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The chronology of the Aegean late bronze age with special reference to the "Minoan" eruption of Thera

Stuart E Dunn

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The chronology of the Aegean Late Bronze Age with special reference to the "Minoan" eruption of Thera

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**Thesis for the degree of
Doctorate of Philosophy**

**Department of Classics and Ancient History
University of Durham**

2002

Dedicated to the memory of Mr. A. Woolley

CONTENTS

Part II: Effects and Fallout

Abstract

The chronology of the Aegean Late Bronze Age with special reference to the "Minoan" eruption of Thera

Stuart E. Dunn

PhD Thesis, Department of Classics and Ancient History, University of Durham

The chronology of the Aegean Late Bronze Age is a vigorously contested area of archaeological study, with "high" and "low" schemes emerging over the last three decades. The chronological lynchpin for this period is the catastrophic eruption of Thera (Santorini), at a point in the mature Late Minoan (LM) I A ceramic period. Two possible calendrical ranges for this eruption have emerged: c. 1540 – 1500 BC, and c. 1645 – 1628 BC. The latter first gained currency in the 1970s, and the controversy focuses on which range is more probable. This thesis examines the chronology of the Late Minoan (LM), Late Cycladic (L Cyc), Late Helladic (LH) and Late Cypriot (LC) periods in detail and their various relationships with the eruption. Because archaeological methods of dating these sequences, which traditionally place the eruption within the later range, are fluid and open to re-interpretation (in favour of the earlier range), the calendrical date of the eruption is of crucial importance. The scientific arguments, which tend to favour the earlier range, are analysed alongside the archaeological arguments. Finally, the effects of the eruption, and their implications for chronology, are considered. A comprehensive catalogue detailing of all Thera's volcanic deposits from around the region is presented, as is a Geographical Information Systems (GIS) spatial analysis of these deposits which suggests that the volume of the eruption may have been up to five times previous estimates, and almost double the largest previous estimate. In conjunction with this study, a reappraisal of the eruptive rate and intensity of the Minoan event using mathematical differential analysis is presented, to provide an integrated investigation of its impact. It is concluded a) that the eruption was far larger than previous thought, and that b) a calendrical date for the eruption between c. 1540 – 1500 BC is more probable than a date between 1645 – 1628 BC.

Preface and acknowledgements

I: Introduction

In his recent biography of Sir Arthur Evans, J. A. MacGillivray states:

> Archaeology, like most scholarly pursuits, has its creators and destroyers. The former are those who originate theories and go into the field to find the tangible evidence to support them. The latter are those who nip at the explorers" heels from a cozy study or university library, demanding irrefutable proofs. In between are those who prefer to synthesize the results of their more adventurous colleagues, and who in doing so sustain the critical process necessary to screen doubtful or insufficiently supported conclusions. Not all these 'armchair archaeologists' – as the diggers in the field who dismiss those who stay at home – lose sight of their critical obligations and become full-time detractors, perpetually dissatisfied with the evidence. But a small number become such destroyers, insatiable critics with an overall negative attitude towards archaeologists and an indefatigable insistence on calling all of the evidence into question.[1]

MacGillivray was referring to Evans's detractors, men such as Sir William Ridgeway of Cambridge. Reading this passage (in the comfort of an armchair), I feel the need to comment, as this thesis is not based on fieldwork. I wish to discuss the possibility of my being a "synthesiser" of more "adventurous colleagues," or, at worst, a "full-time detractor."

This thesis concerns the chronology and history of the Aegean region, c. 1700 – 1400 BC. To visit, never mind assist in the excavation of, every relevant site would be

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[1]   MacGillivray 2000: 211.

impossible in three years of doctoral study. My main sources are, not material as it comes out of the raw earth, but published and unpublished documentation, supplemented by extensive personal communication and conference with those who are in a position to supply first-hand knowledge. The many scholars who have been kind enough to respond to my approaches are cited and thanked in the text. I do not consider myself a "destroyer" of the critiques of excavators. On the contrary, as a general rule, it is my belief that – in the absence of substantial and cross-checked evidence – the opinion of an excavator about a site should prevail, although it is never free from being subject to legitimate critical scrutiny. It is interesting to compare MacGillivray's sentiments with the following passage, which I fully endorse:

> ...[I]nternational scholarship in the humanities or sciences should be entitled to judge, analyse interpret, and criticise on the basis of published materials. This is how academic scholarship works ... Attention and examination must [therefore] follow. Further I stress that rigorous scholarship means that ideas, arguments, and conclusions *must* be both capable of scrutiny and capable of falsifiability.[2]

Admittedly, modern excavations are generally more reliable, being carried out with more rigorous attention to recording and classification, as opposed to older excavations where various issues can become blurred and difficult. A case in point is that of Sir Flinders Petrie's excavations at Gaza. Petrie classified the LBA Cypriot wares he found there into "Anatolian" and "Cypriote" classes; the former was completely erroneous as no pottery of this type has every emerged from Anatolia. It is now established that both types originated on Cyprus, and they have been

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[2] Manning 1999: 84 (n. 374).

scientifically classified by Popham as White Slip I and White Slip II (See Chapter 3). This point having been made, we must guard against the facile assumption that we are "better" than our predecessors.

Secondly, this thesis is as much about methodological innovation as it is about archaeology. The chronological debate *vis a vis* the Aegean Late Bronze Age revolves around the dating of the Minoan eruption of Thera (Santorini). This introduces a host of scientific and geological issues, above and beyond archaeology. A definitive and incontestable resolution of this problem, placing the eruption either in the seventeenth or sixteenth centuries BC, would necessarily settle the chronological debate in favour of one camp or the other. The present thesis, which will favour the "low" option, aims to explore new ways of synthesising archaeological and scientific evidence. It would be extremely hubristic of me to claim that I intend to resolve the entire Thera / chronological question at one fell swoop. However I hope to investigate methodologies that can usefully take the debate forward, and to illustrate how science and archaeology can answer questions when used together.

II: Terminology

The use of terminology employed needs some mention. The standard chronological abbreviations are used (EH, MH, LH etc = Early, Middle and Late Helladic, EM, MM, LM etc = Early, Middle and Late Minoan), although the Early, Middle and Late Cypriot and Cycladic Bronze Ages are distinguished by using "C" for the former (EC,

MC, LC) and "Cyc". for the latter. I use the term "Minoan" to describe the mid-second millennium BC eruption of Thera with some hesitation, although it is comprehensively accepted and used throughout the literature (particularly the scientific literature). It is true that the eruption occurred during the Late Minoan I A period, but the main settlement it destroyed, Akrotiri, is on Thera itself, and the extent of Minoan influence over this settlement is open to question. It is not appropriate to go any further in to a discussion that would lead inevitably to the debate about the so-called "Minoan Thalassocracy"; the term "Minoan" merely follows convention, and is applied to the mid-second millennium BC eruption to distinguish it from the other eleven major eruptions in the volcano's history.[3] An important caveat needs to be added. There is now compelling evidence that ash products reached the western Greek mainland (data from Floyd W. McCoy; see Ch. 5). This calls into question the term "Minoan", as the event clearly had a direct impact on the Mycenaean orbit as well.

Radiocarbon references follow the internationally accepted conventions outlined by Stuiver and Polach.[4]

Although the word *"tephra"* is the Greek *Τεφρα*, lit. "ash", it is used generically, in cases where the distinction is unimportant, to describe all volcanic material ejected from beneath or within the earth's crust, that is to say ash and pumice. Other terms, such as lahars etc. are specifically described where appropriate.

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[3]   Although it will be shown that the Thalassocracy issue is relevant, in terms of the length of
        LM IB (see Ch.3).
[4]   1977, esp. 356 - 7.

III. Acknowledgements

First and foremost, I must thank my supervisor, Dr O. T. P. K. Dickinson, and Professor Peter J. Rhodes, who supervised me in Dr Dickinson's absence in the first two terms of this project. Both were sources of constant guidance and support.

As stated above, many scholars have been more than willing to share knowledge and detail, and specific contributions are acknowledged when they arise. The following, however, is a consolidated list. Names which do not appear in the text belong to those who have simply provided encouragement, or very general discussions which have not affected any specific part of this work. Any omissions are unintentional, and all errors, mistakes and interpretations remain mine.

Pamela Anderson, Vernon Armitage, Mike Baillie, Celia Bergoffen, Philip Betancourt, Max Bichler, Manfred Bietak, Tim Burt, Peter Day, Christos Doumas, Warren Eastwood, Tom Elliott, John Grattan, Alan Hall, Claus Hammer, Helen Hatcher, Phil Howard, Charles Jackman, Vassos Karageorghis, Evangelina Kiriatzi,

Part I

Relative and Absolute Dating Methods

CHAPTER 1

GENERAL INTRODUCTION, DEFINITION OF AIMS AND HISTORY OF PREVIOUS RESEARCH

1.1 The problem

1.1.1 Initial overview

The history and chronology of the Aegean region in the period c. 1700 – 1400 BC is one of the most hotly contested aspects of the prehistory of Europe, certainly in the prehistory of the Aegean. Revolving around the absolute dating of the cataclysmic "Minoan"[1] eruption of Thera, this issue goes to the heart of interdisciplinary investigation into the past. It has sustained thesis and antithesis, academic careers have been built around it, and it has drawn contributions, not just from archaeology, but also from the fields of mythology, classical philosophy, literature and a broad range of the physical sciences.[2] Interdisciplinary collaboration reached a head in September 1989, with the Third International Congress on Thera, published under three volumes, *Archaeology, Earth Sciences* and *Chronology*. It was agreed at this Congress that the eruption occurred in a mature phase of the LM I A / LCyc I period, and was therefore not responsible for the great destructions on Crete at the end of LM IB. The latter had been the position adopted by the first excavator of Akrotiri in

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[1] For my comments on the use of this term, see above (Preface).
[2] A recent interdisciplinary overview for the general reader is provided by Friedrich 2000: *passim.*

modern times, S. Marinatos.[3] No resolution, however, was reached, on the absolute

dating of the eruption. The presentations by P.M. Warren and S.W. Manning in the

chronological volume exemplified the nature of the polarisation, between high and

low, and it is this polarisation upon which the chronological debate turns. Given that

we now know beyond doubt that the Minoan eruption occurred in mature LM IA,

wherever one places the eruption in absolute time, one must, by logical extension,

also place mature LM IA. Given that the gap between the suggested dates for the

eruption is so large (c.1650 – 1620 and c. 1540 – 1500 respectively), mature LM IA,

and therefore the Aegean Late Bronze Age ceramic sequence,[4] must move over a

range of between a century and a century and a half, depending on where one puts the

eruption on the absolute timescale.

1.1.2. Chicken or egg? Disciplinary fault lines and the way forward

It is my intention here to explore in more detail some of the issues raised in the

Preface, above. Which comes first, the dating of the eruption or the archaeological

links with absolutely dated cultures of the Near East and Levant? This is the core of

the problem. Those approaching the question using purely, or mainly, excavational

data (as opposed to radiometric or archaeometric analyses) have, with notable

exceptions, tended to embrace the low chronology, while those pursuing the matter

through the "hard sciences" have generally adopted the high. This is, of course, a vast

oversimplification; but accepting, for the sake of argument, that this is broadly the

case, one is led to deeper philosophical questions about the nature of the search for

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3   Marinatos 1939: 38.
4   The controversy falls between the eighteenth and fourteenth centuries BC. Outside this
      bracket, chronology is generally agreed.

truth. Such nebulous concepts as "subjectivity" versus "objectivity", and the differing

approaches to the material world adopted by the humanities and physical sciences

come into apparent conflict. Inevitably[5] this has led to misunderstanding,

misconception and ill-judgement on both sides. In some regrettable cases,

incomprehension of scientific techniques on the part of archaeologists, and the

dismissal of archaeological realities by some leading scientists, have led to a veritable

cacophony of artificial and unilinear discourses. A truly interdisciplinary approach

recognises that there are shades of grey, that some matters concern the balance of

probabilities, and that virtually nothing is beyond reasonable doubt. In this context,

the view of MacGillivray, quoted above (Preface, page i), is not beyond accusations

of simplicity and naivety.

In some quarters, scientific dating has been seen as absolute, and challengeable only

on the basis of the legitimacy of its application. From the point of view of the high

chronology, Manning states on this point:

> The Betancourt-Manning 'high' chronology is not based on radiocarbon
> evidence. Instead it is based on a plausible re-interpretation of all the
> archaeological data, and, [sic] we supported this re-interpretation of the studies
> cited because it was consistent with a wide range of independent scientific dating
> evidence (including particularly radiocarbon data). In contrast, the conventional,
> or 'low', position must reject all this science data.[6]

It was because the re-interpretation of the archaeological evidence supported the

scientific data that Manning adopted it. Extended to its logical extreme, this means

that the scientific date must take ultimate precedence over the archaeological scheme

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[5]   And, in my personal view, sadly.
[6]   Manning 1999: 217 (n. 1046).

(although I must stress that Manning does not stand accused of this here). Without the science, the archaeological re-interpretation remains only "plausible". Compare, from the point of view of the "low" chronology:

[...] I believe the inherent nature of the calibration curve or, rather, the horizontal wiggle at this time to be such that the future for Aegean MBA-LBA chronology no longer lies with radiocarbon dating ... I therefore commend an Aegean LB 1 – 2 absolute chronology derived from cross-links to Egypt.[7]

There exists, therefore, a gulf in opinion on which should come first, the scientific chicken or the archaeological egg. High precision dendrochronological dating, underway under the auspices of P. I. Kuniholm of Cornell University, offers the best hope currently available for a final resolution.[8] However, as stated in the Preface, a final resolution is not the purpose of this thesis. Pending Kuniholm's conclusions, an approach incorporating scientific and archaeological information will be attempted here, but beyond that there are far larger issues at stake.

One topic, highlighted by discussion of the very significant site of Tell el-Dabᶜa (the Hyksos Avaris) in the Egyptian Eastern Desert, merits a further brief digression. A review article by E. Cline[9] assessed the evidence from this site, which has been under investigation by an Austrian-led team for over three decades. In particular, Cline questioned the suggestion that the technique of the frescoes from the platform construction in area H/I as was Minoan, or at least heavily Minoanized,[10] the conclusion of the principal excavator, M. Bietak. In response, Bietak wrote a

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7   Warren 1998: 324, 328.
8   As Professor Warren states, *ibid,* n. 5: 324.
9   1998: *passim.*
10   *ibid.* For my own discussion, see below Ch. 3 (section 3.5)

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bombastic, and, to a degree, highly personal response:[11] "He relies in this respect primarily on colleagues who have never seen the originals, nor have evaluated and published original Aegean paintings."[12] There are allegations of "misrepresentation", "exaggerated glossing", Cline's paper is said to "lose its hold on objectivity and fairness." Most importantly for the point I am trying to illustrate:

> Eric Cline has to the best of my knowledge never tried to visit Tell el-Dabᶜa, nor has he studied its topography, stratigraphy and materials, i.e. pottery, the wall paintings, and other items. All this would have been the precondition for making an informed assessment of a complex site and casting justified doubt on the conclusions of an excavator, who naturally must have a profounder knowledge of the archaeology of the place than any outsider, especially before final publication.[13]

It is in the light of these sentiments that I have attempted to construct my arguments. As a general rule, I hold that an excavator's opinion about a site that I have not been able to visit must be taken to a certain extent on trust, and where I refer to sites under modern excavation, I have tried, wherever humanly possible, to consult with the excavator first.

Approaches not involving new data are vulnerable to entrenched (and not always, by any means, unjustified) criticism. Many workers feel that such critiques cloud the issues, and that re-interpretation upon re-interpretation increases uncertainty instead of providing clarification. For example, Manning, in responding to Warren 1999 states: "Does Warren advance any new data, or new arguments beyond those he discussed in papers up to 1998 already dealt with in *A Test of Time* [i.e. Manning

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[11] Bietak 2000: 185.
[12] *ibid*: 195.
[13] *ibid*: 201.

1999]? No. But let us nonetheless review the arguments he lists."[14] (Peter Warren

would presumably contest that Manning had dealt with the arguments in question.)

This is an area on which I have been criticised. A referee's commentary on a paper on

ice core dating, which I submitted unsuccessfully for publication to the *Journal of*

Archaeological Science, read "This contribution adds little that is new to the debate,

but meanwhile continues the confusion of comparing analyses of different materials

... [T]he only resolution is for another lab attempt to repeat this same analysis, along

with a host of other control samples."[15] Furthermore, in a personal communication to

me, Dr. E. Nelson, one of the principal workers in radiocarbon on Thera, says "The

[radiocarbon] data is suspect, and no amount of manipulation can change that."[16]

It is true that, on the scientific side, things move far more quickly. The submission /

review / resubmission process for scientific journals is much more rapid than for

journals dealing with a traditional humanities subject like archaeology. However, on

the archaeological side, many "standard" works, published ten or more years ago,

remain established points of reference, and are themselves, either partly or wholly,

syntheses of earlier research. Kemp and Merrillees (1980) and Warren and Hankey

(1989) are two cases in point. The latest full length book on the Thera dating debate,

Manning (1999) is described on the book's companion website:

> This book reviews and analyses all the available archaeological, art-historical,
> and scientific (radiocarbon, dendrochronological, ice-core) evidence potentially
> relevant to the subject of the date of the Minoan eruption of the Thera (Santorini)

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[14]   Manning (forthcoming), on www companion site to Manning 1999:
        http://www.rdg.ac.uk/~lasmanng/testoftime.html
[15]   Anon 2000.
[16]   Personal communication, 15/8/2000.

volcanic eruption [sic], and the associated phases of the Minoan (Cretan) and other East Mediterranean civilisations.[17]

This book is, by admission here, a synthesis and a review, as are many of its predecessors. I therefore feel fully justified in writing a doctoral thesis whose emphasis is on the analysis, consolidation and criticism of existing data, rather than fieldwork or lab analysis. It is debate, re-evaluation and re-analysis – with the inevitable disagreement that follows from this process – that makes archaeology the exciting and vibrant discipline that it is.

1.1.3: Aims of this thesis

The innovations attempted in this thesis are methodological. Drawing on the expertise of specialists in mathematics and archaeological science, as well as excavators (to all of whom I am greatly indebted), I conduct a detailed examination of these areas:

- The use of radiocarbon dating for the eruption, and recent attempts to establish an internal, fixed absolute chronology for LM I – III using radiocarbon.

- A brief discussion of other absolute dating methods (this discussion is necessarily curtailed due to developments emerging at the time of writing).

- The relevance to Aegean chronology of the Cypriot sequence, and in particular White Slip ware.

- Interconnections with Egypt and other absolutely dated cultures of the Near East.

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[17]   http://www.rdg.ac.uk/~lasmanng/testoftime.html

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- The rate of, and eruptive mass of, the eruption. This will be examined using recently developed mathematical models.

- An analysis of Thera's tephra fan using Geographical Information Systems (GIS). This section will also incorporate the first systematic catalogue / gazetteer of Thera's archaeological and geological tephra deposits around the island and across the region, as derived from published excavation, survey and fieldwork records, and unpublished sea-bed studies.

- The "Troubled Island" hypothesis of Driessen and Macdonald, which will be reviewed in the light of recent evidence.

1.2 The Minoan eruption through the millennia: A history of research

1.2.1 Basic questions

Manning[18] provides a detailed history of the Thera debate, and the following synopsis provides a similar guide to chronological arguments through the ages to the present day, but also attempts to generalise in its conclusions, and assess the significance of Thera in literature, myth and history, as well as in archaeology and in science. This exercise is an important preamble to a thesis such as this, as two questions must be answered: not only "what is the history and current state of scholarly research on Thera", but "why does this research matter?"

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[18]   1999: Chapter II. 1999: Chapter II

1.2.2 Thera and Greek mythology

It seems logical to start the history of research with the earliest references. Given the gigantic scale of the Minoan eruption, the destruction it wreaked on the island and, if one accepts the "Troubled Island" hypothesis of Driessen and Macdonald, Crete, it is very surprising that no durable and identifiable reference to it has been left in Greek mythology. The genesis of the island itself, though, is apparently represented. According to Apollonius of Rhodes, Triton appeared to the Argonauts in the form of a young man, and gave them a clod of Libyan earth. In response to a dream, Euphemos cast the clod into the Aegean and from it the gods fashioned the island of Kalliste. One generation later, the sons of Euphemos were driven out of Lemnos by the Tyrrhenians, and went to Sparta. When they left Sparta, they went to Kalliste under the leadership of Theras son of Autesion, who gave his name to the island.[19] Pausanias (II.3 7) also relates this story, possibly using Apollodorus as his source. Apollodorus, when describing the voyage of the *Argo*, relates that Apollo fired an arrow into the sea, causing a flash of lightning; thus was revealed to the crew of the *Argo* the island of Anaphi, which "appeared" to them suddenly. While it is perhaps tempting to link a flash of lightning in the sea north of Crete with the eruption, it is a temptation that should be resisted as not being adequately supported by the evidence. All one can conclude is that there is a general lacuna of references to the eruption in mythology.

Another tempting, and marginally more plausible, explanation, lies in the formation of Kalliste itself. Although the Santorini island complex changes from day to day –

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[19]   Apoll. Rhod. IV 1551 – 1764 (Hunter 1993: 135 - 140). See also Forsyth 1999: 1.

the fractal-like shape of Nea Kameni's coastline indicates a lack of wave erosion, indicating its, rapid formation processes – the last major change, which occurred over a short space of time, was the Minoan eruption. The major change before that was the so-called "Cape Riva" eruption. In human terms this occurred in the Upper Palaeolithic, c. 18,000 years B.P., well before any possible construct of literary or oral tradition. It seems far more tempting to link the casting of the clod of earth by Euphemos into the sea with the Minoan eruption, simply because of the lack of any other known approximate mythical and historical concurrences (but see below). Indeed there is an - albeit very tentative - positive connection. The clod of earth falling into the sea could be a distant memory of the damage inflicted on the island by volcanic bombs, which was extensive.[20] As a theory, this is little more than speculation, but one which I believe merits further investigation.

Alexander has argued that the impact of the eruption was minimal because 80 of the 172 ships at Troy were Cretan.[21] This hypothesis can be rejected outright. Leaving aside the question of whether or not the Trojan War was an historical event (see below), it, and the Catalogue of Ships, are concepts of the Homeric world, created many centuries after either of the two suggested dates for the eruption. Furthermore, those who argue for its literal historical factuality date the War itself to the thirteenth century BC, three to four hundred years after the eruption.[22]

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[20]   Doumas 1983: 50.
[21]   Alexander 1993: 188.
[22]   Oliver Dickinson, personal communication, 29/3/2002.

1.2.3   Was Thera Atlantis?

The myth of Atlantis has struck a powerful chord through every age since its creator,

Plato, coined it early in the fourth century BC. In the present day it has provided a

focal point for "alternative" theories of various aspects of the past, and has found

expression and parody in the literature of all ages, including a skilful and funny

exposition in Terry Pratchett's novel of 1998, *Jingo*. Further illustration of this

myth's grip on the popular imagination can be gleaned from the fact that a World

Wide Web search using the word "Atlantis" provides 151, 605 pages.

In 1969 two works were published which sought to link the Atlantis legend with the

Minoan eruption of Thera. E. Bacon and A. G. Galanopoulos's rather ambitiously

entitled *Atlantis: The truth behind the legend* read Plato's account as historical fact,

and sought to equate geological evidence from the island with ancient sources, and

reject other geographical places as possible Atlantis locations. J.V. Luce's account,

The end of Atlantis: New light on an old legend[23] was rather more thoughtful and

circumspect in its approach, but arrived at the same fundamentally flawed conclusion.

The main means of support – and the central problem - of the thesis is highlighted by

an argument early on in the book in connection with the "Palace of Nestor" at Pylos.

Luce claims that:

> Homer's picture [of the Mycenaean world] has received remarkable
> confirmation in the dramatic discoveries of Professor Carl Blegen at Epano
> Englianos in 1952 ... [W]hen one sees a finely moulded and decorated bath
> tub still in position in one of the rooms, and when one learns that in a wine
> magazine behind the palace there were clay sealings with signs presumably
> indicating vintage and provenance, one has to admit that the convergence of

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[23]   A thumbnail summary of this book is available at www.laketech.com/AD_LC.HTML

archaeology and Greek literary tradition about this site has become very close and convincing. It is now probably up to the sceptic to disprove, if he can, the identification of the site with Nestor's palace as described by Homer.[24]

This sets Luce's attempt to link Thera with Atlantis into a much more general intellectual context. On page 15 of his book, he states this explicitly: "[This thesis] starts from the belief that the legend of Atlantis, like other Greek legends, may embody a hard core of historical fact." The first point to make in response to this statement is that more recent ideas about Atlantis derive from academically questionable beliefs in lost civilisations. Atlantis hunters of all periods have suggested a very wide range of geographical locations across the globe. Secondly, the concept of attempting to link Greek literary and historical tradition with the archaeological record went back at least to the days of H. Schliemann and Sir Arthur Evans, who sought to identify a factual historicity at the sites of Mycenae, Pylos and Troy in the former case and Knossos in the latter. At the time, these revelations captured the public imagination in a way that archaeology never had before. In its obituary of Evans, *The Times* noted that "A less learned public was attracted by the legendary fame of Minos, by a vague idea that Homer and the miracles of Greek civilisation were being explained[.]"[25] The result was a deep impact on the popular perception of "the high antiquity credited to European civilisation"[26], and it formed the intellectual climate in which the idea of an historical Atlantis, in Greece, was produced.

Today, this climate no longer exists. As M. I. Finley wrote in the preface to the Second Revised edition to his book, *The World of Odysseus:*

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[24]   Luce 1969: 14.
[25]   *The Times*, London: 12th July 1941.
[26]   *ibid.*

On one topic the confirmation has been so strong that I have felt free to make a major deletion. When I wrote [this] book, in the early 1950s, the notion was generally accepted that the world of Odysseus was on the whole the Mycenaean world, which came to an abrupt end, by violence, around 1200 BC. The small heretical minority, of which I was one, were in a difficult polemical position ... Today it is no longer seriously maintained, though it is said often enough, that the *Iliad* and the *Odyssey* reflect Mycenaean society, a modern construct, which no ancient Greek had ever heard of.[27]

This addendum appeared in 1978, only nine years after the books of Luce, and Bacon and Galanopoulos. Its statement, that the works of Homer should not be taken as historical fact, logically extends to the conclusion that even later literary traditions cannot be taken as literal historical treatments. It reflects also the dramatic about-turn of opinion that occurred in the 1970s. Currently, at a stage when archaeological techniques have been refined and improved out of all recognition in comparison those of a century ago, there is absolutely no basis for assigning events described by Plato to the historical timescale. Marinatos' successor as principal excavator of Akrotiri, Chr. Doumas, agrees,[28] concluding by pointing out that Aristotle, who knew Plato personally as his teacher and mentor, dismissed the reality of Atlantis with the words "the man who dreamed it up made it vanish."

Tracing this piece of twentieth century historiography reveals the most extraordinary paradox. From a mythographical point of view, it mattered enough in the twentieth century to sustain the Thera-Atlantis theory, albeit for a relatively short time. It mattered enough to inspire three major international conferences; the debate it inspired rages today. Yet, despite the obvious importance of Akrotiri in antiquity,

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[27]   Finley 1999: 10.
[28]   Doumas 1983: 151 - 156.

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despite the evident scale of the eruption, there is no explicit, immediately unambiguous reference to it in Greek mythology or art of any period, apart from possible cases on Thera itself. Why this should be the case is a question that it likely to remain unanswered, although a good place to start would be the reason why there was no Bronze Age reoccupation of the island (at least in the period directly after the eruption[29]) which, theoretically, would have been safe for reoccupation in quite a short space of time. Given Thera's prominence as the link in the "Western Chain" of islands linking Crete with the Mainland, it is surprising that no such re-inhabitation took place with the re-organisation of Minoan trade which must have followed the eruption. This raises questions in connection with the so-called "Troubled Island" hypothesis, not to mention the so-called "Troubled Island" hypothesis, which will be dealt with below.

1.2.4   Archaeological research I: the modern discovery of Thera

Thera was surveyed in 1848 by Capt. Thomas Graves R.N. Apparently a charismatic figure, Graves commanded HMS Volgae,[30] a research vessel stationed in the Mediterranean, and read a paper (drafted by his adjutant, Lieut. Edmund M. Leycester R.N.) to the Royal Geographical Society in 1850. This paper, *Some Account of the Volcanic Group of Santorin or Thera, once called Calliste, or the Most Beautiful*[31] contains a number of archaeological allusions,[32] and dramatic eyewitness accounts of the 1573, 1650 and 1708 events. The rapidity at which the Santorini complex is prone

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[29]   Forsyth 1999: 115 – 116.
[30]   *Navy List* 1848: 41.
[31]   Leycester 1850: 1.
[32]   e.g. (2): On [Mt. Platanimos"] eastern slopes are cut many rock tombs of a very remote age."
         These are referred to on the map as "rock sepulchres".

to change over time is given by the formation and alteration of the Kameni Islands in the 1866 eruption. Fouqué revised Graves's map accordingly (fig 1.1, a and b). A comparison of the details testifies to the pace of geomorphological change.[33]

"Excavations" were carried out on Thera in the late nineteenth century during the course of mineral extraction for the Suez Canal. This process led to the stripping of some of the upper layers of rock strata, and a primarily geological research program was conducted by the French School at Athens.[34] The story of systematic archaeological research on the island, however, and the first real recognition of the eruption's importance in antiquity began in 1939. In this year, Sp. Marinatos, then Director of the Greek Archaeological Service, published his now-famous article in *Antiquity*, linking the effects of the eruption with the great destructions on Crete.[35] At the time it was a bold move. The Editors of *Antiquity* went to the extent of adding a now-equally famous disclaimer at the end of the paper, stating that they believed that further excavations were necessary to support the theory. Marinatos, however, was sure of his arguments. His prose was powerful and imaginative:

> [Crete] received an irreparable blow, and from then onwards declined and sank in to decadence, losing its prosperity and power ... We can be certain that after the great catastrophe the majority of the inhabitants fled in terror

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[33]   Fouqué 1999: Pl. 1
[34]   Fouqué: 1999: *passim*; Mamet: 1874: *passim.*
[35]   Marinatos 1939: 437.

(a)

(b)

1.1 (a) Detail from 'santorin Island Ancient Thera, surveyed by Captain Thomas Graves F.R.G.S., R.N. HMS Volgae 1848.''; (b) detail of the same area from 'santorin d''après la carte du Capitaine Graves avec indications des modifications apportées par l''eruption de 1866.'' F Fouqué, 1887.

from the island. They thought that the mother-goddess had turned against her island and cursed it.[36]

Marinatos's view, that the eruption was responsible for the second "great catastrophe" – i.e. the end-LM IB destructions – gained a great deal of currency in the half century following the publication of this paper. It had a distinguished analogical precedent. Evans had attributed his Middle Minoan II and III B (the latter now thought of as MM III / LM IA) destructions, to earthquakes[37]. A similar natural disaster, no doubt accompanied by earthquakes, seemed a very good candidate to be the cause of the later destructions. Marinatos" view was endorsed by J.V. Luce, who raised the dating of the eruption to c.1470 BC[38], although even at this early stage S. Hood was proposing an LM IA and *pre*-end LM IB provenance for the eruption.[39]

This brief summary of the excavations of Akrotiri will concentrate primarily on elements relevant to this thesis, namely pottery imports and the phases of the eruption as expressed in the stratigraphy of the site. The purpose of this section is not a detailed review of Marinatos's work at Akrotiri, it is simply a "scene-setting" exercise, to give the following chapters the archaeological context of the importance of the site; the remit of this thesis would not justify anything more. As is already clear, it is one of the subject's eccentricities that the majority of the important archaeological evidence for Thera's chronology lies in geographical regions far away from Thera.

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[36]   *ibid.*
[37]   Evans 1928: 313.
[38]   Luce 1976: 11 - 12.
[39]   1978: 688.

When Marinatos came to investigate the site of Akrotiri in 1967, he was basing his

program on a wide variety of sources: earlier investigations, principally those of

Fouqué and Mamet; accidental discoveries, and "even from the living tradition among

the inhabitants about old finds."[40] It is clear, however, from the introduction of his

account of this first season, that his main psychological impetus for investigating the

island of Thera was a desire to prove the theory that he had articulated twenty eight

years previously, that the eruption had been responsible for the end of the Minoan

palaces. He was quick to recognise the importance of imported LM IA pottery,[41] and

drew parallels between the buildings he was uncovering in trench "Bronos 1a" and

Minoan and Mycenaean palatial style architecture.[42] Perhaps most importantly, he

began to identify evidence for serious earthquake before the pumice fall.[43] This is

now known as the "seismic" destruction, occurring early in L Cyc I, around the time

of the MM III / LM IA transition period in Crete.[44] It was also in this year that the

most famous element of Thera's archaeology came to light: fragments of wall

paintings.[45]

In 1968, excavation continued in "Arvaniti 1" (now Sector Alpha, at the north of the

site). These rooms produced, among other things, rope pattern and floral band

motifs.[46] The most significant aspect of this stage of the excavation, however, was the

series of *in situ* jars in the Eastern part of the magazine complex. In South Corridor,

which was largely excavated during the course of the construction of a shelter for

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[40]   Marinatos 1968: 1 – 2.
[41]   *ibid*: 16.
[42]   *ibid*: 36.
[43]   *ibid*: 37 – 38 and fig. 53.
[44]   See Warren 1991: 338.
[45]   Marinatos 1968: 45.
[46]   Marinatos 1969: pl. 21. 2 & fig. 15.

Sector Alpha, was found evidence of collapsed material from upper floors, and further fresco fragments from the southern wall of the corridor. The moveable finds from this campaign consisted almost entirely of pottery and stone vases; Marinatos speculated that any valuable finds had been removed in the course of a large scale evacuation of the island preceding the eruption (a hypothesis which receives circumstantial support to this day from the absence of any human skeletal remains from the site)[47]. Marinatos considered a large strainer vessel[48] of stylistically advanced LM IA type to be among the most important of the finds, but the "king", according to him, was a light on dark style pithos decorated with lilies. Also in evidence were local imitations of LM IA styles.

In 1969, "Arvaniti 1" became "sector Alpha". It was becoming clear, three years into the excavation, that the abandonment was not contemporary with the "seismic" destruction, and that some modification and activity after the initial earthquake had taken place. These re-builders and re-occupiers were dubbed "squatters",[49] following Evans's designation of the occupants of post-destruction Knossos. Most importantly, Marinatos concluded that not a great deal of time elapsed between the earthquake and the eruption.

It was in the 1970 excavation that the truly Minoan character of the settlement began to emerge, with the exploration of sectors B, Γ and Δ. The latter had been known since 1970, the first trench of the excavation had revealed the extensive of ashlar architecture. The five-pier polythyron in room Δ1 confirmed the Minoan nature of the

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[47]   *ibid*: 36.
[48]   *ibid* pl. 10, 1.
[49]   Marinatos 1970: 7; see also Marthari 1984: 132 and Warren 1990 / 1991: 38.

settlement. In the 1971 report, Marinatos cites only the "most important" ceramics discovered (including imported MH wares),[50] and the bulk of the report is taken up with the discovery of the Boxing Boys, Monkey and Lily frescoes. The most well-known features of the town, such as the West House and the House of the Ladies appeared the following year. Also in 1971, it was confirmed that there were two distinct destruction horizons, and that there had been "artificial levelling" of the debris of the first, before the second, and the re-use of masonry from destroyed buildings.[51] Secondly, the digging of wells uncovered evidence of Early and Middle Cycladic occupation, confirming for the first time that the first habitation of Akrotiri preceded the LBA. The 1974 report is concerned primarily with analysis of the West House Miniature, Shipwreck and Libyan frescoes.

1.3 Relative dating

1.3.1 The eruption in the ceramic sequence

Two strands of evidence now render the Thera = LM IB destructions theory unacceptable. Firstly, it is now beyond doubt that the eruption occurred in a mature phase of LM IA, and is therefore separated from the LM IB destructions by c. 70 – 90 years.[52]   Warren refines this position by proposing a date at the end of LH I, but before the inception of LH IIA, given that there is now evidence that LH IIA began

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[50]   Marinatos 1971: 33.
[51]   ibid: 44.
[52]   See C. Renfrew, closing address, *TAW III.3*: 242.

before the end of LM IA.[53] Secondly, the end of LM IB did not represent the end of

Minoan civilisation. Occupation continued, certainly at Knossos, and the peak

sanctuary of Juktas continued in use until LM III, and at least fifteen sites remained

active in LM II[54]. The modern focus of this debate is not on the relative timing of the

eruption, but on its after-effects. Driessen and Macdonald, in an important recent

study,[55] have argued that the eruption was primarily responsible for a severe

economic downturn in Crete during LM IB, leading to political and social

fragmentation and widespread poverty. This is at odds with the views of scholars such

as Peter Warren, who argue for LM IB as a period of growth and prosperity. The

details of this, as relevant to the chronology of LM I, will be dealt with in a future

chapter, but a further significant issue is the so-called "Minoan Thalassocracy". The

relevance is the length of the LM IB phase: the "high" dating requires a certain period

of "extra" time to be included within this phase, in order to facilitate compatibility

with the Egyptian and Near Eastern sequences (see Ch. 3). If, therefore, it can be

demonstrated that there was a significant phase of Cretan expansion during LM IA,

which was sustained by further development during LM IB, it would be

circumstantially far easier to accept a longer period of time for the latter.[56] This

matter will be assessed in Chs. 3 and 6.

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[53] Warren 1999: 894; see also below.
[54] This also largely negates Peatfield's view that the eruption prompted an abandonment of sky centred religion in favour of chthonic deities. See Peatfield 1983: 278.
[55] Driessen and Macdonald 1997: 117 - 118.
[56] See especially discussion in Manning 1999: 330 - 335.

1.3.2   Egypt, Cyprus and the Levant

The East Mediterranean trading orbit of Cyprus, Egypt and Syria-Palestine is crucial

to this question, mainly through the agency of the domestic Cypriot pottery sequence

and its occurrences in Aegean, Egyptian and Levantine contexts. Two very broad

headings can be used to contain the issue, beyond the simple matter of imports and

exports between the various regions: the White Slip pottery sequence in Cyprus, and

evidence of Minoan contact with Egypt, especially stratigraphical evidence from Tell

el-Dab^c^a.[57] Chapter 3, a discussion of the archaeological methods used for dating the

eruption, will discuss this trading orbit and its relevance for Aegean chronology, and

will use these headings.

It has been suggested that a disproportionate amount of time and ink have been used

on the issue of the lost "Thera milk bowl".[58] However, it will be shown here,

developing the arguments of others, that this piece of pottery presents a very strong

challenge to the "high" dating, and fully merits a detailed discussion. It will be

demonstrated (Chapter 3, section 3.3.2) that analysis of the decorative motifs of the

bowl shows that it is perfectly possible to accept the model of Late Cypriot

chronology set out by Merrillees[59] and advocated strongly by Manning,[60] whilst

accepting that the bowl may continue to provide a strong argument in favour of the

low scheme.

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[57]   See most recently, Bietak 2000: 195 - 200.
[58]   See Bietak 1998: 231- 2; Warren 1998: 328; Merrillees 2001: *passim,* Eriksson 2001: *passim,*
          Bietak and Hein 2001: *passim*; Dunn (forthcoming); below, Chapter 3.
[59]   1971: 74 - 8.
[60]   see especially Manning et al. (forthcoming).

1.4 Absolute dating

1.4.1 Radiocarbon

To paraphrase Sir Arthur Conan Doyle, it would be accurate to say that radiocarbon dating was once regarded as "the best and highest court of detection" for chronology. In the second half of the twentieth century AD, the new absolute, radiometric, independent source of chronological information overturned many previously long-held theories, most notably that concerning construction of Western Europe's neolithic monuments. In its wake came the so-called New Archaeology.[61] The principle of radiocarbon dating is quite simple: content of the carbon isotope ^{14}C remains stable in living organisms until the time of death; after death the level of isotope falls through the process of beta decay. Because levels of atmospheric ^{14}C (which vary from region to region) interfere with this process, raw dates appear too recent, and so need to be calibrated against the tree ring record to ensure their accuracy.

In relation to the Aegean Bronze Age, however, radiocarbon dating has raised far more questions than it has answered. Originally, the central theme was that the available radiocarbon dates were too high to support the archaeological picture, and that the former was too flimsy and insecure to merit any significant chronological revision in the field.[62] A series of papers which appeared in *Archaeometry* in 1978 underlined the inherent ambiguity of the radiocarbon evidence, and reaffirmed the

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[61]   See Renfrew 1976.

[62]   Hood 1979: 198 – 8; Betancourt, et al. 1978: 201.

intellectual supremacy of archaeological cross-dating. The radiocarbon studies presented at the Third Congress did little to clarify matters, although overall a date for the eruption in the seventeenth century BC was accorded a higher probability.[63] Many contextual and analytical problems remained, however, and the whole dataset remains suspect (see chapter 2).

In 1976, Betancourt and Weinstein published a paper in the *American Journal of Archaeology* which argued that the archaeological record was in no way compatible with the earlier radiocarbon evidence, and that the discrepancy was not immediately explicable.[64] In 1987, however, Betancourt published a landmark article in *Archaeometry*, embracing the higher, radiocarbon-derived date for the eruption, and presenting an archaeological re-interpretation of the Egyptian cross-link evidence.[65] This distinguished and established Aegean scholar, who in the 1970s was on record as at best mistrusting the "low" dating, had changed his view and embraced the "high" chronology.[66] In support, he presented reassessments, based on published evidence, of archaeological evidence from El-Amarna, Aniba, Knossos, Kahun and El-Lisht (see Ch. 3 for detailed discussion). Manning[67] describes this as "...one of those critical turning points in any debate: an amazing change of mind, here by a leading Aegean archaeologist." This was followed in 1980 with the study of Kemp and Merillees, arguing for a further raising of the Egyptian record.

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63   See papers in Hardy and Renfrew 1990; also Manning 1990b: 95.
64   Betancourt and Weinstein 1976: 339- 340.
65   Betancourt 1987: 47 - 49.
66   *ibid*: 45 - 49:
67   1999: 27.

The 1990 Thera conference brought little new clarity to the debate. Papers by Nelson et al., Housley, et al., Hubberten et al. and Friedrich et al. produced a wide variety of dates on short lived samples. Broadly, contextual problems of the samples, particularly with those of Nelson et al. of the Simon Fraser University, meant that little headway was made, and the dates were inconclusive. The SFU team did not release its raw data, and in a communication to me, Dr Nelson reiterated his unwillingness to do so. He felt that, as the dates were so inconclusive, a whole new set of data was required, "with some carefully chosen samples and no pre-conceived ideas and get rid of all these different assumptions that are dragged out every time we have a discussion."[68] In an important review article summarising the conference, Manning concluded that the balance of probabilities indicated a seventeenth century date, and the "high" chronology should be considered the new "working hypothesis."[69] In his recent book, Manning argues on contextual grounds that only the data from Heidelberg (Friedrich et al.) should be accepted as the most accurate.[70] However, the problem remains unresolved. The essential problem is the placing of the dates on the calibration curve for this period. The nature of the curve allows both high and low alternatives, although a greater proportion of probability is generally assigned to the former.[71]

Two recent additions to knowledge of Aegean radiocarbon chronology comes from the Minoan sites of Myrtos-Pyrgos and Chania,[72] and from the Dodecanese.[73] From

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[68] Nelson: discussion comment in *TAW III.3*: 206.
[69] Manning 1990b: 96.
[70] Manning 1999: 238 - 239, esp. n. 1133.
[71] See Ch. 2.
[72] Housley at al. 1999: *passim*.
[73] Marketou et al. 2001: 27- 29.

Crete, Housley et al.[74] have reported eight new dates, four apiece from each site, from the LM IB destruction deposits. This exercise is particularly welcome, as the early LBA Minoan chronological system does not yet have its own internal, fixed absolute timescale. These new dates have been prepared and reported to the highest scientific standards, and should take precedence over those previously published. The combined average that these dates give for the end of LM IB is 1525 – 1490 BC at 1σ, which would require a rise in the chronology, but not necessarily a rise of the magnitude proposed by Manning and others.[75] Some leading scholars have expressed concern even with these dates. Warren, for example, rejects the "apparent precision" of the 1525 – 1490 range, and points out that the calibrated data from Myrtos-Pyrgos actually agree with the "low" position, which puts the end of LM IB (on archaeological grounds) at c. 1450 / 40.[76] It must be said, however, that the work of Housley et al. marks the beginning of a long-awaited process, by which Minoan Crete may finally come to have its own absolute, internal chronology.

1.4.2 Dendrochronology

Tree-ring research (dendrochronology) has provided yet another source of controversy for the dating of Thera and the Aegean Late Bronze Age. The subject has been excellently reviewed by Manning;[77] and his section concentrates on putting so-called "landmark studies" in the context of current thinking, and assessing the pre-2000 AD evidence.

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[74]   1999: 161.
[75]   Arguments are presented below (Ch. 2) against combining the two datasets in any case.
[76]   Personal communication, 17/1/2001. See Ch. 2 for detailed discussion and analysis.
[77]   1999: 263 – 9.

The prospect of a correlation between the "Minoan" eruption and a major climatic disruption at 1626 BC in the tree-ring record was first raised by V. LaMarche and K. Hirschboeck[78]. This analysis, from bristlecone pine trees from the White Mountains on the California / Nevada border, closely followed that of Betancourt and Weinstein[79] which had questioned the "traditional" chronology of the Aegean Bronze Age and laid an increased emphasis on the radiocarbon data. Following this radiocarbon analysis, LaMarche and Hirschboeck concluded that "[the date of 1626] falls well within the probable range for the true date of the eruption based on radiocarbon."[80] Four years later, M. G. L. Baillie and M. A. R. Munro produced further evidence from oak trees that grew in the bogs of Northern Ireland for an environmental downturn in 1628 – 1626 BC.[81] They concluded that it was highly likely that the 1620s frost-damaged rings in Northern Irish oaks were caused by the same event – probably Thera - as those of the same period in the Californian pine trees.[82] They went on to suggest that the tree-ring dating method should take precedence over ice-core evidence, because whereas ice-cores typically produce a standard deviation of c. 7 – 20 years, tree-rings are absolute and fixed, to the order of 2 – 3 years at 1σ.[83] More recently, attention has been focused on the efforts of the Aegean Dendrochronology Project of P. I. Kuniholm and others, which is seeking an absolute resolution of the chronology of the whole east Mediterranean through the analysis of tree-rings from Anatolia. This project offers the best prospect of a resolution for the whole Aegean Bronze Age chronological debate:. However,

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78   LaMarche and Hirschboeck 1984: 126.
79   Betancourt and Weinstein 1976: *passim*.
80   LaMarche and Hirschboeck 1984: 126.
81   Baillie and Munro 1988: 344 - 346.
82   *ibid*; see also Ballie 1990: 162.
83   *ibid* : 346. See also Baillie 1995: 108 - 22, and Manning 1999: 266. Kuniholm et al. 1996: 782, state that their identification of the climatic anomaly of 1628 in their ring 854 is subject to "definitive confirmation from the ice-core record."

problems remain. Renfrew[84] has pointed out that the sequence for the mid-second millennium is not yet securely anchored, but an old problem associated with this method is there is no concrete way of linking any particular eruption with any given tree ring event[85] (see below). The Aegean Dendrochronology Project's 1503-year "floating" chronology also contains an event at 1628 BC, at ring no. 854, and Kuniholm et al. have suggested that this is a further Thera correlation.[86] The low growth rate is continuous throughout the width of this ring, and this has led the investigators to conclude that the event that caused the downturn began before the beginning of the spring growth season.[87]

Further confirmation of an event in 1628/27 BC has recently been published from a 200 year "floating" chronology in a region not previously discussed, Hanvedsmossen, Sweden.[88] The authors of this new paper went on to state that "[W]e can be certain that oak trees in different parts of central Europe and the British Isles were affected a period of stressful growth conditions starting in the year 1628 BC."[89]

A clear pattern begins to emerge. Although dendrochronology provides a chronological resolution far higher than any other method could hope to achieve, and has established beyond any doubt the existence of a major climatic event in or very shortly before 1628 BC, there is no definitive way of linking a particular event with

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[84]   1996: 734.
[85]   Buckland et al. 1997: 582.
[86]   1996: 781.
[87]   *ibid.*
[88]   Grudd et al 2000: 2959.
[89]   *ibid*: 2958.

the tree-ring record, or indeed, of being precise about what the event was.[90] The

"missing link" remains missing. This point has been made at eloquent length by

opponents of the "high" Aegean chronology,[91] and it remains a weak link in the

argument for a "high" chronology now.

1.4.3 Ice-core dating

Ice core dating – although relevant for over twenty years - has recently become a

keenly contested issue. The broad logic behind this technique is simple: some large

volcanic eruptions eject quantities of sulphurous material in to the atmosphere. This

material is then transported to the polar regions, where it is precipitated onto the ice

sheets and incorporated into that year's snowfall lamination. A core drilled through

the sheet in an area of precipitation will thus include a layer with a higher than

average content of sulphur. As far as the eruption of Thera is concerned, there are

three relevant cores, all from Greenland: those at Camp Century, Dye 3, the

Greenland Ice-Core Project (GRIP), and the Greenland Ice Sheet Project 2 (GISP 2).

Initially, the Camp Century core yielded a signal at 1390 ± 50.[92] However this date

was retracted on analytical grounds, and the authors suggested a new date, from the

Dye 3 core, of 1644, with a standard deviation of ± 7 years and an error limit of ± 20

years.[93] However, as Hammer and Clausen state in the abstract for the paper they

gave at the Third Congress,[94] the main object of criticism was not the concept of

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[90] See Baillie 1990: 164; 1995: Manning 1999: 264.

[91] e.g. Warren 1998: 328.

[92] Hammer et al. 1980: 233.

[93] Hammer et al 1987: 519.

[94] 1990: 174.

linking the 1645 / 4 signal with Thera, but the dating of the layer itself.[95] Although Hammer and Clausen[96] admit that Dye 3 was "not an ideal case", they reaffirmed their support for it, albeit with appropriate reservations.

A significant recent contribution to the ice-core debate concerns the GISP 2 core of G. A. Zielinski and M. A. Germani.[97] They identified four shards of volcanic glass in a layer corresponding to 1623 BC and containing a large SO_4^{2-} (sulphur) spike. Comparing the major oxide profiles of these shards with eleven samples from Thera, investigated under the same experimental conditions, they concluded that the two sets could not have come from the same source. The Santorini glass was less rhyolitic (containing 72 % SiO_2) than the GISP 2 shards (75%). Further comparative analysis showed that there was no correlation in the individual grain analysis; thus Zielinski and Germani concluded that there was no overlap.[98] Manning, however, has vigorously disputed this,[99] pointing out that the oxide comparison model is too crude for analysis of this kind, and that recent research on the characterisation of Theran tephra have undermined the comparison of Zielinski and Germani. The only conclusion which can be drawn from this rather convoluted debate is that both potential outcomes remain possible.

[95]   Hughes 1988: 212.
[96]   1990: 179
[97]   1998a: *passim.*
[98]   Zielinski and Germani 1998a: 283 – 7 and figs 2 and 3 (a – c)
[99]   Manning 1998a: 1040 - 42; 1999: 288 - 305; most recently Manning et al. (forthcoming): n
         186.

