Radiocarbon: Raw Data to Calendar Dates

Shortly after the Second World War, Willard Libby recognised that the radioactive decay of an isotope of carbon could be used to date archaeological artefacts. Living things, by their continuous interaction with the atmosphere, maintain a more or less fixed proportion of the unstable Carbon-14 to the stable Carbon-12, but when they die, this proportion decreases with imperturbable regularity. The half-life of radiocarbon is 5730 years, so that a proportion of 50% of the original corresponds to an age of 5730 years, 25% to twice that, and so on. [Fig. 1] The equations for determining the remaining proportion of radiocarbon for a given date, and vice versa, are:

$$P = 2^{(-T/h)} \quad \text{and conversely} \quad T = -h \times \log_{10}(P) / \log_{10}(2)$$

where **P** is the proportion of "old" to "current" radiocarbon, **T** is the time since the decay began (the death of the organism), and **h** is the C-14 half-life of 5730 years.

This 'clock' would work perfectly were it not that the concentration of radiocarbon in the atmosphere has varied over time (though at any given time, the proportions of the constituents of the atmosphere are very consistent all over the world). [Fig. 2] That being so, there is not an exact correspondence between the measured decay and the calendar age of the sample. During the atomic bomb tests of the 1950s, atmospheric radiocarbon rose so high that artefacts from that time sometimes appear to date far into the future, and fluctuations during the 14th century mean that a calculated proportion of, say, 92.5% old ratio/new ratio can indicate three different possible dates.

The conversion from the theoretical date based on measurement to an actual calendar date is achieved by dendrochronology, the technique of overlapping matching tree-ring patterns from wood samples of increasing antiquity. Beginning with a living tree, rings from every year to ancient history have been precisely identified, and the radiocarbon associated with them measured. [Fig. 3] While the pattern of the tree-rings, thanks to the vagaries of local weather, varies from place to place, experiments have shown that for any given year the radiocarbon proportion has been remarkably constant across the globe. Now that the radiocarbon proportions of hundreds of tree-ring samples of known age have been determined, an accurate calibration curve has been obtained. [Fig. 4]. The part of the curve that covers the late middle ages has a prominent kink. [Fig. 5]

The twelve samples of the Shroud dated by the three laboratories in 1988 (Arizona cut their sample into six pieces and measured four of them, Zurich cut theirs into five and Oxford theirs into three) illustrate a statistical conundrum. Two of the Arizona pieces and one of the Zurich pieces all cut across the calibration chart at three different places. Two of these places can be discounted historically as the Shroud is known to have been exhibited before then, providing a *terminus ante quem*, which, counter-intuitively, is usually ignored in statistical calculations. The sample with the greatest remaining proportion of radiocarbon is one from Arizona, corresponding to the years 1325, 1345 and 1395. The third of these is of course historically impossible, as the Shroud is known to have existed in 1360, at least. [Fig. 6] Taking experimental error into account, the range is from 1310 to 1400, but the years around 1330, and from 1360 to 1400, which post-date the first known appearance, should be excluded from historical possibility. [Fig. 7]

The sample with the smallest remaining proportion of radiocarbon came from Oxford, corresponding to about 1240, with a range of 20 possible years either side.

Collating the dates achieved for the twelve individual samples was less simple than it might be supposed, and the process has been much criticised statistically. The final mean was the result of several 'averages of averages', the calculation of which, especially their errors, is not explained sufficiently in the paper published in Nature so as to be free of accusations of incompetence or fraud, although neither can be sustained on the evidence. The final date 'Before Present' was 691, corresponding to the Calendar Year 1286. Unfortunately, when the error of plus or minus 31 is considered, the range is not simply 31 years earlier or later than 1286, i.e. 1255 to 1317, but technically includes another section of the calibration curve, namely 1357 to 1389. Although we know that this section is historically impossible, it was included in the final result, rounded to 1260 to 1390. However, the intervening years 1320 to 1350 cannot be included. A more sensible estimate of the radiocarbon findings would be from 1210 to 1320, or 1265 ± 45.

The new data released by the British Museum to Tristan Casabianca does little to clarify the matter. The Oxford papers do not say how many times each sample was tested nor what the individual test results were. The Zurich papers say that each sample was tested forty times, but do not give individual results. The Arizona papers show that their samples were tested ten times each, and give measurements of 'Counts', '14/13' and 'SPL/MOD' for each one and for control samples, but how they relate is not explained and not easy to derive.

Suffice it to say that all twelve samples fall within the hundred years prior to the known appearance of the Shroud in Lirey. This can be compared with the alleged dates of the two radiocarbon tests of the Sudarium of Oviedo, which correspond closely to the documented arrival of its reliquary in Oviedo in 718, although its contents were not enumerated until three hundred years later. [Fig. 7]

Attempts completely to discredit the radiocarbon date rely on outright fraud, surface contamination, reweaving with a more modern thread and C-14 enrichment by nuclear radiation, although none of these have found universal acceptance. Attempts to demonstrate that the results are statistically unsound are more credible, and there is reasonable evidence to suggest a chronological gradient along the sample strip, but they have minimal effect on the overall medieval conclusion.

Radiocarbon: Raw Data to Calendar Dates (Illustrations)

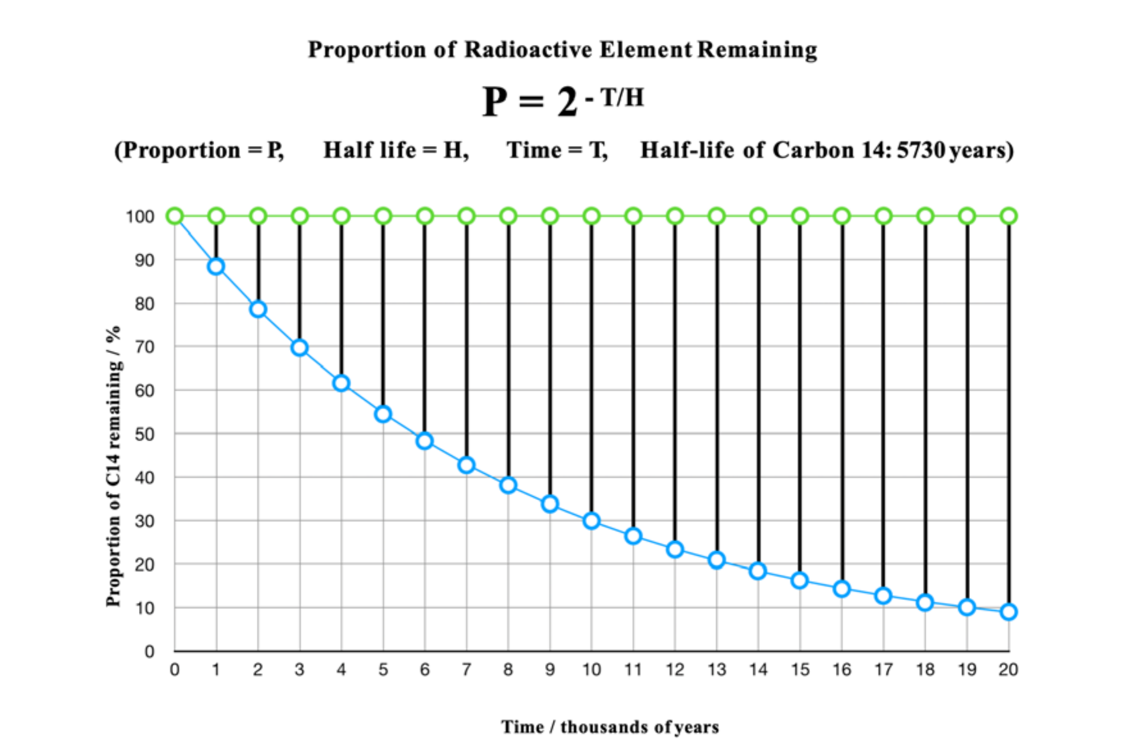

Fig. 1. Graph showing proportion of radiocarbon remaining after thousands of years.

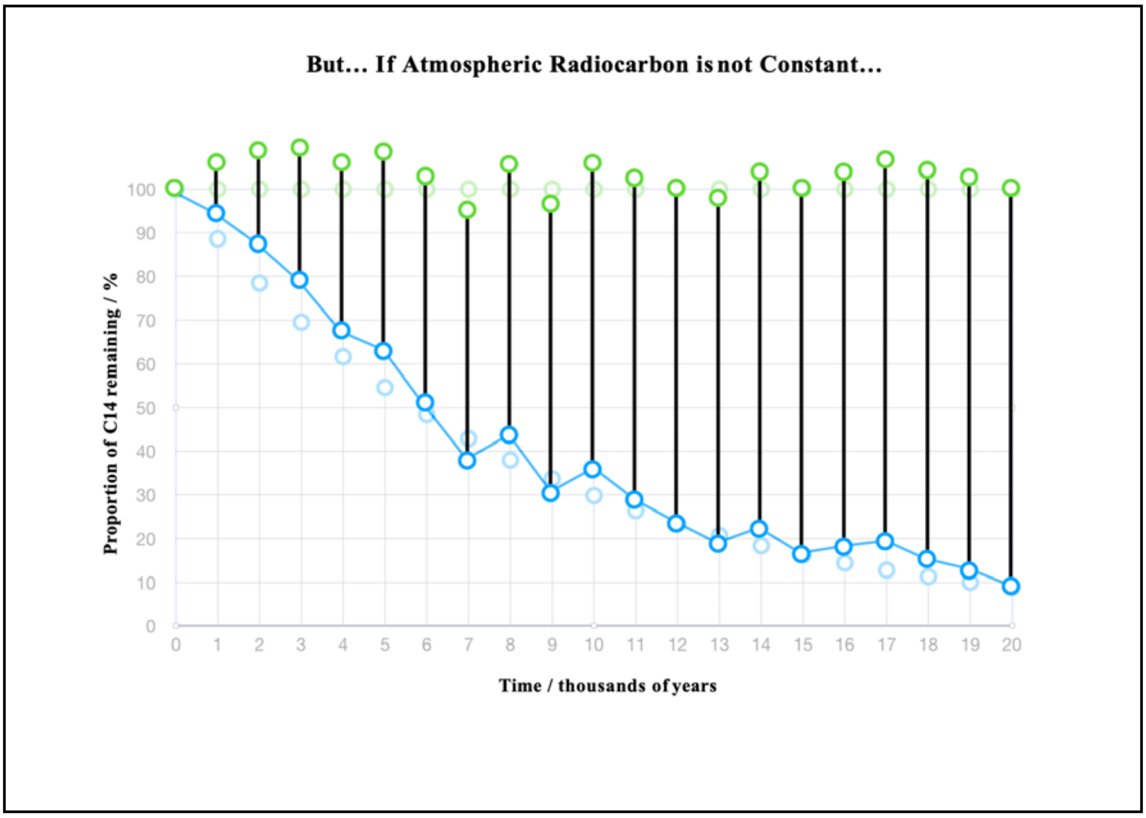

Fig. 2. Graph showing distortions to the smooth curve of Fig. 1 because atmospheric radiocarbon varies.

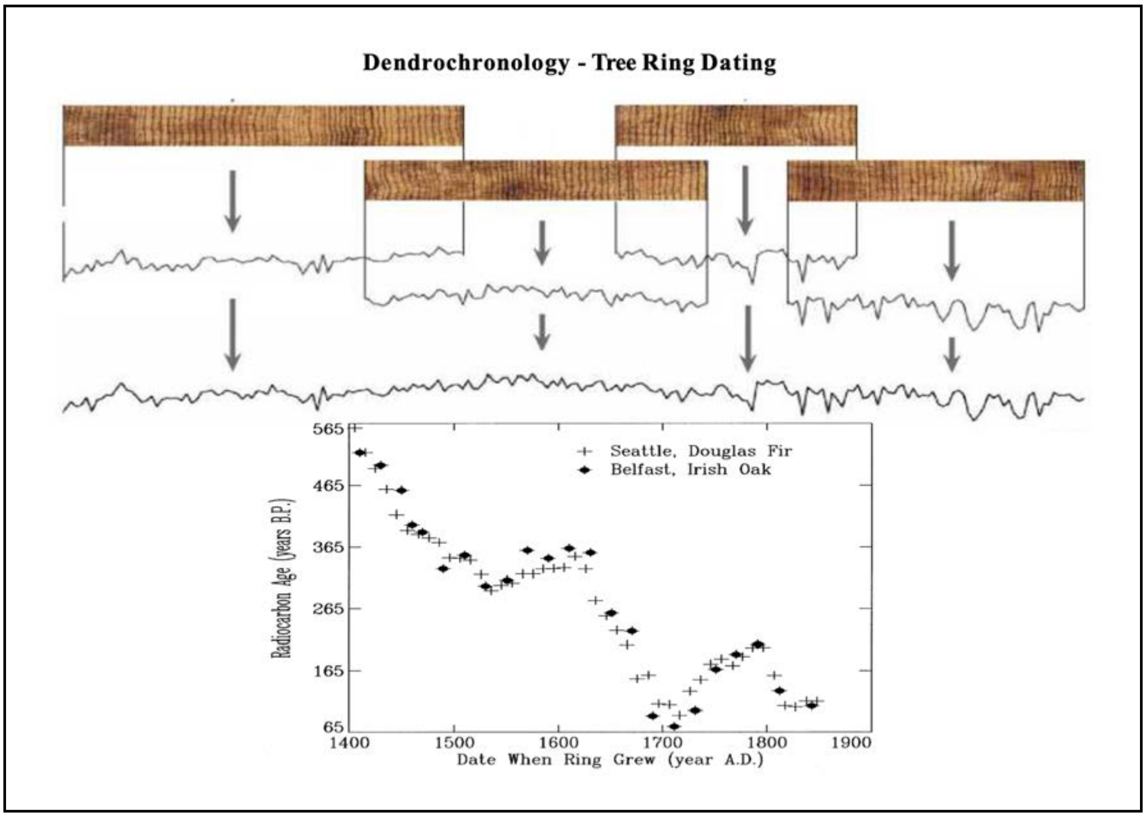

Fig. 3. (Top) Diagram of overlapping wooden panels showing how a continuous series of rings can be established. (Bottom) Graph of radiocarbon proportion from different parts of the world, showing atmospheric consistency.

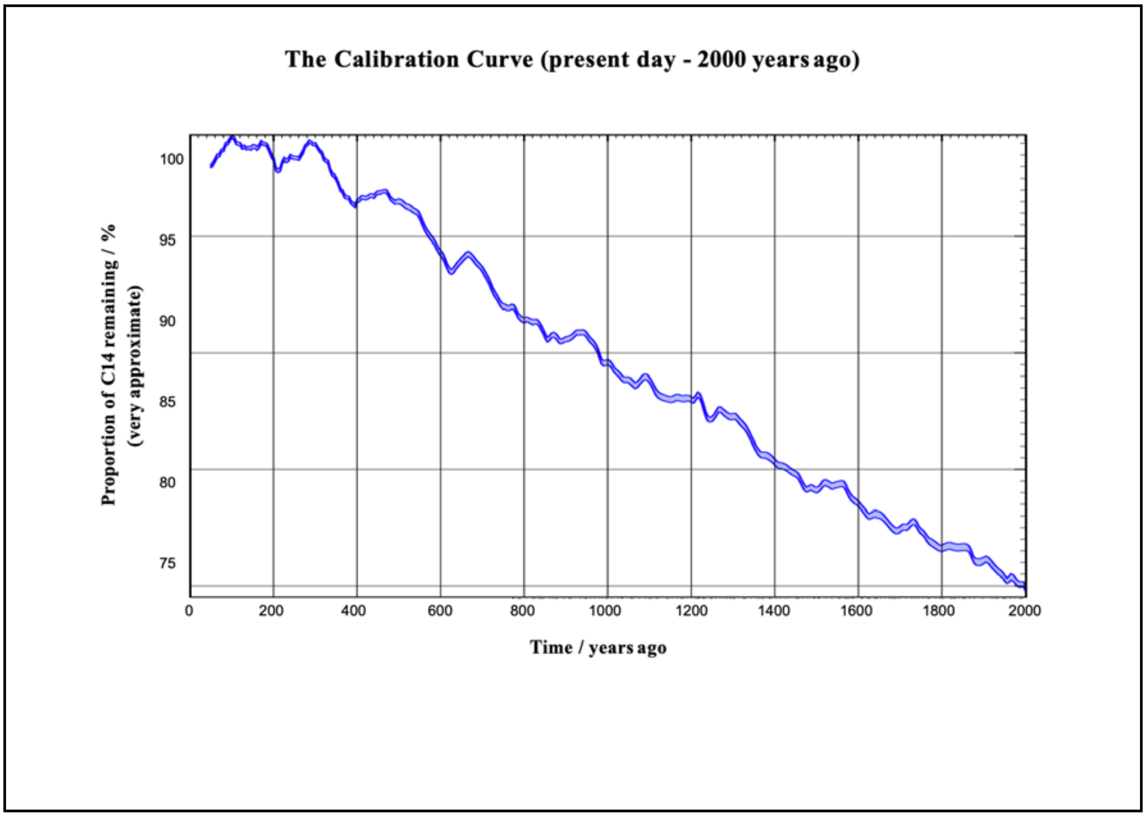

Fig. 4. Calibration curve relating proportion of radiocarbon to calendar age.

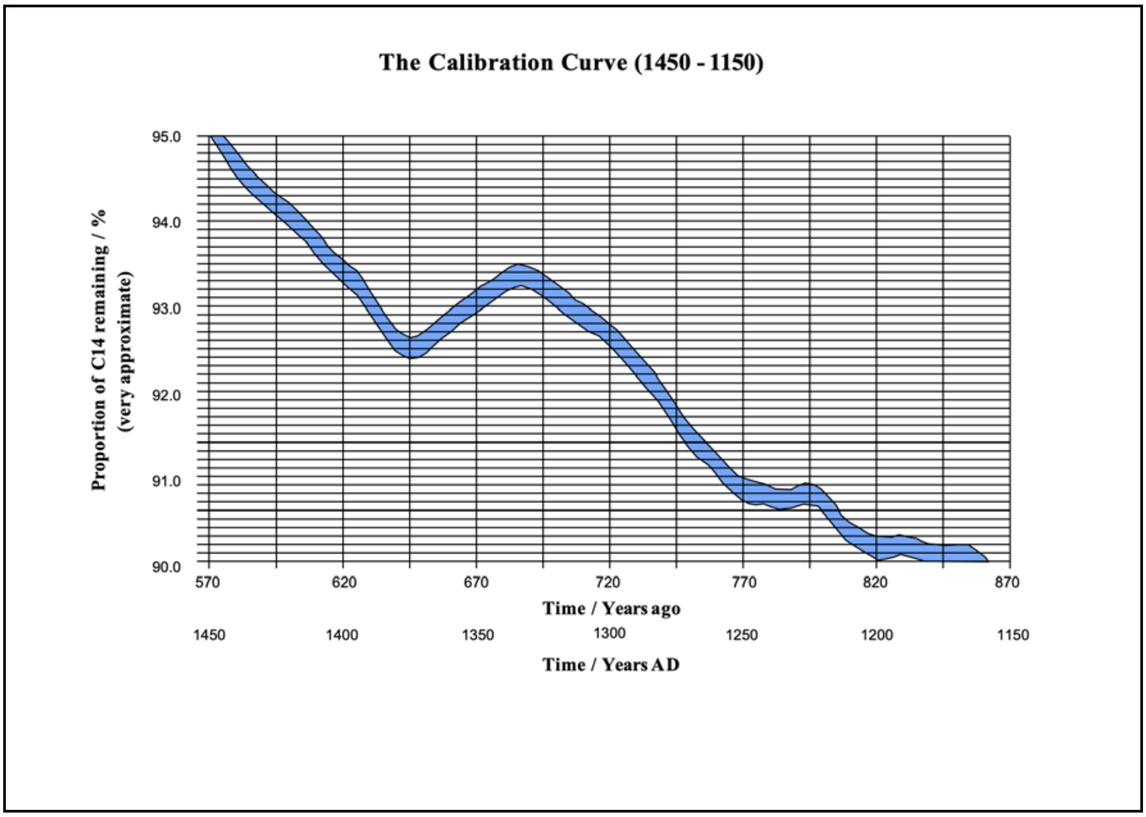

Fig. 5. Detail of the calibration curve for the late middle ages.

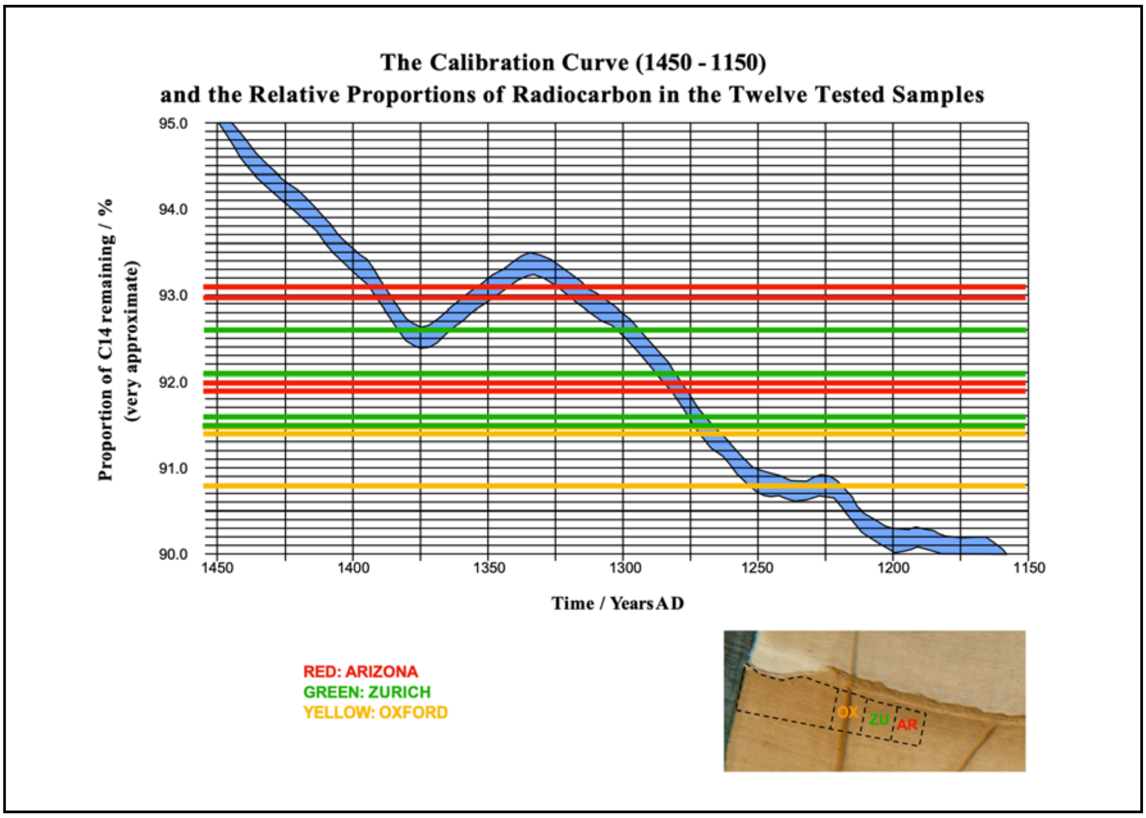

Fig. 6. The twelve measured radiocarbon proportions on the calibration curve, and the position on the Shroud from which they came.

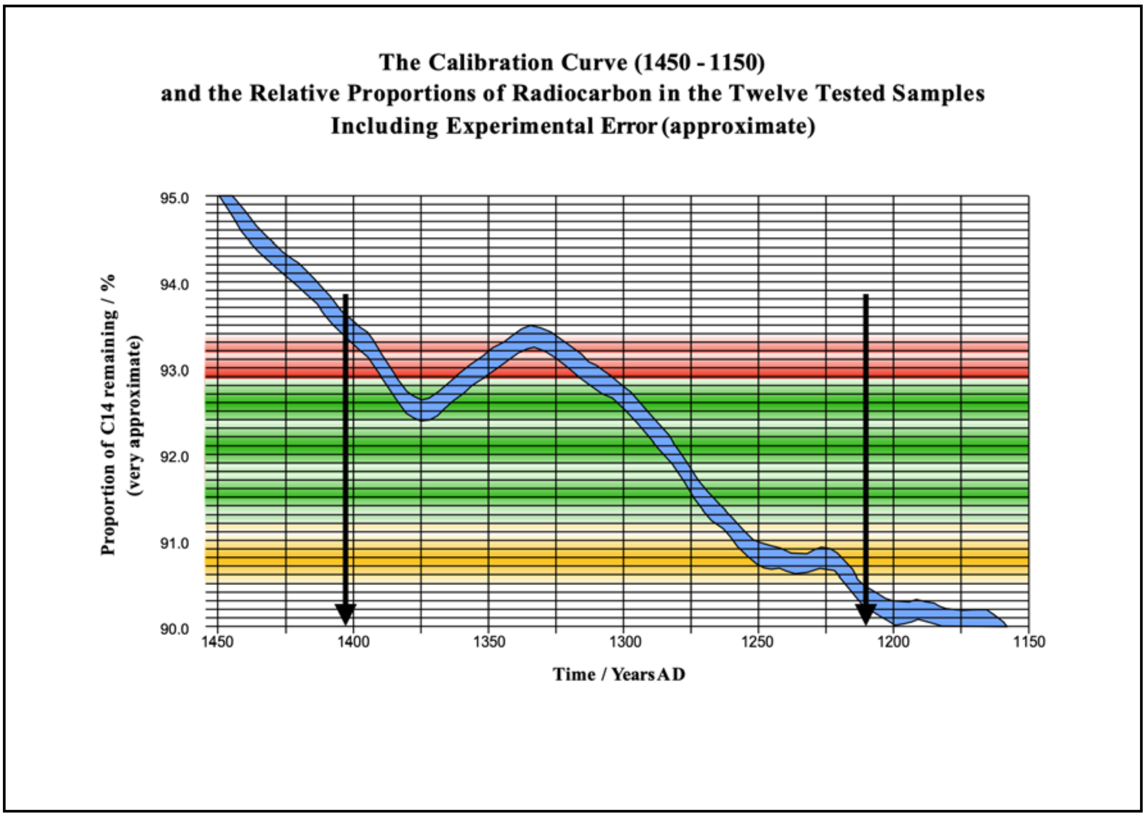

Fig. 6. The twelve measured radiocarbon proportions on the calibration curve, widened to include experimental error. The black arrows show the theoretical extremes of the derived calendar dates.

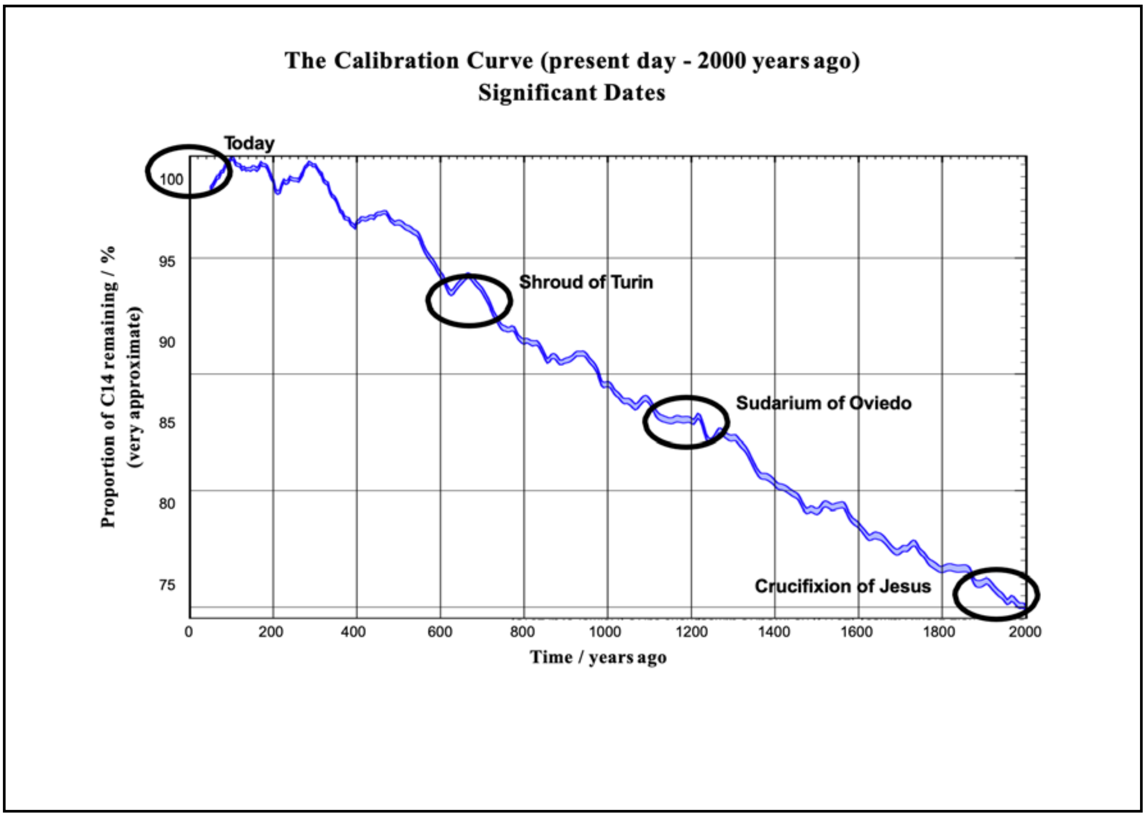

Fig. 7. The radiocarbon dates of the Shroud and the Sudarium of Oviedo, in comparison to the dates of the Crucifixion and the Toronto Conference.