PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Archaeological Evidence and Non-Evidence for Climatic Change

P. I. Kuniholm

Phil. Trans. R. Soc. Lond. A 1990 **330**, 645-655
doi: 10.1098/rsta.1990.0045

Phil. Trans. R. Soc. Lond. A **330**, 645–655 (1990)
Printed in Great Britain

Archaeological evidence and non-evidence for climatic change

By P. I. Kuniholm

Department of the History of Art and Archaeology, Cornell University, G-35 Goldwin Smith Hall, Ithaca, New York 14853-3201, U.S.A.

'Climate' is often used by historians to explain phenomena for which they cannot otherwise account. Accordingly, much of what has been written about climatic effects and climatic change must be read with extreme scepticism. Even though a disturbance may be obvious in the archaeological record, and it may be synchronous with a climatic event, a cause and effect relation should be demonstrated before one can say with any degree of confidence that the evidence is secure. Only when a number of separate lines of investigation agree on the same thing are we safe in positing true climatic 'effect' or 'change'. This paper focuses on several instances in Mediterranean and Aegean archaeology where more or less satisfactory evidence for climatic change may be sought among a number of disciplines.

The title of this paper as originally assigned was 'Archaeological evidence for climatic change'. The qualifying phrase 'and non-evidence' was my addition, reflecting not just routine academic sophistry but a deep-rooted suspicion that we often attribute to 'climate' phenomena in the archaeological record that we cannot otherwise explain. In layman's language climate becomes the historian's cop-out. One example of the lengths to which some writers will go should be sufficient: 'Climate in Greco–Roman history,' (Eddy 1980) in which the author sets out to match two graphs, each one an inverted V, one of the thickness of sequoia tree rings in California, the second of dedications and building starts in Africa between A.D. 138 and 244. The logic seems to be, after the two Vs are superimposed, that because the latitudes of California and the Mediterranean are the same, so should be the climate. Six data points in 2000 years allegedly prove this. So much for non-evidence, but where might we look for something more satisfactory?

First, I have no doubt that climate does indeed change, both over the long and short term, although, after recent reports announcing that there is less than total agreement among the climatologists that the 'Little Ice Age' ever existed and that there is doubt as to whether there is really a so-called greenhouse effect after all, I wonder how the archaeologist is supposed to provide information about events whose very existence has been called into question.

Secondly, I have no doubt that we are in one way or another affected by climatic changes, particularly from single catastrophic events. The severe drought in the mid-western United States last summer and the billions of dollars' worth of damage that resulted, all duly recorded by the press, is a dramatic example of the degree to which we are at the mercy of the climate, and the people who lost their livestock and had the banks foreclose on their mortgages do not need to be informed by a Royal Society Discussion Meeting that indeed 1988 was a bad year. But again I ask whether an archaeologist digging 2000 years from now in the remains of a mid-western U.S. town and coming down to the depressed 1988 level would be able (*a*) to realize that there had indeed been a horrendous drought, and (*b*) to discriminate between the effects of the drought and some adverse aspect of, let us say, Reagan economics. Other less-dramatic climate changes have less obvious effects. Here the problem is simply one of recognition.

There is also the question of cause and effect. The same hypothetical archaeologist continues to dig down to the 1930s level and finds the great 'dust bowl.' Does this have anything to do with the stock-market crash of 1929 or were the two events simply coincident?

At the first International Conference on Climate and History at the Climatic Research Unit, University of East Anglia, Norwich, in 1979, the point was made repeatedly in both the printed review papers and the discussions that went on all week that it is not so much climate that is important but rather man's *perceptions* of it. Colleagues who work with the English Manor House records used as an example a society where conventional father-to-son wisdom is that you have to save one-third of your harvest to survive until the next harvest and still have enough grain for the next year's planting. Then a series of mild years comes along with abundant rain and sun, and very quickly the old verities are forgotten. One-fourth of the harvest, let us say, is saved, and the rest is sold for immediate profit. Then the climate reverts to normal (except that people have forgotten what 'normal' is: the unofficial Norwich after-dinner estimate of how long our memories work was about four years maximum), and people starve. Has the climate really 'changed?' Not at all. Human memory has once again played us false. How, I wonder, is the archaeologist, measuring the human record as it bumbles along in this fashion, going to be able to match it in any meaningful way with the estimates of the palynologists (who, by the way, should have been represented at this Discussion Meeting), the geomorphologists, and the meteorologists, even presuming that nobody has made any faulty calculations?