1.5 Dynamics and geology

1.5.1 Modelling

In order to assess the impact of the Minoan eruption on Aegean civilisation, and to test existing hypotheses, a recent geo-mathematical model[100] will be applied to the Bronze Age event (Ch. 4). This equation uses a schematic model of the magma chamber and variables such as the melt density and volatile content of the magmas to determine a value (Q) for the rate of the eruption. In effect, it mathematically simulates the eruption. The key advantage of this is twofold. Firstly, as a mathematical formula, the exercise can be repeated if new variable data emerge. More importantly it will give a new estimate for the factors of rate and intensity which is not directly reliant on isopach data.[101] A disadvantage should be noted, however, in that some of the raw data for the model is petrologically derived, applying some of the same limits which apply to more traditional means.

Also pertinent to this is the gazetteer / catalogue of all of the regional and proximal ash deposits produced by the Minoan eruption, which I present in Chapter 5 (section 5.2; see also next section). The aim of this exercise is to bring together all data on the "Minoan" ash and pumice deposits from every geological and archaeological context from which it has been reported at the time of writing. A consistent, serialised format is used, with detailed notes on any pertinent stratigraphical and archaeological

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[100]   Bower and Woods 1997 and 1998: *passim.*
[101]   E.g. Bond and Sparks 1976: 3; Watkins et al. 1978: 123.

information where appropriate, together with a decimalised grid-referencing system for use with GIS software (see next section). The importance of such an exercise at this point in the Thera debate is, I believe, self-evident. There is currently no unified and accessible index of such deposits, and this has hindered discourse between geophysicists and archaeologists.

1.6 Ash fallout, tephrochronology and GIS

1.6.1 Thera's ash fan

The first indications of the axis of dispersal from the Minoan eruption came from sea cores.[102] The subsequent discovery of thick land[103] and lacustrine[104] deposits to the east of Thera confirmed early suggestions[105] that this axis might be more easterly that had at first been thought. The effect on Crete is still subject to disagreement. Only one part of the ash layer is known for sure (Mochlos), the remaining trace elements do not suggest an impact of any great magnitude.[106] The possibility that tsunami action affected wide swathes of the north Cretan coast – and recently published evidence from Malia (Hagia Varvara) suggests that this may well have been the case –

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[102]   Ninkovich and Heezen 1965: *passim*; Watkins et al 1978: 122.
[103]   Chiefly Rhodes and Kos: see Keller 1980: 50 - 55; Doumas 1988: esp. 36 - 38; Doumas and
           Papazoglou 1980: 322 - 324; Marketou 1988: 30; Marketou 1990: 104 - 109, and refs.
[104]   Sullivan 1988: *passim*; 1990: 116- 119, 1993: 330; Eastwood et al 1998: 683 - 686; Warren
           Eastwood, personal communication, 6/8/2001.
[105]   Watkins et al 1978: 124 - 126.
[106]   Cadogan and Harrison 1978: 251. They suggest that human action was responsible, a
           prevailing view at the time of this paper's publication.

has been explored[107], but the evidence is thoroughly reviewed in Chapter 5, and possible future research strategies are outlined. The complex thesis of Driessen and Macdonald argues for an indirect and time-lapsed effect, an idea which has caused much lively controversy. On current evidence, the northern limit of the fan lies in the Black Sea[108], and a trace deposit from the Nile Delta[109] may mark the southern extent (it should be noted that the provenance of this deposit is uncertain, although consensus leans towards Thera. My thanks to Warren J. Eastwood for this information). There is, however, an important factor to bear in mind when dealing with trace Minoan eruption deposits in Egypt. As briefly referred to below (section 5.3.1) in relation to Mochlos, large quantities of Theran pumice were used in the construction of the Suez Canal (AD 1854 – 69). It is therefore entirely possible that some deposits, from the Delta southwards, may have been contaminated in modern times. Although, in most cases, the stratigraphical positioning of the traces ought to make it obvious if such contamination did occur, in is an important caveat which must be observed in such circumstances.

These two independently derived parameters, the differentially derived rate estimate, and the GIS-based volumetric estimate will be combined, to provide an overall theoretical minimal timescale for the eruption. There will thus be an integrated, tripartite analysis involving time, space and the time / space ratio. As will be demonstrated in Ch. 6. this will greatly facilitate connections between the geological and volcanological records, and the material culture of human occupation in the region.

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[107]   E.g. McCoy and Heiken 2000b: 1248 - 1251.
[108]   Guichard et al. 1993: 612.
[109]   Stanley and Sheng 1986: 735.

1.6.2 Towards an approach to dispersal issues

Ever since the scale and impact of the Minoan eruption were first appreciated, and its effects linked to the demise of the Cretan palaces, the pattern of ash dispersed by the eruption has been a source of much interest.[110] The impact of the volcano on the people and environment of the time, as well as the importance of estimating the size of the eruption, have both contributed to the development of this interest. However, the concentration of individual studies upon certain locations or on single sites has led to a lesser appreciation of the region-wide impact. The recent paper of McCoy and Heiken goes some way to addressing this,[111] but the tephrochronological gazetteer / catalogue of all sites where samples of Minoan tephra have been identified, whether geological or archaeological (Ch. 5), attempts to bring together all relevant data in an accessible and straightforward serial format. I have relied chiefly on published source material, although in several instances, where the investigator(s) have been kind enough to respond to questions, I have relied on their current views.[112]

This consolidated information is used in a number of ways. It will be examined using ArcView GIS 3.2a. The set of input points is necessarily very small (and incomplete) for such a large area, but one of the principal advantages of using a computer system for an analysis of this type is the fact that the exercise is repeatable and replicable, so the outcome will be a picture based on the state of current knowledge, which can be easily updated in the light of future knowledge. Using current knowledge of airborne

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[110]   E.g. Hood 1978: 681; Vitaliano and Vitaliano 1974: esp. 23- 4; Driessen and Macdonald 1997: 92 - 4.

[111]   2000a: 1249 -1251.

[112]   The co-operation and encouragement of Professor McCoy, who supplied much unpublished material, was especially valuable. Max Bichler was also most helpful.

tephra deposits (including corrected values for sea cores), I shall produce a series of predictions for how much airfall tephra should appear in various locations across the Eastern Mediterranean.

1.7 Conclusion: The case for an interdisciplinary approach

In this chapter, I have discussed a very wide range of methods which have been employed to investigate the past in general, and the particular problem addressed by this thesis in particular. An obvious feature of this review is the *prima facie* conclusion that two philosophically different intellectual approaches have produced two diametrically different answers to the same question. Of course, this is a vast oversimplification, but it is self evident that the nature of the disagreement which has emerged in the literature over the last three decades is not resolvable from any one intellectual angle, or using any one investigative line. This thesis represents an attempt to address this imbalance, to demonstrate that the sciences and traditional humanities have a very constructive conjoined role to play. A very welcome topical development in the literature is that this view is gaining a far wider currency now than in recent years. In a recent article, A. Bernard Knapp, a "traditional" Cypriot scholar of high distinction, wrote

> Archaeological issues cannot be reduced to essential, alternative hypotheses
> whose superiority or likelihood can be established by experiments that

produce unequivocal solution ... the members of different scholarly communities frequently talk past one another, knowingly or unknowingly, because they have not been trained in the manifold and increasingly specialised techniques, approaches, viewpoints, even meta-narratives that characterise and define different disciplines...The current (younger) generation of archaeologists, for the most part, routinely and confidently has no hesitation in employing a battery of techniques and approaches from diverse fields to treat empirical data, develop their own social theory, and establish more nuanced and holistic interpretations of the human past [113]

Aegean chronology in general, and the case of Thera in particular, present a unique challenge, but also a unique opportunity for those who share Knapp's view. That challenge is to bring an overall, holistic interpretation to the data, which finds meaningful ways of linking the various disciplines, and recognises that science and archaeology are different, but not incompatible, philosophies. The overarching aim of this thesis is to overcome the liminal boundaries between these disciplines.

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[113]   Knapp 2002: 41 - 42.

CHAPTER 2

ABSOLUTE DATING METHODS

2.1 Introduction

2.1.1 Calendrical timescale problems

The development and rapid progress of scientific dating methods have formed a
central part of the debate on the dating of Thera in the last ten years. The three
elements of this discourse – radiocarbon, ice cores and tree rings – have provided
proponents of the "high" scheme for the Aegean Late Bronze Age with much of their
ammunition, and have established a series of important questions which followers of
the "low" chronology, based primarily on archaeological data, must answer.[1]
Although the very existence of this interaction highlights the truly interdisciplinary
nature of Aegean BA chronology, a number of major theoretical and practical
obstacles must be overcome. Although, generally, radiocarbon favours the higher
scheme, it is, at the time of writing, generally inconclusive, and determinations
produced for contexts relevant to Thera often have 1 σ error limits of between fifty
and ninety years. Other problems exist (see below). S. Manning's Aegean – East
Mediterranean Radiocarbon Calibration Project may assist in refining knowledge of
the effect of carbon in the atmosphere on the calibrated dates, but it is highly unlikely
that a final resolution will be achieved by these means. The data from ice-cores comes

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[1]   Manning 1999, Ch. V *passim.*

in the form of acidity signals caused by the injection of volcanic aerosols into the atmosphere. These aerosols are transported to the polar regions and deposited in the annual laminae on the ice sheets. Intense controversy surrounds two such determinations, at 1645 ± 7 and 1628 ± 36. The distal nature of such deposits, thousands of miles away from the postulated event that caused them, means that sophisticated comparisons with control samples, based on trace element geochemistry, are necessary to establish their provenance. Finally, with an error limit of ± 1, tree ring dating (dendrochronology) affords the highest level of accuracy of the three techniques, but its main drawback in relation to Thera is the fact that it leaves no trace of what caused the climatic cooling which causes frost damage in individual rings.

As with archaeological evidence for absolute chronology, all three of these methods have advantages and disadvantages in terms of accuracy and relevance. There is, however, a tendency in some quarters to regard any one of these techniques as being the absolute key to the whole question. This is not the case because a) a very large corpus of archaeological data remains to support a low chronology, putting the eruption of Thera c. 1550 – 1520, and b) certain legitimate questions, which deserve answers, remain about whether or not the scientific evidence which has been advanced in support of the high dating actually supports such a scheme. This chapter is an attempt to review and refine what these questions are, and how they should be asked.

2.2 Radiocarbon

2.2.1 Advantages and disadvantages

The history of the application of radiocarbon (C^{14}) dating to the Thera debate is outlined above (1.4.1). Ongoing work as part of the SCIEM 2000 program[2] is conducting a consolidation exercise similar to that of this study, but here I take especial advantage of the increased scrutiny of published dates made possible by the OxCal computer program.[3] This program has made available to non-statisticians complex areas of, for example, Bayseian calibration techniques, the advantages of which are self-evident. With regard to Thera, the problems centre on two issues. The first is that of the calibration curve (fig 2.1). Uncalibrated (raw) radiocarbon determinations, always given in years before present (bp) for the mid-second millennium BC, essentially allow two calibrated options. These two options put the eruption in the seventeenth and sixteenth centuries BC respectively, with a *prima facie* preference for the former. Secondly, the context and integrity of the samples is crucial. Many of the dates from the VDL at Akrotiri have been questioned for one reason or another and, in the early 1990s, were the cause of some acrimony.[4] Much confusion surrounded the pre-treatment and circumstances of the samples, along with inter-laboratory variations of procedure. The Oxford University team published separate values for "contaminant" elements as well as for the samples themselves, but this in itself was not sufficient to allay the confusion.[5] This problem was addressed by

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[2]   Kutshcera and Stadler 2001: 68 – 81.
[3]   Bronk Ramsey 2000.
[4]   See papers and discussions in *TAW III.3*.
[5]   Housley et al. 1990: 212 - 213.
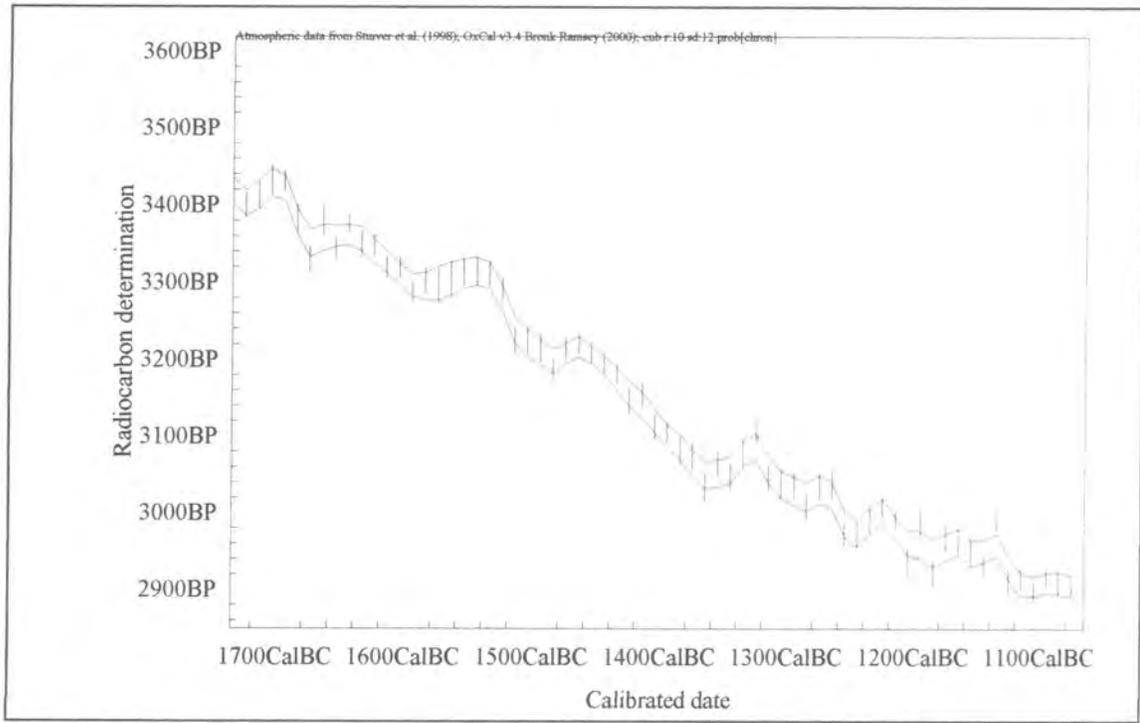
2.1 INTCAL 98 radiocarbon calibration curve, after Stuiver et al. 1998.

Housley et al.[6], whose observation of established radiocarbon pre-treatment procedures put this aspect of their analysis beyond question. In this study, they dated the end of LM IB from well defined destruction levels at Myrtos-Pyrgos and Chania. Examination of this study will form an important part of this chapter. It should be stressed that the only purpose here is to examine the data with further analysis to see if any more useful information can be obtained.

2.2.2 The end of LM IB

The most recent, and arguably the most important, application of radiocarbon to Aegean Bronze Age chronology in Crete is the acquisition of eight high quality determinations for the end of the LM IB level at Myrtos-Pyrgos and Chania (table 2.1).[7] This section discusses these dates.

The archaeological significance of these data is the fact that they come from secure LM IB destruction deposits, and so may be considered to be part of the same archaeological horizon. The first step is to test this hypothesis by using OxCal's correlation function to compare the two datasets. Using the weighted mean dates b.p. for the two destructions – 3289 ± 37 (Chania) and 3219 ± 36 (Myrtos-Pyrgos), employing a simple model:

```
Plot
{
 Sequence "LM IB alignment"
 {
  R_Date "Chania" 3289 37;
  R_Date "Myrtos" 3219 36;
```

---

[6]   1999: 169.
[7]   Housley et al 1999: 161, table 1.

lab number	date (BP)	error	place
OxA-2647	3150	70	Chania
OxA-2517	3380	80	Chania
OxA-2518	3340	80	Chania
OxA-2646	3315	70	Chania
OxA-3189	3270	70	Myrtos
OxA-3187	3230	70	Myrtos
OxA-3188	3200	70	Myrtos
OxA-3225	3160	80	Myrtos

Table 2.1 Radiocarbon dates for the end of LMIB from Myrtos-Pyrgos and Chania, reported by Housley et al. (1999: 161)

dataset	range (Cal BC)	probability (%)
Chania (all)	1612 - 1519	68.2
Chania without OxA-2647	1684 - 1601	49.8
"	1565 - 1529	18.4
Myrtos-Pyrgos (all)	1515 - 1442	68.2
Myrtos-Pyrgos without OxA-3225	1525 - 1438	68.2
all	1598 - 1565	18.8
"	1529 - 1492	35.3
"	1476 - 1455	14.1
all without OxA-2646 and OxA-3225	1607 - 1519	68.2

Table 2.2 Radiocarbon dates reported by Housley et al. (1999: 161) calibrated using Stuiver et al. 1998 and Bronk Ramey (2000)

```
  Correlation "LM IB horizon" "Myrtos" "Chania";
 };
};
```

produces the output correlation graph in fig. 2.2.

The use of the command "Sequence" should be noted. Its inclusion means that, even though there is a theoretical possibility that the two radiocarbon years given could, within their error limits, fall in the same year (i.e. within the span 3252 – 3255 BP), one has to come before the other. This is a reasonable archaeological assumption given that, since they were different events, it is impossible that the end – LM IB destructions at Myrtos-Pyrgos and Chania could have happened at the very same instant.

A more sophisticated model is:

```
Plot
{
 Phase
 {
  Phase "Chania"
  {
   R_Date "OxA-2647" 3150 70;
   R_Date "OxA-2517" 3380 80;
   R_Date "OxA-2518" 3340 80;
   R_Date "OxA-2646" 3315 70;
   Last "Last Chania";
   Span "All Chania";
  };
  Phase "Myrtos-Pyrgos"
  {
   R_Date "OxA-3189" 3270 70;
   R_Date "OxA-3187" 3230 70;
   R_Date "OxA-3188" 3200 70;
   R_Date "OxA-3225" 3160 80;
   Last "Last Myrtos-Pyrgos";
   Span "All Myrtos-Pyrgos";
  };
```

2.2

Sampled Last Chania

68.2% probability
1520BC (60.7%) 1370BC
1340BC (7.5%) 1310BC
95.4% probability
1570BC (94.4%) 1250BC
1240BC (1.0%) 1220BC

(a)

Sampled Last Myrtos-Pyrgos

68.2% probability
1480BC (54.9%) 1370BC
1350BC (13.3%) 1310BC
95.4% probability
1520BC (93.9%) 1250BC
1240BC (1.5%) 1210BC

(b)

2.3

Atmospheric data from Stuiver et al. (1998); OxCal v3.4 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]

Sampled Age Difference

68.2% probability
-140 (68.2%) 110
95.4% probability
-260 (95.4%) 220

(c)

2.3

(d)

(e)

2.3

```
Correlation "1" "Last Chania" "Last Myrtos-Pyrgos";
  Correlation "2" "All Chania" "All Myrtos-Pyrgos";
  Difference "Age Difference" "Last Chania" "Last Myrtos-
Pyrgos";
 };
};
```

In this analysis, the two sets of data from the two sites are treated as unordered
Phases. This means that each dataset (of four) is treated as a constrained, and discrete,
event. However, because the two sets of data are nested within an overall Phase, theo
a priori assumption about the ordering of the two events.

Three different calculations are performed in this analysis, Correlations 1 and 2 (figs
2.3 (d) and (e)) based respectively on the Span and the Last distributions for each
site, and an Age Difference (fig 2.3 (c)), also based on the Last distribution of each
phase. These terms are fairly self-explanatory: the Span ("All Chania" and "All
Myrtos-Pyrgos) calculates the distribution across the whole dataset, and calculates the
most likely length of its (calendrical) duration. In the case of the Myrtos-Pyrgos and
Chania data, this - in reality - should be relatively small, given that it will represent
the "length" of the LM IB destruction horizon, and how those "lengths" correlate in
real time. Such an analysis should provide a useful test for the overall resolution and
accuracy of the data. The Last command (figs 2.3 (a) and (b)) is more relevant to
absolute chronology. The distribution is given in terms of the last constituent of each
dataset, and thus in terms of the "most final" moment of destruction, as given by the
data. The correlation of these values gives a) an opportunity to test independently the
long held archaeological belief that the LM IB destructions form a constant horizon
across Crete, and b) to move towards resolving the date of that horizon.

Figs 2.3 (a) and (b) present the distribution graphs for the Last function command for each of the datasets. They support the view that the two sets are mutually incompatible, and should be treated separately; more importantly they act as a caution against artificially combining the datasets into a single entity. At Chania, it is demonstrated that there is 60.7 % probability, at 1σ, of the end of LM IB falling after 1520 BC; at Myrtos-Pyrgos there is 54.9 % in favour of a date after 1480 BC. It must be noted that these are the very earliest dates possible: it is therefore instructive to compare this with the combined range of c. 1525 - 1490 BC for the end of the period, suggested by Housley et al.[8]

The average Age Difference of < 25 calendar years (fig. 2.3 (c)) is quite feasible, and perfectly in keeping with both accepted archaeological norms for LM IB at Myrtos-Pyrgos and Chania. The very large maxima for the Spans of the data ranges (a massive 590 calendar years at Chania, and 390 years at Myrtos-Pyrgos) can be explained by the very large error limits on the dates (i.e. 70 or 80 radiocarbon years). It is well worth noting that the peak of the probability graph in fig 2.3 (c) (red line) rests at around 10 - 20 years; again, a plausible figure (yet one which underlines the point that there was no single, simultaneous pan-Cretan LM IB destruction.

There is an important issue: OxA-2647, from Chania. This particular determination, 3150 ± 70 bp, calibrating at 1510 – 1378 BC (1σ)[9] is the lowest of the eight data and, on its own, would directly support the "low" dating scheme. The authors of the study note this discrepancy, and argue for OxA-2647's exclusion on archaeological, as well

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[8]   *ibid*: 169.
[9]   Bronk-Ramsey 2000.

as statistical, grounds.[10] They do not, however, provide any detailed justification for this: " [OxA-2647] is significantly later. This itself is not a reason to exclude it from a small data set, but, on examination, the context for this sample is revealed as less certain than the others, as it did not derive from a clear, architecturally defined, context."[11] Although they are correct to draw attention to the fact that replication is low due to the small sample size, the need for a more comprehensive critique of this one sample's context becomes apparent when it is placed next to the other three determinations, and in the broader context of the other seven. The analysis presented above in 2.3 reports no poor agreement statistic, even though the Last command in OxCal places a dominant weight of distribution on the latest sample in the set, so that it would be likely to reflect a disproportionate weight, especially in cases where the latest sample is significantly later. The method for testing this is quite straightforward: An R_Combine, of radiocarbon dates, in OxCal, of all the eight dates produces fig 2.4, again there is no report of an unsatisfactory agreement statistic. This provides a weighted mean of all the dates, and allows the argument in favour of OxA-2647's exclusion on statistical grounds to be discounted. For the Myrtos-Pyrgos dataset alone (fig 2.6), the situation is exactly the same. The agreement statistics do not in any way preclude, or even question, the inclusion of OxA-2647. This is not surprising: as fig 2.7 clearly shows, Chania is generally the older dataset (as is "assumed" to be so by Housley et al, on the basis of Ramsey 1995's "order event" command), and exclusion of OxA-2647 would, in any case, lessen the generally good correlation in 2.3 (d). A similar situation exists with the Myrtos-Pyrgos dataset, in this case with regard to OxA-3225 (3160 ± 80), calibrating at 1σ to 1521 – 1372 (probability 60.4 %) and

---

[10]   Housley et al 1999: 163.
[11]   *ibid.*

2.4

Atmospheric data from Stuiver et al. (1998); OxCal v3 4 Bronk Ramsey (2000); cub r:10 sd:12 prob[chron]

R_Combine Chania : 3289±37BP

68.2% probability
  1612BC (68.2%) 1519BC
95.4% probability
  1685BC (93.3%) 1494BC
  1473BC (2.1%) 1460BC
X2-Test: df=3 T=5.7(5% 7.8)

2.5

Atmospheric data from Stuiver et al. (1998); OxCal v3.4 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]

R_Combine Myrtos-Pyrgos : 3219±36BP

68.2% probability
 1520BC (68.2%) 1440BC
95.4% probability
 1600BC (5.9%) 1560BC
 1530BC (89.5%) 1400BC
X2-Test: df=3 T=1.2(5% 7.8)

2.6

53

Atmospheric data from Stuiver et al. (1998); OxCal v3.4 Bronk Ramsey (2000); cub r:10 sd:12 prob[chron]

Chania 3289±37BP

Myrtos 3219±36BP

all 3253±26BP

2000CalBC   1500CalBC   1000CalBC

Calibrated date

2.7

1341 – 1315 BC 8 %)[12] Housley et al make a similar (and inadequate) statistical

argument for its exclusion, but their contextual case is slightly stronger. This is a soil

sample, whose "strict relevance to the archaeological target event is not without

question,"[13] but, again, a detailed stratigraphical justification for excluding it is

lacking. The ranges of calibrated possibilities for the various alternative data sets, as

determined from their respective combinations, are presented in table 2.2.

This section is concluded with three general issues of interpretation. Firstly, the

obvious point must be made that Housley et al.[14] are justified in "assuming" that

Chania is the older of the two datasets. LM IB at Chania concluded before LM IB at

Myrtos-Pyrgos, although there was no significant time lapse. This much is obvious

from fig.2.3 (d) above, as is a relatively good resolution of the respective "spans" of

the two events, as demonstrated in 2.3 (e). and leads on to the second interpretation:

the complete Chania dataset calibrates before 1519 BC, Myrtos-Pyrgos before 1442

BC. When the eight dates are combined, three "final" dates are presented. In

descending order, they are 1565 BC, 1492 BC and 1455 BC, with 1492 BC being the

most probable (table 2.2). However, it is essential to appreciate that any statistical

combination of the eight determinations must be subject the stratigraphical and

archaeological fact that there are two different events in question. "LM IB" is itself a

ceramic term, not a radiocarbon term, and linking its end at two different sites in

absolute terms using radiocarbon is a major interdisciplinary undertaking which must

be supported by ceramic analysis. The real importance of these radiocarbon dates only

emerges when treated separately at the two separate sites. Any combination model

(using, for example, wiggle matching) must be regarded only as a theoretical guide,

---

[12]   Bronk-Ramsey 2000.
[13]   Housley et al 1999: 163.
[14]   *ibid*: 165.

and in no way binding on the absolute date for the end of LM IB. This emphasis will only change when more, similarly high quality, determinations from LM IB destruction contexts from a range of other sites across Crete become available. Such a secure, well replicated "radiocarbon horizon" could be very usefully compared to the existing ceramic horizon. Thirdly, Housley et al. dismiss two dates from their analysis, for very unsatisfactory reasons. OxA-2647 and OxA-3225 are the latest determinations respectively from Chania and Myrtos-Pyrgos. When the eight dates are combined (theoretically, as above), OxCal reports no disagreement, and no poor T-statistic. Therefore, there are no statistical ground for their exclusion. Similarly, no archaeological or stratigraphical details are given to justify labelling them as aberrant. Therefore, the only methodologically sound course is to regard them as part of the respective datasets.

2.2.3 Radiocarbon dating the eruption

Dating the event of the eruption at Akrotiri using radiocarbon has proved extremely problematic. The main difficulties are:[15] firstly, the radiocarbon calibration curves[16] used in most analyses until the late 1990s were inherently ambiguous, leading to two possible calibrations for the Thera VDL in both the seventeenth and sixteenth centuries BC. However, the latest curve[17], approved by the 1998 Groningen Conference

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[15]   See Manning 1990a: 33 - 35, 1990b: *passim*; 1998: *passim*, 1999: Chapter V.1; Warren 1984:492 - 493; Betancourt 1987: 46- 7; most recently Kutschera and Stadler 2001: 68 – 81.
[16]   Pearson and Stuiver 1986: *passim*; Stuiver et al. 1993: *passim.*
[17]   Stuiver et al. 1998: *passim.*

dataset	range (Cal BC)	probability (%)
Oxford (Series I)	1682 - 1620	68.2
Oxford (Series II)	1611 - 1625	68.2
Heidelberg	1736 - 1710	30.4
	1695 - 1682	11.7
	1667 - 1624	26.1
Copenhagen	1687 - 1606	61.7
	1553 - 1538	6.5

Table 2.3 Radiocarbon dates for the VDL at Akrotiri reported by Housley et al. (1990: 211), Hubberten et al. (1990:184) and Friedrich et al. (1990: 194) respectively, calibrated using Stuiver et al. (1998) and Bronk Ramsey (2000)

(fig 2.1, above[18]) has, at least for the time being, produced a single point of reference upon which all workers are agreed (although it has not resolved the ambiguity). Secondly, contaminant gasses from volcanic fumaroles etc. on the island have been suggested as a source of potential problems with radiocarbon.[19] This has been shown to be unlikely, as such contamination is only effective over relatively small areas immediately around the source point.[20] Manning[21] has made the further sensible observation that the high exposure of Thera to the marine winds of the Aegean would further limit any effects that this factor might have had.[22] The third major problem – which, at the time of the Third Congress, led to a dispute between the Oxford and Simon Fraser (SFU) teams (see below) – is the issue of contaminants and pre-treatments of the samples themselves, caused by a lack of complete carbonisation on deposition. This means that the entire sample, not just the humic acid contaminant, dissolves when washed in HCl, as part of the pre-treatment process to remove such contaminants. The only series which did use completely carbonised matter was that produced by the Copenhagen team (which produced a weighted average of 1687 - 1606 BC, 61.7% probability at 1σ).[23] On this basis, Manning has argued that this set alone should be used, and the other three discarded.[24]

A detailed narrative of this twelve year old debate is unnecessary, but the main points pertinent to the section below are as follows. The SFU team experienced problems isolating (using ultrasonic agitation) the partially carbonised (humic) elements of the samples in their dating run. This led them to reject their own findings (a previous

---

[18]   see also Manning 1999: 235, fig 45 for further discussion.
[19]   e.g. Doumas 1983: 139.
[20]   Hubberten et al 1990: 181.
[21]   1999: 236.
[22]   see also below, Ch. 4.
[23]   Friedrich et al 1990: 195.
[24]   1999: 238-9, n. 1133 and table 7.

paper had also been rejected for publication on the basis of contaminant problems), and call for new research.[25] As a result, no raw data were published. The Oxford team then tried to replicate SFU's pre-treatment procedure, producing two runs of dates. The first, Series I (n = 11[26]) dated the original samples, and Series II (n = 4) dated the "residue" products after pre-treatment as well as the removed "contaminants". Using Bronk Ramsey 2000 and Stuiver et al 1998, the calibrated range for Series I is 3356 ± 20 bp, while for the residues it is 3295 ± 32 bp. Housley et al.[27] report these as 3357 ± 21 bp and 3300 ± 30 bp, as they were using the calibration curve of Pearson and Stuiver[28] and the computer system of van der Pichlt et al 1987, and state that these dates are "not distinguishable." Although this remains broadly the case, an important qualification must be made. The Series I determination calibrates to the range 1682 BC – 1620 BC at 1σ. The Series II residues on the other hand calibrate, also at 1σ, to the much lower 1611 BC –1525 BC, which would admit - albeit at a lower order of probability – a mid sixteenth century date.

2.2.4 The length of LM IB

A possible approach to these data is to statistically model the interval between the radiocarbon dates from the VDL on Thera and the end of LM IB at Myrtos-Pyrgos and Chania. This approach offers a number of possible avenues of inquiry, such as a possible post-eruption LM IA period.[29] More importantly, it will provide a means of comparing directly the "archaeological" length of the period with the "radiocarbon"

---

[25] Nelson et al 1990: 203 - 205.
[26] Only eight of these come from Housley et al's "stages 2/3",i.e. the pre-eruption occupation layer. In this study, the three dates from the earlier "stages 1/2" are discarded
[27] 1990: 213.
[28] 1986: *passim.*
[29] Warren 1999: 895 - 900.

length. This will also highlight any problems which the latter may have had hitting the relevant "target events". This process is carried out using the "Difference" command in OxCal, to measure the age difference between the two radiocarbon horizons. In view of the methodological considerations discussed in 2.2.3 above, both sites will be treated separately, and the results presented coefficiently. To begin with, a simulated model for each of the disputed chronological schemes are presented. This uses the "simulate" capacity of OxCal to project what results should be produced by a pre-conceived calendar date. For the "high" scheme, I follow Manning[30] in placing the eruption in a calendrical time zone between 1645 and 1635, defined by three equally spaced simulated calendar dates, and the end of LM IB similarly defined between 1510 and 1500 inclusive. For the "low" chronology, I use Warren and Hankey[31] and define the eruption as falling in the period 1535 – 1525 and the end of LM IB within 1430 – 1420. In each case the error limit is arbitrarily, but consistently and realistically, ± 50. Illustrating the "high" case, the model is:

```
Plot
{
 Sequence
 {
  Boundary "start 1";
  Phase "simulated VDL"
  {
   C_Simulate "Thera 1" -1645 50;
   C_Simulate "Thera 2" -1640 50;
   C_Simulate "Thera 3" -1635 50;
   Last "last 1";
   Span "span 1";
  };
  Boundary "end 1";
  Boundary "start 2";
  Phase "end LM IB"
  {
   First "first after";
   C_Simulate "LM IB 1" -1510 50;
```

---

[30]   1999: 337 and 339, fig. 62.
[31]   1989: 169, table 3.1.

```
    C_Simulate "LM IB 2" -1505 50;
    C_Simulate "LM IB 3" -1500 50;
    Last "last 2";
    Span "span 2";
   };
  Boundary "end 2";
  Difference "LM IB (1)" "end 1" "end 2";
  Difference "LM IB (2)" "last 1" "last 2";
  Difference "LM IB (3)" "span 1" "span 2";
 };
};
```

The model for the real situation follows the same logic, and is (for the case of the Copenhagen VDL to the end of LM IB at Chania):

```
Plot³²
{
 Sequence "Copenhagen VDL - end Chania LM IB"
 {
  Boundary "start 1";
  Phase "Copenhagen VDL"
  {
   R_Date "K-5353 " 3430 90;
   R_Date "K-4255 " 3380 60;
   R_Date "K3228 " 3340 55;
   R_Date "K-5352" 3310 65;
   Last "last 1";
   Span "span 1";
  };
  Boundary "end 1";
  Boundary "start 2";
  Phase "end LM IB"
  {
   First "first after";
   R_Date "OxA-2647" 3150 70;
   R_Date "OxA-2517" 3380 80;
   R_Date "OxA-2518" 3340 80;
   R_Date "OxA-2646" 3315 70;
   Last "last 2";
   Span "span 2";
  };
  Boundary "end 2";
  Difference "LM IB (1)" "end 1" "end 2";
  Difference "LM IB (2)" "last 1" "last 2";
  Difference "LM IB (3)" "span 1" "span 2";
 };
```

};

As can be seen from the final three lines of the plot, three different types of interval are modelled. The first (1) requests simply the period of time between the "ends", that is to say the ends of the phases, after the VDL sequence and after the LM IB sequences. In other words, it assumes that LM IB occupies the time between the statistical boundaries "end 1" and "end 2" The second (2) models the difference between the final (normalised) dates, theoretically the "final" final destruction at each site. The third (3) calculates the age difference between the spans of the two horizons, which should be fairly small, given that the each set of four dates (in this case) are dating the same event (see above, section 2.2.3 and figs. 2.3 (d) and (e)). Analyses measuring the difference, using all three alternative techniques, are given here for the ages of: Myrtos-Pyrgos and Chania respectively and the VDL dates given by Copenhagen and Oxford Series I, II and I + II. Figs 2.8 (a) and (b) show the results of the analyses plotted on radar diagrams. The twelve "spokes" on each graph represent the measurements that were taken. Statistical problems arose in the cases of three determinations: OxA-2647 (in all analyses involving Chania), OxA-1555 (Chania - Oxford I) and OxA-1559 (Myrtos-Pyrgos and Chania respectively - Oxford I + II). This, of course, provides an arguable statistical case for the exclusion of OxA-2647. However, in the same context, it should be noted that the "later" dataset; that of Myrtos-Pyrgos created no statistical aberrations when compared with the VDL data. Where aberrations occurred, the analysis was performed again, with an OxCal "question" command on the dates reported as aberrant. This command removes the date from the sequence, but calculates the probability that it should be there at all (very low in most cases, ranging from 4.3% - 17.1%). As can be seen from figs. 2.8 (a) and (b), the agreement between the three methods for both sites is generally good,

Chania

1 Copenhagen (1)
2 Copenhagen (2)
3 Copenhagen (3)
4 Ox I (1)
5 Ox I (2)
6 Ox I (3)
7 Ox II (1)
8 Ox II (2)
9 Ox II (3)
10 Ox I + II (1)
11 Ox I + II (2)
12 Ox I + II (3)

250
200
150
100
50
0

1 sigma 2 sigma

(a)

2.8

Myrtos-Pyrgos

Legend: 1 sigma, 2 sigma

Axis labels: 1 Copenhagen (1), 2 Copenhagen (2), 3 Copenhagen (3), 4 Ox I (1), 5 Ox I (2), 6 Ox I (3), 7 Ox II (1), 8 Ox II (2), 9 Ox II (3), 10 Ox I + II (1), 11 Ox I + II (2), 12 Ox I + II (3)

Radial scale: 0, 50, 100, 150, 200, 250, 300

(b)

2.8

64
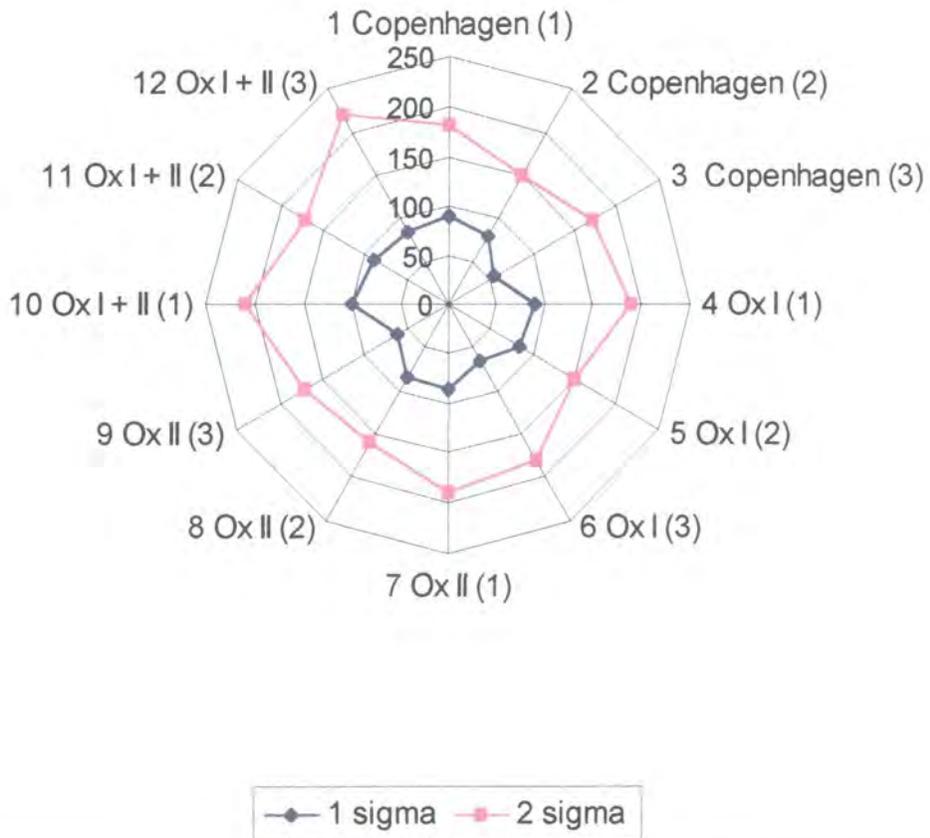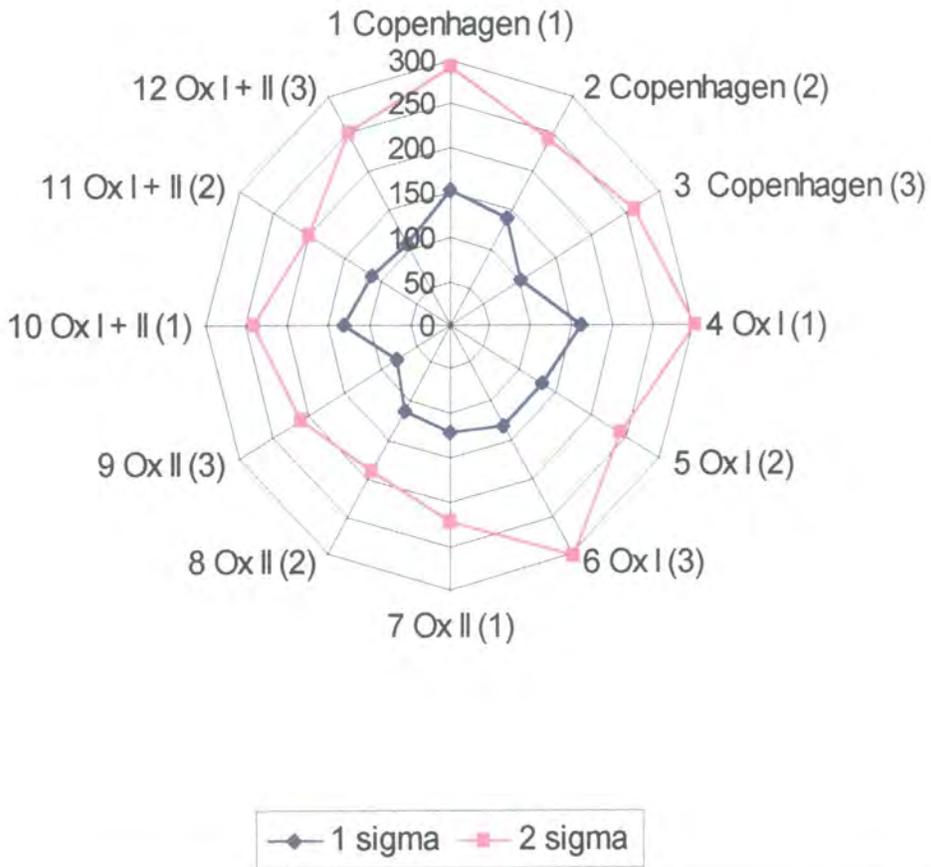
although in both cases method (2) provides the shortest and probably the most realistic time span. The alternative of ranges, at 1 σ is broad, and needs some discussion. It is interesting that both the highest (201> years) and lowest (100> years) ranges both Oxford series 1, respectively to Chania and Myrtos-Pyrgos. In the former case, the question function is applied to OxA-1555, OxA-1557 and OxA-1554 – the three latest dates in this set – and in the latter, OxA-1551 and OxA-1549 the two earliest. It is interesting to compare this picture with simulated models for the period in question. As with the "real life" analyses, a good agreement exists between the ranges involved, underlining the general fact that it is absolute, rather than relative chronology which is at issue.

To conclude this section on radiocarbon: this analysis has not succeeded in estimating with any appreciable accuracy the length of LM IB; at best it is constrained within a period of one century at Myrtos-Pyrgos, and further mathematical refinement is unlikely to shed any more light. Nonetheless, some significant methodological inferences can be drawn:

- In each of the three methods of calculation employed here, and with both simulated sequences there is a high level of relative agreement in all cases. This indicates that in radiocarbon terms, the relative sequence is not significantly disrupted during the calibration process.

- There is a significant difference in age between the radiocarbon dates for the destructions at Myrtos-Pyrgos and at Chania. This was never disputed by Housley et al. (1999). Although the dates they have produced are unquestionably of high quality, their methodology and selection of data are open to serious question. There is no justification on any grounds for the exclusion of the data they propose to exclude, a

point with much bearing on the potential outcomes of their work.[33]

•   Although the LM IB destructions have frequently, and correctly, been described as a horizon, it is simplistic to combine eight dates from two different sources that are very remote from each other. The problems encountered calculating the LM IB range using the Oxford Series I dataset have underlined this. Notwithstanding its interpretational problems and relevance to the VDL,[34] the Oxford Series I run is internally consistent, combining at 3356 ± 20 in Bronk Ramsey 2000, using Stuiver et al. 1998. Yet, as described above, the Difference function using both the Myrtos-Pyrgos and Chania sets produce different problems with different dates within Series I. Myrtos-Pyrgos "upsets" the two earliest dates in this series, Chania the three latest. Thus, combining the two latter is surely misleading. The best that can be said at this stage of statistical refinement is that Myrtos-Pyrgos (1515 BC – 1442 BC a 1σ) strongly supports the low, or at least the "compromise low" dating scheme, whilst the Chania set strongly supports the high scheme (1612 BC – 1519 BC). Combining the datasets, even with the sophisticated technique of archaeological wiggle matching, does not change this. Although this argument may appear destructive, it is not. The essential approach of dating LM IB with radiocarbon is to be applauded, and should be pursued through the acquisition of many more dates from a wide variety of sites, to form a "radiocarbon horizon", coefficient with the ceramic LM IB destructions, *in sani senses*. A carefully integrated approach, relating the target samples to stratigraphical contexts and pottery assemblages is necessary. Such an approach opens up the possibility of an internal independent chronology for Crete.

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[33]   See above, also Peter Warren, personal communication, 17/2/001.
[34]   See discussions in Hubberten et al 1990: 184 - 6; Housley et al 1990: 212 - 215; Manning 1990b: *passim*, and 1999: esp. 243 - 247.

2.2.5 Radiocarbon dating at Ialysos and Seraglio

A recently published data set of eighteen radiocarbon dates from Ialysos (Trianda) and Kremastis on Rhodes and Seraglio on Kos, has been advanced as further evidence for the "high" dating scheme.[35] The implications of this dating and the authors'claim of a very substantially longer LM IB require comment.

It is a matter of record that the LM I stratigraphic sequence at Ialysos closely reflects that of Akrotiri.[36] The two settlements underwent broadly contemporary seismic destructions, and experienced tephra falls which also must have been contemporary.[37] This new dating sequence is thus very significant. The calibration curve employed in this study, INTCAL98, was used in the analysis of Marketou et al, but a different program; Calib rev. 4.3. For consistency, in the (re)analysis below, I continue to use Bronk ramsey (2000).

2.2.6 Early LM IA

Marketou et al present only preliminary results, in the form of three determinations, for the Middle Bronze Age, and the EBA is outside this thesis's scope. Therefore, I shall confine my discussion of this study to the Late Bronze Age findings.

As at Akrotiri (see below, 3.2.2), LM IA on Rhodes and Kos is divided into early and late phases. Two dates in the assemblage under discussion relate to the former; DEM-

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35   Marketou et al 2001: 25 - 26.
36   Marketou 1990: 100; Marketou et al. 2001: 21 - 22.
37   See below, Ch. 5.

lab no.	date (b.p.)	error	context
DEM-862	3869	23	EBA
DEM-864	3895	59	EBA
DEM-92	3417	65	MBA
DEM-863	3538	45	MBA
DEM-95	3907	61	MBA
DEM-94	3347	46	LM IA(b)
DEM-93	3358	48	LM IA(b)
DEM-828	3407	25	LM IA(b)
DEM-830	3449	21	LM IA(b)
DEM-831	3466	23	LM IA(b)
DEM-89	3517	83	LM IA(a)
DEM-859	3568	44	LM IA(a)
DEM-858	3138	50	LM IB(b)
DEM-857	3142	52	LM IB(b)
DEM-829	3171	33	LM IB(b)
DEM-856	3175	41	LM IB(b)
DEM-91	3240	35	LM IB(a)

Table 2.4 Radiocarbon dates from Ialysos and Seraglio,
reported by Marketou et al. (2001: 28- 29)

dataset	range (1 sigma) cal BC	probability (%)	context
DEM-89	1944 - 1738	68.2	LM IA (early)
DEM-859	1972 - 1874	58.4	LM IA (early)
"	1840 - 1822	7.3	LM IA (early)
"	1792 - 1785	2.6	LM IA (early)
DEM-94	1686 - 1598	50.8	LM IA (early)
	1568 - 1530	17.4	LM IA (late)
DEM-93	1730 - 1719	4.8	LM IA (late)
	1690 - 1604	54	LM IA (late)
	1558 - 1537	9.4	LM IA (late)
DEM-828	1741 - 1683	68.2	LM IA (late)
DEM-830	1858 -1847	8.8	LM IA (late)
	1771 - 1733	40.1	LM IA (late)
	1713 - 1693	19.3	LM IA (late)
DEM-831	1870 - 1844	23.4	LM IA (late)
	1811 - 1800	7.3	LM IA (late)
	1766 - 1739	37.5	LM IA (late)

Table 2.5 Radiocarbon dates from Ialysos and Seraglio reported by Marketou et al. (2001: 28
– 29) and calibrated using Stuiver et al. (1998) and Bronk Ramsey (2000)

latter is reported in Marketou et al.'s table as being from "AE 43, Western Wall, near 6 Trench Ash Layer." In the text, it is described as being "under the ash layer". It should be noted, particularly in the second of these occurrences, that the contextual 89 (3517 ± 83) and DEM-859 (3568 ± 44). The former is reported as coming from an "early LBA IA floor", namely Floor II of Square B1, at a depth of 3.01 – 3.1 m. The information available is not very precise. The term "under the ash layer", in particular, is rather vague. This is not a criticism of the authors, it simply highlights the fact that the contextual information is not linked directly to the ash layer. This problem compounded by the nature of the sample itself: "from a beam used as building material". It is not necessarily, therefore, a short lived sample. The respective calibrated ages for the samples reported by the authors are 1940 BC – 1700 BC at 1σ, 2120 BC – 1620 BC at 2σ. Using OxCal, the results are very similar: 1944 BC – 1733 BC at 1σ, 2122 BC – 2091 BC, and 2039 BC – 1625 BC at 2σ. When combined, however, a very slight divergence appears, although broadly the results are easily replicated. The figures quoted in Marketou 2001 are: 3555 ± 41 bp, with ranges at 1σ: 1950 – 1780 BC, 2σ: 2020 BC – 1750 BC. The figures reached here are: 3557 ± 39 bp, with the 1σ calibrated ranges being 1949 BC – 1873 BC, 1842 BC– 1819 BC and 1795 BC – 1779 BC, the ranges 2σ being 2020 BC – 1994 BC and 1979 BC – 1761 BC. The main problems, however, remain the contextual ones outlined above.

2.2.7 Late LM IA

This, of course, is the crucial period in question. The set of five dates provided by Marketou et al., although undoubtedly of the highest scientific quality, illustrate the fundamental contextual weakness to which radiocarbon is prone when applied to the

Aegean Bronze Age (see above). Close analysis of the determinations, and their contextual circumstances, show that far from offering unequivocal support for the "high" dating scheme, the "low" scheme remains very plausible.

The authors report the combined value for their LM IAb (mature) data set to be 3426 ± 15 bp, calibrating to the ranges 1740 BC – 1690 BC (1σ) and 1860 BC – 1670 BC (2σ). OxCal broadly replicates this, with a determination of 3431 ± 12 bp, 1746 BC – 1690 BC (1σ) and 1761 BC – 1682 BC (2σ). No serious scholar would maintain, without revolutionary new corroborative stratigraphical and / or ceramic data, that LM IA started as early as 1690 BC / 1682 BC Therefore, in the absence of such data, some or all of the constituents of this combined average cannot refer to the final levels of LM IA. In the context of the Aegean Bronze Age, radiocarbon dates which do not refer to final occupation levels (particularly destruction horizons; see above) are not very useful for detailed chronological resolution. It is therefore necessary to treat the dates individually.

