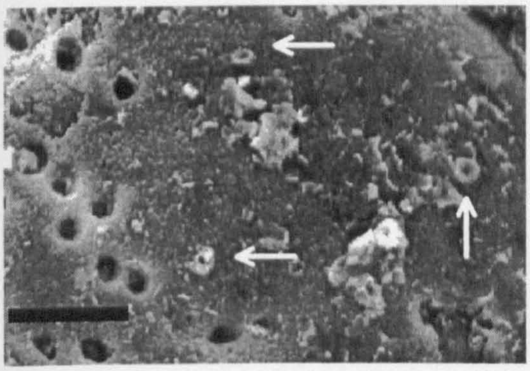
A



B



C



D

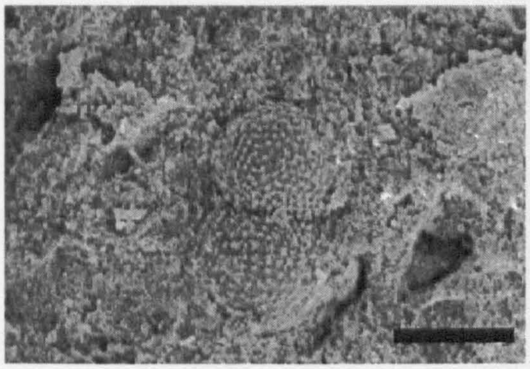


Figure AIV.1 Part 1. Scanning electron micrographs of foraminifera (A, B and D) and calcareous nannofossils (C), in archaeological ceramics (Kn 95/372). A. *Bolivina spathulata*; B. *Bulimina sp.*; C. a close up of B., with calcareous nannofossil specimens on the surface of the foraminifer; D. *Globigerina sp.* Scale bars: A, B and D = 100 μm; C = 10 μm.

