Radiocarbon dating—twenty years later

Willard F. Libby

The new method of radiocarbon dating, developed by Dr. Willard F. Libby at the Institute for Nuclear Studies of the University of Chicago, promises to revolutionize dating problems in archaeology. This method determines the age of things that lived during the past 20,000 years by measuring the amount of carbon 14 they contain.

Carbon 14 is an unstable (radioactive) heavy form of carbon with an atomic weight of 14. Normal, stable carbon has an atomic weight of 12. The half-life of carbon 14 is about 5,500 years. This means that an ounce of carbon 14 is reduced by decay to half an ounce in 5,500 years, that half the remainder decays during the next 5,500 years, leaving a quarter of an ounce, and so on.

Carbon 14 is constantly being formed in the earth's upper atmosphere as the result of the bombardment of nitrogen-14 atoms by cosmic rays (neutrons). The carbon-14 atoms thus created combine with oxygen to form carbon dioxide, which becomes mixed in the earth's atmosphere with the vastly greater proportion of carbon dioxide containing ordinary carbon atoms. The carbon 14 then enters all living things, which, through the life process, are in exchange with the atmosphere. This exchange is carried out through photosynthesis in plants. . . .

When a plant or an animal dies, it ceases to be in exchange with the atmosphere and hence there is no further intake of carbon 14. But the carbon 14 contained at death goes on disintegrating at a constant rate, so that the amount of carbon 14 remaining is proportional to the time elapsed since death. Given the carbon 14 content of contemporary living matter and the disintegration rate of carbon 14 (the half-life), it is possible to calculate the age of an ancient organic sample from the amount of carbon 14 it contains.

—from "New Radiocarbon Method for Dating the Past" by Donald Collier, *Chicago Natural History Museum Bulletin*, January, 1951.

One of the first publications on the radiocarbon dating method was by Donald Collier in this magazine twenty years ago. It described in clear, lucid language the newly born physical technique for determining the lapse of time since death of living organisms. Donald Collier and I were firm collaborators during the gestation period and he helped deliver the baby. He served with Richard Foster Flint, the geologist of Yale, Frederick Johnson of the Phillips Academy, and Froelich Rainey of the University of Pennsylvania Museum to guide Dr. Arnold, Dr. Anderson, and myself in the actual research.

Furthermore, he developed the technique of persuading museum keepers that they should give us materials to measure. This was no small achievement since our method is destructive—a sample from the material to be dated had to be burned—and at that early date we were requiring samples as large as one ounce for measurement.

I recall well when he gave us a sample from the deck plank of the solar boat at the Field Museum, the funeral ship of the Egyptian Pharaoh Sesostris III, which we dated at 3,750 years using the half-life we had then adopted of 5,568 years. We now know that the half-life should be 3 percent longer as the result of further studies by others, so something like a century should be added to the time to make it perhaps 3,875 years. I understand that the solar boat is being redated at the Applied Science Center for Archaeology at the University Museum in Philadelphia by Henry Michael, and I am told that a portion of the same plank used twenty years ago and again now is being reserved for future radiocarbon daters who may want to check the age of this priceless artifact.

During the past twenty years several things have happened which have modified the radiocarbon dating method and brought out its latent capabilities more clearly.

A basic assumption which we made in developing the method was that the cosmic rays that created carbon 14 had bombarded the earth's atmosphere at fixed intensity for the last 50,000 years or so, and that we would be justified in assuming that at the time of death the material being measured had the same proportion of radiocarbon content as does modern wood or any living modern material. It has been found, however, that this is not strictly true.

The first hints of discrepancy were disagreements with the Egyptian historians. Dr. Paul Damon at the University of Arizona noted that even with a lengthening of the half-life of carbon 14 from 5,568 to 5,730 years, the dates for the First Dynasty were later than the historians would have them be from their historical records. Of course, their dates were quite uncertain since these records were among the oldest written history on earth.

There was no proof that a correction was necessary until a new development occurred and Dr. Damon and Dr. Hans Suess of the University of California at San Diego and workers at the Douglas Tree Ring Laboratory in Arizona, Wesley Ferguson in particular, applied a new method of checking. This new method assumes that the wood in an ancient tree which constitutes a single ring is itself datable by radiocarbon. In other words, it assumes that the wood has not been altered since the rings were laid down during growth and that, with chemical purification to remove humic acids and other soluble materials, it can be burned and successfully dated by its radiocarbon content. Thus, by systematically measuring the radiocarbon content in ring after ring of trees of consecutively greater and greater age, both living and dead, this new way to check has already been carried back more than

8,000 years. The bristlecone pine trees in California and Nevada, which can live for several thousand years, have provided the material to work with.

We now know that there is a correction to be made in the direction that modern radiocarbon is less abundant by several percent than it was in these ancient times. Apparently at that time the cosmic ray bombardment rate was higher and caused the concentration of radiocarbon in all living matter throughout the world to be several percent higher than today. A 1 percent change corresponds to 83 years, so this amounts to several centuries. A correction curve has been deduced from this tree ring research. With it in hand and used to recalculate the Egyptian problem, we now find that the historical dates fit well with corrected radiocarbon dates.

