Radiocarbon and the Eruption of Thera: Archiving and updating an unpublished letter to the journal *Science*

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In 2006 considerable publicity was given to two articles published in the leading American journal *Science*, claiming to have finally dated the Bronze Age ('Minoan') eruption of Santorini (Thera) to the late 17th century BC. Sturt Manning *et al*. argued from an analysis of radiocarbon determinations on short-lived samples from the destruction level that the eruption happened in the later part of the 17th-century BC within the range 1660-1613 BC (at 2σ or 95% confidence). The second article, by Walter Friedrich *et al*., reported radiocarbon tests from an olive branch buried by the tephra from the eruption; it was claimed that wiggle-matching dated the branch to 1627-1600 BC (again at 2σ). The two papers were accompanied by an editorial by Michael Balter, whose reasonable summary of the findings stressed the well-known difficulties that such a high date for the eruption would have for the conventional links with standard Egyptian chronology.

Over the years, the *Centuries of Darkness* team has remained highly sceptical of the attempts of Sturt Manning, Peter Kuniholm, Mike Baillie and others to use an array of scientific dating methods to place the eruption of Thera. That is not to say that there is anything intrinsically wrong with such methods, but they cannot be used uncritically. Scientists and archaeologists are still learning how to apply the radiocarbon method properly, while with other methods (such as tree-ring and ice-core dating) the question is whether their involvement in the debate over Thera has been appropriate. Manning used alleged signals of the eruption of Thera from both tree rings and ice cores to date the event to either 1645 or 1628 BC. His arguments utilising these methods represent at least two thirds of the 'scientific' case present in his book *A Test of Time* (Oxford 1999). This publication not only argued for a raising of the date for the Thera eruption from its standard date c. 1500 BC to the late 17th century BC, but even experimented with raising Egyptian chronology in order to ameliorate conspicuous problems which the high dating creates for accepted archaeological synchronisms.

We, and others, have repeatedly pointed out the dangers of such 'proxy dating' (see **FAQ 4**), as there is no certain way to link the eruption to particular tree-rings which show stress or to a given ice-core layer – in the absence of absolutely clear chemical analyses. Manning himself now admits that there is no "clear positive evidence to support any such link" (Manning *et al*. 2009, 314), so he and his colleagues are now dependent on radiocarbon results alone to argue their 'scientific' case for the high dating. Again, Manning and his team have missed the obvious caveats, which we aired as long ago as 1991: when we stressed that "volcanoes often release old carbon before their eruption, something which may well be a contributory source of confusion over dating the explosion of Thera." (*CoD*, p. 323)

A problem of *Science*

After the two *Science* articles were published the *CoD* authors wrote and submitted a short response in the 'letter' style required, within the requested limit of 750 words. The letter was compiled with the assistance of David Pyle, a senior volcanologist at Cambridge University (presently Professor of Earth Sciences at Oxford), who had earlier stressed the dangers of 'proxy dating' the Thera eruption by using tree-rings and ice-cores. Here he joined us regarding the question of old carbon from outgassing and the reliability of the "wiggle-matching" from the olive branch.

The letter, as submitted for publication to *Science* (on 20th August 2006), ran as follows:

Comment on "Chronology for the Aegean Late Bronze Age 1700-1400 B.C." and "Santorini Eruption Radiocarbon Dated to 1627-1600 B.C."

Manning *et al.* and Friedrich *et al.* (28 April 2006, Reports, pp. 565-569; Brevia, p. 548) claim that radiocarbon results date the Minoan eruption of Santorini to the late 17th century B.C. A more critical assessment shows they have seriously underestimated the likelihood that volcanic carbon has "aged" the samples.

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Two recent papers claim that the debate over the Bronze Age eruption of Santorini's volcano is now settled in favour of a late 17th century B.C. date, on the basis of radiocarbon (*1*, *2*).

Despite copious determinations, ^{14}C dating of the eruption has always proved elusive, due to the surprisingly wide range of results (*3*). That a "volcanic effect" (VE) is responsible for this range has long been mooted (*4*, *5*), since it was realised that old carbon released from fumaroles, absorbed by plants, can produce falsely old ^{14}C ages. For example, a living plant from Santorini growing 5m from a fumarole gave an "age" of 1390 years (*6*, *7*).