One final example follows (here I speak as a member of our local volunteer fire brigade). In October 1981 five inches (13 cm) of rain in five hours sent the Ithaca (New York) creeks into full flood, and for the next three days we pumped out basements of houses along the banks of Fall Creek in which an average of six feet (2 m) of water had collected. As we pumped, we noticed that there was not a single nineteenth-century house in the lot. The old houses were up on top of the bluff. Obviously, in the last century the creek had flooded often enough so that any right-thinking house-builder built on high and dry ground. But somewhere around World War I enough time went by without a flood to entice would-be money makers into subdividing the land along the stream banks into house-lots and then building the houses that the fire brigade had to pump. A glance at the flood-scoured walls of the gorge through which the creek flows would have told any moderately competent geologist that this was no place to build houses, either then or now, but avarice won out over common sense.

Antoine Meillet's great comment on his study of Indo-European linguistics was 'La linguistique est une système ou tout se tient,' that is to say, linguistics are a system in which everything hangs together, and so it should be with archaeology and climate. Because much of my own work is with tree rings (Kuniholm & Striker 1983, 1987), I am continually reminded that there are indeed periodicities of one kind or another in all the records with which we work, but all too often our conclusions about climatic forcing mechanisms or stimuli are drawn based on a single line of evidence without independent corroboration and should therefore be treated with extreme scepticism. Moreover, I find the vast majority of speculations on the relation between archaeology and climate to be precisely that: speculation based often on inadequate or unverifiable data. Pollen diagrams down to the end of the Upper Palaeolithic, for example, may be significant indicators for climatic change, but after intensive agricultural exploitation begins in the Neolithic there is always the danger that a certain element of anthropogenic 'noise' has been introduced into the palynological record. Moreover, how should we expect various bodies of evidence to interact in the archaeological record? There will be lags in some cases, parallel change in others, divergent change in yet others. At best the possibilities are precarious. A model might be the careful, cautious, exhaustive work of Emmanuel Le Roy Ladurie whose *Times of feast, times of famine: a history of climate since the year 1000*, first published in 1971, is now again in print and which makes even better reading the second time around. Nothing is too humble for Le Roy's attention: wine harvest dates, advances and retreats of glaciers, grain prices, documentary evidence for crop yields, taxation rates, tree-ring widths, etc., and his conclusions are equally humble: something indeed seems to be going on with the climate, but he refrains from forcing conclusions upon us.

Twenty years ago the British palaeoclimatologist H. H. Lamb, while commenting on the climatic changes that may have put an abrupt end to Bronze Age civilization in Greece and in other areas of marginal agricultural productivity (Carpenter 1966, and see below), issued a challenge to researchers in the Mediterranean and in the Near East (Lamb 1968).

> Our knowledge of this 3000-year climatic sequence in the middle and northern latitudes of Europe has been built up partly from pollen analysis of numerous bog and lake site deposits and partly from analysis of documentary records, especially those which reveal the incidence of extreme warm or cold, wet or dry seasons. By comparison, the Mediterranean is a strangely neglected region despite the many ancient cultures there and the wealth of literature that has survived. Surely, we need not remain for ever ignorant of which years in classical times had unusually long, or short, dry seasons or of which winters were striking for warmth or coldness. What seems most important, if we are to get at the truth of these matters, is to encourage many more historians and archaeologists to dig out the documentary and other sorts of evidence. Every report which is specific as to year and place, giving or implying the general character of a particular summer or winter, or the dates of notable rains or floods at any season, is important. One would imagine that Greek or Roman horticulturists must have recorded the actual dates of the first and last rains. Any compilation of such reports from anywhere and any period in the Mediterranean and Near East is badly needed.

Let us look around the Mediterranean now to see what, if anything, may be said about archaeological evidence for climatic change.

Iran

A comprehensive and cautious survey of a wide variety of evidence is by Butzer (1958). He finds it difficult to correlate evidence for short, minor rainfall ameliorations with anything cultural. He laments the lack of systematic study and systematic observations in both Anatolia and Iran. His final conclusion is that although he believes small-scale variations of climate occurred continually during historical times, he nevertheless strongly negates any overall climatic change within the past 2500 years. More recent, and indeed systematic, work (Van Zeist & Wright 1963; Van Zeist 1967; Van Zeist *et al.* 1968) bears this out. Van Zeist concludes that after about 5500 before present (BP) the climate may have shown minor fluctuations but no major changes.