In combining the dates, and coming up with the weighted average given, the authors conclude that:

> [T]he calibrated radiocarbon chronology suggested above shows a high chronology for the mature LBA IA / LM IA period and gives a terminus post quem for the tephra fall, but does not give a chronology for the eruption in years BC. It dates the abandonment of the site during building activities which were still in progress.[38]

The last statement refers to the buildings that were erected prior to the eruption, following the seismic destruction level (SDL). The presence of such activity cannot be

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[38]   Marketou et al. 2001: 25.

doubted.[39] However, the pattern of calibration distributions for the seven LM I radiocarbon determinations allows a chronological conclusion that is somewhat different to that proposed by the authors. It is clear that, stratigraphically, none of the determinations post-date the eruption. But the five mature-phase dates demonstrate a smooth sequencing from the beginning of the seventeenth century, down into the sixteenth century, in the case of DEM-94 and 93. The lowest possible calibrated dates at 1σ for these two determinations are 1530 and 1537 BC respectively. The find circumstances, as described by the authors, for DEM-94 are particularly intriguing:

> It should be considered, that DEM-94 is the unique sample measured until now from the LBA IA/LM IA cemetery ... A date spanning from the earlier to the later phases of the LBA IA was suggested for the cemetery, *since there were no finds to give a more precise archaeological dating.* However, the above calibrated chronology falls into the mature phase of the period, *suggesting that the burials might be connected with the last phase of the settlement* [my emphases].

If this date could be as low as 1530, and pre-dates the eruption, then the conclusion that the eruption may have been after c.1530 BC does not need highlighting. (It is also noteworthy that there is no supporting stratigraphical or ceramic evidence to suggest that this level is even "late".) Admittedly, this does require the lowest possible extrapolation of the data. However, the "running flush" (fig 2.9) of calibrated distributions makes this the most likely scenario: that the five dates represent different temporal points in the chronology of early to late mature LM IA, and DEM-94 and 93 represent the latest points of this sequence.

Further evidence for a late end to LM IA from this dataset can be provided by employing OxCal's Last Event function (see above, section 2.2.3). This analysis

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[39] See Marketou 1990: *passim.*

M. Stuiver, A. Long and R.S. Kra eds. 1993 Radiocarbon 35(1); OxCal v3.4 Bronk Ramsey (2000); cub r:4 sd:12 prob usp[chron]

DEM-94 3347±46BP

DEM-93 3358±48BP

DEM-828 3407±25BP

DEM-830 3449±21BP

DEM-831 3466±23BP

2200CalBC 2000CalBC 1800CalBC 1600CalBC 1400CalBC 1200CalBC

Calibrated date
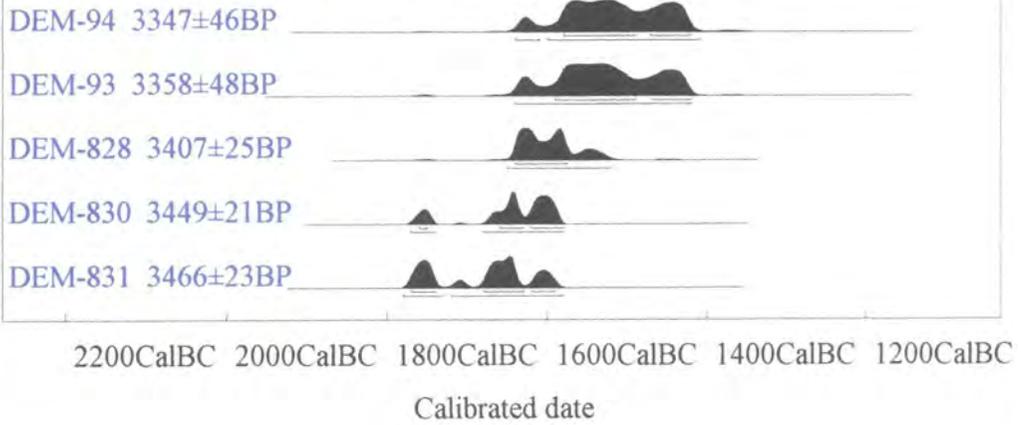
2.9

interrogates the data for the whole LM IA period at Ialysos and Seraglio, to identify the period of calendrical time in which the end of the sequence is most likely to fall. The probability that this is the case is then quantified. A Phase is used within Boundaries, thus making no *a priori* assumption about what order the determinations fall in, whilst recognising that they make up a discrete set. Thus, the model employed is:

```
Plot
{
 Boundary "Start";
 Phase "Ialysos / Seraglio LM IA"
  {
   R_Date "DEM-94" 3347 46;
   R_Date "DEM-93" 3358 48;
   R_Date "DEM-828" 3407 25;
   R_Date "DEM-830" 3449 21;
   R_Date "DEM-831" 3466 23;
   R_Date "DEM-89" 3517 83;
   R_Date "DEM-859" 3568 44;
   Last "Ialysos / Seraglio LM IA";
  };
 Boundary "End";
};
```

This extrapolation demonstrates that the "low" or "compromise low" dating is actually more probable, with a 44.5 % likelihood of the end of the phase falling within sixty years before 1520 BC, as opposed to 23.7 % probability for the fifty years down to 1590 BC (fig 2.10), almost half. However, further resolution of this issue will only be possible through archaeological measurement of the time elapsed between the levels which have been dated, and the eruption level.

Last Ialysos / Seraglio LM IA

68.2% probability
1640BC (23.7%) 1590BC
1580BC (44.5%) 1520BC
95.4% probability
1680BC (95.4%) 1510BC

2.10

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2.3 The Minoan volcanic dust veil and climate alteration: some general comments

2.3.1 Problems and issues of interpretation

This aim of this section is to provide a brief technical commentary on the climatic effects of the Minoan eruption, and their relevance to the two indirect dating methods of dendrochronology and ice-cores discussed below.

A complex and controversial series of arguments has been produced linking the Minoan event to frost damaged tree-rings and acidity signals in ice-cores from Greenland. As these anomalies occur in the middle and later seventeenth century BC, these methods, the latter in particular, form the strongest arguments in favour of the high dating scheme, to the point where Manning has described the whole debate as "effectively over".[40] The evidence may be summarised as follows: Minoan eruption products have apparently been identified in a layer of the Greenland Icecore Project (GRIP) / Dye-3 ice-core pair, under the principal direction of Claus Hammer.[41] The paper presenting this information has, at the time of writing yet to be published, but in a recent personal communication, Professor Hammer has been kind enough to confirm that he (still) regards the event in question as datable to 1645 BC ± 7 years. A major climatic event had previously been reported as having occurred at this time from a major sulphur dioxide peak here, but the discovery of trace elements has added a significant new dimension to this issue.

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[40] Manning (forthcoming).
[41] Hammer et al. 1980: *passim*; Hammer et al. 1987: *passim*; Hammer and Clausen 1990: *passim*.

A further ice-core, the Greenland Ice Sheet 2 (GISP2) project, has added to the complexity of this issue. In a paper published in 1998, Greg Zielinski and Mark Germani presented four tiny shards of volcanic glass in a layer dated to 1623 ± 36 BC.[42] They presented the results of a microprobe analysis of major oxide elements which, they claimed, strongly suggested that the shards were not Theran. There are undeniable problems with this model, pointed out at length by Sturt Manning and others. There were problems focusing on error limits of the microprobe analysis, with Manning arguing that the limits do allow a correlation to be made, also that the dating of the ice-layer could be out by up to 3%, (some decades), due to the fact that the core was incomplete. The most serious problem with the Zielinski and Germani model, however, was the fact that major oxide elements are not very diagnostic: trace-element or rare earth analysis are the only suitable methods of proceeding. This episode only serves to highlight the fact that we must be wary of using ice-core dating to draw any broad conclusions on Aegean chronology.

It has also been claimed that the climatic effectiveness of the Minoan eruption is manifested in a series of tree-ring sequences, in the form of frost damaged rings. This event is precisely dated to 1628/7, with the sequences replicated in the western United States,[43] Northern Ireland[44] and Germany.[45] Two further sequences, from Sweden and Anatolia, are floating chronologies which report interesting aberrations. Latest information[46] concerning the former (from the peat bog at Hanvedsmossen, south central Sweden), indicate an anomaly caused by a severe cooling event at 1637 ± 65 years.

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[42]   Zielinski and Germani 1998a: *passim.*
[43]   LaMarche and Hirschboeck 1984: 121 - 126.
[44]   Ballie and Munro 1988: 344 - 6.
[45]   E.g. Manning 1999: 265.
[46]   Grudd et al 2000: 2959.

The point has been made at great length by proponents of the low dating scheme that it is not possible, at this stage, to identify the cause of such growth-stunting events as a volcanic eruption at all, still less as the Minoan eruption. This point remains valid. However, the identification of apparently Theran trace-elements in the GRIP / Dye-3 data has led those proposing the high dating to argue that the event recorded in these cores must now be definitely linked to Thera. With the obvious drawback that the detailed correlation information is not yet available (see above and below), it is necessary to trawl back through the debate's history to identify the potential difficulties and benefits of this approach.

The central problem was outlined in an *Antiquity* paper of 1997. In it, Buckland et al. make the central point that there is no "smoking gun", there is no demonstrable link between climate change documented in ice-core and tree-ring sequences and the Minoan eruption.[47] Hammer's paper, if and when it is published, may, of course, alter this, but this would not remove problems associated with core dating and the accuracy of ice laminar resolution. There is an ice-core date of 1645 ± 7 BC, and a tree-ring date of 1628 or 1627 BC. Without concrete further information on the standard deviation or other error limits of the GRIP ice-core, we have a gap of at least ten calendar years. As I have not yet had the opportunity of studying the evidence that Professor Hammer will shortly be presenting, I must suggest that this is a problem which requires a definitive resolution before either method can be used to carry forward the Thera debate. Any further discussion at this stage merely serves to complicate an already very complex issue.

A final point should be made regarding this matter. A suggestion, which has not

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[47]   Buckland, et al. 1997: 582 - 584.

received wide circulation, was made in 1998 by the excavators of Palaikastro. There, the excavators discovered evidence of some kind of alluvial destruction in the Middle Minoan III phase, several decades before the Minoan eruption. They tentatively suggested that the (otherwise unknown) event which caused this may be linkable to an event or events which caused the tree-ring and ice-core anomalies.[48] Incidentally, a non-Theran cause, spread over ten to fifteen years, for these anomalies would remove the single-event problem that exists for Thera. I must stress that the basis for this suggestion is entirely circumstantial, but I am unaware of any attempt to investigate it further.[49]

Pending the detailed paper by Professor Hammer and others on the subject of the trace elements, this essentially brings us up to date. I would now like to make some remarks to conclude this brief review, and outline some specific ways in which we can indeed move towards "an interdisciplinary approach to scientific dating techniques." By very definition, the thing to be most avoided is to hang an entire thesis or dating scheme on one strand of methodology, still less on one application of one strand of methodology. This must apply in all cases, be it ice-core dating in Greenland, or (for example) a lost White Slip bowl from Thera (see below, 3.3.2). It is true that to admit this awkward fact is to leave the Thera debate at loggerheads. One set of scholars insists that the ice-core date of 1645 BC is unanswerable, an opposing set regard the archaeological evidence as equally incontrovertible. It seems little more than a matter of which system the individual chooses to follow. One is reminded of the old philosophical conundrum: what happens when an unstoppable force hits an immovable barrier? In

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[48]   MacGillivray et al. 1998: 241.
[49]   It is worth mentioning in this context the view expressed by Mike Baillie, a scholar who has otherwise embraced the Thera / 1645 correlation, in his 1998 paper, that cometary impact may, in fact, have been responsible for the seventeenth century event.

one thing I am certain: I reject outright the notion that the issue is resolved. The low dating scheme remains plausible in some aspects, and preferable in others.

2.4 Conclusion: The place of absolute dating methods in Aegean Bronze Age chronology

One common factor emerges from all three of the case studies of radiocarbon application discussed above. The context of the event being dated has to be paramount. It is extremely dangerous to use weighted averages, or combinations of dates, when the constituents of these datasets come from different levels, areas or even sites. The apparently contradictory data from Myrtos-Pyrgos and Chania illustrate this. There is no statistical argument, and only unspecific and unsubstantiated archaeological and contextual arguments, in favour of excluding any date from this set. With their various ranges, the data from Myrtos-Pyrgos and Chania support respectively the low and high dating schemes. The authors are correct to state that the two horizons should, archaeologically, be very close together. But clearly they are not in radiocarbon terms. Thus, I conclude that extreme caution is necessary in the interpretation of those data. For a reason or reasons unknown, these contexts are producing different dates. I reject the methodology of simply combining all of them, and hoping for the best. To do so is to greatly oversimplify the final LM IB horizon.

The story is very similar at Ialysos. Although this study should be welcomed, as

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should any which contribute to the Aegean Bronze Age corpus of radiocarbon dates, again the methodology of combining the results across different contexts should be rejected. This is far truer of this site, where the narrowest possible resolution of stratigraphy is a division between LM IA "early" and LM IA "mature", when clearly the dates come from seven separated points from throughout the duration of the early Late Bronze Age. Although, under individual calibration, the results still exhibit the familiar bias towards the higher dating, it becomes abundantly clear that the data do permit the eruption of Thera to be placed after c. 1530 BC. As pointed out above, a far clearer picture will surely emerge if this vital and complex site can yield a measurement for the time-lapse between the final abandonment of the cemetery from which this determination (DEM-94) comes, and the level equivalent with the tephra fall itself.

CHAPTER 3

THE ART HISTORICAL AND ARCHAEOLOGIAL DATING OF THE AEGEAN BRONZE AGE

3.1 Introduction

3.1.1 Relative versus absolute dating

The purpose of this chapter is to complement the scientific dating methods discussed in Chapter 2 by providing an analysis of "traditional" methods of dating the Minoan eruption. I hope to conclude this chapter, and Part 1 of this thesis, by providing an interdisciplinary framework in which the problem of the date can be approached.[1] It is true that new material is constantly emerging, and that the emphasis is shifting more and more to the Levantine coast, with the emergence of new pumice deposits (see Chapter 5) and a very sigficant new layer at Tell el-Ajjul.[2] It will not, of course, be possible to cover every aspect in exhaustive detail, but I hope to use a combination of the most significant aspects, under a series of thematic headings, to construct a useful approach. I shall not be discussing any aspect of Thera's tephrochronological horizon, as this will be dealt with in detail below (Ch. 5).

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[1]   I must express gratitude to the Institute for the Study of Interdisciplinary Sciences (ISIS) for giving me the opportunity to outline this approach in its biennial Vronwy Hankey Memorial Lecture, *The Theran Eruption: A Lynchpin for Absolute Dating. Towards an Interdisciplinary Approach to Scientific Dating Methods*, University College London, 3rd November 2001. See also Dunn (forthcoming).

[2]   Max Bichler personal communication 11/9/2001; Peter Fischer personal communication 12/9/2001.

I also wish to anticipate Part 2, and Chapter 4 in particular, with a stratigraphical critique of the geological and archaeological sequences at Akrotiri. It is evident at this site that the L Cyc. I / LM IA sequence prior to the eruption involved complex and interlocking human and geological processes. I hope to define and illustrate these, and relate them to the wider archaeological and geographical picture.

3.2 Crete and Akrotiri

3.2.1 Some general remarks on ceramic sequences in relation to chronology

A full exposition of the Minoan, Cycladic and Helladic pottery sequences is well beyond the scope of this thesis. This section merely provides a general critique of the various problems involved, and analyses current views on the subject.

The main problem is twofold. The nature of ceramic evidence is, *ipso facto*, unsuited to answering questions that demand such precise answers as Bronze Age chronology. The eruption of Thera occurred, at least theoretically, at a precise and quantified moment in history, whereas the boundaries between the ceramic phases of the Late Bronze Age cannot be thus defined. There is therefore a major, and intrinsic, problem in contextualising the Minoan eruption within the archaeological record. Improved resolution of the picture achieved by this method can only be gained with constant replication across a wide geographical area at a large number of sites, a variety of ceramic taxonomic systems, and by good agreement between different

contexts. Usually, the last of the three is only gained by good fortune and the chance find of a relevant vessel in an appropriate context.

To a great extent, the problem is compounded by ceramic taxonomic systems themselves. These tend to be unilinear, unwieldy, regionally exclusive and dominated by the pioneering work of individual scholars (for example Sir Arthur Evans in Crete and A. Furumark on the Mainland). Any ambiguities in the compatibility of these systems are vastly magnified when projected onto chronology. The issue of how the ends of LM I and LH I should be aligned is, for example, a major sticking point, and one that is crucial for defining the Minoan eruption's chronological relationship with the Mainland.[3] Such problems can only be resolved via cross-cultural comparison of well-known decorative motifs on individual vessels in incontestable stratigraphic contexts. As stated above, however, such finds are extremely rare, and the cases which do exist present as many questions as they do answers.

One such "chance" finding is a well-known bridge-spouted jug from Akrotiri (Fig 3.1).[4] This vessel has often been described as being very late LH I, quite possibly LH IIA.[5] The (obvious) implications for the relative dating of the eruption are very significant. If this jug was manufactured in LH IIA, a *terminus ante quem*

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[3]   E.g. Lolos 1990: *passim*; Warren 1999: *passim*.
[4]   Marthari 1990: 63, fig 8.
[5]   Especially Oliver Dickinson personal communication, various occasions.

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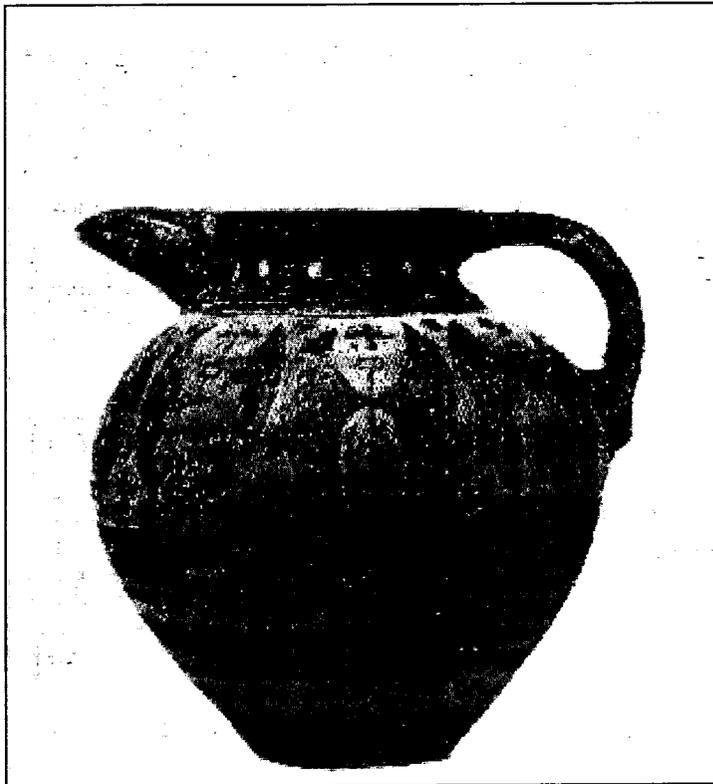
3.1: Bridge-spouted jar from Akrotiri (Mathari 1990: 63, fig. 8).

significantly later than LHI for the eruption would be necessary. I refer, however, to

the opinion of Dr O. T. P. K. Dickinson, who states that it is not <u>definitely</u> LH IIA,

but could be very developed LH I. If this is placed within the context of a possible,

but unproven, manifestation, of the eruption before the end of LH I at Nichoria (see

Chapter 5), this would constrain the event to a very late point in that phase. All of this

puts pressure on any such "post-eruption LM IA" or "LM IA final" phase. However,

the mixture of ill-fortune (the non-preservation of the pumice sample by the

University of Minnesota, and thus an unresolved and irresolvable obstacle to

establishing its provenance[6]), and the subjectivity of interpretation of the dating of the

jug's decoration, highlight the limitations of one-case answers to interregional

problems.

In any case, such instances where individual vessels merit special importance are rare

in the Aegean. A more abstract problem lies in linking the relative dating schemes of

the Aegean with the absolutely dated cultures of the Near East (and indeed

information provided by scientific methods; see above). In a recent paper, S. Hood[7]

has outlined these problems, pointing out that whereas the king-lists of the early 18th

Dynasty are generally dateable to individual years (some with controversy, including

various regime changes, and the co-regency of Hatshepsut and Tuthmosis III),

Minoan, Cycladic and Helladic pottery cannot be so conveniently badged, for exactly

the reasons outlined here. This is critical caveat which must be uppermost in the mind

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[6]   George Rapp Jnr., personal communication, 16/4/2001.
[7]   1999: 384 - 386. This issue was also cogently discussed in an oral presentation by Susan
    Sherratt at the Vronwy Hankey Memorial Symposium, held at the Institute of Archaeology,
    London, 29/5/2002.

of anyone investigating Aegean Bronze Age chronology using "conventional" means.

3.2.2 Akrotiri, its sequence, and the interplay of geological and human processes

The pottery groups of the West House have been examined in detail by Marisa Marthari,[8] and they reflect the ceramic sequences from other buildings at the site. Linking the sequence at Akrotiri with other assemblages from outside Thera, especially those at Trianda and Seraglio, is crucial for an interregional perspective. The new radiocarbon campaigns in Rhodes and Kos serve to highlight the chronological importance of such links (see above, 2.2.5).

L Cyc. I at the town has been divided by Marisa Marthari into two, A and B, phases.[9] The beginning of Phase A is defined by the construction of new buildings, and starts conterminously with the Middle – Late Minoan transitional period on Crete. At some point, soon after the inception of Phase A, and ending it, a major seismic destruction hit the town. There is extensive evidence that, following this early L Cyc I / Late Minoan IA destruction, the townsfolk undertook a complex and wide ranging reconstruction program. The mature L Cyc period was a time of great innovation and experimentation, although in general, and almost paradoxically, a pronounced Cretan influence becomes apparent. Minoan-style ashlar façades were adopted on buildings which bore little relation to Minoan-style floor-planning. The Minoan weights and measures system was adopted. Minoan pottery was imported and copied locally and, in the most famous and spectacular manifestation of Minoanization at Akrotiri, Cretan style frescoes, of religious and secular character appear.

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[8]   Marthari 1984: 119 – 133; 1990: 61- 69.
[9]   *ibid.*

After this program of rebuilding and development, further earthquakes followed. It was during the process of repair and restoration following this later destruction that the eruption occurred.

This interaction of human and geological processes is fundamental. Petrologic studies, along with other geological techniques, have put the duration of the Minoan eruption at around four days to a week, certainly not a great deal more.[10] Therefore, in the broad chronological scheme, it is a single-event marker, a horizon whose presence defines contemporaneity between different areas.

3.2.3 The "Minoan Thalassocracy"

The issue of Crete's political relationship with the rest of the Aegean is another vast and complex area of debate, and it is my intention here to touch only briefly on its relevance to chronology. As indicated in Ch. 1., Mountjoy and Ponting identify a series of LBA pottery from Phylakopi and Ayia Irini as LH IIA, not its Cretan equivalent, LM IB.[11] This, they argue, suggests that, if there was a thalassocracy in mature LM IA, it did not survive into LM IB.[12] The main significance of this point is the length of the LM IB phase. The "high" dating scheme requires this phase to be significantly longer than the estimates of previous studies.[13] *Pace* Mountjoy and Ponting (I refer to the very general implications of their conclusions, and do not

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[10]   See Sigurdsson et al.1990: 104 for the conventional view, but this is reconsidered below (Chs. 4 and 5).
[11]   2000: 147.
[12]   *ibid*: 184.
[13]   e.g. Warren and Hankey 1989: 169.

suggest that Manning questions their scientific findings), a general argument advanced by Manning[14] concerns the progress of LM IB pottery styles, trade routes and urban development. Partly by suggesting that these development were significant and long-lived, he attempts to "fill" this longer ceramic phase with such activities. Although the loss of Thera in LH I or early LH IIA, and the absence of any LM IB / LH IIA reoccupation may circumstantially oppose this view, it is unwise to assume a lateral connection between pottery deposition and political domination, or indeed any political system at all. The notion of a "Thalassocracy", and the consequent implication of a single Minoan political entity, remains only arguable, and it is very difficult to posit any scenario involving direct Minoan control at any site outside Crete.

3.3 Egypt and the Near East[15]

3.3.1 The Keftiu[16]

Egypt provides the central chronological arguments behind the "traditional" dating methods of the Aegean Bronze Age. In recent years, the site of Tell el-Dabᶜa, in the Eastern Desert, has assumed a place of fundamental importance in the cross dating scheme. It was a node in the network which received Cypriot White Slip Pottery (see

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[14]   1999: 330 - 335.
[15]   A separate section, 3.5 below, is devoted to the dating of the strata at Tell el-Dabᶜa.
[16]   Much of this section was originally presented as a seminar paper in the Department of Classics, University of Durham, 25/5/2000.

below), and the discovery of magnificent Aegean-style frescoes in the Ezbet Helmi citadel area has underlined the importance of the site for Aegean chronology, as well as evidence for Aegean external contacts. Elsewhere, at Thebes, the so-called "Keftiu" tomb paintings have been a source of much information and controversy. To put the Keftiu paintings in context: the tombs are not pharaonic, but their occupants all held high office under the Hatshepsut - Tuthmosis III co-regency (c. 1479 BC – 1457BC[17]), Tuthmosis III's period of sole rule (1457 BC - 1425 BC), and in one case, the early years of his successor Amenhotep II. These paintings depict people in Aegean style dress bearing Aegean style vessels of varying size and design, and in a number of instances they are labelled "Keftiu". There is a consensus among Egyptologists that "Keftiu" is a place name, interchanged with "People from the Isles in the midst of the Great Green (sea)," and there seems very little doubt that the people depicted in these tombs are Cretans. It is possible that the word itself equates, at least approximately, with *Kaphtor* in the Semitic languages.[18] As for the originators of the paintings, is widely accepted[19] that the Keftiu scenes were painted by Egyptian artists working either from first hand knowledge of the vessels and garments worn by the Keftiu, or work based on such knowledge. The most plausible conclusion to draw is that this was an embassy, from Crete, to the Egyptian court. Further extrapolation of this particular issue is beyond the scope of this thesis, but I deal below with the chronological implications of these depictions of cultural crossover.

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[17] I follow here the Egyptian chronology of Kitchen 2000: *passim* etc. The term "co-regency" is correct in the strictest sense, but Hatshepsut was *de facto* ruler until 1457 BC.

[18] The fundamental studies remain those of Vercoutter 1956 and Wachsmann 1987. For a trenchant and detailed analysis of the vessels carried by the Keftiu, see Mätthaus 1995: *passim*.

[19] e.g. Manning 1999: 209 - 211; Rehak 1998: 45; Barber 1991: 311.

Correlation with pharaonic Egypt of the 13th Dynasty and Second Intermediate Period (c. 1648 BC - 1540 BC), and of the 18th Dynasty (c. 1550 BC - 1295 BC on the High Egyptian chronology) with an LM IA period beginning c. 1600 BC, and with the start of LM IB falling within the reign of Tuthmosis III, forms the basis of the traditional "low" chronology of the Aegean Late Bronze Age.[20]

The low chronology correlates LM IA with the last stage of the Hyksos / Canaanite Second Intermediate Period (SIP) and the beginning of the 18th Dynasty at Avaris - i.e. after the capture of that city from its non-Egyptian (Hyksos) occupiers by the first pharaoh of that Dynasty, Ahmose. The conquest of Avaris took place in or near 1530 BC[21]; thus, according to Warren and Hankey, LM IA began around 1600 BC in absolute terms.[22] According to the low chronology, the subsequent LM IB phase begins at some point in the later reign of Tuthmosis III (1479 – 1425 BC). This is followed by the LM II phase, which is followed in turn by LM IIIA:1, whose Egyptian correlation is perhaps best documented by a scarab of Amenhotep III (1390 – 1352 BC), which is stratigraphically associated with that ceramic phase in Sellopoulo Tomb 4 at Knossos.[23] According to the "high" chronology of the Aegean Bronze Age however, LM IA correlates with the Hyksos SIP, and ends before 1550 BC. Tuthmosis III's reign is contemporary with LM IIIA:1, not LM IB.

A crucial aspect of the paintings from one of the tombs, that of Rekhmire - who was vizier to Tuthmosis III and to Amenhotep II in his early years - is that, at some point

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[20]   See especially Warren 1998: *passim.*
[21]   Internal Tell el-Dab[c]a chronology as in Bietak 1996: 6, fig 3, see also below (section 5.5).
[22]   1989: 169, table 3.1.
[23]   Popham et al. 1974: 254 - 257.

after they were first painted, the clothing was altered. In the original, the processors wear traditional "Minoan" style dress, characterised by breechcloths and codpieces. Some time during, or shortly after the tomb's completion the breechcloths and codpieces were painted over with kilts, leaving a palimpsest. This is a question of some importance. Kilts used to be traditionally associated with the Mycenaean culture, which has been reckoned to exert a marked influence at Knossos from around Late Minoan II onwards. Whether this was by the agency of invasion or takeover following internal collapse is uncertain, but the fact that they were there is attested by a wide corpus of data, including most prominently the archives of proto-Greek Linear B tablets at the Knossos. It was therefore postulated that a second embassy was despatched to Egypt by a Mycenaean, or heavily Mycenaeanized elite at Knossos sometime after LM II. Given that Rekhmire would probably have started work on his tomb soon after his appointment by Tuthmosis III, and that the traditional date for the tomb coincides with the end of LH II A/LM IB, it is obvious why the Keftiu are a chronological hot potato in Aegean terms.

S. Manning has proposed, after Barber[24], that the "new-look" Keftiu would be better placed in LM IIIA:1. He argues[25] that the patterns on the kilts from the tombs of Menkheperrarsonb and Rekhmire are similar in stylistic terms to pottery of the LM IIIA:1 period, and should therefore be considered contemporary. The instances of this similarity occur in the kilt of the fourth Keftiu in Rekhmire's tomb, kilts of the fifth and possibly the sixth Keftiu in Menkheperrasonb's tomb, and in the decoration on the ceiling of that tomb. To start with, this seems a rather flimsy basis on which to

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[24]   1991: 315.
[25]   1999: 215.

argue for the up-dating of the Late Minoan IIIA:1 sequence by almost a century. On only one decoration band of one of the kilts is it possible, in my opinion, to argue for a genuinely close match, and in this case, the pot referred to by Manning - with a zig zag pattern from the west magazines at Knossos - could also be early LMIIIA:2, requiring an even more extravagant updating - possibly even <u>after</u> the final destruction of the palace that was supposed to have sent them. It should be added at this point that Manning[26] also attempts to invoke LM IB / LH IIA parallels in the ivy motifs on the area H/III frescoes at Tell el-Dab[c]a, and the "heirloom effect".

The "heirloom effect", whereby vessels or other materials, appear in different cultures long after their manufacture, is employed by Manning on several occasions in relation to links between the Aegean and Egypt. Among the most significant instances of this effect suggested by Manning is the case of the metal vessels represented in the tomb paintings of Senmut. In seeking to date the tomb to LM II at the earliest, he invokes Driessen and Macdonald's[27] heirloom theory. In a review of Manning's book, Macdonald[28] rejects this as "out of context", and goes on to highlight the discrepancy between this, and Manning's use of LM IIIA:1 motifs with the patterns on the Rekhmire and Menkeherrasonb kilts as good correlations. I must concur with Macdonald that this approach is "unsettlingly selective.[29]"

Rehak[30] has shown why, in any case, the depiction of kilts in the Keftiu paintings are of limited chronological value, at least in terms of correlating the Mycenaean (or

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[26]   1999: 106, fig. 25.
[27]   1997: 62 – 70.
[28]   2001: 529.
[29]   *ibid.*
[30]   1996: 48 - 51; 1998: 39 - 44.

Myceneanizing) presence at Knossos with the 18th Dynasty. He points out that the kilt predates the neopalatial period in the Minoan world, with the first examples appearing on terracotta figurines at the peak sanctuary of Petsophas, in MM II. The first painted example comes from Phylakopi, and dates from the late Middle Cycladic period. At least four examples from the LM IA Thera frescoes add to the corpus. The central point to be made is that the kilt is a phenomenon that exists in the south Aegean from at least MM II - LM III. It is not a feature exclusively imported by LM II Mycenaeans. Therefore, at least in stylistic terms, the Keftiu paintings cannot be used decisively to ascribe the tombs to either Aegean chronology.

Are there any ways other than the style of the clothes or the patterns on them for determining where they are in the Aegean sequence? Litsa Kontorli-Papadopolou, among others, has suggested that the "nearest parallel" to the Keftiu paintings in the Aegean world is the Procession Fresco at Knossos, which is most often dated to LM II. She argues[31] that the procession theme forms a link between the two cultures, and that therefore the Keftiu probably predate LM III. Rehak[32] opposes this view, arguing that the Procession Fresco figures are rendered in a stylistically different mode, with different cultural characteristics, and on a much larger scale. He is probably correct in this. The processional theme is not the preserve of the LM II phase, a fact to which the LM IIIA:2 Aghia Triada sarcophagus ritual scene testifies.

An intriguing possible reflection of the visit of the Keftiu comes from a Syrian cylinder seal, now in Vienna. It depicts characters very similar to the Keftiu, and Joan

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[31]   Kontorli-Papadopolou 1996: 169.
[32]   Rehak 1998: 43 - 44.

Aruz[33] has proposed a link. Aruz's connection is based on the manner in which the bodies are depicted: slim, with square shoulders and squared-off masses of hair. She believes that a good parallel lies in the "mistress of the animals" fresco from Xeste 3 at Akrotiri on Thera. The most obvious connection is the posture of the seated deity, and the rampant griffin behind her. This is just about acceptable, especially as the motif above the griffin's head on the cylinder seal could be an attempt to represent crocuses, which form an important part of the Thera fresco in question. However, connecting the two scenes chronologically would require a link between the Keftiu and LM IA – and it would not be easy to find any prehistorian prepared to countenance such an early relative date (in Aegean terms) for the Theban tombs.

At a more detailed level, the comparisons are not as good. In the seal, the griffin's tail is curled, like the antithetic dogs on the Minoan gold pendant from Tell el Dab^c a. In the iconography of domestic animals, this is generally taken to be a sign of domestication (this accurately reflects the physiology of the domestication process in dogs). There is no indication on the seal of the tripartite platform arrangement on the Thera fresco; which is also associated with priestesses/deities elsewhere in ritual iconography (for example the "sacrifice seal" from Chania[34]). Perhaps better parallels can be drawn between this cylinder seal and sealstones from the Minoan and Mycenaean worlds. The seated figure is holding a sceptre or sword. This is very familiar from LM IB and LM II iconography, as epitomized by the Chania sealstone mentioned and by the "Mountain Mother" sealstone from Knossos.[35] It appears to be a symbolic gesture, the deity (or her priestess-representative) handing down the

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[33]   1994: 48.
[34]   Warren 1988: 17.
[35]   Marinatos 1993: 155, fig. 133.

authority to rule, thus legitimising the recipient of the sceptre or sword. Animals of the type represented on the Syrian seal are also known from Aegean iconography, in poses like those shown on the former. There is good reason to reject a connection with the Xeste 3 fresco, on stylistic and, if they are Keftiu, chronological grounds. There are, however, good parallels with LMIB – LM II Minoan seal-stone iconography. If, therefore, Aruz is correct in making a connection between the people shown on the Syrian cylinder seal and the Keftiu in a heavily Aegeanized piece of art – and I accept that it requires a certain leap of faith – then it provides good, albeit circumstantial, evidence for a late LM I date for the tomb paintings.

3.3.2 White Slip (WS) pottery

I include my discussion of the WS sequence in the "Egypt" section of this chapter (rather than allocating a separate section on Cyprus), because the appearance of these wares at the Egyptian site of Avaris (Tell el-Dabᶜa) forms one of the most significant elements of the cross-dating issue, and also because a full exposition of Cypriot chronology would be outside the scope of this thesis.[36] Furthermore, in spite of the central role played by WS, it is not generally possible to use Cyprus as a "hinge" for interlinking the Aegean and Egyptian sequences. As discussed extensively in the Cypriot archaeological literature, relevant ceramic contexts are often funerary, and

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[36]   See Merrillees 1971: *passim*, Warren and Hankey 1989: 115- 119, Manning et al.
(forthcoming) and Manning (forthcoming).
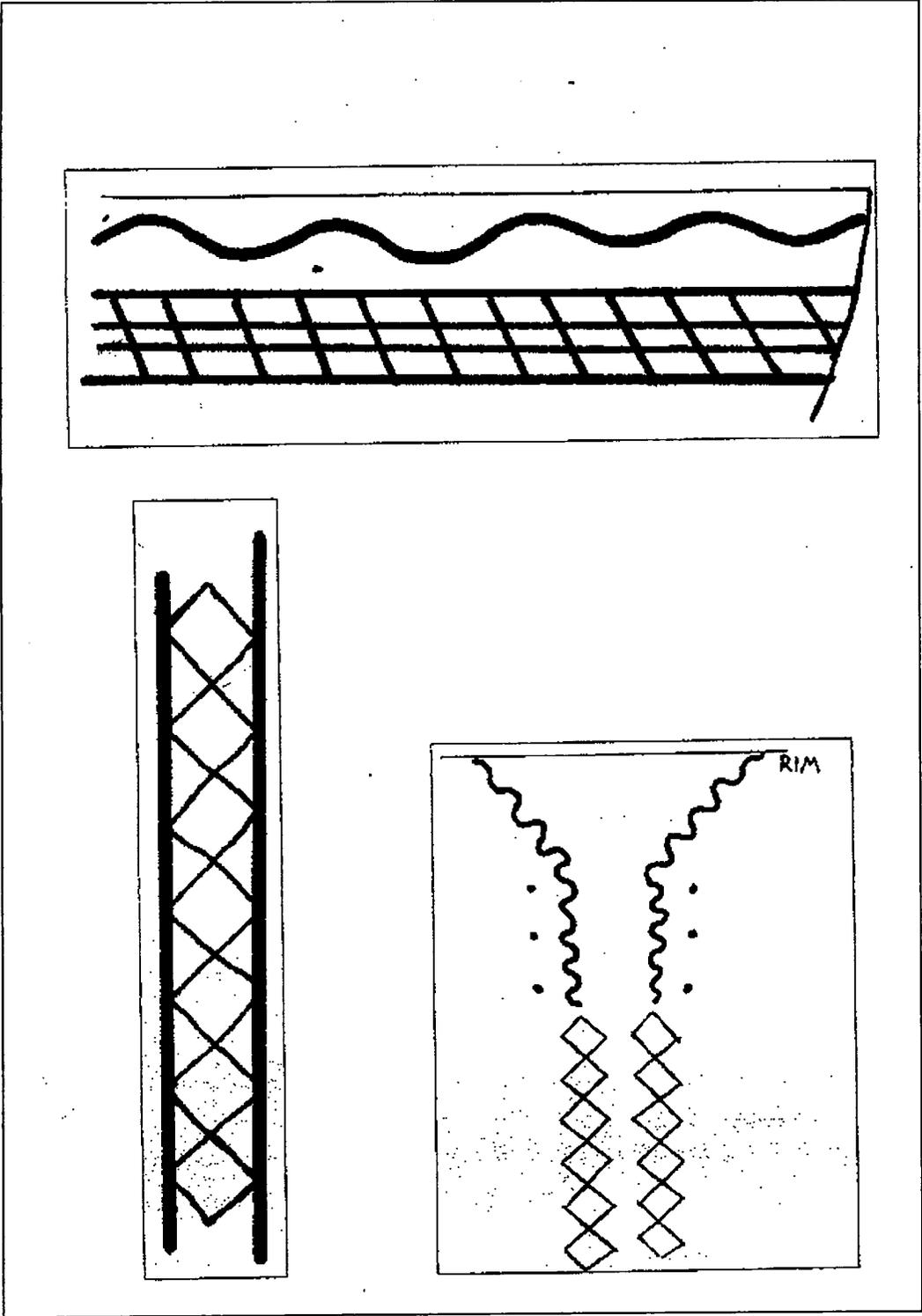
3.2 White Slip I decorative motifs associated with the "lost" Thera bowl (drawings: the author).
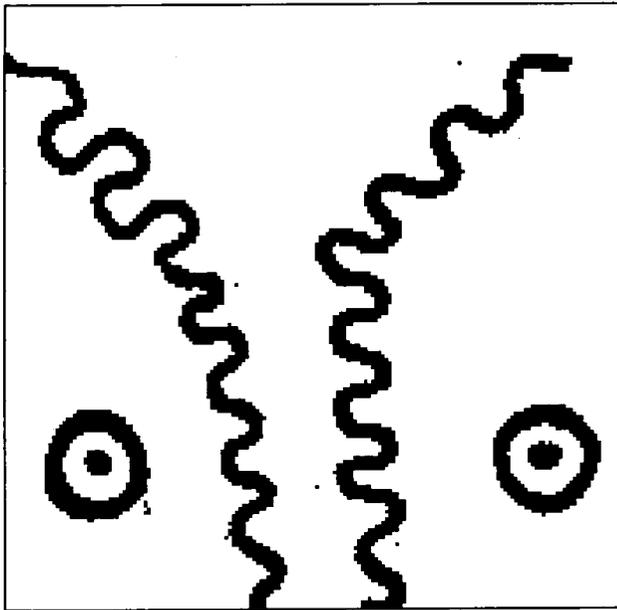
(a)
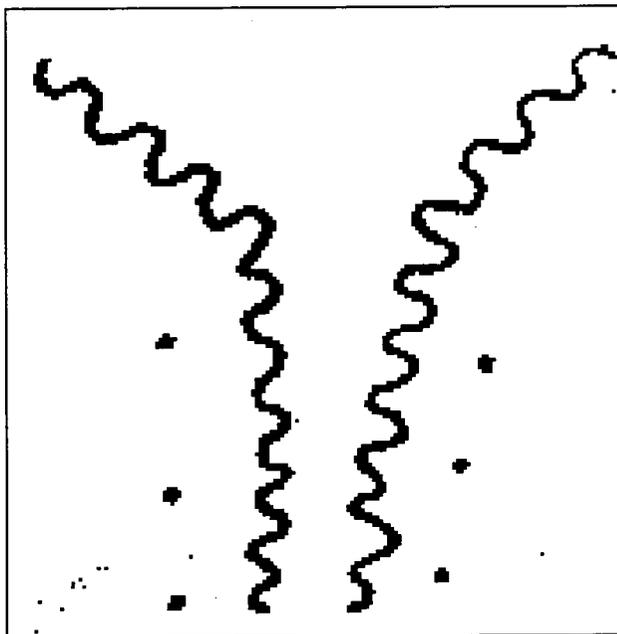
(b)

3.3 White Slip decorative motifs; "eyes and nose"
(a) and wavy lines bordered by dots.

that it is possible to establish strong likelihoods that individual vessels can be assigned by their motifs to particular "assemblages." The "re-discovery" of the now-famous lost Thera milk-bowl by Robert Merrillees[37] has placed a serious obstacle in the path of the high dating scheme, and as such much attention has been drawn to this matter by its opponents.[38] Here, I develop the arguments.[39]

White Slip pottery has been a source of much discussion in a variety of contexts. Of the three major classes of White Slip – Proto, I and II – WS I is most significant for Aegean chronology, because it occurs in early New Kingdom levels at the Ezbet Helmi citadel of Avaris – that is to say, *after* its fall to the Thebans in c. 1530 BC[40]. Crucially, it also occurs under the volcanic destruction layer on Thera itself. Furthermore, at Tell el-Dab^c a, the preceding, Hyksos / SIP, stratum contained examples of PWS.[41]

The example from under the Thera VDL is a milk bowl of typical WS type. It was discovered by French excavators in the 1870s (probably 1870 itself), and is now lost. It was, however, the subject of a detailed paper given by Robert Merrillees, at the Nicosia conference on WS in 1998. Using contemporary documents and illustrations, Merrillees[42] has been able to piece together various fragments of evidence and present a plausible re-construction of the bowl. His re-construction (Figs 3.2 and 3.3) is as follows:

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[37]   Merrillees 2001: (esp.) 93. I thank him for supplying an offprint prior to publication.
[38]   See especially Warren 1998: 326 – 7; Bietak 1998: *passim.*
[39]   See also Dunn (forthcoming).
[40]   Bietak 1996: 70; Bietak and Hein 2001: *passim.*
[41]   *ibid.*
[42]   Merrillees 2001: 93.

Hemispherical bowl with round base and sides incurving to a plain rim in the same contour; bifurcated handle set diagonally on the upper body, restored as a loop but probably originally in the shape of a wishbone. Painted decoration, consisting of a wavy line round the top of the body, below the rim; underneath a horizontal band consisting of four parallel straight lines with diagonal hatching; descending from this band on either side of the body, two vertical bands, each of four parallel straight lines with diagonal hatching, either side of a vertical row of cross-hatched lozenges framed on each side by a vertical straight line; descending down the front of the body, two parallel vertical rows of cross-hatched lozenges, each linked to the horizontal band by a short wavy line and framed on the outer sides by a vertical row of four parallel vertical lines with diagonal hatching; descending from the horizontal band on either side of the handle base, a vertical band of four parallel straight lines with diagonal hatching; between them and the next vertical band on the side of the body, a vertical row of dots or dashes ... Height: approx. 11.7 cm, Width of body: approx. 23.7 cm. Diameter of rim: approx. 22.8 cm. Said to have been repaired in antiquity.[43]

This reconstruction has apparently met with the satisfaction of the Cyprus specialists. The significance of this artefact is immediately obvious: If the WS bowl from Thera can be related to the stratigraphic sequence on Cyprus, which is further represented in a datable stratum at Tell el-Dab°a, the bowl's deposition must form an approximate but calendrical *terminus post quem* for the eruption. The key questions are: did the bowl arrive on Thera in the seventeenth, or the sixteenth century B.C.? And where, in the chronological Cypriot sequence, is the bowl to be placed? In other words, is the bowl contemporary with the WS I from the early New Kingdom strata?

Those supporting the "high" dating for the Aegean point to the significance of regional and temporal variation in the development of Late Cypriot types on Cyprus.[44] The argument is that a "novel" tradition developed out of the Middle Cypriot sequence of LC IA:1 in the north west, the region of the site of Toumba tou

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[43]   *ibid.*
[44]   See particularly Manning 1999: 158 – 192. and forthcoming.

Skourou,[45] with the south and east coastal areas following later (see map 3.2). The WS I and BR I types define the therefore mixed: it is rare for a "level" of primary deposits defining any particular period of the ceramic history of Cyprus to be recovered. I contend below, however, LC IA:2 period; complete typological homogeneity was not achieved across the island until LC IB. According to this scheme the Thera bowl is dated very early in the WS sequence, and is therefore an LC IA:2 artefact of the north westerly "novel" tradition. The Tell el-Dabᶜa examples are much more mature and developed specimens from the south and east. This explains the long gap between the deposition of the Thera bowl and the early NK assemblages.[46]

In opposition, it must be said in the first place, that the underlying assumption in this model, i.e. that there was a clear distinction in Cypriot trade where early northwest / Toumba tou Skourou = export to Thera and Tell el-Ajjul and mature southeast / Enkomi etc. = export to Egypt is not verifiable, there simply being no direct evidence to support this. However, exciting new developments in provenancing Cypriot pottery using thin-section analysis may well hold the key to providing such evidence, for or against.

From this, the question that must be asked is: are the stylistic arguments placing the Thera bowl early in the sequence (i.e. in LC IA:1/2) sound? There are a number of stylistic clues, for example the cross-hatching on the lozenges. Although a very early drawing of the bowl in the 1886 publication of Furtwaengler and Loeschcke appears

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[45] Vermeule and Wolsky 1990: *passim.*
[46] Grateful thanks to Sturt Manning for providing two unpublished manuscripts in which this hypothesis is developed in detail.