Contra Manning *et al.*, a VE is not "typically only relevant either close to a vent or in low-lying areas or sinks" (*1*). Recent work has shown that volcanoes, even when dormant, lose more old carbon than previously thought – by diffuse gas loss through and around their flanks (*8*, *9*, *10*). On Santorini, such degassing, with consequent ^{14}C

"aging" of modern plants, has been detected "far from any visible gas emission" (*9*). Degassing must have occurred before the Late Minoan eruption.

Manning *et al.* state that the determinations from the Volcanic Destruction Level (VDL) on Santorini do not "exhibit the large old-age offsets typical of such contaminated samples" (*1*). But it is not necessary that they should. Analysis of samples from the Azores recorded much lower ^{14}C "aging" (as small as 180 years) (*9*).

Manning *et al.* argue that volcanic carbon is unlikely to have "consistently affected" different crop samples, as those from the VDL show "a consistent age of 3344.9 ± 7.5 ^{14}C years" B.P. (*1*). But there is no "consistent" age in the normal sense of the word. The figure is actually a weighted average of 28 results, which *vary considerably*, with a difference of 350 ^{14}C years between the mid-points of the 'oldest' (3490 ± 80 B.P.) and 'youngest' (3140 ± 70 B.P.) (*11*). No argument was offered to demonstrate the appropriateness of averaging results from a site where there are reasons to suspect volcanic contamination.

Elsewhere Manning stated that a VE should be "evident" from anomalous $\delta^{13}C$ values but that this "does not appear to be the case" at Santorini (*3*). Yet, a VE cannot be readily excluded on the basis of $\delta^{13}C$, since this parameter is more sensitive to environmental factors than to a small contribution of volcanic carbon. Volcanic CO_2 in the Aegean presently has $\delta^{13}C$ of ~ 0‰ to -4‰ (*12*), compared to a Bronze Age atmosphere of -6.5‰, as known from carbon dioxide trapped in Antarctic ice (*13*). A 1% volcanic contribution to the CO_2 ingested by a plant would age a sample by c. 80 years, but would only shift $\delta^{13}C$ by 0.2‰. This shift cannot be resolved without more careful work, since barley and other C3 plants may show more variability in $\delta^{13}C$, of an order of magnitude greater (4 - 6‰), depending on water availability during growth (*14*).

Further work on carbon and other isotopic ratios is needed to demonstrate that volcanic contamination has been ruled out. If old carbon has "aged" the samples, then the youngest ^{14}C results (*and not an average*) are the most important for dating the VDL. The youngest (3140 ± 70 B.P.) calibrates to 1610-1210 B.C. at 2σ, allowing the explosion to have taken place much later than Manning *et al.* require.

Manning *et al.* argue that the ^{14}C dates from other LMIA Aegean contexts are "compatible" with the short-lived results from the VDL on Santorini. Yet the 23 LMIA (late) results from Kommos (3), Miletus (14), Trianda (3) and Tsougniza (3), are long-lived, from charcoal subject to the well-recognised "old wood problem" (*4*, *15*) producing falsely high ages.

Finally, Friedrich *et al.* state that determinations date the outermost ring of an olive-branch, killed during the eruption, to 1627–1600 B.C., at 2σ (95% confidence). They "excluded a significant local offset of the ^{14}C ages by volcanic CO_2", because "then it would be impossible to match our ^{14}C sequence anywhere to the shape of the calibration curve" (*2*). It is difficult to understand how this can be claimed with a set of only four results. Visual matching alone shows that other positions fit the shape, e.g. 30 or 70 years ^{14}C years later, a

situation possible with steady absorption of volcanic CO_2 during the lifetime of the sample. Irregular absorption would have produced other false matches.

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The letter was refused publication by *Science* after receiving referees' comments. To the best of our knowledge, it was sent for comment only to the two teams of authors whose very work we were criticising: Manning *et al*. and Friedrich *et al*. Theirs were the only remarks sent to us by an editorial assistant to justify rejection of our contribution. We find it an extraordinary procedure for a scientific journal to have a critical assessment *refereed by the very authors under review*. Unfettered by the 750-word limit by which we were constrained, Manning *et al*. and Friedrich *et al*. wrote some 16 pages of referees' reply to our short letter. Another short letter, submitted at much the same time by mathematical scientist Douglas J. Keenan, addressed statistical issues in the paper by Manning *et al.* and was also rejected: again, because of remarks sent to the editors of *Science* by the authors under criticism. There were no external referees (pers. comm. Keenan 30/11/12).