Mesopotamia

Despite millennia of written records, Mesopotamia is a frustrating area with which to deal, partly because the evidence is very unevenly distributed, partly because there has been hardly any research done on its ecological microstructures (Nissen 1988). Plant cultivation must have been always precarious at best with the bulk of the water coming through irrigation channels

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

rather than from the wretched 200 mm a^{-1}† rainfall of southern Mesopotamia (Van Zeist 1969). The most entertaining single item for a climatic event is Sir Leonard Woolley's finding of a water-borne layer, 8–11 ft (2–3 m) thick, of clean mud and silt at Ur between 'Ubaid I and II levels. Mrs Woolley took one look at it and said, 'Well, of course, it's the Flood!' (Woolley 1954). Spoilsports (Lees & Falcon 1952) have cast doubt on this, saying that the date is not contemporary with other early floods, and that the major cause is tectonic subsidence rather than the simultaneous rising of the Euphrates and the Tigris that can set southern Mesopotamia awash (and see now Nützel 1976). Whatever the cause or combination of causes (downward sea-level change, tectonic uplift, silting-in of the floodplain, or climatic amelioration), H. J. Nissen's new (1988) book on Mesopotamian prehistory concludes that southern Mesopotamia at last became inhabitable in the 4th millennium B.C. only because the land was finally dry enough to farm and raise animals. Another excellent but cautious recent paper (Neumann & Parpola 1987) lays out climatological, meteorological, and Assyriological data for a significant climatic change at the end of the Bronze Age (see also Brinkman 1984).

Egypt

The major review of Nile flooding and its causes is by Lyons (1905), updated by Bell (1975) with an historical commentary particularly regarding the low flood levels that might have helped bring on the so-called Little Dark Age at the end of the Middle Kingdom sometime after *ca.* 1768 B.C. Bell notes that this took place at a time when there was unusual uncertainty about the proper order of succession to the Kingship, a general increase in governmental instability, and numerous short reigns. She does not claim that low water caused the concurrent political upheaval, but poor crops certainly did not help matters. What bothers me about the evidence from the Nile is the apparently deliberate falsification of the Nile records for revenue purposes (Lyons 1905), which certainly should cast doubt on their utility as a reliable source for climatic change unless supported by external evidence.

The Levant

The most comprehensive recent study I have seen is by Horowitz (1979). Yet his climatic evidence boils down to pollen analysis from a grand total of two bore holes, one in Lake Hula and one in the Mediterranean, with one uncalibrated radiocarbon date for each. More evidence is needed here. A recent paper by Koucky (1987) on the Roman frontier in central Jordan goes at long length into 570-year cycles of drought and plenty, and indeed one of his graphs is quite impressive, but I am suspicious of his chronology, and his references, albeit somewhat more recent than Eddy's, do not inspire confidence.

Turkey

Careful, competent work (they call their observations on climate 'speculations') is being done by Van Zeist and others in the Gröningen group, but a major portion of their work (1975) concerns only prehistory for which we have no corroborating evidence. In a limited study in southeastern Turkey (1968) their pollen diagrams for three different lakes show that the climate has not changed noticeably during the last 3000–4000 years.

† mm a^{-1} is millimetres per year.

The Roman world

Clive Foss's (1979) explanations for the silting-in of the harbour at Ephesus dodge between deforestation and *possibly* (my emphasis) climatic change. In his own words, 'the evidence is scattered and ambiguous, and subject to much controversy and variety of interpretation... A theory of climatic change, if it could be developed and maintained, could do much to explain the decline of the ancient world and the conditions which prevailed in the early Byzantine period.'

Last month David Whitehouse, whose scepticism about the lack of evidence for climatic change at the end of the Roman period has been in print for some time (Hodges & Whitehouse 1983), was kind enough to show me part of an expanded manuscript on which he is now working concerning the apparent absence of climatic change in Roman and early post-Roman times. After considerable thought he concludes that the evidence is disappointing: the written records of the River Tiber floods neither support nor contradict the hypothesis of a Dark Age drought. A second class of evidence, Vita-Finzi's (1969) so-called Younger Fill, can be shown, says Whitehouse upon reconsideration, to be equally explicable without climatic change.

