

**Lecture Notes in
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177

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(Editors)

Tools for Constructing Chronologies

Crossing Disciplinary Boundaries



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The Synchronization of Civilizations in the Eastern Mediterranean in the Second Millennium BC: Natural Science Dating Attempts

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Summary. This chapter reports on work undertaken during the first three years of a ten-year project which aims to synchronize a range of relative and absolute dating evidence arising from archaeological records of the civilizations of the Eastern Mediterranean in the second millennium BC. At present the team is collecting chronological information from many different geographical locations. Some of the chronological methods are covered in more detail elsewhere in this volume (e.g. tephrochronology, Chapter 8 and radiocarbon dating with Bayesian models, Chapters 1 and 2) and other methods such as dendrochronology and astrochronology are explained in detail here. It is already clear that the different dating methods do not lead directly to a coherent chronological picture for the region. Consequently, one of the major issues that must be tackled by this project is the synchronization of chronological evidence from different sources. This chapter outlines the nature of the evidence available and explains some of the techniques that the project team plans to use to link together the diverse dating evidence and thus develop their final chronological understanding.

4.1 Introduction: the SCIEM 2000 Project - Archaeological methods of creating and documenting chronology

The SCIEM 2000 project (a major research programme of the Austrian Academy of Sciences, the Institute of Egyptology at the University of Vienna and the Austrian Science Fund, FWF) started in 1999 and has recently completed the first three years of its planned ten years of existence (Bietak 2000). As the name indicates, the project's aim is the "Synchronization of Civilizations in the Eastern Mediterranean in the second millennium BC". In order to create a definite chronological framework for the history of the second millennium BC both archaeological and scientific methods are applied in 15 subprojects. The remarkable financial and personal effort is justified by the

immense importance of the Middle and Late Bronze Ages for the rise of European culture and the history of the Ancient Near East, Egypt and Anatolia. The regrettable lack of knowledge concerning exact chronological data in this relevant period of time seems to be reason enough for a combined effort of all disciplines available. The first three years brought to light the gaps between different schools, sites and disciplines. It is the ultimate goal of our project to bridge those gaps by using both long-established and newly discovered links in material culture. Tell el Dab'a in the Eastern Nile Delta has been confirmed to be the site of ancient Auaris by Manfred Bietak and thus now offers a point of reference for our efforts.

The need for a new evaluation of the overall chronological situation became apparent especially in Egypt because High and Ultra High chronologies (Manning 1999) seemed to put a tremendous strain on the well-established Egyptian chronology based on the historically and epigraphically reconstructed kinglist. In spite of the fact that for most periods of Egyptian history names of kings together with the years of their reigns are known (Beckerath 1997; Kitchen 2000), significant gaps and uncertainties are still unsolved. Especially in the Second Intermediate Period the consistency of the historical Egyptian record shows serious lapses. There is much discussion on co-regencies and other possibilities that tend to weaken the relevance of the Egyptian list for absolute dating in this part of the second millennium (Ryholt 1997). The chronology of the Middle Kingdom on the other hand, is generally assumed to be accurate. The absolute chronological dates are gained by calculating the known lengths of regencies and taking the reported and recalculated Sothis dates as fixed points. The traditional one-sided picture of the Egyptian part of the link producing the absolute dates for Aegean and other neighbouring sequences seemed to change when the Santorini eruption was dated with scientific methods. Unfortunately this new, very early date (17th century BC) seemed to make the sequences drift apart. It appears to be quite impossible to squeeze an additional 150 years out of the traditional sequence of time based on the regencies of Egyptian kings. Scholars who were used to chronological discrepancies of 20 to 30 years suddenly saw themselves confronted with a completely new, utterly irritating situation.

There are several important reasons for the prominent position of Tell el Dab'a in the project. First of all it is a node in the network of Bronze Age interrelations, ethnically, culturally and with respect to the material culture of the Eastern Mediterranean. This fact has been established by long, continuous excavations that have tried to meet the highest standards both of excavation technique and documentation from the beginning (Bietak 1976). A population of Levantine origin dwelt in the Eastern Delta together with Egyptians for hundreds of years and produced a material culture that shows both Egyptian and Levantine traits. Recent finds of Minoan wall paintings and weapons of Aegean origin gave further evidence of the multicultural nature of the site.

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The traditional way of arranging objects in sequences is the typological method. The contexts that are required for the construction of typologies in the Montelian sense have been found in Tell el Dab'a in the form of numerous tombs, some of them undisturbed. Recent work tries to focus on the problematic nature of this way of creating chronological sequences. The linking of highly "ideological" deposition in the funerary context to settlement contexts may produce an incorrect picture of chronological development.

The Data Management Branch of the SCIEM 2000 project constitutes a node within the project where scientific and archaeological efforts are fused with the help of a specially developed software package. Flexible data management and the necessity of a certain degree of standardization are important features of modern relational database design and help to enforce terminological and other conventions while providing abundant possibilities for output and analysis. The more general aim of constructing databases for input of all relevant data has been approached during the first part of the project and will now be expanded further to new projects, like the so-called "Handbook of Middle Kingdom Pottery". This is intended to be a guidebook where any pottery shapes found in the Eastern Mediterranean can be compared with the corpus of Middle Kingdom pottery found in Egypt. This corpus will be as complete as possible. Both a traditional publication in two volumes and an interactive database accessible via the Internet are planned. The database is based on traditional typological labels and newly developed shape-recognition software that allows a user to access the database, and to compare a shape with the corpus even in ignorance of the typonyms of Egyptian Archaeology, with the degree of similarity evaluated by means of a seriation package. The archaeologist is thus able to find the links in material culture to verify whether a given vessel is of Egyptian origin. If it turns out to match then information as to where and how the vessel clusters within the corpus of Egyptian pottery is promptly available. Databases on the pottery of other epochs of Egyptian history are planned for the future.

For more information on projects, collaborators, conferences, publications see our homepage at <http://www.nhm-wien.ac.at/sciem2000/>.

Archaeological evidence from nine archaeological projects is currently being investigated and compared. Particular emphasis is being placed on the synchronization of the Egyptian chronology of the Middle Kingdom and Second Intermediate Period with the period of transition from Early Minoan/Middle Minoan to Late Minoan strata in the Aegean. The aims and possible problems are discussed at length in the proceedings of an international symposium at Haindorf Castle in 1998 (Bietak 2000).

To produce absolute data, independent from the relative results of archaeology, four science projects working with different materials and approaches are involved. They are the focus of this chapter.

