Environmental Archaeology of Prehistoric NW Crete

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The occurrence of Central European tree-types no longer growing on Crete indicates that Neolithic and Bronze Age climates were moister than at present. Of equal significance is the appearance of large quantities of olive pollen in Late Neolithic levels, suggesting the practice of olive cultivation. Early Bronze Age levels show a disappearance of some Central European tree pollen and an increase in Mediterranean tree types, suggesting that the climate became somewhat drier. The pollen findings are used along with other environmental and archaeological data to reconstruct landscapes for the Neolithic and Bronze Age of NW *Crete.*

Introduction

On Crete, a number of archaeological projects have successfully integrated geological, botanical, and faunal approaches to reconstruct earlier environments (Warren 1972; Doe and Holmes 1977; Bintliff 1977; Roberts 1979; Shaw 1981). Before now, palynology has played only a minor role in such studies since pollen is poorly preserved in stratified deposits in southern Greece. The first pollen core from Crete was published by Bottema in 1980 and was taken independently of archaeological research from the bed of the Aghia Galini River on the south coast (FIG. 1). In 1979 we sampled two fossil pollen sites at Tersana and Limnes on the Akrotiri Peninsula in NW Crete (Gennett 1982) during an archaeological and environmental survey.

This paper places the Akrotiri pollen cores in their modern environmental context and then discusses the pollen distributions, relating them to the geological, botanical, and archaeological studies we conducted on the peninsula from 1978 to 1984. We draw broad conclusions about the landscape history of NW Crete but resist extrapolating our results to the island as a whole, especially in light of the current absence of prehistoric fossil pollen sites in eastern Crete (Hayden and Moody 1990).

Archaeological Setting

Bronze Age antiquities have been known from the Khania Nomos since 1895 (Bosanquet and Dawkins 1923: fig. 73) but not until the mid-1960s did excavations at the Kastelli of Khania reveal the existence of a major Bronze Age town (Tzedhakis 1985; Tzedhakis and Hallager 1983). The Akrotiri, the focus of the Khania Archaeological Survey Project (KASP), formed part of the hinterland of Bronze Age Khania and now more than 245 prehistoric sites have been identified on the peninsula (Moody 1987).

A significant percentage (for Crete) of the KASP sites date to the Neolithic (7%, about 18 sites; FIGS. 2A, 2B). These include the earliest documented site in western Crete, the Cave of Aghios Ioannis, which is located on the isthmus of the peninsula. During the Final Neolithic many cave sites were abandoned while the number of settlements in the open increased (FIG. 2B; about 14 sites). Except for its participation in the obsidian procurement system (Torrence 1986), the Khania area, like most of Crete, seems to have been relatively isolated throughout most of the Neolithic. During the Final Neolithic, however, a number of new pottery shapes appear that echo Cycladic and Anatolian types (Betancourt 1985), indicating that the end of isolation was near.

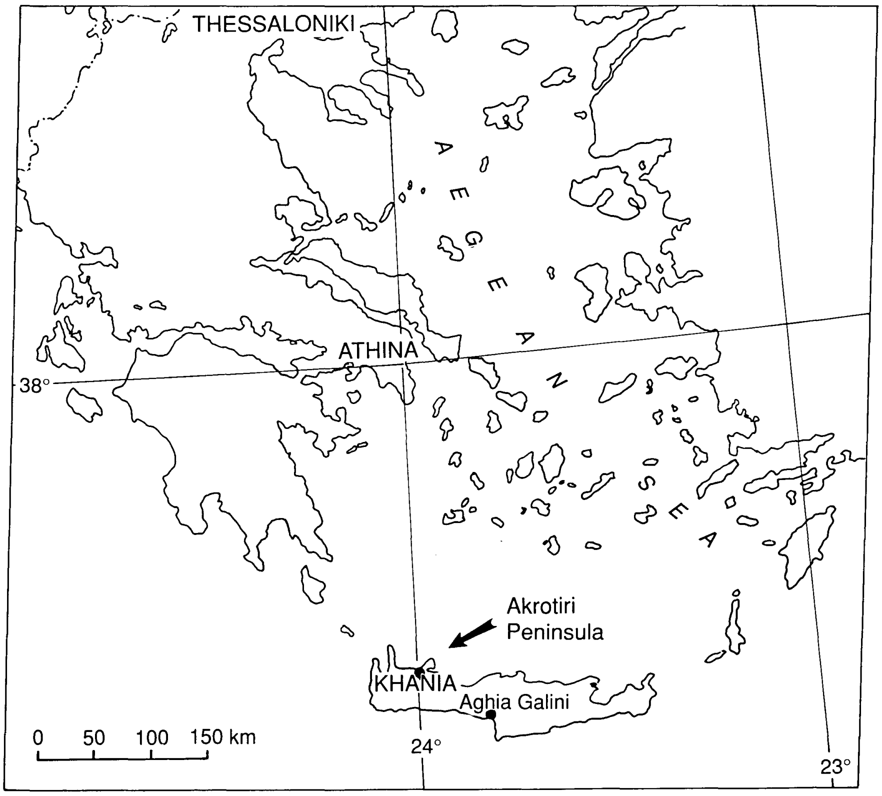


Figure 1. Map showing the study area.

Contacts with the larger Aegean world, especially the Cyclades, increased in the Khania area during the Early Bronze Age (EBA), as indicated by finds such as sauceboat sherds and a proto-Cycladic figurine at Platyvola Cave (Tzedhakis 1970). Sauceboat fragments were also found at Lera Cave (Guest-Papamanoli and Lambraki 1980). Melian obsidian is present at all Early Bronze Age sites, and is especially abundant at several coastal locations in the survey area. Contacts within the island are reflected by ceramic styles generally similar to those of central and south Crete, such as Pyrgos, Vasiliki, Scored, and Aghios Onouphrious wares. On the Akrotiri, Early Bronze Age settlements increased (FIG. 2C; about 56 sites) suggesting that settlement hierarchies may have begun to emerge by the end of the Early Bronze Age (Moody 1987).

The Old Palace period (Middle Bronze I–II) is less well known in the Khania region than either the preceding Early Bronze period or the succeeding New Palace period (Middle Bronze III/Late Bronze I) because there are no excavated settlements. The data suggest that the area did not interact as intensively either overseas or within the island as it had in the Early Bronze Age. Local ceramics seem to share fewer features with other important Middle Bronze centers like Knossos and Phaistos. A case in point is the scarcity of Kamares Ware, the hallmark of Middle Minoan I–II in central, east, and south Crete (Walberg 1976). Instead, local styles seem to have developed which emphasize textured over painted decoration.

The settlement pattern, however, seems at odds with this static view of west Crete in the Middle Bronze Age. The increase in site numbers along with the development of a marked settlement hierarchy suggest a period of peace and prosperity (FIG. 2D; about 147 sites) when small sites proliferated around larger centers.

It is likely that the Kastelli at Khania was the primary center for NW Crete during the New Palace period—probably on a par with the Minoan centers of Knossos and Phaistos (Bennet 1990). The site's importance is reflected by the presence of at least 80 tablet fragments of Linear A, 108 rhondels, and 28 prismatic sealings (Hallager 1975). The architecture recalls the fine houses around the palaces at Mallia and Zakro, and ceramic styles closely mirror those found elsewhere in Crete, indicating that the area was fully participating in Minoan culture.

Activity on the Akrotiri seems to have peaked at this time (FIG. 2E; about 150 sites). Population of the survey area (including Khania) could have been as high as 13,000—about what it was in Late Venetian times.

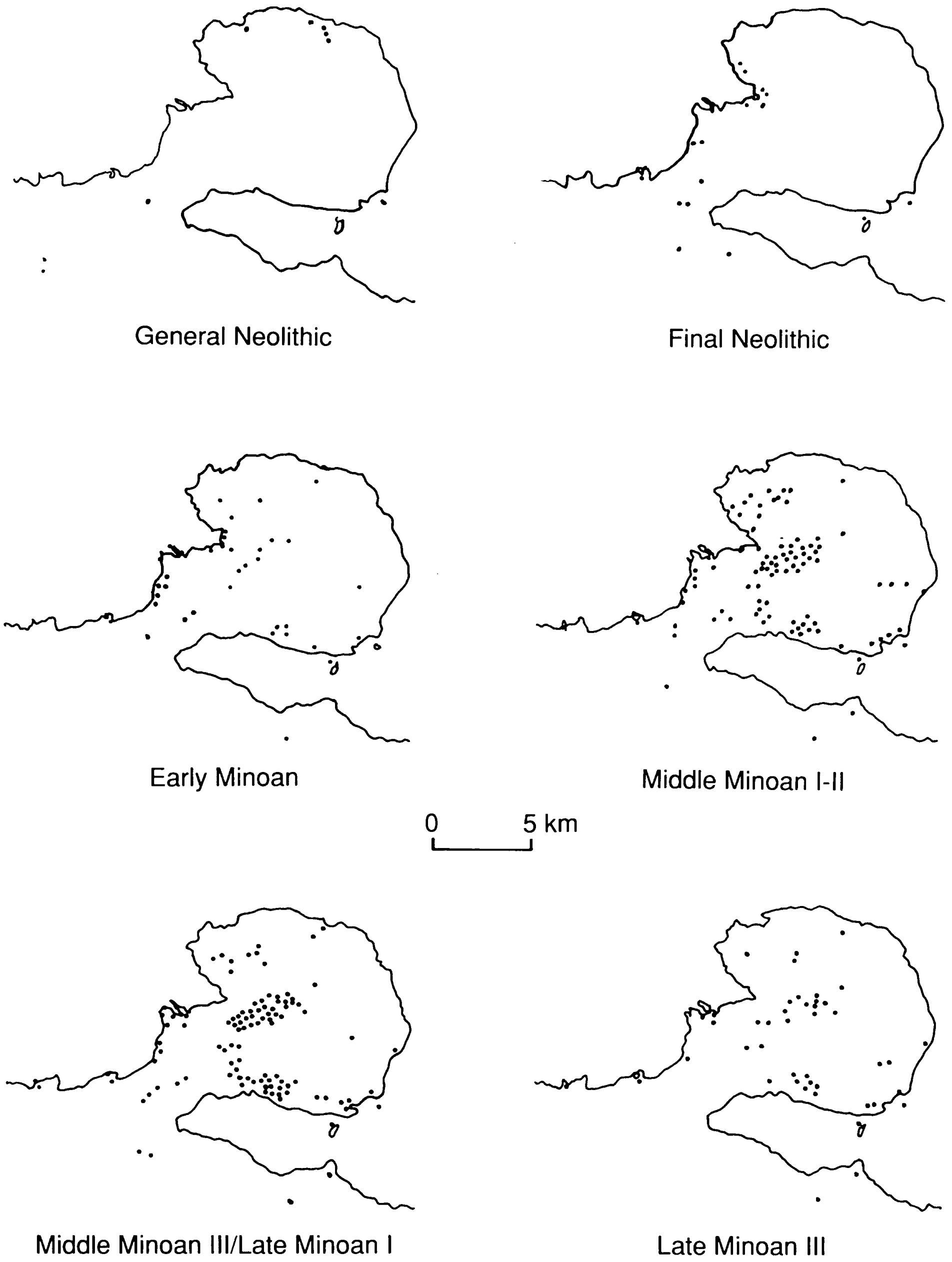


Figure 2. Series of maps showing the settlement pattern on the Akrotiri: A) General Neolithic; B) Final Neolithic; C) Early Minoan; D) Middle Minoan I–II; E) Middle Minoan III/Late Minoan I; F) Late Minoan III.

The Khania region seems to have thrived especially in the Post-Palatial period (Late Bronze III). In addition to extensive architectural remains and rich tombs (Kanta 1980), Khania's importance may be best illustrated by stirrup jars inscribed in Linear B. These have been found at numerous locations around the Aegean, and chemical analyses of their clays indicate that most were manufactured in west Crete (Jones 1986). Khania and Knossos are the only sites on Crete where Linear B tablets have been found. Since clay tablets seem to have been used primarily for economic record-keeping, their occurrence at Khania underlines the intensity of this site's economic activity in the Late Bronze III period (Hallager, Andradhaki-Vlazakis, and Hallager 1990).