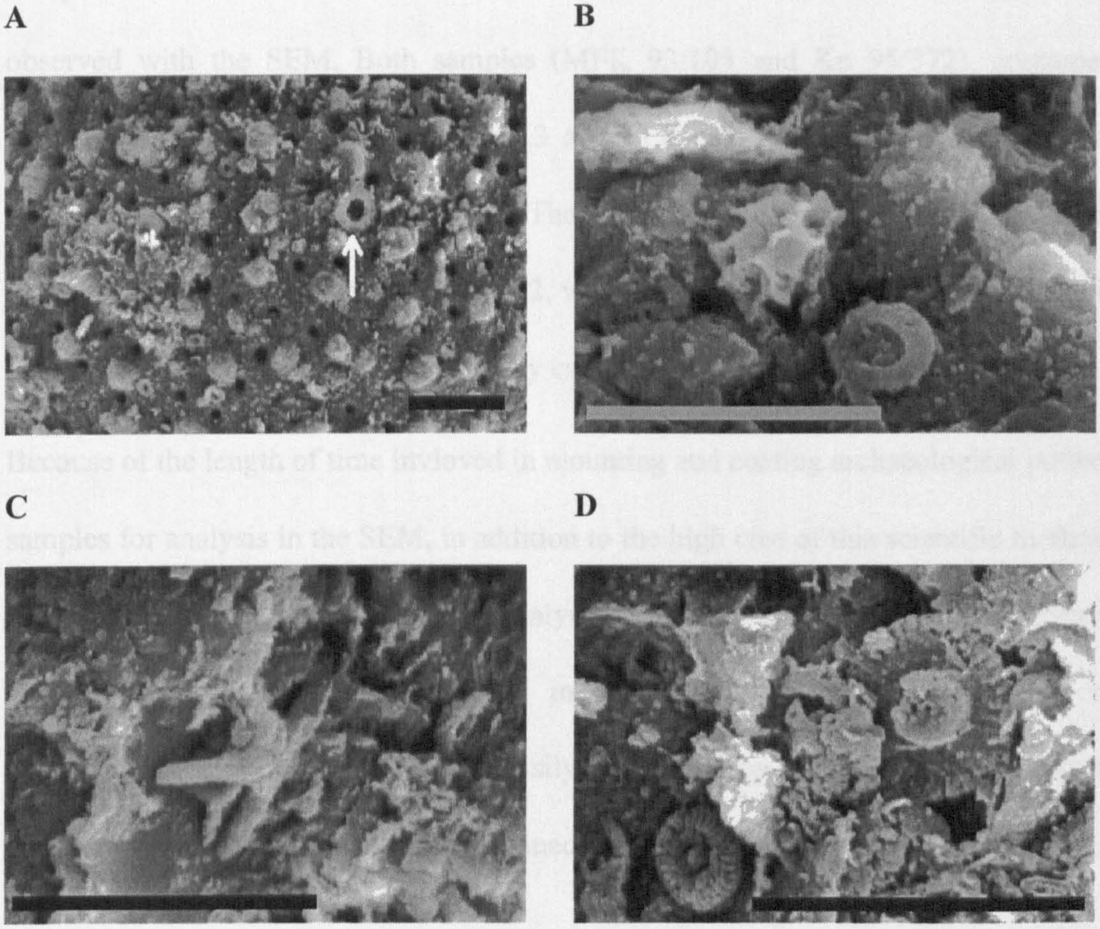


Figure AIV.1 Part 2. Scanning electron micrographs of calcareous nannofossils in archaeological ceramics (Kn 95/372). A. a close up of Figure AIV.1 Part 1 D. with calcareous nannofossils on the surface of the planktonic foraminifer; B. *Reticulofenestra minuta* (left) and *Sphenolithus sp.* (right); C. *Discoaster brouweri;* D. *Calcidiscus leptoporus* (left) and *Geminlithella sp.* (right). Scale bars = 10 μm.

sections of microfossils, exposed on the surfaces which were produced during by thin sectioning process. The resolution of reflected light, binocular microscopy however, is too poor to view calcareous nannofossils in this way. Therefore, two sherds were observed with the SEM. Both samples (MFK 93/105 and Kn 95/372), contained foraminifera in thin section Figures 11.3 and 11.8, and rich calcareous nannofossil assemblages (Sections A2.2 and A2.4). The scanning electron micrographs presented in Figure AIV.1 are of sample Kn 95/372, which contained well-preserved planktonic and benthic foraminifera, as well as many calcareous nannofossils in the SEM.

Because of the length of time invloved in mounting and coating archaeological pottery samples for analysis in the SEM, in addition to the high cost of this scientific method, it has little routine application for the analysis of microfossils in ceramics, however it is a useful technique for illustration in scientific reports. The description of microfossil assemblages are far more easily carried out by analysing thin sections or liberating specimens from sherds as outlined in the preceeding chapters of this report.

Appendix V Catalogue of archaeological pottery samples

#20984 MBA II inscribed sherd possibly from a storage Jar, Tel Haror, western Negev, Israel.

KAC 94/12 EM IB body fragment of a jug, Kalo Chorio, Crete.

KAC 94/27 EM IB fragment of a perforated baking pan, Kalo Chorio, Crete.

KAC 94/28 EM IB fragment of a baking plate, Kalo Chorio, Crete.

KAV 93/76 EM I, Kavousi.

Kn 86/1 MM IA Dark Faced Incised Ware, AE 1076, Knossos.

Kn 86/2 MM IA Dark Faced Incised Ware, AE 1077, Knossos.

Kn 86/4 MM IA Dark Faced Incised Ware, RR/S S353, Knossos.

Kn 86/5 MM IA Dark Faced Incised Ware, D2AII12#103 KO3, Knossos.

Kn 86/6 MM IA Dark Faced Incised Ware, OI9 #1378 D7, Knossos.

Kn 86/7 MM IA Dark Faced Incised Ware, AII11 #95 KO3, Knossos.

Kn 86/8 MM IA Dark Faced Incised Ware, BI23 #359, Knossos.

Kn 86/9 MM IA Dark Faced Incised Ware, BII11 402, Knossos.

Kn 86/10 MM IA Dark Faced Incised Ware, RR/S S350 F28A, Knossos.