4.2 The Thera Ashes Project

The general idea of this project is to fix the "Minoan" eruption of the Santorini volcano during the 2nd millennium BC within the relative chronologies of the regions of the Eastern Mediterranean by finding the eruption products of this event within well-defined stratigraphies of archaeological sites. Although the date of the eruption is still the subject of intense debates, the eruption products, wherever they are found, can be used as tangible evidence for contemporaneity or at least post-eruption dating of the strata. During this strong explosive event a large volume of magma was erupted in a short time span of not more than a few days and the eruption products were distributed over a large area. The majority of the erupted material consists of chemically rather homogeneous pumice tephra and pumiceous flow deposits, the "Minoan tuff" or "Oberer Bimsstein" (Bo, upper pumice; Vitaliano et al. 1978, 1990; Francaviglia and DiSabatino 1990; Sparks and Wilson 1990; Druitt et al. 1999). The volume estimations range from 16 to 35 km³ of dense rock equivalent (Sigurdsson et al. 1990; Pyle 1990). The impact on the contemporary civilizations is evident and alluvial pumice as well as direct fallout from the eruption cloud is reported from several sites on Greek islands and Asia Minor (Marinatos 1932; Zeist et al. 1975; Watkins et al. 1978; Keller 1980; Pichler and Schiering 1980; Vinci 1985; Francaviglia 1986, 1990; Sullivan 1988; Marketou 1990; Soles and Davaras 1990; Warren and Puchelt 1990; Guichard et al. 1993; Eastwood et al. 1999). The fallout formed a synchronous layer of volcanic ash (tephra with a grain size of less than 2 mm) that can be used directly as a datum line. Assuming a reliable identification, it can be used for chronology wherever it is found in primary deposits (Einarsson 1986). Furthermore, pumice is a very useful abrasive and has been collected and traded since prehistoric times, as reported by Pliny in his *Natural History* book XXXVI (Faure 1971). The applicability for chronological purposes has been checked in earlier studies by demonstrating that the "Minoan" pumice is sufficiently homogeneous and can be distinguished from the numerous other Aegean pumice sources by its trace element distribution pattern ("chemical fingerprinting"; Bichler et al. 1997; Peltz et al. 1999; Schmid et al. 2000). The identification of distant tephra layers and the possible sources of errors are discussed in Schmid et al. (2000) and Saminger et al. (2000).

4.2.1 Pumice Results

Ninety-six samples of archaeologically stratified pumice found in excavations in Egypt, Palestine and Israel were investigated and identified. One sample from Tell el Dab'a could not be related to an Aegean volcanic source. Their geographical locations are shown in Figure 4.1, a sample overview is given in Table 4.1.

The sample preparation is described in detail in Peltz et al. (1999). The analytical results allow a clear identification of the volcanic sources (Bichler



Fig. 4.1. Geographical locations of pumice sources in the Aegean Sea and archaeological excavation sites with finds of pumice.

Table 4.1. Identified pumice samples. Period abbreviations are MB: Middle Bronze Age; LB: Late Bronze Age; LC: Late Cypriote.

Excavation site	Period	Number	Provenance
Tell el Dab'a	MB/LB	32	1 Nisyros, 29 Santorini, 2 Kos
Tell el Herr	Roman	1	Santorini
Tell el Hebwa	LB	10	all Santorini
Ashkelon	MB	3	1 Giali, 2 Nisyros
Tell el Ajjul	MB/LB	48	46 Santorini, 2 Nisyros
Maroni	LCIIC	1	Santorini
Lachish	13th cent. BC	1	Nisyros

et al. 2002). To graphically demonstrate the identification, a normalization procedure is carried out; the concentration of an element is divided by the mean concentration of that element in bulk Minoan pumice. Thus the graphs show only the deviations from the composition of the Minoan pumice.

First, investigations on well-defined volcanic strata of several Aegean volcanoes were carried out to clearly define their individual chemical compositions. Figures 4.2 to 4.5 show the natural variation ranges of these Aegean pumice sources and the agreement with some typical samples from excavations. Our results demonstrate that the pumice samples found in archaeological excavations only show minor changes in composition due to leaching effects, although glass hydration effects and strongly weathered rock surfaces were observed, especially in the water-saturated sedimentary environment of Tell el Dab'a. The samples identified as related to the Kos Plateau Tuff eruption show a significant depletion of some elements (Sc, Co and Sb). This is due to the special mineralogical properties of this material and does not interfere with the identification (see Peltz et al. 1999). From the chronological point of view, the results obtained for the excavated samples agree with the present dating range of the Minoan eruption between 1650 and 1450 BC.

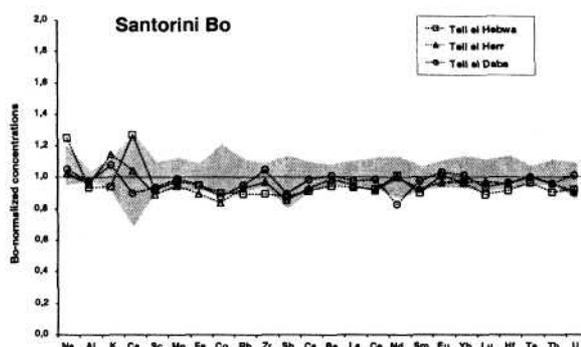


Fig. 4.2. Normalized element abundances of pumice samples from Egypt identified as "Minoan" pumice from the Santorini Bo-layer. The shaded area shows the natural range of variation of elements in Bo-pumice. Normalization factors and natural variations from Peltz et al. (1999).

4.2.2 Volcanic Ash Results

Tephra particles have been sought in 114 stratified soil samples from Miletos, Ebla, Megiddo and Cyprus. Additionally, drill cores from Delphinos (Crete,

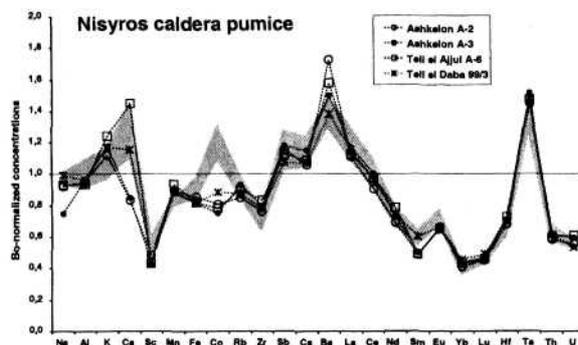


Fig. 4.3. Normalized element abundances of selected elements found in pumice samples from Egypt and Palestine identified as pumice from Nisyros. The shaded area shows the natural range of variation of elements in Nisyros pumice. Normalization factors and natural variations from Peltz *et al.* (1999).

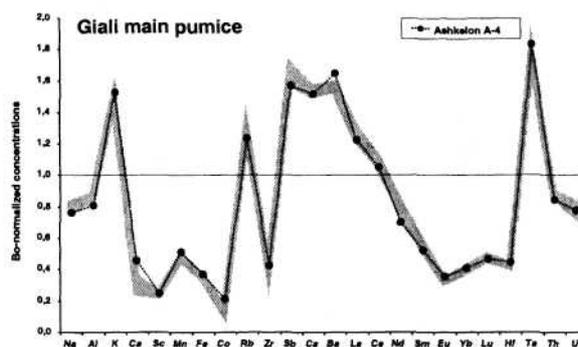


Fig. 4.4. Normalized element abundances of selected elements found in a pumice sample from Ashkelon identified as pumice from Giali. The shaded area shows the natural range of variation of elements in Giali pumice. Normalization factors and natural variations from Peltz *et al.* (1999).

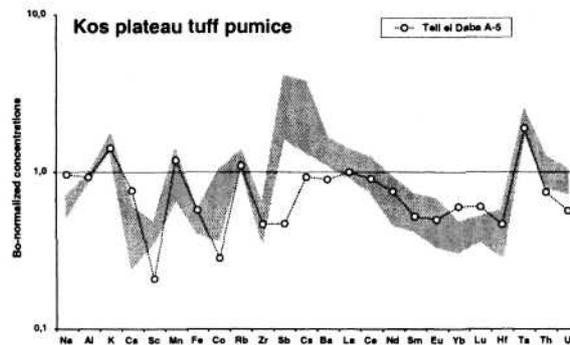


Fig. 4.5. Normalized element abundances of selected elements found in a pumice sample from Egypt identified as pumice from Kos. The shaded area shows the natural range of variation of elements in Kos pumice. Normalization factors and natural variations from Peltz et al. (1999).

