Introduction essay

The discipline of archaeology can open up the past to us in a way in which we can enter into a dialogue with our ancestors. There are many ways it can do this: stratigraphic excavation, pottery typology, socio-historic interpretation, etc. However, one thread running through this increasingly focused pursuit is that of dating the physical findings to a particular cultural timeline. This is crucial if we are to know, with as much certainty as is allowed, who we are speaking with. Indeed, dating may be the proverbial thread that holds entire pursuit together, without which the individual pieces of the puzzle might be compared to the children of Israel, who the author of Judges describes as each going off in their own direction. Like the king Judges so wistfully imagines, dating brings cohesiveness and direction to a potentially (or real?) chaotic situation.

In this paper I will explore the particulars of radiocarbon dating; from its background and origin, to discussion of samples, method, results, and calibration.

Background

With the explosions of the first atomic bombs echoing in his thoughts, Willard F. Libby, working with A. V. Grosse, Ernest Anderson, and several students, pioneered the work on a theory that natural C14 not only existed, but that it could also be used as a method for dating certain artifacts of antiquity. Working under the premise of his 1946 paper that suggested C14 might exist in all living organisms, a team including Libby and Grosse collected readings from the Baltimore sewer system. It was discovered that methane collected from these sewers contained radiocarbon activity, whereas methane derived from petroleum did not. These findings gave strength to the theory suggested in his paper, but several years of additional research were needed. After their sewer experiments, global samples of wood were gathered in which the researchers discovered a consistent level of radiocarbon deposits. From that point on, the theory developed until it became widely accepted within the scientific community, culminating with Libbys acceptance of the Nobel prize for chemistry in 1960.

The Origin of C14

Natural C14 is formed in the upper atmosphere when nitrogen reacts with neutrons. Neutrons are produced by cosmic rays bombarding the earth, and are thus dependent upon the level of cosmic ray bombardment, as well as the earths natural ability to receive the rays from space. The only known deterrent to cosmic ray absorption is the earths magnetic field. The stronger it is, the less the cosmic rays reach the earth. Once the C14 is produced, it exists in a very small quantity in carbon dioxide, a product of oxygen and carbon. From here, all living organisms take in C14 by either photosynthesis (plant life) or the food chain (breathing life). Since C14 is radioactive, and therefore destructive to life, it is necessary for all organisms to release C14 at basically the same rate they consume it. Those that do not release radioactive carbon as quickly as they absorb it, it is assumed, would not survive as a species. Consequently, in principle, there exists an equilibrium between the levels of C14 in the atmosphere and that which exists in all living organisms. When an organism ceases to live, it ceases also to take in C14, and the rate of release (radioactive decay) can then be measured and compared to values pertaining to the half-life of the isotope. At present, the best estimate for the half life of C14 is 5730! 40 years, thus making it an almost ideal determinant to archaeologists, and in particular archaeologists concerned with excavations in the middle east.

Samples

Because of the very nature of radiocarbon dating, the ideal sample pool is limited. Preferably the sample is organic in composition, and is free of any contamination, such as exposure to other organic material that would skew the readings. This is particularly important in terms of packing and shipping the sample to a radiocarbon laboratory. Below is a list of some potential samples and concerns for each.

Charcoal and Wood are predominant among samples found at archaeological sites. Both are preferred because there is little chance of contamination. However, the possibility of underground water causing a change in C14 saturation needs to be considered with the charcoal. And, while not considered contamination per se, precut growth in wood samples needs to also be taken into account. For instance, if the wood being sampled was cut from the center of a tree, the date read from the analysis would be the date the tree started to grow, not the date the tree was felled for use in construction. Most of the time this would account for an error on the line of 100-200 years. However, it could potentially be greater than that considering the life span of some trees like the Bristle cone Pine is 4000+ years.

“ Short-lived” Samples include items such as seeds, hides, paper, cloth, grass, and grains. These are usually preferred to the wood samples because of the potential problem of precut growth. They are called “ short-lived” due to the fact that they are, or are made from, items with a relatively short life span. Like the wood and charcoal listed above, there is little chance of contamination.

Ivory is an excellent candidate for dating because it is rare that the specimen will be contaminated. This is due to compaction in its structure and the fact that it, for the most part, remains in a state of preservation comparable to that of contemporary samples. There have been tusks found over 40, 000 years old that were first suspected to have come from modern-day elephants. Like trees though, care needs to be taken in ascertaining where in the tusk the sample originated. Whereas in trees, the center is the oldest, it is just the opposite for tusks.

Bones are often found at archaeological sites, but they present a unique problem for carbon dating. First, the carbon found in bones is mostly inorganic and unsuitable for testing. Second, bones are very porous. Unless a good seal is established around the sample, it is very likely the sample will be contaminated by ground water. This can throw a date off considerably. The best bones to use then, are ones that have been preserved within a heavy layer of charring from a fire or volcanic activity. Collagen in bones can also produce carbon, but to date it has performed poorly in establishing a reliable result.

Pottery and Iron are not usually used as samples in C14 testing, but there are times when they can produce accurate dates. However, pottery must be contain at least 1% organic carbon to agree with normal control samples. Other tests using the same or even higher percentage, however, produced inconsistent results. Certain types of iron can be used, but requires a high temperature furnace to combust the carbon in the iron. Iron from meteors cannot be used.

As I have already alluded to above, shipping involves special care in how the sample is prepared, and what the sample is sent in. Below are steps for consideration in getting a sample from the site of the dig to the laboratory for a successful date.

Collection of the sample to be analyzed is the first step. Care should be taken not to contaminate the sample with contact of human skin or other organic materials. However, this is not always a troublesome task. Large pieces of wood covered with earthen material, and storages of grain and such can usually be dealt with with little fear of contamination by human contact. Nevertheless, proper tools such as trowels, tweezers, spades, and the like should be present to deal with smaller items like pieces of charcoal embedded in dirt. Especially with the smaller samples, it is wise to separate them from as much of the earthen material as is possible to avoid further breakdown and homogenization during the shipping. And, as with all samples collected from a site, it is important that some detailed record be maintained of the radiocarbon samples stratigraphic context so that its readings might be cross-checked with other readings pertaining to a particular level.

Packaging the sample is relatively easy, but the importance cannot be overstated. The container one chooses really depends on what form the sample is in. If the sample is large and/or sufficiently solid, even cloth or paper will do. However, most samples necessitate something like the organically neutral environment of plastic or metal, sealed with a strongly adhesive tape. If possible, samples should be dried before shipping to prevent the growth of mildew. Finally, each container should be labeled on the outside to ensure proper identification.

Contamination at this point needs to be better defined. There are many factors that may contribute to a sample becoming contaminated. When saying " contaminated," I am referring to the result of any process that causes a theoretically pure sample to become impure, and thus produce a skewed reading. So far we have only dealt with the human element. However, events such as atmospheric C14 variations, natural changes due to glaciation advancement or retreat, human activity, deep marine effects, exposure to hard water, and volcanic activity can all contribute to a samples contamination. Recognizing these factors as potentially being present in the stratigraphic context of a find is crucial to obtaining an accurate date.

Methods of Dating

Solid-Carbon dating was the first method developed back in the early 1950s by Libby and some of his students. It is no longer used to three drawbacks associated with it. First is self- absorption. When its beta particle disintegrates, the energy level produced by the breakdown is very low, and difficult to detect. Thus it required a large sample to detect something more than a fraction of the disintegration. Secondly, carbon absorbs rather well. Many samples were contaminated due to the fallout in the air from atomic tests in the 50s. The samples could be cleaned, but not with the certainty needed for accurate readings. Last, the reaction rate of carbon dioxide varied when exposed to magnesium during the procedure, perhaps giving way to a few dates that were clearly too old for the control sample.

Gas-Counting was the method that replaced the solid-carbon method. This method was popular for a time in the late 50s, after which time many laboratories switched to using proportional counting or scintillation counting. Gas-counting basically involves the rapid combustion of a sample (acidification in the case of inorganics), and then many stages of chemical removal of electronegative and radioactive impurities. Then, because of the presence of radon (half-life of 3. 82 days), the sample is stored for two weeks until this impurity has decayed below the limit of detection. This can make the entire process stretch out to as much as a month for a reading.

Liquid Scintillation Techniques are also used in some laboratories. Though the chemistry involved is considerably more complicated, it usually achieves the same quality of results as obtained with the gas counting method. However, there are two advantages to the scintillation process. One is that the equipment needed for counting is more readily available than is for the gas counting method. This is an important cost factor because, while the gas counting method requires much human intervention and processing, the equipment used for scintillation is usually semiautomatic, and therefore uses less manpower. Secondly, there is a much greater flexibility with the scintillation process. With the flip of a switch, the laboratory can change from calibration to a reading for an unknown sample.

Accelerator Mass Spectrometry is the latest technique being used to date samples. Whereas the other three are based on observing the decay products of C14, AMS counts the number of C14 atoms present relative to the number of C12 and C13 atoms in a particular sample. To do this, the AMS system was built on the technology of the mass spectrometer. With the MS, a magnetic field is applied to a moving charged particle, and the particle is deflected from the straight path along which it was traveling. If charged particles of different mass, but the same velocity, are subject to the same magnetic field, the heavier particles are deflected the least. The AMS works similarly, however, the charged particles are driven to very high speeds by large voltages of electricity. This allows the minute levels of C14 to be detected among the higher levels of elements such as N14 and CH13.

The AMS system has two major disadvantages. The first is the high construction and maintenance costs. Building the facility alone can run as much as $2 million. The second is the need for rigorous pretreatments (such as the removal of calcium hydroxyapatite from bone, and cellulose from wood) to keep even minute levels of contamination from causing major errors in dating results. However, AMS is more efficient than the conventional methods for several reasons. 1) It can accurately date a sample 1000 times smaller than can conventional techniques. This means smaller artifacts or specimens can be, for the most part, preserved by the archaeologist instead of being destroyed in the dating process. 2) Other chemicals can be detected more easily in a sample. This allows the laboratory to detect the effects of contamination on the results. 3) With AMS a laboratory can run as much as 1000 tests per year because of the 2-3 hour testing time. With conventional methods, it can take 1-3 days.

Test Results

Most of the controversy and misunderstanding surrounding radiocarbon dating revolves around the test results pointing to a date or dates that someone does not agree with. As with all scientific methods, there are limits to what radiocarbon dating can and cannot do. Also, there are questions concerning errors, accountability, and a consistency of standards to be considered.

The Maximum age limit for conventional methods is about 40 000 years, whereas the limit for AMS is controlled by the individual machines stability and contamination introduced or missed during the processing of small samples. As the sample gets older, levels of C14 can drop to the point where it is difficult to measure against the background level naturally present. When this is the case, results are quoted as either “ infinite” or “ background.”

The Minimum age limit for all methods is not less than 200 years. Results pointing to an age of less than 200 years are reported as “ modern.” Contaminations here can occur due to the worlds fossil fuel and atomic bomb activity, and results showing more C14 than would normally be seen in contemporary samples have been quoted.

Error is present in every scientific process. Normally, experimental error is calibrated by repeating the measuring process. However, this is not very practical in radiocarbon dating due to the sample size, time, and cost factors. The error term (s), then, is estimated for each sample and applied as a known measurement. Going with the normal distribution curve, the true result is expected to have a 68. 3% chance of being within 1s of the experimental result, a 95. 4% chance of being within 2s of the experimental result, and a 99. 7% chance of being within 3s of the experimental result.

To date there is no accepted convention as to just how a laboratory should apply the error estimation. All laboratories include an estimation based on Poisson statistics (industry wide standard based on known counts). But how those statistics are applied will differ from lab to lab. This is because, over a short time period, the decay rate for C14 is not exactly predictable. However, the percentage of error can be reduced significantly by an increase in count time in the conventional methods. Liquid Scintillation gives eight counts per minute per gram for a modern sample. To insure a maximum error of 1% (an error term of approximately 80 years), a five gram sample would need to be counted for about 250 minutes. The older the sample, the longer it takes to produce the same error term. Increasing the minutes of counting, or the size of the sample will also affect the outcome in the way of a more accurate result. In addition, several samples must be sent out to different laboratories so that a “ blind” and impartial result will be produced.

Finally, accuracy and precision are often used interchangeably when speaking in terms of error. However, they are quite different. Accuracy refers to systematic errors in relationship to a true result. There may or may not be precision associated with these results. Precision, on the other hand, refers to how tightly associated the results are with each other. It basically measures the randomness of errors. These results may or may not be accurate in terms of the true results in this case. Thus, an accurate result is more desirable than a precise result because of the relationship between it and the true result. If possible, though, both are pursued. Lastly, a statistical model will be applied to eliminate any extreme results before a test result date is settled upon.

Calibration

Radiocarbon dating works very well when trying to establish a broad estimate of age. The problems start when trying to establish calendar dates. This is where calibration, specifically that of dendrochronology, is most helpful. Dendrochronology, the establishing of calendar dates through the study of tree rings, can calibrate with great accuracy radiocarbon dating so that it can more efficiently be used to establish specific ages and dates for the archaeologist. Long chronologies can be plotted by starting with living trees and overlapping them with older, felled trees. This process is continued as far back as possible. Through use of trees like the Bristle Cone Pine, we now have chronologies dating back 8 000 years. Dating these findings by radiocarbon methods then gives us a statistical curve of calibration based on the comparison of absolute dates (tree rings) and approximate ages (radiocarbon). Laboratories can then use this statistical model to account for any natural error inherent in the radiocarbon process.

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