Greece

A useful new book, *Beyond the Acropolis: a rural Greek past* (Van Andel & Runnels 1987), has just appeared, with commentary on the Argolid, including its climate, from the earliest times to the present. Speculations on droughts in Attica or at least changes in the water levels in the 8th, 4th and 2nd centuries B.C. as attested by the filling in of Attic wells and the digging of other, deeper wells have been published by John Camp (1979, 1982, 1984). One obvious criticism of Camp's work is that wells go dry for a variety of reasons besides drought, including heavy consumption of water by a large population, but Camp is also able to bring to bear both epigraphical and textual evidence for drought, shortage, and famine datable to specific years, plus the need for Athens to import large amounts of grain from abroad.

We have also the Sanctuary of Zeus Ombrios or Rainy Zeus on the top of Mt Hymettus (Langdon 1976), a rural sanctuary to which local farmers brought offerings in inverse proportion and quality to the known prosperity of Athens. When Athens was prosperous and importing goods from all over the Mediterranean world, the Sanctuary of Rainy Zeus languished; but when Athens fell upon hard times and was forced to patronize the local farmers, the sanctuary flourished. In isolation this does not seem like very hard evidence, but taken together with Camp's wells, and the inscriptions, and the literary texts, it seems to me a promising beginning.

Another useful new work, fulfilling a number of Lamb's *desiderata*, is Peter Garnsey's *Famine and food supply in the Graeco–Roman world: responses to risk and crisis* (1988). His commentary on the Eleusis First Fruits inscription (*Inscriptiones Graecae* II^2 1672), concerning the harvest of 329–328 B.C. that yielded enough wheat and barley to feed only some five-eighths of the Attic population is both fascinating and frustrating because we simply do not have that kind of detailed documentation for other years besides 329–328. Would that we had an absolute Mediterranean tree-ring chronology in place for those centuries to test these snippets of evidence, but for the moment we have only disconnected dendrochronological sequences.

Now that the *Thesaurus Linguae Graecae* is largely complete, containing some 60000000 words from almost 3000 authors on compact disc, plus the 20000 or so Attic inscriptions we have been adding at Cornell, we are at last in a position to begin part of the textual searching, at least for the Greek world of which Lamb spoke. Although some of the literary references are no doubt metaphorical, others are probably every bit as literal as the fourth-century lead tablet from Dodona in which a supplicant asks the oracle, 'Is the present severe winter due to the impiety in the city?' (Parke 1967). And of course the cuneiform and hieroglyphic evidence needs to be searched as well.

After all these remarks about other people's work, here are a few speculations of my own, arrived at during the last fifteen years' work of building tree-ring chronologies in the northeast corner of the Mediterranean, which I think might represent evidence rather than non-evidence for climatic change.

Example 1. Short-term events: the Great Drought of 1873–74 in Turkey

The first is a typical short-term event. In 1874 in the Province of Ankara, District of Keskin, a drought occurred of such devastating proportions that 81% of the cattle and 97% of the sheep died. Of the population of 52000, some 7000 moved out of the district and 20000 died (Christiansen-Weniger & Tosun 1939). The traveller C. Naumann reported that in the Provinces of Kastamonu, Ankara, and Kayseri 150000 people and 100000 head of livestock (40% of all herds) died. Hunger and sickness through the 1873–74 winter killed another 100000 people (Naumann 1893).

Plots of tree-ring growth for 11 sites in or near the area of the reported catastrophe show subnormal growth for 1873 and 1874, following four other years of significantly subnormal growth, as described in table 1.

Table 1

site	1873 growth index (%)	1874 growth index (%)
Mihaliççik	25.2	20.8
Çeltikçi	23.0	54.2
Çamlitepe	46.7	87.8
Hamidiyeköy	54.6	85.7
Yozgat	66.1	67.7
Ovacik	66.3	73.9
Güdül	74.4	69.6
Kizilcahamam	70.9	70.0
Bağlum	59.4	94.4
Yarakin	69.1	95.1
Çatacik	84.6	87.1

This is not to say that every time a band of narrow rings appears on Turkish trees one is to judge that a disastrous famine has occurred, but we feel that this is more than just coincidence, and at least the trees are a lot closer to the troubled area than the California sequoias. Eventually, we hope to be able to reconstruct more sophisticated palaeoclimatic anomalies for the Aegean as have been done most recently for Europe by Schweingruber *et al.* (1987) and Briffa *et al.* (1987) to whose work we were able to contribute nine chronologies from the southeast corner of Europe. Another potentially rich source of information is the Ottoman Prime Ministry Archives in Istanbul with their estimated 40000000 documents covering the past 500 years.