A second major result is that the corrected dating seems to require some fundamental changes in archaeological evaluation in prehistoric Europe and the Middle East. This result is just coming out in the open, as I learned from Professor Colin Renfrew, of the Department of Ancient History at the University of Sheffield in England. Two lines of thought in European prehistory have come into conflict recently. One adheres to the diffusion explanation for the spread of skills; the other postulates independent invention. The corrected dates at present point strongly in favor of the latter view. In other words, as I understand it, Professor Renfrew is maintaining that even though writing was invented in Mesopotamia and Egypt, such matters as the development of copper and bronze metallurgy may have developed independently and have coexisted in the prehistoric period in several places. Previously it had been thought that metallurgy came first from Egypt and the ancient Sumerian civilization of

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Mesopotamia to the Aegean and then north and west through the Balkans to the rest of Europe. Likewise, the custom of burying the dead in monumental tombs was thought to have traveled a similar route. But the whole matter is apparently up for reassessment in view of the corrected radiocarbon dates.

A third point is the value of the corrections themselves for the understanding of geophysical phenomena. Something caused the cosmic rays to vary—and we now have a record of the extent to which they did vary—for the only way the concentration of radiocarbon could have changed was that its rate of production in the atmosphere must have changed. The volume of the ocean is known to have varied only to a very slight extent over the last several tens of thousands of years, and the ocean is the main diluting reservoir of the atmospheric radiocarbon.

There are several possible explanations for cosmic ray variation. One is that Earth's magnetic field was somehow weakened, letting more cosmic rays hit the atmosphere. At the present time about half the cosmic rays which would otherwise hit Earth are deflected away by Earth's field because cosmic rays are charged particles. So if Earth's field became weaker, more would come in and produce radiocarbon and thus raise the modern concentration.

Another possibility is that the sun was somehow less active in emitting solar wind. Studies in recent years with space satellites and space probes have shown that the sun is constantly emitting ionized matter which is racing outward, and cosmic rays are deflected to a considerable extent by this solar wind.

Most cosmic rays originate outside the solar system in an as yet unknown source, so we have the exciting possibility of relating our climate to the deviations if there be a correlation between the total emission of energy from the sun and the strength of the solar wind, which seems entirely reasonable on physical grounds. Of course, such a correlation has yet to be established, but it seems reasonable, in fact almost certain, that such a correlation must exist.
Some evidence has been obtained by studying the magnetism induced in ancient brick kilns which have been radiocarbon-dated. The magnetic minerals in the bricks were oriented in direction by the magnetic field then present when the bricks were last fired. So by studying the bricks, the direction of the ancient magnetic field can be obtained. Its intensity also can be obtained by the intensity of the magnetization, at least roughly. Now, the direction of the magnetic field has little bearing on the question since radiocarbon mixes over Earth's surface quite rapidly, in a matter of a few hundred years, but the intensity is indeed a serious question, as was pointed out many years ago by Elsasser and others. At the present time the source of Earth's magnetic field is unknown, though we have begun to suspect that Earth's field must be connected somehow with its rotation. This suspicion is based on the fact that Venus, which in other respects is very similar to Earth, has no magnetic field and does not rotate. Of course, we know that the rotation of Earth has not changed abruptly in the last several thousand years, so if there was a

A single specimen of bristlecone pine, *Pinus aristata*, growing at an elevation of 10,800 feet in the White Mountains of east-central California. Photo from Laboratory of Tree-Ring Research, University of Arizona.

weakening of Earth's magnetic field, we are essentially in the dark as to the geophysical mechanism.

But the important point is that radiocarbon dating has given an additional set of data on the history of the intensity of Earth's magnetic field, if it indeed can be shown that this is the cause of the variation in cosmic rays; or, alternatively, it has given additional data on the history of the sun. It is difficult at this point in time to know which the true explanation of the variation is, but we have every reason to hope that further research will settle this uncertainty. It may well be that both factors are involved, as Dr. Suess has suggested.

Another benefit which has come out of the twenty years' experience with radiocarbon dating is the clear demonstration of the ability of the physical scientist and the archaeologist to collaborate wholeheartedly and successfully; of the ability of each to learn the other's trade and to understand the difficulties in the other's field. It is clear that interdisciplinary science and interdisciplinary collaboration throughout all fields of knowledge are essential for the problems associated with the protection of our environment, and I take pride that radiocarbon research was one of the first collaborations to demonstrate in modern times that this melding together of specialists in widely different disciplines can be done successfully.

Dr. Willard F. Libby is now at the University of California, Los Angeles, Department of Chemistry, and Institute of Geophysics and Planetary Physics. He won the Nobel Prize for Chemistry in 1960 "for his method to use carbon-14 for age determination in archaeology, geology, geophysics, and other branches of science."