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NO SYSTEMATIC EARLY BIAS TO MEDITERRANEAN ^{14}C AGES: RADIOCARBON MEASUREMENTS FROM TREE-RING AND AIR SAMPLES PROVIDE TIGHT LIMITS TO AGE OFFSETS

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ABSTRACT. Existing data and theory do not support a recent assertion that upwelling of old carbon has led to systematically 100–300 yr too old radiocarbon ages for the Mediterranean region. Similarly, the prehistoric tree-ring record produced over 3 decades by the Aegean Dendrochronology Project is shown to provide robust, well-replicated data, contrary to a recent unfounded assertion. ^{14}C and dendrochronology provide an accurate and precise chronometric framework for the Mediterranean region.

INTRODUCTION

In a recent paper, Keenan (2002) asserted that radiocarbon ages from the Mediterranean region from "earliest historical times (*sic*) until the mid-second millennium BC" are too old. He then put forward a hypothesis (upwelling of old carbon from the stagnant Mediterranean) to explain his initial assertion. Finally, he claimed that Anatolian dendrochronological evidence did not disprove his assertion or hypothesis. Further, he stated that the "Anatolian dendrochronology should be regarded as suspect and in need of independent scrutiny."

We respond as this paper is seriously flawed. We briefly review the evidence to show that:

1. There is no basis to his initial claim or starting point of systematically too old ^{14}C ages of "between one and three centuries", and instead good evidence to the contrary.
2. Keenan's review of literature in support for his theory is highly selective; there is, in fact, no sound database to support his claims.
3. The Anatolian dendrochronology, and in particular the key Bronze-Iron Age master sequence, is built on robust and well-replicated data using standard dendrochronological techniques.
4. Significantly, and inexplicably ignored by Keenan, ^{14}C research reported in 2001 using the Anatolian dendrochronology, in fact, demonstrates over long time intervals that there is no systematic distortion of Mediterranean ^{14}C ages versus those from the rest of the mid-latitude Northern Hemisphere. And, even at times of dramatic and rapid change in solar activity when a small short-lived offset has been detected between ^{14}C data on contemporary wood from the Mediterranean and Germany (and in turn Ireland), this is an order of magnitude less than Keenan's claim of disparities of between "one and three centuries."

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1. SYSTEMATICALLY TOO EARLY ^{14}C DATES IN THE EAST MEDITERRANEAN? NO

Keenan (2002:225) claims that ^{14}C ages are too old for the Mediterranean region from the "earliest historical times until the mid-second millennium BC" (*sic*–the earlier Holocene is meant). He makes this assertion not on the basis of unambiguous evidence, but instead, by the rather selective citation of some assorted publications. A few of these studies do report ^{14}C ages for some contexts older than the dates previously best estimated by archaeologists and ancient historians from little hard evidence through interpretation of various partial (2nd millennium BC) to largely non-existent (3rd millennium BC and earlier) proto-historical records and cultural associations, or speculative astronomical conjecture (e.g. Spence 2000; Rawlins et al. 2001), but none actually demonstrate ^{14}C ages systematically 100–300 yr older than any historically fixed date. The other literature cited consists of statements by archaeologists expressing concern that scientific dating techniques (most often ^{14}C) are sometimes yielding ages earlier than those conventionally assumed or best estimated but not known. Again, in no case, do any of these studies demonstrate ^{14}C ages significantly earlier than any actually known date. Moreover, in all cases careful and rigorous analysis of materials dated, and their association with the contexts for which dates are sought, would be necessary to support Keenan's assertion (cf. Bruins et al. 2003 and literature cited).

The major data resource is the study of Bonani et al. (2001), which reports ^{14}C ages for fragmentary organic samples obtained (with difficulty, in many cases) from a number of major Egyptian monuments. There are wide spreads of ages in several of the sets, which the team involved suggests to be partly accounted for by an "old wood" issue. All available trees in the region, of widely varying ages, were consumed by the pyramid builders and as older settlement debris was recycled in fires (Lehner et al. 1999); and the association of measured age for the sample (biological age unless other contaminating processes were involved) versus the date for monument construction is not demonstrated or clear in a number of instances (e.g. "charcoal" from mudbricks or from mortar [see Bonani et al. 2001:1297–98]—may easily represent "old" tree rings). Interestingly, the 2 secure datasets from early 2nd millennium BC Middle Kingdom monuments (Pyramid of Senusret II at Illahun and Pyramid of Amenemhet III at Dashur) yielded calibrated ages compatible with historical estimates (Bonani et al. 2001:1320 and Figure 1). This indicates no *a priori* problem with the 2nd millennium BC ^{14}C dates in the Mediterranean region, and, thus, negates Keenan's suggestion that other 2nd millennium BC ^{14}C series from the region may be too old. For the 3rd millennium BC Old Kingdom, Bonani et al. do report 17 date sets as older than the historical estimate, 6 as compatible, and 4 as more recent than the historical estimate. But, apart from noting that the historical age estimate is commonly regarded as ±100 yr for this period. The interpretation of Bonani et al. is based on the inappropriate use of average values for the ^{14}C age of sample sets, which contain significant internal variation, and is thus misleading. For example, an examination of Bonani et al. (2001:Figure 1) shows the Khafre Pyramid (object number 16) to yield one of the apparently tighter calibrated age ranges and to be some 2 centuries older than the estimated historical age. But examination of the 25 ^{14}C data from charcoal samples from the monument (Bonani et al. 2001:1306) reveals ages varying by 536 ^{14}C yr! As we show in Figure 1, a number of the individual samples do, in fact, offer calibrated ages compatible with the estimated historical age of 2558–2532 BC (Bonani et al. 2001:1316), and only some are older—"old" wood would appear the obvious 1st hypothesis (see Lehner et al. 1999). Such a pattern—younger ages corresponding to, or close to, context date and older ones reflecting old wood—is quite common and expected when dealing with wood/charcoal samples (for an example from Troy II, see Kromer, Korfmann and Jablonka 2002:48 and Figure 4). Similar observations may be made about the datasets for: Step Pyramid of Djoser at Saqqara, Temple Complex associated with the Step Pyramid, Pyramid of Sekhemkhet at Saqqara (Bonani et al. 2001:1303), Pyramid of Khufu at Giza (p.1305), Pyramid of Djedefre at Abu Roash, Sphinx Temple of Khafre at Giza (p.1306), Pyramid of Menkaure at Giza, Mortuary Temple of Shepseskaf at South Saqqara (p.1307), Mortuary Temple and Pyramid of Sahure at Abusir (p.1309), and Pyramid of Teti at Saqqara (p.1310). In contrast, it is notable that the ^{14}C ages from a modern excavation at the Royal Production Centre at Giza offer both a reasonably consistent set and calibrated ages more recent than the surrounding Old Kingdom datasets from the monuments (Bonani et al. 2001:Figure 1, object 12, contrasted with other objects 10–19). Similarly, the Pyramid of Snefru at Meydum offers interesting evidence (Bonani et al. 2001:1304). Six of the 7 dates are closely comparable (SMU-1412 on a "log" is either aberrant or very old wood nothwithstanding the stated dating of its "outer rings") and 5 of the determinations date outer rings from wood from the burial chamber or shaft thereto. The calibrated age range of the average of these 6 similar ^{14}C ages is entirely compatible with the historical age estimate (Bonani et al. 2001:1314). Thus, with appropriate samples or good contextual association, there is no evidence of any systematic ^{14}C offset of 100–300 yr as argued by Keenan (2002).