In spite of numerous indications of prosperity at Late Bronze III sites in the Khania area, there seems to have been a decline in population in the Khania hinterland. The overall decrease in settlement numbers visible in the KASP data (FIG. 2F; about 76 sites) exceeds the increase in average settlement size, suggesting both an increase in settlement nucleation and a loss of rural population. But perhaps sites were more densely settled than in previous periods, thus accounting for the alleged population decrease. Alternatively, perhaps people moved to the urban center to participate in economic prosperity—an exodus similar to that seen today (Moody 1990).

Modern Setting

Climate

The climate of NW Crete is Mediterranean: characterized by wet, mild winters (coldest months 10–12°C) and dry spring, summer, and fall (hottest months 26–28°C). The prevailing winds come from the west in the winter and the north in the summer, and sometimes the hot, dry sirocco from North Africa blasts the area from the SE. All of these winds can be strong enough to stunt tree growth in exposed coastal areas.

Rugged topography creates rain and wind shadows, which have influenced the distribution of plant communities. Generally, rainfall increases at higher altitudes from E–W and from S–N, making NW Crete the wettest part of the island (Grove, Moody, and Rackham 1991). In Khania, an average precipitation of 686 mm has been recorded between the years 1961 and 1987, with a range between 367 and 1295 mm.

At Khania the average temperature ranges between 23°C and 15°C. Slight frosts can occur every four or five years on the north coast.

Geomorphology

The Akrotiri, one of three prominent peninsulas in NW Crete (FIGS. 3, 4), covers some 100 sq km and is joined to the island by a neck 3 km wide. Immediately SW of the peninsula is the city of Khania, the second largest settlement on Crete. About one-third of the Akrotiri is mountainous, rising to 528 m at Mount Sklokas. The remainder, the *kampos*, is a less rugged surface, sloping gently down to the NW, with many karst hollows and sinkholes. Except for several small harbors, the coasts of the peninsula are otherwise rocky and quite steep.

The kampos, which covers the southern two-thirds of the peninsula, is highly karstified with sinkholes created by the collpase of caverns in the underlying Mesozoic limestones. Vothanos, the largest sinkhole on the Akrotiri, has an area of about one-seventh of a sq km (34.6 acres) and a depth of 70–100 m.

Sediments

In places, two much younger sedimentary units overlie the Mesozoic hard limestones and Neogene deposits: aeolianites and red paleosols of Pleistocene age. Aeolianites are lithified, windblown sand and shell deposits and are believed to have been laid down during periods of lower absolute sea level (Butzer 1971: 217–219). Occasionally the aeolianites overlie the red paleosols, and sometimes the two are interbedded.

Aeolianites and paleosols are easily eroded and have a fragmentary distribution. Occasionally the former are overlain by unconsolidated terra rossa soils and redeposited soil sediments. On the Akrotiri such sediments fill hollows and rock fissures, and partially fill most sinkholes. They seldom contain cultural debris. Such redeposited red soils, enclosing angular bedrock fragments, are of the type originally identified by Vita-Finzi (1969) as the pan-Mediterranean "Older Fill." Although rare on the Akrotiri, similar sediments are packed with artifacts and can be broadly characterized as "Younger Fill."

Groundwater

The Akrotiri is poor in springs because the aquifer Mesozoic limestones do not overlie barrier formations. The one known spring is at Aghios Ioannis on the east cliffs of the peninsula, where Mesozoic limestones have been faulted against the marly barrier limestones of the Akrotiri formation.

Lack of water has been an obstacle to historical and modern settlement until recent years, when it has been piped in from outside the peninsula. We have worked in the area for seven years (at all times of year), and have never seen running water in either of the major ravines, the Kalathorevma and Nerokampos. Nevertheless, oleanders grow in places along the bottoms of these ravines, indicating a water table not far below the surface. In antiquity the situation may have been a little better, as suggested by a Hellenistic or Roman spring house in the Vathyrevma ravine.

Water tapped by wells at Tersana and Limnes is brackish but still usable for irrigating certain types of crops. Well-water in the Vothanos doline is fresh but scanty.

Vegetation

The modern vegetation of Crete is, like that in most of southern Greece, predominantly a mosaic of *maquis*, *garigue*, and steppe, with some deciduous woodland and

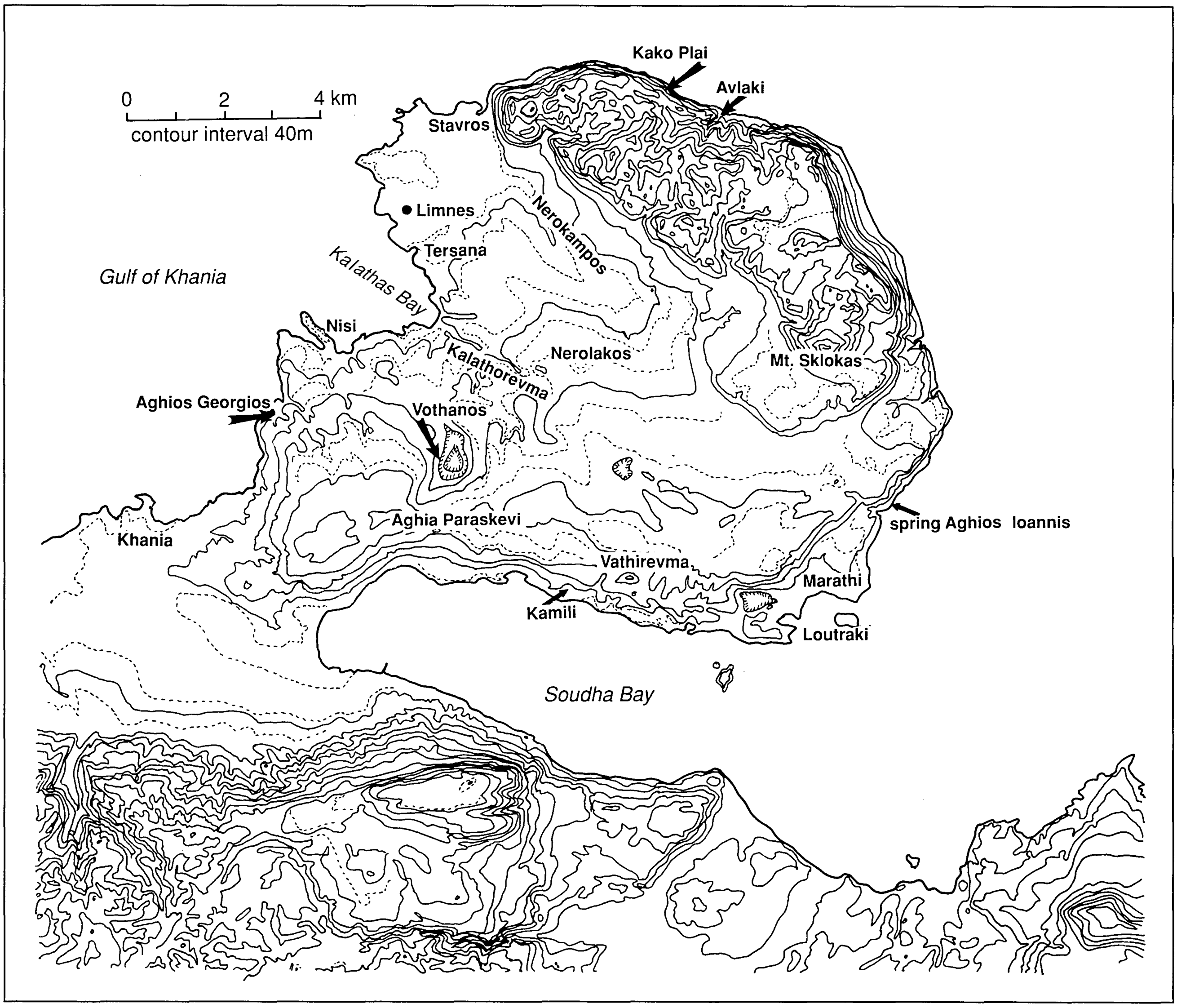


Figure 3. Topographic map of the Akrotiri showing place names mentioned in the text.

coniferous forest. We define *maquis* as evergreen trees that have been reduced to shrubby, low stature by some combination of browsing, burning, and woodcutting (Rackham 1983). The most conspicuous maquis plants are carob, lentisk, prickly oak, and wild olive. *Garigue* consists of the gray-green, often aromatic shrubs familiar on Greek hillsides. Unlike maquis plants, garigue species are not young trees but are undershrubs, permanently of low height. Many of the common garigue plants are members of the rock-rose, mint, and pea families. Steppe consists of herbaceous plants, including grasses, bulbous or tuberous perennials, and annuals.

In west Crete today maquis is growing into woodland, and deciduous trees are on the increase. This is no doubt a result of the decline in herding, and a retreat of agriculture from more difficult terrain, especially since World War II. Natural vegetation is now being encroached upon by new building, and somewhat by a revival of agriculture through piped irrigation. But where maquis vegetation survives, it is growing into woodland because it is no longer held in check by browsing animals and woodcutting. Only about one-fourth of the Akrotiri is cultivated today, mostly with olives and some vines. The remainder is a mosaic of garigue, steppe, and some maquis. Although grazing in the Akrotiri Mountains is still intensive enough to keep most of the mountain vegetation in shrubby forms, elsewhere

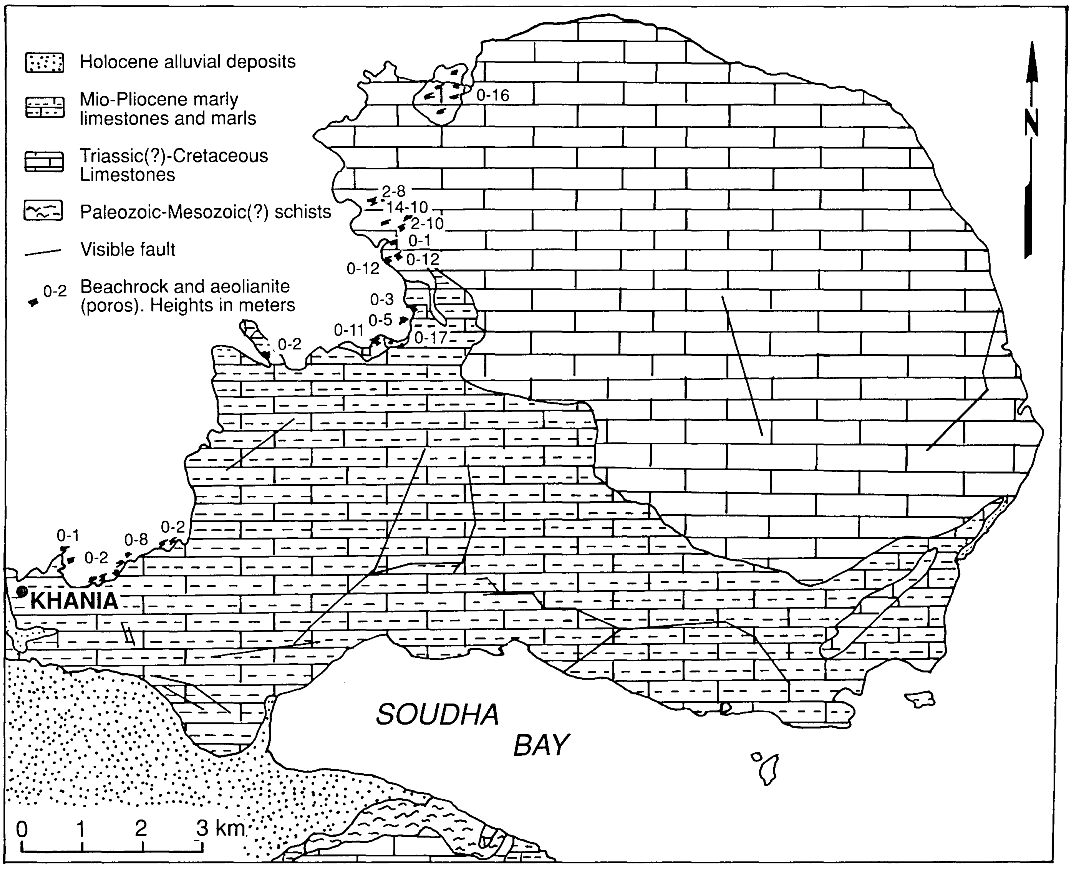


Figure 4. General geologic map of the Akrotiri.

prickly-oak shrubs are growing into trees. No doubt similar cycles of woodland decline and expansion have occurred many times during the history of Crete.