Outgassing and olive branches

Six years later the problem of outgassing has still not gone away for the high Thera chronologists. In particular Malcolm Wiener has done sterling work on this question, noting many geological case studies that contradict Manning *et al*.'s insistence that outgassing on pre-eruption Thera would have been very localised and only affected

plants growing near vents (fumaroles). (See further James 2012, 146.) He cites key expert opinion:

> Floyd McCoy, the volcanologist engaged in a long-term study of the Theran eruption, notes that ^{14}C-deficient CO_2 gas in the soil commonly leaks upward from a magma chamber prior to an eruption, to the point that such leakage is one of the major signals of an impending eruption used today ... McCoy further comments that in general he finds it "surprising that the potential influence of magmatic CO_2 on ^{14}C dating is not more appreciated ... especially on an active volcano such as Santorini." (Wiener 2009b, 329.)

Only two years later astrophysicist Steven Soter (2011) published an extremely important paper in the *Radiocabon* journal. His review of the literature discusses several regions where outgassing of old carbon has been detected over widespread areas, in some cases many *kilometres* from known vents. He continued by discussing two mechanisms whereby old carbon would have entered both short and long-lived samples. One is through root absorption, the other through a canopy effect. In the latter any thick covering of vegetation, from a woodland to patch of crops, will ingest recycled old carbon. As Soter (2011, 57) notes:

> A plant that acquired only 1% of its carbon from old CO_2 would have an apparent ^{14}C age increment of 80 yr. The above data alone therefore suggest that in areas where the diffuse emission of old CO_2 is comparable to that from soil respiration, plants in dense canopies may take up enough old carbon to increase their apparent ^{14}C ages by a few hundred years.

Regarding the olive branch dated by Friedrich *et al*., Wiener has challenged their automatic assumption that it was alive when it was buried by the eruption. The surrounding tephra contained leaves, but they are not necessarily from the branch in question. Wiener (2010, 373) cites authorities on olive cultivation to the effect that dead branches are not removed from olive trees as a matter of course: "owners are reluctant to remove the branches for fear of damaging trees which represent a significant investment over time." One authority he quotes is Harriet Blitzer, the leading specialist in the ethnography of pre-industrial Cretan agricultural practice, who states (pers. comm. to Wiener July 2008) that:

> ... certain parts of a mature tree may die and other parts of the same tree may continue to grow and bear fruit. The decision to prune the dead branches is based in part on the overall structure of the tree (its stability and balance) and on whether the dead sections prove an obstacle to further growth in other parts of the plant. In many cases, among older trees, there are massive dead branches that have been left untouched for the above reasons. In those instances, the remainder of the tree is alive, growing, and producing fruit.

With respect to the claimed wiggle-matching Wiener's enquiries produced these salutary responses (Wiener 2010, 373):

> Olive trees do not generally produce annual rings, but rather irregular seasonal rings, so that the number of years represented by the 72 rings observed by X-ray tomography is uncertain. A University of Zürich Masterarbeit by T. Humbel which examined living olive trees from Thera concluded that reliable ring counts were unobtainable and that the problems associated with the identification of individual growth rings were impossible to overcome. A blind test involving several leading dendro labs produced widely divergent ring counts. The author notes that it is unfortunate that Friedrich *et al*. have made so little detailed information available (e.g. there are no images published of the 3-D X-ray computer tomography), which

> makes replication and evaluation of the work very difficult, and concludes that the results reported by Friedrich *et al*. have rightly been called into question.

In short, these facts are enough to question whether wiggle-matching *is possible at all with olive trees*. With respect to both issues (the question of outgassing and the nature of olive growth and cultivation), one feels that Manning and Friedrich and their teams have either not sought or *chosen to ignore* the opinion of the relevant experts in earth and life sciences. Wiener, to his credit, cites them in spades.

Finally, several years ago a second branch or limb of an olive tree was recovered from Thera for examination. A photograph was distributed at the University of Aarhus conference on the dating of the eruption in 2007. From this Wiener (2009b, 330) notes that it is "so large that it took four people to carry it, a size seemingly sufficient to permit samples to be sent to several laboratories not involved in the examination and publication of the first branch ..." Five years, at least, have elapsed and nothing has been reported about tests that might have been done on this second olive sample. One wonders about the delay.

We feel vindicated by recent research and discoveries about the strength of the arguments as set out in our rejected letter to *Science*: that the C14 dates from Thera are very likely skewed by an old carbon effect from volcanic outgassing, and that the 'wiggle-matching' of the buried olive branch is unreliable.

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