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The Use of Miniature C-14 Counters in Dating and Authentication in the Museum*

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In the course of our work with carbon 14 in the museum setting, we have found that curators and others whose specialties are in the fine arts and art history often do not understand the basis for the C-14 method of age determination and, consequently, its limitations. The purpose of this paper, then, will be to fill in that background for them, by describing the underlying principles, and how these must influence the interpretation of the radiocarbon measurement of a museum specimen in terms of "age". Several techniques for that measurement will be described briefly, focussing on the miniature proportional counters which we developed for the Smithsonian Institution, and then we shall describe three actual museum problems which we have attacked, and some interesting further research on museum objects that has been proposed. Finally we conclude with some projections on the future applications of the different methods, in the context of museum work.

Carbon 14 is produced in the upper atmosphere by the steady bombardment of nitrogen atoms by cosmic-ray produced neutrons. The carbon-14 atoms so generated are oxidized quickly to carbon dioxide, which then completely mixes over a period of a few years with the carbon dioxide already present in the atmosphere. Thus the atmospheric carbon dioxide--about one part in 3000 of air--is uniformly "labeled" with radioactive carbon, which is almost indistinguishable chemically and biologically from ordinary carbon. The C-14 concentration amounts to about one atom of C 14 to every million million of normal carbon. That concentration is what we measure when we wish to determine the "radiocarbon age" of something. Plants, trees, animals, etc. have about that concentration of C 14 when they are alive; when they die, however, the radiocarbon, being a radioisotope with half life 5720 years, begins to die away, according to the law

$$C = C_0 \exp(-\lambda t) \qquad (1)$$

where C is the measured activity of the sample of carbon, C_0 the same thing when the carbon was living matter, λ a decay constant which is the reciprocal mean life of a C-14 nucleus, and t the "age". Rearranging the equation to give the age:

$$t = (1/\lambda)\ln(C_0/C) \ . \qquad (2)$$

This idealized equation would let us calculate the age t of something if only C could be measured accurately, and if C_0, the assumed value of C when the carbon was alive, could be known as well. In the early years of C-14 dating it was assumed that modern carbon, i.e. living plants, carbon from carbon dioxide in the atmosphere, etc. could be measured for C 14 and this would give you not merely the C_0 for today but for all previous epochs as well. Then it was discovered that the extensive burning of coal during the Industrial Revolution and later, diluted out the "living" natural C 14 with "dead" carbon--coal has no C 14 in it. Hence C_0 could change from year to year and century to century. Finally, after a great deal of study, C_o has been found to vary over the last 7 or 8 millennia in two ways—a smooth, long-term variation and a very erratic short-term fluctuation around the smooth long-term trend. What is done now is that an artificial C_o based on an agreed standard is taken, C is measured and C_o/C calculated. An arbitrary value of λ is then fed in to equation (2) and the resultant t, called the "conventional radiocarbon age", is taken as a rough indication of the age, subject to corrections which can be read off curves or found in tables (1,2).

These corrections apply equally to the counting or to the newer accelerator method of C-14 age determination. In the latter, which is discussed in another paper, the ratio C_o/C is determined not by radioactivity measurements but rather by direct counting of C-14 ions in the standard and unknown samples. In both cases C actually measures the ratio of C-14 atoms to normal carbon (C 12) in the sample. Figure 1, which is taken from a paper by Stuiver (1) illustrates the variation in C_o. In trees, the rings tell you the age of the wood, and measurement of C 14 in tree-ring dated wood samples gives you an absolute age calibration that is rather reliable. In Figure 1, the tree-ring (dendrochronological) age of the wood is plotted horizontally against the conventional radiocarbon age as determined by, basically, Equation (2) above under the assumption of constant standard C_0, on the vertical scale. If C_0 were forever constant, forever equal to the modern value, this wiggly line would be straight and the conventional radiocarbon age would everywhere almost equal the dendrochronological age--almost, because the value of λ used in calculating the conventional age via Equation (2) is not the right one, but about 3% off. So you can see that C_0 fluctuates rapidly and significantly. What does this mean to the curator?