The Pollen Cores

Cores aimed at recovering pollen were taken from six sites in 1979: 1) the coastal delta of the Keritis River; 2) Kalathas beach; 3) Tersana depression; 4) Limnes lake; 5) Georgioupolis peat; and 6) the brackish marsh at Georgioupolis (FIG. 5). Only two of the locations, Tersana and Limnes, yielded significant amounts of pollen.

The Tersana core (430 cm long) was taken with a vibrocorer and that at Limnes (450 cm long) was taken with a hand auger. Sediment samples were taken from the center of the cores every 5 to 10 cm. Any levels containing sufficient organic matter—shell, plant fragments, or charcoal—were sampled separately and dried for radiocarbon dating. All materials were analyzed at the Archaeometry Laboratory at the University of Minnesota, Duluth, while chronometric assays were performed by the Radiocarbon Laboratory at the University of California, Riverside.

Coring Sites

Tersana and Limnes are solutional dolines that were dissolved into hard Mesozoic limestone during a time of higher sea level. They eventually collapsed and formed the present sinkholes. The vegetation at Tersana and Limnes consists of wetland plant communities of reeds and other grasses, sedges, and chenopods surrounded by a dryland vegetation which is a patchwork of maquis, garigue, and steppe.

TERSANA

The Tersana depression covers about one-eighth of a sq km (about 31 acres) and lies between 20 and 30 m below the surrounding land surface (FIG. 6). Most of the flat bottom, although saline, is cultivated in melons and maize with the lowest part a well-developed salt marsh. The dominant plant is the creeping grass *Aeluropus littoralis*. Oleander (*Nerium oleander*), sedge (*Scirpus lacustris*, Cyperaceae), and yellow composites (*Dittrichia viscosa* and *Lactuca saligna*) are locally abundant, with occasional *Salicornia*.

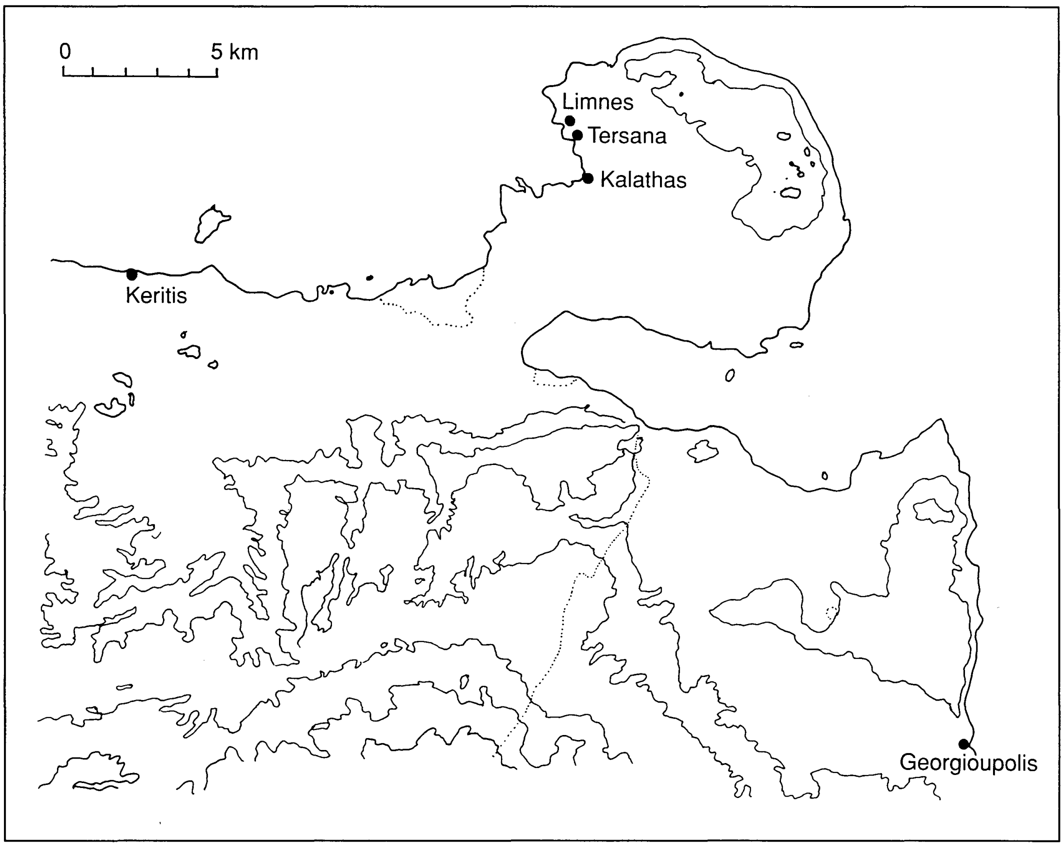


Figure 5. Map of coring locations.

The surface around the Tersana depression has a distinctive kind of garigue, in which the dominant plant is heather (*Erica manipuliflora*). A spiny legume (*Anthyllis hermanniae*), and thyme, (*Thymus capitatus*) are abundant, with a little *Cistus* and rock-rose (*Fumana thymifolia*). Maquis is absent except for a few low lentisk bushes. There is very little steppe, but about 30% bare ground.

LIMNES

The Limnes depression covers about 50,000 sq m (12 acres) and lies about 14 m below the surrounding surface (FIG. 7). The floor is a shallow brackish lake, surrounded by a gently sloping zone of sandy soil, cultivated until recently, overlying aeolianite. The sides of the Limnes depression are steeper than those at Tersana.

Limnes Lake is largely filled with reeds (*Phragmites australis*) that have undoubtedly fluctuated through time. The lake is subdivided by two built walls, suggesting that at some time it may have been nearly dry. Around the margin of the lake is a narrow brackish marsh of grasses (e.g., *Elymus farctus*), rushes (*Juncus cf. heldreichianus*), sea-lavender (*Limonium bellidifolium*), and occasional mint (*Mentha sp.*).

The Limnes cliff, higher and probably damper than that of Tersana, supports a well-developed maquis with trees of lentisk, olive, carob, and occasional strawberry-tree (*Arbutus unedo*). Undershrubs include heather (*Erica manipuliflora*) and spiny broom (*Calicotome spinosum*), with occasional *Petromarula pinnata, Campanula tubulosa,* and an unknown Geranium. At the foot of the cliff, probably on a spring line, are abundant myrtle (*Myrtus communis*) and occasionally the sedge *Schoenus nigricans;* an old cistern contains maiden hair fern (*Adiantum capillus-veneris*), indicating trickles of moisture.

Hydrology

The hydrology of the Tersana and Limnes sinkholes has varied over the millennia because of tectonism and sedimentation. It is likely that at times the Tersana depression contained a saltwater lagoon fringed by a salt marsh, and connected to the sea by a narrow channel. Were the present sea level to rise 1 m, part of the Tersana basin would become such a lagoon today. There may also have been periods when the sill of the lake was raised enough to cut off the basin from the sea and create a fresh or brackish lake like Limnes. Eventually, Tersana became so silted, or

Figure 6. Photograph of the Tersana sinkhole.

the relative sea level fell so low, that the basin was no longer permanently wet and preserved no further pollen.

Limnes, on the other hand, is well separated from the sea and is unlikely ever to have been fully saline, but fluctuations in its water table are likely to have occurred. Taking the situation from Tersana and Limnes together, four different hydrological states can be proposed:

1. Freshwater lakes with deep central parts suitable for aquatics of open water, such as *Callitriche, Nuphar, Myriophyllum,* and *Hippuris,* and fringed by shallow water supporting *Phragmites* reedbeds sometimes accompanied by *Sparganium* and Cyperaceae. This is the present state of Limnes.
2. Freshwater lakes shallow enough to be entirely occupied by reedbeds.
3. Lagoonal salt marsh dominanted by grasses such as *Aeluropus littoralis* or *Elymus farctus,* accompanied by *Salicornia* (Chenopodiaceae) and yellow-flowered Compositae. Many Greek salt marshes contain no plants that produce distinctive pollen (Rackham 1983).
4. Dry or seasonally wet sinkholes with small salt or freshwater marshes. No pollen would be preserved in the strata deposited when the basins were in this state, which is that of Tersana today.

Radiocarbon Dates and Rate of Deposition

As in most southern Greek pollen cores, material suitable for ^{14}C dating was scarce. Two dates were obtained for Tersana: 5800 ± 130 b.p. at 335–350 cm (on plant fragments), and 2110 ± 130 b.p. at 45–50 cm (on shell). When calibrated according to the tables of Klein et al. (1982) the dates become: 5070 to 4415 B.C. and 415 B.C. to A.C. 210.

Although there are no ^{14}C dates for the Limnes core, some chronological inferences can be made. The top 50 cm contain pollen of *Ostrya* (hornbeam), which no longer

Figure 7. Photograph of the Limnes sinkhole.

grows on Crete, and must therefore include nonmodern sediments. The bottom contains *Olea* (olive) pollen and is therefore unlikely to predate Tersana Zone 3. The middle of the core contains *Tilia* pollen and probably does not postdate Tersana Zone 4, although it is possible that basswood/linden lingered on the damp Limnes cliffs later than on those at Tersana.

The two radiocarbon dates from the Tersana core permit an estimate of the deposition rate (TABLE 1). About 285 cm of sediment accumulated over a period of 4000 to 5280 years (using the two 95% confidence limits). This gives a deposition rate of between 0.7 and 0.53 mm per year. We shall use an average rate, 0.62 mm per year to correlate events in the cores to dated cultural phases.

The bottom of the core, then, should date to the Early Neolithic (ca. 6100 B.C.), and the last stratum that preserves significant pollen should date to the Middle Bronze Age (ca. 1950 B.C.). While the accuracy of the suggested rate is unknown, the closer an event in the core is to a ^{14}C date, the more reliable is its extrapolated date and, therefore, its cultural association.

No deposition rate can be calculated for the Limnes core because no ^{14}C dates for it exist. The amount of sediment, however, that accumulated between the two chronological indicators mentioned above (140 cm at Tersana vs. 200 cm at Limnes) suggests that the rate of aggradation was faster at Limnes than at Tersana.