Meanwhile, Keenan has carefully avoided citing any of the other studies that have found that, in general, Mediterranean region ^{14}C dates usually agree perfectly well with the relatively secure early historic dates (e.g. Bruins et al. 2003; Hassan and Robinson 1987; Weninger 1990, 1997; Betancourt and Lawn 1984). Thus, for example, in the 14th–12th centuries BC, when vast numbers of material culture linkages tie the east Mediterranean regional chronologies together very tightly with a fairly solid Egyptian proto-historical chronology, ^{14}C evidence yields wholly compatible and mutually reinforcing data (e.g. Manning et al. 2001; Manning and Weninger 1992). Similarly, where there is reasonable to good proto-historical evidence for the date of the destructions in Palestine at the close of the Middle Bronze Age, a significant set of data (Jericho) yields consonant data (Bruins and van der Plicht 1995). Nor does Keenan note that detailed studies of ^{14}C evidence from, for example, the 3rd millennium BC Aegean region yield dates both consistent with conventional views and, in fact, sometimes younger than pre-existing archaeological opinion (e.g. Korfmann and Kromer 1993; Kromer, Korfmann and Jablonka 2002; Manning 1995, 1997). In contrast, the couple of well-known "problem" areas where ^{14}C and previous archaeological interpretation disagree, such as the start of the Aegean Late Bronze Age, are notable as periods where the conventional archaeological evidence for chronology is widely recognized as ambiguous and capable of alternative interpretations (e.g. Kemp and Merrillees 1980; Betancourt 1987, 1998; Hallager 1988; Manning 1999; Manning et al. 2002). These debates offer no support to the hypothesis of Keenan.

The test for Keenan's hypothesis would be ^{14}C data on independently and securely dated samples. Are they too old as he suggests, or not? Such material is not plentiful. Egypt is the obvious place to look, as here there is an historical chronology, with mutually reinforcing linkages with the independent Assyrian chronology, known within small errors back to the mid-2nd millennium BC, at least (Kitchen 1996a, 1996b, 2000, 2002; von Beckerath 1994, 1997). However, although analyses of available ^{14}C data from the 2nd millennium BC have found that dates are generally compatible with historical chronology (Shaw 1985; Hassan and Robinson 1987; Weninger 1990, 1997), much of the data employed is less than ideal or even appropriate. Most of the samples employed did not derive from modern archaeological excavation or they derived from monuments or objects not necessarily offering biological ages contemporary with the supposed historical connection. However, 1 suite of data from Egypt demands attention. These are 5 dates on a range of materials (bone, horn, skin, wood, and charcoal) collected specifically and carefully for a high-quality program of ^{14}C dating (Switsur, in Kemp 1984:178–188) from modern excavations at Tell el-Amarna (Akhetaten) (Kemp 1984). Amarna was the short-lived capital of Egypt during the "Amarna Age." Construction began

