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Radiocarbon Dating

The method is of increasing use to the archeologist, the geologist, the meteorologist, and the oceanographer.

W. F. Libby

Radiocarbon dating had its origin in a study of the possible effects that cosmic rays might have on the earth and on the earth's atmosphere. We were interested in testing whether any of the various effects which might be predicted could actually be found and used. Initially the problem seemed rather difficult, for ignorance of billion-electron-volt nuclear physics (cosmic-ray energies are in this range) was so abysmal at the time (and, incidentally, 14 years later is still so abysmal) that it was nearly impossible to predict with any certainty the effects of the collisions of the multi-billion-volt primary cosmic radiation with air.

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Formation of Radiocarbon

However, in 1939, just before the war, Serge Korff of New York University and others discovered that the cosmic rays produce secondary neutrons in their initial collisions with the top of the atmosphere. The neutrons were found by sending counters, designed to be sensitive to neutrons, up to high altitudes, and they were found to have an intensity which corresponded to the generation of about two neutrons per second for each square centimeter of the earth's surface.

Whereas it was extremely difficult to predict the types of nuclei that might be produced by the billion-volt primary cosmic rays, the neutrons, being secondaries, were in the million-volt energy range and, therefore, subject to laboratory tests. So at this point the question was: What will million-electron-volt neutrons do if liberated in the air? The answer to this question was already available—in fact, Korff noted in one of the papers announcing the discovery of the neutrons that the principal way in which the neutrons would disappear would be by forming radiocarbon. The reaction involved is a simple one. Oxygen is essentially inert to neutrons, but nitrogen is quite reactive. Nitrogen-14, the abundant nitrogen isotope, reacts essentially quantitatively to form carbon-14 with the elimination of a proton. It also reacts about 1 percent of the time to produce tritium (radioactive hydrogen); this is another story, leading to a method of dating water and wine.

To return to radiocarbon dating, knowing that there are about two neutrons formed per square centimeter per second, each of which forms a carbon-14 atom, and assuming that the cosmic rays have been bombarding the atmosphere for a very long time in terms of the lifetime of carbon-14 (carbon-14 has a half-life of about 5600 years), we can see that a steady-state condition should have been established, in which the rate of formation of carbon-14 would be equal to the rate at which it disappears to reform nitrogen-14. This allows us to calculate quantitatively how much carbon-14 should exist on earth (see Fig. 1); and since the two atoms per second per square centimeter go into a mixing reservoir with about 8.5 grams of carbon per square centimeter, this gives an expected specific activity for living matter of 2.0/8.5 disintegrations per second per gram of carbon.

The mixing reservoir consists not only of living matter, which dilutes the radiocarbon, but of the dissolved carbonaceous material in the oceans, which can exchange carbon with the atmospheric carbon dioxide and thus dilute it. In fact, the ocean is the larger part of the diluting carbon reservoir (see Table 1). For each square centimeter of the earth's surface, there are about 7.25 grams of carbon dissolved in the ocean in the form of carbonate, bicarbonate, and carbonic acid, and the biosphere itself contains about 0.33 gram per square centimeter of surface. Adding all the elements of the reservoir, we get a total of 8.5 grams of diluting carbon per square centimeter, and the two carbon-14 atoms disintegrating every second should be contained in 8.5 grams of carbon. Thus, the specific activity of living carbon should be that number. We find this to be the actual value observed, to within about 10 percent (see Table 2). Of course, the times for mixing of all parts of the reservoir must be short as compared to the average lifetime of radiocarbon, 8000 years. The time for mixing of the oceans is the longest, about 1000 years on the average.

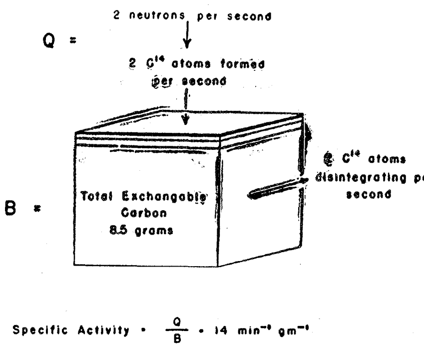

Fig. 1. Radiocarbon genesis and mixing.

This is interesting, for it means that the present intensity of the cosmic radiation (unless there have been canceling errors in our calculations) corresponds to the average intensity over the last 8000 years, the average life of carbon-14. It tells us, also, that the ocean is mixed nearly perfectly to its bottom depths in 8000 years. This we know because we included all of the dissolved carbon in the sea. Also, direct measurement of the carbonate and bicarbonate in deep ocean water confirms this. These conclusions could be false if errors in the very different quantities—the intensity of the cosmic rays and the mixing rate and depths of the oceans—should happen just to cancel one another. Since these factors are so unrelated, we believe this to be very unlikely and conclude that the agreement between the predicted and observed assays is encouraging evidence that the cosmic rays have indeed remained constant in intensity over many thousands of years and that the mixing time, volume, and composition of the oceans have not changed either.

We are in the radiocarbon-dating business as soon as this has been said, for it is clear from the set of of assumptions that have been given that organic matter, while it is alive, is in equilibrium with the cosmic radiation—that is, all the radiocarbon atoms which disintegrate in our bodies are replaced by the carbon-14 contained in the food we eat, so that while we are alive we are part of a great pool which contains the cosmic-ray-produced radiocarbon. The specific activity is maintained at the level of about 14 disintegrations per minute per gram by the mixing action of the biosphere and hydrosphere. We assimilate cosmic-ray-produced carbon-14 atoms at just the rate that the carbon-14 atoms in our bodies disappear to form nitrogen-14. At the time of death, however, the assimilation process stops abruptly. There is no longer any process by which the carbon-14 from the atmosphere can enter our bodies. Therefore, at the time of death the radioactive disintegration process takes over in an uncompensated manner and, according to the law of radioactive decay, after 5600 years the carbon that was in our bodies while we were alive will show half the specific carbon-14 radioactivity that it shows now. Since we have evidence that this has been true for tens of thousands of years, we should expect to find that a body 5600 years old would be half as radioactive as a currently living organism. This appears to be true. Measurements of old artifacts of historically known age have shown this to be so within the experimental errors of measurement.