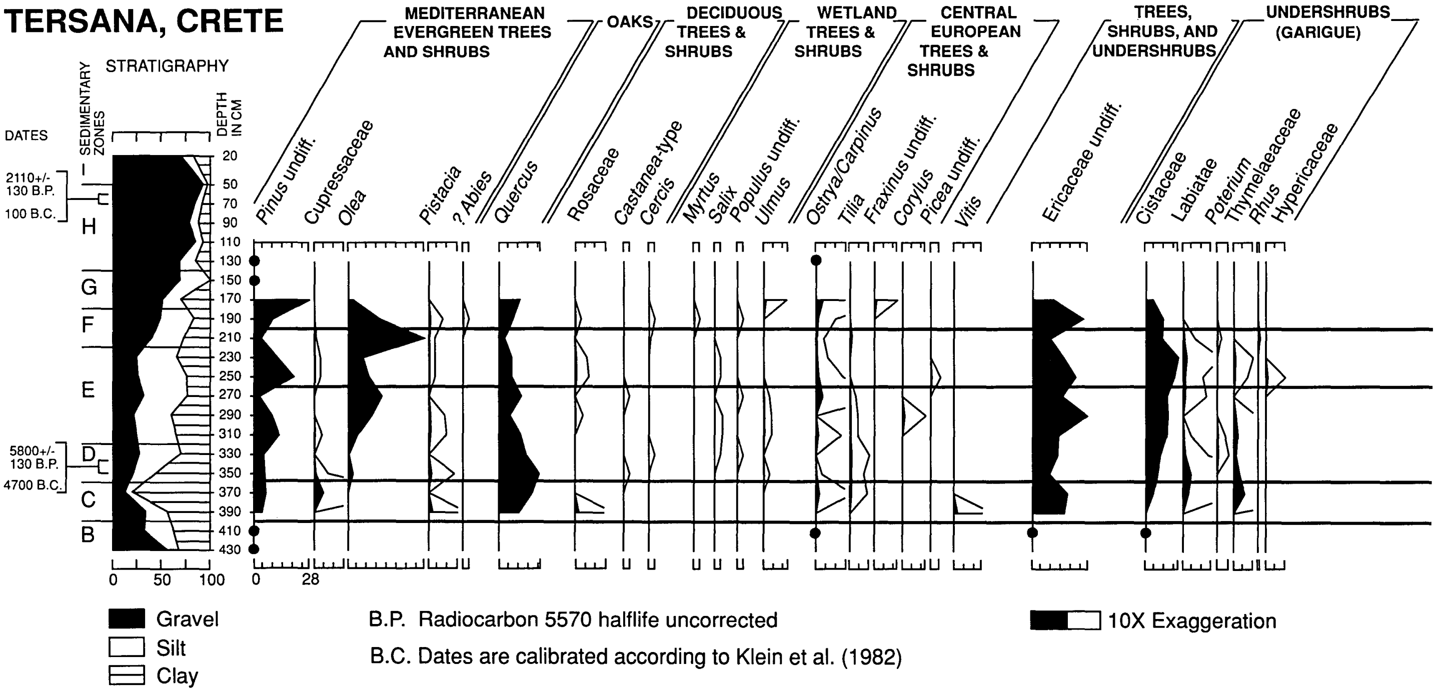
The Tersana and Limnes Diagrams

The diagrams (FIGS. 8, 9) are based on the standard format developed for more northern climates, but adapted to the very different vegetation of southern Greece. Palynologists conventionally divide pollen into tree pollen (arboreal pollen, AP), non-tree pollen (NAP), and aquatic pollen. In southern Greece the situation is not so straightforward. Most "shrubs" in the Greek landscape are mini-

Table 1. Estimated chronology for the Tersana core. The extrapolated dates, based on an average deposition rate of 0.062 cm/year over 7000 years, are, of course, tenuous. The closer a spectrum is to a radiocarbon date the more reliable its cultural correlation will be.

Pollen	*Radiocarbon dates (b.p.)*	*Calibrated dates (b.p.)*	*Depth below surface (cm)*	*Calendric dates* *Maximum–Minimum*	*Average*	*Cultural phase*
Absent	–	–	30	150 A.C.–775 A.C.	463 A.C.	Roman to Early Byzantine
Absent	–	–	50	173 B.C.–452 A.C.	313 A.C.	Hellenistic to Early Byzantine
Absent	2110 ± 130 (shell frags.)	415 B.C.–210 A.C.	65–70	415 B.C.–210 A.C.	102 A.C.	Classical to Late Roman
Absent	–	–	90	738 B.C.–113 B.C.	426 B.C.	Archaic to Hellenistic
Absent	–	–	110	1061 B.C.–436 B.C.	749 B.C.	Early Iron Age to Classical
Occasional	–	–	130	1384 B.C.–759 B.C.	1072 B.C.	Late Bronze III to Archaic
Occasional	–	–	150	1707 B.C.–1082 B.C.	1395 B.C.	Middle Bronze II/III to Early Iron Age
Present	–	–	170	2030 B.C.–1405 B.C.	1718 B.C.	Middle Bronze I to Late Bronze I
Present	–	–	190	2353 B.C.–1728 B.C.	2041 B.C.	Early Bronze II to Middle Bronze II
Present	–	–	210	2890 B.C.–2235 B.C.	2563 B.C.	Early Bronze Age
Present	–	–	230	3213 B.C.–2558 B.C.	2886 B.C.	Final to Early Bronze I
Present	–	–	250	3536 B.C.–2881 B.C.	3209 B.C.	Final Neolithic
Present	–	–	270	3859 B.C.–3204 B.C.	3532 B.C.	?Late to Final Neolithic
Present	–	–	290	4182 B.C.–3527 B.C.	3855 B.C.	Late to Final Neolithic
Present	–	–	310	4505 B.C.–3850 B.C.	4178 B.C.	?Middle to Late Neolithic
Present	–	–	330	4828 B.C.–4173 B.C.	4501 B.C.	Middle to Late Neolithic
Present	5800 ± 130 (plant frag.)	4415 B.C.–5070 B.C.	335–350	5070 B.C.–4415 B.C.	4743 B.C.	Middle Neolithic
Present	–	–	370	5393 B.C.–4738 B.C.	5066 B.C.	Middle Neolithic
Present	–	–	390	5716 B.C.–5061 B.C.	5389 B.C.	?Early to Middle Neolithic
Occasional	–	–	410	6039 B.C.–5384 B.C.	5712 B.C.	Early to ?Middle Neolithic
Occasional	–	–	430	6362 B.C.–5707 B.C.	6035 B.C.	Early Neolithic
Occasional	–	–	450	6685 B.C.–6030 B.C.	6358 B.C.	Early Neolithic or earlier

Figure 8. Tersana pollen percentage diagram. Analysis by Judith A. Gennett, 1979–1980.



ature trees and many of these plants—whether full-sized trees or shrubby, maquis forms—produce pollen, obscuring the distinction between woodland and maquis. Therefore we have included most Mediterranean shrubs with the trees in the AP sum.

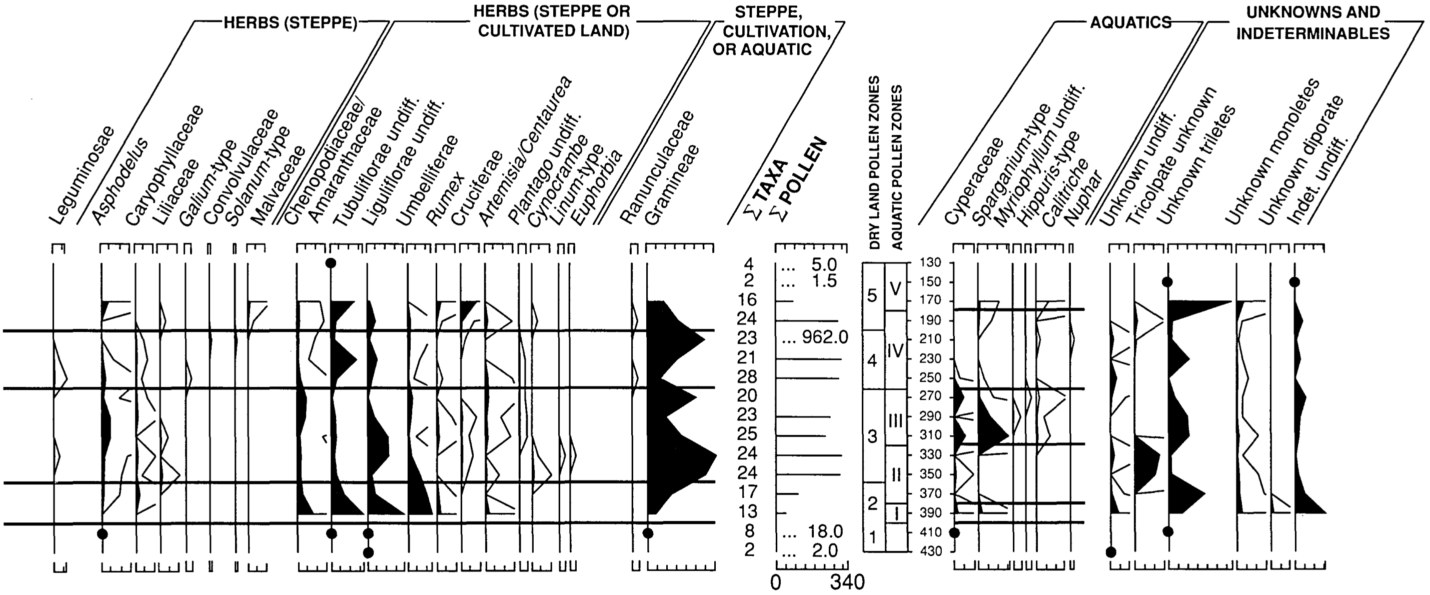
Similar considerations have caused us to separate Ericaceae (heathers) and Gramineae (grasses) pollen from the other dryland types. Ericaceous pollen can represent tree or garigue species and to assign it to AP or NAP would muddle the question of which was the common species. Similarly, Gramineae pollen can include wetland, salt-marsh, and dryland species. Although the pollen of dryland cereals and wetland reeds can, with difficulty, be separated from other grasses, these distinctions could not be made in the Akrotiri material. Therefore, as with Ericaceae, it seemed best to place Gramineae pollen in a separate category.

Two considerations suggest that most of the Gramineae pollen identified in the cores came from wetland vegetation. First, the topography and sedimentology of the basins almost exclude the possibility that the water they contained was ever too deep or too wide for fringing wetland vegetation to exist. Second, pollen would not have been preserved if the basins had ever been too dry for reeds or salt-marsh grasses. Not only are grasses more likely to have been dominant in wetland than in dryland vegetation, but wetland grasses probably would have grown directly over the deposition site. We therefore group aquatic and grass pollen together in the following discussion.

We have followed the usual practice of dividing pollen diagrams into horizontal zones defined by striking changes in pollen. But we have, however, used separate zones for the dryland pollen, the aquatic-and-grass pollen, and the sediments since each group represents a slightly different landscape history.

Variations in dryland pollen can reflect both regional and local changes in climate and land use. Changes in aquatic and grass pollen, however, are poor regional indicators because they are particularly affected by local fluctuations in hydrology, salinity, and sedimentation, but not appreciably by the changes in climate and land use that have influenced dryland pollen. Like aquatic and grass pollen, sediments and shells deposited in the basins reflect local changes in hydrology and salinity and are of limited value as indicators of regional environment. The detailed study of such sediments can, however, provide important information on local sea level changes and erosion.

Plant species vary greatly in the amounts of pollen they produce and the distances over which pollen is dispersed. Poorly-produced pollen types, therefore, may be more significant than their well-produced cousins. Small quantities of well-dispersed types can even come from plants



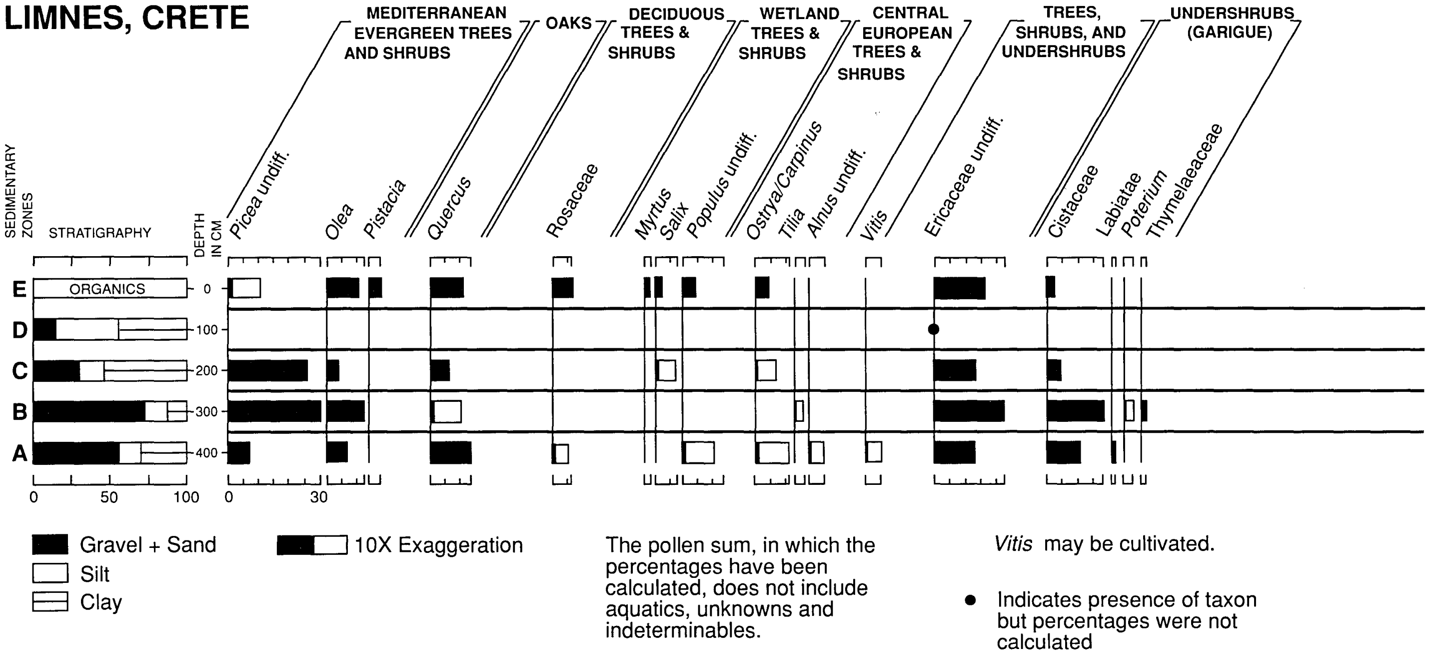
The pollen sum, in which the percentages have been calculated, does not include aquatics, unknowns and indeterminables.