Kn 86/11 MM IA Dark Faced Incised Ware, F27 RR/S S351, Knossos.

Kn 86/12 MM IA Dark Faced Incised Ware, F28 RR/S S351, Knossos.

Kn 86/13 MM IA Dark Faced Incised Ware, D8OII3 #1385, Knossos.

Kn 86/14 MM IA Dark Faced Incised Ware, HH 57/36 G58, Knossos.

Kn 86/15 MM IA Dark Faced Incised Ware, HH G3 110, Knossos.

Kn 86/16 MM IA Dark Faced Incised Ware, HH H16, Knossos.

Kn 86/17 MM IA Dark Faced Incised Ware, BII10 #398, Knossos.

Kn 95/172 EM IA small chalice pedestal with vertical scribble burnishing (cf. DFIW), Knossos, Crete.

Kn 95/187 MM IA large steep sided bowl with everted rim, soft red/brown slipped and burnished, Knossos, Crete.

Kn 95/211 MM IA open jar with interior flange and red band at rim, Knossos, Crete.

Kn 95/212 MM IA open jar with interior flange and red/black band at rim, Knossos, Crete.

Kn 95/214 MM IA shoulder and handle fragment of bridge spouted jar, light brown slip, Knossos, Crete.

Kn 95/222 MM IA large pan rim, soft red slipped and burnished, Knossos, Crete.

Kn 95/223 MM IA red slipped and burnished two handled jug/jar with flattened pellet on neck (Early Cypriot III import?), Knossos, Crete.

Kn 95/233 MM IB flaring bowl, scribble burnished over soft buff sandy fabric, Knossos, Crete.

Kn 95/234 MM IB body fragment from bowl, highly polished, Knossos, Crete.

Kn 95/235 MM IB jar collar, soft red slipped and burnished, Knossos, Crete.

Kn 95/236 MM IB globular cup, black monochrome interior and black band on exterior, Knossos, Crete.

Kn 95/237 MM IB straight sided cup with clear rilling on interior and exterior, Knossos, Crete.

Kn 95/238 MM IB carinated cup with red band at rim, Knossos, Crete.

Kn 95/239 MM IB rounded bowl with noticeable rilling on interior, Knossos, Crete.

Kn 95/240 MM IB wheel made small flaring bowl with plain pale buff surface, Knossos, Crete.

Kn 95/246 MM IB base of jar/pithos with red banding on exterior and added white outlining, Knossos, Crete.

Kn 95/250 MM IB tripod pan, Knossos, Crete.

Kn 95/277 MM IB body fragment from jug/jar with black decoration on light ground, Knossos, Crete.

Kn 95/361 MM IIB fruit stand rim with red slipped and burnished exterior and feather wave on interior, Knossos, Crete.

Kn 95/372 MM IIB bowl base, red slipped and burnished, Knossos, Crete.

Kn 95/376 MM IIB ring base of large thick walled bowl with shell ripple on exterior and feather wave on interior, Knossos, Crete.

Kn 95/382 MM IIB rim of deep bowl with band of stamped circles below rim with border of small stamped triangles, Knossos, Crete.

Kn 95/384 MM IA low collared jar with offset neck and burnished exterior

Kn 95/387 MM IA upper body of beaked spouted jug with light brown/monochrome slipped exterior and shallow groove at base of neck , Knossos, Crete.

Kn 95/400 MM IB jug/jar base with greyish buff burnished surface and black decoration, Knossos, Crete.

Kn 95/407 MM IB large circular dish, Knossos, Crete.

MAK 96/3 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MAK 93/6 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MAK 96/9 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MAK 96/21 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MAK 96/136 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MAK 96/137 Late Neolithic sherd, Dimini Phase II, Makrygialos near Thessaloniki, Greece.

MFK 93/3 EM IIB baking plate, Myrtos Fournou Korifi Crete.

MFK 93/12 EM IIB cooking pot, Myrtos Fournou Korifi Crete.

MFK 93/17 EM IIB baking plate, Myrtos Fournou Korifi Crete.

MFK 93/18 EM IIB bowl, Myrtos Fournou Korifi Crete.

MFK 93/19 EM IIB long spouted jar, Myrtos Fournou Korifi Crete.

MFK 93/20 EM IIB basin, Myrtos Fournou Korifi Crete.

MFK 93/27 EM IIB jug, Myrtos Fournou Korifi Crete.

MFK 93/28 EM IIB piriform jar, Myrtos Fournou Korifi Crete.

MFK 93/37 EM IIB jug, Myrtos Fournou Korifi Crete.

MFK 93/38 EM IIB jug, Myrtos Fournou Korifi Crete.

MFK 93/48 EM IIB deep bowl, Myrtos Fournou Korifi Crete.

MFK 93/55 EM IIB shallow bowl, Myrtos Fournou Korifi Crete.

MFK 93/58 EM IIB small jug, Myrtos Fournou Korifi Crete.

MFK 93/68 EM IIB basin, Myrtos Fournou Korifi Crete.

MFK 93/69 EM IIB spouted basin, Myrtos Fournou Korifi Crete.

MFK 93/71 EM IIB basin, Myrtos Fournou Korifi Crete.

MFK 93/87 EM IIB jug, Myrtos Fournou Korifi Crete.

MFK 93/94 EM IIB incurving bowl, Myrtos Fournou Korifi Crete.

MFK 93/99 EM IIB small jug, Myrtos Fournou Korifi Crete.

MFK 93/102 EM IIA baking plate, Myrtos Fournou Korifi Crete.

MFK 93/105 EM IIA jug, Myrtos Fournou Korifi Crete.

MFK 93/110 EM IIA jug, Myrtos Fournou Korifi Crete.

MFK 93/116 EM IIA deep bowl, Myrtos Fournou Korifi Crete.

MFK 93/117 EM IIA strainer, Myrtos Fournou Korifi Crete.

MFK 93/127 EM IIA basin, Myrtos Fournou Korifi Crete.

MFK 93/129 EM IIA incurving bowl, Myrtos Fournou Korifi Crete.

MFK 93/133 EM IIA jar, Myrtos Fournou Korifi Crete.

MFK 93/138 EM IIA flaring bowl, Myrtos Fournou Korifi Crete.

MFK 93/142 EM IIA incurving bowl, Myrtos Fournou Korifi Crete.

MFK 93/148 EM IIA jug, Myrtos Fournou Korifi Crete.

MFK 93/169 EM IIA jug, Myrtos Fournou Korifi Crete.

MFK 93/173 EM IIB piriform jar, Myrtos Fournou Korifi Crete.

MFK 93/180 EM IIB amphora, Myrtos Fournou Korifi Crete.

MFK 93/185 EM IIB pithos, Myrtos Fournou Korifi Crete.

MFK 93/196 EM IIB loomweight, Myrtos Fournou Korifi Crete.

MFK 93/197 EM IIA potter's disc, Myrtos Fournou Korifi Crete.

MFK 93/198 EM IIA potter's disc, Myrtos Fournou Korifi Crete.

MK12 Punic amphora support Mozia kiln, Sicily.

MK16 Punic dish, Mozia kiln, Sicily.

MPY 93/10 EM II bowl with horizontal handle, Myrtos Pyrgos, Crete.

MPY 93/17 EM I-IIA unidentifiable body and base sherd, Myrtos Pyrgos, Crete.

MPY 93/20 EM II? storage jar, Myrtos Pyrgos, Crete.

MPY 93/24 EM IIB leg of tripod cooking pot, Myrtos Pyrgos, Crete.

MPY 93/25 EM IIA baking tray, Myrtos Pyrgos, Crete.

MPY 93/26 EM IIB rim of baking tray, Myrtos Pyrgos, Crete.

MPY 93/27 EM II base of jug, Myrtos Pyrgos, Crete.

MPY 93/37 EM II shallow bowl with over-turned rim, Myrtos Pyrgos, Crete.

MPY 93/40 EM II shallow bowl with over-turned rim, Myrtos Pyrgos, Crete.

MPY 93/48 EM II shoulder and neck of pithos, Myrtos Pyrgos, Crete.