Example 2. Longer-term events: the Celali Rebellions of *ca.* 1585–1640

The second kind of event is rather longer term, from a decade to several decades. Again archival and tree-ring evidence, even in raw form, can be combined with intriguing results. Below (figure 1) is a profile of tree-ring growth from 1560 to 1620 in five forests and two archaeological sites in and around west-central Anatolia. The oscillations below and above the base-line represent departures from mean annual growth. Note that only 13 out of 61 years have above-normal growth, and the cumulative depletion of ground water and the subsequent effect on cereal crops must have been much more severe than on mature forest trees that at least have deep root systems and food reserves which enable them to survive a long-term drought.

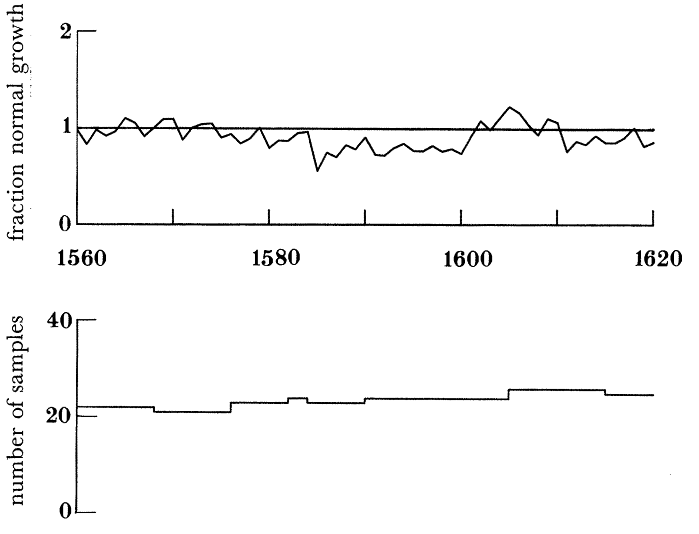

Figure 1. Çatacik, Elmadağ, Antalya, Grevena conifers and the archaeological oaks.

Now compare this composite table of archival information and travellers' reports from 1564 to 1612 compiled independently by Professor H. Inalcik and Professor W. Griswold and kindly communicated by them to me as in table 2.

The late sixteenth and early seventeenth centuries in Anatolia were marked by peasant unrest, even revolt (the so-called Celali Rebellions), large-scale changes in land use, and unexpectedly large fluctuations in urban populations (Griswold 1977, 1983, 1989). Obviously, climatic change is not to be blamed for all otherwise inexplicable occurrences in history, especially in a period of great political and economic turmoil, and the correlation between the two sets of information may be merely fortuitous, but it is interesting that there is such a high correlation between years of poor tree-ring growth and years reported to be years of shortage or famine. Remember, too, that the drought effect was undoubtedly cumulative, and a look at the table will show that often the year or years immediately preceding a reported famine are notable for reduced growth. Although the export grain market reopened in 1591 after a year in which tree-ring growth reached only 90%, 1590 was still the best year out of the previous six, and one imagines that the Ottomans must have been sorely pressed for foreign exchange. Of course there are years of subpar tree-ring growth that go unmentioned in the chronicles, and

TABLE 2

year(s)	report of conditions	tree-ring growth (%)
1564	Widespread shortage in Anatolia	96
1565–67	Ottoman prohibitions on grain export	110 105 91
1570–71	More prohibitions. The Venetian ambassador to the Sublime Porte complains that prices have quadrupled	109 87
1574–76	Grain shortage. Famine in Anatolia and Istanbul	105 90 94
1579	Shortage in Archipelago and Syria	100
1580	Shortage in Western Asia Minor and Archipelago	79
1583	Shortage in Archipelago and Aleppo	95
1584	Shortage in Western Anatolia, Syrian coasts, Tripoli	96
1585	No rain in January and February in Istanbul; no rain in summer in Rumeli, Edirne. Shortage in Western Anatolia, Rumeli (Edirne, Berkofca, Temesvar), Lepanto, Zulkadriye in Eastern Asia Minor	55
1586	Famine in Çorum	74
1588	Shortage in Istanbul	82
1589	Great shortage in the Levant	78
1590	Shortage in Damascus. Great shortage in Italy; wheat imports from Northern countries	90
1591	Shortage in Skoplje. Re-opening of the Levant wheat market	72
1592	Fall famine in Damascus; cold January, plague	71
1594	Plague, storms, Ottoman prohibitions. Land 'remains uncultivated because there are no farmers....' Italy makes massive imports from Northern countries	84
1595	Famine	76
1598	Famine. Caspian area hot; rough seas in July on Mediterranean; Sir Anthony Sherely reports exceeding barrenness in Anatolia	76
1599	Unusual contrary winds in the Adriatic. Drought in Zante	78
1610	'Unhusbanded plaines for many miles together,' says traveller Charles Robson. Plague of grasshoppers	106
1611	Famine in Anatolia. Aleppo snow awful	75
1612	French Consul 'killed when snow broke through his house on him'	86

the poor French Consul seems to have survived years in which growth rates reached as high as 122% without succumbing to any snow.