(a)

(b)

3.4 WS I / LC IB tankards from Toumba tou
Skourou; (a) T II. 9 p 588 (b) T II. 72 p 590
from Ch. 3.9 (figures after Vermeule and
Wolsky 1990: pl 136, A and C)

NICHORIA

MELOS THERA RHODES

Trianda

CRETE Knossos

TOUMBA TOU SKOUROU •   Enkomi
    •
CYPRUS • Kalopsidha

TROODOS
MOUNTAINS

Meggido •

Jericho •

Tell el-Ajjul •

• **TELL EL DAB^cA**

TOUMBA TOU SKOUROU •   Enkomi
    •
CYPRUS • Kalopsidha

TROODOS
MOUNTAINS

Meggido •

Jericho •

Tell el-Ajjul •

• **TELL EL DAB[c]A**
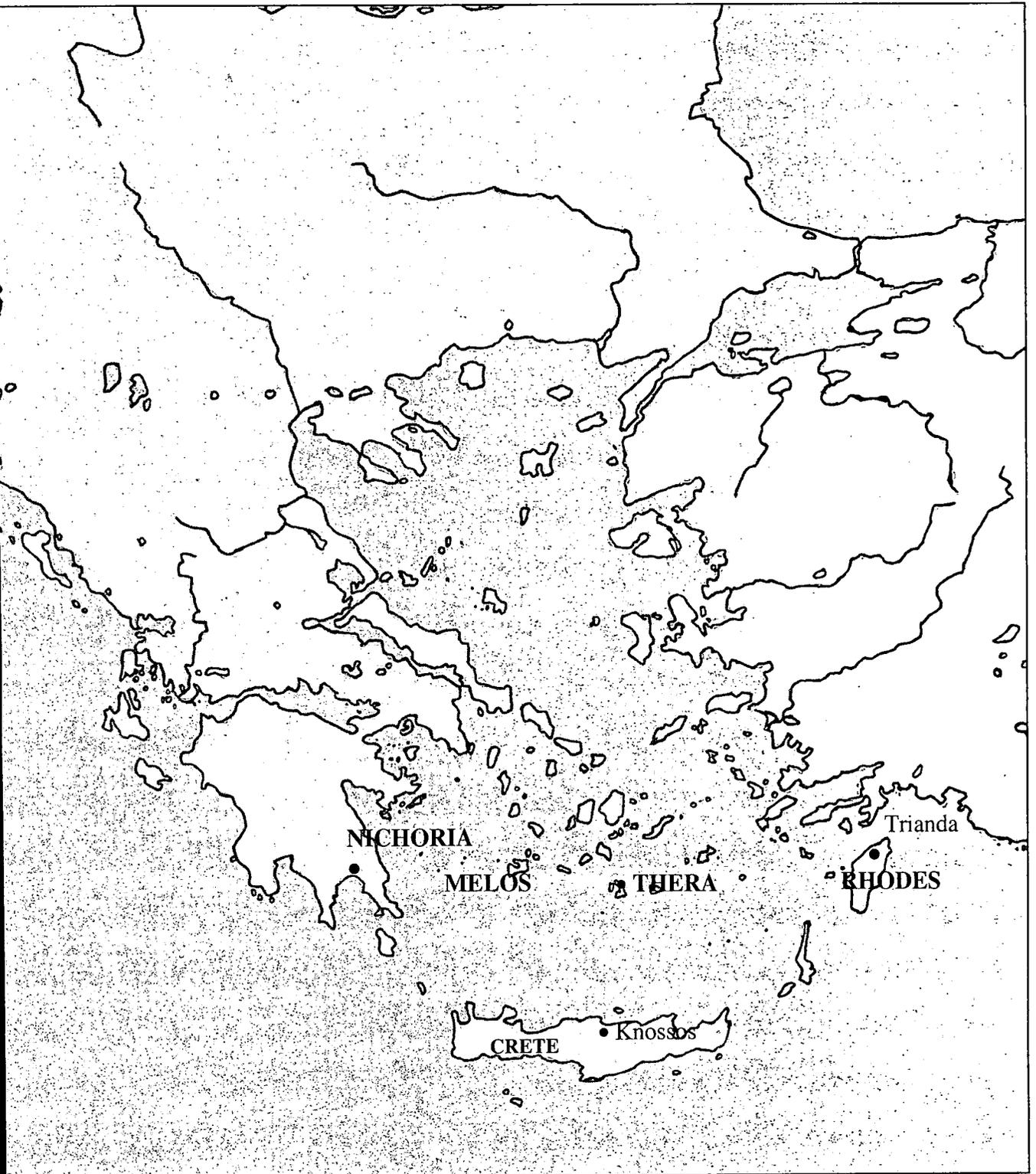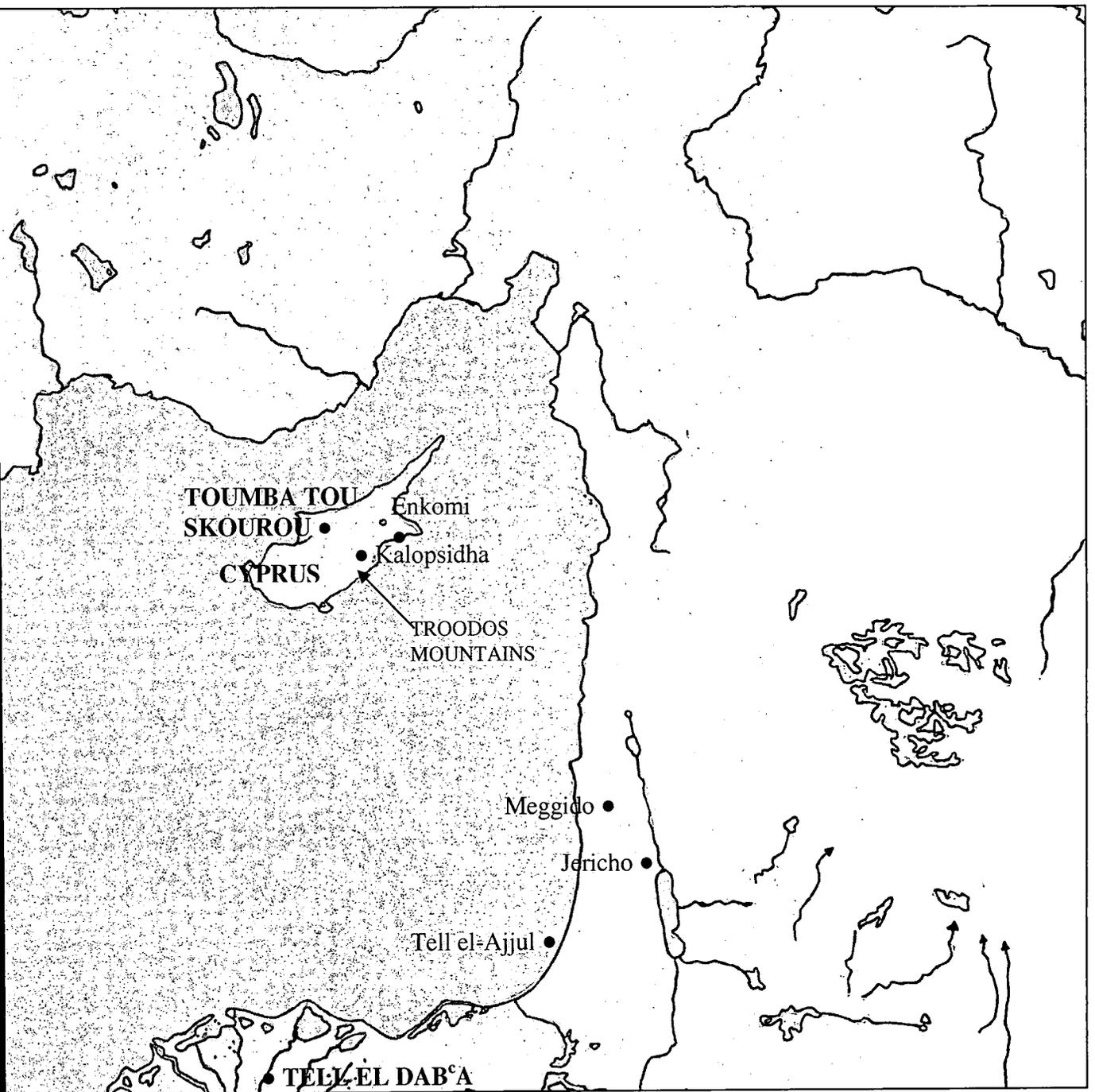
to show double cross-hatchings,[47] Merrillees is unable to specify whether or not the hatching is single or double, although he is clear that it is diagonal, rather than right angular. Double cross-hatched lozenges appear on both PWS and WS I; if the lozenges on the Thera bowl are double cross-hatched, this would allow an early PWS / WS I border assignation for the bowl, although a later assignation would by no means be ruled out. Conversely, single hatching is confined to mature WS I, and if this particular decorative motif did appear on the Thera bowl, an early date for the bowl would be less likely. On the other hand, the "rope-pattern" around the rim is a classic PWS feature and, on its own, constitutes the strongest argument for an early date. However, the sequence at Toumba tou Skourou on Cyprus itself, exemplified by the vessels depicted in fig 3.4, shows clearly that the rope pattern continues in assemblages belonging to the following LC IB phase, demonstrating that the rope pattern should not be considered in isolation. The wavy line bordered by dots is a further possible argument in favour of a later date for the bowl. Mervyn Popham, one of the pioneers of WS studies, noted that the "eyes and nose" motif, comprised of thick wavy lines connecting with the rim between two open circles somewhat resembling targets, is a clear PWS forerunner of the later, WS I, wavy lines with dots.[48] That these motifs occur in good order elsewhere makes the idea of the lost bowl being produced at the same time as late PWS, or even during PWS / WS I transition, less likely. It is of further significance that Popham tentatively identified a possible late PWS expression of this motif; a pair wavy lines enclosed by open circles and parallel vertical lines. Although the latter would fit the lost bowl rather well, there is no reference to the former, which seems to be the main diagnostic feature of this

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[47]   1886: pl. XII, reproduced in Merrillees 2001: 91, fig 4.
[48]   Popham 1972a: 433.

motif.

If a PWS / early WS I assignation is not so likely, is it possible that a positive correlation with vessels from known LC IB contexts can be made? Tomb 2, chamber 3 at Toumba tou Skourou, has produced possible comparanda. Vessel number T II.9 P 558, a WS I tankard, is the best example (see fig 3.4). It exhibits double rows of cross-hatched lozenges, with both vertical and horizontal rope-pattern bands, as well as vertical wavy lines framed by dots. Another tankard, T II.72 P 590 displays similar features, with vertical four line ladder lattices, enclosing a framed row of double cross-hatched lozenges, with a similar horizontal frieze on the neck (fig 3.4). On inspection of the photographs, both of these seem to offer close matches for the bowl described by Merrillees. Incidentally, the double cross-hatching on both also matches the illustration of Furtwaengler and Loeschcke, although this should be given less weight than the reconstruction of Merrillees, who does not specify whether the cross-hatching was double or single. From the same chamber, T II.67 P 585, a milk bowl, illustrates the framed wavy lines bordered by dots. Both these items come from LC IB dominated assemblages, raising the possibility that the Theran bowl should move towards the later, more mature WS I of the type found at Tell el-Dab^{c}a, rather than away from it. This argument is not without problems, the greatest of which is the insecurity of the sequence at Toumba tou Skourou. It should be emphasised that to speak of an LC IB "level" at Toumba Tou Skourou would be misleading; the term "assemblage" is better. Nonetheless, it seems that the Thera bowl displays a good affinity with stylistic motifs which were in circulation in LC IB.

3.3.3 WS elsewhere

Investigations of White Slip ware have been undertaken at Levantine sites, most notably at Shechem in Palestine and at Tell el-Ajjul. At the former site, Wright identified two styles, the "flowing" and the "cross-hatched,"[49] and pointed out useful similarities between the Palestinian material and that published by Benson from the US excavations at Bamboula on Cyprus.[50] Arguably the most important individual specimen from the region comes from Petrie's 1934 excavation season at Gaza. This bowl (Fig 3.5), Petrie's catalogue number PB 988,[51] provides a very good match with the Thera bowl, as described by Merrillees. It has a wavy line around the rim, underneath which is a rope pattern. Like the Thera bowl it has pendant rows of cross-hatched lozenges, framed by parallel straight lines.

The frontal design on the Gaza bowl consists of two vertical rows of cross-hatched lozenges, each is linked to the rim band by short wavy lines, and framed on the outside by vertical rows of dots (a WS I feature, not PWS). There are also pendant rope patterns separating the vertical patterns. To all intents and purposes, Merrillees could have been describing the Gaza bowl, rather than that of Thera. They seem virtually identical. This point should be taken together with B. Hennessey's statement, quoted by Wright:

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[49]   Wright 1967: 61 - 66.
[50]   Benson 1961: esp. Plate V, figs. 1 - 4.
[51]   Petrie 1934: 1932: 10 - 11, Pls. V and XXXVII.

(a)
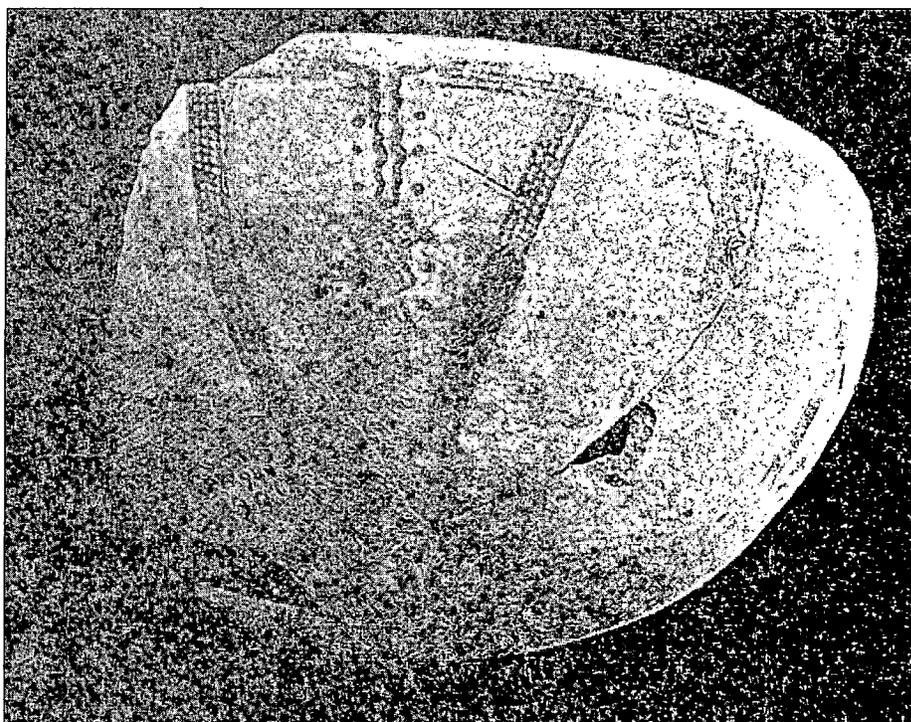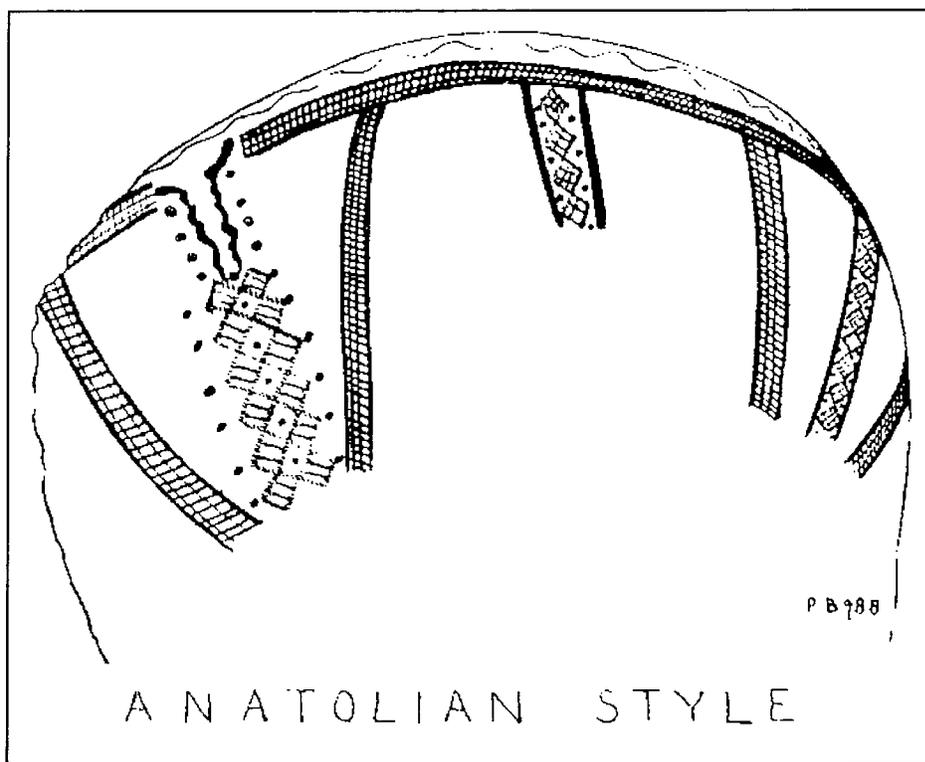
ANATOLIAN STYLE

(b)

3.5 Bowl PB 988 from Gaza (after Petrie 1934: Pls. V and XXXVII), "Anatolian Style"(WS I)

It is worth remarking that the White Slip ware of Ajjul, Petrie's 'Anatolian Ware,' is the carefully drawn and Bichrome White Slip ware of the Stephania tombs. In neither of their Palestinian occurrences (i.e. Megiddo and Ajjul), however, need one suppose a date before the middle decades of the sixteenth century BC.[52]

If Hennessy is even approximately correct, that the WS material from Tell el-Ajjul, and thus Petrie's PB 988, can not date earlier than the mid quarter of the sixteenth century BC, explaining the manufacture of a virtually identical bowl a century or more earlier – necessary to fit the "high" chronology" - becomes almost impossible.

3.4 Other Comparanda

There now follows a survey of the remaining elements of the cross-dating case. Essentially, the purpose of this survey is to update and contextualise the comments of Warren and Hankey 1989, although their conclusions remain unchallenged here.

3.4.1 The Kerma Sherd

The Kerma Sherd (SU.183), part of an imported vessel uncovered in G.A. Reisner's excavations, is a significant early element. W. S. Smith says that Kerma "obviously lacked direct contact with the Aegean and Western Asia",[53] and attributes the sherd to LM I. Kemp and Merrillees, however, state that it is too undistinctive to be attributed

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[52]   Hennessey 1963 : 56 in Wright 1967: 65.
[53]   Smith 1965: 39.

to LM I, and that the most that can be said is that it is of foreign manufacture.[54] However, P. Lacovara cites a personal communication from E. Vermeule, who attributes it to LH I.[55] It is very important to note, however, that this view is not that of current expert opinion. Dr Oliver Dickinson[56] has expressed the view that, although the sherd is probably of Aegean provenance, the decorative motifs are not specific enough to assign to it a "pure" LH I source.

The exact find spot was not recorded. It came from buildings around the base of the stairway leading to building labelled KI, the "Lower Deffufa". Extensions to the east contained cellars which were filled with over 700, mostly Hyksos, seal impressions. Kemp and Merrillees consider the sherd (along with all other imported material from the north) to have a *terminus ante quem* of the earlier part of the reign of Kamose.[57] Warren and Hankey, however, cite updated evidence for one 18th Dynasty occupation level at the site.[58] Lacovara dates the context (upper levels of the Lower Deffufa) to the late SIP / early 18th Dynasty.[59] Manning[60] states that this should not be later than "the very beginning of the 18th Dynasty." He cites the "classic" SIP associations with the styles of the other imports at Kerma i.e. from Cyprus, WP IV, Tell el-Yahudiyeh, Levantine MB II etc, in general see Lacovara 1997. Manning suggests that it may be a "late SIP [period] import" via the Nile delta region, and says it should not date after 17th Dynasty Theban-Nubian-Hyksos conflicts, and the campaigns of Kamhose

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54   Kemp and Merrillees 1980: 244.
55   Lacovara 1997: 61.
56   Personal communication, 18/2/2002.
57   Kemp and Merrillees 1980: 161.
58   Warren and Hankey 1989: 135.
59   Lacovara 1997: 61.
60   1999: 110 – 111.

(Kamhose's second victory stela cites military operations early in his reign in this area).[61]

The most secure conclusion to draw, after Warren and Hankey,[62] is that all this sherd can do is provide a link between the SIP / early 18th Dynasty and LH / LM I. This in itself is significant, but a correlation between this period of Egyptian history and LM IA or LM IB (or LH I and LH IIA) is required.

3.4.2 The Kom Rabia sherd

Another chronologically significant sherd was located above the SIP level, and below a level containing a scarab of Tuthmosis I (i.e. pre - 1504 BC) at Kom Rabia. It has been suggested that it was from a LH IIB piriform jug.[63] Warren and Hankey, however, suggest that LM IB is a more likely assignation or, less probably LH IIA, on the grounds of form and decoration[64]. LM IA is also a possibility. The Egyptian pottery associated with this sherd is early 18th Dynasty, and should be considered to date between Ahmose – Amenophis I (1550 BC – 1504 BC).

K. Eriksson[65] points out that this sherd came from a level of sand on *top* of a context containing a BR I juglet, in a good state of preservation, which was found in a context containing SIP pottery. The sand layer on which it was found "has been interpreted as an interval between the SIP and early 18th Dynasty," and below the Tuthmosis I

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61   *ibid.*
62   1989: 141.
63   Borriau and Eriksson 1997: 115.
64   Warren and Hankey 1989: 139.
65   1992: 169.

scarab. Deposit 530, from which the sherd came, was preliminarily dated Ahmose –
Amenhotep I.

3.4.3 Red Lustrous Wheel Made Ware (RLWMW)

There is now no doubt that production of the RLWMW pilgrim flask type correlates

securely with LM IB. The lower complex of Building J at Kommos yielded a vessel

of this type,[66] and a RLWMW pilgrim flask has come recently from a secure LM IB

context at Mochlos.[67] Relating this type to the Egyptian sequence is therefore a matter

of some importance.

Merrillees[68] states that there are four RLWMW vessels in Egypt which could date to

the end of SIP: Tomb 158, Deir Rifeh (1) and Chamber A, Tomb SA 29, Aniba (3).

However, Eriksson points out, with regard to the Dier Rifeh material, the local vessels

associated with the RLWMW spindle bottle have standard, long-lived forms, and thus

that Merrillees is unjustified in assigning the assemblage to the end of the SIP on this

basis. The local pots have 18th Dynasty as well as SIP parallels. Merrillees's basis for

an early assignation for the Aniba vessels was the presence of black-topped Kerma

ware and Tell el-Yahudieh vessels in the tomb; however Eriksson points out that these

latter styles also continue into the early 18th Dynasty.

S. Manning[69] dates RLWMW no earlier than the beginning of the sixteenth century

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[66]   Watrous 1985: 7 - 10.
[67]   Presented by Soles and Davaras at the October 2001 Cretological Congress. I thank Peter
         Warren for this information.
[68]   1968: 146, 151, 171, 191.
[69]   1999: 63.

Eriksson[70], however, believes that the ware does not, in fact, pre-date (or only very slightly pre-dates) Amenhotep I (1525 BC – 1504 BC). Its first appearance on Cyprus is LC IA, but the evidence is very scanty and contaminated; the first secure appearance is LC IB, with a floruit in LC IIA. Manning's argument rests on two strands: a LC IA date for the first *secure* appearance of RLWMW on Cyprus, and Merrillees's early dating of the type in Egypt. This would allow a LC IA / end SIP correlation. As Eriksson has shown, neither of these possibilities is very likely.

Even if RLWMW did appear on Cyprus in LC IA, this does not lend any additional credence to a correlation with the Hyksos / SIP culture. The fact that there was evidently very little production before LC IB makes it very unlikely that it would have been exported prior to the LC IA / LC IB transition. Given that RLWMW (=LC IB) can now be definitively linked to the close of the LM IB period, what are the implications then for the Cypriot bowl from Akrotiri? It displays PWS and mature (=LC IB) motifs (see above). The obvious conclusion, therefore, is that was made at a time when old, and established, motifs remained in use, but also at a time when new decorations were being experimented with. Translated in to relative ceramic terms, this means the LC IA / LC IB transitional period, significantly pre-dating the mature LM IB / LC IB destructions at Mochlos and Kommos.

3.4.4 The Abydos sherd

From J. Garstang's excavations, the Abydos sherd (328.A.07.5), illustrates well the

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[70]   1992: 179.

pitfalls of dealing with Aegean material in Near Eastern contexts. Warren and Hankey[71] date this sherd to LM IB, after Kemp and Merrillees. The context of the tomb is "predominantly" 13th Dynasty / Hyksos, but a squat jar (328.07.8) is associated with the time of Tuthmosis III. On this basis Warren and Hankey correlate the sherd with that pharaoh.[72] A detailed discussion is provided by Kemp and Merrillees.[73] The piece is a rim sherd, approx. 6 – 7 cm broad and 5 cm deep, probably wheel made and with a fine, hard fabric. Under the rim is a horizontally symmetrical adder pattern, with single dots between the notches. Five such dots are visible on the lower band, four on the top. The two bands are separated by a narrow line. A slight swelling in the cross-section of the rim on the right hand side of the shed may, in the opinion of Kemp and Merrillees, be the beginning of a handle, now lost. Parallels cited by them for the shape of the vessel include Coldstream and Huxley's number 294 from Kythera.[74]

A very similar sherd came from the 1896 – 9 excavations from Phylakopi (Athens National Museum catalogue no.12158, excavation. find no. FS 141).[75] This has been proven by ICP-AES to be of Mainland origin (i.e. LHII A),[76] and from this it is evident that extreme caution must be exercised when attempting to separate Minoan from Helladic wares outside the Aegean. The pertinence of the "Minoan Thalassocracy" model to the eruption is argued below.

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[71]   1989: 141.
[72]   *ibid.*
[73]   1980: 233 - 4, fig 72, pl 31.
[74]   Coldstream and Huxley 1972: fig 42.17 and 18; fig 56.194-205.
[75]   Mountjoy and Ponting 2000: 147, fig 4: 14.
[76]   *ibid*: 172.

3.4.5 The Khyan Lid

An important chronological connection between Hyksos / SIP Egypt and Minoan

Crete exists in the form of the alabaster lid of a vessel inscribed with the cartouche of

the Hyksos / Canaanite king Khyan, in a disputed context at Knossos. This lid, of an

alabastron of typical Egyptian Middle Kingdom type, was found by Evans in the north

west of the Palace.[77] The lid comes from a deposit sealed by a low rubble wall of a

later building, and was among fragments of typical late MM III pottery: "fragments of

stone ewers with plait-work decoration ... inlaid pots and similar shards." The

inscription itself reads *Ntr nfr s, wsr-n-R", Hy"n* – Suserenra, son of the Sun,

Khyan.[78]

The conventional placing of the lid – and thus of Khyan - is in MM III. Since Khyan

cannot be later than the overthrow of the Hyksos in c. 1530 BC (see below, section

3.5) such a proposition would vindicate the "low" chronology. This lid formed an

important element of the thesis of Warren and Hankey, who argued that Evans's

critique was set out in "complete clarity", and cite scarab evidence that Khyan was the

first of the six Hyksos Pharaohs, thus dating him c. 1648 – 1630 BC.[79] Such a

situation would effectively put a ceiling of c. 1600 BC on the beginning of the all-

important LM IA period, thus placing the eruption of Thera in the second half of the

sixteenth century, the only constraint being the relative length of LM IA. However,

this position has been questioned.[80] In particular, Manning states that the deposition is

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[77] See especially Evans 1921: .417 – 421.
[78] *ibid.*
[79] Warren and Hankey 1989: 136 - 137.
[80] e.g. Palmer 1969: 63; Manning 1999: 79.

(a)

LEVEL OF TOP OF UPPER TERRACE WALL

WALL OF RUBBLE MASONRY

PAINTED STUCCO

CLAY PAVEMENT

FOUNDATIONS OF WALL

EARTH DEPOSIT

EARTH DEPOSIT

STRATUM CONTAINING CHARCOAL, LID OF ALABASTRON ⊗OF HYKSOS KING KHYAN ⊗ AND FRAGMENTS OF STONE VASES AND POTTERY
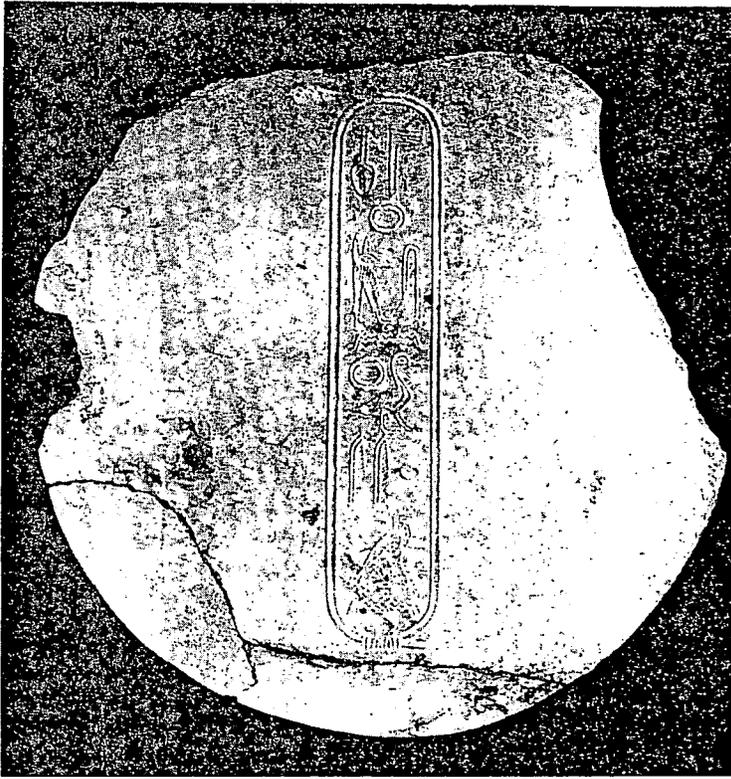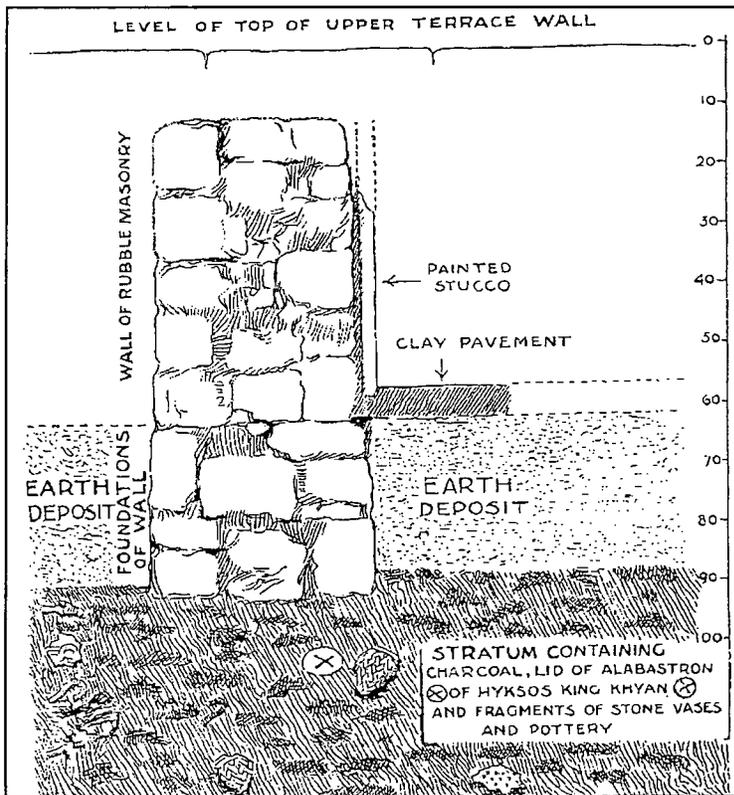
(b)

3.6 The Khyan Lid (a), and its find-spot at Knossos (b). From Evans 1921: 418 - 9,figs 304b and 303 respectively.

"unstratified",[81] and that the context is, therefore unsatisfactory. Palmer, arguing that

the Khyan Lid deposit was one of the "hinge points in Aegean chronology",[82] further

notes that at least one piece of pottery from the deposit has been classified by "expert

opinion" as being LM IIIA. Basic archaeological

methodology, however, stipulates that there can be only two simple options: either the

lid is in a MM III context below the rubble wall, or the deposit is contaminated and

the lid should be discarded completely as a piece of chronological information. My

own view tends towards the former, as a ceramic sherd (hypothetically, in this case,

LM IIIA) is far more likely to percolate downwards through a stratigraphic system

than a large stone lid. In the absence of more assessable evidence to establish anything

beyond reasonable doubt, this general premise tips the balance of probabilities in

favour of an early date for the lid's context.

3.4.6 Tell el-Yahudiyeh ware

Much of the debate surrounding Tell el-Yahudiyeh ware focuses on recent published

exchanges between Kathryn Eriksson and Robert Merrillees. Tell el-Yahudiyeh ware

offers a clear linkage between Thera, Cyprus (both eastern Cyprus and NW Cyprus),

and the SIP at Tell el-Dab^c^a, since it is found along with LM IA / L Cyc. I imports at

Thera and Toumba tou Skourou.[83] A key question, asked by Eriksson[84]: is the BSW

imitation of Tell el-Yahudiyeh from Stephania tomb 10 MC III (as postulated by

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[81]   Manning 1999: 79.
[82]   Palmer 1969: 64.
[83]   Manning 1999: 129.
[84]   1992: 158.

Hennessy), *pace* Merrillees[85], who dates it to LC IA? The latter would prove, or at least strongly suggest, an overlap between LC IA and the late SIP (assuming that Tell el-Yahudiyeh was defunct before the end of this period). A further problem concerns Stephania Tomb 10,[86] which is dated by Hennessy to MC III, and by Merrillees to LC IA. Merrillees based his re-dating on the sequence at Myrtou-Pighades. Here, the first LC pottery appears in period IIA, although this period is dominated by MC wares. Merrillees re-definition of tomb 10 at Stephania equated the MC / LC I pottery ratio of this tomb, with that of period IIA at Myrtou-Pighades. However, as Eriksson points out, there is no Bichrome wheel made ware, BR I or WS I in tomb 10, making Merrillees's re-dating scheme highly unlikely. In Tomb 12 at the same site, there is a notable absence of MC III pottery, described by Eriksson as "the first true LC I tomb of the cemetery."

Eriksson[87] cites the Tell el-Yahudiyeh jug from Toumba tou Skourou (T V.24 P 969), in a MC III context, who does not exclude the possibility that imitated Tell el-Yahudiyeh at Toumba tou Skourou may have continued to be made after imports had ceased. In Toumba tou Skourou tomb I, there is imitated Tell el-Yahudiyeh and a high percentage of LC I pottery. In any case, Åström has proposed that three unprovenanced Tell el-Yahudiyeh juglets from Thera should date to the LM IA level, and Eriksson states that the form appears in early 18th Dynasty contexts anyway.

One Tell el-Yahudiyeh juglet comes from tomb D 114 at Abydos.[88] This context

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[85]   1971: 60.
[86]   Eriksson 1992: 158 – 159.
[87]   1992: 159.
[88]   Eriksson 1993: 80 – 83.

contained scarabs of Tuthmosis III, although Merrillees argues that the tomb has a very long period of use (SIP – Dynasty 18B) but Eriksson disputes this. Merrillees's argument for such an early start for the tomb is based upon the occurrence of a Tell el-Yahudiyeh juglet, which he says cannot date after the inception of the 18th Dynasty. Bearing in mind the other Tell el-Yahudiyeh comparanda, this approach seems to put the cart before the horse. A further Tell el-Yahudiyeh juglet comes from Abydos Tomb E, Cemetery E. The find spot is not known. Merrillees argues for two different deposits, of SIP (containing the Tell el-Yahudiyeh juglet) and Tuthmosis III date respectively. However, Eriksson[89] points out that the juglet was associated with a RLWMW spindle bottle and a Red Polished vessel, neither of which occur in SIP, and argues that Tell el-Yahudiyeh was in circulation during the reign of Tuthmosis III.

As regards to Tell el-Yahudiyeh, Cyprus and Tell el-Dab[c]a: Manning[90] compares (after Bietak) the Tell el-Yahudiyeh in Tell el-Dab[c]a, strata G – E 2-1 with that from Tomb V at Toumba tou Skourou. There is no LC in T. V. Manning and Merrillees wish to link the beginning of LC IA with strata E / 1-2. However, as Eriksson[91] points out, such a correlation proves only that MC III (as represented by Tomb V) was "in part contemporary with stratum E2-1."

3.4.7 Summary and conclusion

It is clear from this brief survey that the evidence for dating the eruption from cultures outside the Aegean is complex and convoluted. A common thread in the interpretation

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[89]   1992: 161.
[90]   1999: 130.
[91]   1992: 161.

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of most if not all of these pieces of evidence, is that they involve the linking of individual strata and or / finds in the Near East with the Minoan ceramic system. This has numerous attendant problems, the most significant of which are outlined above (section 3.2.1). Again, much revolves around the subjective assignation of individual sherds and / or assemblages to particular chronological brackets (the Eriksson – Merrillees disagreement over the BSW imitation Tell el-Yahudiyeh ware from Stephania is a particular case in point), and around stratigraphical uncertainties (e.g. the Khyan Lid). Although the strengths and weaknesses of each individual interpretation highlighted above leaves the balance of probability in favour of an LM IA / early 18th Dynasty correlation (at least in part), it is far better to be honest about these intrinsic limitations in the cross-dating case, that will always constrain the existing evidence. This is why the focus of the chronology debate must now move towards new methods, and to a more interdisciplinary plane.

3.5 Analysis of the stratigraphy of Tell el-Dabᶜa and a historical model for the early New Kingdom

3.5.1 Elements of controversy

Of crucial importance to the matters discussed above is the dating of the stratigraphy at Tell el-Dabᶜa itself. This has been a very controversial subject for Aegean chronology, with disagreement focusing on Manfred Bietak's re-dating of the H/1 construction platform F in the Ezbet Helmi citadel. The excavators originally dated

this massive structure (70.5m x 47m) to the Hyksos period,[92] but new evidence emerged in the course of further excavation which showed that its north-east corner cut an earlier Hyksos fortification wall (wall A), and overlaid an associated garden with regular tree-pits. The exact wording of Bietak's amendment is "the only solution ... is to date the platform to the years immediately after the fall of Avaris and assume that it was in official use for only a short time."[93] Concerns have been raised about this re-dating of H/I from the Hyksos/SIP to the early 18th Dynasty.[94] In addition to issues raised in the literature, in the discussion following my lecture to ISIS in November 2001 (see Dunn, forthcoming), David Rohl advanced an intriguing proposition, namely that the wall cut by the platform dated from the very start of the Hyksos/SIP and H/I was probably a late Hyksos construct. Set out here is a review of this debate, and my own reasons for rejecting Rohl's view.[95]

3.5.2 The original (Hyksos) dating, its proponents and opposing arguments[96]

Bietak[97] has provided a statement of why the platform was originally dated to the Hyksos period. The case was simple, and the evidence essentially derives from scarabs. A sequence of scarabs of Ahmose through to Ahmenotep II proceeded through three phases of the building's occupation. Fragments of hard lime plaster from the frescoes associated with palace Palace F were found in the (Hyksos) stratum underneath. The arguments of Manning echo those of David Rohl (above). He states:

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92   Bietak 2000: 194 - 195.
93   Bietak 1996: 68.
94   e.g. Manning 1999: 84 – 94; Cline 1998: *passim.*
95   I must stress, however, that I remain very grateful to Professor Rohl for his constructive criticism. This section is added partly in response to it.
96   See Bietak 2000: 194 – 195.
97   *ibid.*
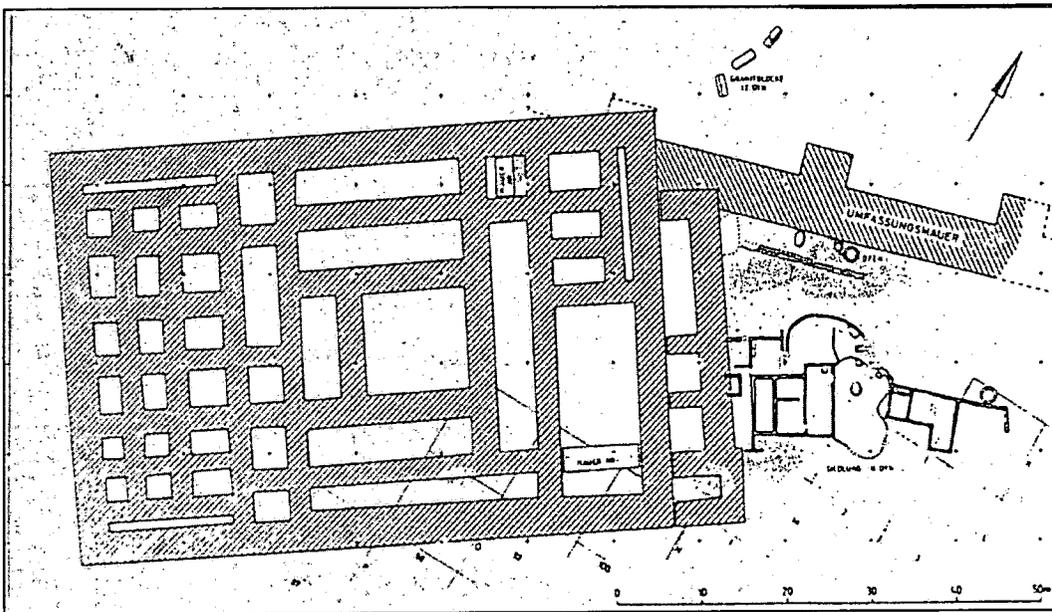
(a)
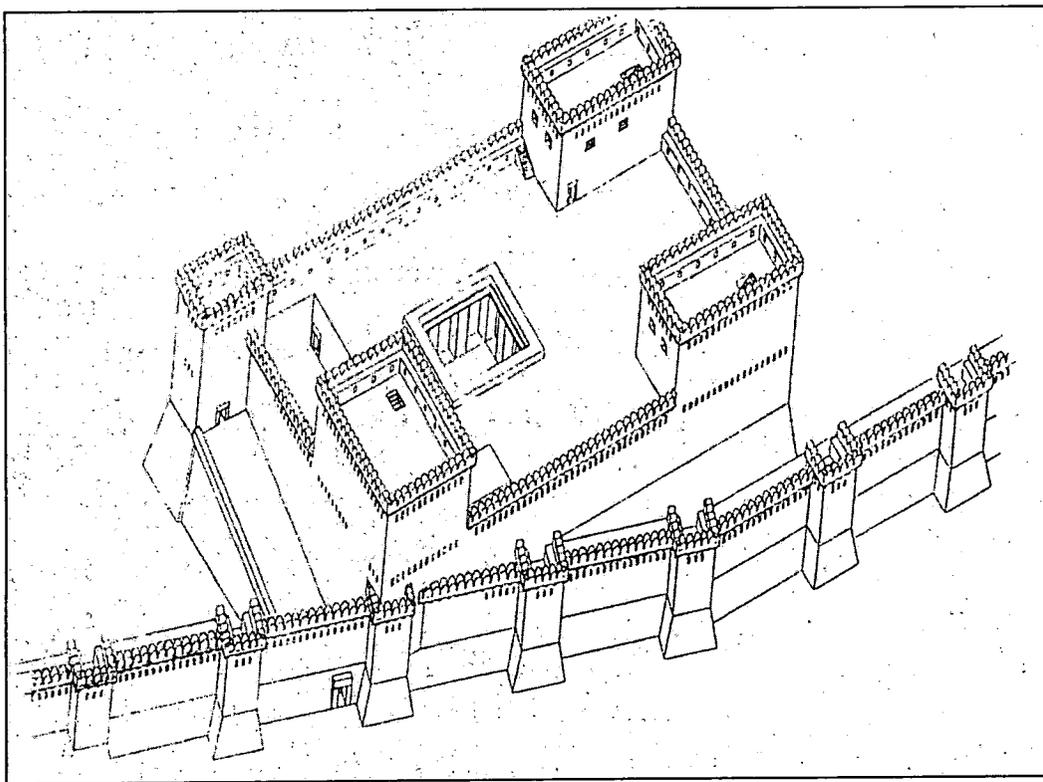
(b)

3.7 The H/I palatial platform at "Ezbet Helmi. Reproduced from Bietak 1996: 71, figs. 57 and 58.

A building cutting in to earlier Hyksos fortifications (i.e. re-modelling) ... does not of itself require a post-Hyksos date. This defensive re-modelling and strengthening could make good sense as the work of either Apophis or Khamudy under threats from Kamose or Ahmose. [I]ndeed ... such military re-modelling and building seems very likely in the late Hyksos period under the direct threat of siege by the Theban kings.[98]

This historical model is extremely implausible. Firstly, as various publications by Bietak from 1996 to 2001 make abundantly clear, platform F can hardly be described as "defensive re-modelling," if this term is defined as a modification of an existing structure. It is a matter of record – as Manning himself explicitly states - that there was no earlier structure under the H/I platform,[99] so the term "re-modelling" is itself inappropriate. The structure now visible must reflect the original building (although a change of use after construction is probable – see below). Secondly, although the sequence and chronology of the Second Intermediate Period pharaohs is not well understood, the history of this period leaves little room for the construction of H/I before the fall of the city. As Manning[100] states, the original citadel (H/III) and fortification / garden construction is probably contemporary with a high point in Hyksos power, and ought to be associated either with Khyan (length of reign, 20+ years) or Apophis (length of reign believed to be 41 years), the only two rulers with monuments to their names outside Avaris (and the former at least was probably powerful enough to have some form of diplomatic relationship with Knossos[101] – see above, section

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[98]   Manning 1999: 90 – 91.
[99]   Bietak 1996: 67 - 70.
[100]   1999: 86.
[101]   Although, of course, the Khyan Lid makes no specific reference to such a relationship, bearing only the cartouche of Khyan. It _may_ have arrived in Knossos by other means, but, given the importance of Egypt and Crete at the time, some sort of direct link can be safely inferred.

3.4.5). Furthermore, it has been shown that the reigns of these pharaohs should be approximately juxtaposed, with Apophis succeeding, either immediately or otherwise shortly after, Khyan.[102] The Kamose stela (see below), in particular refers to the opulence and ostentation of Apophis, to his "gold, lapis, silver, turquoise, bronze axes without number," etc.[103] As Manning points out, the reference in this document to the women of the citadel looking out of the windows at his approach proves that it was in existence at this time.[104] This has been taken by W-D. and B. Niemeier to be evidence for the existence of platform F before the fall of Avaris.[105] However, equating the latter with the former requires a substantial leap of faith, given the other stratigraphical, architectural and historical evidence. Bietak reports major Hyksos building activity in H/III (see above, a platform of 39.5 x 26m) and H/II ("under a huge palatial building of the early 18th Dynasty, ... some evidence of a big construction of the late Hyksos period"). Either of these could easily be the structure referred to by Kamose. The central point is that it seems likely that only the two powerful, wealthy Hyksos rulers, Apophis and Khyan, would have had the resources to undertake such a large building program, but arguing this implies that it was part of an ongoing fortification program (especially when the Hyksos reaction to the ongoing Theban military operations of Kamose and Ahmose is included in the equation)[106] Bearing this in mind, three strong circumstantial arguments suggest that the

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[102] Based on the Turin Canon. See Ryholt 1997: 43.
[103] A similar caveat should be appended to this evidence. It may have been standard political rhetoric, but analogy with later times such as the Roman period suggest that monuments and inscriptions recording success had some foundation in reality. For example the Ara Pacis Augustae (13 – 9 BC), the Arches of Titus (AD 81) and Constantine (AD 312 – 315) and Trajan's Column (AD 113) all referred, however extravagantly, to factual historical situations.
[104] After Redford 1997: 13 – 15.
[105] 1998: 86.
[106] See Manning 1999: 86 – 94.

function of the H/I platform is not of Hyksos or, indeed of military function.

Firstly, cutting (and therefore weakening) the original (and definitely Hyksos-date) fortification may even have compromised its effectiveness in withstanding a siege.[107] This is particularly evident from a 3-dimensional model of the platform presented by Bietak.[108] The northern corner of the platform structure actually cuts in to one of the Hyksos-period bastions. This could only serve to weaken the wall at that point. Also, the angle of the north-western wall of the platform creates an odd oblique angle to the fortification wall which would surely have rendered that section very awkward to defend. Secondly, if the resources had existed to build such a palatial platform and an attack by Theban forces was deemed imminent, it would make far more sense to channel those resources into strengthening the wall itself, in its original form. Thirdly, the association with fine Aegean-style frescoes is itself a strong argument that the function of this structure was not purely military; that it was first and foremost supposed to be seen as a symbol of power. Such structures are best associated with a conquering regime which wished to assert its victory over a vanquished foe specifically, in this case, the armies of the early New Kingdom.

3.5.3 The frescoes

A large number of Aegeanizing fresco fragments were recovered from various parts of the Hyksos and 18th Dynasty compounds. It is not my intention here to rehearse in

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[107] W-D. and B. Niemeier (1998: 86) themselves comment on "this strategically important area of the Hyksos citadel", and the fact that the (in their view, unlikely) 1995 re-dating would require that it was not built up in the Hyksos period. This is true but, as stated here, all the published plans show clearly that the area <u>was</u> enclosed by fortifications in this period.

[108] 1996: fig. 58. see fig 3.7 (b).

great detail the arguments surrounding the stratigraphy of the fragments, or their date in stylistic terms. The former problem is still under consideration by the excavators, and with regard to the latter, it is virtually impossible to assign with any certainty their stylistic date in Aegean terms. Suffice to say that the published view of Bietak to date is the fresco fragments are of early 18th Dynasty provenance. If this is the case, then, to support a low dating for the Aegean, the frescoes would have to have to correspond to LM IA. The case for revising them up into LM IB (as the high Aegean dating requires) rests on the longevity of the motifs displayed in the Tell el-Dab°a frescoes, and certain stylistic affinities with LM IB ceramic types and wall-painting styles.

3.6 Conclusion

This chapter, and the last, have analysed the impasse which Aegean Bronze Age chronology has reached, as of A.D. 2002. The resolution suggested indicates that the "low" system of dating is preferable to the alternative early scheme. However, from many angles, especially in terms of the conflict between the ice-core dating and Egyptian cross-links, the problem appears intractable.

To move towards overcoming this situation, I suggest the following process. The attempt to date the eruption has to begin with the VDL at Akrotiri, and the recognition that what is a well defined event here is a single event horizon for many other sites in

the region (see below, 5.3). The radiocarbon evidence for this event on the island of Thera is less than satisfactory, and the compatibility of the tree-ring and ice core evidence is, as yet unresolved. Therefore, we must proceed to the question of how do the orbits of Mainland Greece, Crete, Cyprus, the Levant and Egypt link? How can scientific methods be used to answer this question?

The evidence from Nichoria, as well as the absence of later ceramic types at Akrotiri (and more general, and generally accepted, evidence for the relative starting points of LM IA – B and LH I – IIA) places the eruption no later that Late Helladic IIA. However, if the unconfirmable circumstantial evidence from Nichoria is correct in suggesting a *terminus ante quem* of LH I, this would require LH IIA to be underway before the close of LM IA, a significant revision to the accepted orthodoxy. The discovery of Theran tephra in a sea-core off the Peloponnesian coast is likely to focus further attention on the likely impact of the eruption on this region. Furthermore, a thin (>1 cm) sample of ash has been recovered from the western Greek mainland, at Limni Trikhonis, Akarnania (see below, 5.2 and 5.3)[109].

As pre-eruption Akrotiri had very close cultural links with the Minoan world, it is unsurprising that it is Crete, and her close neighbours in the Dodecanese, that provide the best relative resolution of the date of the eruption. It is clear that there are only two ways of converting this in to an absolute resolution. Firstly, an enhanced and expanded network of radiocarbon dates, taking in to account the stratigraphy and ceramic chronology of the periods surrounding LM I. It has been demonstrated that

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[109] It made clear below (Ch. 5) that the Minoan provenance of this ash has not been scientifically confirmed. It is merely inferred from its stratigraphical place and the absence of any other major eruption at this time.

this is theoretically possible, and it is an avenue that must be vigorously pursued. Secondly, there is the more traditional method of linking Minoan material culture with that of Egypt. The salient general point to emerge from this method is that we are dealing, not in absolute dates for Crete and Thera, but in *termini ante* and *termini post quos*. To assess the most important of these:

The fundamental question is whether LM IA ended before or after the takeover by the 18th Dynasty at Avaris. I suggest that it is at this point that understanding the nature and chemistry of pumice becomes a scientific dating method. The *"ante"* of the *terminus ante quem* is not scientifically or archaeologically quantifiable, but it provides a definite point of reference to Thera after the crucial inception of the New Kingdom at this site. It is to be hoped that similar, and indeed better, stratigraphical resolution may be achieved elsewhere in the Near East. However, as has been noted in the past, only a definite layer of definitely Bronze Age Theran ash in a securely dated pharaonic context, will resolve the issue in this way.

Precisely the same problem arises, but in reverse, with regard to the lost Thera WS I bowl. It fixes only a *terminus post quem* for the eruption which, if the argument that it is of LCIA:2 date is accepted, merely allows - but does <u>not require</u> a seventeenth century date for the eruption. Conversely, accepting a later date for the bowl would require a later date for the eruption which buried it. Can scientific methods help resolve this problem?

A clue may be found in a paper given to the Symposium on Mediterranean

Archaeology conference in Liverpool in 2001.[110] Helen Hatcher's work, and that of others in the field, involves petrologic analysis of a range of Cypriot pottery, including WS. At Hala Sultan Tekke, for example, there are two groups within the assemblage, one a local clay also used elsewhere, and clay from a different source. In other works, WS I from sites in the northwest has been linked petrologically to clay deposits in foothills of the Troodos mountains. Extension of this technique to the Tell el-Dabᶜa assemblage may help to resolve the issue of where these pieces came from, and thus place the sherds in the northwest / east and south chronological division scheme of Merrillees and Manning. Again, this is a good example of a scientific method not normally associated with dating which has the potential to provide important chronological information.

The distal data from ice-cores and tree-rings are the hardest datasets to fit into an interdisciplinary approach to dating. By nature they are stand-alone, the calendrical agreement between the event(s) recorded by two methods is questionable, and further uncertainties remain with the GISP2 core. It may be possible to move towards their integration within the broad scheme through a better interregional understanding of the ancient Aegean environmental and climatic conditions. It might be worthwhile to research wind patterns in the troposphere and stratosphere, examine how exactly these may have changed since the Bronze Age, suggest routes that the material may have taken on these winds. However, the research presented below (5.3 – 5.5, and Chapter 6) raises serious questions about even this.

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[110]   Hatcher 2001. I thank Helen Hatcher for providing a copy.

As the higher date for the eruption was first proposed on the basis of scientific dating methods, and the re-interpretation of the archaeological record conducted as a result of this proposition, the burden of proof must continue to lie with this hypothesis. My own view is that the high dating has yet to achieve this proof. We need a resolution of the apparently different dates from the GRIP / Dye-3 ice-cores and the well replicated tree-ring sequence. We need a better radiocarbon chronology for the Aegean. These factors, together with a better understanding of the sites on the Levant seaboard within an Aegean context is the way we must proceed.

Part II

Effects and Fallout

CHAPTER 4
THE GEOLOGICAL DYNAMICS OF THERA

4.1 Introduction

4.1.1 Volcanology and Thera

The purpose of this chapter is to provide a scientific assessment of the impact, scale

and destructive potential of the Minoan eruption, and also the scientific aspects of its

absolute dating and the chronology of the Aegean Late Bronze Age. In particular, it

complements the spatial analysis of the ash fan set out in the next chapter. This

approach will be based on existing knowledge of the geology of Santorini and the

compositional data available on the magma, and various general mathematical models

developed elsewhere.

