DATING

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There are basically three lines of investigation that are involved in geochronology – the dating of rocks and other earth materials. First, there are the physical and chemical dating methods which give us numerical estimates of age. Second, there is the reconstruction of the order of events in sections of sedimentary rocks – those laid down by water and wind. What is done is to find rocks which can be dated within a sequence of strata in order to establish the ages of fossils found within it, since the fossils themselves are not directly datable. The third line of investigation is called geologic correlation, in which one establishes that two or more events happened at the same time, or very nearly so.

Here I will discuss briefly three dating methods that are useful in dating what are called Cenozoic rocks, those of the last great division of geologic time during which the mammals became dominant. This encompasses about the last 60 million years. The methods I will discuss are sometimes called primary dating methods because they allow us to arrive at numbers for the age of things. The first method is radiocarbon dating, useful only for about the last 50,000 years of geologic time, although recently the method has been extended to about 100,000 years.

How does radiocarbon dating work? High in the atmosphere, radioactive atoms of carbon are formed and then oxidized to carbon dioxide by various reactions. This mixes into the rest of the atmosphere so some carbon dioxide in the atmosphere is radioactive, and plants become radioactive by using the carbon dioxide to make their tissues. Animals, too, become radioactive because they eat the plants. As long as the plant or animal is living, the carbon in it continues to be exchanged with the atmosphere. The carbon 14 is continually replaced as time goes on. When the organism dies, that exchange ceases. So a radiocarbon age determination dates the time of death of the organism. Even in rather recent archeology we sometimes have to worry about how the organic material itself relates to the archeological record. Those who have worked in Southwest archeology are very familiar with this problem. People who built pueblos would sometimes use beams out of older pueblos, made from trees, the inner tissues of which were dead and ceased exchanging carbon perhaps some hundreds of years before the building of a pueblo.

Some carbon dioxide is always dissolved in the oceans and the rest of the waters of the earth, so that carbonate minerals which are precipitated by organic or inorganic means from the lakes and the ocean are also radioactive. When shells stop forming and are deposited in sediments, they become material for dating as well. In radiocarbon dating we measure the amount of carbon 14 which still remains in a sample. This is one of the few cases in geochronology where we measure the amount of parent remaining, and this leads to an assumption. We assume that the amount of parent being produced over geologic time is the same as today. We now know that this assumption is invalid. It is a good first approximation, but refinements are necessary to arrive at a precise age.

A second dating method is potassium-argon, developed by John Reynolds, Garniss Curtis and Jack Evernden at the University of California at Berkeley in the mid-1950s. Shortly after the method was developed, it was used to provide an age for the hominids at Olduvai Gorge of about 1.75 million years. That date, produced that long ago, is still an exceptionally good determination.

The problem with this method is that fossils cannot be dated directly by it. Instead we have to find a volcanic rock, a piece of obsidian, or some mineral which can be used. Not all potassium is radioactive – only one isotope is, and this makes up only a small fraction of the total potassium in a sample. As potassium decays within mineral crystals, argon gas accumulates. What we measure is the ratio of argon produced from the decay of potassium in a crystal to the amount of potassium.

A third method, fission track dating, again is mainly applicable to volcanic rocks. It works in quite a different way from potassium-argon dating. One of the isotopes of the element uranium (not the one we fission to make bombs, but the other one) fissions spontaneously, naturally, very slowly. Fission is a very violent process, and when each of the single uranium atoms decays within a crystal, it damages the crystal, and leaves a trail through it which can be viewed by various means. If we measure the amount of uranium in the crystal, and count up the number of tracks, we have a measure of age. Again, this works only for volcanic minerals insofar as we are concerned here.

In both of these latter two cases there is an event we are dating, just as in the radiocarbon method where we are dating the death of an organism. In the potassium-argon and fission track methods we are dating the time of cooling of volcanic minerals.

Some of the error sources that are encountered are common to all techniques. One of the most common problems is contamination of samples by older or younger materials. In the case of potassium-argon dating, for example, we are trying to date materials in East Africa that are about one to two million years old. The basement rocks of East Africa are one to two *billion* years old. A single grain of billion year old material in a low potassium sample that is only a million years old will make it appear much older than it is. We cannot allow even a single sand-sized grain of material to contaminate our samples. This is one of the largest problems in potassium-argon dating of young rocks where old rocks are also exposed.

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Radiocarbon dating has similar problems. Contamination by modern carbon is the worst, sometimes brought about by the collection containers such as paper bags which are made of modern cellulose. Less serious is contamination by "dead" carbon, such as that in plastic bags made from petroleum products. It is called "dead" carbon because it is so old that all the radiocarbon has decayed away long ago.

Another problem, peculiar to the radiocarbon method, is that the amount of carbon available has changed with time. We have learned that even over short times the radiocarbon can become diluted. As we burn up stacks and stacks of dead carbon from the petroleum we pump out of the ground, we dilute the amount of carbon 14 in the atmosphere, so that its activity is now less than it is in tree material that is 100 years old. That is, it was less until atomic bombs were tested in the atmosphere; now it is higher again.