Vitis may be cultivated.

- Indicates presence of taxon but percentages were not calculated

Sum = $\Sigma P + \Sigma$ Aquatics

Sum = $\Sigma P + \Sigma$ Unknowns & Indeterminables



The pollen sum, in which the percentages have been calculated, does not include aquatics, unknowns and indeterminables.

Vitis may be cultivated.

● Indicates presence of taxon but percentages were not calculated

Figure 9. Limnes pollen percentage diagram. Analysis by Judith A. Gennett, 1979–1980.

growing outside Crete. (In general, wind-pollinated plants produce more pollen and disperse it more widely than those pollinated by insects.)

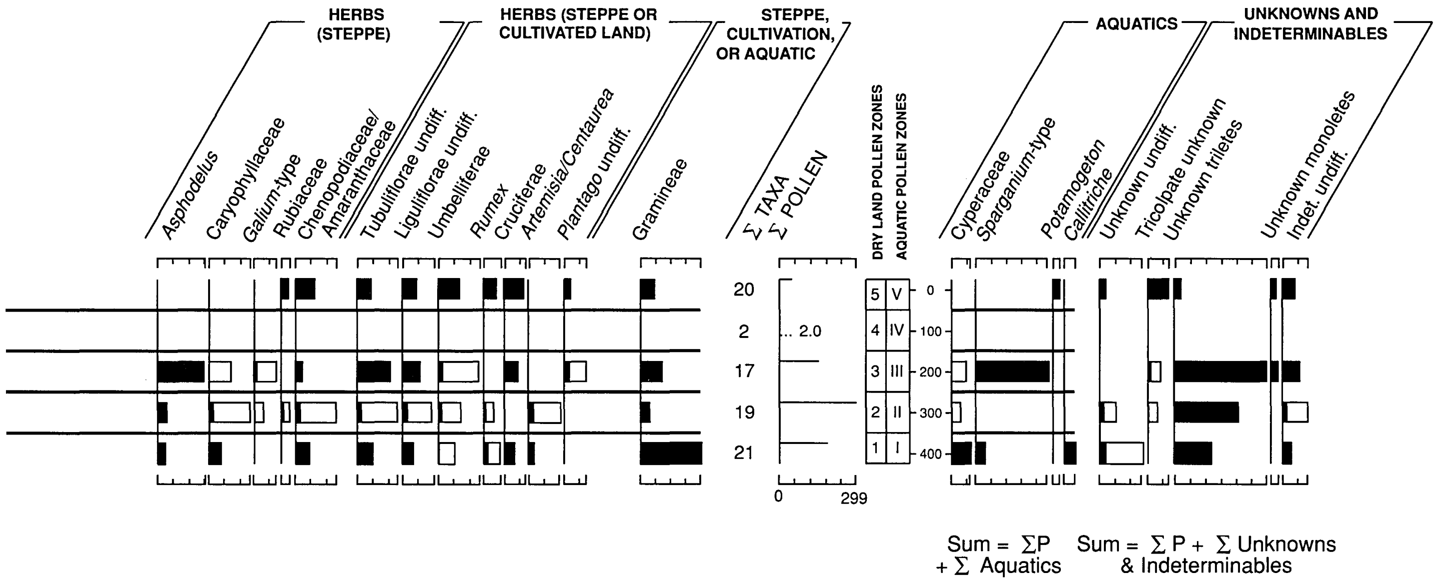
Most maquis species are wind-pollinated and tend to be over-represented in terrestrial sediments. Most garigue plants and most bulbous and herbaceous plants of steppe environments are insect-pollinated; they tend to be under-represented in the pollen rain. The same is not necessarily true for grasses. Reeds, for example, produce enormous amounts of pollen, as do many steppe grasses; but grasses associated with woodland environments do not generate much pollen. On the whole, then, the Tersana and Limnes basins would have received most of their pollen from their central salt marshes, the rest of their basin floors, their sloping sides and cliffs, and the surrounding plateau; some could have been blown in from more distant sources.

To sum up, Mediterranean evergreen tree-type pollen can represent woodland or maquis; Ericaceae can represent woodland, maquis, or garigue, and Gramineae can represent wetland, salt marsh, dryland steppe, or cultivation. A woodland-maquis mix tends to be over-represented in pollen diagrams, whereas garigue and steppe are under-represented. Dryland pollen reflects regional and local environmental trends but aquatics, grasses, and sediments mainly reflect local phenomena.

At no span during the history of either core has the local vegetation been continuous forest. Even if we assume that all the Ericaceae were trees and all the grasses grew in fens and salt marshes, the pollen of trees and shrubs only once exceeds 75% of the total pollen of dryland plants. If the opposite assumption is made, then tree pollen amounts to well under half the total dryland pollen. A ratio of tree/shrub pollen to shade-intolerant herbs for the Tersana and Limnes cores equals about 1:1 throughout. Although such a ratio suggests that 50% of the landscape was woodland and 50% non-woodland, the reality may have been that it was less wooded since tree pollen is often over-represented in pollen samples.

The natural vegetation of Tersana and Limnes during the Neolithic and Bronze Age was thus a mosaic of woodland and non-woodland. Garigue and steppe covered more than half the local land area. Given the dates of the Tersana core it is not clear if the garigue, which covered much of the local landscape in the lower three-fourths of the diagram (FIG. 8), was wholly natural or was an early result of human activity. Nor is it possible at this time to judge the role played by the indigenous browsing animals of Crete in creating and maintaining garigue-type vegetation.

The occurrence of *Tilia* (basswood/linden), *Ostrya* (hornbeam), and *Corylus* (hazel) pollen in the two cores is of special note because none of these trees is now known to grow naturally on Crete, not even on cliffs inaccessible to browsing goats. These trees are characteristic of Central Europe; their presence in both the Tersana and Limnes cores indicates that the climate of Neolithic and Bronze Age Crete was substantially less arid than the modern one.



The overlap of these temperate trees with such characteristic Mediterranean plants as olive, prickly oak, and lentisk, however, indicates that the minimum winter temperature could not have been more than 6°C cooler than that of today. Rackham and Moody have personally observed *Tilia* and *Olea* growing together on a cliff in the Acheron gorge of Epirus, suggesting that the Neolithic climate of NW Crete was similar to that of modern Epirus.

Human manipulation of the local vegetation is first suggested in Tersana Zone 3 by the appearance of *Olea* pollen at 350 cm (ca. 4750 B.C., corresponding to the Middle Neolithic). The reliability of this cultural correlation is very good because the appearance of olives at 350 cm is supported by a ^{14}C date of ca. 5800 ± 130 b.p. from a sample taken between 330 and 355 cm.

Olive preserves a continuous pollen record from the late Pleistocene to the present in SW Turkey and NW Syria (van Zeist and Bottema 1982), and it is likely that these regions served as refugia for many frost-sensitive Mediterranean plants during the Ice Ages. Small quantities of *Olea* pollen dating to ca. 7000 B.C. have also been identified in a core from the SW Peloponnese (Kraft, Rapp, and Aschenbrenner 1980). This is the earliest post-Pleistocene evidence of olive in southern Greece, and, with such an early date is unlikely to represent introduced, cultivated trees. It therefore seems probable that pockets of olive survived the Ice Age on the Greek mainland as well as in the Levant and Anatolia (FIG. 10). So far there is no evidence for olive in Crete at such an early date. It does not appear in the Tersana core until the Middle Neolithic nor in the Aghia Galini core until the Early Bronze Age. Nevertheless, if olive could survive the Pleistocene on the cooler and wetter west coast of the Peloponnese, it seems probable that if it had been indigenous to Crete, it could have survived hidden away in one of the island's hundred gorges. Olive pollen is present throughout the Limnes core, so we think it likely that olive has been a natural element in Cretan woodland throughout the Pleistocene and Holocene. Its cultivation could have been an imported practice or could have developed locally.

Following Melena (1983) and Hansen (1988), we consider olive cultivation to include the systematic tending of "wild" trees. According to Hansen (1988: 46)

> . . . the surrounding maquis would have to be removed and prevented from regrowth and the [olive] trees would have to be protected from grazing animals by pruning the branches to above 5 ft., the height the goats could reach by standing on their hind legs.

In fact, once trees reach a height that puts the canopy out of range of browsers, it can be beneficial to mix herding and olive culture. The trees benefit from the natural manuring and the "pruning" of their lower branches by the browsing animals. Hansen further notes that in the event of "wild" olive culture, the removal of the natural maquis vegetation should be evident on the pollen spectra, accompanied by an increase in olive pollen. Although it is

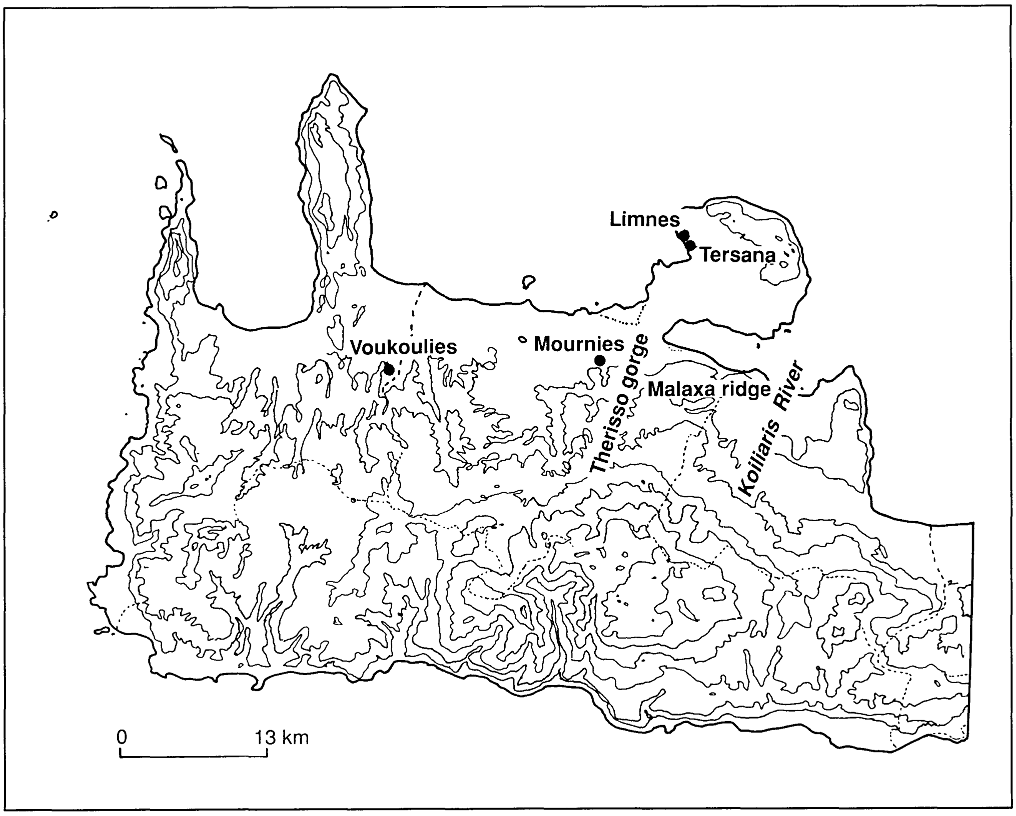


Figure 10. Map showing locations mentioned in the pollen section.

not impossible for the olive pollen at 350 cm in the Tersana diagram to have come from such tended trees, no other accompanying features suggest "cultivation." We therefore suggest that the initial appearance of olive in the Middle Neolithic was as a natural part of the oak woodland, then at its peak.