Table 1. Make-up of the carbon reservoir (grams of carbon per square centimeter of surface) according to Anderson and Libby and W. W. Rubey.

	Anderson and Libby	Rubey
Ocean "carbonate"	7.25	6.95
Ocean, dissolved organic	0.59	0.78 (Ocean, dissolved organic + Biosphere)
Biosphere	0.33	
Humus	0.20	0.125
Atmosphere	0.12	
Total	8.5	7.9

Initial Research

The research on radiocarbon dating was carried out in several stages. In the first place, my collaborator, E. C. Anderson, and I had to determine whether the living material actually had the radioactivity expected. At that time we had no measurement techniques sufficiently sensitive to detect the radioactivities involved directly because these levels are quite low. Later we developed methods for making the measurement, but at that time we did not have them, so we used the method of concentrating the heavy isotope of carbon. An apparatus for this purpose had been built by and was being used by A. V. Grosse of Temple University, then of the Houdry Process Corporation at Marcus Hook, Pennsylvania. Grosse was concentrating the carbon-13 isotope for medical tracer purposes and kindly agreed to try to concentrate some biological methane for the test so crucial to our research. We had to use biological, as contrasted with petroleum, methane, for we had at this point arrived at a distinction between living and dead organic chemicals. We had both "dead" methane and "living" methane in the sense that methane from oil wells in which the oil has been long buried would be expected to be entirely free from radiocarbon while the methane made from the disintegration of living organic matter should contain radiocarbon with an activity of 14 disintegrations per minute per gram of carbon. The task was to take this living methane and concentrate it in the isotope separation column to see whether the heavily enriched product was radioactive. Happily for our research, it was found to be so, and to about the expected degree. The material used was methane gas from the sewage disposal plant of the city of Baltimore.

The second stage of the research was the development of methods of measurement sufficiently sensitive to eliminate the use of this $10,000 thermal-diffusion isotope column, which was so expensive to operate that it cost thousands of dollars to measure the age of a single mummy. Obviously, radiocarbon dating would have been an impractical method of measuring archeological ages if this phase of the research had been unsuccessful.

Counting Technique

The counting method developed involves measuring the radioactivity of the carbon directly. We convert the samples by chemical methods into a suitable form—carbon dioxide or acetylene gas or even solid carbon—which then is placed inside a Geiger or proportional counter, where it itself constitutes the gas or lies on the inner counter wall. This is possible because carbon as lampblack is an electrical conductor, and the gases carbon dioxide and acetylene are satisfactory counter gases. In this way a maximum count rate is achieved.

The counter itself is shielded from the background radiations in order to accentuate the carbon-14 count. A typical shield is shown in Fig. 2. It consists of 8 inches of iron to absorb the radiations from terrestrial sources, such as uranium, thorium, and potassium. The cosmic rays, however, which consist at sea level largely of μ-mesons, penetrate the thick iron shield readily, and whereas the count rate in the absence of the shield is about 500 counts per minute, the rate is decreased to about 100 counts per minute by the iron shield. This remaining activity, due in main part to μ-mesons, has to be removed. In order to do this, we surround the counter, with the carbon dating sample in it, with a complete layer of Geiger counters in tangential contact with one another and wire them so that when any one of these counters counts, the central counter with the dating sample is turned off for about one thousandth of a second. In this way the μ-mesons are eliminated from the record, so the background radiation comes down to something between 1 and 6 counts per minute, depending on the details of counter and shield design. This is for a counter of about 1 liter volume, capable of holding up to 5 grams of carbon with counting rates of 75 counts per minute for living carbon, 37.5 counts for 5600-year-old carbon, and 18.7 and 0.7 count, respectively, for 11,200-year-old and 56,000-year-old carbon.