EXAMPLE 3: MAJOR CATASTROPHES

This leads me to my final kind of event, the catastrophic event that occurs only once or twice in a millennium, the hardest kind to document convincingly, and about which most of the nonsense unfortunately gets written. When Rhys Carpenter first published his *Discontinuity in Greek civilization* in 1966, suggesting climatic reasons for the disaster attendant upon the end of the Late Bronze Age in the Mediterranean – specifically a northward shift of the winds that now desiccate the Sahara so that they desiccated instead Crete, the Peloponnese, and Anatolia – he was roundly condemned by the meteorologists with the exception of Professor Reid Bryson, who did the logical thing: assign the topic to a graduate student, David Donley. What Donley found in his dissertation – summarized succinctly and neatly in an apologetic article in *Antiquity*, 'Drought and the decline of Mycenae' (Bryson *et al.* 1974) – was the winter weather pattern of 1954–55 that yielded precisely the conditions posited by Carpenter, i.e. 60% normal rainfall and significantly higher temperatures in Crete and the Peloponnese. The mechanism was not as simple and linear as Carpenter's first scheme. Some areas, Elis and Athens, showed no change whatever. Other areas, particularly in the north, were much wetter than normal.

Bryson *et al.*, however, in their discussion make the following noteworthy point that echoes Lamb's quoted above:

> It is reasonable to say that if the pattern of the winter of 1954–55 had dominated the climate around 1200 B.C., or even if that pattern had been a good deal more frequent than in modern times, Mycenaean agriculture would have been very precarious indeed. A short, more intense episode might have been disastrous.... Clearly more field data are needed, especially in critical areas. It is likely that the yet uncovered record of the past contains the answers we seek – if we are wise enough to ask the right questions.

Donley's climate diagram for 1954–55 did not include Anatolia, but this has now been done by Weiss (1982), and his diagram deserves careful study. Several interesting new additions can be pointed out: the southwest corner of Anatolia had very heavy precipitation, up to 140%. The North Syrian coast received 40% normal precipitation. The Anatolian plateau east of Ankara was dry, with the area around Malatya having as little as 7% of normal precipitation, suggesting that it was not just the Aegean proper that experienced unusual climatic phenomena. This is not to say that this is *exactly* what happened at the end of the Late Bronze Age in the twelfth-century B.C., but it represents what could have happened if Carpenter's modified scenario is correct.

What, in fact, do we know about what happened in the twelfth-century B.C.?

1. A large number (70–90%, depending on whose figures are used) of Mycenaean sites are destroyed or abandoned or both.

2. Troy, Boğazköy on the Anatolian plateau, and Ugarit on the North Syrian coast are destroyed. In one of the so-called 'oven texts' at Ugarit (i.e. the last day's mail before the city was destroyed) mention is made of famine.

3. The Pharaoh Ramesses fights off the so-called Peoples of the Sea (whoever they were), who were 'restless in their isles.'

4. The Greenland ice-core researchers have a big acidity layer, indicating that Hekla 3 erupted in 1100 ±50 B.C.

5. M. G. L. Baillie (1988*a*, *b*) finds that the Irish tree rings dwindle to practically nothing in 1159 B.C. and the two decades following, no doubt a direct result of the Hekla eruption.

6. For Mesopotamia Neumann & Parpola (1987), mentioned above, cite both textual data for nomadic incursions and unrest from the middle of the twelfth century onward as well as evidence for notable warming and aridity.

7. Even as far away as China in documents of Chou, the last king of the Shang Dynasty, the effects of Hekla 3(?) were noted: dust and ash rains, a foot of snow in July, all five cereals killed by frost (Pang *et al.* 1988).