By the end of Zone 3 (270 cm, ca. Late to Final Neolithic), however, *Olea* pollen percentages of 15% leave little doubt that olives were being cultivated on the Akrotiri (Wright 1972). There is also a simultaneous decline in oak pollen, suggesting that areas of oak woodland/maquis were being grubbed out. Thus, both of Hansen's criteria for pollen indicators of olive cultivation are satisfied in the Akrotiri diagram by the Late Neolithic. We propose that the gradual increase in *Olea* pollen during the Late Neolithic represents its initial cultivation on the Akrotiri.

At the top of Zone 4 (210 cm, ca. Early Bronze Age) *Olea* pollen percentages reached almost 40%, suggesting large-scale olive culture on the peninsula. Such early dates for olive cultivation on Crete contrast with those proposed for the Greek Mainland by Runnels and Hansen (1986), who suggest that although olive cultivation may have been under way since the Early Bronze Age, it did not become significant until the Late Bronze Age.

Tilia pollen disappears from the Tersana diagram at the beginning of Zone 4 (250 cm, ca. Final Neolithic), reappears as a single grain at 210 cm, and then vanishes completely by the beginning of Zone 5 (190 cm, ca. Early Bronze Age). Turner (1962) proposed that this tree disappeared from other parts of Greece because of woodcutting and field clearance during the Neolithic, and over-browsing by livestock. But *Tilia* is a very resilient tree and forms coppices easily when cut; to be cleared it must be grubbed out by the roots, as when clearing land. At present, *Tilia* is only found in middle and southern Greece in damp places at high altitudes, often on cliffs out of reach of browsing livestock. Such a specific modern distribution is in contrast to the distributions of other goat-palatable trees that continue to grow in the Cretan landscape today. These trees grow in such varied cliff refugia that browsing is clearly more of a constraint on their distribution than is climate.

Tilia also disappears from most other pollen diagrams from southern Greece at about the same time, as seen in a second core recently published from Koiladha in the Argolid (Bottema 1990). The modern ecology of the tree suggests broad climatic changes to a drier, more strongly seasonal climate. This topic is controversial and has been examined most recently by Bottema (1990).

A general decline in garigue species in Zone 5 and concomitant increase in herbs of steppe and/or cultivated land could also indicate a drier climate. During the Early Neolithic the wetter environment of NW Crete supported a natural vegetation mosaic of woodland and garigue, while the drier environment of south-central Crete supported a mosaic of woodland and steppe. The combination of woodland and garigue on the Akrotiri during the Neolithic suggests that garigue plants were not starved of water by the roots of adjacent trees, as they commonly are when woodland expands today (Rackham 1983). Perhaps a decrease in soil moisture prompted the change from woodland-garigue to woodland-steppe at the top of the core.

The decline in *Olea* pollen at the top of the core probably reflects a decline in olive cultivation not related to climate change. At 210 cm (ca. 2600 B.C.) olive comprised almost 40% of total tree-and-shrub pollen; at 170 cm (ca. 1700 B.C.) it composed only about 2%. In short, olive pollen production was reduced by 95% over a period of about 900 years. The reversion of cultivated trees to their wild forms, which happens when grafted trees are neglected, may reduce their pollen production, but this explanation can not completely account for such a marked decline. Olive trees are long-lived and some have been estimated to be more than 2000 years old (Gavrielidhes 1976). They are drought-resistant and recover from fire and woodcutting. Olives do not tolerate hard frosts, but at present there is no evidence that the Middle Bronze Age on Crete was unusually cold. Another possibility is that the winters were too warm and did not allow the trees the dormant period they are said to need to flower (Panisot and Rebourd 1961), but this should also have affected temperate deciduous trees—which it did not. We think it most likely that the trees were killed locally by salt through a rise in relative sea level on the west coast of the Akrotiri.

The decline in Gramineae pollen seen at the top of the core may also result in part from a decline in grain cultivation. The proposed retreat of cultivation in Zone 5 seems to have allowed the natural vegetation—a mosaic of oak maquis/woodland and steppe with only a little garigue—to recover. Although such a vegetation mosaic is similar to that of today, the continued presence of hornbeam, ash, poplar, and elm indicates that the climate of the last pollen-preserving stratum—probably of the Middle Bronze Age—was still wetter than the modern one.

The dryland pollen from Limnes seems to confirm the reconstruction proposed for the latter part of the Tersana core. There is the same large proportion of Ericaceae and infrequency of grass pollen. In general, the landscape around Limnes seems to have been a little more arid than that around Tersana, with slightly less oak and fewer undershrubs and distinctly more indications of steppe.

Although freshwater aquatics are not well represented at Tersana, there are three periods with frequent pollen of specifically aquatic types, separated by periods with only occasional grains. In the peak periods (Zone I: 390 cm; Zone III: 310 cm; Zone V: 170 cm) there is enough *Sparganium*, *Cyperaceae*, and *Callitriche* to indicate reedbeds surrounding a freshwater lake. During these periods, the relatively modest amounts of grass pollen are likely to represent *Phragmites*, which probably formed the bulk of the reedbeds. There may also be a wetland component in the peak of Compositae Tubuliflorae at 390 cm; some Greek fens have a zone of tall thistles (*Cirsium creticum*) behind the reedbeds (Rackham 1983).

In Zone II (370 to 330 cm; ca. 5200–4500 B.C.) and Zone IV (250 to 190 cm; ca. 3200–2300 B.C.), aquatics form less than 2% of the pollen. The sedimentology favors freshwater reedbeds rather than salt marsh for the earlier period and probably for the later one. How much of the grass pollen at these times came from reeds is difficult to say, but the rather large amounts at 350 cm (ca. 4900 B.C.), 330 cm (ca. 4500 B.C.), and 210 cm (ca. 2300 B.C.) could have resulted in part from the pollen of dryland grasses or cereals.

Sediment Column

The sediments at the bottom of the Tersana core (Sed. Zone A) are characteristic of a dry, terrestrial depositional environment that would require a relative sea level substantially lower than that of today. By 390 cm (Sed. Zone C, ca. Early to Middle Neolithic), however, some part of the basin was wet and probably fluctuated between a freshwater pond and a marsh until 190 cm (Sed. Zone F, ca. Early Bronze Age), when it seems to have become more saline. This circumstance is indicated by a drop in fragments of the oogonia of the alga *Chara*, and their disappearance from all later levels (Sed. Zones G, H, and I: 170 cm and up). The increase in salinity was probably a combined result of eustatic sea level rise and tectonic subsidence, mostly the latter. The upper sediments (Sed. Zones H and I: 150 to 0 cm) can be characterized as beach deposits. It is unlikely that the basin was ever entirely occupied by a saltwater lagoon during the history of the core.

Small fragments of charcoal were found in all sediment samples examined for them and indicate periodic fires in the area since at least the Early Neolithic. Charcoal fragments were especially abundant in Sed. Zones C, E, and F

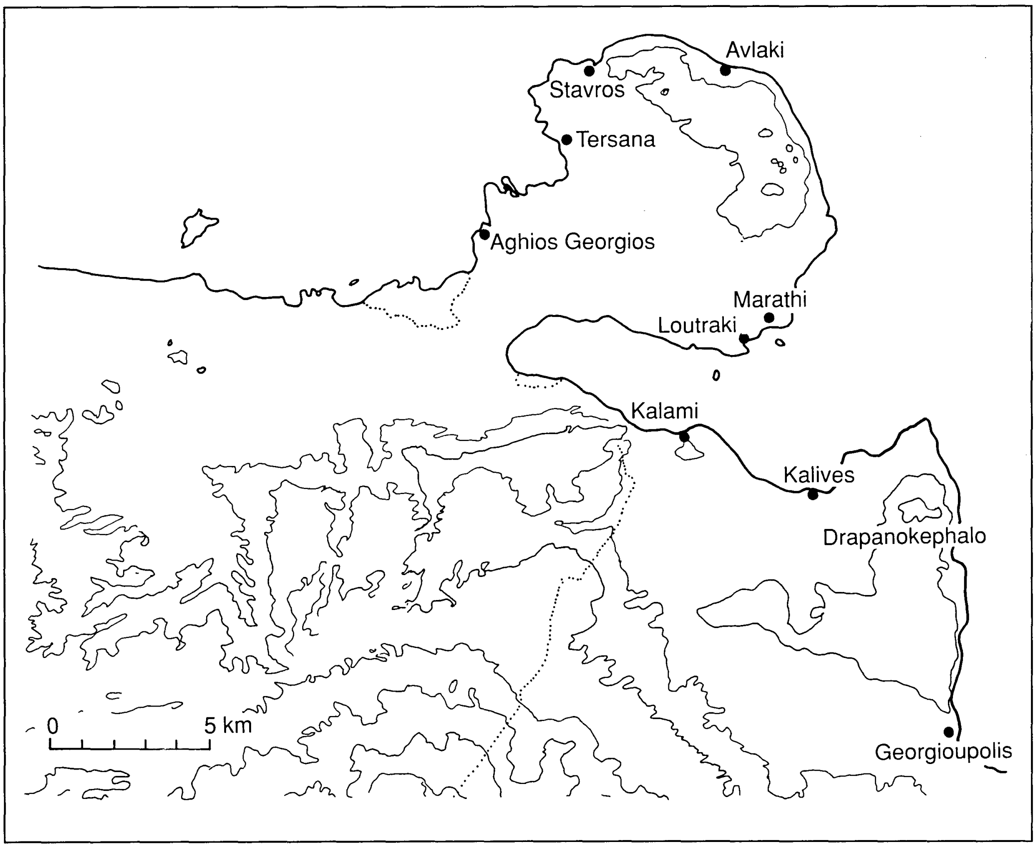


Figure 11. Map showing locations mentioned in the sea level section.

at Tersana and in Sed. Zones A and B at Limnes. It is difficult to tell how frequent or extensive such fires were. As recently as 1801 it was customary to burn the reedbeds of Lake Copais in Boeotia when dry in late autumn, in order to improve the pasture (Dodwell 1819; Rackham 1983). The existence of large tracts of heather and cistus garigue, a fire-dependant plant community, at the same time that abundant charcoal fragments occur, suggests that the fires were extensive.

Local Sea-Level Changes

The Akrotiri had essentially attained its present configuration by the beginning of the Middle Pleistocene (600,000 b.p.). Three shorelines around the Akrotiri date from the Middle to Late Pleistocene (Zamani and Maroukian 1981), with the youngest marked by a pronounced notch along the west coast between 16 and 18 m. It was probably during this most recent high sea-level stand that many of the coastal sinkholes were formed, including Limnes and Tersana. Zamani and Maroukian (1981) propose that this shoreline dates to the last interglacial (ca. 90,000 b.p.).

There is mounting evidence around the coast of the Akrotiri that sea levels have been both higher and lower than the present during the Late Holocene. Along the west coast of the peninsula we have noted partially drowned quarries with solution notches etched into quarried surfaces now 1–1.5 m above present sea-level (Aghios Georgios; Stavros; FIG. 11). These observations allow us to reconstruct three sea level stands since the quarries came into use: 1) a sea level at least 1 m lower than the modern one that would allow the now flooded sections of the quarries to be exploited; 2) a sea level 1 to 1.5 m above the present one; and 3) modern sea level. Sea Level 2 must postdate initial quarrying activity and is likely to postdate Sea Level 1, suggesting that sea level rose from Level 1 to Level 2 and then subsided to Level 3. Total displacement amounted to about 2.5 m or more.