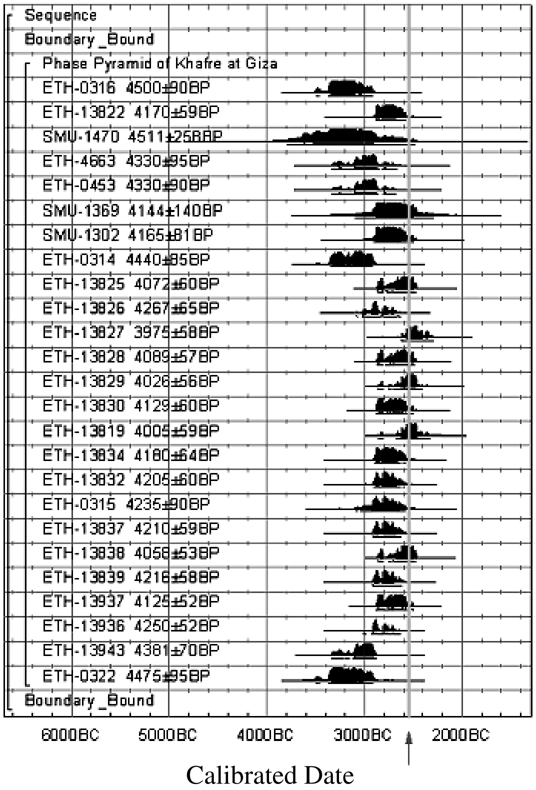
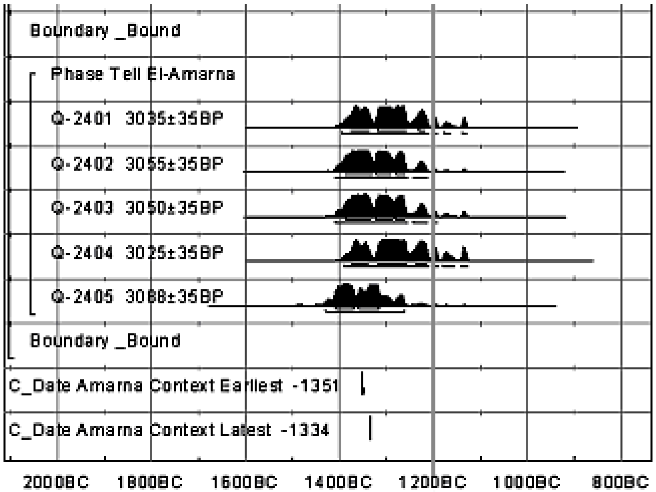
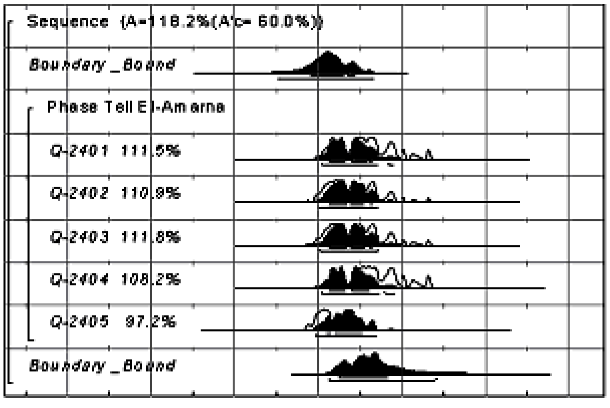


Figure 1 Calibrated age ranges for the ^{14}C ages reported from the Pyramid of Khafre at Giza by Bonani et al. (2001). The historical age estimate employed by Bonani et al. (2001) is 2558–2532 BC, indicated by the grey bar above the arrow. Samples are all of charcoal; they offer *termini post quos* ranges for human use. Eleven of the 25 samples—the more recent ones—offer ages compatible with this historical age estimate within their 2σ calibrated age ranges. The other older ages may, in most cases, be considered likely to reflect "old wood" or re-used material. The upper and lower lines under each histogram indicate, respectively, the 1σ (68.2%) and 2σ (95.4%) calibrated age ranges. Calibration and analysis employing OxCal 3.5 (Bronk Ramsey 1995; 2001 and later versions, with curve resolution set at 4) and INTCAL98 (Stuiver et al. 1998).

in year 4 of Amenhotep IV (Akhenaten) and the city became the capital by year 9; it was then no longer capital from about year 2 of Tutankhamun, and was being destroyed by the reign of Haremhab (Kemp 1984, 1987; Murnane 1995; Aldred 1988). The accession of Amenhotep IV is dated at about 1355–1351 BC and the accession of Haremhab about 1323–1319 BC by Kitchen and von Beckerath (Kitchen 1996a, 1996b, 2000, 2002; von Beckerath 1994, 1997). Letters preserved on clay tablets from the site (Moran 1992) provide synchronisms with Assyria and Babylonia and these confirm and require the dates given above within very narrow margins (Kitchen 1996a, 1996b, 2000, 2002; von Beckerath 1994, 1997). The specific context of the dated samples was a midden probably deposited early within the site's (very short) history and "thus during the reign of Akhenaten rather than that of Tutankhamun" (Switsur, in Kemp 1984:182–183). Hence, the historical date range might be narrowed to between about 1351/47 BC to 1338/34 BC. The Amarna ^{14}C ages on both known shorter-lived samples (skin, bone, and horn) and on the wood and charcoal samples tested, offer a tight and coherent set of results entirely consistent with the historical dates and very clearly provide no evidence at all for any systematic bias towards 100–300 yr too old ^{14}C ages as proposed by Keenan (2002) (see Figure 2).



A Calibrated Date



B. Calendar Date

Figure 2 A) Calibrated calendar ages for the ^{14}C data reported from Tell el-Amarna, Egypt (Switsur in Kemp 1984:178–188) compared to the historical date for the context (see text—indicated by grey bar). The upper and lower lines under each histogram indicate, respectively, the 1σ (68.2%) and 2σ (95.4%) calibrated age ranges. B) Sequence analysis (solid histograms) of the Amarna data (with the individual probabilities from (A) indicated by the hollow histograms) as a phase within calculated boundaries. The Amarna data are entirely consistent with the historical age for the context and exhibit no evidence for any systematic bias for ^{14}C ages 100–300 yr older than real age as asserted by Keenan (2002) (indeed, if there is any scope for movement, it is in the opposite direction). Calibration and analysis employing OxCal 3.5 (Bronk Ramsey 1995; 2001 and later versions, with curve resolution set at 4) and INTCAL98 (Stuiver et al. 1998). Q-2401, wood; Q-2402, charcoal; Q-2403, skin; Q-2404, horn; Q-2505, bone. Weighted average of all 5 data: 3050 ± 16 BP (1), weighted average of just the 3 definitely shorter-lived samples 3054 ± 20 BP (2), 2σ (95.4%) confidence calibrated ranges respectively (1) 1388–1331 BC (46.6%), 1322–1260 BC (48.8%), and (2) 1393–1260 BC (94%), 1228–1222 BC (1.4%).

In sum, there is no body of evidence indicating systematic significantly too old ^{14}C ages compared with any robust historical dates for the east Mediterranean (and there is no proto-historic evidence prior to the mid-1st millennium BC for the central-west Mediterranean). But, rather than merely continuing to cite examples from the vast archaeological and archaeometric literature where the evidence is heavily weighted against Keenan's assertions, we instead offer a clear empirical test for his claim, and thereby, demonstrate that it is incorrect: see Section 4 below.