Volcanological modelling is very much a developing field. Recent studies, notably

those of Sally Bower and Andrew Woods, have made significant contributions,

although these are, as the authors state, end products of over a decade of research.[1]

This research has produced a number of mathematical expressions by which factors

such as eruption rate, the mass erupted, the overall scale of the eruption and the

eruptive nature of the magma can be estimated. Quantities for these factors are

calculated from a number of known geological parameters, such as rock density,

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[1]   Bower and Woods 1997: 10,273; Bower and Woods 1998: *passim.*

chamber compression and pumice volatility. The research in this chapter will focus primarily on the rate of the Minoan eruption and how it developed over time. Other issues that will be discussed include the volume of the eruption, estimated most recently to be in the region of $27 - 30$ km^3.[2] In the present study (Ch. 5), this figure is estimated to be very significantly higher. The issue is clearly vital, as this modelling exercise depends on compression in the chamber, a direct factor of which is the actual amount of magma in the chamber at the point at which compression became too great to contain the magma (i.e. the point of "critical overpressure").[3] This interlocks with the issue of the geological history of the island before the Minoan eruption. Before the time of the Second International Congress it was generally assumed that before the eruption there was a single, roughly circular island, dubbed "Stronghyle".[4] The main geological justification for this was the massive, poorly sorted lithic blocks in the Bo3 phase (but see below).[5] This would mean that the present caldera and the islands of Thera, Therasia and Aspronisi were formed in the same single event. Although this view persisted in some quarters,[6] conclusive evidence has been advanced to suggest that the Minoan caldera is the second major caldera in the Santorini volcanic system.[7] Naturally, this would reduce dramatically the volcanic impact and explosive potential of the Minoan eruption, as the overall volume erupted would be significantly lower. In the opinion of Heiken and McCoy 1984, such an earlier caldera was formed during the Bu (Lower Pumice Series) eruption of c. 100,000 B.P., and was c. $5 - 6$ km in

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[2]   Pyle 1990: 121.

[3]   In section 5.5.4 below, it is shown that the results reported in this chapter are compatible with the GIS results in the next.

[4]   Pichler and Friedrich 1980: 16.

[5]   *ibid*: 20.

[6]   e.g. Lister and Durkin 1985: 6.

[7]   Heiken and McCoy 1984: 8461; Heiken et al. 1990: 374; Druitt and Francavigilia 1990: 368.

diameter, and mere 19 km^3 in volume[8]. At the time of the Third Congress, the published estimate for the total volume of fallout, taking in to account the reduced scale due to the pre-eruption caldera was c.28 – 29 km,[39] and the height of the column is now put at c. 36 km.[10] More recent estimates put the volume of ejecta in the region of 40 km^3.[11] However, the research presented in Chapter 5 suggests that the eruption could have been very considerably larger than this, possibly as much as 100km^3. It would seem that an eruption on such a scale <u>could theoretically</u> have a global impact, which means that the case of Hammer, Manning and others has to be treated accordingly.

In tandem with modelling the eruption on the island itself, must go the task of modelling the fallout of that eruption; an issue addressed in the next chapter. Such fallout is expressed in the bulk volume of tephra which is identifiably from Thera, from other parts of the Aegean, although it is clear that substantial complications are raised by the highly irregular, not to say erratic, preservation patterns of tephra, a friable and delicate compound.[12]

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[8]   *ibid*, but see Chapter 5.
[9]   Pyle 1990: 121.
[10]   Sigurdsson et al. 1990: 100.
[11]   Haraldur Sigurdsson, personal communication, 8/2/2001.
[12]   See next chapter, and McCoy and Dunn (forthcoming).

4.1 Simplified map of the Thera geological formation (after Druitt et al. 1988: 97, fig 2)

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4.2 The four phases

4.2.1 Introduction

It is extremely important to remember that the Santorini archipelago is a complex, and

constantly evolving, volcanic sub-system of a far larger seismic structure; i.e. the

Hellenic Trench. The emergence of the Kameni (literally "furnace") Islands, in the

middle of the present-day caldera, is the manifestation of this process as it continues

today (fig. 4.2). The Minoan eruption was one of the largest and the most significant

elements of this process. A number of landmark studies[13] have identified four major

phases of the Minoan eruption (fig 4.3), although they were first described by Reck's

Santorin – Der werdegang eines Inselvukans und sein Ausbruch (1936)[14]. They are

reviewed here with special reference to their relevance to the volcanological

modelling proposed in this thesis.

Most recently, Druitt et al. have updated the literature with a major study of history

and volcanology of the Santorini complex.[15] Their commentary on the Minoan

eruption[16] does not, by their own admission, provide any new data on the complex's

volcanology; it summarises the studies reviewed in more detail in this section. Two

important facts to record in relation to this study is a) that, in the authors" map (an

updated version of that accompanying Pichler and Friedrich: 1980), the Bronze Age

deposits are recorded as "Minoan Tuff" and rp7, and b), they (very commendably)

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[13]   E.g. Bond and Sparks 1976: 2 - 14; Pichler and Friedrich 1980: 17 - 30; Sparks and Wilson
        1990; 90 -94.
[14]   Reck 1936 vol 1: *passim.*
[15]   Druitt et al. 1999: *passim.*
[16]   *ibid*: 43 - 48.
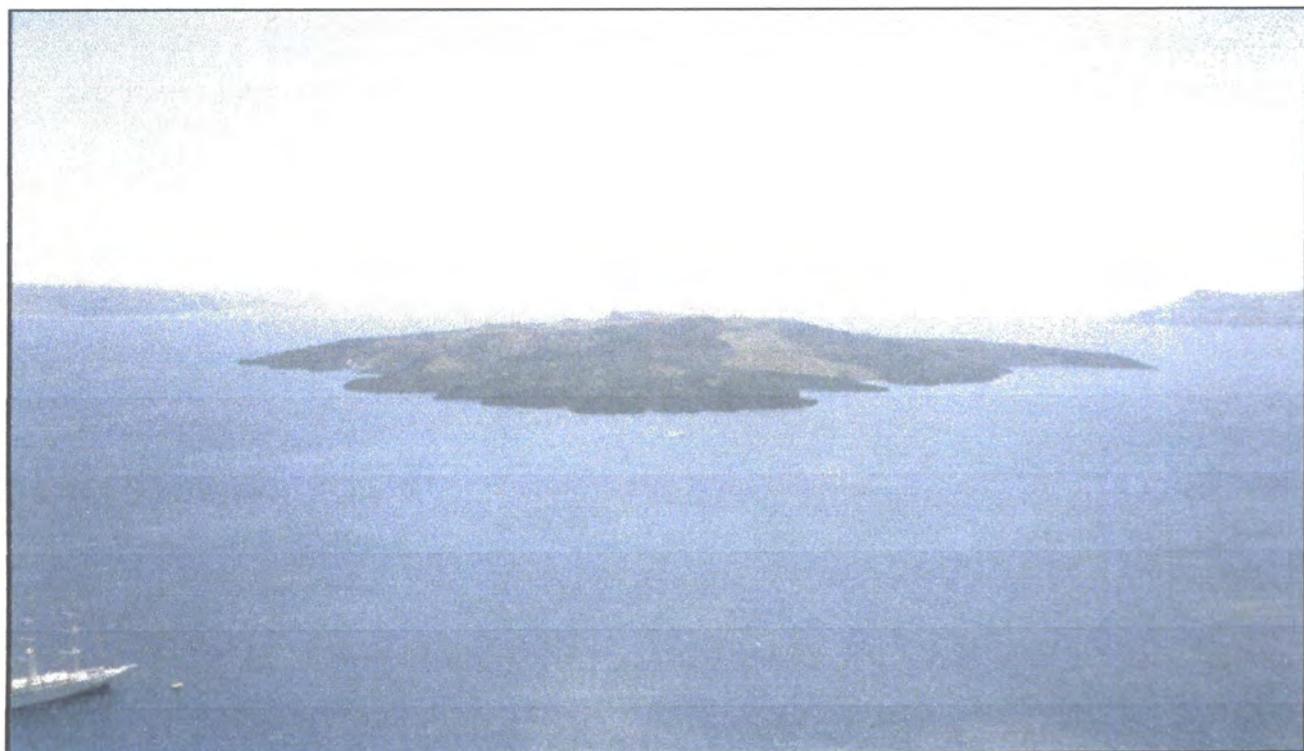
4.2 Nea Kameni (photo: the author)

Minoan Tuff

Pyroclastic / co-ignimbrite phase (Bo 3 and 4)

Phreatomagmatic phase (Bo 2)

Plinian ash fall (Bo 1)

Precursorary ash fall
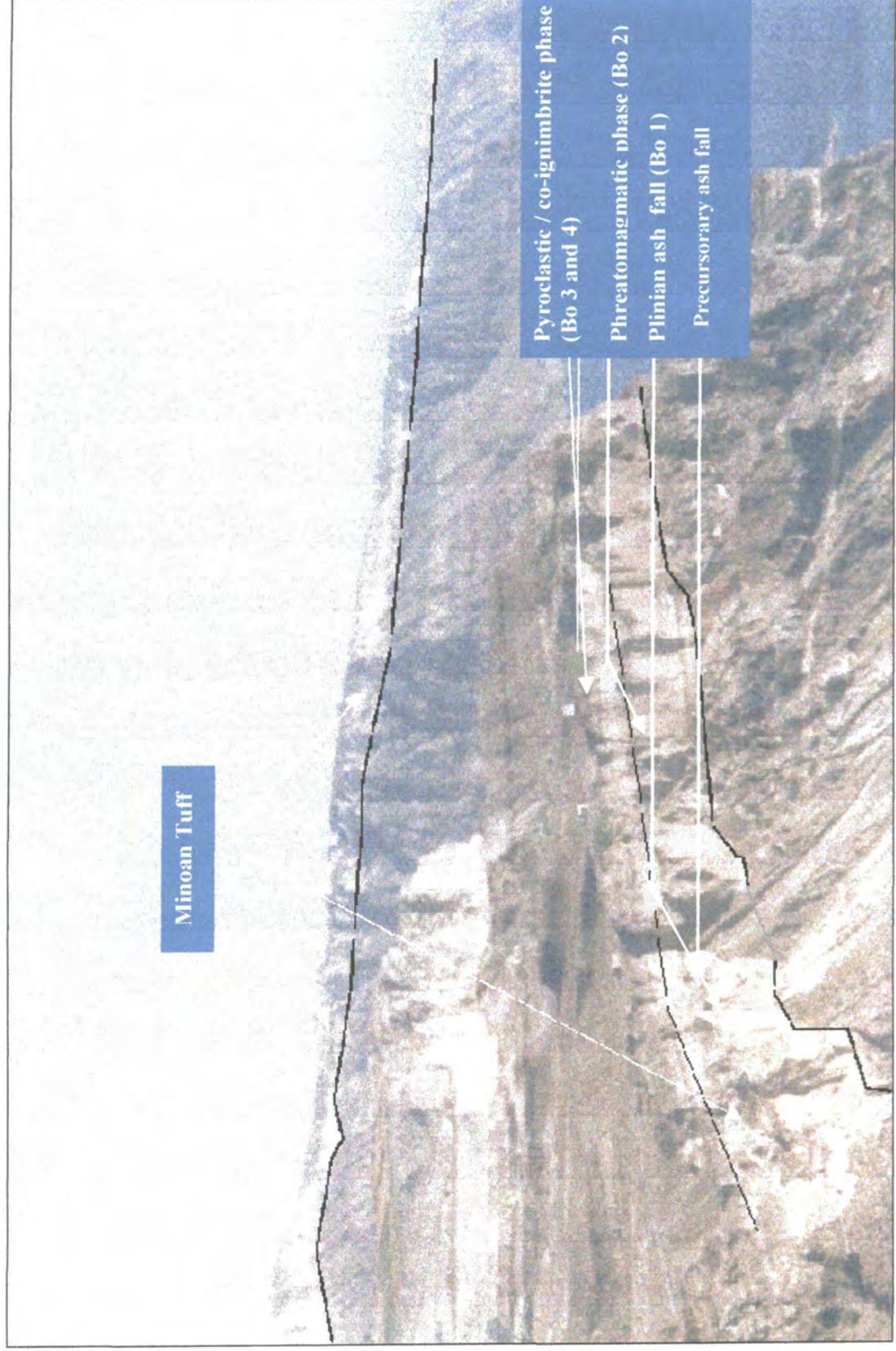
4.3 The phases of the eruption viewed in the caldera cliffs (photo: the author)

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2 Mt. Profitis Elias viewed from the northern part of the island (photo: the author).

remain neutral on the date, noting the two proposed timescales.[17]

4.2.2 Bo1

This is the least controversial phase of the eruptive sequence. It is known to be a thin ash fall layer, followed a main plinian deposit[18]. The airborne origin of this layer is confirmed by its presence on top of Mt Profitis Elias, the highest peak in the Santorini (fig 4.4) islands. It is a reverse-graded and poorly sorted deposit, rich in lithic material towards its top and reaching a maximum thickness of 1 km.[19] A similarity to phreatomagmatic ashes observed elsewhere point to a limited exposure of the vent to water.[20] It is estimated to have contributed around $1.0 - 1.2 \text{ km}^3$ dense rock equivalent (DRE) to the total volume of the eruption,[21] and had a precursory phase which left a deposit 10 to 600 cm thick throughout the Santorini volcanic system.[22] Its main composition is white to pale pink pumice clasts, with angular lithic fragments and bombs of up to 25 cm in length. The reason normally given for the pink colouring is the re-oxidisation of ferric materials coating the xenoliths, and the leaching of this recrystalised material through the facies.[23] An alternative, and equally plausible hypothesis is that hyrothermal alteration of existing material within the facies reddened the matrix. The upper part of the deposit contains bright red and orange lithics that were clearly hydrothermally altered.[24] This argument for would fit with the bright red becoming pink lower down in the sequence where there were fewer ferric oxides necessary for the hydrothermal alteration process – such oxides only being

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[17]   *ibid*: 47.
[18]   Heiken et al. 1990: 80.
[19]   Bond and Sparks 1976: 2.
[20]   Sparks and Wilson 1990: 90.
[21]   Pyle 1990: 117.
[22]   Heiken and McCoy 1984: 8451.
[23]   Bond and Sparks 1976: 2.
[24]   Sparks and Wilson 1990: 90.

present in and around the xenoliths. Secondly, the presence of the phreatomagmatic flow above Phase 1 would provide the large quantities of water and heat that could have acted as an initial catalyst for hydrothermal alteration. Thirdly, recent field research on the other major volcanic island in the Cyclades, Melos, has demonstrated that there is direct correlation between the presence of ferric sulphates and hydrothermal reddening. This reddening has been reproduced experimentally[25] and it seems likely that there were similar processes at work on Santorini. Fourthly, the "leaching" has been observed in detail only on naturally exposed sections of the pumice. It is entirely possible that some of the reddening is indeed caused by re-oxidisation and leaching, caused by rain and sea salt. This is not an easy problem to resolve, as the difference between oxidisation and hydrothermal alteration is often difficult to spot. However, it seems possible that the "Rose Pumice" acquired its eponymous colouring through hydrothermal action on mafic material in the emplaced pumice.

4.2.3 Bo2

The second phase of the Minoan eruption saw the transition from plinian ash fall to a phreatomagmatic "base surge" horizion[26]. It was the first such phase of the eruption, caused by the opening of radial dykes in the north east of the caldera in the region of Mikro Profitis Ilias and the Mt Megalo Vouno lava shield, and / or by similar volcanic or tectonic activity, which admitted sea water to the magma[27]. This caused rapid vesiculation and fragmentation of the pumice, producing fine bedded, poorly sorted

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[25]   Photos-Jones et al 1999: 324.

[26]   Bond and Sparks 1976: 4; Pichler and Friedrich 1980: 19.

[27]   *ibid.*

flows with radial waveforms.[28] These radial wave forms are consistent with a lateral rather than a vertical mode of ejection, and therefore some similarities can be made between volcanic activity of this type and thermonuclear explosions.[29] On Santorini, the wave forms are asymmetrical in section, and mantle the topography of the islands, depositing dunes on slopes of 10 - 30°. They exhibit a wavelength of a few meters to 50m in the proximal areas, where they form large dunes.

Bo 2 can be broadly divided into three sections, defined by bomb sag horizons, observable at the Phira quarry.[30] These horizons are important, as they demonstrate that this phase of the eruption was accompanied by the ejection of large clasts along ballistic trajectories, and they are known to have caused considerable damage at Minoan Akrotiri.[31]. However, the bombs in Bo 2 are far larger than any that fell during the plinian phase, in some cases up to 1 meter in diameter,[32] adding weight to the archaeological interpretation that the inhabitants would have had time to evacuate the town with few or no casualties (but see also below, section 4.3.6). The lower half to third of the deposit contians 1% - 2% of lithic fragments, the middle 3% - 20%, while the upper level is characterised by large bombs of > 50cm.[33]

The variation in grain size is considerable, and the deposit's most striking feature is the extent of cross stratification and cross deposition.[34] Chiefly, they are rounded to

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[28]   Bond and Sparks 1976: 4. Heiken and McCoy 1984: 8452.
[29]   Bond and Sparks 1976: 4.
[30]   Pichler and Friedrich 1980: 19; Sparks and Wilson 1990: 90; Wilson and Houghton 1990: 126 and fig 3.
[31]   Pichler and Friedrich: 20, fig 2.
[32]   Sparks and Wilson 1990: 90.
[33]   Heiken and McCoy 1984: 8453.
[34]   Sparks and Wilson 1990: 90.

subrounded pumices which, importantly, contain hydrothermally altered lithics.[35] There are bands of fine, vesiculated ash, 70% - 90% of the grains of which is less that 1 mm in diameter. These beds indicate the presence of water on deposition. Sparks and Wilson report that the walls of these vesicles range from between 5 and 10 nannometers.[36] This has important consequences when considering the evolution and volatile content of the eruptive and pre-eruptive magma (see below). Sparks and Wilson[37] have suggested that there is compelling evidence for an intermittent continuity of plinian activity throughout the (largely) phreatomagmatic Bo 2 phase, denoted by the presence of the very fine white ash beds. Furthermore, Bond and Sparks[38] suggest a short break in phreatomagmatic activity, a shown by a pumice belt some 15 - 30 cm thick across all three ancient islands. This must lead us to treat with some caution Heiken and McCoy's assertion that Bo 2 was "entirely phreatomagmatic".[39]

In common with base surge deposits from other volcanic eruptions, it is believed that the temperature of this material was fairly low on deposition.[40] This is likely to have been the case in some areas, as the vast majority of heat energy contained in the magma would have been lost in the conversion of sea water to steam. However, Sparks and Wilson[41] point out that some of the pumices have developed pinkish colorations as a result of much higher temperatures. This would suggest that there was a range of temperatures, constrained at the very lowest end by the temperature of sea

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[36]   *ibid*: 91.
[36]   Heiken and McCoy 1984: 8453.
[37]   Sparks and Wilson 1990: 91.
[38]   1976: 4.
[39]   Heiken and McCoy 1894: 8452.
[40]   Bond and Sparks 1976: 5.
[41]   1990: 91.

water (c. 25°) and a temperature capable of causing hydrothermal alteration in the material of Bo 2. McClelland and Thomas's study[42] places the possible range of emplacement temperatures between 100° and 250°. Hall et al's experiments in connection with the Aghia Kyriaki landscape project on Melos have demonstrated that sedimentary materials on the island contain minerals that produce haematite (i.e. redden in a manner similar to that described by Sparks and Wilson 1990) under "moderate geothermal conditions" - i.e. 120°C.[43] Although the mineral they cite as being most susceptible to alteration under these conditions - jarosite - is not present on Santorini, they qualify their stance by stating that other ferric sulphate materials may behave similarly.[44] It seems very possible, therefore, that the deposition of Bo 2 was subject to different temperatures, probably caused by the uneven distribution of water over the topography. It also leaves open the possibility that some isolated pockets of magma had only highly limited contact with sea water.

4.2.4 Bo 3

The third phase of the Minoan eruption is probably the most enigmatic and controversial. It has been described variously as a mud flow,[45] a pyroclasic ash flow[46] and (at least partly) a phreatomagmatic tuff.[47] What is not in doubt is that it is by far the largest of the four major deposits, accounting as it does for 57% of the entire

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[42]   1990: 134 and fig 4.
[43]   See preliminary findings discussed in Photos-Jones et al. 1999.
[44]   *ibid.*
[45]   Bond and Sparks 1976: 6.
[46]   Pichler and Friedrich 1980: 21.
[47]   Heiken and McCoy 1984: 8454.

Minoan tuff, and reaching depths of 40 m at Phira quarry and 55 m elsewhere.[48] It is characterised by unsorted and unstratified pumice and ash deposits, and no indications of any further plinian activity. Bond and Sparks[49] believed it to be a mud flow for a number of reasons. Firstly, there is a lack of grading, even in the case of the very largest lithic blocks (> 1m).[50] Secondly, there is deposition even on the steepest slopes, including massive glassy brecciated blocks of glassy lava of > 10m, which could only have been deposited by mud flow action on account of their very poor sorting within the deposit, are further deployed to support the argument. A gaseous ash flow, they argue, would allow the massive lithics to sink to the bottom. However, Heiken and McCoy's[51] detailed analysis of the matrices surrounding these lithics identified traces of smaller lithics surrounding the large clasts. This phenomenon implies impact craters which have not been disturbed by mud flow. The conclusion to draw from this is that the lithics were not emplaced by mud flows at all, but by ballistic ejection. If Heiken and McCoy are correct, it would also rule out Pichler and Friedrich's conclusion[52] that the lithics fell into the crater from the caldera wall, were encapsulated by the ash, and brecciated and emplaced accordingly.

Heiken and McCoy have identified three gradational facies in the third phase.[53] The first is a proximal base surge. This feature grades west into "well bedded pumice lapilli" west of Akrotiri. Secondly, there are distal mud flows which appear to have had a strong erosional character; in some places the second and first phase deposits

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[48]   *ibid.*
[49]   Bond and Sparks 1976: 6.
[50]   *ibid.*: 7.
[51]   1984: 8454.
[52]   Pichler and Friedrich: 21.
[53]   Heiken and McCoy 1984: 8454 - 8456.

have been completely cut away, in a few areas the country rock itself has been cut. This part of the deposit seems to have been influenced by topography, confined as it is to coastal plains and valleys. The third feature is massive slump deposits on steep slopes, most notably on the north face of Mt Profitis Elias. These deposits have not formed lenses, but slump patterns, demonstrating that they were pushed up the incline and fell back once gravity became greater than the yield strength of the flow.

Broadly the interpretations of Heiken and MCoy[54] and Sparks and Wilson 1990[55] are agreed with in the present analysis. The geological evidence appears to offer substantial support for the theory that this was chiefly a phreatomagmatic horizon, emplaced a fairly low temperatures, uncontrolled by topography, powerful enough to deposit blocks of up to 10 meters in diameter, and subject to impact from large ballistic clasts.

4.2.5   Bo 4

The fourth phase of the Minoan eruption is yet another problematic chapter in the volcano's history. It takes the form of ignimbrite - the depositional unit or units left by the passage of a pyroclastic flow - which form very large fan-shaped deposits, chiefly on the coastal plains of Thera and Therasia. There is clear evidence that alluvial fans caused by flash flooding overlay this phase[56] but, being post eruptive, they are not included in this review. Although these flows, even more so than the phreatomagmatic phases 2 and 3 which preceded them, would have had a highly

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[54]   Heiken and McCoy 1984; 1990: *passim.*
[55]   1990: *passim.*
[46]   Sparks and Wilson 1990: 94.

destructive nature, the island would have been abandoned long since (or the inhabitants killed already), and Akrotiri covered, so consideration of the Minoan ignimbrite is of purely geological rather than archaeological interest. Nevertheless, it is also vital to obtain an accurate picture of the postscript to Minoan life on Thera, and for the volcanological modelling of the earlier phases.

The deposits on the coastal plains are massive, forming cliffs of 40 m reported by Heiken and McCoy,[57] but Bond and Sparks[58] report cliffs of up to 60 m in height. There appears to have been a high degree of topographic control over these deposits, with the fans forming on low coastal plains, and the flows being contained by the high ground of the Platinamos ridge / Mt Gavrillos in the south, Mt Profitis Elias and Mesa Vouno in the south east, and Mts. Mikro Profitis Elias and Kokkino Vouno in the north east. On Therasia the deposit is limited to a strip on the north eastern coast, presumably an original extension of the deposit visible on north Thera west of Cape Koulombo. The fluidity of the ignimbrite has led to its complete detachment from its source, as it has not deposited on slopes less than 5°.[59] There are, however, thin veneer deposits of 0.7 to 2 m around the rim of the caldera, containing low dunes and a matrix of small pumice lapilli and small (> 2 cm) lithics.[60] The difference between phase 4 ignimbrite and phase 3 tuff is subtle, being a colour grading from white to creamy white. The coastal fans thin out towards their edges, where they become less than 10 m thick with an increase in channelling of earlier layers.[61]

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[57]   1984: 8456.
[58]   1976: 7.
[59]   Bond and Sparks 1976: 7.
[60]   Heiken and McCoy 1984: 8456; Sparks and Wilson 1990: 93.
[61]   Heiken and McCoy 1984: 8456.

An important feature of this deposit individual flow units, with a wide variety of pumice and lithic grading, that are visible in the cliff faces.[62] These units are generally less than 3 m thick, and indicate that at this time the eruption was proceeding in a series of separate paroxysms. Between these units are a number of lithic breccia lenses, some of which are the origins of gas fumarole pipes. These pipes, 2 - 30 cm in diameter, are clear evidence that the gravel breccias of the lenses contained liquid, presumably water, which the high temperature of the flow units (see below) would have heated. Bond and Sparks[63] interpret them as being the result of flash flooding. This theory has an important possible implication for the time that elapsed between the deposition of the flow units. Bond and Sparks's schematic profile of the eruptions sequence[64] show that the lenses are long, and occupy very shallow gradients. This implies that the reservoirs containing them would also have been flat and shallow. If the ignimbrite on which they were deposited was hot at the time, the reservoirs would very rapidly have boiled dry, leaving no liquid in them to form the fumarole pipes at all. This would require the overlying unit to be deposited within hours, suggesting a rapid series of eruptive events. If, however, the underlying materials were cool, the question becomes more difficult. If the eruption happened in hot (spring / summer) conditions, the normal process of evaporation would limit the time between flows to weeks if not days. However, the period between the cooling of the lower layer and deposition would have to be added.

There is, however, an alternative possibility that does not constrain the time lapse.

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62   Bond and Sparks 1976: 8; Sparks and Wilson 1990: 93.
63   1976: 8.
64   *ibid* 1976: 8, fig 3.

Sparks and Wilson[65] cite the range of matrices in the breccias from ignimbrite to fines poor deposits, and instances where the two types are mixed. They interpret these as "lag breccias", and their formation near the steep inner slopes of the island suggest an association with the breaks in slopes, caused by the rapid deceleration of the flow and consequence deposition of lithic material.

The temperature of the deposit was far higher than any other phase of the eruption. Bond and Sparks suggest an emplacement temperature of well over 100°; Heiken and McCoy cite paleomagnetic studies suggesting a temperature of around 500°. However, the most recent paleomagnetic study, that of McClellend and Thomas, indicate a temperature of 200 - 400°.

4.2.6 Summary and main questions

To précis this fairly extensive review of the literature of the Minoan eruption's volcanology: the deposits on Thera, and in particular the caldera cliff faces, present a complex document of a complex event. The crucial point in terms of the effect of the eruption has to be the phreatomagmatic mixing of seawater with the melt, although it seems likely that any inhabitants would have either evacuated or died by this time (see below). The impact of water entering the vent also has unquantifiable implications for conduit geometry, although there is no direct evidence to suggest that water entering the subterranean volcanic system had any direct effect on the surrounding geomorphology, i.e. caldera formation seems to have followed normal patterns. This

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[65]   1990: 93.

four-phase event evolved from massive plinian activity through, water interaction, to high intensity co-ignimbrite / pyroclastic activity. The timescale cannot be directly inferred from the deposits, although estimates are made by other means below.

4.3 The intensity and volume of the eruption

4.3.1 Previous work on volumetric analysis

The main purpose of this section is to anticipate section 5.5 below, where I set out my own estimate for the eruption's volume, based on a volumetric spatial analysis of the ash beds. Here I review previous work on the subject.

The volume of material ejected by major volcanic eruptions, ancient or modern, are notoriously difficult to quantify. Indeed the word "constrain", within wide margins of confidence, would be more appropriate than "quantify". Essentially, there are two methodological approaches. Firstly, spatial analysis of distal and proximal tephra deposits from the event are scrutinised using various linear, mathematical or other quantitative techniques in which ash thicknesses are the primary data source. In Thera's case this approach is employed partly by Pyle,[66] and McCoy and Dunn (forthcoming). Pyle[67] used a formulae based on the linear decay of the isopach (deposit thickness) and isopleth (clast size) values with the increase in distance from the vent. Pyle concluded that the total volume of ejecta was "27 – 30 km^3, and most

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[66]   1990: *passim.*
[67]   *ibid.*

probably 28 – 29 km^3." Secondly, in caldera collapse events such as the Minoan eruption, estimates can be derived from paleotopographic reconstruction and comparison of the surface overlying the magma chamber before and after the event. This approach has been employed by Heiken and McCoy (1984), who inferred a volume of c. 19 km^3. However, the spatial analysis presented below (Chapter 5), and McCoy and Dunn (forthcoming) demonstrate that this is a serious underestimate, with a figure up to five times that being proposed here. Although it is not possible to be certain at this stage, it can be speculated that the most probable reason for such a large discrepancy is that the Minoan magma chamber only partially collapsed during the caldera formation process, leaving a far smaller depression in the surface topography than would have been the case in the event of total collapse.

4.6.2 The intensity of the eruption inferred from differential analysis

This section was prepared jointly with Dr J. Vernon Armitage of the Department of Mathematical Sciences, University of Durham, who developed and performed the calculations in consultation with me. His long commitment to our cooperation on this subject is gratefully acknowledged as a *sine qua non* of this chapter. The purpose of this analysis is twofold: to provide a theoretical construction for estimating the intensity of the Minoan eruption, that is to say the rate at which material was ejected in volume / time and, in conjunction with section 5.5.4, to demonstrate that relatively complex analyses such as these are essentially compatible with GIS approaches such as those employed in the next chapter. This is an important element of the

interdisciplinary philosophy which this thesis is striving to cultivate (see Ch 1., esp. section 1.6).

It must be declared at the outset that many of the variables and parameters are, *ipso facto*, derived from geological field and laboratory results already available in the literature. This inevitably leads to a degree of circular reasoning, and makes it difficult, at this stage, to verify the conclusions reached here independently. Some variables in particular are the products of what is, essentially, educated guesswork. For example, it not possible to measure the dimensions of the Minoan magma chamber for the simple reason that it does not exist any more, collapsing as it did during the Minoan event. Here, the values representing these dimensions, are defined by volcanological convention. Another example is the quantity of exolved sulphur. Below (11), the weighted percentage estimated by Sigurdsson et al.,[68] namely 5.5×10^9 kg is employed: however, the recent estimate of Michaud et al.[69] for the same variable is vastly higher, at $1.8 - 2.7 \times 10^{11}$. Generally, the *TAW III* of Sigurdsson et al. 1990[70] is relied on as being broadly uncontroversial at the time of writing, but it is recognised that these conclusions are far from infallible, and are subject to revision and reappraisal. Equally, however, it is not the purpose of this section to provide infallible answers, but to consider possibilities for a range of parameters. What is strongly proposed is that these calculations can unify all the data, however unsatisfactory, as well as the GIS results of the next chapter, in a single, integrated analysis. This is a new departure, and surely one which merits further investigation.

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[68] 1990: 110.
[69] 2000: 213.
[70] 1990: *passim.*

This analysis is dependent on establishing values for a set of constants and variables. Mineralogic composition of the Minoan products are consistent with a magma reservoir temperature (T) of $850°$[71], and a chamber between 8 km and 15 km beneath the surface (fig 4.5).[72] With a caldera-forming volcano such as Thera, the radius (R) of the chamber can be inferred from the dimensions of the caldera, the surface dimensions of which ought to broadly equate with those of the compartment.[73] Values for radius of the vent (r), which enlarges through time through erosion caused by the passage of the ejecta, have been determined using separate volcanological calculations; they range from 160 m at the start of the eruption to around 480m at the end.[74] Thus, the latter is taken to be c. 10 km north-south and 5 km east-west.[75] Thus, if a total surface area of 50 km^2 is assumed, the value of R can be obtained from rearranging the simple formula $A = \pi R^2$, where A = 50,000,000 m^2. Thus R = 3990 m (see fig 4.5).

Woods[76] gives an example of volcanic activity in which the pressure in the magma chamber is 800 atmospheres and the overpressure is 100 atmospheres. Here, it is assumed that the two are constant over a time-interval, although theoretically they could have a constant ratio (in that case $\Delta p/p$ = 1/8). For the purposes of this model, the former is assumed to be the case, with overpressure assumed to be 100. The value for Q, eruption rate, is given in terms of the velocity (v) at the top of the chamber

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[71]   *ibid*: 110.
[72]   *ibid*: 109.
[73]   Haraldur Sigurdsson, personal communication, 8/2/2001.
[74]   As in Wilson 1980: 34.
[75]   Although the chamber is clearly not circular in shape, it can be modelled as such in this theoretical construction. See fig 4.5.
[76]   1995: 505.

Inferred maximum extent of magma chamber

Minoan caldera

2 km

r

H_t

H_b

R
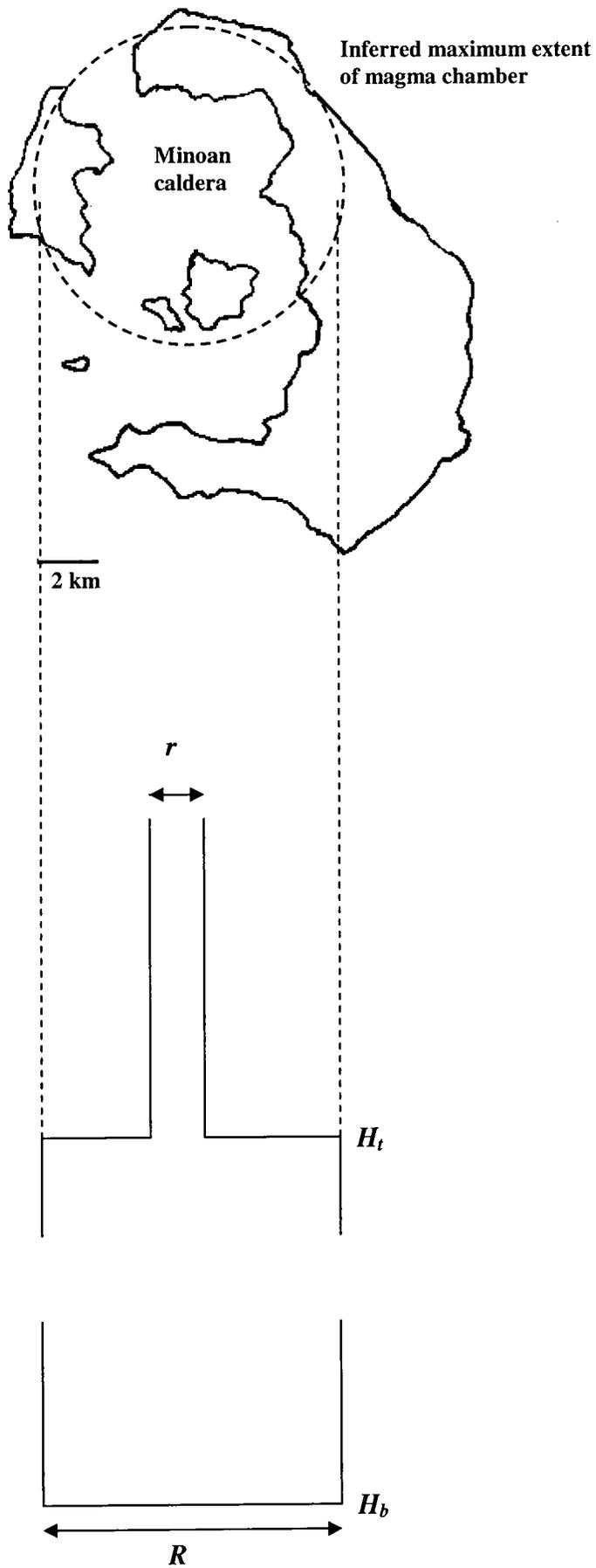
4.5 Schematic representation of the Minoan magma chamber (vertical extent not to scale).

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below the surface. Although this figure has not been geologically identified, it is likely to be significantly less that the range of peak velocity at the surface calculated by Sigurdsson et. al.,[77] 380 – 520 m / s. This set of values is derived from the quenching into glass of aliquots of magma trapped by phenocrysts during their growth in the magma reservoir.[78] The range thus reflects the uncertainties inherent in measuring this process. v is the velocity at which the ejecta rises; H_t and H_z are, respectively, the depth of the top and bottom of the magma chamber.

The Thera variables employed here are: two separate values for v, to reflect the minimum and maximum peak velocities estimated on petrologic ground by Sigurdsson et al.[79] These are respectively 380 and 520 m/s, $R = 3990$ m (see above), $z = 0.75$m, $T = 850°$, $n_s = 4.11 \times 10^{-6} \times p^{1/2}$; $n_0 = 0.05$ wt % (exolved and present volatiles respectively), $\rho_1 = 2800$ kg/m^3 (overpressure), $g = 9.81$ m / sec^2 (acceleration of ejecta). Four different values are inferred

If the overpressure, $\Delta p = C$, a constant,

$$p(z) = \rho_1 gz + C \qquad (1)$$

For $n = n(z)$, Bower and Woods give

$$n = n_0 - n_s = n_0 - sp^{1/2} \qquad (2)$$

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[77]   1990: 108 - 109.
[78]   Haraldur Sigurdsson personal communication, 21/03/2002.
[79]   1990: 109.

and, combining those formulae with Bower and Woods's (3), i.e.

$$\frac{d}{dt}\left\{\int_{z=H_t}^{H_b}\left[\frac{A\rho_m p(z)}{\rho_m RT(n_0 - sp(z)^{1/2} + (1 - n_0 - sp(z)^{1/2})p(z)}\right]dz\right\} = -Q \qquad (3)$$

Put

$$p == (z) = q(z)^2 = q^2$$

so that (1) reads

$$q^2 = \rho_1 gz + C$$

and

$$2qdq = \rho_1 gdz. \qquad (6)$$

When

$$z = H_t, q = \sqrt{\rho_1 gH_t + C} = qt, \qquad (7)$$

and when

$$z = H_b, q = \sqrt{\rho_1 gH_b + C} = q_b. \qquad (8)$$

Where H_b is fixed, and H_t is a variable; thus $H_t = z$.

Thus (5) can be written as:

$$-Q = \frac{d}{dt}\left\{ \int_{q_t}^{q_b} \frac{A\dfrac{2\rho_m}{\rho_1 g}q^3 dq}{\rho_m RT(n_0 - sq) + (1 - n_0 + sq)q^2} \right\}$$

$$= \frac{d}{dt}\frac{2\rho_m A}{s\rho_1 g}\int_{q_t}^{q_b} \frac{q^3 dq}{sq^3 + (1 - n_0)q^2 - \rho_m RTsq + n_0\rho_m RT}$$

$$= \frac{d}{dt}\frac{2\rho_m A}{dts\rho_1 g}\int_{q_t}^{q_b} \frac{q^3 dq}{q^3 + aq^2 + bq + c}, \tag{9}$$

where, as above, q_t and q_b denote the values as given by (7) and (8) at the top and the

base of the chamber, measured from the surface, and where the numbers a, b, and c

are given by

$$a = \frac{1 - n_0}{s}, b = -\rho_m RM, c = \frac{n_0\rho_m RT}{s}; \tag{10}$$

so that their values are given by the values of n_0, s, ρ_m, R, T.[80]

Thus, if

$$A = 50.0145 \times 10^6 m^2; R = 3990m, T = 850°; C = \Delta P = 10356.389kg/m^2;$$
$$n_0 = 0.05wt\%; s = 4.11 \times 10^{-6}; \rho_1 = 2800; \rho_m = 2300; n_s = sp^{1/2}; g = 9.81m/s^2. \tag{11}$$

The pressure $p = p(z)$ at depth z meters below the surface and the related properties

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[80]   Bower and Woods 1998: 71 - 72.

of $q = q(z) = p^{1/2}$ are given by:

$$p(z) = \rho_1 gz + \Delta p = 27468z + 10356.389 kg/m^2 \qquad (12)$$

and

$$q(z) = (27468z + 10356.389)^{1/2}. \qquad (13)$$

If, for example, $z = 200$m (although other values for z are possible),

$$q(200) = 2346.0512. \qquad (14)$$

Standard methods of algebra and calculus are then used to evaluate the integral in (9), to provide a specific value for Q. Those methods give a value for Q in terms of qt, which by definition depends on t, where t denotes "top" and, in particular on z, the distance below the surface. It is necessary to differentiate $q(z)$ with respect to *time, t* and use $\frac{dz}{dt} = -v$, where v denotes the velocity upwards. More precisely:

$$\frac{dq}{dt} = \frac{1}{2}\frac{d}{dz}(27468z + 10356.4)^{1/2}\frac{dt}{dz} = \frac{v}{2}\frac{27468}{\sqrt{27468z + 10356.4}}.$$

Taking $z = 200$ obtains

$$\frac{dq}{dt} = \frac{v}{2}\frac{27468}{2346.0512}. \qquad (15)$$

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From (10), for the coefficients a, b, c in the cubic denominator of (9), it is possible to

obtain[81]

$$a = 23.11435 \times 10^4; b = -78.0095 \times 10^8; c = 94.896 \times 10^{12} \qquad (16)$$

Standard algebraic methods and integral calculus ("integration by partial fractions"),

one obtains for the expression in (9):

$$-Q = \frac{2\rho_m A}{s\rho_1 g}\frac{dq}{dt}\left\{1 + \frac{\lambda}{(q_t - \eta_1)} + \frac{\mu}{(q_t - \eta_2)} + \frac{\nu}{(q_t - \eta_3)}\right\}, \qquad (17)$$

where η_1, η_2, η_3 denote the roots of the cubic equation $q^3 + aq^2 + bq + c = 0$ and

where λ, μ, ν are given by

$$\lambda = \frac{\eta_1^3}{(\eta_1 - \eta_2)(\eta_1 - \eta_3)}, \mu = \frac{\eta_2^3}{(\eta_2 - \eta_1)(\eta_2 - \eta_3)}, \upsilon = \frac{\eta_3^3}{(\eta_3 - \eta_1)(\eta_3 - \eta_3)}. \qquad (18)$$

It must be recalled that q_t denotes the value q "at the top" and q_b the value at the base.

On the other hand, "t" in $\frac{d}{dt}$ denotes "time" (because one is measuring the rate of

change). In the following extrapolations, q_b is assumed to be constant, and q_t varies,

and, in general, is given in terms of z (i.e. the distance below the surface in meters) by

(12) (q does not depend on R).

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[81]   Using the values for the variables stipulated in (11); extrapolations using the same procedure
for different possibilities are presented below: see section 4.6.3 for full discussion.

Using the data in (10) and (11), the roots of the cubic are:

$$\eta_1 = -262267, \eta_2 = 15561.9 - 10938.7I, \eta_3 = 15561.7I$$

where I denotes the square root of minus 1, $\sqrt{-1}$. The values of λ, μ, v as given by (18) are then:

$$\lambda = -233348, \mu = 1102.22 - 255.627I, v = 1102.22 + 255.627I.$$

On substituting those values in the expression (17) for-Q and taking $v = 100$,

$$Q = 4.55342 \times 10^{13}$$

If z is taken to denote the depth of the top of a cylindrical magma chamber, i.e. $z = 8000$ meters, then

$$Q = 1.84666 \times 10^{13}$$

For application to the Thera problem, $z = 0, v = 380,520; r = 160,165,285,480$. For example, take $r = 160; A = 50435.2; v = 380; z = 0$ whence

$$a = 231143.5; b = -31280 \times 10^4; c = 38.053527 \times 10^{11}$$

and we obtain

$$\eta_1 = -232559, \eta_2 = 707.698 - 3982.73I, \eta_3 = 707.698 + 3982.73I,$$

from which

$$\lambda = -231083, \mu = -30.4643 - 18.4539I, \nu = -30.4643 + 18.4539I$$

On substituting the earlier formulae,

$$Q = 1.85116 \times 10^8$$

In extenso, the calculations results for the remaining variables, as defined by the volcanology, are given in table 4.1.

4.6.3. Results and discussion

Fig 4.6 plots the "zone of probability" for all the values of conduit "*r*", as constrained by the petrologically ascertained variables for velocity "*v*". The most obvious point to note is the bell-shape of the graph. It seems that the evolution of the conduit is of critical importance to the intensity of an eruption such as the Minoan, with a peak

r (meters)	v=380 (m / s)	v=520 (m / s)
160	2.03772×10^8	2.53317×10^8
165	2.03772×10^8	2.78846×10^8
285	7.89265×10^8	1.08005×10^9
480	1.08005×10^8	3.29732×10^8

Table 4.1 Values for Q across the two plausible peak rates for v, and values of r between 160 and 480 meters.
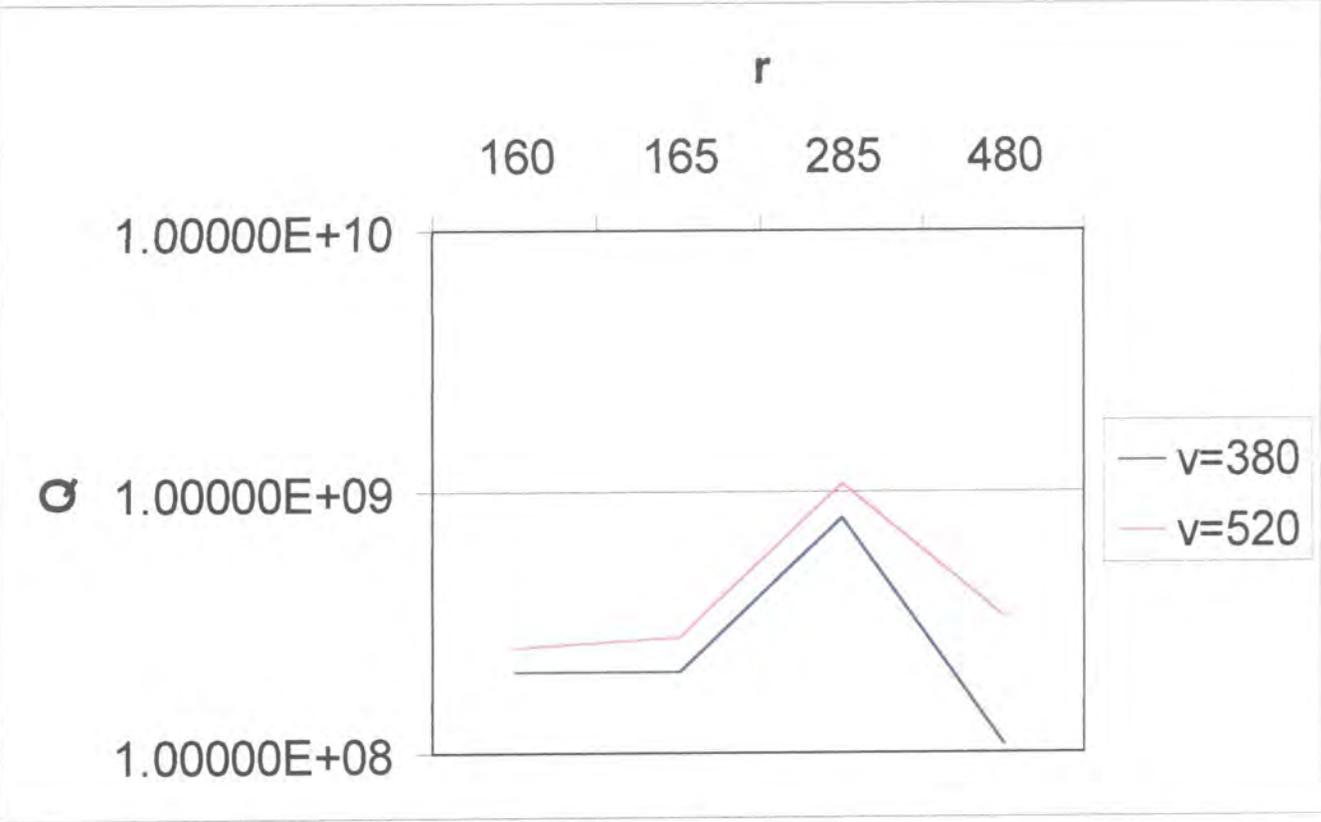
4.6 Values for Q over the respective maxima and minima of v and the most likely range of r for the Minoan eruption. The y axis is logarithmic.

forming around $r = 285$ meters. This allows one to posit a tentative theory as to the apparent evacuation of Akrotiri (bearing in mind that the exact, of even mildly approximate timescales remain unknown) prior to the town's burial. If the rate of the eruption during the plinian phase at $r = 160$ meters was comparatively low, and grew by an order of magnitude over the course of the eruption (assuming, at this latter point, that the velocity of the eject was at or near the upper maximum of "v", i.e. 520 m/s; not an unreasonable assumption from a volcanological point of view), then the "need" for a time lapse between the precursorary / plinian / Bo1 phase and the main burial event is not necessary. Fig 4.6 shows that the eruption built up to a climax at some point considerably later than its inception; thus the inhabitants would have been warned prior to the climax, although not necessarily by a precursorary ash fall or by a temporally removed pre-event. This would fit the commonly accepted volcanological view that such a time-gap is ruled out by the geological stratigraphy.[82]

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[82]   E.g. Sparks and Wilson 1990: 94 - 96.

CHAPTER 5
WIND SYSTEMS, THE THERA TEPHRA FAN AND SPATIAL ANALYSIS

5.1 Introduction

5.1.1 Old and new approaches

Wind system data have been employed before in Aegean archaeology, usually in the context of inferred shipping routes.[1] A recent study has examined weather imagery and its significance in the Bible.[2] The primary aim of this chapter is to analyse the ash fan of Thera in the light of wind and other climatological data. This follows the work of McCoy[3], although his thesis was a broader interpretation of Theran ash in deep sea sediments. By comparing a digital model of the entire fan, compiled from a database of all known tephra deposits for which a good *in situ* thicknesses exist, a good inference can be made as to what climatic circumstances were prevailing at the time of the eruption. A problem with addressing the issue in this way is that our knowledge of the tephra fan is necessarily incomplete, making the model necessarily inaccurate. This problem, I believe, can be overcome using Geographical Information Systems (GIS). If a GIS-based model is used for determining the relative thicknesses of the tephra beds, and their inter-relationships, then new data can be easily added (see below, section 5.5). Thus, if a new deposit emerges as a result of future excavation, it can be added to the model, which is then recalibrated accordingly.

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[1]   e.g. Lambrou-Phillipson 1991: 12 - 13.

[2]   McGinnigle 2001. This book is aimed at the general reader. A more specialised up-to-date study of this fascinating subject would be warmly welcomed.

[3]   1980: 68, fig 8.