But when did these changes take place? The quarrying techniques employed, which range in date from Bronze Age to Venetian (Shaw 1972–1973), are of little help. A similar sequence of sea level changes, however, has been documented and radiocarbon dated for a number of localities in western Crete, and it is tempting to extrapolate these dates to the Akrotiri. Observations from the west end of Crete suggest a stepped subsidence beginning in the Early Bronze Age and ending in the Late Roman/Early Byzantine period, resulting in a gradual rise in relative sea level. Then, between A.C. 400 and 600 the entire west end of the island seems to have been uplifted along a SE-NW axis, lowering relative sea level more or less to its modern level (Pirazzoli 1986).

High and dry, Roman or Medieval rock-cut "fishtanks," (Leatham and Hood 1958–1959; Davaras 1974), found along the west coast of the Akrotiri (Aghios Georgios; Avlaki), suggest that sea level was higher when they were built. The evidence indicates that relative sea level along the west coast of the Akrotiri gradually rose from the Early Bronze Age until at least the Roman period (TABLE 2).

This situation contrasts with that observed along the south coast of the Akrotiri (Marathi, Loutraki), where coastal cliffs full of Roman and earlier cultural features (floors, walls, etc.) are being eroded into the sea. A Roman "villa" excavated by Theophanidhes (1939) has been partly washed away by wave action, indicating that relative sea level has risen since it was constructed. These and other observations suggest that the Roman and earlier sea levels along the south coast of the Akrotiri were lower than the present; the opposite of what seems to have happened along the west coast of the peninsula (TABLE 3).

Between the Early Bronze Age and sometime in the Late Roman to Early Byzantine period, the west coast of the peninsula became increasingly submerged—drowning coastal plains and sinkholes such as Tersana along the west coast and, conversely, exposing coastal flats along the SE coast. This trend was reversed in post-Roman times (ca. A.C. 500), when the peninsula tilted in the opposite direction—uplifting the west coast and submerging the SE coast—bringing the sea to its present level.

Neolithic to Late Bronze Age Landscape History

Neolithic: ca. 6100–3000 B.C.

The pollen spectra at the bottom of the Tersana core indicate that at the time of human settlement, or possibly just before it, the local vegetation was a mosaic of garigue and mixed oak woodland or maquis. Along this exposed coast, tree growth could have been stunted by the prevailing north and west winds, preventing trees from growing tall enough to escape the reach of herbivores. Greater precipitation, in addition to wind exposure and browsing, probably led to the development of garigue and woodland along the north coast, while the more protected and drier south coast at Aghia Galini continued to support woodland and steppe.

Table 2. Evidence for higher sea level.

Site	*Evidence*
Aghoi Theodoroi	A wave-cut notch located 3.1 m above sea level with a ^{14}C date of 1850 ± 70 b.p. (Thommeret et al. 1981a, 1981b).
Aghios Georgios	1) An aeolianite quarry with a wave-cut notch between 1 and 1.5 m above sea level occurring on a quarried surface. The very earliest this quarry could date is Bronze Age, because the quarrying techniques required to cut the stone were not in use prior to that period (Shaw 1972–1973). Although no diagnostic Bronze Age quarrying features have been recognized here, this type of stone was extensively used to build Middle and Late Bronze Age structures at Khania:Kastelli and must have been quarried somewhere nearby. A few traces of characteristic Roman quarrying have been observed at this site on a face that would have been well above the 1–1.5 m sea level stand. Occasional use of aeolianite quarry occurs today. Therefore, according to archaeological data, it is possible that the Aghios Georgios quarry has been in use off and on since the Bronze Age. 2) Quarried depressions at a height of about 6 m above sea level now filled with waterworn cobbles (up to 30 cm in diameter). 3) A feature that looks like a fishtank is now dry and would require a rise in sea level of about 1 m to be operational. 4) A boatslip that is now high and dry. This feature is associated with both Roman and Medieval structures and material. Since these observations were made, this locality was largely destroyed by the construction of a sewage processing plant for the city of Khania.
Kalathas	An aeolianite quarry with a wave-cut notch about 1.1 m above sea level on a quarried surface. Like the quarry at Aghios Georgios, this quarry cannot date earlier than Bronze Age.
Tersana	Sediments and microfossils from the pollen core indicating an increasingly marine environment in the depression from ca. 2000 B.C. to the upper end of the core.
Stavros	An aeolianite quarry with a wave-cut notch about 1.5 m above sea level occurring on a quarried surface. Records from the Venetian period describe the quarrying of building stone from Stavros (J. Tzedhakis, personal communication). It is possible, however, that parts of the quarry date to the Bronze Age. The quarry is still used today.

The co-existence of olive and such Central European trees as basswood/linden, hazel, and hornbeam in the Middle, Late, and Final Neolithic levels of the Tersana core place certain constraints on the seasonal distribution of moisture and the temperature range. It seems likely that during the Neolithic, precipitation was more evenly distributed throughout the year. Winter temperatures along

Table 3. Evidence for lower sea level.

Site	*Evidence*
Aghios Georgios	A coastal quarry partially submerged by a meter of water.
Kalathas	A coastal quarry partially submerged by a meter of water.
Stavros	1) A coastal quarry partially submerged by a meter of water. 2) A square rock-cut fishtank(?) submerged by 1 to 1.5 m of water.
Avlaki	A coastal quarry partially submerged by the sea. The lower sea level indicated by these four submerged quarries cannot be older than Bronze Age because the technology to quarry the stone did not exist until then.
Kalami	A coastal site with stratified Hellenistic material including floors, walls, and sherds currently being eroded by the sea. The projection of the slope of these strata would require a sea level about 2–2.5 m lower than the present.
Marathi	A coastal site with stratified Roman sherds currently being eroded by the sea. The projection of the slope of these deposits would require a sea level approximately 2–2.5 m lower than the present. Since there are no associated walls, it is possible that the strata were secondarily deposited; however, the fact that the sherds are not waterworn suggests that at the time of their deposition sea level was a good deal lower than it is today.
Georgioupolis	Partially submerged walls associated with Roman and later sherds. The nature of the walls is ambiguous. Parts of the walls are covered by a material that may be the underwater cement used in Roman and later times. It is therefore possible that these walls were harbor installations that have been raised rather than dry walls that have been submerged. This interpretation agrees better with the evidence of the wave-cut notch 1.5 m above sea level that dates to 2030 ± b.p. (Thommeret et al. 1981a).

the exposed NW coast could not have been more than 6°C cooler than at present or olive would not have survived. Most of the Cretan Neolithic coincides with the postglacial climatic optimum, making it likely that average annual temperatures were warmer than today (Goudie 1983). Overall, the Neolithic climate of NW Crete was substantially less arid than that of today.

Our knowledge of the Khania area in the Early and Middle Neolithic is poor. The earliest well-documented human settlement on Crete, at Knossos, dates to about 6100 B.C. (Evans 1971; Cherry 1981). There seems to have been little time lag between the settlement of central and west Crete: Lera and Aghios Ioannis caves, on the Akrotiri, have produced ceramics that parallel Early Neolithic I shapes at Knossos (Treuil 1970; Guest-Papamanoli and Lambraki 1980). In west Crete all Early or Middle Neolithic sites are located in caves; there are no known open sites.

Neolithic settlers brought with them a full range of domesticated animals: sheep, goat, cow, pig, and dog (Evans 1971; Broodbank and Strasser 1991). The invading herbivores, if left to range on their own, would have competed with any indigenous mammals for browse and graze. Humans and dogs would have created another source of pressure on the larger native Cretan fauna which does not seem to have lasted long after the first settlement.

The abundant remains of livestock in Early Neolithic deposits in west Crete bespeak a great deal of herding (Tzedhakis 1970). Charcoal found in contemporaneous sediments at Tersana, if not from natural fires, suggests the practice of burning tracts of countryside to improve pasture or to help clear farmland.

Although there is no hard evidence that a transhumance system existed in the Neolithic, there is a mounting body of data indicating that the lower mountains of western Crete were being exploited as early as the Middle Neolithic. Lentaka Trypa (540 m) and Platyvola Cave (440 m) are located deep in the foothills of the White Mountains, about 10 km from the sea, and both contain Middle and Late Neolithic occupation levels (Hood 1965; Treuil 1970; Warren and Tzedhakis 1974). These sites were most likely involved in some form of pastoral livelihood.

The pollen record from the Akrotiri cores indicates a temperate coastal environment that was capable of providing plenty of year-round pasture. To therefore suggest that these mountain caves represent seasonal (transhumant) herding sites makes little sense. Perhaps caves like Lentaka and Platyvola were perennially occupied by small groups of full-time pastoralists.

Occupation of these upland sites by full-time pastoralists would indicate an increase in subsistence specialization (Halstead 1980). Lowland communities may have begun to emphasize cereal and olive cultivation over herding, allowing the pastoralists to supply them with meat and dairy products in exchange for flour, dried pulses, and oil. The increase in olive cultivation noted in the Tersana core during the Late Neolithic lends support to this view, as does the fact that important fodder plants like hornbeam, linden, hazel, elm, and poplar either stay the same or increase. The possible Late Neolithic introductions of red deer, agrimi (the wild Cretan goat), donkey, and hare (H. Jarman, personal communication 1991) also hint at a growing interest in specialized forms of animal husbandry.

The Final Neolithic landscape was quite different. The pollen in the Akrotiri cores for the Final Neolithic suggests a temporary decline in local agricultural activity: both olive and grass pollen decrease. Curiously, evidence for burning increases. Charcoal is present in the sediments, and fire-dependent plants flourished (pine, Ericaceae, Cistaceae, *Asphodelus*, etc.). The increase in pine suggests that open fields were no longer kept clear for cultivation, so burning may have been intended to maintain pasture. Simultaneous declines in popular fodder sources—including linden, hornbeam, hazel, elm, and poplar—are also suggestive.

Why would herding increase at low elevations at this time? One possibility is a change in climate masked by human interference in the Akrotiri pollen cores. In a number of caves, Faure (1964a, 1964b) noted a relatively thick calcareous layer between Late Neolithic and Early Bronze levels and proposed that this is the result of increased runoff from greater precipitation. McCoy (1980) collected fluvial and temperature data from around the Mediterranean that suggest increases in precipitation and erosion and cooler temperatures in Greece and Turkey at about this time. Grove (1979) documented a minor glacial advance between 5800–4900 b.p. (Late to Final Neolithic), especially in the eastern Alps. Similar advances during the Medieval Little Ice Age (A.C. 1550–1850) caused colder temperatures and increased storminess around the Mediterranean (Goudie 1983). Taken together, the data suggest that the climate of the Final Neolithic may have been similar to that of the Late Venetian and Early Turkish period on Crete—a time of unpredictable weather, drought, cruel winters, and torrential rains (Grove, Moody, and Rackham 1991). Such a weather regime could have discouraged year-round exploitation of upland pastures, forcing herders to, at least seasonally, move to the coastal plains, inadvertently initiating a system of pastoral transhumance. Why the farmers would allow the herders to dominate the coastal landscape is not so clear.

Another change during the Final Neolithic noted by several scholars is a general increase in open settlements at higher elevations and a concomitant decline in cave habitations, especially at lower elevations (Warren and Tzedhakis 1974; Vagnetti and Belli 1978). Examples of new settlements on high ground include the sites around the Lasithi Plain identified by Watrous (1982), the settlements in the hills around the Mesara (Vagnetti and Belli 1978), and Final Neolithic/Early Bronze I sherds at 1900 m in the Madares of the White Mountains (Nixon et al. 1990). Given the above climatic reconstruction, these sites could be seasonal pastoral settlements.

Open settlements also increased at lower elevations during the Final Neolithic. At least 10 open sites have been identified along the west coast of the Akrotiri (FIG. 2B). Why cease to live in caves? Increased precipitation may have flooded caves (Vagnetti and Belli 1978), but such an explanation is difficult to accept because limestone caves are commonly inhabited in areas of relatively high rainfall such as the Dordogne. Alternative explanations include: 1) increase in community size, making caves less suitable as habitations; and 2) the perception that caves had become unsafe.