2. OLD SEA AND OLD AIR? REALITY

No one doubts that the reservoir age of the Mediterranean surface water has changed over time, nor that surficial sediments in deltaic plains, including in the Mediterranean, can yield significantly old ^{14}C ages due to erosion and transport of old carbon-bearing materials (Stanley 2000; Stanley and Hait 2000). The reservoir age of the modern pre-bomb Mediterranean, based on ^{14}C measurements of known-age shells, is on the order of 400 yr (Siani et al. 2000; Reimer and McCormac 2002). Unfortunately, there are currently no measurements of the marine reservoir age for the Mediterranean between the 19th century AD and about 3800 ^{14}C yr BP. Comparison of ^{14}C ages of planktonic foraminifera to those of associated tephra layers and of paired shell and charcoal samples support a reservoir age comparable to that of the modern pre-bomb measurements from about 3800–6000 ^{14}C yr BP (Facorellis et al. 1998; Siani et al. 2001). Between about 7400–8800 ^{14}C yr BP reservoir ages were larger at around 515 ± 22 ^{14}C yr (Facorellis et al. 1998). These increased reservoir ages are coincident with the S1 sapropel formation (Siani et al. 2001). Sapropel events are observed in sediment cores throughout the Mediterranean as 1 or 2 dark bands of high organic carbon content, which are formed during periods of summer insolation and monsoon intensification. These wet periods may increase water column stability, increase surface productivity and decrease ventilation of the deep water, which could result in increased surface reservoir ages (Mercone et al. 2000). Ba/Al ratios provide a more persistent criterion than organic carbon content or color for defining productivity pulses (Thomson et al. 1999). Ba/Al in 7 cores taken throughout the Mediterranean increases from background levels starting around 10,000 ^{14}C yr BP (marine, uncorrected) with peak levels between ~9000 to 6500 ^{14}C yr BP and ending ~5300 ^{14}C yr BP (Mercone et al. 2000). After that, Ba/Al ratios remain near background levels to the present day and no sapropel event more recent than S1 is observed in the Eastern Mediterranean cores (Mercone et al. 2000). The Mediterranean stagnation ended by ~5000 ^{14}C yr BP with increased overflow to the Atlantic as observed in the sedimentology and in the planktonic δ^{13}C of a series of cores east and west of the Gibraltar sill (Vergnaud-Grazzini et al. 1989), not the 1000–0 BC quoted from this same study by Keenan, and surface reservoir ages returned to near modern values by 6000 ^{14}C yr BP (Siani et al. 2001). All available evidence indicates approximate equivalency of the Mediterranean surface reservoir with the mid-Atlantic reservoir (Siani et al. 2001:1918 and refs.) with the exception of the sapropel event ~8500 yr B.P.

However, even if the Mediterranean surface reservoir age had been older than has been observed, there is little evidence that a large ocean reservoir age translates into a large air reservoir age. We presently lack recent marine-terrestrial data from the Mediterranean to demonstrate this, but an analogy exists from the North Atlantic. Here, we may compare data on the sea surface ^{14}C reservoir from sea shells against ^{14}C ages for tree rings growing "downwind" in the British Isles from the 19th–20th centuries AD (Figure 3). It is apparent that changes in sea surface reservoir age do not translate into changes in air reservoir ^{14}C ages as recorded by oaks in the British Isles. In general, regional differences have been difficult to observe in tree rings because they are of the order of the measurement error and may be masked by laboratory differences (McCormac et al. 1995). For instance, if we compare decadal ^{14}C measurements of tree rings from the northwest coast of the United States with those from the British Isles, we find an average offset from AD 950–1850 of just 4 ± 2 ^{14}C yr despite the upwelling of old water along the west coast of the United States (Stuiver et al. 1998; Hogg et al. 2002). Other regional differences of up to a few tens of yr in multi-ring and single-ring samples are summarized by Stuiver et al. (1998) and Stuiver and Braziunas (1998).

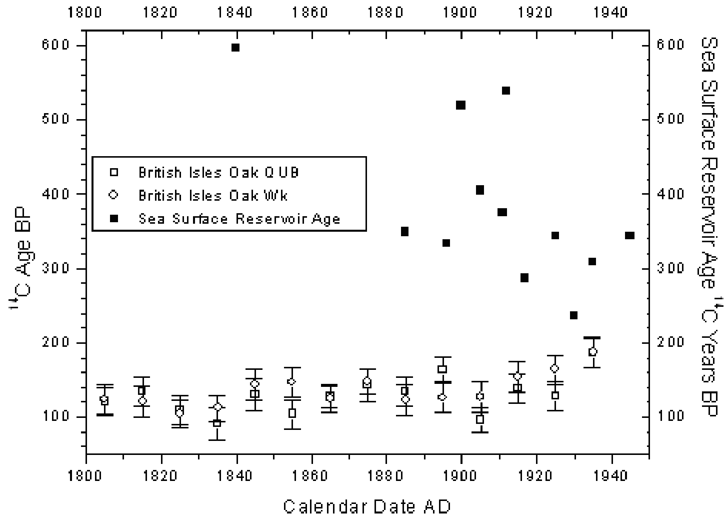


Figure 3 Comparison of ^{14}C ages for decadal samples of oak from the British Isles measured at the Queen's University Belfast (QUB) and Waikato (Wk) Laboratories (McCormac et al. 1998) versus the North Atlantic marine reservoir age as determined from measurements of sea shell data from <65 ºN (and hence not potentially affected by changing ice cover) as tabulated from cited sources by Siani et al. (2000:Table 2 with refs. in text p 276). There is no correlation of sea surface reservoir age and air reservoir age as recorded in these downwind trees.

Turning now to the 5 specific examples cited by Keenan, we find that they appear to be highly selective and none of them actually provides support for systematic offsets of 1–3 centuries.