8. At Gordion, Turkey, ever since we first measured the rings of our 806-year-long tree-ring chronology that extends from the sixteenth century B.C. to the eighth century B.C., we have known that there was one 20-year period where annual growth was abnormally large, accompanied by abnormal fluctuations both up and down. Now that Bernd Kromer at Heidelberg has successfully wiggle-matched 18 sets of specifically numbered rings from the Gordion chronology with the high-precision oak curve from Europe (Kuniholm & Kromer 1990), we also see that this 20-year anomaly is centred on 1159 B.C. and the two decades following.

9. And finally Professor Donald Sullivan (personal communication) has now found in one of his cores at Gölcük, a small lake above Sardis in Lydia in Western Turkey, a section showing

that the lake deepened drastically between 1200 and 1100 B.C., with peat giving way to lacustrine mud. The date is based on three calibrated radiocarbon determinations. Taken in isolation, the Gölcük core could be blamed on the spread of agriculture in the region, but a period of extraordinary rainfall as is suggested by the Gordion tree rings could also have produced this effect.

In and of themselves these anomalies do not yet prove Carpenter right, and whether there is a convincing cause and effect relation among these various concurrent phenomena has yet to be determined, but Gordion and Gölcük are two more pieces of evidence to show that the middle of the twelfth century B.C. was not a normal time in the Aegean and elsewhere. When similar twelfth-century tree-ring sequences and more carefully studied and dated cores are available from additional sites in the Aegean, and with additional help from a wide variety of specialists such as phytologists, palynologists, ecologists, vegetable crops specialists, micro-faunal analysts, and others, we may one day be able to say that Carpenter was right all along about the twelfth-century catastrophe, and, more importantly, that a number of less-dramatic climatic events also had a significant impact upon the human affairs of the past 9000 years. The exercise seems to me well worth the effort.

Endnote

The Aegean Dendrochronology Project is supported by the National Endowment for the Humanities, the National Geographic Society, the Institute for Aegean Prehistory, the Samuel H. Kress Foundation, the David and Lucile Packard Foundation, and a number of private contributors.

References

Baillie, M. G. L. 1988*a* Irish oaks record volcanic dust veils drama! *Archaeology Ireland* **2**(2), 71–74,

Baillie, M. G. L. 1988*b* Marker dates – turning prehistory into history. *Archaeology Ireland* **2**(4), 154–155.

Bell, B. 1975 Climate and the history of Egypt. *Am. J. Archaeology* **79**, 223–269.

Briffa, K. R., Wigley, T. M. L., Jones, P. D., Pilcher, J. R. & Hughes, M. K. 1987 Patterns of tree-growth and related pressure variability in Europe. *Dendrochronologia* **5**, 35–57.

Brinkman, J. A. 1984 Settlement surveys and documentary evidence: regional variation and secular trend in Mesopotamian demography. *J. Near Eastern Stud.* **43**(3), 169–180.

Bryson, R. A., Lamb, H. H. & Donley, D. L. 1974 Drought and the decline of Mycenae. *Antiquity* **47**, 46–50.

Butzer, K. W. 1958 Quaternary stratigraphy and climate in the Near East. *Bonner Geographische Abhandlungen* **24**, 103–128.

Camp, J. M. II 1979 A drought in the late eighth century B.C. *Hesperia* **48**, 397–411.

Camp, J. M. II 1982 Drought and famine in the 4th century B.C. *Hesperia Suppl.* **20**, 9–17.

Camp, J. M. II 1984 Water and the Pelargikon. *Studies Presented to Sterling Dow on His Eightieth Birthday. Greek, Roman, and Byzantine Monographs* **10**, 37–41.

Carpenter, R. 1966 *Discontinuity in Greek civilization*. New York: Norton.

Christiansen-Weniger, F. & Tosun, O. 1939 *Die Trockenlandwirtschaft im Sprichwort des anatolischen Bauern*. Ankara.

Eddy, S. K. 1980 Climate in Greco–Roman history. *Syracuse Scholar* **1**, 19–30.

Foss, C. 1979 *Ephesus after Antiquity: a late antique, Byzantine and Turkish city*, appendix III, pp. 185–187. Cambridge University Press.

Garnsey, P. 1988 *Famine and food supply in the Graeco–Roman world: responses to risk and crisis*. Cambridge University Press.

Griswold, W. J. 1977 The Little Ice Age: its effect on Ottoman history, 1585–1625. (Paper presented at the Middle East Studies Association Meeting, New York.)

Griswold, W. J. 1983 *The Great Anatolian Rebellion 1000–1020/1591–1611*. Berlin: Klaus Schwartz Verlag.

