Radiocarbon Dating: Radiocarbon age and Calendar Age

The traditional way of dating organic material is through carbon dating. Carbon-14 (^{14}C) is produced in the upper atmosphere are the result of cosmic rays interacting with matter in the atmosphere. Cosmic rays are particles of matter traveling at substantial fractions of the speed of light. They are very energetic, because of their high velocity. They can be ducted around by the Earth's magnetic field, so they tend to come in more readily near the magnetic poles, where they participate in producing optical displays. The flux of cosmic rays produces free neutrons in the upper atmosphere, with the density of free neutrons peaking near 40km. Above that level the neutrons have a high probability of passing back into space because they are moving so fast. The energy received by Earth in the form of cosmic rays is comparable to that received from starlight, but because each particle is so energetic, significant effects on the atmosphere are produced.

The free neutrons in the upper atmosphere interact readily with the most common isotope of nitrogen, ^{14}N, which is about 99.62% of the total nitrogen. ^{15}N is the next most common isotope. The neutron is added to the ^{14}N, while it knocks off one proton and one electron giving ^{1}H.

$$^{14}H + n \Rightarrow {}^{14}C + {}^{1}H$$

^{14}C is called radiocarbon, perhaps both because it is produced by cosmic radiation and because it is radioactive and decays. If this carbon is taken into a plant and buried below the surface, the source of ^{14}C is cut off and the amount of ^{14}C begins to decay with a half-life of 5,730 years. The carbon decays to ^{14}N via beta decay. A neutron disintegrates into a proton, an electron and an anti-neutrino.

$$^{14}C \Rightarrow \beta- + {}^{+14}N$$

If we assume that the atmospheric abundance of ^{14}C remains constant, meaning that the cosmic source remains constant, then the time since organic samples were living in contact with air can be estimated by the ratio of ^{14}C /^{12}C compared to the ratio in air, which must be assumed constant. Such dating techniques put the time of the last glacial maximum at 18,000 years ago (18kBP).

The rate of production of ^{14}C in the atmosphere depends on the flow of cosmic rays from the sun, and the diversion of cosmic rays around Earth by earth's magnetic field. So if either the solar output of cosmic rays or earth's magnetic field change, then the ^{14}C clock will run fast or slow. If cosmic ray production of ^{14}C increases for a period, then this time will appear earlier by the ^{14}C clock. Recent studies using ^{234}U-^{230}Th (uranium-thorium) dating of coral heads has shown that the actual time of the last glacial maximum is about 21,000 years ago (Bard, et al., 1990). So the radiocarbon dates are off by about 3,000 years, as little as 21,000 years ago. When paleoclimatic data are viewed, one must check whether the timings are given in radiocarbon years or calendar years. Many of the references we will read put the last glacial maximum at 18,000BP, but those are radiocarbon years. The last full ice age was probably closer to 21,000 years ago.

The big errors in the radiocarbon dates over the last 20,000 years are believed to be associated with slow changes in Earth's magnetic field. On shorter time scales, over the last millennium, evidence can be given that differences between radiocarbon dates and dates estimated from other methods arise from variations in the output of cosmic rays from the sun. This is because on this time scale variations in the radiocarbon dates vary in synchrony with other measures of solar activity such as ^{10}Be (Bard, et al., 1997).

In recent times, the ^{14}C abundance in air has changed because of fossil fuel combustion. Fossil carbon is very old (in the sense that it has not been in air for a long time) and has no ^{14}C. Therefore, as we burn fossil fuels we deplete the ^{14}C abundance in air. This is one of the arguments for why the atmospheric CO_2 increases we are observing are caused by fossil fuel burning (Stuiver and Quay, 1981).

References:

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