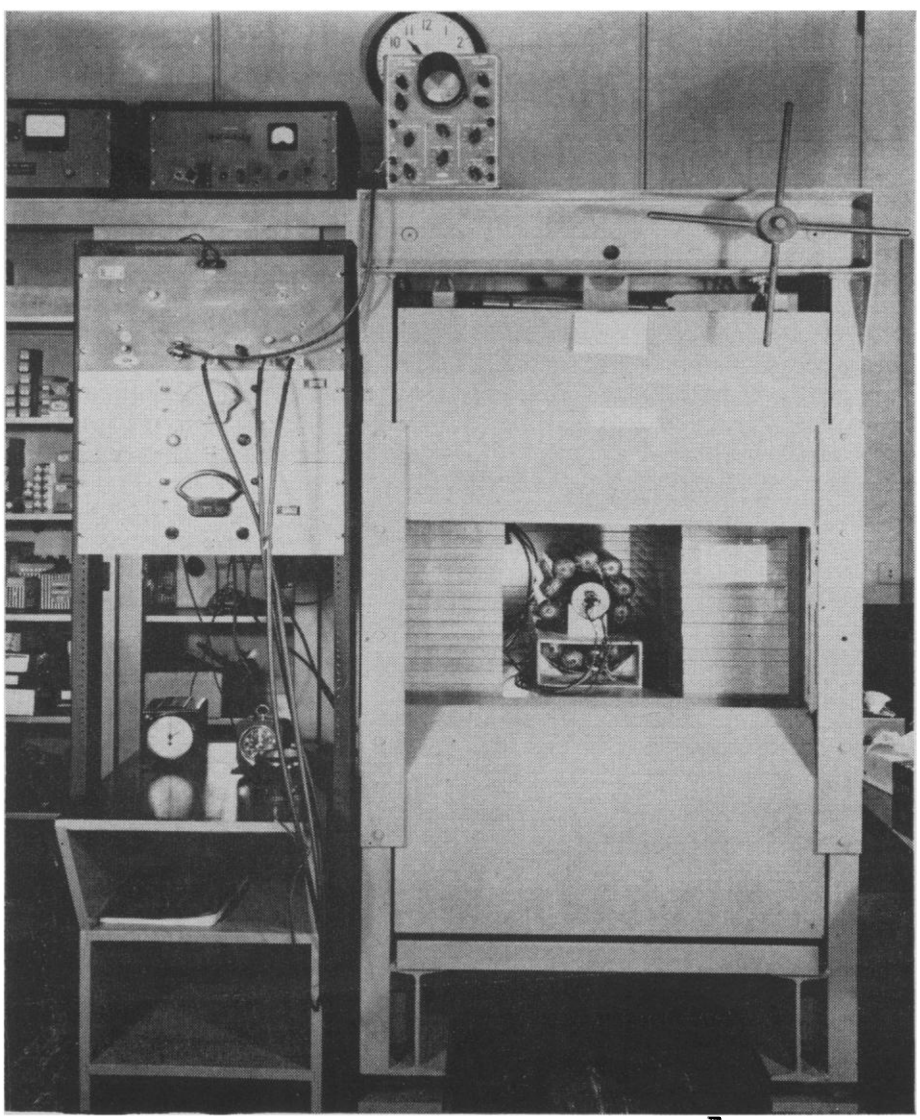

Fig. 2. Radiocarbon counting apparatus.

After we had developed a technique for measuring natural carbon relatively inexpensively with the requisite accuracy, our next job was to determine whether the following assumption was sound: that the variation of radiocarbon production due to the variation of the cosmic rays with latitude (which is very strong indeed) would be wiped out by the movement of the winds and the ocean currents in the 8000-year lifetime of carbon-14. The plan was to measure living materials from various places on earth and to see whether they had the same radiocarbon content per gram of carbon. These data on the natural abundance of radiocarbon in the earth were presented by E. C. Anderson for his doctoral thesis at the University of Chicago. They showed no appreciable differences, even though the samples came from places varying in latitude

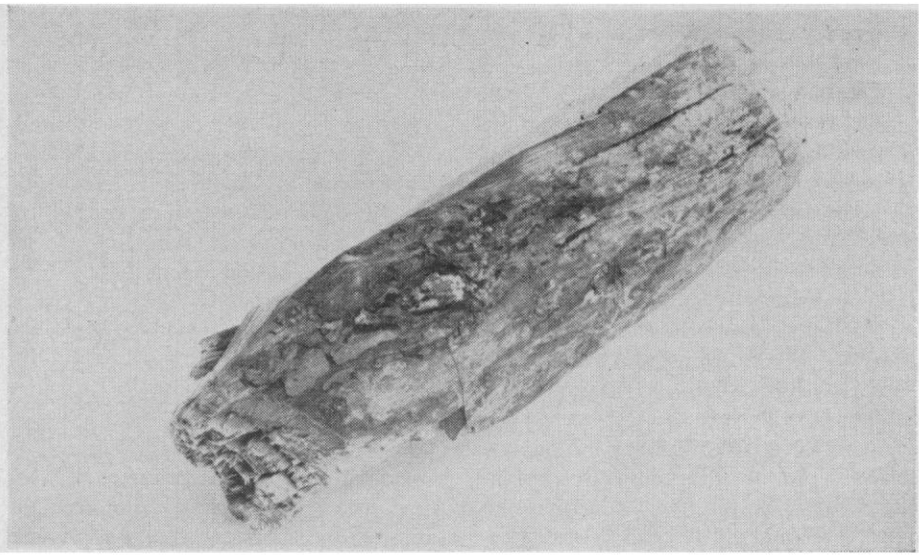

Fig. 3. (Above) Human hair, 5020 ± 290 years old, of an Egyptian woman. (Right) Preglacial wood, more than 20,000 years old, from a glacial moraine in Ohio.

from near the South Pole to near the North Pole (Table 2) (*1*). At the present time, 10 years later, no evidence for variation has been found except in areas of extensive carbonate deposits where the surface waters may carry a considerable amount of old carbon dissolved, and thus reduce the carbon-14 level below the world-wide average for the biosphere-atmosphere-ocean pool as a whole. Fortunately, such conditions are relatively rare and generally easily recognized.

Dating Technique

After the study of the natural occurrence of radiocarbon, the next stage was to see whether we had a method of dating artifacts of a known age, a problem which led us to mummies. J. R. Arnold joined us at this stage. We had a decay curve drawn which predicted, with no unknown factors and no adjustable constants, the specific activity of ancient organic matter. And so the question was to see whether it worked. The first thing we had to do, of course, was to get the materials for measurement. This was done by enlisting the cooperation of the American Anthropological Association and the Geological Society of America. Geologists have been quite interested in the results of this dating technique from the beginning, even though its reach in time is short for many of their problems. A committee of advisers, consisting of Donald Collier, Richard Foster Flint, Frederick Johnson, and Froelich Rainey, was appointed to select the samples for us and to help us collect them. These gentlemen worked hard for several years, assisting and collecting the samples and advising us.

The research in the development of the dating technique consisted of two stages—dating of samples from the historical and the prehistorical epochs, respectively. Arnold and I had our first shock when our advisers informed us that history extended back only for 5000 years. We had thought initially that we would be able to get samples all along the curve, back to 30,000 years before the present; we would put the points in, and then our work would be finished. You read statements to the effect that such and such a society or archeological site is 20,000 years old. We learned rather abruptly that these numbers, these ancient ages, are not known accurately; in fact, the earliest historical date that has been established with any real certainty is about the time of the 1st Dynasty in Egypt. So we had, in the initial stages, the opportunity to check against samples of known age, principally Egyptian artifacts, and in the second stage we had to go into the great wilderness of prehistory to see whether there were elements of internal consistency which would lead one to believe that the method was sound or not.