Greece), Ova Gölü (south-western Anatolia) Gölbasi and Amuq (Orontes plain, Turkey) have been sampled. The geographical locations are shown in Figure 4.6. The preparation included a separation procedure (decarbonatization, sieving fraction 0.01 to 0.25 mm) to enrich tephra particles prior to polarization microscopy. Only five soil samples, all from Miletos, and one drill core (Delphinos) were found to contain volcanic particles. From these samples a satisfying pure tephra fraction (>95%) has been separated to enable the analytical identification. The results certify a Santorini "Minoan" origin (see Figures 4.7 and 4.8). The enrichment of chromium and antimony in the Milesian samples is caused by local soil contamination.

4.2.3 Discussion of Thera Ashes Results

On the basis of the results obtained we draw the following conclusions: the area, where direct fallout from the eruption plume could be expected in detectable quantities in prehistorically inhabited regions, is restricted to Aegean islands and Asia Minor. It can be assumed that low-altitude tropospheric currents led to a "tephra fan", which is in accordance with earlier estimations based on deep-sea drill cores (Richardson and Ninkovich 1976; Pyle 1990). Fine particles reaching higher atmospheric levels obviously followed a different, ENE-oriented distribution trend (Figure 4.9). This agrees perfectly with the reported tephra findings in Anatolia and the Black Sea (Guichard et al. 1993; Eastwood et al. 1999; Pearce et al. 1999). Previous studies (Stanley and Sheng 1986) that report tephra particles from the "Minoan eruption" even

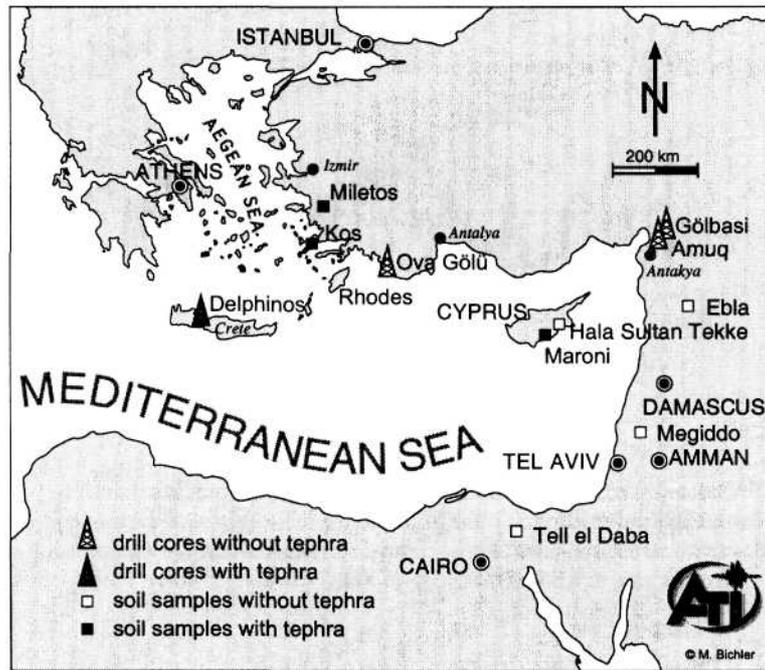


Fig. 4.6. Geographical locations of soil samples and drill cores.

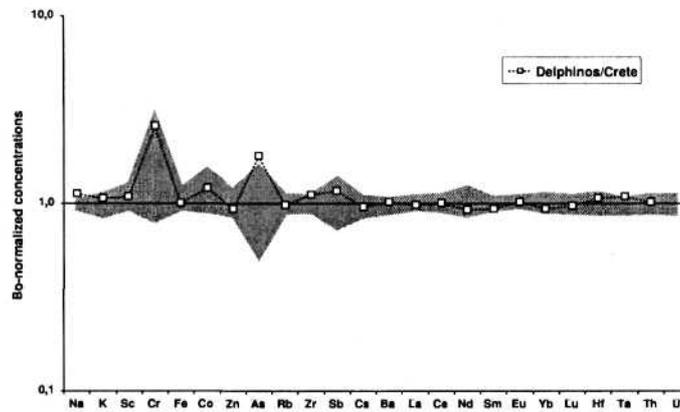


Fig. 4.7. Normalized element abundances of volcanic glass particles separated from the Delphinos (Crete) drill core identified as "Minoan" tephra. The shaded area shows the natural range of variation of elements in Bo-pumice. Normalization factors and natural variations from Peltz *et al.* (1999).

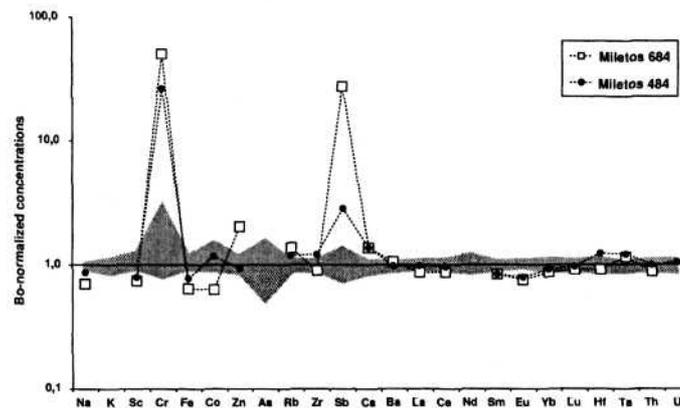


Fig. 4.8. Normalized element abundances of volcanic glass particles separated from soil samples from Miletos, identified as "Minoan" tephra. The shaded area shows the natural range of variation of elements in Bo-pumice. Normalization factors and natural variations from Peltz et al. (1999).

in Nile delta sediments are not necessarily erroneous, but might have identified particles produced by fragmentation of alluvial pumice deposits or even by human use of pumice as an abrasive. The numerous findings of "Minoan" pumice in Tell el Dab'a prove the extensive use of this pyroclastic material in more or less contemporary Egypt. Consequently, the search for pumice in settlements being excavated has been intensified and yielded a large number of samples in cooperation with the archaeologists responsible. Surveying the first appearances of "Minoan" pumice in well-stratified sites will enlarge the region where the products of this eruption can be used to establish a datum line across the Eastern Mediterranean and will contribute significantly to the determination of the absolute chronology of the eruption.

4.3 The Astrochronology Project

4.3.1 Introduction

According to the astronomer Sosigenes the ancient Egyptians had been developing their own calendric system since about 3000 BC and started off with a lunar calendar. Egypt is unique in early civilizations in being especially dependent on one event: the flooding of the Nile. The moon consistently failed to predict this but the stars were very serviceable. The Egyptian priests soon noticed that the heliacal rising of Sirius (first day visible just before sunrise) always preceded the flood by a few days (Library 1983; O'Neil 1986; Paul 1993; North 1994). They eventually had a system of 36 stars to mark out the year and ultimately had three different calendars working concurrently



Fig. 4.9. Proposed regional distribution of the Minoan tephra deposit.

for over 2000 years: a stellar calendar for agriculture, a solar year of 365 days (12 months x 30 + 5 extra) and a quasi-lunar calendar for festivals.