A possible objection to this approach is that climatic changes since the Bronze Age might render comparisons with modern observations suspect. There is, however, a good corpus of work which shows that the weather was broadly the same in the Bronze Age as it is now.[4] Furthermore, a consensus has developed among Classical historians that weather in the second half of the first millennium BC, where far more information is available, was similarly constant.[5] It is beyond the scope of this thesis to digress in detail on the subject of Holocene weather, but a viable working assumption is that the weather in the Aegean Sea area is broadly the same now as it was in the Bronze Age. In any case, my methodology is such that, should future and more specialised research prove this wrong, appropriate corrections can be made, using the GIS techniques outlined here.

There will also be a point by point discussion of the tephra deposits (providing, where necessary justification for any particular point's inclusion in the database). The model itself is constructed and analysed using the GIS program ArcView 3.2a. It will be shown that GIS is an exceptionally powerful interdisciplinary tool for archaeological investigation, and possibilities for future research using this method will be sketched out. Specifically, my discussion of the input data takes the form of a consolidated gazetteer / catalogue of all relevant tephra deposits. The aim of this process is to provide an integrated basis for future research, and to assimilate all current knowledge of the ash fan into a single corpus. This is absolutely essential to achieve the goals set out above.

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[4]   *ibid.*; McGinnigle 2001: 63 - 7
[5]   Sallares 1991: 390 – 2. I thank Peter Rhodes for this reference.

5.2 Gazetteer / catalogue of Theran material

5.2.1. Format and terminology

All information is derived from published material and / or personal communications with excavators or surveyors. Grid references are given in unprojected ArcView decimal degrees. In most of the original reports, the coordinates are given in standard Geographic degrees (i.e. degrees / minutes / seconds), but the software employed here recognises only the decimal variety. Although the degree units remain unchanged, the conversion for the minute units is carried out by the simple formula x / 60 x 100. Where no Geographic coordinates are given, the locations have been determined using a digital map in ArcView 3.2, and these must be regarded as approximate.[6] In cases where more than one deposit comes from an individual site, each deposit usually has its own entry, unless individual assemblages are involved. Such cases are treated under a single entry, with the contexts and significance of each sample made clear in the "Archaeological context" field (if, however, a particular individual sample has an especial stratigraphical or other chronological significance, it is treated as a single entry). Where the excavator or surveyor has assigned their own catalogue number or letter to the deposit, this is also given. A "sample" here refers to an individual piece of pumice or ash, with no associated layers, which have been removed for analysis and are, or is, in the best opinion of the investigator, associated with the Minoan event. Obviously, in these cases, no dimensions can be given for the size of the deposit. The terms "ash" and "pumice" layers are self-explanatory.

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[6] I must record grateful thanks to Tom Elliot of the Interactive Ancient Mediterranean project at the University of North Carolina (http://iam.classics.unc.edu), for providing the digital maps upon which this work is based, and to Phil Howard and Karl Pedersen for technical advice on the use of ArcView.

There are specific interpretational problems in the cases of deposits identified in sea-cores. The recovery of layers using this method is not an exact science, in the sense that it is perfectly possible for any one core which contains identifiable Minoan tephra to have proximate neighbours which are completely ash-free. The issue is complicated by the particular bathymetry of the sea bed in any given location, and submarine deposits are very susceptible to slumping, secondary deposition, and bioturbation. However, where the data set is relatively large, as it is in this study, the isopachs ought to average out to a model at least reflecting reality.

5.2.2. Catalogue / Gazetteer of Theran material

I: THE CYCLADES

(1)

Place name: Santorini island

Deposit type: Proximal emplacement material.

Grid reference:

Area: Mantles the whole of the island's Minoan topography.

Thickness: up to 8m.

Deposition method: Ash fall, pyroclastic flow, lahar.

Archaeological context: Mature LM IA.

Comments: -

Literature: Most recently Druitt et al. 1999: 43 - 8. Also Heiken and

                         McCoy 1984: 8450 – 8460; Pichler and Friedrich 1980 16 - 25;

                         Sparks and Wilson 1990: 89 - 94; above Ch. 4.

(2)

Place name: Santorini archipelago (channel between Oia and Therasia)[7]

Deposit type: sea-floor sediment (▼ 200m)[8]

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[7]   The following thirteen records were provided by Floyd McCoy for this analysis. As indicated,
         all are derived from seismic exploration of the sea-bed in the proximity of Thera. See text
         (section 5.3.5) for discussion of the particular problems associated with this kind of data.
[8]   ▼ = water depth

THERA

ANAPHI

▲ Tephra measurement (see Gazetteer) Attributes of Points.shp

10   0   10   20 Miles

Map 5.1

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Grid reference: 25.25N; 36.37E

Area: -

Thickness: 20m

Deposition method: composite[9]

Archaeological context: -

Comments:[10]   -

Literature: Heiken and McCoy 1984: 8454.

(3)

Place name: Santorini archipelago (S.E. of Therasia)

Deposit type: sea-floor deposit (▼ 200m)

Grid reference: 25.42E; 36.37N

Area: -

Thickness: 20m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

                      Cruise # 61, ref. no. 67 – 34.

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[9]   See section 5.3.5

[10]   *ibid*

(4)

Place name: Santorini archipelago (northern caldera basin)

Deposit type: sea-floor sediment (▼ 400m)

Grid reference: not given

Area: -

Thickness: 40m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

Cruise # 61, ref. no. 67 – 34.

(5)

Place name: Santorini archipelago (E. of Therasia)

Deposit type: sea-floor sediment (▼ 150m)

Grid reference: 25.27E; 36.43N

Area: -

Thickness: 20m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

Cruise # 61, ref. no. 67 – 34.

(6)

<u>Place name:</u>	Santorini archipelago (Point between Thera and Koloumbo Bank)
<u>Deposit type:</u>	sea-floor sediment (▼350m)
<u>Grid reference:</u>	25.44E; 36.49N
<u>Area:</u>	-
<u>Thickness:</u>	30m
<u>Deposition method:</u>	composite
<u>Archaeological context:</u>	-
<u>Comments:</u>	-
<u>Literature:</u>	Woods Hole Oceanographic Institute Research Vessel Chain Cruise # 61, ref. no. 67 – 34.

(7)

<u>Place name:</u>	Santorini archipelago (E. of Monolithos)
<u>Deposit type:</u>	sea-floor sediment (▼ 250m)
<u>Grid reference:</u>	25.50E; 36.45N
<u>Area:</u>	-
<u>Thickness:</u>	30m
<u>Deposition method:</u>	composite
<u>Archaeological context:</u>	-
<u>Comments:</u>	-
<u>Literature:</u>	Woods Hole Oceanographic Institute Research Vessel Chain Cruise # 61, ref. no. 67 – 34.

(8)

Place name: Santorini archipelago (E. of Mesa Vouno)

Deposit type: sea-floor sediment

Grid reference: 25.52E; 26.38N

Area: -

Thickness: 30m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

         Cruise # 61, ref. no. 67 – 34.

(9)

Place name: Santorini archipelago (S.E. of Exomiti)

Deposit type: sea-floor sediment ($\blacktriangledown$ 200 - 300m)

Grid reference: 25.46E; 36.33N

Area: -

Thickness: 15m

Deposition method: composite

Archaeological context: -

Comments: This deposit comes from a basinal depression in the sea-floor,

         and may be eroded. Its thinner section may be explicable by the

         fact that it is in the lee of the high ground at Mesa Vouno,

         Profitis Ilias and the Gavrilos Ridge.

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

Cruise # 61, ref. no. 67 – 34. Hoskins and Edgerton 1971.

(10)

Place name:	Santorini archipelago (S. of Akrotiri peninsula)
Deposit type:	sea-floor (▼ 200m)
Grid reference:	25.36E; 36.34N
Area:	-
Thickness:	30m
Deposition method:	composite
Archaeological context:	-
Comments:	-

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

Cruise # 61, ref. no. 67 – 34.

(11)

Place name:	Santorini archipelago (S. of Exomiti)
Deposit type:	sea-floor sediment
Grid reference:	25.36E; 36.34N
Area:	-
Thickness:	30m
Deposition method:	composite
Archaeological context:	-

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

                     Cruise # 61, ref. no. 67 – 34.

(12)

Place name: Santorini archipelago (S.E. of Akrotiri peninsular)

Deposit type: sea-floor deposit (▼ 400m)

Grid reference: 25.35E; 36.32N

Area: -

Thickness: >10m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

                     Cruise # 61, ref. no. 67 – 34.

(13)

Place name: Santorini archipelago (Northern caldera basin)

Deposit type: sea-floor sediment (▼ 390m)

Grid reference: 25.36 E; 36.43 N (exact point not given, map reference taken as

                     centre of basin)

Area: -

Thickness: 68m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Perissoratis et al.1990: 303.

(14)

Place name: Santorini archipelago (southern caldera basin)

Deposit type: sea-floor sediment (▼ 290m)

Grid reference: 25.37 E; 36.39 N (exact point not given, map reference taken as

                   centre of basin).

Area: -

Thickness: 24m

Deposition method: composite

Archaeological context: -

Comments: -

Literature: Woods Hole Oceanographic Institute Research Vessel Chain

                   Cruise # 61, ref. no. 67 – 34.

(15)

Place name: Anaphi

Deposit type: outcrop

Grid reference: 25.75 E; 36.37 N

Area: -

Thickness: 2 m

Deposition method: airborne

Archaeological context: -

Comments: Road cut exposure.

Literature: Unpublished. Floyd W. McCoy personal communication,

                    23/1/2002.

(16)

Place name: Anaphi

Deposit type: outcrop

Grid reference: 25.75 E; 36.37 N

Area: unknown

Thickness: 2 m

Deposition method: airborne

Archaeological context: -

Comments: Road cut exposure.

Literature: Unpublished. Floyd W. McCoy personal communication,

                    23/1/2002.

(17)

Place name: Anaphi

Deposit type: outcrop

Grid reference: 25.81 E; 36.33 N

Area: unknown

Thickness: 2 m

Deposition method: airborne

Archaeological context: -

Comments: Road cut exposure.

Literature: Unpublished. Floyd W. McCoy personal communication, 23/1/2002.

(18)

Place name: Mochlos

Grid reference: 25.89 E; 35.20 N

Deposit type: ash layer

Area: 7.5 m^2

Thickness: 0.05 – 0.1 m

Deposition method: airborne

Archaeological context: Directly between LM IA pit deposit and LM IB (Marine

Style) floor.

Comments: Soles et al 1995's Deposit A from this site. Was originally

much larger in area, the deposit having been disturbed by

excavation in 1908. Lies directly beneath House C.1, the floor

level of which contains Marine Style.

Literature: Soles et al. 1995: 386; Driessen and Macdonald 1997: 242.

(19)

Place Name: Mochlos

Grid reference: 25.89 E; 35.20 N

Deposit type: ash layer

Area: 1 – 2 m^2

Thickness: 0.01 –0.02 cm.

CRETE

32 31
33
23
20 18
19
24 25 21
29
26
27 28

▲ Tephra measurement (see Gazetteer)

N

60 0 60 120 Miles

179
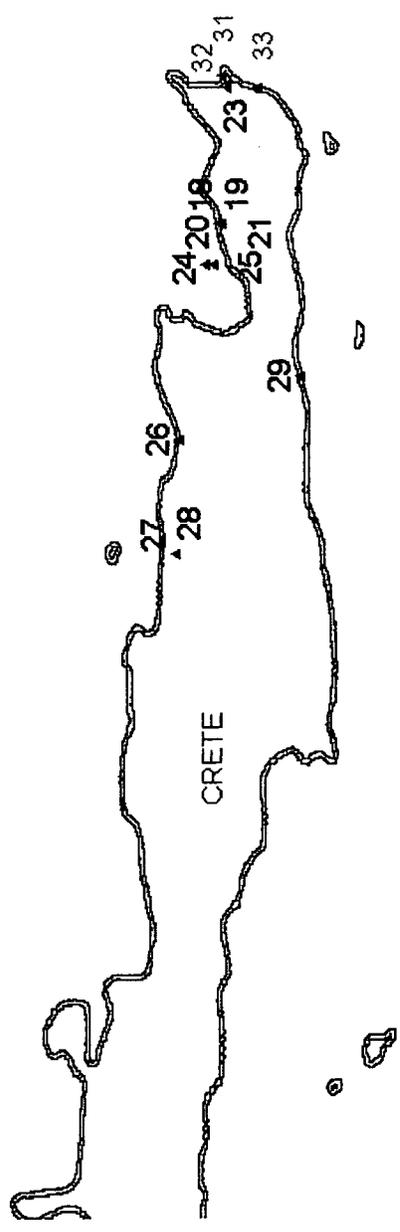
Map 5.2

Deposition method: airborne

Archaeological context: *supra* (1)

Comments: Soles, Taylor and Vitaliano's Deposit B. Later occupation disturbs the layers below; sherdage includes Byzantine material. The layer immediately above the tephra level is associated with House C.1, and is thought to be contemporary with it.

Literature: Soles et al. 1995: 386; Driessen and Macdonald 1997: 242.

(20)

Place name: Mochlos

Grid reference: 25.89 N; 35.2 E

Deposit type: ash layer

Area: 0.3m long

Thickness: 0.05 m

Deposition method: airborne

Archaeological context: "Good" LM IB assemblage from directly above (i.e. from House B.1).

Comments: Soles et al's Deposit C. A small deposit, about 35m to the west of (18).

Literature: Soles et al 1995: 389; Driessen and Macdonald 1997: 244.

(21)

Place name: Mochlos

Grid reference: 25.89 N; 35.2 E

Deposit type: ash layer

Area: unknown

Thickness: 0.1 m

Deposition method: airborne

Archaeological context: Sterile bedrock below, roughly paved landing area and stairs leading to Building B.A directly above. An industrial establishment constructed in LM IB.

Comments: Soles et al's Deposit D. Clear evidence of compaction, the material being hard and packed down. This could be due either to traffic on the modern road or deliberate mixing with water in antiquity to form a base for the landing and stairs.

Literature: Soles et al. 1995: 387 – 8.

(22)

Place name: Mochlos

Grid reference: 25.89 E; 35.2 N

Deposit type: ash layer

Area: c. 6.5m x 0.4 - 0.8m

Thickness: 0.03 – 0.05m

Deposition method: airborne

Archaeological context: Rear of building A

Comments: Soles et al's Deposit E. No occupation underlying this deposit.

Literature: Soles et al 1995: 387.

(23)

Place name: Kato Zakro

Grid reference: 26.24 E; 35.11 N

Deposit type: ash samples

Thickness: -

Area: -

Deposition method: airborne

Archaeological context: Five samples from the LM IA level. At least one was sealed below LM IB.

Comments: "Microscopic particles" of tephra, identified as Theran through RI (refractive index) analysis.

Literature: Vitaliano and Vitaliano 1974: 22 - 24; 1978: 217 - 219.

(24)

Place name: Pseira

Grid reference: 25.85 E; 35.21 N

Deposit type: tephra sample

Area: -

Thickness: -

Deposition method: airborne

Archaeological context: LM IA rubble from beneath the floor of the Shrine (room AC 1). Sherds PS 1619, PS 66, PS 55 and PS 104 cited as evidence for the LM IA date.

Comments: The dating is absolutely secure. This sample comes from a lower level of the context containing (25).

Literature: Betancourt et al 1990: 97, and figs 1 and 2.

(25)

Place name: Pseira

Grid reference: 25.85 E; 35.21 N

Deposit type: pumice samples

Area: -

Thickness: -

Deposition method: human agency

Archaeological context: The best samples for dating come from Building AC, rooms AC1 and AC10. A trench dug below the floor along the SE wall of AC1 (with the rest of the floor on bedrock) contained three pieces of pumice and LM IA sherds. The floor belongs to the room's final phase, indicating a secure LM IA date for the pumice. One piece from room AC10 was in the LM IB destruction level. The pumice samples were in the lower level of the AC1 trench.

Comments: The pumice (more than fifty examples) was confirmed as Minoan by refractive index. A very interesting addition was the discovery of a piece with a hole drilled through – possible a fishing float - in the LM IB level of the Plateia House.

Literature: Betancourt et al. 1990: 96 – 99.

(26)

Place name:	Hagia Varvara
Grid reference:	25.46 E; 35.29 N
Deposit type:	pumice layer
Area:	unknown
Thickness:	5 – 10 cm
Deposition method:	waterborne or human agency

Archaeological context: LM IA or possibly IB cup included in pumice layer and filled with pumice, immediately below a surface layer containing LM III pottery.

Comments: Very badly eroded by modern tourist pathways. Illegal development in the area has further damaged the stratigraphy. As far as the author is aware, however, this is the only instance where a vessel is included *in situ* with the volcanic material.

Literature: Blackman 2001: 138; Müller Celka 1996: 928 – 8; also Müller Celka personal communication, 6/8/2001.

(27)

Place name:	Knossos, Stratigraphical Museum
Grid reference:	25.17 E; 35.33 N
Deposit type:	pumice sample
Area:	-

Thickness: -

Deposition method: human agency

Archaeological context: Pumice sample from 0.33m below LM IB paved floor,
associated with MM IIIB / LM IA transition and LM IB
pottery.

Comments: Warren and Puchelt's Sample A. This is treated separately
here because its interpretation is not entirely clear. Certain
direct chemical comparisons pointed to a correlation with the
Bu pumice event, but correlation with other control data led
the authors to conclude that the sample was Bo (Minoan). It is
regrettable that further chemical certainty could not be
obtained, as linking this particular area of stratigraphy (MM
IIIB / LM IA – LM IB) with the Minoan event would provide
an important cross-link.

Literature: Warren and Puchelt 1990: 80 and Peter Warren, personal
communication, 9/7/2001.

(28)

Place name: Knossos, Stratigraphical Museum

Grid reference: 25.17 E; 35.33 N

Deposit type: pumice samples

Area: -

Thickness: -

Deposition method: human agency

Archaeological context: Warren and Puchelt's Samples D – J. Samples D – I

range in context from LM II to Geometric, Sample J is LM IB,

with elements of MM IIIB / LM IA.

Comments: All seven samples are assigned to the Minoan event on

geochemical grounds.

Literature: Warren and Puchelt 1990: 80.

(29)

Place name: Myrtos-Pyrgos

Grid reference: 25.60 E; 35.00 N

Deposit type: glass / ash samples

Area: -

Thickness: -

Deposition method: airborne

Archaeological context: LM IB destruction level of Pyrgos IV (country house).

Comments: A total of 15 samples indicate this deposit, of which 8

contained volcanic glass, shown by refractive index (ri) to be

Theran. ENQ 2490, the fill of a large pot fallen on a bench,

contained particularly conspicuous volcanic material.

Literature: Cadogan et al. 1972: 112 - 115; Cadogan and Harrison 1978:

240 – 55.

(30)

Place name: Myrtos-Pyrgos

Grid reference: 25.60 E; 35.00 N

Deposit type: trace

Area: -

Thickness: -

Deposition method: airborne

Archaeological context: Soil sample containing volcanic glass (ENQ 2389), from the east side of the Pyrgos IV settlement. The context is LM I in date, and there is no evidence of destruction by fire.

Comments: -

Literature: Cadogan and Harrison 1978: 238.

(31)

Place name: Palaikastro (Building 6, Room B)

Grid reference: 26.29 E; 35.19 N

Deposit type: alluvial ash layer

Area: 0.65 x 0.60 m

Thickness: 0.1m

Deposition method: airfall, followed by inwash

Archaeological context: From the floor of the room, associated with a LM IA round cup with medallion spirals.

Comments: The building seems to have been abandoned and roofless prior to the volcanic event.

187

Literature: MacGillivray et al 1998: 241, 256 and fig. 2.

(32)

Place name:	Palaikastro
Deposit type:	Exposure on promontory.
Grid reference:	26.28 E; 35.19 N
Area:	-
Thickness:	12 cm
Deposition method:	airborne
Archaeological context:	Intact fragment contained within wall collapse debris.
Comments:	Original location derived from surveying post on the tip of the promontory.
Literature:	J. Driessen, in MacGillivray et al 1998: 263.

(33)

Place name:	Palaikastro
Deposit type:	exposure
Grid reference:	26.28 E; 35.19 N (as (31)).
Area:	unknown
Thickness:	3 cm
Deposition method:	airborne
Archaeological context:	Exposure in Building 6.

Comments:	The deposit has been subject to erosion.
Literature:	J. Driessen, in MacGillivray et al 1998: 263.

III: CYPRUS

(34)

Place name: Maroni

Grid reference: 33.62 E; 35.03 N

Deposit type: abrasion (?) particles

Area: -

Thickness: -

Deposition method: see deposit type

Archaeological context: The particles, provided for analysis by S. W. Manning, were of Late Cypriot date, but could not be dated with confidence to either LC IA or IB.

Comments: Prof. Max Bichler is of the opinion that this deposit is abrasive.

Literature: Manfred Bietak, personal communication, 1/10/2001.

CYPRUS

34 ▲

▲ Tephra measurement (see Gazetteer)

N

0   60   120 Miles

60
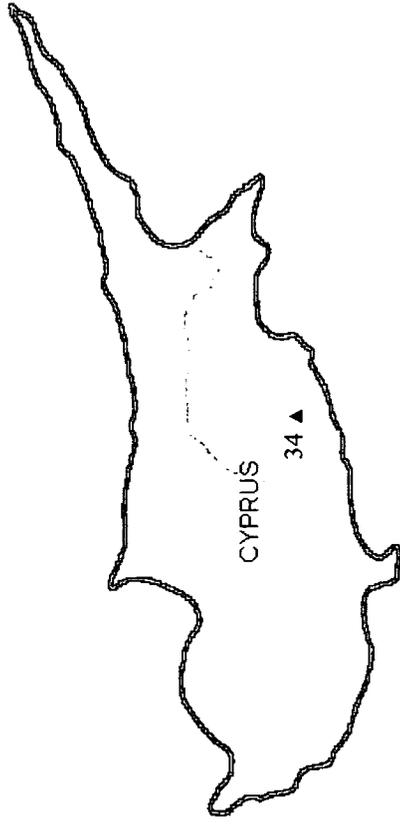
Map 5.3

IV: THE DODECANESE

(35)

Place name: Seraglio

Grid reference: 27.33 E; 36.86 N

Deposit type: ash layer

Area: unknown

Thickness: 0.1- 0.2m

Deposition method: airborne

Archaeological context: There is a clear division between early and late LM IA at this site involving earthquake destruction and rebuilding, reminiscent of Akrotiri. LM IA is characterised by large scale building and development. The tephra layer partially seals the later stratum.

Literature: Marketou 1990: 102 – 4.

(36)

Place name: Kos (500 m n. of Cape Fokas)

Grid reference: 27.25 E; 36.91 N

Deposit type: alluvial ash layer / outcrop

Area: unknown

Thickness: 0.3 – 0.6m

Deposition method: alluvial
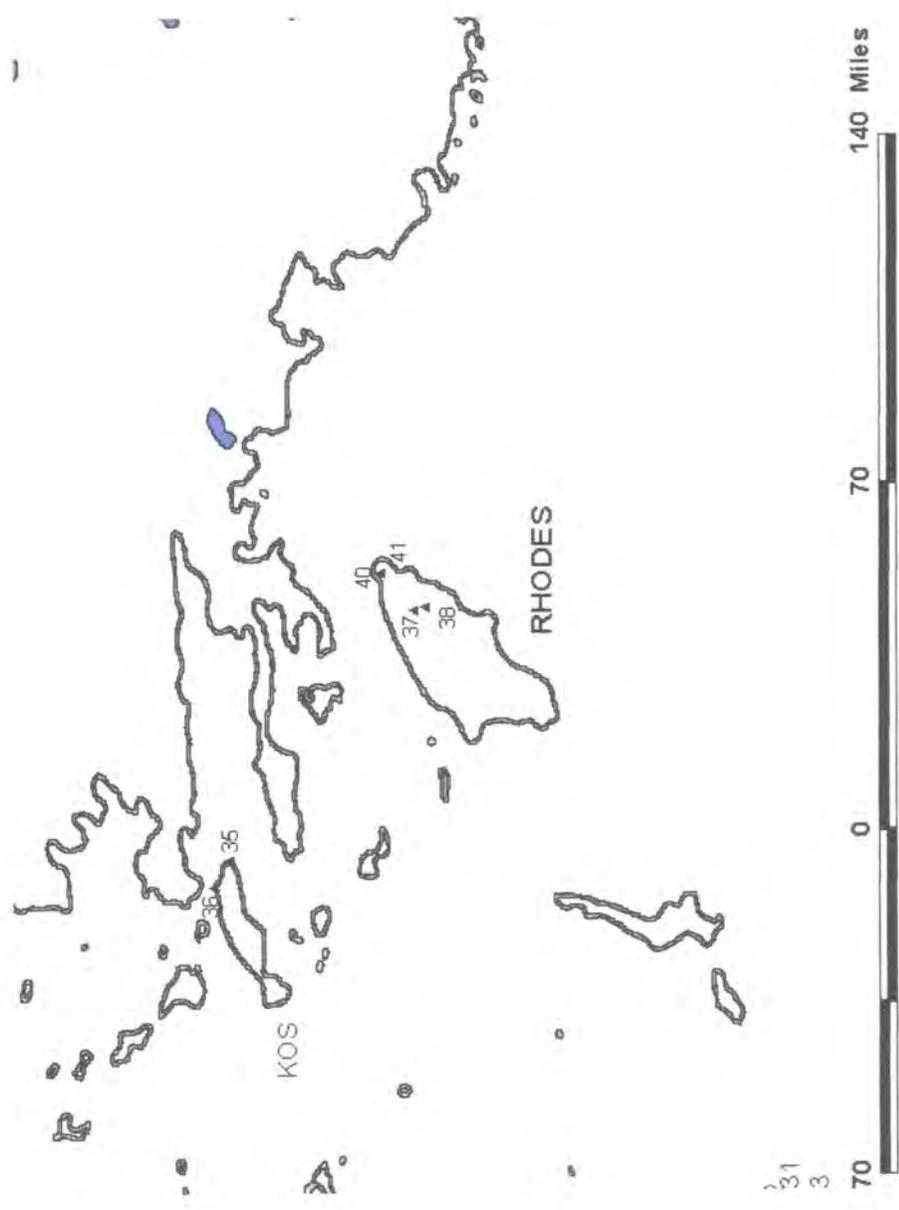
Map 5.4

Archaeological context: none

Comments: The very thick (0.6m) section of the layer may be due to secondary deposition.

Literature: Keller 1980: 50 – 1.

(37)

Place name: Vari (Paradeisi Airport), Rhodes

Grid reference: 27.98 E; 36.37 N

Deposit type: ash layer

Area: 730 – 1000 m long

Thickness: < 1m

Deposition method: airborne

Archaeological context: Identified in 17 vertical trenches at depths of c. 1 – 3m. Underneath was a layer of hard white clay (ασπρόπιλος), containing LM IA conical cups, including one example of ripple pattern. Above was virgin soil, apart from part of a N – S orientated building.

Comments: The slope here is very steep, giving rise to the possibility of secondary deposition.

Literature: Doumas 1988: 36 – 38; Marketou 1988: 32; Marketou 1990: 105.

(38)

Place name: Mt. Philerimos (Pr. Elias), Rhodes

Grid reference: 27.90 N; 36.27 E

Deposit type: ash layer

Area: unknown

Thickness: 0.1 – 0.2m

Deposition method: airborne

Archaeological context: Above a layer containing LM IA pottery.

Comments: Secondary deposition at the southern end of the

settlement meant that the layers of 3 – 4m were encountered.

Literature: Marketou 1988: 28 and n 8; Marketou 1990: 105.

(39)

Place name: Kolymbia, Rhodes

Grid reference: 28.13 E; 36.23 N

Deposit type: ash layer

Area: unknown

Thickness: 0.4 – 0.9m

Deposition method: airborne

Archaeological context: -

Comments: Located at a depth of – 1.7m

Literature: Marketou 1990: 105.

(40)

Place name:	Trianda (Bombylas)
Grid reference:	28.17 E; 36.44 N[11]
Deposit type:	ash layer
Area:	-
Thickness:	c. 0.7m
Deposition method:	airborne
Archaeological context:	LM IA level.
Comments:	This is the thickest level so far from Trianda.
Literature	Marketou 1990: 105.

(41)

Place name:	Trianda (*polythyron*)
Grid reference:	25.40 E; 36.44 N
Deposit type:	ash layer
Area:	-
Thickness:	0.2- 0.3m
Deposition method:	airborne

Archaeological context: From Plot 3, in the NW of the town. The *polythyron* was constructed in the re-building period (shortly before end-LM IA) after the first earthquake, and prior to the second, and forms a central part of the Minoanizing character of this phase. The *polythyron* was constructed on the debris of the first

---

[11]   This site lies on precisely the same latitudinal parallel (36.44) as the approximate location of the Santorini vent, as determined in this study (based on McCoy and Heiken 2000a: 52).

earthquake. Some tephra was undisturbed on the SE pier, and the outside of the S pier was covered with volcanic material.

Comments: -

Literature: Marketou 1988: 30; Marketou 1990: 107 – 9.

(42)

Place name: Gölhisar Gölü

Grid reference: 29.60 E; 37.01 N

Deposit type: sediment

Area: -

Thickness: 0.04m

Deposition method: airfall / alluvial inwash[12]

Archaeological context: -

Comments: Lacustrine silt core, correlated with Thera by LA ICP-MS. The sediment underlying the tephra at the core site is (probably serge) peat, so good stratification occurred. No visible layer appeared in a subsequent central lake core, where there is no peat layer. Airfall ash at this point would have settled on, and become assimilated in, unconsolidated mud. The proportions of airfall and inwash material are thus unclear, although future research is planned to clarify this.[13]

Literature: Eastwood et al. 1998: 678.

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[12]   Warren Eastwood, personal communication, 6 / 8/ 2001.
[13]   *ibid.*

ANATOLIA

N

▲ Testing measurements &co gazetteers

47
46
43
44
45
42

100   0   100   200 **Miles**

Map 5.5

199
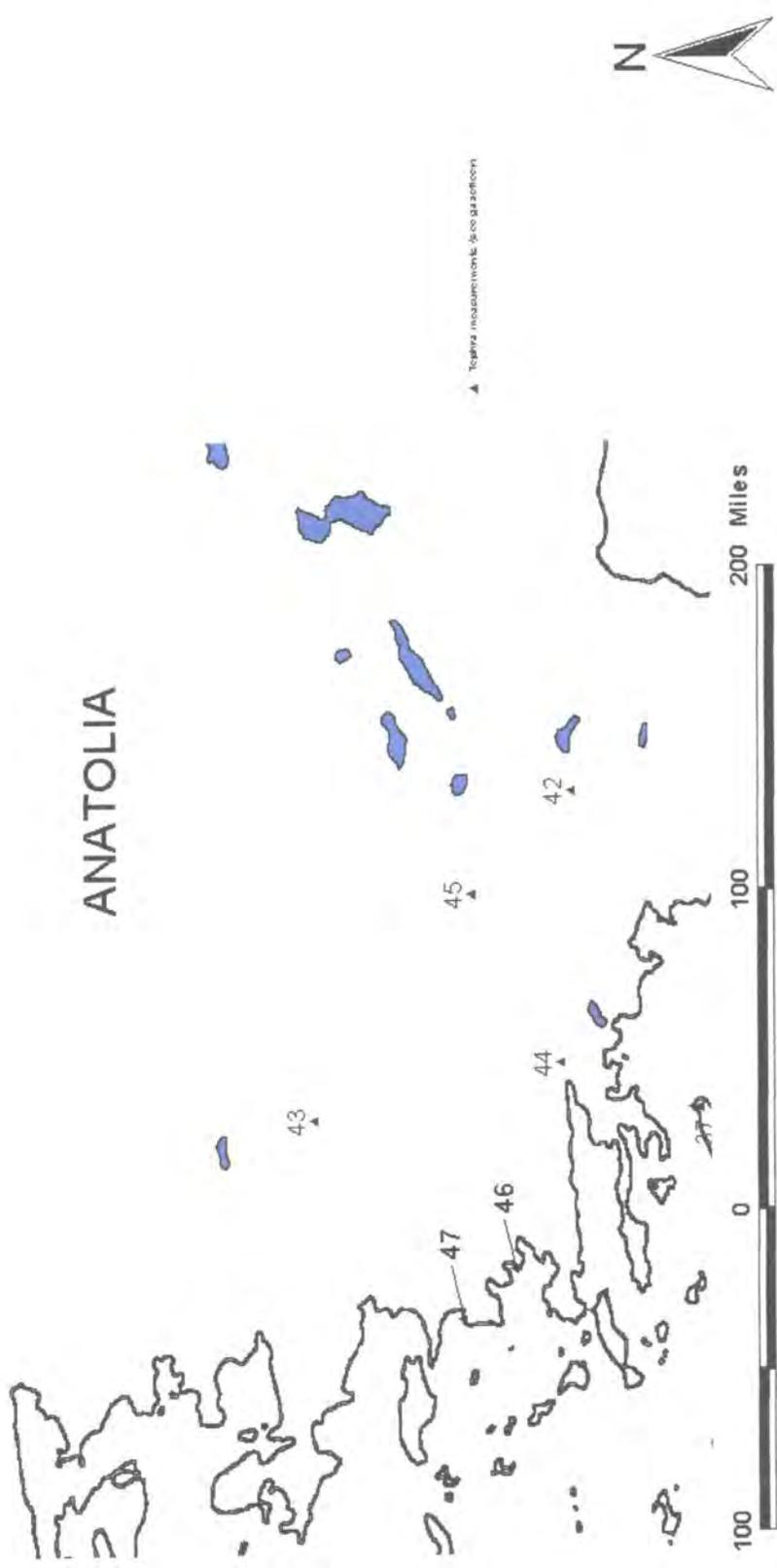
(43)

Place name: Gölcük

Grid reference: 28.12 E; 38.19 N

Deposit type: sediment

Area: -

Thickness: 12 cm.

Deposition method: airfall / inwash

Archaeological context: -

Comments: Montane lake sediment core. The depositional issues are similar

to those of (12).

Literature: Sullivan 1990: 115.

(44)

Place name: Köyceiz

Grid reference: 28.38 E; 37.06 N

Deposit type: sediment

Area: -

Thickness: 0.09m

Archaeological context: -

Comments: Core from a small coastal lake.

Literature: van Zeist et al 1975: 132; Sullivan 1990: 115 – 6.

(45)

<u>Place name:</u>	Sogut
<u>Grid reference:</u>	28.28 E; 37.64 N
<u>Deposit type:</u>	sediment
<u>Area:</u>	-
<u>Thickness:</u>	-
<u>Deposition method:</u>	airfall / inwash
<u>Archaeological context:</u>	-

<u>Comments:</u> Lacustrine sediment core. Geochemistry is currently unavailable, determination rests upon C14 dating. Further information is unavailable at the time of writing.

<u>Literature:</u> Warren Eastwood, personal communication, 6/8/2001.

(46)

<u>Place name:</u>	Iasos
<u>Grid reference:</u>	27.44 E; 37.27 N
<u>Deposit type:</u>	ash layer
<u>Area:</u>	unknown
<u>Thickness:</u>	~ 0.2m

<u>Archaeological context:</u> From "Edificio B" and "Saggio g", and sandwiched between LB 1 pottery, including Minoanizing wares.

<u>Comments:</u> This layer was missed in the 1969 excavation, and is (mid-2001) being re-examined.

<u>Literature:</u> Momigliano 2001: 12.

(47)

Place name:	Miletus
Deposit type:	ash layer
Grid reference:	27.25 N; 37.52 E
Area:	unknown
Thickness:	1 – 2 cm (but see comments)
Deposition method:	airborne
Archaeological context:	unsure

Comments: This layer was under investigation at the time of writing, although preliminary investigations show that around 5% of the material is glass. Bioturbation makes accurate assessment of the layer's thickness impossible at this stage.

Literature: Max Bichler, personal communication, 10/9/2001.

VI: THE GREEK MAINLAND

(48)

Place name:	Nichoria
Deposit type:	pumice samples
Grid reference:	22.66 E; 36.84 N
Area:	-
Thickness:	-
Deposition method:	sea borne / human agency
Archaeological context:	possibly LH I; LH IIA

Comments:	Four of the samples (#s 50, 52, 53 and 126), from L23Pfg, levels 11 and 12 (Level 3: LH IIA) were tested. A further sample, not tested, was from trench K24-1, lot 211 Level 3 (not Level 2, *pace* the Master Pottery List), and was undoubtedly LH I in date. If this latter sample were Theran, it would have significant ramifications for Aegean relative chronology, requiring the eruption to have occurred before the inception of LH IIA, thus putting pressure on any conjectured "post LM IA" phase.

Literature:	Oliver Dickinson personal communication; Nancy Wilkie personal communication. 9/5/2001, 1/7/2001 and 12/9/2001, Macdonald and Wilkie (eds.) 1992: 31, 41 and 445; see also Dunn (forthcoming).

(49)

<u>Place name:</u>	Limni Trikhonis (Akarnania)
<u>Deposit type:</u>	sediment
<u>Grid reference:</u>	21.25 E; 38.50 N
<u>Area:</u>	-
<u>Thickness:</u>	<1 cm
<u>Deposition method:</u>	airborne
<u>Archaeological context:</u>	-
<u>Comments:</u>	No chemical or petrological analysis to confirm Theran provenance; the provenance of the Minoan eruption is inferred from the deposit's sedimentary position.
<u>Literature:</u>	Bottema 1992: 130.

(50)

Place name:	West Tartus ridge
Deposit type:	sea-floor sediment (▼ 1500 m)
Grid reference:	34.97 E; 34.58 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	UNESCO 1992; report 56.

(51)

Place name:	West Tartus ridge
Deposit type:	sea-floor sediment (▼ 1500 m)
Grid reference:	34.77 E; 34.48 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	UNESCO 1992; report 56.

BLACK SEA

CYPRUS

▲ Tephra measurements (see gazetteer)
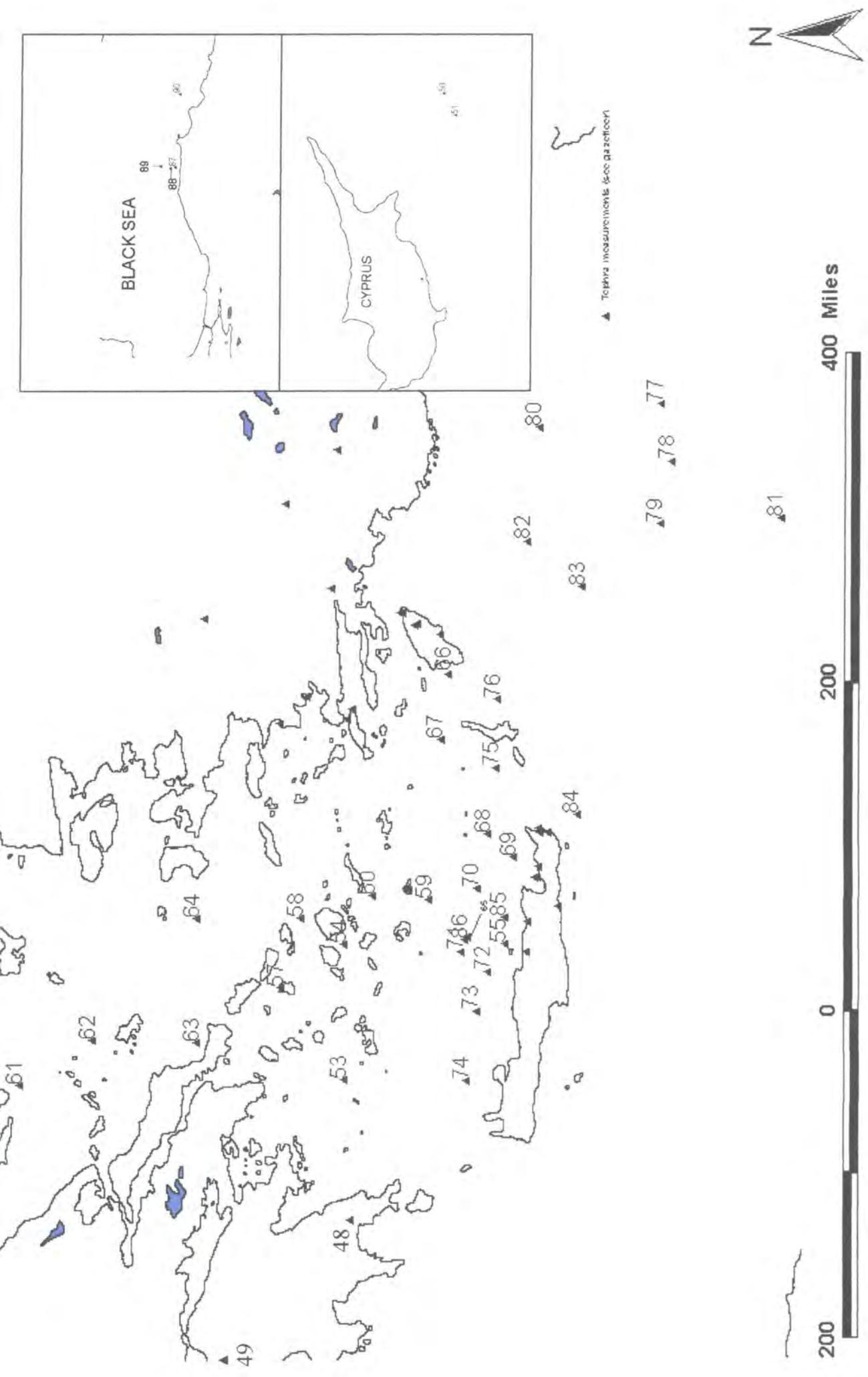
Map 5.6 (NB: insets not to scale)

N

200   0   200   400 Miles

(52)

Place name:	West Tartus ridge
Deposit type:	sea-floor sediment (▼ 1500 m)
Grid reference:	34.77 E; 34.48 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	UNESCO 1992; report 56.

(53)

Place name:	Myrtoon Basin
Deposit type:	sea-floor sediment (▼ 853 m)
Grid reference:	24.06 E; 36.93 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Geraga et al 2000: 5; fig 2.

(54)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼500m)
Grid reference:	25.27 E; 36.93 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Chronis et al 2000: 152.

(55)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼1000m)
Grid reference:	25.27 E; 35.50 N
Area:	-
Thickness:	1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Chronis et al 2000: 152.

(56)

Place name:	North Aegean trough
Deposit type:	sea-floor sediment (▼500 m)
Grid reference:	24.42 E; 40.17 N
Area:	-
Thickness:	10 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(57)

Place name:	South Skyros basin
Deposit type:	sea-floor sediment (▼500m)
Grid reference:	24.88 E; 37.50 N
Area:	-
Thickness:	20 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(58)

<u>Place name:</u>	South Ikaria basin
<u>Deposit type:</u>	sea-floor sediment (▼ 600m)
<u>Grid reference:</u>	25.50 E; 37.32N
<u>Area:</u>	-
<u>Thickness:</u>	30 cm
<u>Deposition method:</u>	airborne
<u>Archaeological context:</u>	-
<u>Comments:</u>	sea-core
<u>Literature:</u>	Aksu et al 1995: 34.

(59)

<u>Place name:</u>	Karpathos basin
<u>Deposit type:</u>	sea-floor sediment (▼ 800m)
<u>Grid reference:</u>	25.65 E; 36.17N
<u>Area:</u>	-
<u>Thickness:</u>	20 cm
<u>Deposition method:</u>	airborne
<u>Archaeological context:</u>	-
<u>Comments:</u>	-
<u>Literature:</u>	Aksu et al 1995: 34.

(60)

Place name:	Turkey margin
Deposit type:	sea-floor sediment (▼100 m)
Grid reference:	25.65 E; 36.68 N
Area:	-
Thickness:	50 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(61)

Place name:	North Aegean trough
Deposit type:	sea-floor sediment (▼900 m)
Grid reference:	24.02 E; 39.83 N
Area:	-
Thickness:	20 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(62)

Place name:	North Skyros basin
Deposit type:	sea-floor sediment (▼600 m)
Grid reference:	24.42 E; 39.18 N
Area:	-
Thickness:	20 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(63)

Place name:	South Skyros basin
Deposit type:	sea-floor sediment (▼800 m)
Grid reference:	24.40 E; 38.25 N
Area:	-
Thickness:	20 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Aksu et al 1995: 34.

(64)

<u>Place name:</u>	South Skyros basin
<u>Deposit type:</u>	sea-floor sediment (▼700 m)
<u>Grid reference:</u>	25.50 E; 38.25 N
<u>Area:</u>	-
<u>Thickness:</u>	40 cm
<u>Deposition method:</u>	airborne
<u>Archaeological context:</u>	-
<u>Comments:</u>	sea-core
<u>Literature:</u>	Aksu et al 1995: 34.

(65)

<u>Place name:</u>	Cretan trough
<u>Deposit type:</u>	sea-floor sediment (▼1000 m)
<u>Grid reference:</u>	25.33 E; 35.82 N
<u>Area:</u>	-
<u>Thickness:</u>	20cm
<u>Deposition method:</u>	-
<u>Archaeological context:</u>	-
<u>Comments:</u>	sea-core
<u>Literature:</u>	Aksu et al 1995: 34.

(66)

Place name:	Rhodes margin
Deposit type:	sea-floor sediment (▼1170 m)
Grid reference:	27.85 E; 36.07 N
Area:	-
Thickness:	9 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.: 153.

(67)

Place name:	Karpathos basin
Deposit type:	sea-floor sediment (▼2340 m)
Grid reference:	27.07E; 36.07 N
Area:	-
Thickness:	10 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(68)

Place name:	Cretan trough
Deposit type:	sea-floor sediment (▼2287 m)
Grid reference:	26.23 E; 35.65 N
Area:	-
Thickness:	19 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(69)

Place name:	Cretan trough
Deposit type:	sea-floor sediment (▼ 722 m)
Grid reference:	26.03 E; 35.42 N
Area:	-
Thickness:	10 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(70)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼1251 m)
Grid reference:	25.75 E; 35.75 N
Area:	-
Thickness:	10 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(71)

Place name:	Cretan trough
Deposit type:	sea-floor sediment (▼1861 m)
Grid reference:	25.20 E; 35.88 N
Area:	-
Thickness:	17 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(72)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼900 m)
Grid reference:	25.02 E;35.65 N
Area:	-
Thickness:	4 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(73)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼1034 m)
Grid reference:	24.67 E; 35.75 E
Area:	-
Thickness:	6 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(74)

Place name:	Crete margin
Deposit type:	sea-floor sediment (▼1047 m)
Grid reference:	24.05 E; 35.83 N
Area:	-
Thickness:	3 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(75)

Place name:	Karpathos basin
Deposit type:	sea-floor sediment (▼ 2444 m)
Grid reference:	26.82 E; 35.58 N
Area:	-
Thickness:	3 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Vinci 1985: 153.

(76)

Place name: Hellenic trough

Deposit type: sea-floor sediment (▼2225 m)

Grid reference: 27.42 E; 35.57 N

Area: -

Thickness: 15 cm

Deposition method: airborne

Archaeological context: -

Comments: sea-core

Literature: Vinci 1985: 153.

(77)

Place name: East Mediterranean

Deposit type: sea-floor sediment

Grid reference: 30.00 E; 34.10 N

Area: -

Thickness: 1.7 cm

Deposition method: airborne

Archaeological context: -

Comments: sea-core

Literature: Watkins et al. 1978: 123.[14]

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[14]   Although Watkins et al. (1978) present the locations of 18 cores with megascopically visible
        Minoan tephra, only 10 are given with corrected thicknesses. For this reason, these 10 only
        are included in this study.

(78)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	29.50 E; 34.00 N
Area:	-
Thickness:	2 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(79)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	28.95 E; 34.10 N
Area:	-
Thickness:	
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(80)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	29.80 E; 35.20 N
Area:	-
Thickness:	5.5 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(81)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	29.00 E; 33.00 N
Area:	-
Thickness:	
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(82)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	28.80 E; 35.30 N
Area:	-
Thickness:	3.1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(83)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	28.40E; 34.81 N
Area:	-
Thickness:	4.8 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(84)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	26.40 E; 34.85 N
Area:	-
Thickness:	1.2 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(85)

Place name:	East Mediterranean
Deposit type:	sea-floor sediment
Grid reference:	25.50 E; 35.50 N
Area:	-
Thickness:	1.2 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Watkins et al. 1978: 123.

(86)

Place name: East Mediterranean

Deposit type: sea-floor sediment

Grid reference: 25.30 E; 35.85 N

Area: -

Thickness: 1.3 cm

Deposition method: airborne

Archaeological context: -

Comments: sea-core

Literature: Watkins et al. 1978: 123.

(87)

Place name: Black Sea

Deposit type: sea-floor sediment

Grid reference: 34.16 E; 42.13 N

Area: -

Thickness: <1 cm

Deposition method: airborne

Archaeological context: -

Comments: sea-core

Literature: Guichard et al. (1993): 611.

(88)

Place name:	Black Sea
Deposit type:	sea-floor sediment
Grid reference:	34.12 E; 42.29 N
Area:	-
Thickness:	<1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Guichard et al. (1993): 611.

(89)

Place name:	Black Sea
Deposit type:	sea-floor sediment
Grid reference:	34.18 E; 42.57 N
Area:	-
Thickness:	<1 cm
Deposition method:	airborne
Archaeological context:	-
Comments:	sea-core
Literature:	Guichard et al. (1993): 611.

(90)

<u>Place name:</u>	Black Sea
<u>Deposit type:</u>	sea-floor sediment
<u>Grid reference:</u>	36.52 E; 42.00 N
<u>Area:</u>	-
<u>Thickness:</u>	<1 cm
<u>Deposition method:</u>	airborne
<u>Archaeological context:</u>	-
<u>Comments:</u>	sea-core
<u>Literature:</u>	Guichard et al. (1993): 611.

VIII: EGYPT

(91)

Place name: Nile Delta

Deposit type: ash in mud sediment

Grid reference: 31.10 E; 30.83 N

Area: -

Thickness: <1 cm

Deposition method: airborne

Archaeological context: -

Comments: From a 1m long core of delta mud. Some initial disagreement as to the provenance of this deposit has now been (largely) resolved in favour of its being Minoan. McCoy (personal communication, 2/11/2001) has raised with me the intriguing possibility that this deposit may be modern day contamination from pumice material transported from Santorini during the building of the Suez Canal. However the fact that the ash is stratified in the core renders this most unlikely (as McCoy states in the same e-mail.)

Literature: Stanley and Sheng 1986: 734 - 735.

(92)

<u>Place name:</u>	Tell el-Dab^cª / Avaris
<u>Deposit type:</u>	pumice lumps
<u>Grid reference:</u>	31.39 E; 31.05 N
<u>Area:</u>	-
<u>Thickness:</u>	-
<u>Deposition method:</u>	human agency

<u>Archaeological context:</u>　　New Kingdom (early 18th Dynasty) gardens / waste strata in area H/I. Thus material and its context are extensively discussed below, section 5.3.4.

<u>Comments:</u>　　-

<u>Literature:</u>　　Bietak 1996: 76 – 78.

5.2.3 Summary

Drawing together this survey of Thera's ash and pumice deposits leads to some very interesting conclusions, and poses some equally interesting questions. Firstly, the presence of ash in cores from the Peloponnesian coast, and particularly from Limni Trikhonis on the Mainland itself, means that the boundary of the conjectured ash fan must be extended westward. In particular, if the Limni Trikhonis ash were to be chemically provenanced as Theran, then this position would mark the westernmost point of a fan previously thought to extend mainly if not wholly to the east. In the interim, however, we must rely upon the (admittedly unsatisfactory) criterion of the stratum's place in the layering of the site to assign it to Thera.

Of by far the greatest archaeological significance is the proposal, evident from the maps presented here, that most or all of Crete was affected by ash fall. Apart from the direct impact at least as far as Knossos (Fig 5.1), such a scenario is a logical extension to the presence of ash off the Peloponnesian coast, and on the (western) Greek Mainland. Clearly, there are serious implications for Minoan society. A reassessment of the short and long term effects may prove necessary. *Prime facie*, this adds strong support to the eruption-induced economic downturn theory of Driessen and Macdonald's "Troubled Island" hypothesis[15]; ironically far more so than the map produced by Driessen and Macdonald themselves (Fig 5.1). Nevertheless, the archaeological realities must caution against jumping to such conclusions: Macgillivray et al.[16] report evidence that rebuilding and management of the tephra were carried out effectively at Palaikastro, in what was obviously one of the worst affected parts of the island (although admittedly some were abandoned in LM IB). Furthermore, the magnificent LM IB Marine Style pottery[17] is hardly an art-form one would automatically associate with a society in steep economic decline.[18]

The implications of the very large amount of core material reported here from the sea floors of the Aegean and east Mediterranean are more difficult to judge due to the bathymetric complications referred to above. [19] It is clear, however, that much of tephra was deposited in the central Aegean as well as to the east, west and south. Such a greatly enlarged area affected by ash-fall is consistent with the new, massive

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[15]   1997: *passim*.
[16]   1998: 226 – 238.
[17]   For example, Betancourt 1985: 140 - 145.
[18]   This is consistent with the apparently very limited impact of the eruption on the human occupation process on Rhodes; see esp. Doumas and Papazoglou 1980: 324.
[19]   Indeed, several leading scholars have privately expressed to me the view that no analysis of these implications is possible because submarine preservation patterns are erratic, and do not conform to any consistent parameters. However, arguing this misses the point and seriously underestimates the potential offered by GIS (see below).

a)

b)
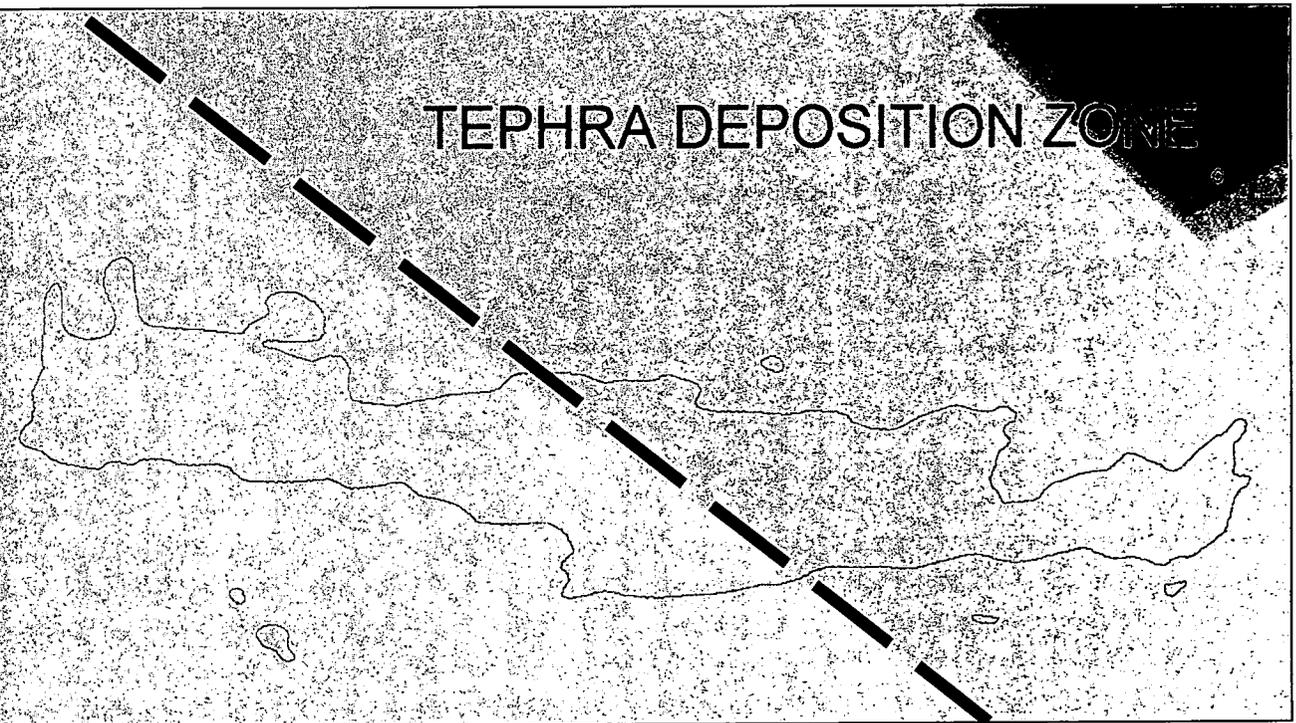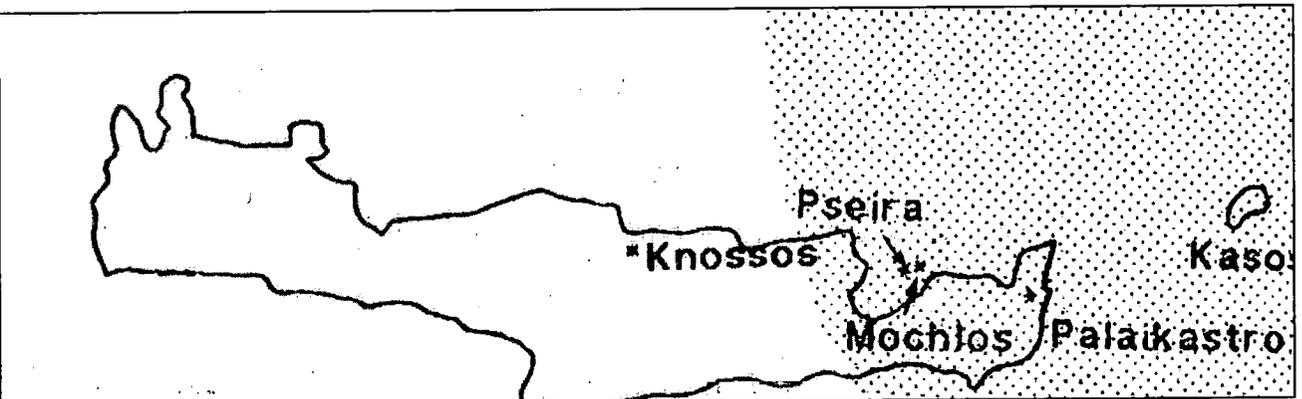
.1 Inferred minimal tephra deposition zones on Crete, (a) this study (below, section 5.5 and Map
), (b), Driesen and Macdonald 1997: 93, fig 5.2).

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deposits recently discovered by F. McCoy on Anaphi, and with the extension of the fan to the west. The seismically measured deposits clearly over-estimate the thickness of the Minoan tephra, and adjustments are made accordingly (see below, section 5.4.2).

5.3 Interpretation of the tephrochronology of Thera

5.3.1 General principles

It has now been established beyond any doubt that the "Minoan" eruption of Thera took place in a mature phase of LM IA , and was not responsible for the destruction of the Cretan palaces at the end of LM IB[20]. However, number of highly significant archaeological questions remain. Firstly, was there a "post – eruption" phase prior to the inception of LM IB, which might be termed "LM IA late"? Stratigraphical information from certain east Cretan sites such as Mochlos[21] suggests not, yet Warren[22] has argued cogently for such a phase, based on the nature of the overlap of LM IA and LH I / IIA at Akrotiri and in Crete.[23] Secondly, what is the position of the MM III / LM I transition, which has been linked (although the geological connection is tenuous) with the "seismic event" of early LCyc I?[24] In addition to the deposits used

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[20] See papers in *TAW III.3*, and Chs. 1 and 3 for discussion and references.
[21] Soles et al 1995: 391.
[22] Warren 1999: 894 – 5.
[23] Although LH IIA at Akrotiri is limited to a single bridge spouted jug. See Marthari 1990: 63, fig 8.
[24] See above, Chapter 3, for full discussion of this and the issues raised by Macdonald (forthcoming).

by Evans for this period, the "extensive and truly noble"[25] assemblage published by P. Warren from the Stratigraphical Museum excavations at Knossos is central.[26] Thirdly, where in the Cypriot / East Mediterranean / Near Eastern sequence(s) should the eruption be placed? If a pure, closed, deposit of air-fall tephra could be identified, which could be linked by Laser Ablation Inductively Coupled Plasma -Mass Spectrometry (LA ICP-MS)to Thera and related unambiguously to the reign of a Hyksos or 18th Dynasty ruler, the chronological problem would be resolved. In the absence of such a deposit, the discovery of Cypriot material and Theran pumice from Tell el-Dabᶜa and Cypriot material in the Near East, has raised many questions, but also suggested some persuasive answers.[27]

There is a further complication. The Minoan eruption left volcanological deposits, whether primary or secondary, in the territory of all four Aegean chronological sub-systems: the Greek Mainland, Crete, the Cyclades, and the Eastern Mediterranean / Cyprus. Each of these systems has is own internal relative ceramic sequences expressed across countless deposits, some of them excavated over a hundred years ago. It is my intention in this chapter to examine all three of these systems, not comprehensively, but where they pertain directly to the eruption – that is to say, where and only where pumice deposits have been identified. The purpose is to create a stratigraphical database focussing on connections and cross-references for the Theran ash fan. Discussion will be limited to this exercise of putting pottery deposits into their tephrochronological contexts, it will be for the experts to fit the mechanisms of this database into their "home" ceramic sequences.

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25   Hood 1996: 10.
26   Warren 1991: *passim.*
27   Bietak 1996 76- 78; above Ch. 3, papers in Karageorghis (ed) 2001, esp. Bietak and Hein
        2001: *passim*; Merrillees 2001: *passim,* Eriksson 2001: *passim* and. Bergoffen 2001 *passim.*

Warren and Puchelt[28] stipulate two important criteria that stratified pumice must meet in order to have chronological value, that is to say it must have a _proven_ Theran provenance and specified stratigraphical dated contexts. The former point is not so much a problem now as it was in 1990; advances in analytical technique and the publication of an index[29] have led to a great deal more certainty in this respect, as have advances in LA ICP-MS[30], although the application of the latter to a wider sample set throughout the Aegean is eagerly awaited. However, as the stratigraphical picture in the Aegean and East Mediterranean has become clearer, as well as understanding of the geometry of the ash fan itself, assignation on the basis of pottery levels alone has, to a degree, become possible.[31] It must be stressed, however, that "calibration" using LA – ICP MS allows confirmation beyond doubt, and given the very small necessary sample size, its application is to be urged for future discoveries of tephra in LBA contexts. The following tephrochronological interpretation of Theran ash below is developed from the catalogue presented above.

5.3.2. Crete.

The first theoretical connection between the eruption and the LM IB destructions on Crete was made by Spyridon Marinatos.[32] _Antiquity_, which carried his paper, inserted a now-famous disclaimer: "The Editors wish to point out that in their opinion the main thesis of this article requires additional support from excavation on selected sites. They hope that such excavations will in due course be carried out."[33] The

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[28]   1990: 71.
[29]   Peltz et al. 1999: 364 – 369.
[30]   Eastwood et al. 1998 685 – 6.
[31]   e.g. Momigliano 2001: 12.
[32]   1939: 430.
[33]   _Antiquity_, 1939: 439.

excavations that did follow confirmed the presence of the eruption's product on Crete, but initiated a whole new paradigm to Late Minoan studies. The first definite discovery of Theran tephra in Crete was reported from Myrtos-Pyrgos in 1972.[34] This was followed by the first broad and systematic survey of tephra material on the island, undertaken by C. and D. Vitaliano, who initially set out to investigate how much later than the end of LM IA the eruption could have occurred.[35] It should be noted, however, that many of the samples involved were very small, and, due to very poor stratification, of no real chronological value; although the work of the Vitalianos demonstrated, for the first time, that the volcanic material from Zakro was LM IA in date. The rest of their samples were unconstrained above LM II.

Evans makes no mention of ash at Knossos or anywhere else, although he does refer to imports from Thera[36] and speculated, after the 1926 earthquake, that earthquakes were responsible for the destructions.[37] The presence of volcanic materials has also attracted subsequent archaeologists to this theory.[38] However, as has been stated extensively here and elsewhere, there can be no direct link between the destructions of the palatial centres and the eruption, and there is no point reiterating the discussion of this above (Chs. 1 and 3). At Myrtos-Pyrgos, the majority of the relevant samples come from the "country house" of Pyrgos IV, namely the LM IB level, which is discussed in some detail in connection with the radiocarbon arguments of Housley et al. in Ch 2. Of particular note is ENQ 2490, the fill of a large pot, which included very conspicuous amounts of volcanic glass. The remainder (eight samples from this

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[34]   Cadogan et al. 1972: 112 – 3.
[35]   Vitaliano and Vitaliano 1974: 20.
[36]   Evans 1935: 280.
[37]   Evans 1928: 313.
[38]   Hood 1978: 684; discussed by Macdonald 1990: 82.

building), were traces, and no depth for the layer could be ascertained at this point.[39]

Although this period ends with fire destruction, the amounts of tephra involved are too small for the phenomena connected with the eruption to have been directly responsible; in any case a further trace deposit from outside the building was not associated with any burnt destruction at all. There is no coherent layer at this site, only individual shards of volcanic glass identified in the matrix of the soil itself. At the time, supporters of Marinatos" volcanic destruction theory, notably J. V. Luce,[40] pointed to the LM IB context as an argument in favour of it. The excavators, however, argue convincingly that the very small amounts of material involved could not have led directly to a fire destruction.[41]

On the north coast, at Mochlos, the only ash layer from Crete completely published so far has been found.[42] A series of five deposits makes up this tephrological assemblage, from domestic as well as industrial contexts. The first of these was enclosed between an LM IA pit deposit and a floor level containing distinctive LM IB Marine Style pottery. At this point the deposit reaches a thickness of ten centimetres, and an area of seven and a half meters. The second layer is thinner, with a maximum depth of only two centimetres, but its archaeological context is much the same. Both these layers are directly associated with House C.1. Thirdly, we have a very small deposit, only thirty centimetres long and five thick, some thirty five meters to the west of the first two. Again, it is clearly below LM IB pottery. The final two deposits from Mochlos are both from industrial complexes at Buildings B.A and A. The former is, at one

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39   Cadogan and Harrison 1978: 246 - 254.
40   1969: 14.
41   Cadogan and Harrison 1978: 246 - 254.
42   Soles et al. 1995: 386. There are strong indications that such a layer exists at Palaikastro. See below (section 5.5) and Maps 1 - 3 for extrapolations of the data points which suggest that the layer covered the whole of Crete.

centimetre, very thin, and underlies a staircase leading into the building. The shallowness of this deposit could be due to traffic on the modern road or even artificial mixing with water to form a cement like mixture upon which the stairs were constructed. Use of Theran volcanic material for building in antiquity would form a very interesting study, not least because it has been used in our own age, most famously in the construction of the Suez Canal.

The second layer for which there is evidence is from Hagia Varvara on the north coast at Malia, and it consists not of ash, but of pumice.[43] This may form part of the corpus of evidence that Crete was, to some extent, affected by tsunamis caused by the eruption. It cannot be ruled out, however, that it was deliberately laid down as a construction platform, or some other artificial structure. The layer is 5 to 10 centimetres thick, and just below a surface layer containing LM III pottery. Of great chronological interest is an LM IA, or possibly IB, cup *in situ* within the layer and filled with pumice. The cup also lends credence to the tsunami theory: it would make more sense for it to have been washed into position than deposited in an artificial stratum. The layer is visible in a naturally eroded section, and the point at which the cup was found was badly mutilated by the passage of tourists. Thus, the area of the deposit is unknown, although its determination would almost certainly resolve the manner of deposition.

To the west of Hagia Varvara, at Knossos itself, lie the Stratigraphical Museum excavations. 10 pumice samples were removed for analysis, of which 4 came from contexts described as LM IB or earlier. One of these came from a MM II context, and

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[43]   Sylvie Müller-Celka personal communication, 6/8/2001.

was determined, on geochemical grounds to be from a much older eruption than the Minoan event. A second piece was shown not to be Theran, possibly originating from Melos. The context of this sample is given as MM IIIB –LM IA, although the lack of similar traces of pumice from the Bronze Age on Melos itself (especially at the well-known town site of Phylakopi) suggests that such an eruption should pre-date this period completely. The 7 remaining Knossos samples were interpreted as being Minoan, from a variety of levels post-dating the LM I period.[44]

A far better stratigraphical resolution comes from the town of Pseira, in the east of the island. Here, Philip Betancourt's excavations retrieved samples of both windborne ash and water borne pumice.[45] One sample of the former was linked geochemically to the Minoan eruption. This came from the lower level of a trench along the south east wall of room A1 of Building A, the Shrine. The trench was cut in to the bedrock on which the remainder of the room rests. It contained a rubble fill and was covered by a contemporary, and final, floor, and LM IA pottery. One piece of Minoan pumice came from the upper level of this fill, with three further pieces being found in the LM IB destruction of room A10, in the same building. The trench in A1 categorically places the eruption in mature LM IA. The find of a piece of pumice with a hole drilled in it, from the LM IB destruction of the Plateia House, supports this. This piece, probably a fishing float, was evidently in use for some time after the rest of the pumice assemblage was deposited.[46]

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[44]   Warren and Puchelt 1990, esp. table on p. 80; Peter Warren personal communication 9/7/2001.
[45]   Betancourt et al. 1990: 96.
[46]   *ibid*: 98.

5.3.3. The Greek Mainland

At Nichoria in the Messenia region of south west Mainland Greece, a series of deposits of pumice was unearthed by the Minnesota Messenia Expedition in the 1960s and 1970s.[47] The samples were analysed using the refractive index procedure, and the results published in 1973 in a now well-known paper by Rapp, Cooke and Henrikson.[48] This analysis showed that the sources of the deposits were Melian and Theran. The material was predominantly associated with pottery of the Late Helladic IIA period, roughly contemporary with LM IB. One piece of pumice came from a deposit definitely assignable to LH I. Tantalizingly, however, the potential importance of this issue was not perceived at the time, and this piece was not provenanced. If it had been, and if had been shown to be Theran, the implications would have been very significant. Such a scenario would require the eruption to be placed before the inception of LH IIA, and thus at the very end of LM IA, putting severe pressure on any possible "post-LM IA" period.

5.3.4   The Tell el-Dab^c a pumice

The appearance of pumice in a workshop context at Tell el-Dab^c a, the Hyksos capital Avaris, in the Eastern Desert, has provoked intense speculation and controversy. Thanks to the "Thera Ashes" project of the Austrian Spezialforschungsbereich, *Synchronization of Civilisations in the Second Millennium BC*,[49] these pumices have been chemically fingerprinted, and shown to be Theran. The site's chief excavator, Professor Manfred Bietak, has shown that this pumice is confined within a single

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[47]   Macdonald and Wilkie (eds.) 1992: 31, 41 and 445.
[48]   Rapp et al. 1973: 472.
[49]   Bietak (ed) 2000: 30.

stratum line in the early 18th Dynasty, after the fall of Avaris in the reign of Ahmose, and before that of Tuthmosis III – that is to say between 1530 (or very close to) and 1479 BC (or very close to).[50] It is very important to state here that only one categorical fact may be deduced from this, i.e. that this deposit indicates that this stratum is a *terminus ante quem* as far as the eruption is concerned. The *"ante"* is extremely difficult to quantify.

Thus, the key issue for Aegean chronology is: does the context of this pumice deposit approximately correspond with the actual date of the eruption, or, as some have argued, was there a time lapse of a century or more between the pumice's source-production and its deposition at Tell el-Dab^{c}a?[51] Fairly obviously there are two possible ways in which this pumice could have arrived in Egypt: natural processes of tide and current, or importation by human agency. If the former, then it must be remembered that it has been estimated that a tennis-ball sized lump of Minoan pumice will float, on average, for three months (but see section 5.4.4 below). Therefore, if it floated to Egypt as a raft, on the Aegean tides and currents, it would have had to have done so fairly rapidly. It is of course possible that this could have happened in the seventeenth century but, if so, why has there been no evidence of usage during the Hyksos / SIP? Why did a hundred years or more pass before the exploitation of this inexpensive, yet valuable resource? These questions, first asked by Professor Bietak, have yet to receive any satisfactory answer.

On the other hand, if the lumps were imported artificially, there is a similarly limited possibility for a long time lapse between its arrival and deposition. The pumice was

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[50]   Kitchen 2000: 39 - 52.
[51]   Esp. Manning 1999: 145 - 50.

found in a workshop environment, where it would have been used as an abrasive. Thus, it would not have physically survived such a long period. As to the further counter argument that the pumice may have already been old when it was imported into the New Kingdom, exactly the same objections remain: Why was the process not conducted sooner? Why the delay until the inception of the New Kingdom?[52]

5.4 The physical properties of ash and pumice: dispersal and preservation issues

5.4.1 General problems

A major difficulty in the study of an ancient volcano's ash distribution is the fact that tephra is very susceptible to erosion and secondary formation. The preservation of volcanic deposits is a process that is erratic up to, and beyond, unpredictability. Most or all of the ash-fan of a given eruption can be lost within a few months of the event. On the other hand, chemical isotope analysis of volcanic products form the basis of dating the emergence of complex animal life 555 – 590 million years before present.[53] The spatial analysis of Minoan tephra beds from across the Aegean and East Mediterranean below attempts to address this. The importance for the region's chronology is examined in detail in Chapter 6. First, however, it is necessary to explore in some detail the mechanisms of ash and pumice dispersal in the specific case of Thera.

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[52]   See section 5.4.4 esp. n. 67 for further discussion of this matter.
[53]   For an excellent recent summary, see *National Geographic Magazine*, September 2001: 96.

5.4.2 Proximal seismic data

A number of preservation and depositional factors affect the integrity of the observed

thickness of the tephra layer in the sea-bed around the Santorini archipelago. These

thicknesses are derived from seismic records of the sea-bed topography (above,

section 5.2, (1) – (14)). The *primary* layer is defined as the tephra materials laid down

by airfall and the entry of pyroclastic flows into the sea during the Minoan event.

However, it is certain that other materials will also be present within the layer,

increasing its thickness. These include: reworked tephra from events such as lahars,

mudflows and tsunamis, geological debris from the collapse of the pre-Minoan

caldera complex and tephra re-deposited since the Minoan event, through slumping,

bioturbation, ocean storms and currents.[54]

To compensate for these factors, Professor McCoy and myself suggest the following

modifications to the reported thicknesses. The readings from inside the caldera should

be halved. As McCoy has pointed out in a personal communication[55], if the reported

thicknesses (<68m) actually reflected reality, the vent would have become choked and

the eruption may even have been overwhelmed by its own ejecta. Clearly, therefore,

the factors outlined here greatly inflate the readings. For measurements taken outside

the caldera area, we estimate that the primary deposit accounts for 40% of the

reported thickness. This, unfortunately, is an issue where educated guesswork has to

stand in for science. Without detailed fresh analysis of the sea-bed around Thera, the

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[54]   Floyd McCoy, personal communication, 28/1/2002. See also Watkins et al 1978: 124 for
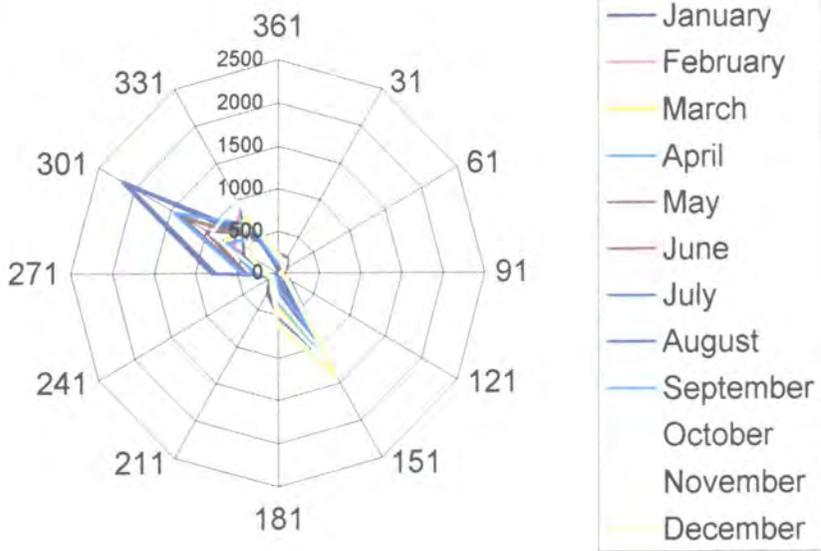   further discussion.
[55]   *ibid.*

actual corrected values may never be known for certain. We are confident, however, that these corrections reflect approximate reality, as far as is currently possible.

5.4.3 Wind

All surface wind data used in this section come from three weather stations: Heraklion (35° 20" N; 25° 11" E, 37m above MSL), Naxos (37° 06" N; 25° 23" E, 9m above MSL) and Skyros Airport (38° 58" N; 24° 29" E, 27m above MSL).[56] The data for wind directions are provided in the form of thirteen sets of frequencies for each month, speeds are measured in the standard nautical measurement of knots (1 nautical mile per hour, or 1.15 mph, fig 5.2 (a) - (c)). Each set represents the number of measurements taken in 30 degree directional brackets, at the given station. In general the dominant wind speeds in the south central Aegean are north-easterly, with the great majority of wind measurements at Skyros, Naxos and Heraklion lying in the 0° bracket. Again, the readings of all three stations are roughly equal in the 30° (NNE) bracket, and at 60° (ENE), the Heraklion and Skyros readings follow inverse patterns from January to July with a stronger bias towards the southern latitude, before realigning in August. It is not until 180° (S) that a serious difference emerges between the central Aegean area and Crete. Here, there is a very striking winter and early summer bias at Heraklion, which is not present in the islands. It should be noted that there is a slight dip in the southerly winds between March and June, with a corresponding slight rise in the northerly currents at Heraklion. An obvious conclusion to draw is that the mountains of Crete absorb much of these winds,

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Heraklion

Legend:
- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

(a)

5.2

243

Naxos

(b)

5.2

Skyros Airport

Legend:
- January
- February
- March
- April
- May
- June
- July
- August
- September
- October
- November
- December

(c)

5.2

Average Aegean wind speeds

Legend: Heraklion, Naxos, Skyros

(d)

5.2
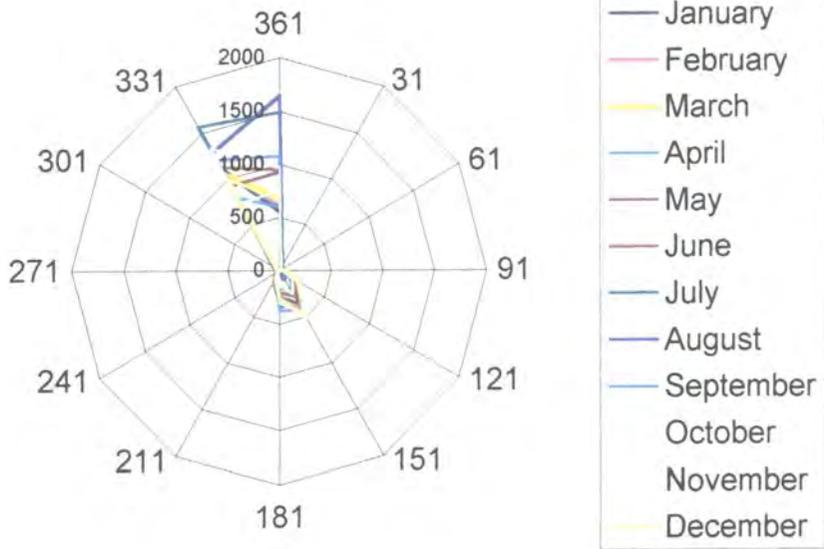
shielding the Cyclades. In practical terms, this is illustrated by the presence of red African dust in Crete at some times of the year, with little or no reporting of this phenomenon from more northerly land masses. The situation is similar, but the scale smaller, at 210° (SSW), 240° (WSW), and 270° (W).The manner of ash and pumice deposition is an important consideration of any ancient volcano's relationship with human culture. The role of wind and weather must be considered so far as is possible. Generally speaking, and this is certainly true in the case of Thera, deposits fall in to two categories. Firstly, there are distal deposits which are generally airborne, having been dispersed by atmospheric and stratospheric winds. Secondly, there are proximal deposits around the volcano itself, mainly detectable through seismic 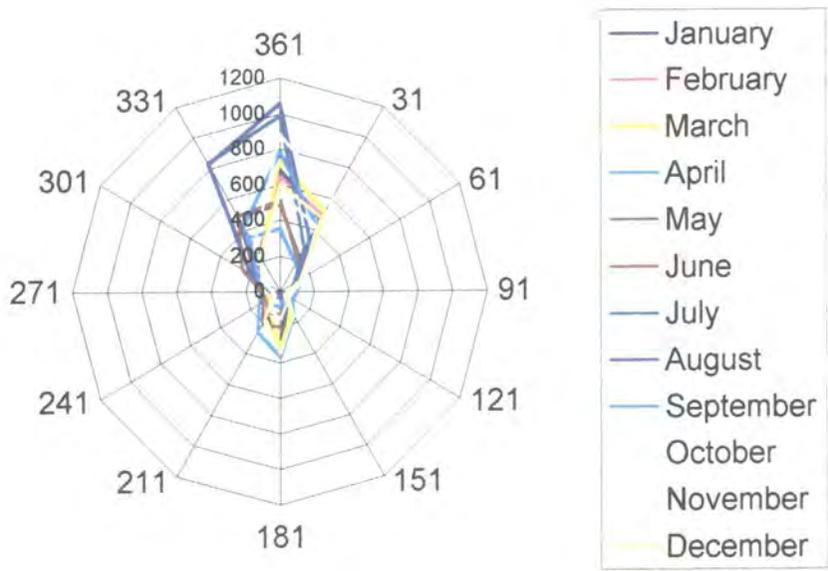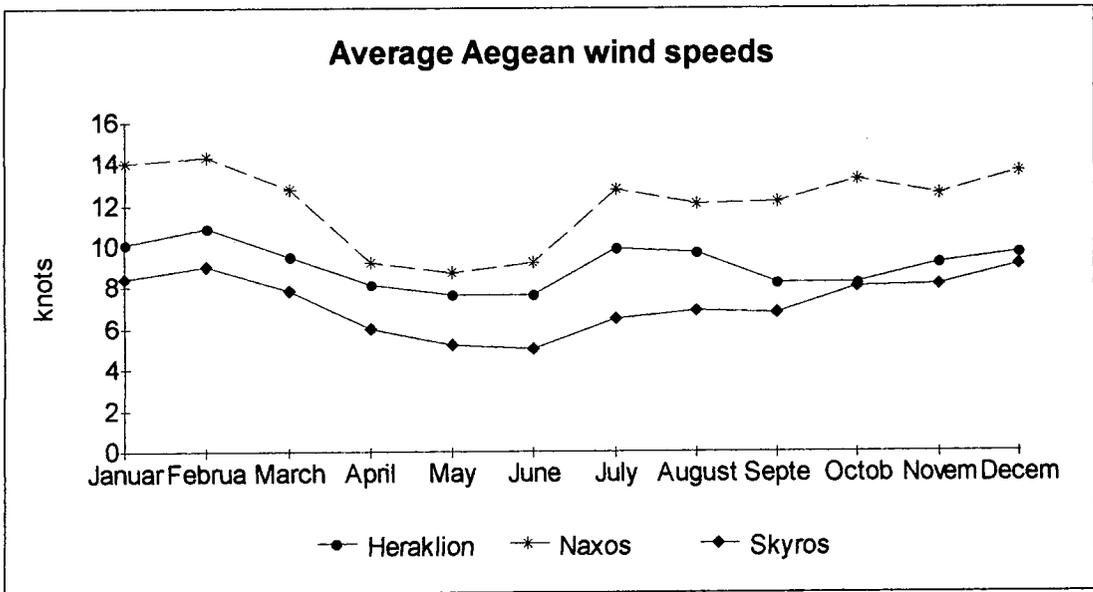study of the sea-floor as well as surface survey on the island. A possible third category (although it is more of a sub-category) is that of tsunamigenic deposits on landmasses surrounding the main eruption zone. The deposit from Hagia Varvara is a possible representative of this category; the Amnisos layer is a more certain example. In terms of the first of these, the effects of wind are an important factor in evaluating human response. For example, although no protection against tsunamis, a strong on-shore gale on the north Cretan coast during the course of the eruption may well have mitigated the effect of the fallout on Minoan agriculture and economy, likewise, a strong northerly wind would have exacerbated it.

The effect of crosswinds on volcanic plumes is not, in general, very well understood. Although there are many theories concerning the effects of crosswind, most centring around the downwind distance being raised to the 2/3 power,[57] there is a wide range of factors which complicate the application of any formulae to volcanic plumes. The

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[57]   Scorer 1959: 210 - 16.

model described by Scorer[58] is concerned with the plumes of industrial smoke-stacks, which are far weaker than all but the very smallest volcanic emissions. As plinian columns generally extend far above the earth's surface (36km in Thera's case, see Chapter 4 above), they are almost certain to encounter a variety of different crosswinds in the atmosphere and troposphere. Carey and Sparks have addressed this problem in general terms, and have shown that an "umbrella region" of the eruptive column, between the point where gravity and the upward thrust from the vent reach equilibrium, and the point at the very top of the cloud which is attained by some of the material through momentum is the area most susceptible to dispersal by wind.[59]

The only reliable way to proceed in this field is to study satellite imagery of modern volcanic plumes. As far as I know there are no such pictures of Thera "in action", but comparative conclusions may be drawn from images such as those of Mt Etna presented overleaf.[60] The pseudo-coloured Modis image in Fig 5.3 (e) shows a long displacement; the curve to the south may be caused by a gradual change of wind direction or, more likely, the rotation of the earth. From this it is obvious that, almost paradoxically, if the ratio of plume intensity / wind speed is high in favour of wind speed, the land or water mass affected is noticeably less than if the intensity is stronger and the wind weaker. A situation closer to the latter seems to have existed on 20th May 2000 (Figs 5.3 (a) and (b)), where the plume dispersal is broader, although the wind appears to have changed to a more northerly direction between 0328 and 1503, leaving a curvature similar to that seen in 5.3 (e). These are all useful factors when considering the impact of the Minoan eruption, and it demonstrates how such eruptions form smooth, elliptical ash-fans.
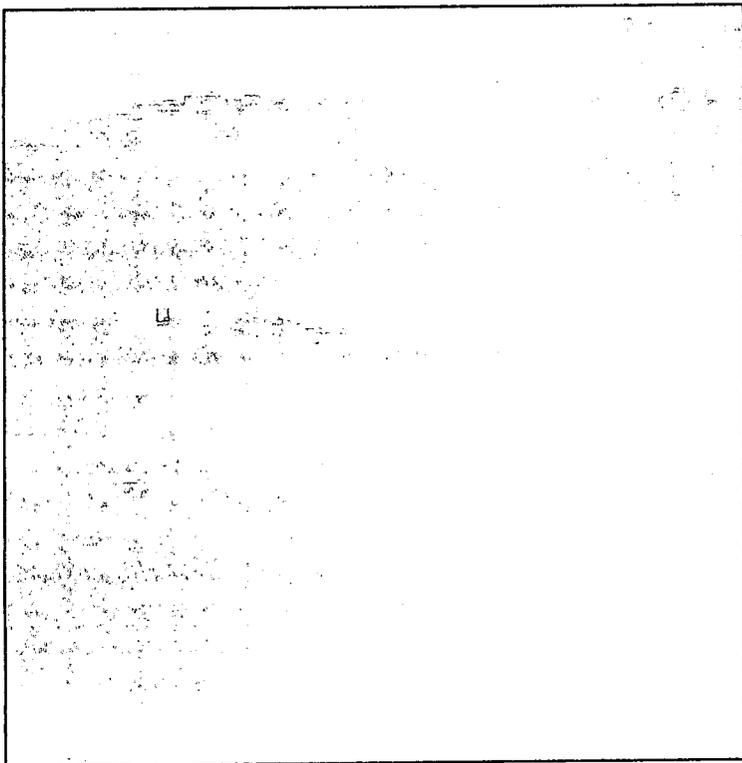
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[58]   *ibid.*
[59]   Carey and Sparks 1986: 115 – 123.
[60]   All pictures from the Dundee Satellite Receiving Station: www.sat.dundee.ac.uk

(a)

(b)

5.3

(c)

(d)

5.3

(e)

5.3
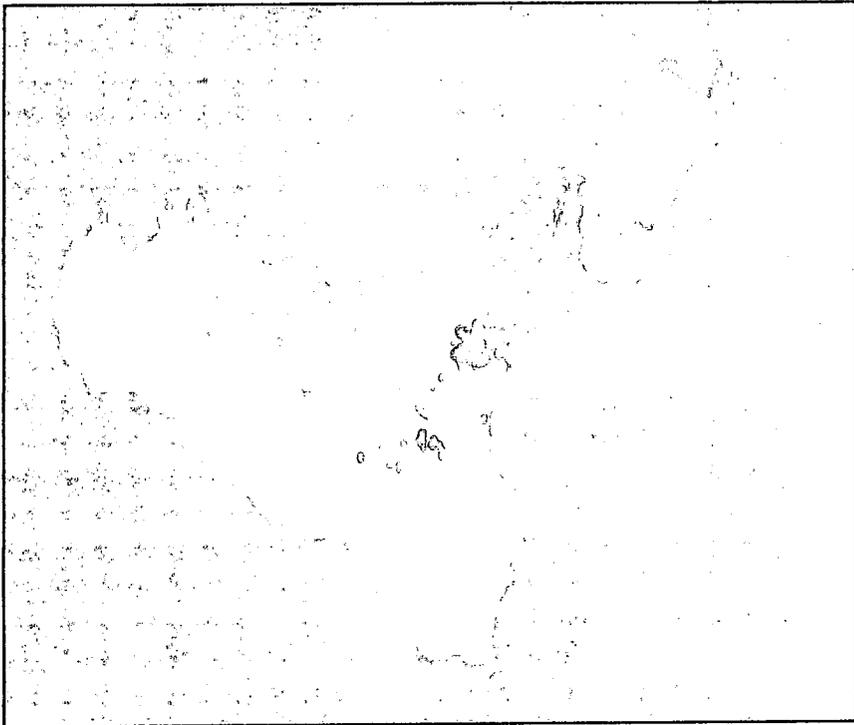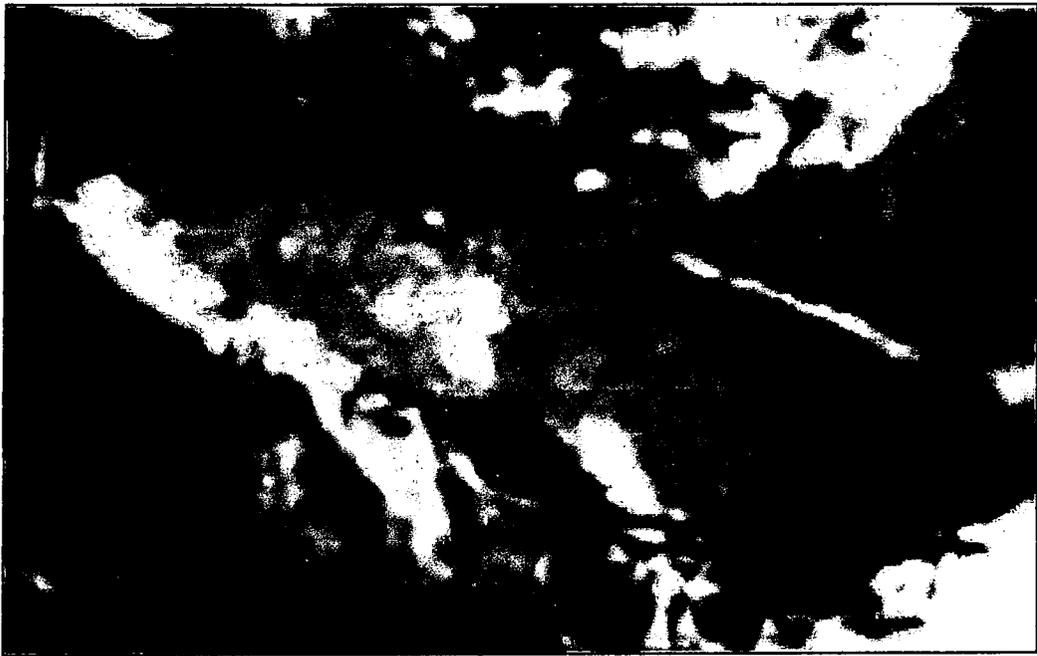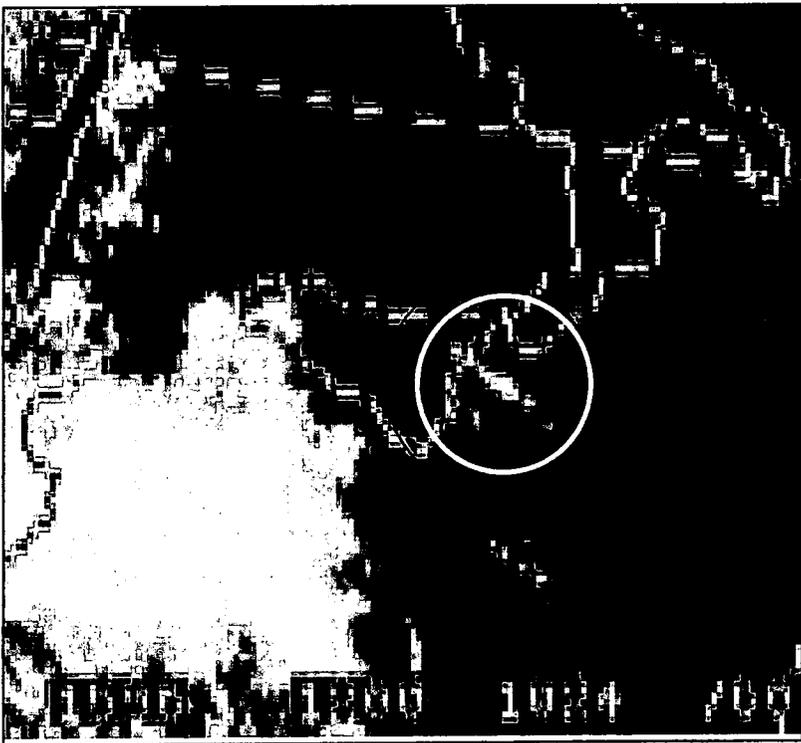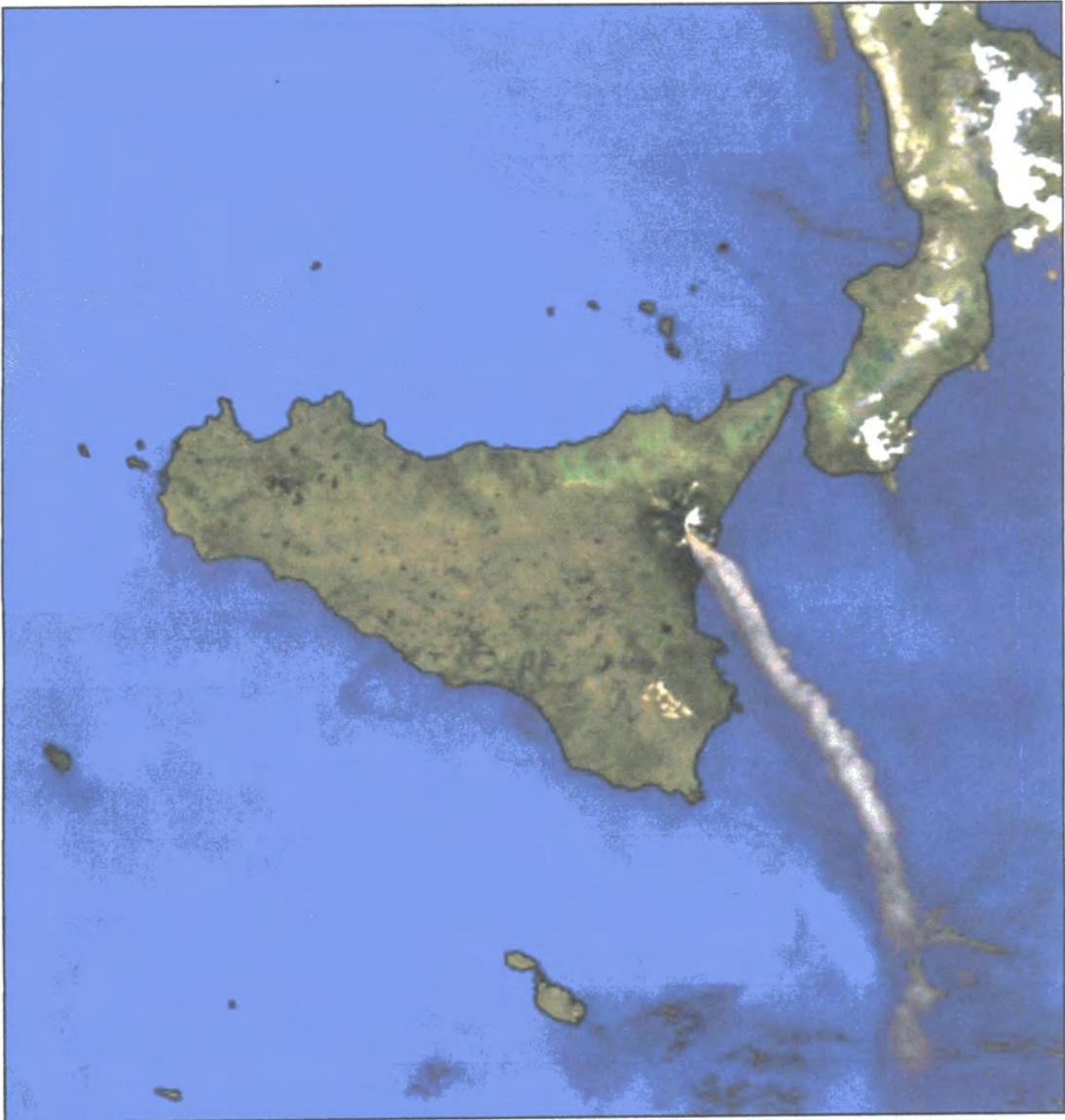
It is pointed out above (section 5.4.3) that surface winds and ground–level drift are major factorsin the formation of tephra deposits.[61] Below is an assessment of this factor for the Aegean. One of the main conclusions of McCoy and Dunn (forthcoming; see below, section 5.5.1), is that two levels of wind, at tropospheric and stratospheric level respectively, were responsible for the majority of the ash dispersal. Map 1 supports such a hypothesis. Regional dispersal of the distal deposit is overwhelmingly towards the east and south (as noted by Watkins et al.[62]), and it is suggested here that low-level atmospheric winds were responsible. Dispersal towards the east and north-east is inferred to have been via high-level stratospheric winds, most likely the jet stream. The deposits to the west of Thera are more difficult to account for: either the ash was carried west by a weaker contraflow or, more likely, a mechanism of the eruption itself (for example a massive phreatomagmatic blast) may have injected a large quantity of ash into the atmosphere over the Mainland, where it dispersed.[63]

5.4.4 Water

There is no evidence that seawater had any contact with the first, plinian (Bo 1) phase of the eruption (see above, Chapter 4); and that all phreatomagmatic activity appears to have been confined to the subsequent three major phases. Such clear compartmentalisation is very convenient for discussion of the dispersal of volcanic material. Whereas the plinian ash fall must account for the vast majority of distal deposits (see above), the effects of the pheratomagmatic and co-ignimbrite phases

[61] ᵇ, Max Bichler personal communication, 1/10/2001.
[62] 1978: 125 – 6.
[63] The ash fallout model of Carey and Sparks 1986 is not applicable here as it pertains only to plinian, not phreatomagmatic, eruptions.

would have been largely confined to a relatively smaller area centring on the island. These effects can be determined from two sources: the bedding structures of the geological deposits on Thera itself, and the evidence from elsewhere for tsunamis. The most recent study of these phenomena points out that tsunami activity could have occurred where pyroclastic flows entered the sea around the island.[64] Interestingly, this paper also reports that the Bronze Age eruption layer is not visible in sea-core analysis of tephra deposits (homgenites) strata from basins on the Mediterranean floor.[65]

One of the most significant conclusions of McCoy and Heiken[66] is the constraint they place upon the distance from Thera, within which tsunamis could have created deposits. They conclude that the discrepancy between the speed at which pumice is rafted in the East Mediterranean and the very high speed of volcanic tsunamis means that no waterborne deposit outside a radius of 100km from Thera can have been tsunamigenic. This does not, of course preclude the possibility of pumice rafts reaching much further on the Mediterranean currents.[67]

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[64]   McCoy and Heiken 2000b: 1239.
[65]   *ibid*: 1242.
[66]   2000a 58 – 69.
[67]   *Pace* Manning 1999: 146, who notes this distance, but highlights the further possibility of deposition by later tsunamis. He does not however, refer, to the estimated upper limit quoted by McCoy and Heiken 2000b: 1248, for arrival of pumice by non-tsunamigenic means in the Levant, a vector distance of around 1000 km: 350 days. Although a long time in terms of the eruptive sequence, this is still less than a year, and does not detract from – indeed reinforces – the tephrochronological scheme for Tell el-Dabᶜa suggested above (section 5.3.4).

5.5 GIS based spatial and volumetric analysis of Minoan tephra beds[68]

5.5.1 The application of GIS to archaeological and volcanological problems

The role of GIS in Thera studies is explored comprehensively in this section, and includes a GIS based spatial analysis of the Minoan tephra beds, and their relationships with each other. An estimate for the volume of the eruption is advanced which is far larger than any previous estimate, and the archaeological implications of this new estimate are reviewed in the concluding chapter. It is difficult to underestimate the importance now attached to GIS in archaeology in general (see section 5.1, above), but it has not hitherto been applied to the Thera problem. In addition to databasing and storing the information contained in the gazetteer (above), GIS can be used to identify patterns of tephra thickness across wide geographical areas, and to predict roughly how much ash product should have fallen at any particular point.

It must be stressed that the results presented here are preliminary. Much still needs to be done on this specific problem, which is being addressed in detail by McCoy and Dunn (in preparation), and this paragraph summarises our presentation at the June 2002 American Geophysical Union Chapman Conference on Volcanism and the Earth's Atmosphere. We showed the principles (discussed in detail below) behind the new volumetric calculations, and proposed a far larger event than previously thought: up to 100 km^3 of tephra may have been discharged (VEI [Volcanic Explositivity Index] = 7.0). This is more than double previous estimates (about 40 km^2; VEI=6.9) and has important implications to the magnitude and regional effects of the eruption,

particularly for modelling possible climate change. Such a magnitude would make the Minoan eruption one of the largest in historic times, and equivalent to the 1815 eruption of Tambora. These new calculations of tephra volume are derived from the newly identified exposures of pumice and ash on the islands of Anaphi and Crete (some at archaeological sites), from seismic data in the vicinity of Thera (reappraisal of older unpublished data; other published data), as well as from ash recovered in deep-sea cores taken during the past decade. All of these deposits are discussed in the gazetteer, above. Ash deposition was widespread: from the coastline of the Peloponnese to the west, over all of Crete to the south, over western Anatolia to the east, and as far as the Black Sea to the north-northwest. Regional dispersal of this distal deposit was towards the east and south via low-level atmospheric winds, and towards the east and north-east by high-level stratospheric winds (likely the jet stream). Proximal tephra deposits on and near Thera were deposited from (1) the eruption column, (2) accumulations on the central pre-eruption edifice that collapsed to form the modern caldera, and (3) the entry of pyroclastic flows into the ocean. Calculations of tephra volumes are approximate and made complicated by the lack of better criteria for estimating proportions of redeposited material.

The GIS model on which the new estimates are based assumes a three-dimensional plane, with x and y representing the geographic coordinates (see section 5.2, above), while z represents the thickness of the tephra layer (fig 5.3). It is then possible to use the various analytical techniques of the program ArcView GIS 3.2 (see below). A rough estimation of the shape and extent of the fan, based on extant knowledge, is thus possible, providing that discrimination is employed in the selection of the ash layers used. The conditions I impose are as follows. The layer must be a clearly

identified air fall ash deposit; obviously sea borne ash or pumice is no good. The ash must be analytically shown to be Theran. Great care must be taken to ensure that the layers used re present an approximate true thickness of the original layer. This means rejecting secondary slump deposits (for example that from Mt. Profitis Elias on Rhodes), and any layers which have been re-used in building activity, although pumice seems to be more susceptible to this form of modification. In the case of sea-cores containing ash, only values published as "corrected", to take account any submarine secondary processes, such as current movement and bioturbation, must be used. At the present time, the various ongoing programs of extracting cores from lacustrine sediments in west Turkey provide the soundest means for establishing the most accurate picture of the layer in the east. A complication is that it is not always possible to distinguish between direct airfall material, and material which has fallen on adjoining hillsides and washed in: a process to separate the deposits in these situations using microchemical transection is planned for the near future.[69] In the meantime, each "z-value" must be taken on a strictly case by case basis, each being judged on its own merits. It is extremely important to bear in mind the volcanological sourcing processes of the deposits under analysis. As pointed out above (section 5.4.2, Chapter 4 and references), the first, plinian, major phase of the eruption is very well defined, and seawater had no access to the vent. It is almost certain that the vast majority of the distal deposits listed in 5.2 originated in this phase, with the fallout from the later, phreatomagmatic phases was much more locally confined (excluding the effects of tsunamis caused by slumping etc.). The latter are represented in the seismic records. Rafting of pumice is another issue, and it is entirely possible that very large pumice rafts (like those produced in the AD 1883 Krakatoa event) may

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[69]   Warren Eastwood, personal communication, 6/8/2001.

have been created and dispersed. This would render any estimate using this method for the volume of material produced, and effects on local populations, a minimum. Thus, the plinian phase is treated separately here, and inferences drawn from comparison of the results of this method with more traditional volcanological means.

5.5.2 Map projection

Because the isopach model developed here is GIS-based, it isnecessary, to take into account the curvature of the earth. This is done by the process of map projection, whereby the raw data are interpolated onto a flat surface, and then projected onto a curved plane. The system used to interpolate the data is the generic Greek Grid, a regional system for the east Mediterranean supplied by the ArcView Projection Utility. The Geographic coordinate system of the unprojected data is thus converted to meters and the Prime Meridian maintained at Greenwich; the full input / output process being:

```
Input Coordinate System:
                 Name: GCS_WGS_1984[70]
                 POSC: 4362
                 Unit: Degree
                Datum: D_WGS_1984
       Prime Meridian: Greenwich

Input Geographic Transformation:
        None

Output Geographic Transformation:
        WGS_1984_To_GGRS[71]_1987  [8181]

Output Coordinate System:
                 Name: Greek_Grid
                 POSC: 2100
```

---

[70]   Global Coordinate System, World Grid System,1984. A generic unprojected grid used by Global Positioning System (GPS) units.
[71]   i.e. the Greek Grid system.

```
              Unit: Meter
   Geographic CSYS: GCS_GGRS_1987
    Prime Meridian: Greenwich
     False Easting: 500000
    False Northing: 0
   Base Projection: Transverse/Mercator[72]
   Central Meridian: 24.0
   Central Parallel: 0.0
      Scale Factor: 0.9996
```

5.5.3 Various methodologies: the volume of the ash fan [73]

Three GIS methods can be employed to approach this problem: the Triangulated

Irregular Network (TIN) model, and the grid interpolations, Spline and Inverse

Distance Weighted (IDW). A full explanation of the mathematical premises behind

these analyses, and their computer programming protocols, is beyond the scope of this

thesis, but I examine here the advantages and disadvantages of each, and present their

respective applications to the data listed above (section 5.2.2).

The TIN (Map 1) model is more traditionally used for computing hill topography

from a set of x, y and z parameters. The ash fan is thus assumed to be a set of very

shallow "hillsides" over a very wide area. The data are interpolated as a series of

contiguous and non-overlapping triangles, with each data point representing the apex

of a triangle. As the TIN in Map 1 shows, the new data supplied by McCoy strongly

suggests that the whole of Crete, and not just the eastern end, was directly affected by

ash fall. In any case, the revised deposition zone extends at least as far as Knossos.

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[72]   The standard longitude / latitude grid system devised by Gerhardus Mercator (AD 1512 –
        1594), which enable bearings to be drawn in straight lines on a curved surface.
[73]   The GIS Good Practice Guide, laid down by the UK Archaeology Data Service, is followed
        here. See also the excellent "help" function and manuals for ArcView GIS, and *Using ArcInfo
        and ArcView GIS – an introduction*, Guide 37 published by Durham University Information
        Technology Service. Grateful thanks also to Karl Pedersen for advice and discussion.

The difference can be appreciated when this scenario is compared with Driessen and Macdonald (above, Fig 5.1).[74]

This could have been as much as 1 – 3 cm across the whole of the island. The appearance of Minoan ash in a core from Akarnania, and in cores from Peloponnesian seaboard area suggests a westerly as well as the well-known easterly pattern of dispersal, whilst further core evidence from the north and east Aegean indicate that the impact of the Minoan event must have extended in a northerly direction too. However, the nature and extent of this impact on the Mycenaean population is not possible to judge at this stage.[75]

So that the units were consistent across the exercise, the z statistics (tephra thicknesses) were entered in to the TIN database as kilometres. Thus, 1 cm = 0.00001 km. This data set was then converted from a standard 2-dimensional point theme to a 3-dimensional event theme, to be projected (see above) and converted to a TIN. Using these figures, it is possible to calculate the area and volume statistics of the TIN. This is the basis of the new estimate given here, and forms part of the argument of McCoy and Dunn (forthcoming).The volumes given for the TIN in Map 1 appeared to over-estimate, which indicated that TIN needed to be calibrated. Part of the reason for this is likely to be the fact that all areas within the maximum lateral extent of the data (the Nile Delta, the Black Sea, the western Greek mainland and the Levantine seaboard) appear, *prima facie*, to be covered in ash. This is very unlikely to be the case in reality, and takes no account of the wind patterns that dispersed the ash. However, it is obvious from all the maps that actual data points in these areas are scanty. Knowledge

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[74]   1997. 93, fig 5.2.
[75]   It may therefore be wise to re-consider the term "Minoan eruption". See Preface.

of the patterns of relative concentrations and lacunae where there are much more data (i.e. Crete, the Aegean and east Turkey) allows what must be a fairly accurate inference to be drawn about which areas are being over-represented.

In ArcView GIS 3.1, it is possible to obtain accurate distance and volume measurements directly from a TIN of the type used here. This facility, for specifying units for the primary database, is contained in the "Area and Volume Statistics" dialogue box in the Surface menu. A full general account of how TINs are created and interpolated in an ArcView theme is not necessary here, but it suffices to say that they are created and assigned in direct and consistent proportion to the volume and area of the area of interest (AOI). This relationship can be exploited to give a precise value for the area and volume of the Thera TIN. Through analysis of the patterns therein, a figure for the volume of the eruption may be given.

The output statistics are given in cells but, over such a large and irregular area and volume, it is possible for errors to occur. To establish the nature of the error margin, a regular cube of 1 decimal degree x 1 decimal degree x 1 z was created in an unprojected view. Using exactly the same procedure as described above (5.5.2), it was projected into a fresh view. The projected dimensions of the cube were 112.070 km x 92.387 km x 1 z; = 10353.811 km^3. The volumetric count for this feature, established from the Area and Volume Statistics dialogue box, was 10062727687.565. Thus 1 km^3, expressed in cells, =

$$\frac{10062727687.565}{10353.811} = 971886.360 \tag{1}$$

To test this, a second cube was created, but with a random, and unknown, dimensions. The volumetric cell count of this new object was given as 43105608327.528 cells. Thus:

$$\frac{43105608327.528}{971886.360} = 44352.519 \tag{2}$$

The dimensions of the cube were then determined manually. They were 106.213 km x 61.386 km x 7 km = 45639.938 km.^{3} Thus, this "calibration" method has an error margin of 2 – 3%. This is certainly due to the inherent inaccuracy of any map (i.e. that no map with a scale smaller than 1:1 can be infinitely accurate). In any case, it is well within the accuracy required by this study.

Not including the seismic data (gazetteer records (1) – (14)), the total volume under the Thera TIN in Map 1 is 132508783.441 cells. Thus, a provisional estimate for the bulk volume of the eruption, as reached by this method, is 136.343 ± 4km^3, with an affected planimetric surface area of around 393,671 square miles. It must be stressed that this takes into account only the present-day preservation pattern, rather than the actual situation immediately after the eruption (see above, section 5.4). However, even taking this into account, it points to an eruption very much larger than previously thought (Pyle's estimate, for example, being only 28 - 29 km^3.[76]). As stated above (section 5.5), this figure is not yet fixed, and taking into account the effects of wind-

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[76]   Pyle 1990: 121.

drift, I (currently) estimate that other depositional factors is likely to cut this figure by between 30 and 40km^3 from the estimate given here. This, however, is still far higher than Kuniholm's recent estimate of 60km^3.[77]

It is important to note that the physical geography of the AOI is not taken into account. This is not necessary: it would unnecessarily overcomplicate matters, on the theoretical basis that the height or depth above or below sea-level will not have had any effect on the amount of material deposited from above, and my own - admittedly subjective - filter process (above) deals, as far as possible, with issues of secondary expansion and reduction. However, it is undeniable that a systematic site-by-site fieldwork study of how local topography and climate affect the formation process of tephra beds, thus placing more scientific constraints on their expansion and reduction, would be extremely welcome, and would improve these models greatly. As it is, the base line for each analysis is a horizontal plane at sea-level, i.e. at 0 ± 0 m.

The problem can also be approached by interpolating a Surface over the points. There are two ways of doing this. The Inverse Distance Weighted (IDW) model (Map 3) assumes that each data point (i.e. each measurement of tephra location and thickness) has a localised influence on the surface which diminishes with distance. A very large value for any one point will have a more profound impact on the shape of the surface, and weaken the "influence" of its "neighbours". On the other hand, the Spline function model (Map 2) fits the minimum curvature surface over each of the z values, described in ArcView's "help" function entry on the subject as "Conceptually ... like

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[77]   Floyd McCoy, personal communication, 20/1/2001.

bending a sheet of rubber to pass through the point, while minimizing the curvature of the surface".

A common difficulty affecting all these approaches in the case of the Thera ash fan is that the thickness of the plinian deposits on the island (circa 7m) and nearby is very much greater than most of the other deposits. The smaller distal deposits are measurable in centimetres rather than meters. This means that there is a large discrepancy between the levels of accuracy achievable from measurements of the large deposits on Thera and Kos, and the much smaller differences between (for example) the layers from the beds of the Anatolian lakes. The most straightforward way to address this in ArcView is to conduct the analysis with a very large number – 200 are used here - of thickness measurement categories. This achieves the highest possible resolution across the whole AOI. In the case of the TIN presented in Map 1, for example, this provides 70 classifications, which is within the required accuracy for tephra beds which begin at a thickness of 4cm (excluding trace deposits – see above, 5.2.1).

The main disadvantage of the IDW interpolation model (Map3) is that the reported elements of the Thera ash fan contain several significant planar outliers, specifically the four points from the Black Sea and the Nile Delta measurement. In practice, this means that the coordinated points have to be given a very low power, to maximise their interdependence (according them a higher power would create artificial "pools" around the outliers). What this power should be cannot be calculated exactly until the true outer limits of the AOI are located. The Spline model (Map 2) has the advantage of being consistent across all the points, but its appropriateness is questionable

because of the very large variations of z over relatively small areas of x / y. This means that the surface created "overshoots" at the top and bottom of the range by as much as two meters. Therefore, as a tool for calculating volume, it is of little use, but if the classification figures attached to Map 2 are disregarded, it provides a useful and consolidated visual assessment of the relative concentrations of volcanic material.

Regardless of which visual approach is used, it seems most probable that the estimate of the eruption's volume, derived from spatial analysis of its tephra beds, is substantially larger than any figure that has been previously advanced. If this is correct, it will be necessary to upgrade Thera on the Volcanic Explositivity Index from 6 to 7, equivalent to the AD 1815 eruption of Tambora.

5.6 Integration of GIS-based volumetric hypothesis with the geomathematical analysis in sections 4.6.2 and 4.6.3.

5.6.1 Combination of analyses In order to test the feasibility of both sets of results, a hypothetical scenario is constructed, where a (conservative) approximation of the eruption's bulk volume determined from the foregoing sections is taken as 100 km^3, and the intensity is the various rates of Q presented in Ch. 4, in Table 4.1 and Fig 4.5. Straightforward arithmetic is used to estimate the timescale of the eruption, assuming that these two parameters are true. A "realistic" answer will provide a check on the consistency of the results. Two further calculations are necessary: the plume density of the eruption

(i.e. the average ratio of solids to gas in the emissions from the vent), and a conversion of Q which, as a measure of intensity, is a factor of mass / time, to a measure of volume / time. As the values of Sigurdsson et al.[78] were used as the primary source of the geological parameters in section 4.6.2, I also use them to calculate the plume density. Although the bulk volume estimate in this study is massively greater than the 39km^3 DRE (or 8.4×10^{13}) estimated by them[79], the ratio is assumed to be constant, within the caveats outlined above, section 4.6.2, about the accuracy of sulphur measurement. Thus, given the non-solid elements, i.e. sulphur and water are estimated by them at 5.5×10^9 kg and 4.6×10^{12} magmatic water, and the total magma output at 8.4×10^{13}.

Thus:

$$\frac{5.5 \times 10^9 + 4.6 \times 10^{12}}{8.4 \times 10^{13}} \tag{1}$$

gives a value of 12% of the plume being composed of gasses. Thus, the ratio of solid : gas is taken here to be 88:12. The density of the bulk deposits themselves are even harder to identify. David Pyle has estimated from a separate analysis that the plinian deposits are in the order of 500 kg / m^3, and that the distal ashes are heavier, at 800kg m^3.[80] These values are adopted

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[78] 1990: 109 - 110.
[79] ibid.
[80] 1990: 117.

45.00

40.00   39.68682

35.00   34.93335

Time (hours) 30.00

25.00

20.00

15.00

10.00

5.00

-              1.52 ♦ ♦1.72

100,000.00 Q 1,000,000.00
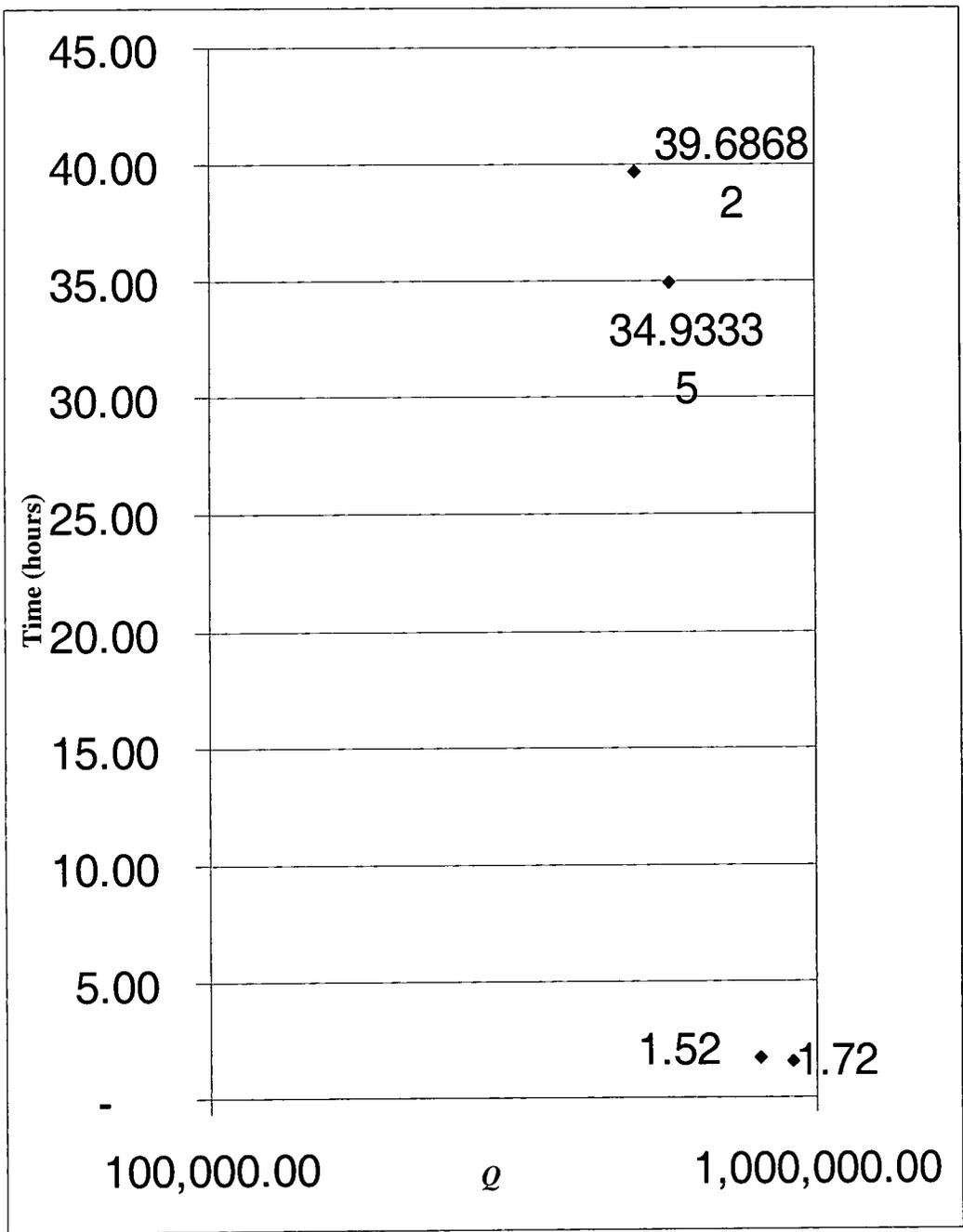
5.4

here as the hypothetical minimum and maximum, as is a notional division of the ash

fan of 10% : 90% of the two respective types.

A completely unknown quantity is the consistency of the rate of the eruption over

time. Table 4.1 represents peak rates for the value of Q as it changes over different

properties of r, for the maximal and minimal estimates for the peak velocities. How

rapidly r evolved cannot be measured directly, all it has proved possible to is to take

measurements at various points of r throughout the eruption. Thus, an average across

all four rates is taken. This rate is then divided by 88% of the bulk density to give a

value of m^3 / s, i.e. 440 in the case of the plinian material, 704 for the other matter:

$$\frac{(b \times 10^3)\rho_b}{Q}$$

where b is the relevant portion of the bulk volume estimated by GIS in meters, ρ_b is

the density of that portion, and Q is the average rate.

As in fig 4.5, in fig 5.4, two values are plotted for both estimates of v. They are

respectively 1.5 and 1.7 hours for the plinian phase, and 34.93 and 39.69 hours for the

remainder. In practice, these are far too low to be volcanologically realistic. Most

estimates put the length of the event at four days to a week. But in the context of Ch.

4, they confirm the model's applicability. These values represent the timescales of the

eruption if it had sustained its peak potential intensity across each value of r, with no

interruption or slowing - and if that had been the case, such a short-lived eruption

would be perfectly plausible. However, this scenario is also volcanologically

impossible. As stated above, the exact timescale of vent evolution cannot be estimated at this time, and this "total peak" scenario is the only one that can be constructed on the primary data available. It confirms that the peak rates for Q given in Ch. 4 are perfectly plausible, and that the GIS-based value for the bulk volume of the eruption is also theoretically and contextually possible. Furthermore, the highest possible peak rate produced by the calculations above, which occurs at $r = 285$; $v = 520$, is 1.08005×10^9; very much higher than the conventional peak estimate of 2.5×10^8;[81] which, again, would be consistent with a much larger bulk volume.

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[81] Sigurdsson et al 1990: 109.

CHAPTER 6

CONCLUSIONS: AN INTERDISCIPLINARY APPROACH FOR THE STUDY OF AEGEAN BRONZE AGE CHRONOLOGY AND THE EFFECTS OF THERA

Overview and general conclusions

The arguments discussed above deal with a wide and complex range of data. This chapter attempts to draw all of the various strands together, and present an overall framework through which Aegean Bronze Age chronology can be viewed. There are two aims. The burden of proof in Aegean Bronze Age chronology remains with those who advocate the "high" dating scheme. Firstly, I will attempt to assess whether or not the arguments, discussed above, which they have advanced, constitute such proof, and to what extent. Secondly, I wish to extrapolate on the aim I presented in my lecture to ISIS in November 2001, namely the formulation of an interdisciplinary model through which the debate can advance.

6.1 The role of scientific dating methods

There can be no doubt that absolute scientific dating methods have a pre-eminent role to play in the construction of this approach. As a discipline, the longest-established of these is radiocarbon analysis. The conclusion reached in Chapter 2 states that this method is only applicable if it is accompanied by a detailed understanding of the archaeological circumstances of each event being dated, and of the various calibration

issues involved and that, unless there is a demonstrable and specifically quantifiable contextual link between any two or more dates, they should almost certainly not be combined. Above, I show that doing so frequently biases outcomes in favour of the earlier dating schemes. This is clear in the case of the Seraglio / Ialysos set, where an ordered sequence of the events in a defined statistical model shows that there is a demonstrable sequence. It is not appropriate, in this case, to artificially reduce the data to a singe determination, and a single calibrated range, as a simple combine function does. At the extreme lowest extrapolation, the data set would allow a date as low as 1530 calBC, and it has been statistically demonstrated above that this is, indeed, most probably the final range for the set. Given that all of these dates are pre-eruption anyway, I do not find this compelling evidence for the "high" dating. It is necessary, in the future, to attempt to measure the time lapse between all of these dates and the eruption, and also to acquire more detailed stratigraphical information on their whereabouts within LM IA. At present, the only statement that goes into such detail is the table of probability sequences above. This is not sufficient. Further detailed resolution of the archaeological sequence is essential.

A very similar error has been commonly made in processing the data from Myrtos-Pyrgos and Chania. I must stress that, as with the Dodecanese data, I have no doubts about the scientific integrity of the samples or the dates, merely the way in which they have been interpreted. I dispute the overall assumption of this study that one event (i.e. the end of LM IB) is under examination. I contend that eight dates from two sites do not constitute an appropriate representation of this complex and convoluted period of Cretan history. Instead, I suggest that the end of LM IB at Myrtos-Pyrgos and at Chania are under discussion and that, in radiocarbon terms, the objective assumption

must be made that they are contextually independent, and should be treated as such, however much archaeological common sense may dictate to the contrary. I suggest that the overarching combination presented in fig 2.4 above, and relied upon heavily in his discussion of radiocarbon by proponents of the high dating[1] is inappropriate. With a 1σ calibrated range of 1612 – 1519 B.C. for the end of LM IB at Chania and 1515 – 1442 B.C. for Myrtos-Pyrgos, the only conclusion to be drawn from this deconstruction is that Chania broadly supports the "high" dating of Manning etc., whereas Myrtos-Pyrgos broadly supports a "low" or at least a "compromise low" scheme. As at Rhodes, the only way to clarify this situation is further archaeological resolution, not further statistical manipulation of the data.

This demonstrates the crucial role that radiocarbon has to play in future research. It may well be that with a better stratigraphical resolution and with the caveats of interpretation suggested here, radiocarbon could well prove or disprove either dating scheme. This is, after all, the only scientific dating method which can be related directly to stratigraphy and human occupation levels.

The place of the proxy methods of dendrochronology and, more particularly, ice-core dating, is far less certain, and its future direction much less easy to define. It is undoubtedly true that this approach has provided the "high" dating scheme with its singe strongest argument to date, with the forthcoming paper of Hammer (in preparation) concerning the Dye 3/GRIP cores likely to promote this. However, the discrepancy between the ice-core date and that from global replication of a narrow-

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[1]   E.g. Manning 1999: 247 - 55.

growth tree ring event remains unresolved. Manning (forthcoming) does provide a satisfactory answer, and the ten calendar year gap, at the levels of accuracy claimed by proponents of this method, seems to be a major difficulty. To discard the tree-rings in favour of the ice-cores (which puts severe pressure on the earlier ice-core date) seems unduly selective. On this matter, I concur with Colin Macdonald, who states that "For the moment, despite the great potential of these proxy-dating mechanisms, they must be kept on one side with anticipation."[2]

6.2 The effects of Thera, and their implications for Aegean chronology

I deal now with the issues raised in Chapter 5, before moving back to the archaeological and volcanological matters of Chapters 3 and 4. It is clear, from Maps 1 – 3 that the ash fan of the eruption of Thera has to be considered in a new light. It can now be regarded as a matter of record that the a great proportion, if not all, of Crete was affected, not just the eastern section, as previously thought. A general thickness of 1 – 3 cm across the whole island, allowing for factors such as wind drift is plausible. The implications for Minoan society and economy are difficult to judge, but it appears to provide *prima facie* support for the severe dislocation suggested by Driessen and Macdonald.[3] The rate at which the bulk volume of material which covered Crete is not, however, likely to have been significantly different from that already posited in the literature; although an increase over the course of the eruption by almost a whole order of magnitude at its climax is not impossible. Again, this would fit well with a "decline and fall" scenario precipitated by the event. However,

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[2]   Macdonald 2001: 530
[3]   1997: 117 - 8.

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the archaeological caveats in 5.2.3 above remind of the development and expansion of a remarkable pottery style in LM IB (Marine Style), and a general lack of those features which characterise a society "in decline" (although few anthropologists woul today accept the very existence of such a simplistic notion). The final evaluation must be that the immediate term impact of the eruption was crushing but not overwhelming, and that the long term material effects were far less pronounced.

Much of the data on which the new volumetric estimate for the ash fan is based come from sea-bed cores (see section 5.2). As stated above, and as discussed extensively in the literature, several factors influence the distribution pattern visible in such cores, and the specific effect of these for individual data points is not easy to calculate. Sea floor bathymetry, current and other tide dispersal, slumping, basinal accumulation and bioturbation all alter the picture. However I believe that, with the relatively large dataset employed here, these factors have averaged out, and that the computer models presented above do approximately reflect the true situation. Future research will improve these models by a) analysis in the field of how tephra beds form and how they are affected over time, b) a more rigorous assessment of the effects of wind drift and c) refinement of the application of GIS.[4]

Another possible platform of future research is the implications of the deposition of so much ash within the Aegean and East Mediterranean region. The current lack of a "smoking gun" to link Thera with the acidity signals and tree-ring growth anomalies in the seventeenth century BC (I stress the word "current", see above), and the lack of

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[4]   I hope to employ Alaska University's Puff volcanic ash tracking model. See Searcy et al. 1998: *passim.*

any such signal in the sixteenth century, may be explained if the overwhelming majority of tephra particles were dispersed "locally". Far less attention has been paid to the environmental mechanisms by which volcanic products <u>may</u> have reached the Greenland ice sheet of GRIP / Dye 3, than to the cores themselves (an understandable circumstance). However, if the tephra products are largely accounted for in the Aegean and East Mediterranean sea-beds, this may, in the future, offer a tentative explanation as to why a conjectured sixteenth century eruption left no such trace.

6.3 Archaeological cross dating and chronology of the tephra horizon

Apart from the absolute dating of LM I, L Cyc. I and LH I / IIA, there are two crucial questions: was there a "post-eruption" LM IA period, and how long was LM IB? As Manning (1999) and Marketou et al (2001) make clear, it is in the LM IB phase that the "extra" years, to fit the earlier date for Thera with the Egyptian and Near Eastern sequence must be placed.

The fresco evidence from Akrotiri, Tell el-Dab^ca and the Theban tomb paintings remains inconclusive, but the balance of probabilities points to a low dating scheme for the Aegean. Dealing with the crucial period of Hatshepsut – Amenhotep II underlines this. In the context of the question of "how long was LM IB", I begin by repeating the point made above that equating the zig-zag patterns on the kilts of some of the Keftiu with LM IIIA pottery is an extremely insecure methodology. It ignores the common-sense general principle that an aristocratic tomb painting is a one-off,

major work of ostentation, whose stylistic attributes are, if anything, likely to influence (and therefore anticipate) innovations in lesser media such as ceramics. This objection goes hand in hand with that of Macdonald[5], who points out, *pace* Manning,[6] that vessels carried by figures represented in the paintings in the tomb of Senmut are highly unlikely to represent heirlooms, a virtual presupposition if the tomb is to be dated no earlier than LM II. In addition, there are *prime facie* grounds for employing the cylinder seal illustrated by Aruz for linking LM IB / II, in the form of seal-stone iconography in Crete in this period, with the Keftiu of the later reign of Tuthmosis III. Although I admit, as elsewhere, the link is by no means concrete, it is not difficult to contrast the relative selectivity required for accepting the high dating model compared with the relative consistency for the low.

It is, however, in the study of Cypriot ceramics , and in particular White Slip I, that the inconsistency of the high dating is in danger of becoming special pleading. It is quite correct to point out that there is no easily definable system of archaeological layers in Cyprus. This contrasts with the much higher stratigraphical precision available in Crete and Egypt. As above I follow others (e.g. Popham[7]) in approaching the WS problem through analysis of attributable stylistic motifs.

By employing such an approach, it is clearly perfectly possible to accept the model of Cypriot ceramic history presented by Merrillees[8], and followed enthusiastically by

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[5]   2001: 529.
[6]   1999: 217- 20.
[7]   1972a: *passim*; and 1972b: *passim.*
[8]   1971: *passim.*

Manning.[9] As outlined above, this model stipulates a regional and temporal variation of the development of WS across Cyprus, with the PWS / LC IA:1 transitional period developing first in the north west of the island, and being adopted in the east and south later. WS I and BR I define the LC IA:2 period, with the imbalance of development stabilising across the whole island with the coming of LC IB. Manning thus contends that the "lost" bowl from Thera is of LC IA:1 date, of the transitional PWS / "WS I early" tradition. Summarising the points made above (pp 91 – 100) once again contrasts the relative selectivity of the high dating case with the more consistent low scheme. There are two specific grounds for supposing this: firstly, there is no stratigraphical indication that the process of manufacture / transmission through export / arrival on Thera / eruption of Thera happened in rapid succession, as the high dating would require. Indeed, the bowl has signs of repair in antiquity, which circumstantially contradicts this scheme. Secondly, and more importantly, some of the motifs on the bowl have links with vessels from Toumba tou Skourou that are of LC IB date. The best examples of this are: the dots bordering the wavy line, the double rows of cross-hatched lozenges, vertical four line ladder lattices, and framed wavy line bordered by dots. At Toumba tou Skourou tombs 2 and 3, all these motifs are associated with vessels dated by the excavators to LC IB. Although I would hesitate to disagree with Neimier (1980) on this subject, my own estimate would place the bowl "LC IA:2 – early LC IB". This, of course, is before the link between "WS I mature" and the early (i.e. post-1530 BC) New Kingdom at Tell el-Dab'a strata are factored in. The arguments of Bietak,[10] Bietak and Hein[11] and Warren[12] hardly need

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9 Esp. 1999: 174 - 6.
10 Esp. 1998: 321 - 2
11 2001: *passim.*
12 Most recently 1999: 901.

reiterating. If the bowl from Thera is even approximately contemporaneous with the WS sherds from Tell el-Dabᶜa, as contended by these writers, then this *terminus post quem* for the eruption must also date to approximately 1530 BC.

This leads on to the issue of where the LC and LM sequences are to be respectively placed. My argument, that the bowl is roughly contemporary with LC IB, requires further substantive information. Some such substantiation arguably comes from the corpus of Red Lustrous Wheel Made Ware. Although this type appears in the repertoire of Cypriot exports to Crete, it is not widespread on the island, and conclusions based upon its presence treated with appropriate reservation. However, it certainly has a role to play in the Thera debate.

The acknowledged expert on RLWMW, Kathryn Eriksson, does not consider the type to appear on Cyprus in a <u>secure</u> context until LC IB, with a *floruit* in LC IIA.[13] This is crucial. Two examples of RLWMW from Crete, at Kommos and, more recently at Mochlos, associate this type of jar securely with LM IB. Although the latter runs inevitably into the old problem of merely setting a *terminus ante quem* for its appearance on Crete, it is not expected that members of a non-exotic and fairly utilitarian form of vessel such as this would be exported before their native *floruit*, or kept as heirlooms for long after their arrival. Therefore, the Cretan examples of RLWMW are later, rather than earlier, than the Thera bowl. This analysis constrains the end of LM IA and the beginning of LM IB towards their lowest possible places respective to the Cypriot timescale, correlating LC IA:2 – early LC IB with mature

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[13]   Eriksson 1993: 31 - 35; 57.

LM IA, and suggesting that the end of LC IIA equates roughly with (and, possibly, even slightly before) the end of LM IB. The relationship between LC IIA and LM IB is of fundamental importance in resolving this matter. Accepting this analysis would, for example, create problems for a much-elongated LM IB phase, not least in projecting this requirement onto LC IB / LC IIA.

The interpretation of individual sherds of Aegean material from Kom Rabia, Kerma and Abydos, summarised above (section 3.4) is, admittedly, a matter of fact and opinion in each case. The only continuation of the discussion of these fragments that can be usefully carried out here concerns the sherd from Kerma: E. Vermeule's view of it, quoted by Lacovara, as definitely LH I, can now be discarded.

6.4 Tephrochronology

Based on the simple commonsense premise that the destruction of Akrotiri and the tephra fall on the Aegean and East Mediterranean from the Minoan eruption was broadly contemporary, I use this term for relating the VDL to ash horizon elsewhere. Pumice is a different story, since it is far more susceptible to re-use and re-deposition. This is not to say that ash is not similarly vulnerable. In each case, it is essential to assess whether or not the ash is *in situ*, and what its associations are. A key issue which requires resolution is the distinction between airfall and inwash tephra in the lakes sediments of Anatolia. The fact that in certain lakes under fresh investigation (e.g. Sogut), there appears to be no volcanic material in the centre implies that inwash

is a factor, and this may be exaggerating the estimate for the ash-fan's thickness in these areas.

In terms of the archaeological definition of the Thera ash horizon, the fundamental position of Vitaliano and Vitaliano[14] and Hood,[15] *pace* Marinatos (1939) remains unaltered. The best prospect for further resolution is the layer from Iasos, and Momigliano's analysis is eagerly awaited. However, section 5.2 above is the first data point by data point analysis of the whole ash fan in both its geological and archaeological perspectives. It confirms, up to a point, the general prediction put forward by Watkins et al.,[16] that the majority of the dispersal was to the east. Points (15) - (17), the two thick (2 m) outcrops from Anaphi, partly satisfy this conclusion. However, as stated above (this Chapter and Chapter 5), the highly erratic behaviour of preservation patterns remains a major problem. Tephra, and in particular its ash components, is a very fragile and easily eroded commodity, so the balance of probability is that any calculation based upon thicknesses of it will underestimate. This situation is, in some cases, further complicated by archaeological considerations. At Rhodes, Mochlos, and the settlement of Palaikastro, LM IB construction on top of the level(s) containing the ash layer mean that the material was re-worked by human activity. At Miletus, bioturbation and erosion are issues. Present day activity (tourism and illegal hotel development) at Hagia Varvara graphically illustrate that such problems are not confined to ancient site formation processes. Except in very obvious cases of slumping and / or the deposition of re-worked material (Mt Philerimos, the two measurements from inside the caldera, proximal seismic-derived estimates from

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[14]   1974: 23 - 4.
[15]   1978: 682 - 3.
[16]   1979: 125 - 6.

the sea bed around Thera), the assumption, in most cases, should be that secondary processes have decreased, rather than increased, the thickness at any individual point. The extraordinary find of a layer of <9 cm thick at depths of up to 3000 m underline this, and also support the conclusion that a very large amount of material was ejected.

The finding that the Mainland was also directly affected by ash fall has further ramifications. Although the eruption is not archaeologically visible in the material culture of the Mainland in the way that it is on Crete, the eruption clearly had some kind of impact on Mycenaean culture. This was obvious from the use of pumice (Melian, as well as Theran) at Nichoria, but the presence of airfall ash at Limni Trikhonis, Akarnania, adds a new dimension to this relationship.

It can be, and has been, argued that the pumice deposit at Tell el-Dabᶜa is of limited chronological use, as it represents merely a *terminus post quem* for the eruption in terms of the site's stratigraphy. There is no concrete rebuttal for Manning's objections[17] that the pumice may have lain on the sea-shore for years before being collected, but it can be shown, through McCoy and Heiken's tide dispersal model, and the upper time limit of 350 days from production to that this "time-lag", that Manning's analysis requires almost the longest possible construction on this time-lag. Despite this, it is possible to use an interdisciplinary approach whereby certain elements of the ceramic evidence are employed in clarifying this *terminus post quem*. Essentially, this problem revolves around a conjectured "post-eruption LM IA phase". Manning[18] is quite correct to state that no such horizon is widely defined, and that if

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[17]   Manning 1999: 147.
[18]   *ibid*: 337.

it existed, it could not be any longer than a few decades. It would, of course, be very desirable is this *terminus ante quem* could be contextualised with a solid LH I *terminus post quem* at Nichoria, but of course insurmountable doubts remain with regard to the latter. The pumice itself was not provenanced, and there remains the possibility that it intruded from a higher level.

This brings me at last to the fundamental question upon which a chronology not dependent on proxy dating methods must be based: the length of LM IB. As Manning (rightly) states, this is a "difficult and subjective"[19] matter. But some answers can be suggested. If a late LC IA:2 – early LC IB date for the Thera WS bowl is accepted (and I quite accept that problems remain with this analysis), an upper limit of mature LM IA is placed on the production of this style. The first secure appearance of RLWMW is LC IB, and its *floruit* is LC IIA, and exports of it turn up in Crete in LM IB. Given the caveats outlined above, and the likelihood that this type was very probably not regarded as heirloom material, this model constrains the length of LM IB between (shortly) before the inception of LC IB and the *floruit* of RLWMW.

More generally, Manning[20] discusses the building program in Crete within LM IB, and the emergence of dominant LM IB styles as evidence of a long process of cultural development. Many arguments could be constructed for and against this hypothesis. Suffice to say that, given the new model for ash fall over Crete given here, it is difficult to avoid the conclusion that the Driessen and Macdonald hypothesis looks more plausible, now that a far wider impact of the eruption can be demonstrated. The

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[19]   *ibid*: 334
[20]   *ibid*: 334 - 335.

view of Mountjoy and Ponting, that LH IIA, rather than LM IB was exported in quantity to Ayia Irini and Phylakopi puts a question-mark over proposed direct cultural dominance of LM IB north of Crete.[21] An indirect influence is more arguable, given the stylistic sway LM IB appears to have held of LH IIA. The very large age-ranges between the various VDL dates and the end of LM IB (Chapter 2) at Myrtos-Pyrgos and Chania mean nothing in terms of LM I chronology, but their usefulness lies in the questions they raise about the integrity of the VDL samples, the use of the calibration curve and, above all, the need to place stratigraphy and context before all else when dealing with the Aegean Bronze Age. The cases of Ialysos and Seraglio highlight this further.

As regards the absolute date of the eruption: I estimate that the WS evidence requires a date no earlier than 1550 BC, and probably some decades later, based on the time taken to produce, export, transmit and bury the Thera bowl, and the appearance of closely related types after 1530 BC at Avaris. The radiocarbon data from Ialysos and Myrtos-Pyrgos both provide a very similar conclusion.

The chronological value of the art historical links between the Aegean and Egypt have been rather over-emphasised in recent years. Motifs, which once had chronological significance ascribed to them (i.e. kilts), and appear in the Keftiu paintings in the tombs of Senmut and Rekmire, are long lived. If there is any link to be drawn between ceramic (specifically LM III:A 1) styles and the dress of Keftiu of Tuthmosid date, then the relationship between ceramic decoration and wall-painting must be studied

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[21] Mountjoy and Ponting 2000: 184. Although I observe the caveat that Crete could theoretically have ruled the entire Aegean without exporting one sherd of pottery. The wider socio-political interpretation of Mountjoy and Ponting's findings is inevitably subjective.

carefully. There is no reason to assume that one followed the other and, as suggested above, arguing that LM III is contemporary with Tuthmosis III (and LM IB is contemporary with the early New Kingdom etc.) requires some selection of what evidence is employed.

Also as stated above, the jury is still out on the proxy ice-sheet and dendrochronological data. It is to be hoped that shards of glass etc. can be associated definitively with the various acidity signals, there is clearly much potential for future development of this technique and, as with the rest of the chronology debate, it is certain to be a much argued area of Aegean prehistory in the future. The real test for the coefficiency of science and archaeology with be the future success, or otherwise, of interdisciplinary crossover between the two. This thesis has attempted to sketch out such a crossover. Much still needs to be done, and nothing is yet proven. It seems appropriate to end with the same quotation with which I concluded my 2001 Vronwy Hankey Memorial / ISIS Lecture:

And don't speak too soon, for the wheel's still in spin.

APPENDIX
MODERN WIND DATA USED IN CHAPTERS 3 AND 5

Wind directions

The units in the left hand column are compass degrees (0 = due N), and the figures given are the total frequency of readings taken when the wind direction corresponded to the given 30° section. The period of study is AD 1/1/1980 – 31/12/2000.

Heraklion

Deg.	J	F	M	A	M	J	J	A	S	O	N	D
0	491	420	577	834	850	770	468	451	527	550	561	490
30	187	174	219	194	233	212	111	57	116	166	226	236
60	105	134	178	221	210	156	58	47	136	187	159	91
90	85	60	102	126	128	84	19	18	52	85	81	69
120	30	30	28	38	31	16	7	2	4	17	26	27
150	121	79	114	161	141	118	85	79	64	87	128	112
180	1218	1137	1202	1144	995	834	553	620	832	1120	1261	1403
210	513	500	408	337	202	123	81	85	180	304	465	615
240	254	175	166	101	54	21	11	20	35	86	140	183
270	127	98	106	97	96	61	62	56	63	64	84	116
300	182	245	264	289	393	422	799	763	432	202	150	164
330	479	625	738	711	998	1348	2167	2127	1437	944	454	355
360	878	916	771	502	548	455	430	507	671	989	847	794
total	4670	4593	4873	4755	4879	4620	4851	4832	4549	4801	4582	4655

Naxos

Deg.	J	F	M	A	M	J	J	A	S	O	N	D
0	1837	1707	1811	1989	2043	1249	1011	1031	1108	1133	1057	1130
30	556	611	685	599	925	945	1490	1642	1077	972	769	671
60	32	41	27	20	23	27	43	54	38	26	37	34
90	11	8	15	7	5	3	3	3	5	9	6	14
120	70	59	54	48	20	15	7	10	27	36	72	71
150	168	174	222	216	149	117	39	41	122	145	215	198
180	384	397	361	427	360	274	77	104	218	254	506	460
210	337	294	294	376	251	209	58	48	163	129	257	307
240	102	134	95	84	32	24	2	5	17	29	50	83
270	23	40	37	45	21	6	2	3	7	10	18	26
300	29	31	39	31	16	23	5	5	13	15	25	29
330	42	59	57	72	54	42	19	18	37	29	25	39
360	1106	1067	1065	795	927	1121	1563	1287	1195	1328	728	955
total	4697	4622	4762	4709	4826	4055	4319	4251	4027	4115	3765	4017

Skyros Airport

Deg.	J	F	M	A	M	J	J	A	S	O	N	D
0	2368	2066	2366	2527	2752	2017	1753	1656	1702	1583	1528	1519
30	684	651	742	352	487	514	989	1061	784	882	554	605
60	465	490	515	181	222	206	282	338	422	610	417	477
90	99	132	170	141	142	163	93	102	150	174	164	138
120	59	62	73	98	85	82	57	52	88	74	75	44
150	34	65	36	87	26	28	13	15	32	23	54	30
180	77	148	123	160	77	51	25	11	42	72	143	153
210	331	321	307	367	197	129	36	32	84	154	347	327
240	152	172	129	260	207	135	27	32	79	114	189	174
270	58	84	83	140	117	95	41	15	47	28	43	57
300	54	97	68	110	107	106	72	69	48	48	47	90
330	130	120	115	149	159	252	189	198	150	80	109	125
360	238	227	230	350	489	490	836	829	424	301	217	233
total	4749	4635	4957	4922	5067	4268	4413	4410	4052	4143	3887	3972

Average Aegean wind speeds (knots)

Heraklion

YEAR	January	February	March	April	May	June	July	August	September	October	November	December
1980	12.4	12.5	9.7	7.2	8	5.4	6.1	8.8	7.9	6.4	7.4	9.1
1981	10	8.7	8.3	5.6	7.2	5.5	8.9	7.5	6	7.1	8.1	9.4
1982	10.9	12.7	15.1	10.2	8	7.8	11.7	11.1	11.5	9.4	14.6	13
1983	14.6	18.7	14.9	9.2	10.2	10.8	11.4	13.1	11.2	9.1	10.9	10.4
1984	11.6	9.5	10.9	11.5	10.8	11	13.9	11.8	8.9	8.2	10.5	8
1985	9.5	11.6	7.9	9.4	6.5	7	12	10.7	11.6	9.4	9.5	8.7
1986	12.5	14.4	8.1	7.8	9.1	7	8.2	8.8	8.5	9.1	9.9	8.7
1987	11.1	10.5	10	10	7.4	7.2	8.8	9.2	7.9	11.4	9.1	11
1988	7.4	8.7	9.3	5.7	6.1	4.8	10.6	8.9	6.6	10.2	10.2	9.7
1989	11.3	10.4	7.4	5.5	5.7	5.6	10.2	7.4	7.2	10.6	8	8.2
1990	8.2	11.9	8.2	7.1	5.5	7.7	9.6	9.8	7.1	7.1	8.3	8
1991	9.7	8.1	6.5	8.6	8.6	7.2	9.2	10.4	6.3	6.7	9.1	14.1
1992	7.2	10.3	6.9	8.4	8.7	7.4	10.1	9	10.7	5.5	8.4	11.2
1993	10	12.3	9.2	8	6.3	6.9	10.2	9.9	8.1	6.3	10.1	7.6
1994	10.1	9.2	10.6	8.8	7.3	9.3	10.1	10.1	7.6	6.1	11.9	10
1995	9.8	10	9.1	6.6	9	6.1	10.8	8.3	7	9	8.4	8.9
1996	9.4	9.7	9.6	8.4	6	9.6	10.3	8.9	8.4	6.8	6.5	10
1997	8.7	8.9	9.4	8.7	7.1	6.8	8.1	9.7	9	9.1	7.9	9.4
1998	7.1	10.7	11.2	8.9	8.4	8.4	9.6	9.4	6.9	7.8	7.4	9.3
1999	9.1	9.1	8.1	7.7	7.5	9	9.7	9.9	6.4	9.2	11.1	9.2
2000	11.9	10.1	9.8	7.6	6.7	9.7	8.3	10.6	8	9.1	7.2	9.4

Naxos

YEAR	January	February	March	April	May	June	July	August	September	October	November	December
1983	*	*	*	*	*	*	*	*	*	*	*	*
1984	*	*	*	*	*	10.1	15.8	13	8.9	12.1	12	13.1
1985	12.4	15.4	11.2	7.7	6.2	6.4	12.8	10	16.9	15.7	11.8	10.7
1986	10.8	15.1	16	7.9	11.4	7.5	11.3	11.9	13.8	14.9	17.3	15
1987	16.3	14.8	13.4	13.1	7.5	8.1	12.6	13	11.7	18.3	8.9	14.6
1988	11.4	14.4	10.5	9	7.6	6.6	13.2	10.4	11.7	17.1	14.5	12.5
1989	21.3	15.5	11.5	9.4	9.9	4.5	13.8	9.1	10.5	16.9	12.3	15.5
1990	15.5	20.2	14.3	10.4	11.6	10.3	14.2	14	11.6	14.3	9.9	10.3
1991	17.1	14.4	14.8	12.5	9.2	10.7	12.1	17	12.8	11.8	13	20.5
1992	16.5	17	14	10.4	14.3	8.5	12.5	11.4	18.4	8.2	13	18.8
1993	17.9	20.4	13.8	11.6	8.6	9.4	14.6	12.9	12.4	10.7	16.3	13.2
1994	13	13.2	17.6	11.7	8.6	13.9	13.5	12.3	10.2	10.6	19.2	14.2
1995	15.1	16.7	13.4	8.7	10.3	5.6	15.4	11	9.8	17.7	11.8	12.5
1996	16.5	15	18.2	13.5	9.2	14.1	15.1	12.5	8.7	14.2	13.2	14.8
1997	16.9	16.3	20.1	13.4	11.4	9.8	11	14.2	20.1	15.6	11	14.6
1998	12.2	19.6	17.1	11.2	9.9	11.8	14.3	14.7	13.9	10.7	11.2	19.1
1999	17.7	14.9	10.1	7.9	12.1	12.7	14.3	13.8	12.1	12.1	19.2	10.4
2000	21.7	14.8	13.1	8.1	9.5	15.5	12.5	15.3	15.2	16.9	12.1	15.3

* indicates that no data are available for this month

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Skyros Airport

YEAR	January	February	March	April	May	June	July	August	September	October	November	December
1983	*	*	*	*	*	*	*	*	*	*	*	*
1984	*	*	*	*	*	6.3	6.7	6.3	4.6	6.4	9.1	10.3
1985	10.8	9.8	8.2	6.5	4.1	4.6	6.2	7.9	8.4	8.6	7.7	8.4
1986	8.9	10.6	10.3	5.5	6.3	6.7	5.9	8.4	7.5	10.1	10.2	7.8
1987	11.6	12.5	13.4	10.5	5.4	3.7	6.1	6.4	7.2	10.5	9.3	9.7
1988	8.8	11.6	9.5	5.9	4.1	4.8	7	6.9	7	9.7	8.1	8.6
1989	10.2	10.4	7	6.7	6.9	4.7	7.4	6.1	6.5	9.3	7.7	6.4
1990	8.9	11.3	9	9.8	6.6	8.5	10.9	10.8	6.3	11.5	9.1	8.2
1991	10.8	9.9	7.5	7.4	6.8	3.8	7.1	11.2	9.2	8.4	9.3	13.5
1992	9.8	10.4	10.3	5.1	7.9	6	7.2	7.4	8.3	7.8	8.6	13.1
1993	9.1	10.7	6.6	5.4	2.8	3.7	4.7	5.2	5.3	5.6	10	7.9
1994	8	9.1	7.9	6.7	5.3	6.6	7.3	5.5	4.6	7.1	9.4	7.8
1995	8.4	8.3	9.3	6.5	7.7	5.1	7.3	6.1	5.8	11.2	8.4	9.9
1996	11.7	9.3	9.3	5.3	5.5	6.6	7	6.2	7.6	8.2	8.2	9.8
1997	7.3	8.4	8.6	6.3	4.3	3.5	6	7.7	10.5	9.9	5.5	8.9
1998	6	9.3	9.9	8.6	8.3	5.8	8.8	9	7.9	8.7	10.5	15.6
1999	11.1	11	8.1	6.4	6	5.4	6.9	5.3	7.2	5.2	10.2	9.8
2000	10.8	9.4	7.1	5.2	5.3	4.9	4.8	7.9	7.6	7.4	5.4	8.5

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