The problems that arise in potassium-argon dating are several. Aside from contamination, which is extremely important, it is possible in some materials for argon to leak out, even at low temperatures. By low temperatures, we mean those commonly encountered on the surface of the earth, about 0 degrees to about 20 degrees centigrade. Age in the potassium-argon dating method is proportional to the ratio of argon over potassium. If some argon leaks away, it makes the number in the numerator smaller, and it means that the age that one computes is too young. There are other ways in which argon leaks out, for example by secondary heating from later volcanic events.

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If some argon is present that shouldn't be when the material forms, the ratio is also changed. We call that sort of argon "extraneous" argon. It is not a very common phenomenon, but it is an important one for understanding what is going on. The source of this extraneous argon is the depths of the earth. Volcanic rocks come from extremely deep within the earth (as much as 120 km below the surface). Potassium exists down there, and that potassium, like potassium everywhere, is decaying to argon all the time. If any of this argon is captured in a rock as it cools, it leads to ages which are too old.

A third problem shows up mainly in dating volcanic glasses. These materials tend to lose or gain potassium rather easily, upsetting the ratio of argon to potassium and therefore the age, making it either too old or too young.

In fission track dating, the biggest problem is track fading. The best way to get around it is to avoid materials that we know are susceptible to track fading at low temperatures. If track fading has occurred, the ages are younger than they should be.

In all of these methods there are two ways of speaking about errors. First, there is a parameter that we call precision. If we have an extremely precise determination of the age of some material we can, for example, state that it is one million years old, plus or minus one percent. That would be an extremely precise age. The second thing that we talk about is accuracy — more difficult to assess. Accuracy means the nearness to the true result. It involves the philosophical idea that there is a real number that should be gotten out of the sample. One may have a very precise age, and it may be dead wrong; it is a very inaccurate one.

I have spoken of only three of the dozens of methods of dating which are currently available. Another kind of dating method, often termed "secondary," is often important at sites where the materials cannot be dated by primary means. The traditional way of correlating between sites is by looking at the associated animal fossils. If we can calibrate these animal fossils at one locality, we can look at those at a different place and find out how old the deposits at that second place are.

Paleomagnetic polarity changes can also be calibrated. These are changes in the magnetic polarity of the earth itself. At various times in the past — the first change being about 700,000 years ago — if you had a compass in your hand and you stood in one place for 5000 years, you could watch the north arrow of the compass turn around and point south instead of north. That would be called a time of reversed polarity. There is now a very fine structure worked out for the paleomagnetic polarity record and dates have been assigned to all the transitions. So if you start from a single potassium-argon age or fission track age, and have a paleomagnetic polarity stratigraphy, you can make further guesses about where you are in time. Archeomagnetic variations occur over a much smaller time span; they are mainly useful to the later periods of archeology where we can calibrate a curve of the direction to the north pole in a particular region as a function of time.

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Relating some datable material to a hominid fossil brings up the problem of stratigraphy. There is a very ancient law, laid down by Steno in the late 1600s, that says that rocks that lie on top of others must be younger than those on which they lie. However, it is difficult to apply the law of superposition in some cases. In any case not all fossils are found in strata which can be easily related. Because of the scarcity of hominid fossils, paleoanthropologists try to take collections from everywhere and put them all together. They would like to know what order to put them in and this must be done by correlating from one locality to another. The correlation can be done using fauna or paleomagnetic polarity. It can be done directly by dating materials, or it can be done by correlation of volcanic ashes. If we want to correlate between localities as widely separated as Olduvai Gorge and Hadar, or between Lake Turkana and Hadar, we have to find something in common between them. At some geographic separation every one of the correlation methods fails except primary radiometric dating and the paleomagnetic reversal records.

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I want to make one final comment. Very often in anthropology something like this happens. There is a tuff dated at, say, 2.0 ± 0.0 M.Y. Below it in the section is a tuff dated at 2.4 ± 0.1 M.Y. We find a hominid fossil between these two tuffs. How old is the hominid? In general, people would say this hominid is 2.2 million years old. But that attaches an element of certainty to the determination which is really not there. It would be better to say that it falls between 2 and 2.4 million years; or, if you take the analytical errors into account, between 1.9 and 2.5 million years. We really have no other information about it.

This article is adapted from Dr. Brown's presentation at the Leakey Foundation symposium in Salt Lake City earlier this year. □

OPPORTUNITY

We have been funded by the National Science Foundation to conduct research on the phenomenon of quartz hydration which may lead to a dating technique useful for paleolithic quartz artifacts. We are now seeking dated quartz artifacts from the Old World in the range from 8,000 - 20,000 years. Please contact Professor J.E. Ericson, Division of Geochemistry, MS 170-25 Caltech, Pasadena, CA 91125. □