Keenan incorrectly states that trees in the northwestern United States, Olympic Peninsula, increased in ^{14}C age by 125 yr during 1868. This jump in ^{14}C age was observed in single-ring samples from trees growing on thawing permafrost in the MacKenzie River area of the Northwest Territories of Canada, in a particularly warm summer (Damon et al. 1996), not in trees from the Olympic Peninsula (Stuiver and Braziunas 1993; Stuiver et al. 1998). Thawing may have released CO_2 from centuries-old reservoirs of organic matter in close proximity to the location of tree uptake. This situation is not applicable to the scenario proposed by Keenan.

Hua et al. (2000a) gave $\Delta^{14}C$ results for single-ring samples from a cross-dated *Pinus kesiya* tree in northwestern Thailand which indicated depletions equivalent to 100–200 yr in 1953 and 1954, and stressed the need for confirmation of those results. Preliminary results from a longer series of data (1938–1951) were subsequently presented in a poster by Hua et al. (2000b) and showed depletions no greater than those for northwestern USA (Stuiver et al. 1998). This small depletion was observed despite air mass movement during the monsoon growing season from a potentially significant source of oceanic CO_2 outgassing in the Indian Ocean between 20º N and 5º S, where excess partial pressure of CO_2 in the surface ocean is up to 30 μatm (Keeling 1968) and the $\Delta^{14}C$ of surface water is low (~100‰ in 1977–1978, compared with ~140‰ at 30ºS: Stuiver and Östlund 1983; 19th–early 20th century AD coastal reservoir ages of about 400–650 yr, equivalent to depletions of 50–80‰: Dutta et al. 2000a, 2001; Southon et al. 2002).

Bhushan et al. (1997) found an old ^{14}C age of air collected during the season of maximum upwelling in the Arabian Sea in only 1 of 8 sampling sites and concluded that "upwelling effects have to be very localized and time specific." Dutta et al. (2001b) reported variable ^{14}C in maritime air over the Bay of Bengal, but the abstract does not give details of locations and times.

We observe some further issues with respect to Keenan (2002). In Levin et al. (1987) the difference in atmospheric Δ^{14}C between the Northern Hemisphere and Neumayer Station on the Antarctic coast of the Weddell Sea was reported as –11‰ (equivalent to 88 yr, not 175 as claimed by Keenan). It was hypothesized that, based on unpublished South African data, the offset from equatorial latitudes could be greater. Meanwhile, however, a rich dataset exists and has been published (Levin and Hesshaimer 2000) but ignored by Keenan. The recent data result in a difference of Δ^{14}C between subtropical and Southern Ocean/Antarctic stations of about 3–5 ‰ (Levin and Hesshaimer 2000: Figure 3b), despite a more than 200‰ difference in surface water Δ^{14}C (Levin and Hesshaimer 2000:Figure 3c) (see Figure 4). We consider the Southern Ocean, and especially the Weddell Sea, the closest modern analogue of the scenario proposed by Keenan, as the surface waters are substantially depleted in ^{14}C and wind speeds are high, leading to enhanced gas exchange. Yet, the atmospheric memory of the old CO_2 is barely measurable (in fact, part of the difference may be caused by remnant bomb (^{14}C still being released during the 1990s from the tropical biosphere, as the difference has decreased in more recent years). On the other hand, Northern Hemisphere Δ^{14}C was higher in pre-industrial times and has been depressed relative to the Southern Hemisphere in the 20th century due to fossil fuel burning (Stuiver and Braziunas 1998; McCormac et al. 1998); the difference between the Southern Ocean and the subtropical Northern Hemisphere may, therefore, have been a little more than the current value of 3–5‰.

We disagree with Keenan's interpretation of the Rozanski et al. (1995) data as showing an atmospheric response to outgassing of old Pacific waters during an El Niño event. The very transient depletion occurred over a period of July to September in 1992. One of us operates a $^{14}CO_2$ sampling station in the equatorial region at Llano del Hato, Merida, Venezuela (early data shown in Rozanski et al. 1995), which, after more than 6 yr of monitoring to date, has not shown any ^{14}C depletion when compared with subtropical sites. One may argue that atmospheric diffusion acting in the transport of air from Ecuador to Venezuela masks the ^{14}C depletion, yet based on our measurement precision we would expect to be able to detect any significant systematic large-scale signal if there was one (the Ecuador site is about 250 km from the coast, and about 3000 m altitude; the Venezuela site is about 1000 km from the coast, and about 3600 m altitude).

In summary, there is currently little evidence anywhere for a sustained large-amplitude regional depletion of ^{14}C in terrestrial samples due to the influence of old CO_2 from the surface ocean and maritime air carried onshore. A limited number of measurements directly on maritime air show highly localized and variable results (Bhushan et al. 1997; Dutta et al. 2000b); such small-scale depleted air parcels would be expected to dissipate rapidly over short distances with atmospheric mixing, as is observed in air-sampling stations in the Southern Ocean/Antarctica (Figure 4). Where differences of up to a few ‰ (or a few tens of ^{14}C yr) do occur in tree-rings, they appear to vary on a relatively short timescale and may be partly or wholly due to other causes (McCormac et al. 1995; Damon 1995; Stuiver et al. 1998; Knox and McFadgen 2001; Kromer et al. 2001; Hogg et al. 2002; Hua et al. 2002). Even in extreme instances, such as in the Southern Ocean, where deep ventilation does occur, and some effect is observed in the air reservoir ^{14}C age as noted above, the terrestrial impact is nonetheless significantly less than required for Keenan's hypothesis. There is no evidence for such processes in the Mediterranean since the S1 sapropel episode.