For the prehistoric period, members of our committee set up a network of problems which were designed to check, in as many ways as possible, points of internal consistency. They set out about a dozen major projects, and we collected samples (see Fig. 3) from each of these projects and worked hard and measured them; similar measurements are still going on now, 10 years later.

Table 2. Activity (in disintegrations per minute per gram) of samples from the terrestrial biosphere.

Source	Geomagnetic latitude	Absolute specific activity
White spruce, Yukon	60°N	14.84 ± 0.30
Norwegian spruce, Sweden	55°N	15.37 ± 0.54
Elm wood, Chicago	53°N	14.72 ± 0.54
Fraxinus excelsior, Switzerland	49°N	15.16 ± 0.30
Honeysuckle leaves, Oak Ridge, Tenn.	47°N	14.60 ± 0.30
Pine twigs and needles (12,000-ft alt.), Mount Wheeler, N.M.	44°N	15.82 ± 0.47
North African briar	40°N	14.47 ± 0.44
Oak, Sherafut, Palestine	34°N	15.19 ± 0.40
Unidentified wood, Teheran, Iran	28°N	15.57 ± 0.31
Fraxinus mandshurica, Japan	26°N	14.84 ± 0.30
Unidentified wood, Panama	20°N	15.94 ± 0.51
Chlorophora excelsa, Liberia	11°N	15.08 ± 0.34
Sterculia excelsa, Copacabana, Bolivia (9000-ft alt.)	1°N	15.47 ± 0.50
Ironwood, Majuro, Marshall Islands	0°	14.53 ± 0.60
Unidentified wood, Ceylon	2°S	15.29 ± 0.67
Beech wood, Tierra del Fuego	45°S	15.37 ± 0.49
Eucalyptus, New South Wales, Australia	45°S	16.31 ± 0.43
Seal oil from seal meat from Antarctica	65°S	15.69 ± 0.30
Average		15.3 ± 0.1

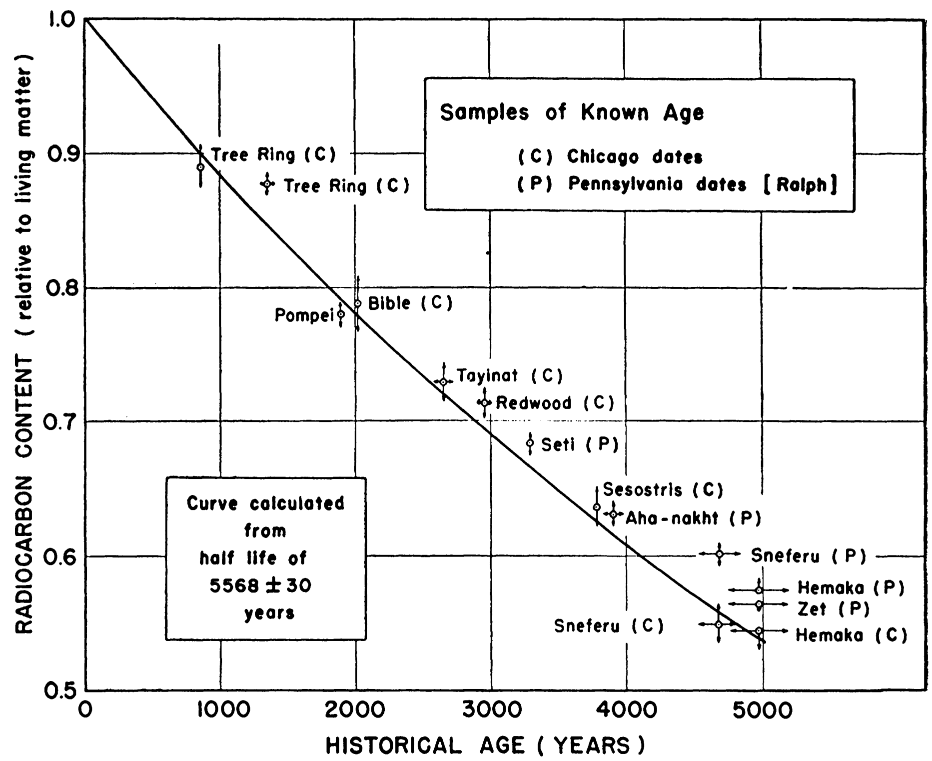

Fig. 4. Curve of knowns.

Curve for Samples of Known Age

Figure 4 shows the curve of "knowns" —the results obtained for samples of known age as compared to the carbon-14 decay curve drawn with the value of 14 disintegrations per minute (the value for living matter) taken as unity and with a half-life of 5568 ± 30 years. The half-life itself was measured in 1949 in collaboration with A. G. Engelkemeir, W. H. Hamill, and M. G. Inghram and found to be 5580 ± 45 years, a value which, when combined with independent values of 5589 ± 75 obtained by W. M. Jones and 5513 ± 165 obtained by W. W. Miller, R. Ballentine, W. Bernstein, L. Friedman, A. O. Nier, and R. D. Evans, gave 5568 ± 30 by weighting according to the inverse square of the errors quoted. Remeasurements are now being made, by Mann at the National Bureau of Standards in Washington and by Olsson at the University of Uppsala.

The knowns are in two main groups—those measured by us at the University of Chicago and those measured by Miss Ralph at the University of Pennsylvania, labeled (*C*) and (*P*), respectively. One sample, "Pompei," was measured by E. A. Olson and W. S. Broecker of the Lamont Geological Observatory.

The oldest samples of known age measured were "Hemaka" and "Zet" from the Ist Dynasty in Egypt. Both were wood found in the subterranean brick structures of the Ist Dynasty tombs of the Vizier Hemaka and of King Zet, both at Saqqara. Hemaka was contemporaneous with King Udimu, and both tombs were generally agreed to date from 4900 ± 200 years before the present. The next oldest samples were cedar wood from the upper chamber of the Southern Pyramid of Sneferu at Dahshur. The next sample, marked "Sesostris," is a very interesting one. It is a part of the deck of the funeral ship which was placed in the tomb of Sesostris III of Egypt and is now in the Chicago Museum of Natural History. It is about 20 feet long and six feet wide and is quite an imposing object, complete with paddles. The next sample is "Aha-nakht." It consists of wood, probably cedar, from the outer sarcophagus of Aha-nakht, at El Bersheh. It was found in the tomb, which was covered with earth. The coffin was presumably excavated by the natives at the same time as the El Bersheh coffin obtained for the British Museum by E. A. W. Budge, after 1895.

As we proceed up the curve, the next sample is the heartwood of one of the largest redwood trees ever cut. The tree was known as the "Centennial Stump," felled in 1874. There were 2905 rings between the innermost (and 2802 rings between the outermost) portion of the sample and the outside of the tree. Therefore, the known mean age, determined according to the tree-ring method of Douglas, was 2928 ± 51 years, as of the time it was cut. This is an interesting point, as it shows that, in the heartwood of the *Sequoia gigantea* at least, the sap is not in chemical equilibrium with the cellulose and other large molecules of the tree. In other words, the carbon in the central wood was deposited there about 3000 years ago, although the tree itself was cut just a few years ago. The next sample, which is marked "Tayinat," is from a house in Asia Minor which was burned in 675 B.C. It was wood from the floor of a central room in a large *hilani* ("palace") of the "Syro-Hittite" period in the city of Tayinat in northwest Persia. Its known age is 2625 ± 50 years.

The next sample is the linen wrapping of one of the Dead Sea scrolls, the Book of Isaiah, which was found in Palestine a few years ago (Fig. 5). The next sample, labeled "Pompei," was carbonized bread from a house of ancient Pompeii; still looking like an overdone roll, it was charred by the volcanic ashes that buried the city in 79 A.D., roughly 1880 years ago. The other samples are wood, dated by the Douglas tree-ring-counting technique. When results from these samples are taken all together, the agreement with the predicted radiocarbon content seems to be satisfactory. The errors are given as the counting errors (standard deviations) only.

It is certainly possible that the decay curve, which is drawn on the basis of a half-life of 5568 years, could be drawn somewhat differently. However, it is well to know that all radiocarbon dates published today have been calculated on this half-life, and in order to avoid confusion we should be careful about changing the basis of the calculation of radiocarbon ages before the evidence for a change in half-life is definite. The curve of knowns seems to indicate that a slightly longer half-life might be permissible. However, there are other possible explanations of a deviation of the curve of knowns from the theoretical curve. We all await the results of the half-life researches of Mann and Olsson with great interest.

Perturbations

It has been observed that fossil carbon dioxide from the combustion of coal and oil, after about 1870, began to dilute the biosphere and to reduce

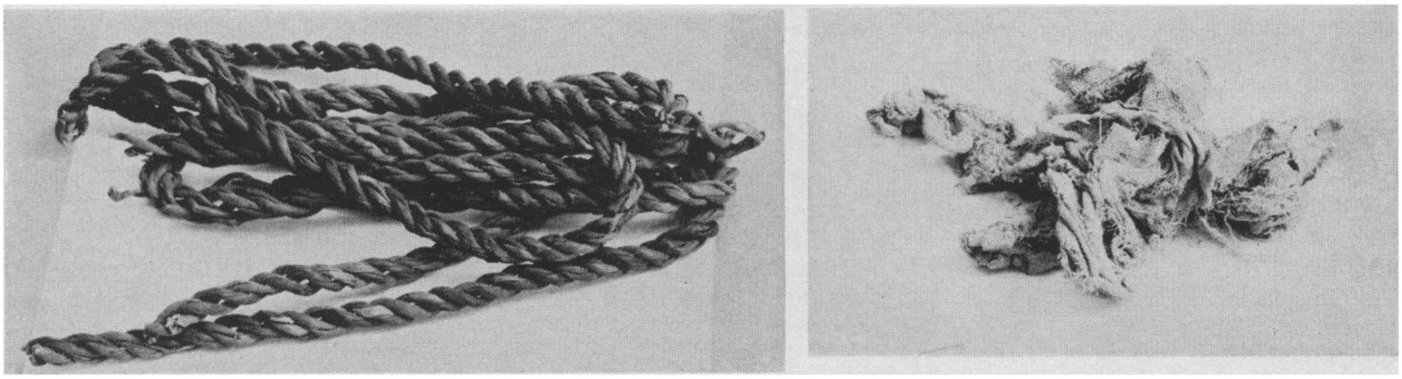

Fig. 5. (Left) Peruvian rope, 2632 ± 200 years old. (Right) Linen wrapping, 1917 ± 200 years old, of the Book of Isaiah, one of the Dead Sea scrolls.

the radiocarbon content, and that the trend continued until 1954, when the explosion of atomic devices reversed it. The carbon-14 introduced by the neutrons produced in the explosions more than compensated for the reduction by the fossil carbon—a reduction which at that time had amounted, in the Northern Hemisphere, to about 3 percent of the primeval level as far back as it has been possible to measure it, from tree rings. H. L. de Vries and Hans E. Suess have been particularly active in research on this point. It was Suess, in fact, who discovered that fossil carbon dioxide had been reducing this specific activity in recent biospheric material, since 1870.

Broecker and Olson have made careful studies of the carbon-14 content of ancient woods as well. And the general result is that there appear to have been, prior to 1870, only very minor variations, of the order of 1 percent or less, in the radiocarbon content of living matter. The recent perturbations are of no great concern for archeologists and geologists now living. Of course, in the future it will be difficult to correct for the period when these perturbations were active; that is, 5000 years from now there may be some difficulty in understanding why, for a period of a century or so, beginning in 1870, the radiocarbon level was so perturbed. However, the written records may well explain the anomaly; in fact, radiocarbon dating as such may not be needed to establish historical fact.

Dating the Last Ice Sheet

After the curve of knowns had been drawn, the next step in the research was to test in the great periods of prehistory to see whether the dates obtained were reasonable. Perhaps the most interesting single general result for this prehistoric period is the time in which the last ice sheet moved down to cover the northern part of the United States and the European continent. The result, 11,400 ± 200 years, has now been well established by the radiocarbon technique. The radiocarbon dates for this cataclysmic development show that it happened simultaneously in Europe and in North America and that the phenomenon was very widespread, and that it had a tremendous impact on the living habits of people the world over. The oldest sign of man in northern Europe and in England is younger than this, presumably because of the thoroughness with which the glacier removed all sorts of human artifacts. Therefore, the oldest of the Scandinavian, the English, and the North American occupation sites are all about 10,400 years old, dating back, presumably, to the time when the ice sheet receded.

In Fig. 6 are plotted, for the Americas, the number of occupation sites versus age. It is quite clear that there is an abrupt discontinuity at about 10,400 years. In Europe, however, if instead of examining sites in the northern regions we look at sites in the Mediterranean basin, there is no discontinuity, and evidences of human occupation extend back as far as the radiocarbon dating technique can reach —50,000 years or so. There seems to be some contrast between this and the situation in the Americas, where, as shown in Fig. 6, one sees a decided difference in the total number of sites in preglacial times. In view of the fact that it is known that extensive areas of the Americas were not glaciated by the last ice sheet, this raises something of a question. There is, of course, the definite possibility that this is pure accident, and it even seems possible that we do now have human sites in the Americas which are definitely older than 10,400 years. However, the weight of the evidence seems to indicate that something in the nature of a discontinuity occurred at that time. Most of the sites that are older than 10,400 years are equivocal in one way or another, at least so it seems to the chemist or physicist who overhears the archeologists arguing about them. We have noticed that there is considerable unanimity of opinion about American sites of 10,400 years or younger being human sites, whereas, there is considerable discussion and debate concerning the older sites. This is not true in Southern Europe and Asia Minor. One of the most remarkable of the sites in Europe is the Lascaux Cave in Central France, which has the beautiful paintings on the walls, showing the ancient animals in such authentic style as to demonstrate the remarkable advancement of the culture of the people at that time. These paintings are presumably older than 15,000 years, the age determined for the charcoal found in the soil of the cave. Around Asia Minor and in the areas of the Middle East there is no scarcity of materials which date back as far as radiocarbon dating can reach, and there is considerable evidence that the sites are human sites.

In Geology, Oceanography, and Meteorology

In addition to its use in the work on human history, radiocarbon dating has been used for geological purposes to a considerable extent. Of course, the time span of radiocarbon is so short, as compared to the history of the earth, that most geological problems are outside the reach of the technique. But recent history and recent events do fall within its scope, and there have been a number of investigations, in particular the sorting out and measuring of the chronological events of the recent ice ages—that is, the relative times of arrival of the various ice advances and the periods of time between them, the points of simultaneity, and the identification of particular moraines with particular advances. On these points, small and perhaps relatively unimportant as they are, the geologists have found radiocarbon dating to be of some use.

In oceanography, the great question of the rate of mixing of the oceans has yielded to the radiocarbon technique to a considerable extent, particularly in the hands of Suess and of Broecker and Olson—Suess particularly in the Pacific and Olson and Broecker in the Atlantic. They have shown that the Pacific mixes relatively less rapidly, the turnover time being something between 1500 and 2000 years, whereas the Atlantic mixes relatively more rapidly, at a rate about twice this, or with a 750- to 1000-year turnover time. It is clear from these researches that the fundamental assumption of radiocarbon dating, that the reservoir of the sea must be counted as a diluent for the cosmic-ray carbon-14, is valid. Further, it has been shown by Suess that there will be opportunities of measuring the deep ocean currents. He finds evidence for velocities and directions of the deep ocean currents in the Pacific corresponding to a requirement of some hundreds of years for the passage northward along the bottom.

In meteorology, radiocarbon dating has been of some use. It has been interesting to observe the changes in the radiocarbon content in living matter near large industrial centers where the rate of production of carbon dioxide from coal and oil was highest, and also to observe the dissemination of the radioactive carbon made by atomic explosions in the atmosphere. From these things we know that world-wide mixing occurs. We observe the effects of changes generated very largely in the Northern Hemisphere quite clearly in the Southern Hemisphere, though they are reduced somewhat in intensity. This is the first time that there has been clear and incontrovertible evidence for such a world-wide circulation, and on a time scale of a very few years; such evidence is particularly clear in the case of the bomb-test carbon-14.

In Archeology

Of course, the main use of radiocarbon dating is in archeology and the investigation of the history of man through the use of chemistry, for most ancient men did not write, and we have no written records except in Egypt, in Asia Minor, and in limited areas of Central America. Yet it is perfectly clear that 10,000 and more years ago people lived in a way that indicates they rivaled modern man in intelligence and capabilities. We have just to look at their handiwork to see this. The paintings in the Lascaux Cave, the handiwork of the ancient Indians in North America—particularly the basketry and the very skillfully made arrowheads (Fig. 7)—attest to their great capabilities. Where they came from perhaps we do not know, but we do know that they were very intelligent and very capable people.

Last spring, on Santa Rosa Island off the coast of California, friends of mine found a 6-foot skeleton, 10,400 years old, to judge by the radiocarbon measurements of Broecker of Lamont Geological Observatory on some charcoal found next to the skeleton. This is the same 10,400-year date which we have observed so often and which now marks the early evidence of man in Santa Rosa Island; the Lindenmeier site in Colorado; the Clovis site; the Lamus Cave in eastern Nevada on the Utah-Nevada border, continuously occupied from the time of the melting of the last glacier 10,400 years ago down to the time when modern man came into the area; the Fort Rock Cave in Oregon, where the most beautiful basketry of ancient man was discovered—grass rope woven into sandals (Fig. 8, left) of beautiful shape and design, 300 pairs of them neatly stacked just as though in a community shoe store 9000 years old; and several other sites in the Americas. We see in this the evidences that man has been a long time learning to *write* history but has been *making* history for many thousands and perhaps tens of thousands of years.

In Central Europe the element of simultaneity, which is revealed by the radiocarbon dates for the people who did not write or leave records, establishes conflicts and clashes between cultures which are interesting to examine and speculate upon. The Neanderthal man and the Cro-Magnon man did not stay long together. The Neanderthal man disappeared, and the Cro-Magnon man won; he may have been the man who painted the beautiful Lascaux Cave paintings, as I understand it from the archeologists.

We learn various details about the ancient peoples. For example, in the time of Hammurabi, the Babylonian king, there was an accurate calendar, but we have been uncertain about the correlation of this calendar with our own. This calendar of the Babylonians was a very good one, but there is an

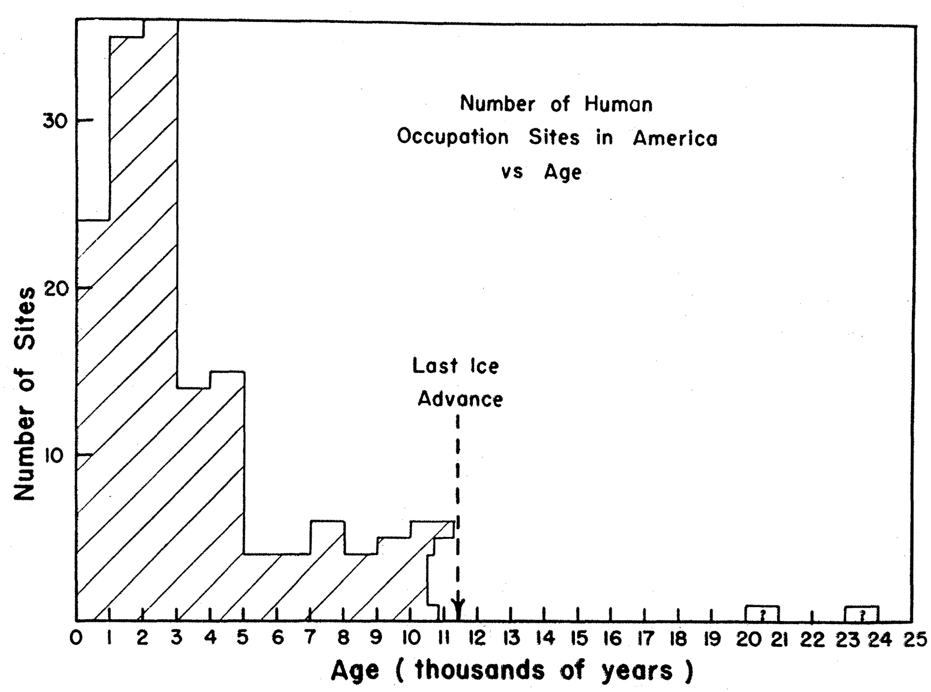

Fig. 6. Number of human sites in the Americas plotted against age.

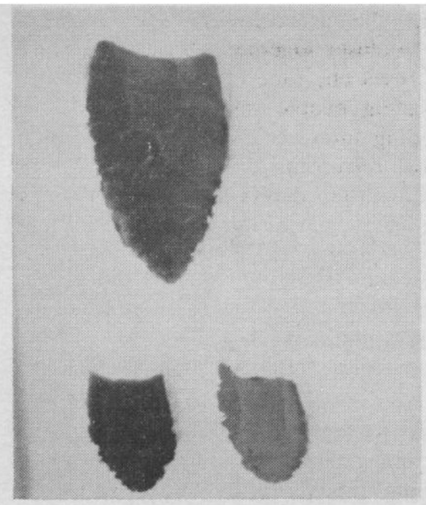

Fig. 7. (Left) Rush matting 3000 ± 250 years old, from a Nevada cave. (Above) Replicas of North American arrowheads from 10,000-year-old sites.

uncertainty which, as I understand it, concerns the identification of a particular eclipse as we calculate it backwards in time in order to arrive at a correlation with our own calendar. Therefore, careful measurements were made on a portion of a house about 4000 years old that was precisely dated by the Babylonian calendar. In this case, a serious attempt was made to test the limit of sensitivity of the radiocarbon dating method. The sample of wood came from a beam from the roof of this house in Nippur, which bore a clear and legible date according to the Hammurabian calendar. The beam was divided into three equal portions; these were carefully measured (the total measurement time was three months), and the results for the three portions were then coordinated to obtain a definite answer as to which of the two most likely correlations of the Christian and Babylonian calendars was correct. We concluded that the younger of the two possible calendars was strongly favored and that the odds against the other being correct were something like 9 to 1.

With the advancement of the radiocarbon dating technique and the consequent increase in accuracy, at least of the relative dates, it is possible to do more of these difficult jobs of pinpointing past events in time so as to drive back history into prehistoric periods and to more clearly delineate what really did happen in the development of man. Determination of the chronology of ancient civilizations may be said to be the main archeological problem and task of radiocarbon dating. As the technique is developed further and more fully and is more widely used, it should be possible to excavate and utilize sites which are now hardly more than dark spots in some remote area. Charcoal is one of the best materials for radiocarbon dating, provided adequate care is taken to see that intrusive rootlets and humic acids are removed before measurements are made.

We intend, at the University of California, Los Angeles, to attempt to make a portable radiocarbon dater which will allow us to work in the field with the archeologists and geologists and thus to obtain dates which, though not as accurate as those which would be obtained in the laboratory, may be useful enough to serve as guides during the digging. The problem is to find a truck that will carry the rather heavy equipment over rough country. If this effort is successful, it will be a development which will bring the carbon daters

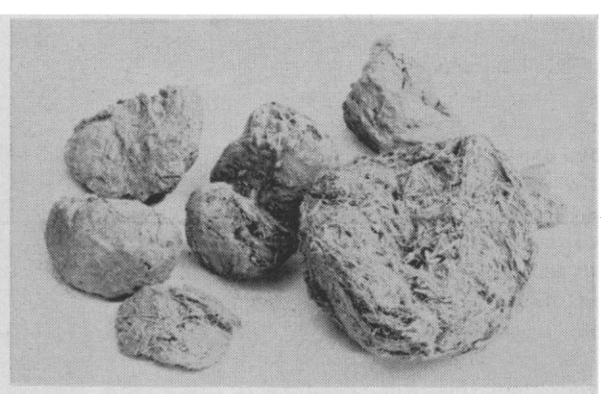

Fig. 8. (Left) Rope sandal found in eastern Oregon cave 9035 ± 325 years old. (Above) Dung of an extinct ground sloth, 10,455 ± 340 years old.

and the archeologists and geologists even closer together. Of all the rewards of research, none is greater than that of meeting people in different fields and finding interests in common. It will be most refreshing and rewarding for the radiocarbon daters to go out and share, at least vicariously, in the great thrill of an archeological dig.

Accuracy of the Results

The many people who have contributed to the development of the radiocarbon dating technique (several of whom I have mentioned but many of whom I have been unable to mention) are largely responsible for whatever success it has had. We now have several thousand radiocarbon dates throughout the fields of archeology, geology, meteorology, oceanography, and other areas. From examination of the results it is possible to form an opinion as to the general reliability and general weaknesses of the method. I am sure that Arnold would agree with me in saying that it has lived up to our fondest hopes.

It was clear from the beginning that there would be difficulties about the samples. Anyone knows that it is possible to get dirt into solid matter which is lying in the ground, even if it is there only for a brief period, let alone many thousands or tens of thousands of years. The saving aspect of the situation, however, is that it is very much more difficult to mix molecules in such a way that they cannot be separated chemically, particularly in the case of substances such as charcoal and wood and cloth, and even, in certain instances, limestone and shale. One can separate and distinguish the contaminant from the original material and in this way disclose the real radiocarbon content. The researches of a number of people have validated the assumption that it is possible and that, indeed, it is not too difficult to obtain authentic samples in the field. In general, the samples may have to be inspected with some care under a relatively high-powered glass and then, possibly, treated with properly chosen chemicals. But all of these things can be done, with techniques that are no more difficult than those used by the average hospital technician, and a sample can be obtained which should give authentic radiocarbon dates. The dating technique itself is one which requires care, but which can be carried out by adequately trained personnel who are sufficiently serious about it. It is something like the discipline of surgery—cleanliness, care, seriousness, and practice. With these it is possible to obtain radiocarbon dates which are consistent and which may indeed help roll back the pages of history and reveal to mankind something more about his ancestors and thus, perhaps, about his future.

Note

1. Our whole research was supported generously by the Viking Fund of New York City (now the Axel Wenner-Gren Foundation), the U.S. Air Force, the Geological Society, the Guggenheim Foundation, and, of course, the University of Chicago, where most of it was done.

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Science in the News

Kennedy on Natural Resources: His Program Covers Same Ground as Ike's, but on a Larger Scale

The Kennedy message on natural resources placed heavy emphasis on the role of the scientific community. The message proposed comparatively little spending for the coming fiscal year (1962), beginning this July. A spokesman for the Administration said he considered an extra $100 million above Eisenhower's recommendations a reasonable guess. If Congress is cooperative, spending will surely be higher than this. But spending, in any case, will involve fairly small sums by the standard of the federal budget, and small also compared with what the program implies Kennedy would like to do in the years to follow.

Most of the recommendations for the coming year have to do with organizing a national attack on the problem of resources. Kennedy asked the National Academy of Sciences for a "thorough and broadly based study and evaluation of the present state of research." He said he wanted the Academy's recommendation for research programs affecting the "conservation, development, and use of natural resources, how they are formed, replenished, and may be substituted for, and giving particular attention to needs for basic research and to projects that will provide a better basis for natural resources planning and policy formulation." This study will take about a year and will cost about $1 million. Its full impact will not show up until the fiscal '64 budget, which must be presented to Congress in January '63. Meanwhile, Kennedy asked the Federal Council for Science and Technology to recommend what can be done more quickly "to strengthen the total government research effort relating to natural resources."

The message included the by now familiar emphasis on oceanography. (The Democratic platform and the State of the Union message also included specific references to this, a continuation of an effort begun under the Eisenhower Administration to draw attention to the field.) The problem has been that the science, or the group of sciences collectively known as oceanography, has had difficulty winning Congressional support partly because it lacks the glamor and the obvious connection with national security that space and atomic energy research have, partly because responsibility for the program is scattered throughout the dozen or so government agencies with an interest in one phase or another of oceanography.

Presentation to Congress

One result has been that there is no single Congressional committee in either house with the authority to ap-