In the last decades BC the calendar had become so confused that Julius Caesar invited the astronomer Sosigenes from Alexandria to renew the basic system for both the Roman Empire and Egypt. Sosigenes replaced the lunar system with a tropical year of 365.25 days (the *solar*, or *tropical*, year is the time interval between successive passages of the sun through the vernal equinox, which is the time of the year when the lengths of the day and the night are equal). Further, to correct the accumulation of previous errors, a total of 85 intercalary days had to be added to 46 BC, meaning that 1 January 45 BC occurred in what would have been the middle of March. To prevent the problem from recurring, Sosigenes suggested that an extra day be added to every fourth February. The adoption of such reformatory measures resulted in the establishment of the Julian calendar, which was used for approximately the next 1600 years (Richmond 1956; O'Neil 1986; North 1994).

As some political events in the Middle and New Kingdom are mentioned in connection with stellar or lunar constellations, the aim of this project is to recalculate these constellations to achieve more precise astronomical dates for these events.

4.3.2 Calculation of Stellar and Lunar Constellations

The present investigation creates a database for heliacal risings of Sirius calculated for the latitudes of Memphis and Thebes during the years 2000 BC until AD 1. The tables are calculated with the *javascript* program *HELIA C* which offers sufficient accuracy to give the correct day of this stellar phenomenon (<http://geocities.com/CapeCanaveral/Launchpad/4633/heliacJAVA.html>).

Depending on the transparency of the atmosphere, heliacal risings can occur when Sirius is 3° to 5° above the horizon. The recalculated results for a height of 3° are in perfect agreement with other recent recalculations (Schaefer 1997), where atmospheric and aerosol components were incorporated as well as an extinction-coefficient.

In order to archive a better temporal correlation with the monthly festival texts of the Illahun tablets, a database for the dates of the last lunar crescent visibility and the first lunar crescent visibility for the years 1861 to 1811 BC are given at the latitude of Thebes. No corresponding tables are given for Memphis, the other astronomical centre of ancient Egypt, as the lunar heights at these special phases differ only by a mean value of 0.3° and thus do not yield any different monthly dates. The program *URANI STAR 1.1* (available at <http://members.eunet.at/vollmann/>) was found to yield the correct dates when compared with the most recent lunar theory by Chapront-Touze and Chapront (1991). Further special lunar quarter phases can be found in the Five Millennia Catalog of Phases of the Moon -1999 to +3000 calculated by F. Espenak (in Chapront-Touze and Chapront 1991, and at <http://sunearth.gsfc.nasa.gov/eclipse/phase/phasecat.html>).

4.3.3 Discussion of Astrochronology Results

Three major uncertainties influencing the interpretation and usage of the reconstructed stellar and lunar constellations still exist:

- When was the actual beginning of the Old Egyptian month? Was it definitely the last lunar crescent?
- Where were the astronomical observers based? Were they working at Memphis or Thebes or somewhere else?
- As the heliacal rising of Sirius was reported only every fourth year, when was the beginning of this cycle? Exactly when did the five extra days per year fall?
- Was the heliacal rising of Sirius defined to happen with an angle of 3°, 4° or 5° above the horizon?

It is not yet possible to find any detailed answers to these questions. Thus the accumulation of all these uncertainties makes it impossible to achieve a resolution better than the time difference between the "High Chronology" and the "Low Chronology". Therefore the results of the project will only be helpful to give more accurate absolute astronomical dates if based on improved

historical knowledge of details (definitions, methods, and locations) of Ancient Egyptian astronomy.

4.4 The Dendrochronology Project

4.4.1 Introduction

The main aim of this project is to carry out dendrochronological investigation of wooden artefacts (building construction parts, coffins, picture tables, objects of art, charcoal) and to establish floating chronologies for the second millennium BC. The aim is to link the objects of the relevant time period to a relative chronology of certain historical events. These efforts are being continued in order to close gaps between existing floating chronologies.

By autumn 2002 we had started collecting data and samples from standing trees, historic buildings and archaeological finds (charcoal, ship's masts, etc.) in an attempt to set up an absolute standard starting in the present and reaching back to the second millennium BC. It would then be possible to establish absolute dates for other wooden objects via the age of the last ring (if the waney edge, which is the last ring grown before the tree's death, is preserved).

4.4.2 Selection of Wood Species for Dendrochronological Investigations

The selection of wood species for investigation depends on their occurrence in the archaeological objects available for investigation and on their suitability for dendrochronology.

Table 4.2. Compilation of results of wood species analysis of Old Egyptian objects from the Louvre (Nibbi 1981), Munich and other collections (Grosser et al. 1992) and the British Museum (Davies 1995).

Wood species	Louvre	Munich and other	British Museum
<i>Ficus sycomorus</i>	32	138	230
<i>Tamarix</i> sp.	>100	106	158
<i>Acacia</i> sp.	35	42	53
<i>Cedrus</i> sp.	5(7)	44	88
<i>Juniperus</i> sp.	2	10	16
<i>Pinus</i> sp.	9	3	37
<i>Cupressus</i> sp.	-	2	7

The results shown in Table 4.2 give a rough idea of the spectrum of wood species used in ancient Egypt for various purposes but do not necessarily reflect the spectrum of samples available for the project.

Cedrus libani is perhaps the most interesting of the species cited below. This species grows in Mediterranean mountain climates and has distinct ring borders. Its life span is said to be as long as 500 years. It has been imported to Egypt since the time of the Old Kingdom. Due to over-deforestation only a few small relict areas are still alive in Lebanon, with larger ones in Turkey (Taurus, Antitaurus) and Syria. The subspecies *Cedrus libani atlantica* grows in the Atlas Mountains of Algeria and Morocco, whilst *Cedrus libani brevifolia* grows in a very limited area in the mountains of Cyprus. These three subspecies cannot be separated by anatomical features of their wood. Hence, because of different interpretations of Egyptian texts mentioning imports of wood from certain countries, a heated debate continues as to whether cedar wood found in Egypt had its origin in Lebanon or somewhere else (Nibbi 1981, 1987, 1994, 1996; Meiggs 1982; Grosser et al. 1992; Davies 1995). Another debate deals with the correct translation of different hieroglyphs which characterize different wood species (Loret 1916; Meiggs 1982).

The degree of deforestation can be estimated by the occurrence of rock carvings marking so-called "Hadrian's forests" (Mikesell 1969). These forests were marked and protected as a resource for building ships for the Roman navy. The area of cedar forests was much larger even in Roman times than it is today.

Substantial investigations on important archaeological sites and the occurrence of cedar wood were carried out by Liphshitz (1986), Bikai (1991), Lev-Yadun (1992), Liphshitz and Biger (1992) Kuniholm (1996), and Newton (1996). Unfortunately, in the literature the term "cedar" was used not only for *Cedrus* sp., but also for wood of *Juniperus virginiana* (Lucas and Harris 1962), as well as a modern commercial name for wood of the Cupressaceae *Calocedrus decurrens*, *Thuja plicata* and *Thuja occidentalis* (Wagenführ and Schreiber 1989).

4.4.3 Objects to be Measured

For a floating chronology (2nd millennium BC): these will mainly be objects of art stored in museum collections (coffins, painted panels, statues etc.), but also new finds in recent excavations (e.g. charcoal).

For absolute standard (from today back to the 2nd millennium BC): samples will mainly be taken from standing trees, construction materials (roof constructions, ceilings, wall supports etc.) of standing buildings, but also from objects of art.

4.4.4 Sampling and Data Acquisition

In most cases it is not recommended to mix samples of different wood species for the construction of a reference chronology. To avoid these problems wood

species analysis (identification of anatomical structures of a very small sample with the help of a light microscope) of all objects available for investigation is the first step.

In order to measure the thickness of all the rings in a particular piece of wood, it is necessary to get a view of its cross-section. Wooden parts of the architecture of a building often allow either a disc to be cut or a radial core to be drilled. After smoothing the surface, the ring borders become visible. For our project in some cases a 14 mm coring tool may be used, as cores can be polished as finely as necessary and doubtful measurements may be re-examined later.

If the surface (square or longitudinal) of a wooden object is not covered with paint and has been well smoothed by the ancient manufacturer, after some cleaning the rings can often be measured directly on the object. For objects coated with paint or other surface covering, equipment for drilling a 5 mm diameter hole to allow endoscopic measurement of the ring widths is under construction.

At least two radii of a sample are measured. The mean is calculated to compensate for biological diversity (e.g. elliptic ring shape, single growth deviations). The result is a list of mean growth-ring thickness for each year contained in the sample.

A sample has to show at least 50 rings, otherwise the statistical methods for dating will fail to work. It is necessary to collect and measure as many promising samples as possible from one complex (a "time-unit") to calculate a reliable mean value list for further analysis.

4.4.5 Measuring the "Samples"

In the beginning we had hoped to use the techniques usually used in dendrochronology to collect data (to cut discs or drill cores), but sampling of any museum objects turned out to be impossible. We might have been permitted to drill the occasional core, but without lots of data a statistical method like dendrochronology does not work. Therefore we were forced to develop non-destructive methods to collect a sufficient amount of accurate data. Different techniques were tested to measure the ring-width on plain and unpainted longitudinal and square surfaces. Two of them are already working properly. For plain surfaces a flat-bed scanner with 2400 dpi resolution was re-designed to work in all positions. It is placed on a monopod or tripod and the scanning direction is orientated parallel to the ring borders. A strip of approximately 4 cm is scanned and stored on the hard-disc of a laptop. It can be studied immediately for sharpness and visibility of all ring-borders. The measurements are made later with the help of the picture analysis program OSM3 especially designed by Bernhard Knibbe (for details see <http://www.sciem.com/main.html>). For each scan a record of collection, object, object number and piece of wood is documented in a database.

For bent surfaces, or situations where special illumination or flexibility of positioning are required, a machine was constructed using a video camera with a magnifying lens moved using a sledge driven by a step motor. This device allows us to sight a ring border on the magnified picture on the laptop and then to move the sledge to the next border. The distance the sledge has been moved is measured to an accuracy of 0.01 mm with the help of the measurement program PAST32 (designed by Bernhard Knibbe, details again at <http://www.sciem.com/main.html>) and is equivalent to the thickness of the measured ring. Simultaneously a picture of each measurement position can be saved to the hard-disc of the laptop to be studied later in dubious cases. Although positioning of the equipment and measurements take much longer and have to be done on the spot, many objects not accessible by scanner (for example those with curved surfaces) can be investigated.

4.4.6 Dating Procedure

Two samples grown at the same time in the same climatic conditions will show a statistically significant correlation of their distribution of thick and thin rings (their mean value lists). Such a pattern is unique to a certain time period, a certain climatic region and, unfortunately in many cases, only within one genus (or species) of tree. Cross-dating (statistical comparison of two mean value lists) seeks to synchronize different samples and may find the relative time span between them.

If two samples do not completely overlap in time, their combined matched pattern will be longer than one of the single samples. Many successfully cross-dated overlapping samples from different periods - the youngest one being of known age (e.g. a recently cut tree) - allow a tree ring standard (a dated chronology) to be defined which is valid for a certain wood species and a limited growth area. If a dated sample is missing, the result is a so-called floating chronology.

Dating a sample means comparing all overlapping positions of a sample with a standard and finding the best matching position. In many cases there is more than one position possible from a single statistical analysis. To find the correct position "pointer years" and various statistical tests are used.

Gleichläufigkeit

This value represents the percentage of slope equivalence of a given sample and reference within the overlapping parts of these two records. The Gleichläufigkeit (which can be translated as "synchronicity value", but according to Kaennel and Schweingruber 1995, the expression "Gleichläufigkeit" is also used in English due to lack of proper translation) is calculated in the following manner. Both reference and sample values are "digitized" in one-year steps. Possible values are -1 for decreasing slope, 0 for no change and +1 for years

with increasing values. The digitized values of the overlapping parts of reference and sample are compared and one-year intervals with similar slopes are counted. The ratio of the resulting value to the number of overlapping years gives the Gleichläufigkeit value (0 to 100%).

Pointer Year Calculation

When setting up the standard by cross-dating all its samples, certain years form pronounced peaks in the graph. If, for example, more than 75% of all rings belonging to one year have the same trend (increasing or decreasing growth compared with the ring before), this year with especially strong influence on growth is called a "pointer year" and is specially marked. In dubious cases, in a second match, only these pointer years are compared with the corresponding rings of the sample. The correct position will then show a significantly higher correlation of these special years than the other positions in question. If the reference record is a chronology with stored density data, the synchronicity value of pointer years represents only the pointer years, which should exceed the overall synchronicity value.

t-Test

An adapted Student's *t*-test is performed with the sample and reference records as two data sets. The results measure the degree of similarity of two data sets in a certain position to each other.

Skeleton Plot

The Skeleton Plot view is a traditional approach to check for the integrity and fitting of two records. Usually the smallest ring of the sample will be drawn as a long bar, small rings with small bars, rings with average width and wide ones are not drawn. This method helps to solve the problem of missing rings, but has no formal statistical approach associated with it.

As these different approaches have been developed worldwide and step-by-step and are used differently (for example the skeleton plot is not used in Europe), documentation in literature is widely scattered. A good example for a modern approach of American methods of synchronization is the study of Engle (2000).

Measuring Problems and Dating Results

In years with bad growth conditions it happens with many species that one or more rings are completely missing or are not present all the way around the circumference of a stem or branch. If this missing ring is not detected the sample will not match well with the standard. Of course, this is even more

misleading if it occurs when the standard is being set up in the first place. Detection is possible by comparing many samples (usually the same ring is not missing in all of them). The best possibility for detecting incomplete rings is given on cut discs by comparing different radii.

In years with a temporary period of low temperature or drought during the growing season a "false ring" may occur. But this "latewood formation" within the ring has a much smoother outer border than the real latewood formed at the end of the growth season. Hence, it can be detected under the microscope.

Trees grow outwards from their centres one annual ring at a time. To avoid confusion, the age of a wood sample is usually defined as the absolute age of the outermost ring preserved in the sample. If this ring is the last one grown before death of the tree (the so-called waney edge, in some cases preserved with bark), it is possible to date the felling year and also to identify the felling season.

Problems can arise from samples of wood in secondary use or an undetected repair, for they may give a false higher or lower age respectively for the complex within which they were found (for this and other reasons mentioned above, it is of advantage to sample as many promising specimens as possible).

4.4.7 Discussion and Future Work for Dendrochronology

In the first three years of "Project 7 / Dendrochronology", data have been acquired at Kunsthistorisches Museum, Vienna (1 object), Egyptian Museum, Cairo (14 objects), Metropolitan Museum of Art, New York (13 objects), Museum of Fine Arts, Boston (49 objects) and British Museum (16 objects). Most objects consist of several pieces of wood, each usable piece was measured two or three times.

The data already acquired have been synchronized and combined to create floating chronologies. At present they cover 607 years of the 2nd millennium BC and several shorter sequences; another longer chronology for the New Kingdom is under construction.