Note expecially the portion of this calibration curve (Figure 1) from 1500 to 1950. Actually, by 1960 the radiocarbon age again rises to a peak of about 200 radiocarbon years. Let us consider a hypothetical museum laboratory problem, the authentication of a supposed Stradivarius violin. Stradivari made violins over roughly the period 1680-1730. Therefore you would expect the wood in a Stradivarius to have a real age of typically 250 years: note however that its radiocarbon age would be only ca. 100-110 years, and that this "age" is repeated at several times from about 1815 up to 1880 and again at about 1915. And this is with zero error in the radiocarbon determination. With a little error in this measurement (±80 years, for example, which is the 1% level of precision) you can see that radiocarbon would not help you with this problem, and is in fact rather useless for dating anything after about 1660. Even before that date there are ambiguities in the calibration curve that often prevent one from assigning an exact or unambiguous calendar date to a particular specimen.

Since it is unlikely that one would need to date a Stradivarius violin, consider another example, where C-14 authentication was actually proposed. *The Georges de la Tour* painting "The Fortune Teller" at the Metropolitan Museum was the subject of a recent vitriolic controversy over its authenticity --one group, the Museum, regarding it as an authentic production of ca. 1630 AD and the critics alleging it to be a forgery of 1940 or thereabouts. If the radiocarbon could have been very precisely measured on a sample of the canvas or oil, the Stuiver curve predicts a radiocarbon age of 300 years, and if that were what one observed, then the painting, or at least the canvas, was authentic. But suppose the radiocarbon age were measured as 250 ± 100 years. This age would be consistent with a date of 1630, but also with 1730-1810 and 1930-1940. And you would be as much in doubt as before, except that now both sides would have hard evidence to support their position.

Despite these difficulties there are many museum studies in dating and authentication upon which radiocarbon could shed considerable light. However until about 1975 conventional C-14 measurements required rather large samples--1 to 10 g. of carbon which translates into roughly 3-30 g. of wood, cloth or paper, for example. Certainly museum work was performed, but the relatively large sample size must have been inhibiting to curators, and all but impossibly large for many classes of fine art objects. At Brookhaven, realizing the need for drastic reduction in sample size, and having a great deal of experience through our neutrino detection project with miniature counters and low-background counting, we turned to a simple miniaturization of the proportional C-14 counter, aiming at a sample of 10 mg of carbon. In a number of other laboratories as was mentioned earlier an entirely different approach, C-14 ion counting in an accelerated carbon beam, was developed: this method will be described in another paper in this symposium.

Our work actually began in 1975: the Conservation-Analytical Laboratory of the Smithsonian Institution, mindful of the advantages of milligram-scale dating in general in the museum, but also having several specific problems in mind that demanded small-sample measurements, contracted with us to develop a miniature counter that would do the job. Although the concept was simple and the electronics relatively straightforward, we soon realized that it was not sufficient merely to miniaturize existing counter designs: special techniques of counter construction were required. We however succeeded (3,4,5) and by now several laboratories in addition to BNL are either using our counters or miniature counters of similar design in routine radiocarbon dating of minature samples. The design improvements included constructing the counters essentially totally out of highly purified quartz and metals. Glass is present in them only in the last centimeter of the graded seal at the extremities of legs extending some distance from the counting chamber, which are necessary to seal in the external electrical leads. Construction was such as to permit a thorough high temperature baking out of the detectors under vacuum. The detectors are filled to a pressure of four atmospheres with carefully purified carbon dioxide prepared by combustion of the sample being measured. The purity of this gas sample is checked by analyzing the response of the counter to exposure to test radiation, and the stability of a counter is checked throughout each run by periodic examination of its output. The best reduction of background counts arising from the effect of cosmic ray bombardment was achieved by inserting the counters into a well inside of large single crystal sodium iodide detectors which serve as anticoincidence shields. With such a shield ratios of the counting rate of the detector filled with "contemporary" carbon dioxide to the background counting rate of the detectors filled with "dead" carbon dioxide as high as 8.9 were obtained. The highest such ratios for similar small counters reported previous to our work had been 1.7.

During this same period the alternative technique of C-14 ion counting has also undergone considerable development:

toward the end of this paper we will try to compare the two methods as they stand today.