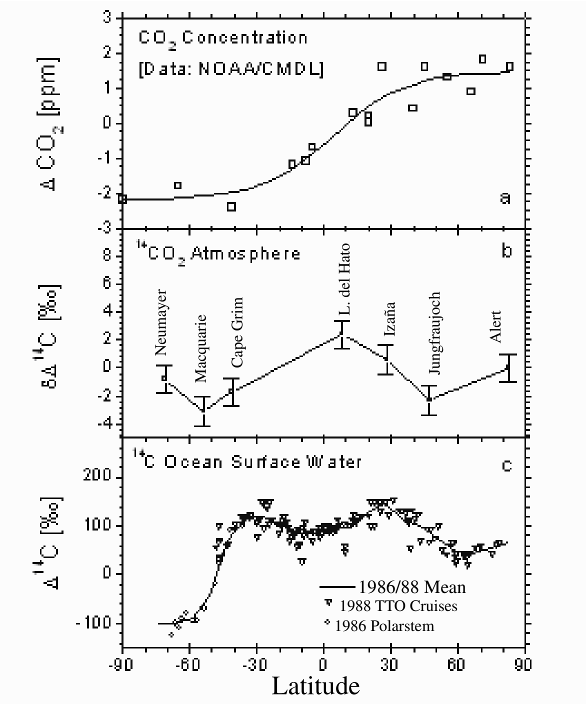


Figure 4 After Levin and Hesshaimer (2000:Figure 3). Mean meridional profiles 1993–1994 of a) CO_2 concentration (data from the NOAA/CMDL global network [Tans et al. 1996]) and b) $\Delta^{14}C$ in CO_2 in the atmosphere (Heidelberg unpublished data). Plotted in (a) and (b) are the deviations ΔCO_2 and $\delta\Delta^{14}C$ from the global mean values; (c) $\Delta^{14}C$ of CO_2 (Dissolved Inorganic Carbon) in surface ocean water derived from cruises of the TTO experiment (Broecker et al. 1995) together with unpublished Heidelberg data collected in 1986 in the South Atlantic Ocean during the Polarstern cruise ANT III. The solid line represents a spline through the 1986/1988 data.

3. ANATOLIAN DENDROCHRONOLOGY

Keenan states that there is “no dendrochronology for the region downwind from the Mediterranean” (2002:232)—exactly where such a “downwind” area lies is not defined, and it should be noted that his diagram (2002:Figure 1) reflects winter wind directions and not those for the key spring-summer growing season. He then turns to what he describes as “nearby” Anatolia—surely as Mediterranean as anywhere else he lists! Here there is an extensive dendrochronological record: the Aegean Dendrochronology Project (Kuniholm 1977, 1993, 1994, 1996; Kuniholm and Striker 1982, 1987; see also annual reports 1990-2001 at <http://www.arts.cornell.edu/dendro/>). This ADP work comprises absolute sequences from the present backwards (longest to the 4th century AD) for several tree species, then various floating sequences backwards over parts of 9 millennia, also in several tree species. Although the ADP began with the study of junipers from Anatolia, and in particular Gordion (Kuniholm 1977), for many years it has also investigated other species from much of the central and eastern Mediterranean and the Near East. In particular, and noted but essentially dismissed by Keenan, there is an extensive 1500-yr floating dendrochronology covering the late 3rd through earlier 1st millennia BC (Figure 5 and see Section 4 below). The core chronology comprises juniper (contra his assertion that different species are mixed); sequences for several other tree species also exist and correlate well to offer independent verification for much of this period. All crossdating employs established dendrochronological techniques (Cook and Kairiukstis 1990); the ADP in published reports has followed the European standards established by the laboratories in Belfast, Birmensdorf, and Hamburg. The statistics used include the standard student's t-test as modified by Baillie and Pilcher (1973) and trend coefficient (cf. Eckstein 1969:38-55), though, again following standard practice, priority is given to visual matching based on experience with given groups of samples (by species). Although Keenan devotes much of his "excursus on dendrochronology" to a critique of the exploratory D-value (Schmidt 1987), he mischaracterizes any use of this value in determining accepted crossdates.

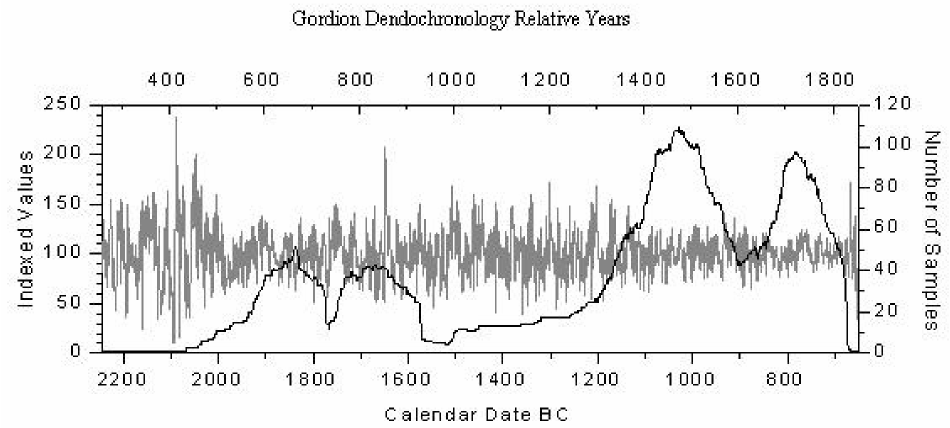


Figure 5 Aegean Dendrochronology Project Bronze-Iron Master Chronology as of AD 2002, shown in terms of the 20-yr moving average of the percent variation in ring-widths around normal (defined as 100) from all constituent data by yr (the "Index Values"—grey line). The number of securely cross-dated samples, an average of 32 trees per yr, which comprise this chronology is shown by the black line. The calendar date scale shown is the near-absolute dating proposed in Manning et al. (2001). For the specific trees from this chronology employed in the ^{14}C wiggle-match dating, see Figure 6. Although sample numbers are not especially large in the mid-16th century BC, we note that for the ^{14}C wiggle-match we employed a long-lived tree, GOR-161 with 861 tree rings, which grew from the 18th–10th centuries BC. It is securely cross-dated on the early end against dozens of juniper trees from Porsuk (Kuniholm et al. 1992 and on-going work since), and then against, progressively, dozens, scores, and finally over 100 trees from Gordion and environs. In addition to the data summarized above, newly developed juniper and pine dendrochronologies from the Hittite site of Kuşaklı match and so reinforce the earlier 17th to later 16th century BC interval. There is, thus, no possibility of dendrochronological error in the placement of the data shown in Figure 6.