Griswold, W. J. 1989 Climatic change: a possible factor in the social unrest of seventeenth century Anatolia. *Studies in honor of Andreas Tietze*. Istanbul: Divit Press.

Hodges, R. & Whitehouse, D. 1983 *Mohammed, Charlemagne & the origins of Europe*. Ithaca: Cornell University Press.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Horowitz, A. 1979 *The quaternary of Israel*, pp. 211–230. London: Academic Press.

International Conference on Climate and History 8–14 July 1979, Review Papers. Climatic Research Unit, University of East Anglia, Norwich, U.K.

Koucky, F. L. 1987 The regional environment. In *The Roman frontier in Central Jordan* (ed. S. T. Parker). *BAR Int. Ser*. **340** (i–ii), 18–25.

Kuniholm, P. I. & Striker, C. L. 1983 Dendrochronological investigations in the Aegean and neighboring regions, 1977–1982. *J. Field Archaeology* **10**, 411–420.

Kuniholm, P. I. & Striker, C. L. 1987 Dendrochronological investigations in the Aegean and neighboring regions, 1983–1986. *J. Field Archaeology* **14**, 385–398.

Lamb, H. H. 1968 Climatic changes during the course of early Greek history. *Antiquity* **42**, 231–233.

Langdon, M. 1976 *A sanctuary of Zeus on Mount Hymettos. Hesperia, Suppl*. **16**.

Le Roy Ladurie, E. 1971 *Times of feast, times of famine* (revised edn 1988). New York: Farrer, Straus & Giroux.

Lees, G. M. & Falcon, N. L. 1952 The geographical history of the Mesopotamian plains. *Geogr. J*. **118**, 24–39.

Lyons, H. G. 1905 On the Nile Flood and its variation. *Geogr. J*. **26**, 249–272; 395–421.

Naumann, C. 1893 *Vom goldenen Horn zu den Quellen des Euphrat*. Munich & Leipzig.

Neumann, J. & Parpola, S. 1987 Climatic change and the eleventh–tenth-century eclipse of Assyria and Babylonia. *J. Near Eastern Stud*. **46** (3), 161–182.

Nissen, H. J. 1988 *The early history of the Ancient Near East 9000–2000 B.C.* University of Chicago Press.

Nützel, W. 1976 The climate changes of Mesopotamia and bordering areas 14000 to 2000 B.C. *Sumer* **32**, 11–25.

Pang, K., Srivastava, S. K. & Chou H.-h. 1988 Climatic impacts of past volcanic eruptions: inferences from ice core, tree ring and historical data (abstract). *1988 Fall Meeting of the American Geophysical Union*.

Parke, H. W. 1967 *The oracles of Zeus: Dodona, Olympia, Ammon*, pp. 261–262. Oxford: Blackwell.

Schweingruber, F. H., Bräker, O. U. & Schär, E. 1987 Temperature information from a European dendroclimatological sampling network. *Dendrochronologia* **5**, 9–33.

Van Andel, T. H. & Runnels, C. 1987 *Beyond the Acropolis: a rural Greek past*. Stanford University Press.

Van Zeist, W. 1967 Late quaternary vegetation history of Western Iran. *Rev. Palaeobot. Palynol*. **2**, 301–311.

Van Zeist, W. 1969 Reflections on prehistoric environments in the Near East. In *The domestication and exploitation of plants and animals* (ed. P. J. Ucko & G. W. Dimbleby), pp. 35–46. Chicago: Aldine.

Van Zeist, W. & Wright, H. E. 1963 Preliminary pollen studies at Lake Zeribar, Zagros Mountains, Southwestern Iran. *Science, Wash*. **140**, 65–67.

Van Zeist, W., Timmers, R. W. & Bottema, S. 1968 Studies on modern and Holocene pollen precipitation in southeastern Turkey. *Palaeohistoria* **14**, 19–39.

Van Zeist, W., Woldring, H. & Stapert, D. 1975 Late quaternary vegetation and climate of southwestern Turkey. *Palaeohistoria* **17**, 53–143.

Vita-Finzi, C. 1969 *The Mediterranean valleys: geological changes in historical times*. Cambridge University Press.

Weiss, B. 1982 The decline of Late Bronze Age civilization as a possible response to climatic change. *Climatic Change* **4** (2), 173–198.

Woolley, L. 1954 *Excavations at Ur: a record of twelve years' work*, pp. 26–36. London: Benn.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES