FORUM

A **CARBON-14** PRIMER

Carbon-14 dating has become the subject of intense debate in the antiques world, but how many people really know how it works or what it can and cannot determine? **Dr Christine Prior** offers a concise guide

WHAT IS RADIOCARBON DATING?

There are two important considerations when planning to submit a carpet, textile, or other object for radiocarbon dating. First, the sample material has to be organic; it must be from something that was once alive. Then you have to think about where the carbon is coming from. In other words, you need to think about the connection between the sample and the event to be dated.

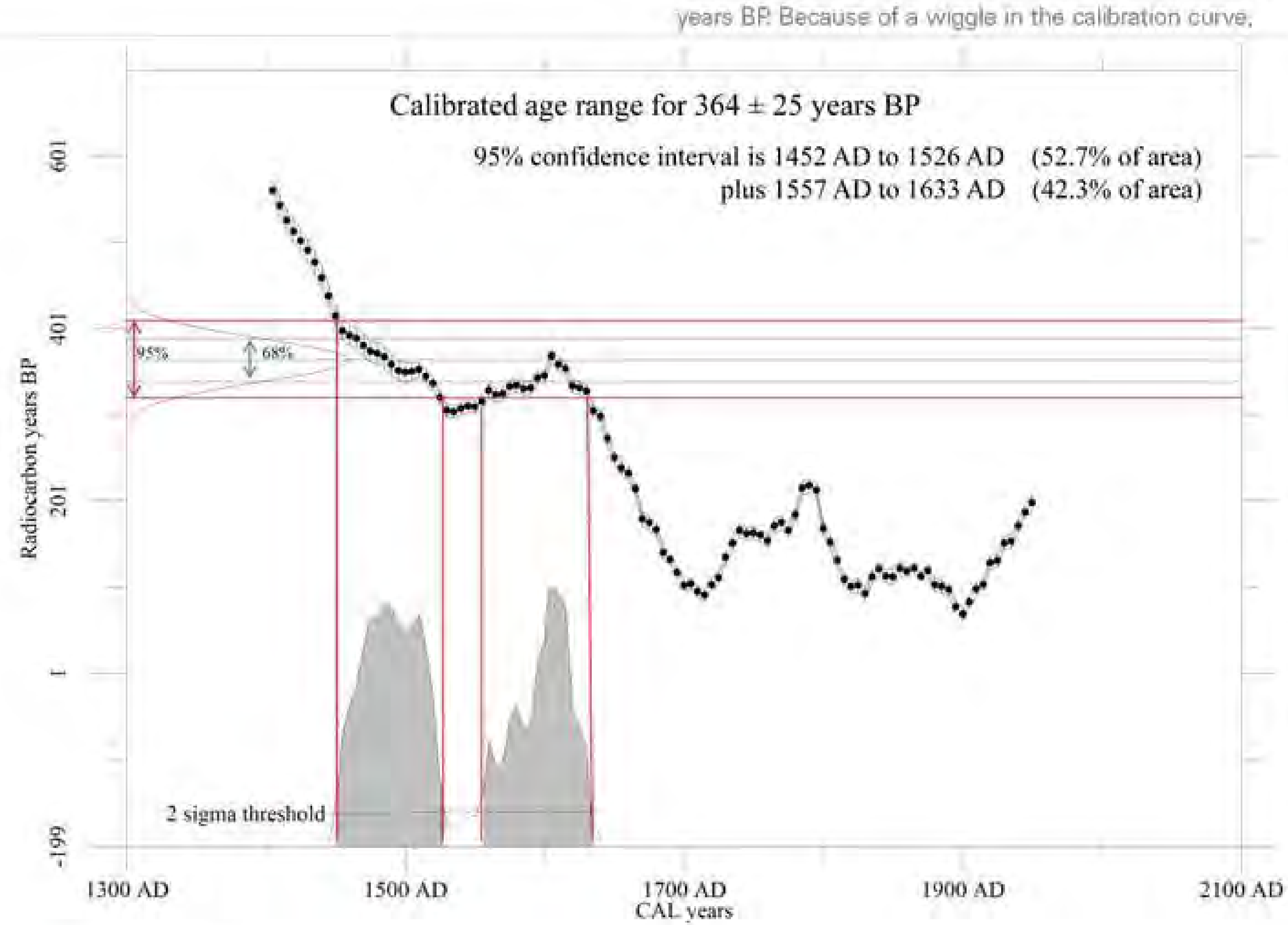
All living things contain the element carbon and there are three naturally occurring forms ('isotopes'): ^{12}C, ^{13}C and ^{14}C. Carbon-12 and carbon-13 are the stable forms, while carbon-14 is radioactive. This means it spontaneously disintegrates to form another element while giving off a small amount of energy. Carbon-14 is continually produced in the upper atmosphere when cosmic rays strike nitrogen. The newly-formed ^{14}C atom combines with oxygen to form carbon dioxide, which is mixed throughout the atmosphere.

By breathing, eating, or photosynthesising, a living organism continually ingests carbon and maintains a constant amount of the three isotopes. As soon as an organism dies, it is no longer taking in any new carbon and the ^{14}C begins to decay. If we know how much ^{14}C was in an organism while it was alive and we can measure how much ^{14}C is left in a sample, we can calculate how much time has passed since the organism died.

Radiocarbon determines how long ago the sample material was alive, not the time of manufacture. For most textiles, this connection is pretty obvious. Fibres will be woven into a textile soon after a cotton or flax plant is harvested, and wool or silk is made soon after sheep-shearing or the collection of cocoons. Making the association between the age of a tree and the manufacture of a table or a sculpture can be more problematic in cases where species may live for hundreds of years. Old wood can be reused when large structures are demolished or ancient trees are reclaimed from swamps. It is difficult for a ^{14}C laboratory to 'date' a painting or document, as the sample to be analysed is usually the parchment, paper, or wood backing. The radiocarbon age will relate to the animal or plant that provided the support material, not to the time the paint or ink was applied.

WHEN IS A DATE NOT A DATE?

A 'radiocarbon date' is not really a date, and 'radiocarbon years' are not the same as calendar years. What we are really measuring is how much *less* ^{14}C is in the sample than we would have expected to find in similar modern material. We do this by comparing the amount of ^{14}C to the amounts of ^{13}C and ^{12}C ('isotope ratios') and then using the known rate of decay ('half-life') of carbon-14 to infer the amount of time that has passed. But these laboratory measurements are subject to instrumental and measurement imprecision; radioactive decay is a slow process taking many thousands of years, and we can measure only a fraction of the whole process. Therefore every radiocarbon age measurement is reported with an assessment of this uncertainty: the plus-or-minus error. If the radiocarbon age is expressed as a normal distribution, the ± denotes one standard deviation. As seen in **2** there is a 68% probability that the age of the sample falls within one standard deviation and the probability rises to 95% if the error is increased to two standard deviations. In modern radiocarbon laboratories using Accelerator Mass Spectrometry (AMS) as the



1 Red *tapis* with human figure, Lampung, south Sumatra: Calibrated age range for NZA-33801, 364 ± 25 radiocarbon years BP. Because of a wiggle in the calibration curve, the 95% confidence interval intersects the calibration curve at two points. While we know that the true age of the *tapis* falls somewhere between 1452–1633 AD, in the absence of other information we cannot tell whether or not the textile was made in the first period, 1452–1526 AD or in the second, 1557–1633 AD. See also 'Red Tapis', HALI 171, 2012, pp.72–9. Courtesy Thomas Murray

Photo Don Tuttle

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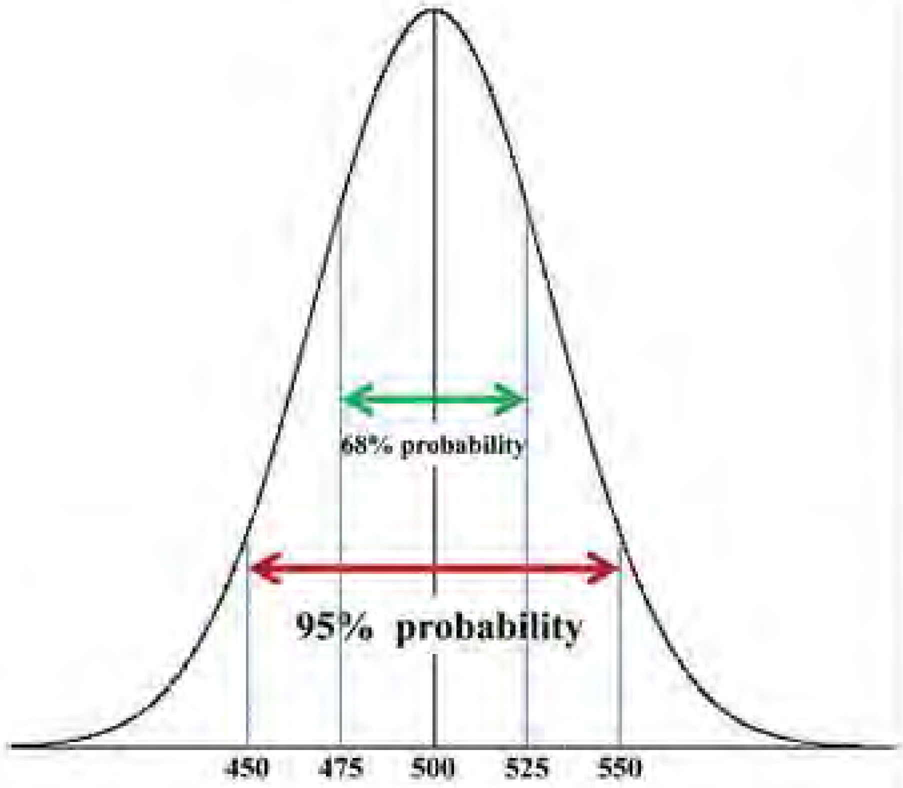

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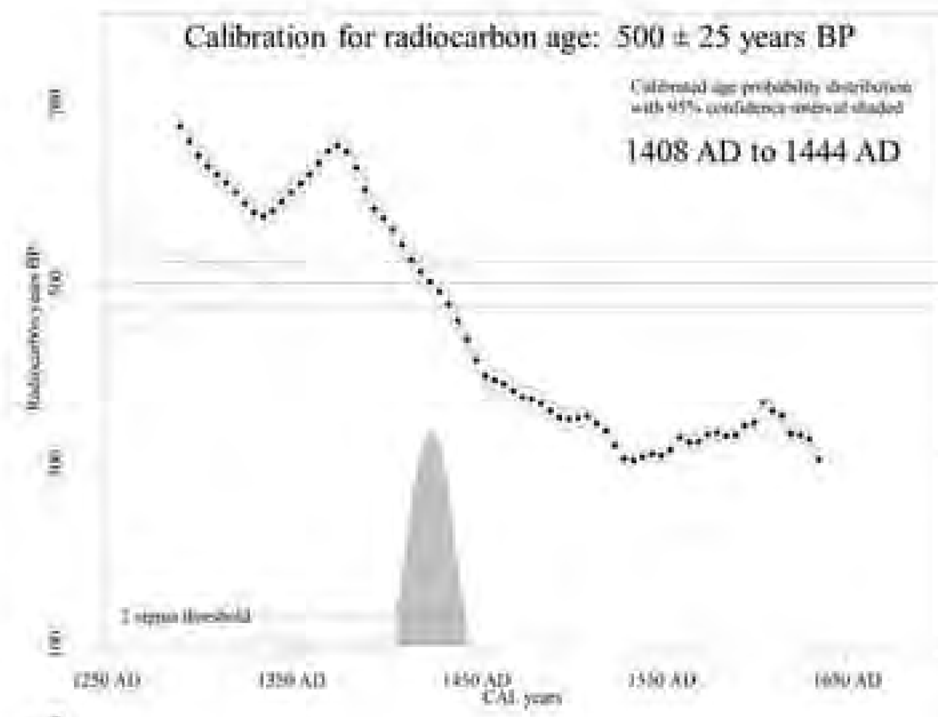

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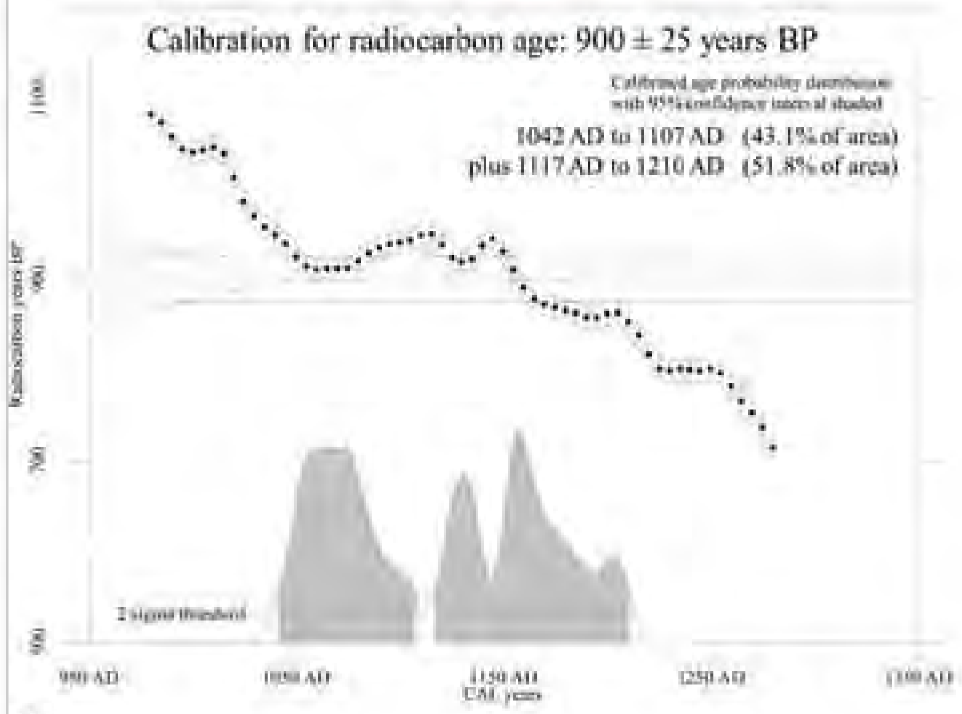

3b

2 Normal distribution graph illustrating 68% and 95% probabilities for one and two sigma

3a–3b Comparison of the calibration graphs for 500 ± 25 and 900 ± 25 years

measurement technique, reported errors are typically 20–30 years. Thus a radiocarbon age is a statement of statistical probability of approximately how much time has passed since the sample was alive.

Calibration is a means of determining how close a radiocarbon 'year' is to a true calendar year. Calibration curves for radiocarbon have been developed by measuring the ^{14}C in known-age tree rings. Most trees grow by adding a ring every year. By analysing the patterns of these growth rings and counting backwards, scientists have developed tree rings sequences extending back more than 10,000 years. A calibration curve can be produced by graphing the tree ring years on the X-axis and the measured radiocarbon age on the Y-axis. If there were a one-to-one correspondence between ^{14}C and calendar years, this would be a straight line.

However, researchers quickly discovered that the calibration line has numerous wiggles. What they learned was that the ^{14}C content of the atmosphere has varied over thousands of years in response to solar activity and variations in cosmic rays. These wiggles have been recorded with great precision through thousands of radiocarbon measurements on known-year tree rings over the past three decades. The data have been combined into the international radiocarbon calibration curves produced and updated periodically. Numerous computer programmes have been written to represent the calibration curves in a graphical format. In order to convert a radiocarbon age to calendar years, it is entered into a calibration programme and matched to the points where it intercepts the calibration curve.

It is commonly stated that 'radiocarbon cannot date materials less than 200 years old'. This is not true. Carbon-14 laboratories can provide very precise ages for materials up to the present; it is the calibrated calendar ages that can be very imprecise. For radiocarbon ages older than about 200 years we are able to determine calendar year ages for a textile with a fair degree of precision, even if the ^{14}C age intersects the calibration curve at more than one location. In the examples seen here, a textile that yields a radiocarbon age of 500 ± 25 years would calibrate to a very precise calendar year age range of 1408–1444 **3a**. In this example, because of the steepness of the calibration curve at that time, the ± 50 years of the radiocarbon age 95% probability converts to a narrower 36-calendar-year age range. Unfortunately, some portions of the calibration curve are wigglier than others, so a radiocarbon age of 900 ± 25 years crosses the calibration curve at more than one point and converts to a calendar year range of 1042–1107 or 1117–1210 **3b**.

The problem with calendar year ranges for radiocarbon dates of less than 200 years is that after 1700 the calibration curve becomes exceptionally wiggly. Radiocarbon age calculations are based on the measurement of how much ^{14}C is in a sample compared with how much of the other two isotopes of carbon are there, and it is this isotope ratio that is converted to a radiocarbon age. Because of the burning of coal and oil starting in the 17th century, large amounts of ^{14}C-depleted carbon dioxide (CO_2) were released into the atmosphere and the 'normal' isotope ratios were disrupted. The effect was similar to the normal wiggles in the

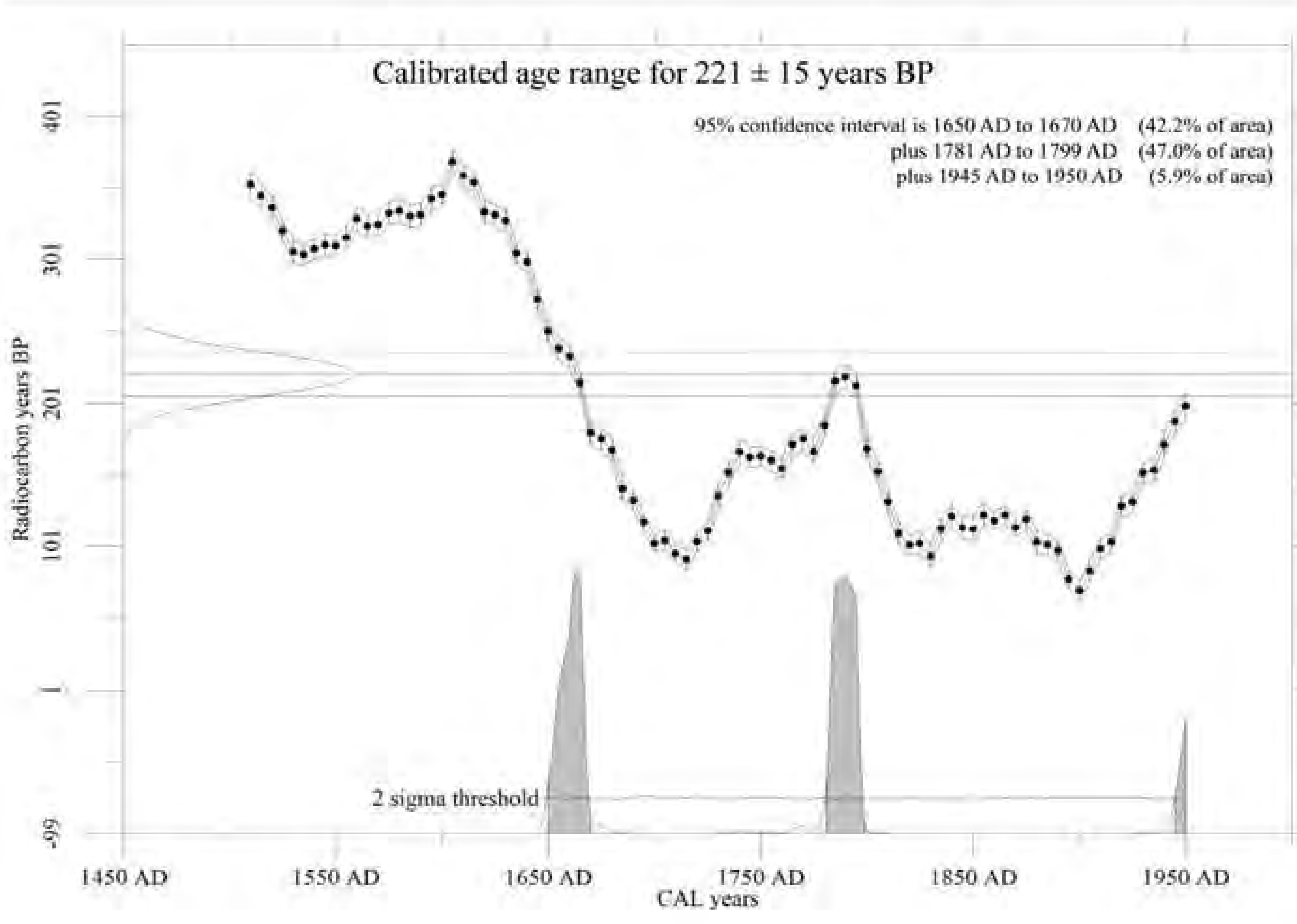

Photo Don Tuttle

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4 Two-band red *tapis*, Lampung, south Sumatra: Calibrated age range for NZA-35105, 221 ± 15 radiocarbon years BP. Because of a wiggle in the calibration curve, the 95% confidence interval intersects the calibration curve at two periods, 1650–70 AD or 1781–99 AD. The small possibility that the textile was made in the period 1945–50 AD has been discounted on the basis of provenance information. Courtesy Thomas Murray calibration curve produced by variation in cosmic radiation, but were much more pronounced. So the radiocarbon content of cotton harvested in 1850 is indistinguishable from that of cotton harvested in 1695, 1730, 1815 or 1920. In the graph illustrating the calibration of the ^{14}C-age for the 'big squid *tapis*' **5**, the fairly precise radiocarbon age of 136 ± 25 crosses the calibration curve at so many points that it is impossible to determine on the basis of a single analysis when within a 300-year span the textile was made. It is only through provenance information that part of the calibrated age range can be excluded.

All is not bleak. Humans disrupted natural carbon isotope ratios before 1950 to the detriment of radiocarbon dating, but further altered the natural ratio after 1950 in a way that has proved most beneficial: we can use ^{14}C to discern forgeries. Radiocarbon analysis can determine with great precision whether or not wool or cotton was grown within the past 60 years by analysing it for 'bomb carbon' – that is, whether or not the object is made of materials that grew after atomic bombs were detonated.

Atmospheric nuclear weapons testing after 1950 released huge quantities of ^{14}C into the atmosphere. We know how much excess bomb-^{14}C was in the atmosphere for any year since about 1950. If this is plotted with calendar years on one axis and a measure of the excess ^{14}C on the other, it produces a graph we call the 'bomb curve'. Organisms alive after 1950 contain *more* ^{14}C than they would have if atomic bombs had not been detonated.

One of our main services for museums, antiquities dealers and art conservators is to identify counterfeits. We can't tell if a carpet was made in exactly 1800, but we can unquestionably tell if it is a fake made in 1970.

INTERPRETING A RADIOCARBON DATE

When a sample is submitted for radiocarbon analysis, the client will receive a detailed report that gives the radiocarbon age expressed in years BP (before present). The age will have a plus or minus error that reflects the uncertainty to one standard deviation. If the calculated age comes out younger than 1950, most laboratories will report the age as 'modern'. There will also be a calibration report converting the radiocarbon age into calendar years.

The question everyone asks when confronted with a calibration report is: 'But how old is it?' Perhaps the best way one might think of it is that the radiocarbon age is the raw data, and the calibration is the interpretation.

Some calibration programmes display the graph in other ways, but the most common show something similar to the illustrations here. In the graph showing the calibration for the radiocarbon age 364 ± 25, the '*tapis* with human figure' **1**, the radiocarbon age is drawn as a normal distribution on the Y-axis with lines drawn to the one and two standard deviations intercepts on the calibration curve. The calendar years corresponding to the radiocarbon age are indicated on the X-axis; the peaks in the graph are proportional to the degree of overlap of the radiocarbon age with its error and the calibration curve with its associated error. This probability function is like asking: 'What is the probability that each point on the calendar axis represents the calendar year corresponding to the measured radiocarbon age?'

Interpreting the calibration results for a radiocarbon age of 364 ± 25 is fairly straightforward. There is a 95% probability that the sample dates to somewhere between 1452–1526 or 1557–1633. We do not have enough evidence based on a single radiocarbon analysis to determine where in those two approximately 70-year spans the 'true' age of the textile falls; just because the 1452–1526 period reflects a slightly larger overlap between the radiocarbon age and the calibration curve (52.7%) than the 1557–1633 period (42.3%) does not mean that the earlier period is more probable. Because the downward wiggle of the calibration curve falls outside the 95% boundary, however, what is fairly probable is that the age of the *tapis* does *not* fall within the 29 years between 1527–56.

The graph illustrating the calibration for the radiocarbon age of the 'two-band red *tapis*' **4**, 221 ± 15 years, is even more striking. This textile was made either between 1650–70 or between 1781–99. Because of the last upward wiggle in the calibration curve, there is a small but not insignificant probability (~6%) that the textile could have been made between 1945–50, but as with the 'big squid *tapis*' **5**, provenance information enables us to discount this possibility.

Some areas of the calibration may be more likely than others, but in the absence of other supporting evidence – such as provenance records, or the knowledge that a certain dye was not used after a certain date – no 'outlier' region of the calibration can be discarded because its peak is smaller.

Calibration is an enormously useful tool for the interpretation of radiocarbon analysis – but it can also be enormously frustrating.

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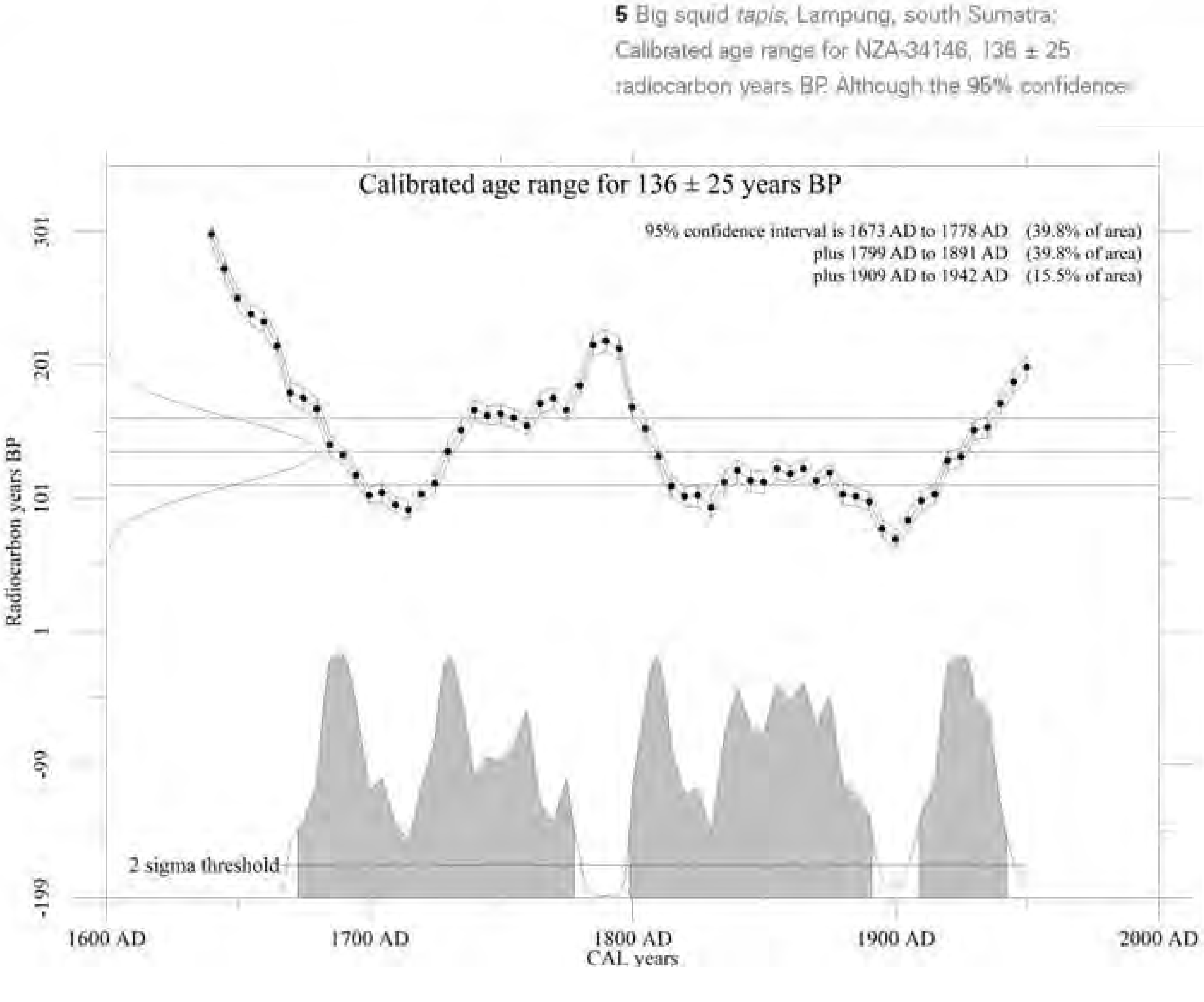

5 Big squid *tapis*, Lampung, south Sumatra: Calibrated age range for NZA-34146, 136 ± 25 radiocarbon years BP. Although the 95% confidence interval for the radiocarbon age of this *tapis* intersects the calibration curve at numerous places between 1673 and 1942 AD, provenance information allows further interpretation of the radiocarbon results. Since the *tapis* predates the 1883 Krakatoa eruption, the 1909–42 portion of the calibrated age range can be excluded. The calendar age of the textile falls in either of the two periods, 1673–1778 AD or 1799–1891 AD, with equal probability. Courtesy Thomas Murray

Photo Don Tuttle

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