Besides the museum objects two other sources are now under investigation. In autumn 2002 we collected charcoal samples from excavations at Arqa (Lebanon) and Qatna (Syria), which are positioned by archaeologists in the 2nd millennium BC. As parts of the collection have arrived in Vienna in spring 2003 the Qatna samples show extremely narrow rings, which requires us to improve our measurement equipment. As both collections contain wood definitely grown in the Lebanese mountains, the comparison of this data set with the Egyptian Museum data will prove whether the Egyptian cedar imports really come from this region.

The museum data are producing doubts in this respect. Most of the objects consisting of several pieces produce more than one floating chronology. This may be the result of mixing wood of different ages or of contemporary wood grown under different ecological conditions. Studying the Lebanese and Syrian

samples may help to understand from a dendrochronological point of view the uniformity or complexity of contemporary wood grown in this region.

Another approach is to collect samples and data to construct a cedar standard for the Lebanese area for producing absolute dates. The sources will be mainly standing or fallen trees from relict areas, wooden parts of buildings (lintels, doors, beams, roof elements), furniture and finds from excavations. To bridge the time span between the Middle Ages and the Roman period will require hard work combined with good luck.

4.5 ¹⁴C Dating Project

4.5.1 Introduction

The aim of this project is to contribute to the synchronization of Eastern Mediterranean cultures by using ¹⁴C dating with accelerator mass spectrometry (AMS), in an interdisciplinary initiative between archaeologists and nuclear physicists. An improved absolute chronology based on precise ¹⁴C dating will lead to a better understanding of the interactions between the cultures of the Eastern Mediterranean in the second millennium BC. The ¹⁴C dating is performed at the Vienna Environmental Research Accelerator, a centre for AMS at the Institute for Isotope Research and Nuclear Physics of the University of Vienna, which came into operation in 1996 (Wild *et al.* 1998). With the help of this facility it is now possible to compete with the best ¹⁴C AMS facilities in the world, obtaining radiocarbon ages with a precision between ± 30 and ± 40 years.

4.5.2 State of Research

In order to measure radiocarbon ages it is necessary to find the amount of radiocarbon in a sample. This can be achieved either by measuring the radioactivity of the sample (the conventional beta-counting method) or by directly counting the radiocarbon atoms using a method called accelerator mass spectrometry (AMS). The main advantage of AMS over the conventional beta-counting method is the much greater sensitivity of the measurement. In AMS the radiocarbon atoms are directly detected instead of waiting for them to decay. The physical sample sizes required are typically 1000 times smaller, allowing a much greater choice of samples and enabling very selective chemical pre-treatment. However, handling small amounts of sample material increases the danger of contamination. Since minute additions of non-genuine carbon can lead to incorrect results, the entire sample preparation has to be performed with utmost care, which is time consuming.

Among a variety of selection criteria for samples, two are particularly important. First, the samples should have a good archaeological context, which

means that their position in the context should be known and the stratigraphy should be clear. Second, these strata or contexts should also contain well-defined remains, which can be dated by archaeological methods. Only in special cases should contexts without a good archaeological dating be dated with ^{14}C (e.g. graves without grave-goods).

Careful sampling and pre-treatment are very important stages in the ^{14}C dating process, particularly for archaeological samples where there is frequently contamination from the soil.

An important issue with ^{14}C dating is calibration. We use the *OxCal* program from the University of Oxford for this purpose (Bronk Ramsey 1995, 1998, 2000, 2001; Bronk Ramsey et al. 2001, and at http://www.rlaha.ox.ac.uk/orau/06_ind.htm).

In contrast to the many ^{14}C dates obtained in the past, without comparable standards of sampling and scattered in many archaeological publications, the aim of this project is to measure a large number of systematically selected samples from well-defined contexts or layers from the whole Eastern Mediterranean from Early Minoan/Middle Minoan to Late Minoan times. Some 48 samples have so far been measured; other samples from excavations in Milet (collected by W.D. Niemeyer) and from excavations in Egypt and Israel/Palestine are in preparation and will be analysed during this year.

4.5.3 Methods

The samples will be selected by the collaborators on the project with respect to the stratigraphy of the respective sites (in the light of the guidance given by Bayliss and Bronk Ramsey in Chapter 2).

A new methodology is being developed to further refine high-precision dating with ^{14}C wiggle-matching by the inclusion of external information (tree-rings, relative chronology by seriation or stratigraphy). For a single date the uncertainty in the calibrated date is, in general, dominated by the "wiggleness" in the calibration curve, and is related to a lesser extent to the precision of the ^{14}C measurement. Although the wiggles are really an obstacle for obtaining a precise absolute date with only a single ^{14}C date, one can take advantage of these wiggles if a series of radiocarbon dates is available. If such a series is combined with external information using Bayesian statistics, a considerable improvement of absolute dating can be reached. The method is also called wiggle matching. It is implemented in *OxCal*. So far, we envision four main applications in wiggle matching:

1. Floating dendrochronologies with a series of ^{14}C samples can be wiggle-matched by using a known tree-ring distance (in years) between the different samples (Christen and Litton 1995).
2. Seriation results are relative chronologies obtained by different methods of combination statistics. If one takes a series of ^{14}C samples one can see if the sequence from seriation correlates with the measured years BP. If there

exists such a correlation one can determine the slope of the correlation in SD/year BP. With the help of this information a "time span" can be calculated between each of the samples, including a sigma uncertainty for the time distance. This information can be used in wiggle matching with *OxCal* procedure V_Sequence (Christen and Litton 1995).

3. In a similar way stratigraphies may be ^{14}C dated. One samples the different layers in a stratigraphy for ^{14}C and takes into account also depth information. If the sedimentation process was continuous one may get a correlation between depth and years BP (Christen et al. 1995). In most cases this may not be possible. If it is, however, one can calculate a sedimentation rate in cm/year. One may then proceed in the same way as described above.
4. If the stratigraphy provides only information about which layer is older and which is younger, and if the sedimentation process was not continuous, there is also a possibility of using Bayesian statistics to shorten the time span of a calibrated sample in a series of ^{14}C dates (Buck et al. 1992).

The precision of the methods and reliability of results decreases from 1 to 4. We expect that these procedures will allow us to date a series of ^{14}C samples to a precision of ± 15 years at the 68% confidence level after calibration.

In *OxCal* procedures 2 and 3 can only be obtained by using external programmes at the moment, thus the realization is complicated. Therefore we will suggest improvements of *OxCal* to Christopher Bronk Ramsey at Oxford University, or, alternatively implement these additions ourselves. The goal is to better combine the four different wiggle matching applications with archaeological methods.

4.6 Process of Combination of the Results of Different Projects

As the discussion of several controversial theories about Egyptian chronology has become quite heated, the main focus of all our projects has to be to produce data that are as independent as possible from one or other of the hypotheses. A compilation at this stage of producing data might unduly influence the interpretation, so this procedure is planned in a later stage of the projects.

To solve the discrepancies of old ^{14}C data with known archaeological contexts new approaches will be adopted (Buck et al. 1991, 1994).

Of course each project tries to support the attempts, and to reconsider the results of the others. For example a pumice layer in the complex stratigraphy of the Miletos excavation investigated by the Thera Ashes project was shown to be a Thera product. Now a sequence of charcoal samples from the same archaeological profile is ready for ^{14}C measurement to fix this pumice layer in time.

The same will happen with the charcoal from Arqa and Qatna. After preparation and dendrochronological measurement, the floating chronologies will be placed in time by ^{14}C to have a rough idea of their relative position and to check the correct synchronization of the single measurement sequences. After combination of many overlapping chronologies, floating in different time spans, the final aim is to develop a Cedar standard to arrive at absolute and precise-to-the-year data.

The comparison and synchronization of archaeological and scientific results will need to be even more sophisticated. We are aware that this final compilation attempt, and not only single project outputs, has to be the main result of all efforts. A successful (i.e. widely accepted) compilation might either support one or other of the existing relative chronologies or create a new system.

4.7 Contacts

The project leaders are:

- Thera Ashes: Prof. Dr. Max Bichler
- Astrochronology: Prof. Dr. Maria Gertrude Firneis
- Dendrochronology: Dr. Otto Cichocki
- C14-Dating: Prof. Dr. Walter Kutschera
Co-worker: DDr. Peter Stadler
- Data Management, Electronic Communication and Quantitative Methods:
DDr. Peter Stadler
Co-worker: Mag. Wolfgang Müller

References

- Beckerath, J. v. (1997). *Chronologie des pharaonischen Ägyptens*. Verlag Philipp von Zabern, Mainz.
- Bichler, M., Egger, H., Preisinger, A., Ritter, D. and Stastny, P. (1997). NAA of the 'Minoan pumice' at Thera and comparison to alluvial pumice deposits in the Eastern Mediterranean region. *Journal of Radioanalytical and Nuclear Chemistry*, **224**, 7-14.
- Bichler, M., Peltz, C., Saminger, S. and Exler, M. (2002). Aegean tephra - an analytical approach to a controversy about chronology. *Egypt and the Levant*, **XII**, 55-70.
- Bietak, M. (1976). Stratigraphische Probleme bei Tellgrabungen im Vorderen Orient. Fs Pittioni. *Archaeologia Austriaca*, 14, 471-493.
- Bietak, M. (1985). Stratigraphie und Seriation. Arbeiten zur Erschließung der relativen Chronologie in Ägypten. In *Lebendige Altertumswissenschaften: Festschrift Hermann Vetters*, A. Holzhausen, Vienna, 5-9.

- Bietak, M. (ed.) (2000). *The synchronisation of civilisations in the Eastern Mediterranean in the second millennium BC*. Contributions to the chronology of the Eastern Mediterranean, vol. 1. Denkschriften der Gesamtkademie, Bd. 19. Australian Academy of Sciences Press, Vienna.
- Bikai, P. M. (1991). *The cedar of Lebanon: archaeological and dendrochronological perspectives*. Ph.D. thesis, University of Berkeley, Berkeley, CA, USA.
- Bronk Ramsey, C. (1995). Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon*, 37, 425-430.
- Bronk Ramsey, C. (1998). Probability and dating. *Radiocarbon*, 40, 461-474.
- Bronk Ramsey, C. (2000). Comment on 'The use of Bayesian statistics for ^{14}C dates of chronologically ordered samples: a critical analysis'. *Radiocarbon*, 42, 199-202.
- Bronk Ramsey, C. (2001). Development of the radiocarbon calibration program OxCal. *Radiocarbon*, 43, 355-363.
- Bronk Ramsey, C., van der Plicht, J. and Weninger, B. (2001). 'Wiggle matching' radiocarbon dates. *Radiocarbon*, 43, 381-389.
- Buck, C. E., Kenworthy, J. B., Litton, C. D. and Smith, A. F. M. (1991). Combining archaeological and radiocarbon information: a Bayesian approach to calibration. *Antiquity*, 65, 808-821.
- Buck, C. E., Litton, C. D. and Scott, E. M. (1994). Making the most of radiocarbon dating: some statistical considerations. *Antiquity*, 68, 252-263.
- Buck, C. E., Litton, C. D. and Smith, A. F. M. (1992). Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science*, 19, 497-512.
- Chapront-Touzé, M. and Chapront, J. (1991). *Lunar tables and programs from 4000 BC to AD 8000*. Willmann-Bell, Richmond.
- Christen, J. A., Clymo, R. S. and Litton, C. D. (1995). A Bayesian approach to the use of ^{14}C dates in the estimation of the age of peat. *Radiocarbon*, 37, 431-442.
- Christen, J. A. and Litton, C. D. (1995). A Bayesian approach to wiggle-matching. *Journal of Archaeological Science*, 22, 719-725.
- Davies, W. V. (1995). Ancient Egyptian timber imports: an analysis of wooden coffins in the British Museum. In W. V. Davies and L. Schofield (eds.), *Egypt, the Aegean and the Levant. Interconnections in the second millennium BC*, British Museum Press.
- Druitt, T. H., Edwards, L., Mellors, R. M., Pyle, D. M., Sparks, R. S. J., Lanphere, M., Davies, M. and Barriero, B. (1999). *Santorini Volcano*. Memoirs of the Geological Society of London, 19. Geological Society, London.
- Eastwood, W. J., Pearce, N. J. G., Westgate, J. A., Perkins, W. T., Lamb, H. F. and Roberts, N. (1999). Geochemistry of Santorini tephra in lake sediments from Southwest Turkey. *Global and Planetary Change*, 21, 17-29.

- Einarsson, T. (1986). Tephrochronology. In B. E. Berglund (ed.), *Handbook of Holocene palaeoecology and palaeohydrology*, John Wiley and Sons, Chichester, 392-342.
- Engle, J. B. (2000). *A computer-assisted tree-ring chronology composition system*. Master's thesis, University of Arizona, Arizona, USA. URL http://www.ece.arizona.edu/~dial/xdatedoc/xdate_thesis_v3.1.pdf
- Faure, P. (1971). Remarques sur la présence et l'emploi de la Pierre Ponce en Crète du Néolithique à nos jours. In X. Y. Marinatos and D. Ninkovich (eds.), *Proceedings of the 1st international scientific congress on the volcano of Thera, Athens*. Archaeological Services of Greece, 422-427.
- Francaviglia, V. (1986). Provenance of pumices from the Kastelli excavations (Chania, West-Crete). In T. Hackens, Y. Liritzis, F. Dachy and G. Moucharte (eds.), *Proceedings of the first South European symposium on archaeometry, Delphi, November 1984*- PACT, Strasbourg, Journal of the European Study Group on Physical, Chemical and Mathematical Techniques Applied to Archaeology, Conseil de l'Europe, 15, 67.
- Francaviglia, V. (1990). Sea-borne pumice deposits of archaeological interest on Aegean and Eastern Mediterranean beaches. In D. A. Hardy and A. C. Renfrew (eds.), *Thera and the Aegean world III: proceedings of the third international congress, Santorini, Greece, 3-9 September 1989, Vol. 2: Earth sciences*. Thera Foundation, London, 127-134.
- Francaviglia, V. and DiSabatino, B. (1990). Statistical study on Santorini pumice-falls. In D. A. Hardy and A. C. Renfrew (eds.), *Thera and the Aegean world III: proceedings of the third international congress, Santorini, Greece, 3-9 September 1989, Vol. 2: Earth sciences*. Thera Foundation, London, 29-52.
- Grosser, D. et al. (1992). Holz - ein wichtiger Werkstoff im Alten Ägypten. In S. Schoske, B. Kreissl and R. Germer (eds.), *"Anch" - Blumen fÄijr das Leben. Schriften aus der ägyptischen Sammlung*, Staatliche Sammlung ägyptischer Kunst, München.
- Guichard, F., Carey, S., Arthur, M. A., Sigurdsson, H. and Arnold, M. (1993). Tephra from the Minoan eruption of Santorini in sediments of the Black Sea. *Nature*, 363, 610-612.
- Kaennel, M. and Schweingruber, F. H. (1995). *Multilingual glossary of dendrochronology: terms and definitions in English, German, French, Spanish, Italian, Portuguese and Russian*. P. Haupt, Bern.
- Keller, J. (1980). Prehistoric pumice tephra on Aegean islands. In D. A. Hardy, C. G. Coumas, J. A. Sakellarakis and P. M. Warren (eds.), *Thera and the Aegean world: papers presented at the second international scientific congress, Santorini, Greece, August 1978, vol. II, Thera and the Aegean world*. Thera Foundation, London, 49-56.
- Kitchen, K. A. (2000). Regnal and genealogical data of Ancient Egypt: the historical chronology of Ancient Egypt, a current assessment. In M. Bietak (ed.), *The synchronisation of civilisations in the eastern Mediterranean in*