Advanced proportional counter technology is all very well, but the payoff is whether you can do worthwhile work in a museum. We would now like to present briefly three such cases. The first concerns an Eskimo mask which was brought into the American Center for Conservation of Art and Antiquities in New York (Director, Dr. K. J. Linsner). Although the mask belonged stylistically to the Recent Prehistoric Culture (1600's to early 1700's AD) it had been found at the level of the much earlier Okvik Eskimo Culture (300 BC to 500 AD) raising the question whether this style had actually begun earlier than previously thought. A sample of ca. 100 mg was removed, and we determined the radiocarbon age. Dendrocorrected it gave a date of 1610 AD ± 105 years, which agreed with the stylistic assignment (6). Here, a clearcut choice was presented, and a clearcut answer given: the possible earlier date could be rejected.

The second study was actually the main reason for our being in the radiocarbon business as it provided the Smithsonian Institution with the incentive to fund our development of the miniature counter. The "Frobisher Bloom", a roughly 9 kilo half sphere of raw iron, was found by the American C. F. Hall about 1860, in the course of his explorations around the coasts of

Baffin Island in the Canadian Arctic. On a tiny island, called "Kodlunarn" by the Inuit, Hall observed many remains of previous non-Eskimo visitors--ceramics, coal, flints, glass, and wooden timbers, and on questioning the natives was told that they had been left there by white men, who had come on three successive summers many years ago, first in two, then three, then a great many ships. In fact "Kodlunarn" meant "white man's" island in the Inuit language. With a shock Hall realized that they were describing the three voyages of Sir Martin Frobisher who came seeking gold and a Northwest Passage in 1576, '77 and '78 (7).

For many years the Smithsonian had exhibited and loaned this object (Accession No. 49459), labelling it "Iron smelted by the Frobisher Expedition AD 1578", but after the discovery of unmistakable Viking remains at L'Anse aux Meadows in Newfoundland by the Ingstads in 1960 Dr. Melvin Jackson suggested that "the bloom might not be a Frobisher relic--since there was no mention of a smelter in any of the extensive Frobisher written records". Hence the desire of the Smithsonian to obtain a date for the bloom.

Fortunately, N. Van der Merwe had perfected a technique for carbon-dating iron in the 1960's (8). The procedure involves extraction and radioactivity measurement of carbon from the iron, and the assumption that the carbon was "living", i.e. in equilibrium with the biosphere at the time the iron was smelted.

Such would be the case if the iron was smelted from ore by means of charcoal obtained from recently-dead trees, but would not if, for example, coal or coke had been used. Unfortunately, bloomery iron is characterized by a very low carbon content--typically 0.1% or less: thus, the entire Frobisher bloom would have yielded barely enough carbon for a conventional C-14 determination. For this reason the development of a miniature counter method was sponsored by the Conservation-Analytical Laboratory of the Smithsonian Institution, as mentioned above.

We have published (4,5) two dates based on minicarbon samples from the bloom which, when corrected by means of the Stuiver curve, are 1293 ± 133 and 1262 ± 107, average 1278 ± 121 AD. Stimulated by these findings, the Smithsonian Institution sponsored an expedition to Kodlunarn Island in the summer of 1981, with Wm. Fitzhugh as leader. Three more "Frobisher" blooms were found, which are now in a Canadian museum under conservation. Adhering to the rough outer surface of one of the new blooms were bits of charcoal which appeared to have remained there from the smelting. These minute bits have been dated using our small counters. The Stuiver correction curve yields three possible dates: 1392, 1322 and 1337 AD, all ±150 years, quite consistent with the dates from the other bloom. All seem too early for the Frobisher expedition unless old wood, for example driftwood, was employed for smelting. Research on the blooms is continuing, and obviously the final conclusions are yet to be drawn, but even at this point we can say that we have opened up the whole question of Viking origin with our minicarbon dates.

The third example involves measurements made on the Stavelot Triptych (9) in the Pierpont Morgan Library, with the collaboration of Dr. Wm. N. Voelkle, curator and Dr. A. J. Yow, conservator. The Stavelot Triptych (Figure 2), a masterpiece of Romanesque art, is decorated with champlevé enamels that are among the finest and best preserved of those made during the twelfth century in the Mosan region of Belgium. It encloses at its center two Byzantine triptychs, dating to the late 11th-early 12th century, and carrying splendid cloisonné enamels. The larger of the two Byzantine triptychs centers on a relic of the True Cross which provides, in fact, one of the themes for the entire Stavelot Triptych.

Art-historical research has linked the Stavelot Triptych to that monastery's great abbot Wibald (d. 1158), although documentation is lacking (9). Wibald travelled to Constantinople twice during the 1150's as ambassador for the Emperor Frederick Barbarossa, and is it presumed that the Byzantine triptychs were brought back by him at this time. Only at the time of the French Revolution does there begin to be a written record: carrying the triptych with him, the last Abbot of Stavelot fled before Napoleon's troops to Hanau where he died in 1796. Nearly a century later it was discovered in the house of the Waltz family, who possessed it until 1909, when it was offered for sale by the Durlacher Brothers of London. In the summer of 1910, on the advice of Sir Charles Read of the British Museum, it was purchased by J. P. Morgan. It remained on loan at the British Museum until 1913, when, after Morgan's death, it was brought to New York and its present home.

We were approached by Dr. Wm. Voelkle of the Pierpont Morgan Library in the hope that minicarbon dating might shed a little light on the rather obscure history of this object. But there was something more than the history of the Triptych itself, interesting as that might be. It had always been known that one of the two dominating themes of the Stavelot Triptych was the discovery and excavation of the True Cross by the Empress Helena, mother of Constantine, during her pilgrimage to the Holy Land, and the reference would seem to have been the small relic of the Holy Cross displayed at the center of the larger Byzantine triptych. When, however, in 1973 the two Byzantine triptychs were removed for examination by the Library's conservation department, a surprise was in store. The removal of the Crucifixion enamel of the small triptych revealed an unexpected cavity hollowed out in the underlying wooden support. In it was a small pouch, 1 1/2 inches long, tightly wrapped in red silk thread; the pouch consisting of a piece of yellow and brown

Byzantine silk, on which was woven the head of a griffin. In addition there was a small pin, perhaps regarded as a relic of a Holy Nail.

When the pouch was opened there was a piece of parchment, stating in Latin that the contents of the pouch came from the Lord's wood (De ligno domini), from the Lord's sepulcher (De sepulchro domini) and from the garment of the Blessed Virgin (De vestimento sancte Marie virginis). The contents referred to on this parchment ticket were, a tiny fragment of wood, a pinch of some unidentified debris and a small piece of fine white silk. Unfortunately, there was no mention of the Abbot Wibald nor any date, nor any clue as to the source of the Holy relics so cunningly concealed within the body of the Triptych.

Using the milligram-scale carbon-14 counters we have dated the red silk thread which wrapped the pouch, the "Robe of the Virgin Mary" and the fragment of the True Cross. To gain information on the history of the Triptych itself we also dated the oak supports of the right half of the center panel and of the right wing. The results are as follows, after fully correcting the counting data for isotopic and dendrochronological effects:

- the wood of the right wing is essentially modern
- the wood of the center panel is 1405 ± 115 AD
- the red silk thread has the same date, 1401 ± 120 AD
- the wood of the True Cross is 595 ± 115 AD
- the Robe of the Virgin Mary is 1260 ± 150 AD

These dates vary in some cases from those given by E. V. Sayre at the Milwaukee meeting of the American Institute of Conservation in 1982: the changes arise from applying the whole range of dendrocorrections and in one case a revised counter background.

What do these dates tell us about the art history of this extraordinarily important museum object? Although some of the dates lead to fairly clear conclusions, others must give rise to speculation.

First, the modern wood of the right wing strongly suggests that that portion was restored by the Durlacher Brothers at about the beginning of the twentieth century. The center panel of 1405 ± 115 AD seems too late to be part of the original construction, if that took place in the era of Wibald, about 1160, although there is a small chance that this might still be so. If the red silk thread wrapping the relics has the same date, it suggests the possibility that when the center panel was rebuilt, the relics were removed, "refreshed" as was often done and restored to their rightful place underneath the Byzantine triptych. The possibility that they were there from the original construction of the Stavelot Triptych is attested by the Byzantine pouch and the mid-twelfth century Latin script on the vellum ticket (9).

The date of the Robe of the Virgin Mary is in agreement with this, 1260 ± 150 AD being consistent within experimental error with Wibald, his trips to Constantinople and the presumed date of construction of the Triptych. But the date of the Robe is clearly not consistent with that of the famous Robe of the Virgin Mary which had been revered in Constantinople at the Church of the Virgin Mary at Blachernae, since at least the year 626 AD (10). Several medieval travellers and the histories of Byzantium place it there up to the sack of Constantinople in 1204, at which it disappears.

What then are we to make of the date of the True Cross? From the Crusades onward, Europe was awash with Holy nails, thorns from the crown of Christ, and pieces of the True Cross but our date is too early for ad hoc relics of that time. It seems too late however to be "authentic", whatever that may mean. We are 5 standard deviations from the birth of Christ and His crucifixion: if the piece of wood we dated were actually from the early part of the first century, truly, it would be a miracle.

In the final days of Byzantium in 1204, Robert de Clari, a Frenchman who accompanied the Fourth Crusade, wrote of the collection of relics that it included "two pieces of the True Cross as large as the leg of a man" (11) kept in the Pharos Chapel of the royal palace. It is tempting to identify these pieces of the True Cross with the relic looted from Jerusalem by the Persian Chosroes II in 615 AD which according to the "Golden Legend" (12) had been left there by Helena after her discovery, as commemorated in the right wing of the Stavelot Triptych.

The Byzantine Emperor Heraclius (575-642) liberated these relics and is thought to have returned with them to Constantinople around 629 BC. (12,13). Although Gibbon (14) tells us that the seals on the box containing the True Cross were not tampered with during the time it spent as Chosroes' prize in Ctesiphon, one still wonders. Our date of 595 ± 115 AD is more consistent with it being produced for the benefit of Heraclius than as the cross of the Savior's martyrdom. In any case, it is entirely consistent with the Stavelot wood fragment being a gift to Wibald on his visit to Constantinople.

It is however, also possible that the Holy wood simply came to Stavelot as a result of the looting of Constantinople in 1204 on the occasion of the Fourth Crusade. Runciman, in describing the after-effects of the debacle, writes that "throughout the West there were paeans of praise and the enthusiasm mounted when precious relics began to arrive for the churches of France and Belgium" (15).

With milligram scale C-14 dating and authentication now available as a routine tool for the curator and conservator, one may ask, what kinds of problems can be attacked? We would like to give a few examples, where carbon 14 has, or could be used.

The Grolier Codex, whose place of writing and provenience of discovery are both unknown, is a document of extraordinary importance to Mayan study, in that it is only the fourth pre-Conquest codex known (16), and the only Mayan codex resident in the country of its presumed origin, Mexico. Its iconography and astronomical content (Venus calendar) have been the subject of scholarly examination (16,17) and a recent study by Carlson summarizes the arguments for its authenticity--an authenticity that had been rejected by the Mayanist Eric Thompson, largely on stylistic grounds (18). The codex was found with three unpainted sheets of bark paper, and these had a conventional C-14 date of 1230 ± 130 AD (19) which works out to an unambiguous 1280 AD if dendrocorrections are applied. A C-14 date of the codex itself, based on milligram sampling, should help to remove any lingering doubt as to its authenticity.

A second study, feasible only with small-sample C-14 analysis, is the famous Vinland map, which resides at Yale and concerning which the University brought out a book "The Vinland Map and the Tartar Relation" with much fanfare in 1965 (20). The map, thought to be of ca. 1440, purports to show Iceland, Greenland and "Vinland" resembling Baffin Island. It has been attacked as a forgery, defended, and exhaustively discussed (21,22) but the strongest bit of physical evidence was McCrone's discovery that the pigment of the ink contained titanium dioxide in the anatase form, which was not generally used until the 1920's (23). However, others have suggested that anatase might have occurred in genuine ancient iron-gall inks if the mineral ilmenite, an iron titanium oxide, had been used for their preparation.

It should be noted that in both these cases what one really authenticates with C 14 is the paper or parchment and not the date of the original written production. Thus, a C-14 measurement may decisively prove that something is a forgery: it cannot prove authenticity but can certainly increase the likelihood. In the case of the Grolier Codex, it was suggested that forgers found old bark paper sheets in a cave, and forged the written codex on these.

A third example of work on what may be called a "museum object" is, of course, the Shroud of Turin. This long strip of linen cloth, which bears the imprint of a man's face and his scourged body, is held by many to be the burial shroud of Christ, or at least, associated in some way with that event. We shall not go into its description or history--that has often been done, best by Wilson (10) who has complete scholarly references. Recently a team of physical scientists under the acronym STURP, for Shroud of Turin Project, have published a book on the very extensive examination made in 1978 of the Shroud itself (24).

Wilson believes that the Shroud might be identical with the Holy Image of Edessa--the so-called Veronica of Christ. This image-bearing cloth was known in Edessa from around 525 AD until 944, when it was taken to Constantinople and where it remained until 1204. In the sack of the city by the Crusaders the Veronica disappeared. The present Shroud of Turin has an uninterrupted history from 1357 onward, when it was first exhibited and also denounced as a fake.

Suppose, then, that one could carry out a carbon-14 measurement of the Shroud, at a precision level of ±100 years. What could it tell you? An examination of the Stuiver curve shows that, if made at the time of Christ's crucifixion, the linen should have a radiocarbon age close to its true age, with little correction or ambiguity. So there is every reason to believe that the C-14 test could reliably disprove the authenticity, if such proved to be the case. Particularly, if the corrected date came out 14th century, it would give great weight to the pronouncement of Pierre d'Arcis, Bishop of Troyes (France) in 1389, who said in a letter to Pope Clement VII, that his predecessor, Henry of Poitiers "after diligent inquiry and examination.....discovered the fraud and how the said cloth had been cunningly painted, the truth being attested by the artist who had painted it, to wit, that it was a work of human skill and not miraculously wrought or bestowed" (25). Finally, if the date came out 6th century, it would lend considerable support to Ian Wilson's theory of the identity of the Shroud of Turin with the Veronica Image of Edessa.

As of today, the status is that the carbon-14 committee of STURP has sent in a proposal for minicarbon measurement, and is also conducting rather delicate negotiations with the Church, concerning this proposal. There are known to be groups in Italy which favor, and which oppose, carbon dating. At this point, there is not the slightest indication that the experiment will take place in the near future, but if it does, it is likely that the measurements will involve a consortium of C-14 laboratories.

By these examples we hope to have shown that C-14 measurement on the milligram scale is a technique that is fast entering routine practice and, as such is available to the curator. The most obvious use at the moment would seem to be authentication: besides wood, materials like paper, leather, cloth of various kinds and bone can be dated. The use of C-14 measurement in Art History is a little more sophisticated and may require series of dates to be taken to correlate the development of a style, for example.

Carbon-14 measurements on the milligram scale are available commercially. An outstanding example of service to the art world was the Harwell Laboratory's recent authentication of a gold treasure, thought to be part of the Vrap hoard, that was of the Avar period. Harwell's client was Sotheby's who placed a value of about a million dollars on the 122 pieces totalling 7.3 pounds of gold and 11.7 of silver. Harwell charged their usual fee, a few hundred dollars, to measure C 14 in bits of flax adhering to the meshes of a massive gold belt, and used Brookhaven counters to do it. The date was 700 ± 100 AD, just right for the Avars and in agreement with the markings of the Byzantine Emperor Constans II (641-651 and 659-663) on two plates found with the gold.

We are often asked whether the small counter can hope to compete with the much faster accelerator method for C-14 measurement on the milligram scale. Several points need to be made.

1) The accelerators are so expensive that very few carbon-14 laboratories will be able to afford them. The counters are inexpensive enough to be installed in existing laboratories and require no new technology.

2) The total length of time needed before a curator can get a date also includes the sample processing time, which appears to be comparable for the two methods, and queuing time, which is utterly unpredictable.

3) Although the counters take longer, the operator is not doing anything during the extra time: the counters are simply accumulating counts by themselves. Therefore, if many counters are available and are set up to run in parallel, many samples can be running at once, and the limiting factor again tends to become the sample preparation. Harwell will soon have 30 counters running simultaneously.

4) In many cases, if authentication, or a rough date is all that is desired, the counting time can be drastically shortened.

5) If the sample available is larger, a larger counter can be used, and the time also shortened. Harwell has found that, for archaeological work, a 30-ml counter holding 60 mg of carbon is especially useful. For museum work, smaller samples will probably

be the rule. Curators should remember that up to half the sample may vanish during pretreatment, and only about 1/3 of wood is carbon hence 10 mg of carbon may require 60 mg of wood or cloth as a sample to be taken from the object for a single determination.

6) For the very smallest samples, much under 10 mg of carbon, the accelerator will be the unique method. There is some indication that samples as small as 50–100 µg of carbon may be accessible to dating, using accelerators. This would be achieved with truly minute samples, which will gladden the hearts of painting conservators, for example.

7) In any case, and whatever method is used, curators would be well advised, before spending museum money on carbon-14 tests, first to see with reference to the Stuiver curve whether the specified measurement at the expected level of precision can possibly be made to yield the kind of answer required.

To summarize: we are still actively gaining experience in a very new field, and there would appear to be plenty of work available for all of us--curators, art historians, conservators and physical scientists.

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FIGURE CAPTIONS

Figure 1 The Stuiver (1) calibration curve for conventional radiocarbon dates.

Figure 2 The Stavelot Triptych (photocourtesy Pierpont Morgan Library).

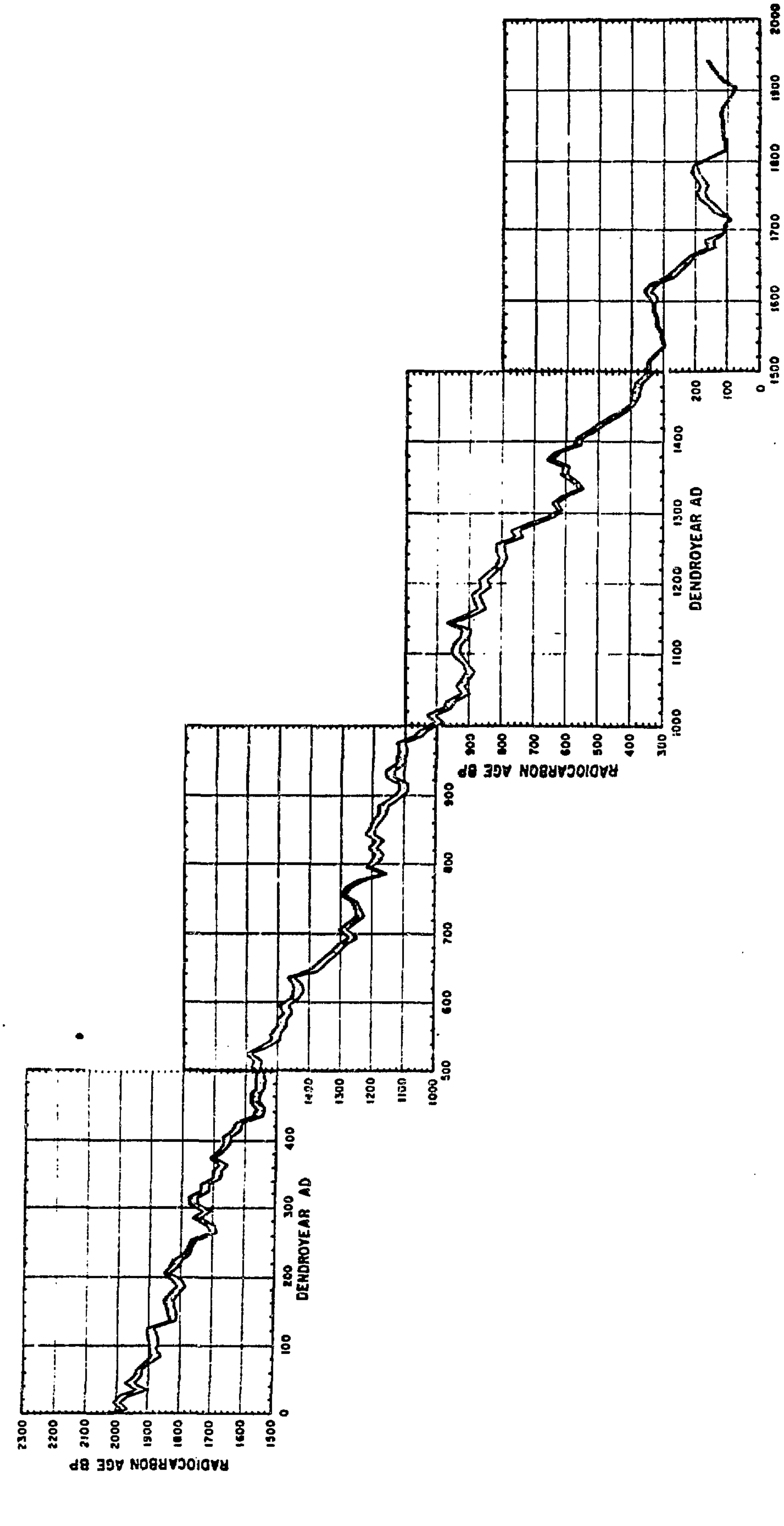
RADIOCARBON AGE BP
DENDROYEAR AD
RADIOCARBON AGE BP
DENDROYEAR AD

Figure 1

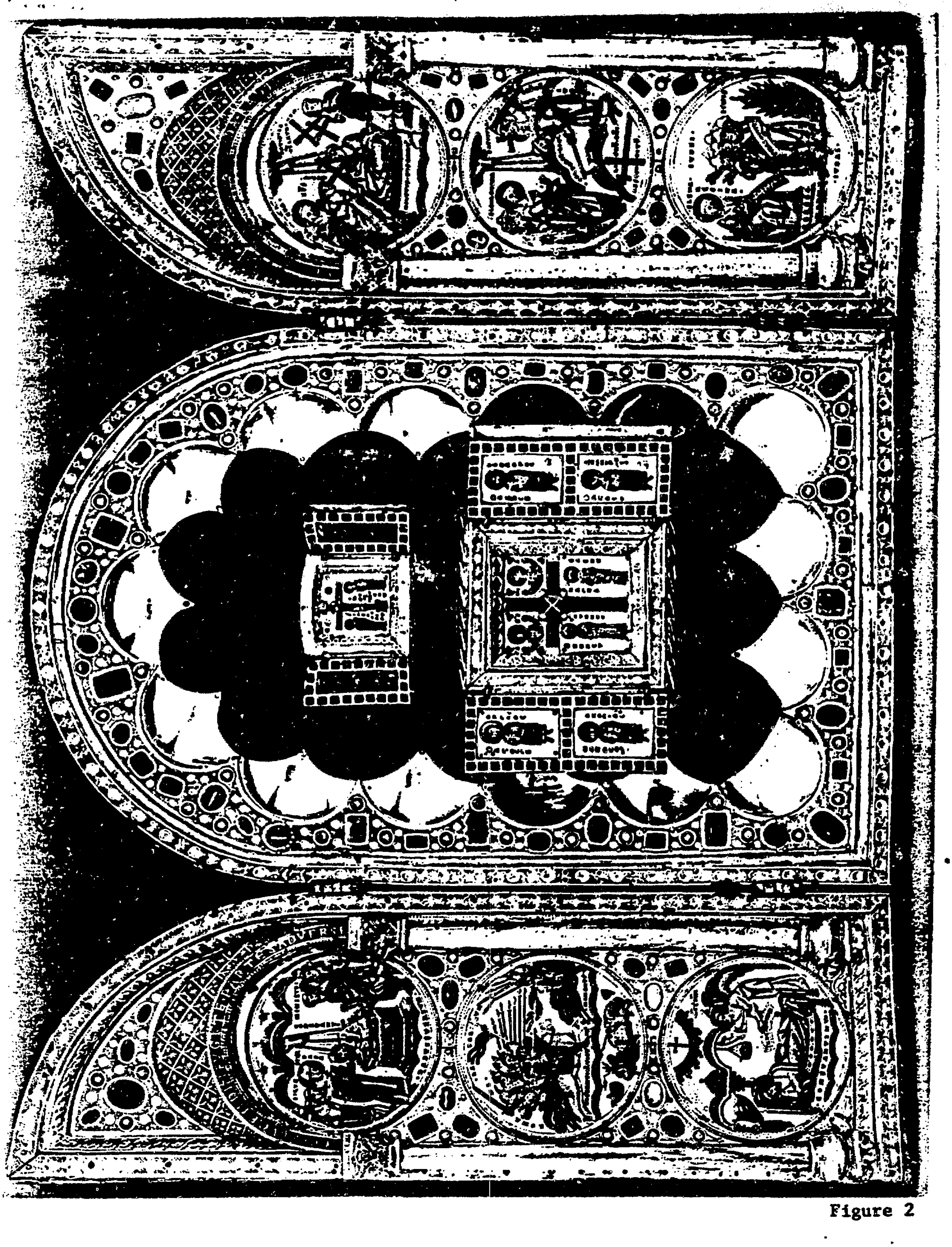

Figure 2