At present the only quantitative data on Neolithic community size in Crete come from Knossos and probably are not typical of the island. Nevertheless, Evans (1971) notes that the settlement at Knossos increased in area from 0.25 ha in its earliest aceramic phase to 5 ha in the Late Neolithic. Halstead (1977, 1980) also noted a substantial increase in the size of settlements in Thessaly between the Late and Final Neolithic; typical Early, Middle, and Late Neolithic habitation was 0.4 to 0.8 ha in size, and increased to 1 ha or more in the Final Neolithic. An increase in community size could have contributed to the decline in cave habitations in the Final Neolithic and Early Bronze Age at low elevations where agricultural communities probably expanded at a rapid pace.

Near the end of the Neolithic, a number of caves in west Crete were completely or partially sealed, most likely by collapse of their ceilings caused by water percolation or earthquakes. The increased precipitation of the time, combined with increased tectonism, certainly could have led to an increased incidence of cave ceiling collapse, making caves less attractive as dwellings, but still suitable as shrines. Thus, environmental and social factors probably contributed to the progressive abandonment of caves as habitations in the Final Neolithic and Early Bronze Age.

The earliest Neolithic inhabitants in the Khania area practiced a mixture of agriculture and herding, and lived in small, dispersed groups of several nuclear families (Halstead 1980). Over the next two millennia they diversified their subsistence strategies to take advantage of the area's natural resources. By the late Middle Neolithic, full-time pastoralists may have come into existence, allowing the lowland agriculturalists to specialize in different crops, such as olives. By the Late Neolithic the lowlanders seem to have been cultivating olives extensively as well as other crops, while the pastoralists may have increased their exploitation of secondary products. By the Final Neolithic the combination of expanding population, increased community size, increased tectonism, and colder, less predictable weather may have encouraged settlement on open and higher ground, and prompted a more seasonal exploitation of upland pastures.

Bronze Age: ca. 3000 to 1100 B.C.

Ash and hornbeam, temperate European trees, continued to co-exist with olive throughout the Bronze Age, indicating that the environment was still less evaporative than the modern one. There are, however, subtle changes in the pollen record that suggest a gradual drying of the climate by the Middle Bronze Age. First is the disappearance of basswood/linden (*Tilia*)—the most sensitive of the Central European trees—from all pollen cores from southern Greece. Second is a general increase in the proportion of xerophytic evergreen oak pollen to mesophytic deciduous oak pollen. Third is the change on the Akrotiri from a "climax" vegetation of woodland and garigue in the Neolithic to one of woodland and steppe in the Early to Middle Bronze Age. These changes could have been caused by increased temperature, increased seasonality of rainfall, lower overall rainfall, or some combination that ultimately resulted in a decrease in soil moisture.

Beginning in the late Final Neolithic or early Early Bronze Age, tectonic activity on the island increased and gradually caused the west coast of the Akrotiri to subside and the SE coast to be uplifted. The west coast experienced slow, progressive salinization in coastal basins, inhibiting plant growth and contaminating the water table. Low coastal habitations around the west shore of the peninsula were eventually abandoned in the Old and New Palace periods (Middle Bronze I to Late Bronze I). The simultaneous decline in olive and grass pollen at Tersana is likely another consequence of the subsidence.

During the Early Bronze Age all plant communities decline except for olive and grasses, which increase strikingly, suggesting that the Akrotiri was intensively cleared and cultivated. Olives are also well documented at Myrtos in east Crete (Rackham 1972) and hinted at in the Aghia Galini core in the south (Bottema 1980), suggesting that olive culture became common throughout the island during the Early Bronze Age. The plow was introduced to the Aegean at this time (Pullen 1992), facilitating the cultivation of annual crops such as grains, pulses, and garden vegetables.

The uppermost spectra from Tersana, which probably date to the Middle Bronze Age, present a changing picture. Olive, garigue plants and grasses decline, while those of noncultivated trees (pine, oak, elm, hornbeam, and ash) and herbs of steppe increase, suggesting recovery of natural vegetation. Charcoal fragments are almost absent, as though there was a decrease in burning. Site numbers decrease along the west coast of the Akrotiri, although there is an overall increase on the peninsula. These data indicate that the local area saw a decline in human activity during the Middle Bronze Age. This decline seems tied to local tectonic activity, and probably does not reflect regional conditions.

The earliest unimpeachable evidence for cereal crops in west Crete dates to Early Bronze I and comes from the small site of Debla (542 m; Warren and Tzedhakis 1974; Greig and Warren 1974). Cereal impressions were identified in chaff-tempered pottery from the site and included emmer wheat, barley, and oats (Greig 1974). It is likely that these crops were grown locally in the foothills, as well as in the coastal plain (Moody 1985). There is also evidence for figs, pulses, and almonds from Late Bronze Khania at Kastelli and at a site on the Akrotiri (Follieri 1982).

Herding continued to be an important part of the west Cretan subsistence system in the Bronze Age. Faunal remains from Debla belong exclusively to sheep/goats (Warren and Tzedhakis 1974). Slaughtered between two and five years of age, the animals must have been primarily exploited for meat (Payne 1985). The absence of other fauna suggests specialized caprine herding and, together with the macrobotanical evidence, the data indicate a system of mixed herding and agriculture was practiced in the Khania foothills by Early Bronze I.

Curiously, we have found no Early Minoan II pottery in the high Madhares, suggesting that transhumance to such extreme elevations ceased. This may be related to the return of the climate to a more stable pattern, or perhaps the introduction of the plow opened new environs to cultivation, causing the Neolithic emphasis on animal husbandry to decline in the Early Bronze Age.

Middle Minoan III/Late Minoan I sherds have been identified at several locations in the Madhares, but the paucity of environmental data for the period makes it difficult to understand why. Whatever the individual factor(s) may have been—increase in population, climate change, change in technology or subsistence, etc.—together they created enough pressure on the land to prompt the populace to exploit the high mountain pastures once again.

Settlements in the Khania area increased in both number and size from the Early Bronze Age through the New Palace period (FIG. 2C: 40 of 75 sites; FIG. 2D: 94 of 130 sites; FIG. 2E: 109 of 156 sites). During the Early Bronze Age a few new habitations were established along the Akrotiri coast, but the majority were located farther inland. The discovery of an Early Bronze Age tomb at Nea Roumata (320 m) indicates that permanent settlements, not just seasonal habitations, existed at moderate elevations. Nea Roumata is interesting since it is on the main N–S route from the Khania area to Rhodhovani (ancient Elyros) and Sougia, and it is in a metalliferous area.

The average size of Early Bronze Age habitations on the Akrotiri accords with observations of those in lowland areas where early farming occurred (0.82 to 1.5 ha; Renfrew 1972; Halstead 1980, 1981). It seems unlikely, however, that west Cretan Early Bronze Age settlements were as densely occupied as those in east Crete. Warren and Tzedhakis (1974: 335) observe

> The most striking feature [at Debla] is that we are concerned with at least three separate single-roomed structures. This arrangement of individual units contrasts with the continuous, cellular, multi-roomed complexes of Myrtos and Vasiliki.

They also note a similar pattern at Elenes in the Amari Valley. On the Akrotiri this tradition of open settlement continues through the New Palace period. Structures are separated by 75 to 200 m.

Average site size for the Old Palace period is slightly less than that for the Early Bronze Age (0.73 to 1.1 ha) because of the proliferation of small isolated hamlets or farmsteads. In the New Palace period average site size increases (1.1 to 1.28 ha) and reflects the proliferation of middle-sized sites rather than a decrease in the number of very small sites. On a small scale the pattern appears dispersed, especially in the Old Palace period, but on a large scale it is strongly nucleated (FIG. 2).

The techniques of cluster analysis, nearest neighbor, and Thiessen polygons suggest that there were three possibly autonomous territories on the Akrotiri in the Early Bronze Age, each encompassing about 40 sq km. By the Old Palace period these territories may have merged into a single territory of about 100 sq km, complete with its own Peak Sanctuary on the summit of Mt. Sklokas (Moody 1987). By the New Palace period the Akrotiri may have been subsumed in the territory of Khania. These changes in territory size are not confined to west Crete and can be documented for central, southern, and eastern Crete (Moody and Lukermann 1985). An increase in territory size requires improvements in communication, transportation, and record keeping. The impressive Linear A archive at Khania:Kastelli indicates that such improvements had taken place by the end of the New Palace period, if not before.

The settlement configuration on the Akrotiri during Late Minoan III is much more nucleated (on both a small and large scale) than the preceding periods. Average settlement size increases to 1.4–1.5 ha, largely because of the abandonment of very small habitations. The number of settlements also drops significantly (FIG. 2D). Economic and sociopolitical variables must have been influential in the development of this settlement pattern, but there is also evidence—from outside Crete—for a significant change in climate near the end of the Late Bronze Age.

In short, as we move through the Bronze Age the impact of environment and climate on the developing culture becomes more and more difficult to separate from demographic, economic, and sociopolitical factors. These problems, however, are eminently approachable through further reconnaissance, additional investigation in climatic proxies, and refinements in chronology.

Concluding Remarks

We suggest that a number of the long-standing theories on the development of complex civilization in the Aegean are no longer tenable. Renfrew (1972) developed the Subsistence/Redistribution model, which emphasized the role of agriculture, and the Craft Specialization/Wealth model, stressing the development of metallurgy and maritime trade. More recent are Halstead's (1981) theory of "social storage" and Sherratt's (1981) "secondary products revolution." Reassessments by van Andel and Runnels (Runnels and van Andel 1987; van Andel and Runnels 1987, 1988) conclude that increased trade and interaction were the primary factors and that a modification of Renfrew's Craft Specialization/Wealth model was the most reasonable scenario. More recently, Pullen (1992) argued for the primacy of agricultural innovation.

All these models, however, assume a climate regime very similar to the modern one. Our data demonstrate that the Neolithic and Bronze Age climate of Crete (and southern Greece as a whole) was significantly less arid than at present, making untenable those calculations of prehistoric agricultural yields and carrying capacities that are based on modern conditions. We believe that climatic and environmental factors were significant variables in the changing organization of culture on Crete: sea level fluctuations have affected settlement distribution at least since the Middle Bronze Age; during the Final Neolithic increased tectonism may have prompted and maintained settlements in the open; and climatic change may have prompted the first exploitation of the high mountain pastures.

Emerging is a complex regional picture. In some areas trade may have been the key stimulus for the emergence of complex civilization (e.g., the Cyclades), while in others it may have been agriculture (e.g., the Corinthia). A single, universal pattern probably does not exist. The Aegean is by nature a very regionalized landscape. This is true climatically, environmentally, and culturally. In west Crete, for example, it now appears that olive culture was well under way in the Late Neolithic, significantly earlier than it seems to have been on the Greek Mainland or in the Cyclades (Runnels and Hansen 1986; Hansen 1988). It is also earlier than was proposed by the Renfrew models, suggesting that the impact of the traditional Mediterranean triad of olive, grain, and vine must be dated earlier for Crete (Sarpaki 1992).

Periodic reassessments of the emergence of civilization in the Aegean will, in time, revise our own findings, particularly with reference to the following points:

1. There is solid evidence that the Neolithic and Bronze Age climate on Crete was significantly less arid than the modern climate. Even taking into account the increasing dryness of the Early and Middle Bronze Age, the climate on the coastal peninsulas of NW Crete must have been similar to that now experienced in Epirus.
2. When attempting to reconstruct agricultural productivity and carrying capacity, the seasonality of rainfall and the timing of the first and last frosts are crucial factors and must be included in the equation.
3. Evidence for olive culture on Crete appears to be 1000 years earlier than that on the Greek Mainland. The precocious development of this industry on Crete may have contributed to the island's rapid cultural development in the Early Bronze Age.
4. Although seasonal exploitation of mountain pastures higher than 1000 m and of other marginal environments are an index of land pressure, the primary factors can vary from one period to the next. For example, climate may have been critical in the Final Neolithic use of the Madhares, while New Palace period exploitation may have been prompted by population pressure.

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