- the second millennium BC*. Australian Academy of Sciences Press, Vienna, 39-52.
- Kuniholm, P. I. (1996). The prehistoric Aegean: dendrochronological progress as of 1995. *Acta Archaeologica*, 67, 327-335.
- Lev-Yadun, S. (1992). The origin of the cedar beams from Al-Aqsa Mosque: botanical, historical and archaeological evidence. *Levant*, 24, 201-208.
- Library, M. (1983). *The Macquarie history of ideas*. Macquarie University, Sydney.
- Lipshchitz, N. (1986). Overview of the dendrochronological and dendroarcheological research in Israel. *Dendrochronologia*, 4, 37-58.
- Lipshchitz, N. and Biger, G. (1992). Israel: historical timber trade in the Levant: the use of *Cedrus libani* in construction of buildings in Israel from ancient times to the early twentieth century. In T. S. Bartholin et al. (eds.), *Tree rings and environment*, Lund University, Department of Quaternary Geology, Lund, 202-206.
- Loret, V. (1916). Quelques notes sur l'arbre « ach ». *Annales du service des antiquités de l'Egypte*, 16, 33-51.
- Lucas, U. and Harris, J. R. (1962). *Ancient Egyptian materials and industries*. Edward Arnold, London.
- Maguire, L. (1992). A cautious approach to the Middle Bronze Age chronology of Cyprus. *Ägypten und die Levante*, 3, 115-120.
- Maguire, L. (1995). Tell el Dab'a: the Cypriote Connection. In W. V. Davies and L. Schonfield (eds.), *Egypt, the Aegean and the Levant*, British Museum Press, London, 54-65.
- Manning, S. W. (1999). *A test of time: the volcano of Thera and the chronology and history of the Aegean and East Mediterranean in the mid second millennium*. Oxbow Books, Oxford.
- Marinatos, S. (1932). Die Ausgrabungen von Amnisos auf Kreta. *Praktika tes en Athenais Archaologikes Hetaireias*, 1932, 76-95.
- Markétou, T. (1990). Santorini tephra from Rhodes and Kos: some chronological remarks based on the stratigraphy. In D. A. Hardy and A. C. Renfrew (eds.), *Thera and the Aegean world III: proceedings of the third international congress, Santorini, Greece, 3-9 September 1989, Vol. 3: Chronology*. Thera Foundation, London, 100-113.
- Meiggs, R. (1982). *Trees and timber in the ancient Mediterranean world*. Clarendon, Oxford.
- Mikesell, M. (1969). The deforestation of Mount Lebanon. *Geographical Review*, 59, 1-28.
- Newton, M. W. (1996). *Dendrochronology at Catal Hoyuk: A 576-year tree ring chronology for the early Neolithic of Anatolia*. Master's thesis, Cornell University, Ithaca, NY, USA.
- Nibbi, A. (1981). *Ancient Egypt and some eastern neighbours*. Noyes Press, Park Ridge, New Jersey.
- Nibbi, A. (1987). Some remarks on the LEXIKON ENTRY: Zeder, Cedar. *Discussions in Egyptology*, 7, 13-27.

- Nibbi, A. (1994). Some remarks on the Cedar of Lebanon. *Discussions in Egyptology*, 28, 35-52.
- Nibbi, A. (1996). Cedar again. *Discussions in Egyptology*, 34, 37-59.
- North, J. (1994). *The Fontana history of astronomy and cosmology*. Fontana Press, London.
- O'Neil, W. M. (1986). *Early astronomy*. University Press Sydney, Sydney.
- Paul, R. (1993). *A handbook to the universe*. Chicago Review Press, Chicago.
- Pearce, N. J. G., Westgate, J. A., Perkins, W. T., Eastwood, W. J. and Shane, P. (1999). The application of laser ablation ICP-MS to the analysis of volcanic glass shards from tephra deposits: bulk glass and single shard analysis. *Global and Planetary Change*, 21, 151-171.
- Peltz, C, Schmid, P. and Bichler, M. (1999). INAA of Aegean pumices for the classification of archaeological findings. *Journal of Radioanalytical and Nuclear Chemistry*, 242, 361-377.
- Pichler, H. and Schiering, W. (1980). Der spätbronzezeitliche Ausbruch des Thera-Vulkans und seine Auswirkungen auf Kreta. *Archäologische Anzeiger*, 1980, 1-37.
- Pyle, D. M. (1990). New estimates for the volume of the Minoan eruption. In D. A. Hardy and A. C. Renfrew (eds.), *Thera and the Aegean world III: proceedings of the third international congress, Santorini, Greece, 3-9 September 1989, Vol. 2: Earth sciences*. Thera Foundation, London, 113-120.
- Richardson, D. and Ninkovich, D. (1976). Use of K₂O, Rb, Zr and Y versus SiO₂ in volcanic ash layers of the eastern Mediterranean to trace their source. *Geological Society of America Bulletin*, 87, 110-116.
- Richmond, B. (1956). *Time measurement and calendar construction*. E. J. Brill, Leiden.
- Ryholt, K. S. B. (1997). *The political situation in Egypt during the Second Intermediate Period c. 1800-1550 BC*. CNI Publications, 20. Carsten Niebuhr Institute of Near Eastern Studies, University of Copenhagen, Museum Tusulanum Press, Copenhagen.
- Saminger, S., Peltz, C. and Bichler, M. (2000). South Aegean volcanic glass - separation and analysis by INAA and EPMA. *Journal of Radioanalytical and Nuclear Chemistry*, 245, 375-383.
- Schaefer, B. (1997). Heliacal risings: definitions, calculations and some specific cases. *Archaeoastronomy and Ethnoastronomy News*, 25, 1 and 3.
- Schmid, P., Peltz, C, Hammer, V. M. F., Halwax, E., Ntaflos, T., Nagi, P. and Bichler, M. (2000). Separation and analysis of Thera volcanic glass by INAA, XRF and EPMA. *Mikrochimica Acta*, 133, 143-149.
- Sigurdsson, H., Carey, S. and Devine, D. (1990). Assessment of mass, dynamics and environmental effects of the Minoan eruption of Santorini Volcano. In D. A. Hardy and A. C. Renfrew (eds.), *Thera and the Aegean world III: proceedings of the third international congress, Santorini, Greece, 3-9 September 1989, Vol. 2: Earth sciences*. Thera Foundation, London, 100-112.