In his "Excursus" Keenan purports to throw considerable doubt on the validity of the 30 yr of ADP work and sequences (of >10 million measurements from 9 millennia) through reference to the dating of 1 case—a "gateway." Keenan does not name the site—it is Tille Höyük—and he merely repeats previous misinformed claims by Porter, and repeated by Rohl (1985:389, with citations). Keenan fails to display a reading of the text by Kuniholm et al. (1993), where they explain what the samples comprise, and the other factors apart from simple statistics—the standard student's t-test and trend coefficient in addition to an excursus on the exploratory D-value—that were taken into account when offering a most likely fit for these undated samples against the Master Chronology. No one claimed this was an exact "scientific" fit for these samples—rather a best interpretation given all the available evidence. But, the fundamental point is that this discussion (Keenan:232, paragraphs 2–4) has nothing to do with invalidating the underlying Master Chronology, contrary to his assertion. At this time the ADP Bronze-Iron Age Master Chronology is a solid strongly-replicated set of—in total

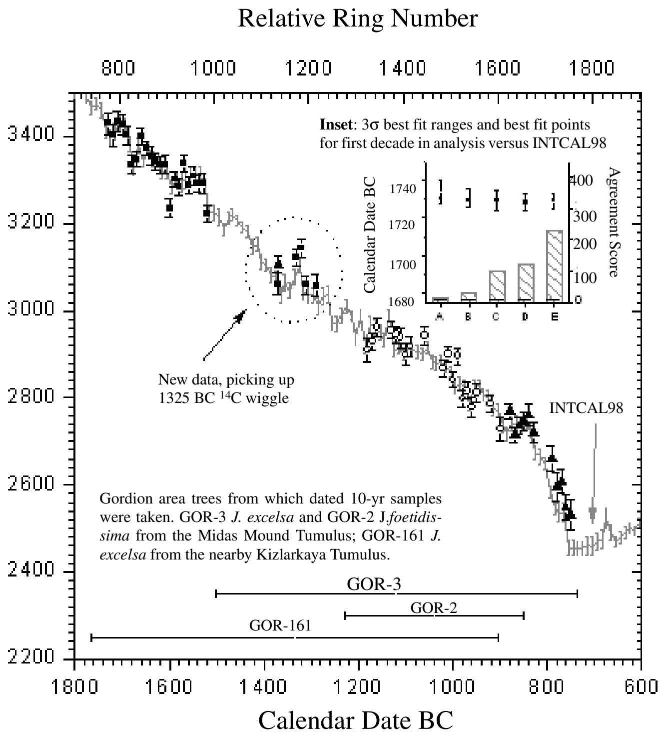


Figure 6 High-precision ^{14}C data, including 6 new data centered around the 1325 BC "wiggle" in the ^{14}C calibration curve, from 10-ring samples of the Aegean Dendrochronology Project Bronze-Iron tree-ring series (Manning et al. 2001 and refs.; Manning et al. 2003) compared at best fit placement against the current internationally recommended INTCAL98 ^{14}C calibration dataset (Stuiver et al. 1998). Samples were taken from 3 of the constituent trees of the well-replicated Gordion area dendrochronology forming 1 of the ADP floating sequences for the prehistoric Mediterranean and Near East. Data indicated by solid squares come from tree GOR-161, data indicated by hollow circles come from tree GOR-2, and data indicated by solid triangles come from tree GOR-3. All ^{14}C measurements were made at the Heidelberg ^{14}C laboratory (see Kromer et al. 2001; Manning et al. 2001 for details). The Heidelberg data include an error enlargement to allow for the likely maximum unexplained inter-laboratory error for the Heidelberg measurements versus Seattle data on similar German oak (Kromer et al. 2001:2530). Inset shows the derivation of the best fit placement for the data series shown under analysis using OxCal (Bronk Ramsey 1995; 2001 with curve resolution set at 1) versus the INTCAL98 dataset (Stuiver et al. 1998). The 3σ fit ranges and specific best fit points are shown versus the quality of fit (Agreement Score, with the horizontal bar across each column indicating the minimum 95% confidence threshold value). A: all data, n = 58. B: set with no 9–8th C BC data (see Kromer et al. 2001; Manning et al. 2001), n = 53. C: set excluding significant outliers from B (values under half the 95% agreement score), n = 49. D: set excluding the one significant outlier in analysis C, n = 48. E: set excluding all data from D, not exceeding an individual 95% agreement value, n = 42. The real errors on the fit described should also include a decade mis-matching allowance (estimated at an additional 2 calendar yr in Manning et al. (2001:2535 n.17), and an additional error for the likely average range of differences between relevant Northern Hemisphere ^{14}C calibration datasets (and possible other such datasets, were they in existence).

(*continued*) Data on Douglas-fir from the prevailing leeward side of the North Pacific Ocean versus British Isles oak from the prevailing leeward side of the North Atlantic Ocean should plausibly indicate a likely maximum factor (e.g. average difference AD 1720–1940 is calculated at 19 ± 3 ^{14}C yr by Knox and McFadgen 2001:98); of available individual datasets the bi-decadal British Isles oak data of Pearson et al. (1986) yields the largest divergence of best fit: +14 calendar yr (all data, n = 58, but poor agreement) or +12 calendar yr (n = 44 with no 9–8th century BC data (see Kromer et al. 2001; Manning et al. 2001) and significant outliers excluded—values under half the 95% agreement score). For the present case, however, comparison of much more proximate central European wood versus Turkish wood is likely to be rather closer in the absence of major ocean input or extreme altitude difference (e.g. for German oak versus Turkish pine the mean absolute difference over 23 paired data from AD 1420–1649 is only 1.4 ^{14}C yr: Kromer et al. 2001:2530). Two-thirds of the relevant part of the INTCAL98 calibration curve already consists of such wood. If the one-third Belfast component is removed, not surprisingly the wiggle-match range against just the Seattle laboratory data for oak from southern Germany (Stuiver, Reimer and Braziunas 1998) offers very similar best fits and total error ranges: the best fit across the same analysis models A-E above varies from +1 to +2 calendar yr and the overall 3σ fit ranges are within ±1–2 calendar yr. Thus, it is likely that overall real total errors will be only a little larger than those indicated in the inset. The choice of wiggle-matching approach employed (here Bayesian using OxCal) is not a significant variable as all current methods for fixed sequence ^{14}C curve fitting determine very similar to identical results (Bronk Ramsey et al. 2001)—demonstrated for the data in Figure 6 in Manning et al. (2001) and Manning et al. (2003).

at present—444 trees. The chronology is based around a core of many dozens of trees from the Gordion area, supported and verified by good juniper, pine, and cedar sequences from other sites.

4. ^{14}C AND ANATOLIAN DENDROCHRONOLOGY

We have an empirical test for whether there are systematic offsets to older ^{14}C ages for the east Mediterranean. We took an internally secure and extensively replicated long tree-ring record from the Mediterranean region covering the 2nd through earlier 1st millennia BC (Figure 5), and determined ^{14}C ages for long sequences of decadal samples from this chronology. The data closely match the standard international calibration dataset (Stuiver et al. 1998) comprised of analyses of German and Irish wood for this period, and do not indicate disparities of 100–300 yr (Kromer et al. 2001; Manning et al. 2001). Subsequent work further confirms these findings, notably picking up the sharp mid-14th century BC "wiggle" in the INTCAL98 calibration dataset (Stuiver et al. 1998), and, overall, offering a strong correlation for a total span of nearly 1000 calendar yr: see Figure 6. These data—58 high-precision ^{14}C determinations on wood from 3 securely cross-dated trees selected from a robust dendrochronology of 444 trees and 56,232 annual rings—and derived dendrochronological dates coordinate well with available proto-historical information (Manning et al. 2001; Veenhof 2000)—with any range for debate an order of magnitude less than the claimed 100–300 yr disparity asserted by Keenan. It is, thus, not possible that we have found a statistically "viable", but incorrect, wiggle-match. In further support of this assessment, we may note that the quality of fit achieved between the ^{14}C series from the BC period Bronze-Iron dendrochronology (Figure 6) is very similar to the fit observed when comparing ^{14}C measurements on known-age AD period Anatolian wood versus INTCAL98 (Figure 7). Thus, if there is no 100–300 yr disparity in the AD period (Keenan admits this, and plentiful evidence confirms this view), then there also cannot have been one in the 2nd through 1st millennia BC either, given both the quality and constancy of the fit, and the agreement of the BC period Bronze-Iron fit with secure historical dating at the recent end (especially 9th–7th centuries BC: see summary in Manning et al. 2001:2534).

In conclusion, available data from a variety of sources are incompatible with claimed systematic regional disparities of 100–300 yr. The only, and interesting, attested offset for the east Mediterranean is a short-lived, and much smaller one (albeit significant), in the 9th–8th century BC during a dramatic solar irradiance minimum (Kromer et al. 2001; Manning et al. 2001; van Geel et al. 1998). But this in no way supports the theory of Keenan (2002), and, in fact, rather demonstrates the opposite.

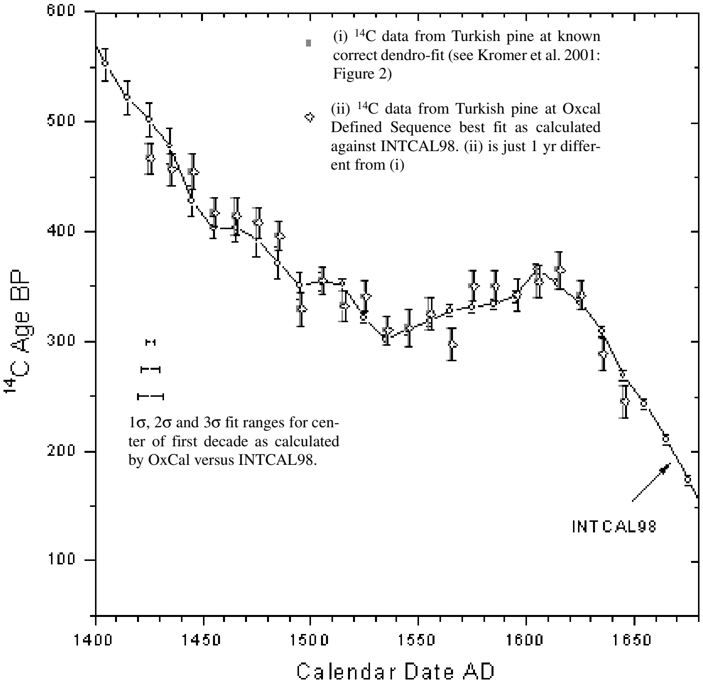


Figure 7 "Wiggle-match" fit of the AD period ^{14}C series on decadal samples of Turkish pine (Kromer et al. 2001:Fig.2) versus the INTCAL98 ^{14}C dataset using OxCal (Bronk Ramsey 1995; 2001, with curve resolution set at 1), compared with the verified/absolute tree ring ages. The ^{14}C wiggle-match best fit is just 1 calendar yr different from the correct date. Very similar results occur if the separate Douglas-fir dataset of Stuiver, Reimer and Braziunas (1998) or the separate Belfast British Isles oak dataset of Pearson et al. (1986) are employed, with the best fits again at AD 1426, just 1 year from the known dendro age. The 1σ, let alone the 2σ and 3σ, ranges around the best fit point include the correct age. Since the Turkish pine decades were cut to match INTCAL98, decade mis-matching is not an issue in this case. We observe a broadly similar quality of fit for the wiggle-match of the floating BC period Turkish wood against the INTCAL98 dataset in Figure 6.

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