GEOLOGIST GIVES DATA ON OLD SITES
Byron Sharp Donates Maps, Artifacts for CSFA Study

Byron Sharp, recipient of the 1993 H. Marie Worrington Award, donated to the Center for the Study of the First Americans a pristine collection of stone artifacts gathered in six Western states during the course of 30 years of fieldwork as an exploration geologist. In addition to the tools, Dr. Sharp has given the Center maps, written descriptions and photographs indicating locations of more than a dozen sites. He spent years mapping the locations of his discoveries. He is a deserving recipient of the Worrington Award, given each year to individuals who have made an exceptional contribution to the field of First Americans Studies.

Ron Bonnichsen, Director of the Center for the Study of the First Americans, said Sharp has provided "a written and photographic record, so we will be able to go back and research the sites, which have the potential to be the focus for many master's theses. Byron has documented, on USGS maps, sites where he had located Paleoamerican materials, so he has provided precise locational information. This is so important for the professional community."

Dr. Bonnichsen said the artifacts donated to the Center range from typical Western stemmed points to flake and cobble implements with desert varnish on their surfaces.

Although the CSFA does not condone the private collection of artifacts, Bonnichsen stressed that the legalities of collecting have changed over time, and that Sharp had done the responsible thing. "He documented the collection and donated them to an institution for study. The collection won't be sold or broken up. He planned for the welfare of the materials so they can be used to further our understanding of Paleoamericans."

Sharp was born in Salt Lake City in 1921 and attended the University of Utah before entering the Glider Pilot Program in 1942. On June 6, 1944, he was a glider pilot in the Normandy invasion. He returned to Utah and earned his bachelor's degree in geology and a master's in geology and mineralogy. He spent four years mapping with the U.S. Geological Survey before returning to University of Utah to earn his doctorate in Geology in 1955. From 1954 until he retired in 1976, he worked as a geologist for... continued on page 2

Simply a Matter of Time

If an archaeologist's primary challenge is to discover clues about ancient peoples, his or her second greatest challenge surely is to determine the age of the discoveries. The unearthing of a stone artifact, a scrap of bone from a prey animal, or a piece of fire-cracked rock inevitably poses the question: "How old is it?"

Because every question regarding the initial peopling of the Americas ultimately concerns the question of time, the Mammoth Trumpet devotes much of this issue to various methods of estimating the age of archaeological materials. In this issue, we briefly examine carbon-14, uranium-thorium, thermoluminescence, optically stimulated luminescence, electron spin resonance, and paleomagnetism. Our December and March issues featured articles touching on carbon-14 dating and dating by stratigraphy, respectively, and our focus will continue in September with a feature on tephrochronology and other dating methods.

To make our articles as accessible as possible to readers who lack technical background, we've opted for newspaper style for chemical terms, for example, using "carbon-14" rather than ""14C" as professionals prefer. But we've listed a number of technical readings for additional details. The day may come when an archaeologist can learn the antiquity of any feature independent of all other factors. But if that time has already arrived, few are yet willing to acknowledge it.

MASS SPECTROMETRY ENHANCES URANIUM-THORIUM COUNTING

Team Makes New Analysis of Zhoubouidian

Scientists are counting atoms, like tallying grains of sand on a beach, as their newest tool to determine the age of one of the most important Paleolithic sites in the world—the Homo erectus site at Zhoubouidian (Zhoubouidian) southwest of Beijing, China. Some scientists believe the Homo erectus series dating process, using a new technique involving mass spectrometry, could revolutionize the dating science of archaeology by giving archaeologists more precise and reliable dates from smaller amounts of material than previously required.

According to Chih-An Huh, the new technique of mass spectrometry pushes the uranium-series dating limit to more than 200,000 years before present, whereas the previous maximum, obtainable through the measurement of radioactive decay by alpha spectrometry, was 350,000 years. Dr. Huh, principal investigator for the Zhoubouidian project, is Associate Professor in the College of Oceanic and Atmospheric Sciences at Oregon State University. His pilot study costing $11,293 is backed by a $5,796 grant from the L. S. B. Leakey Foundation. Guangjun Shen, from Guizhou University in China, and T. L. Ku, at the University of Southern California, are co-investigators in the project.

Archaeologists frequently bemoan the difficulties of getting credible dates on excavated materials. Establishing the absolute age of archaeological materials remains a complicated and hotly debated process, often producing more dissonance than agreement. Lack of confidence in the scientific techniques used to determine antiquity of archaeological discoveries has had a profound effect on thinking about when people first entered North and South America. Conventional radiocarbon methodology for finding the age of once-living materials has a useful time span of 40,000-60,000 years; enhancing the process by using accelerated mass spectrometry—counting the atoms of minute amounts of carbon-14 in materials such as charcoal—pushes that time span further. But a calibrated time scale is critical to the process, a tricky issue at best.

Uranium-series dating using alpha spectrometry (see box on page 8) has been used to determine ages of materials between 50,000 and 350,000 years old. An essential point of the process is that parent uranium isotopes are soluble in water, while daughter elements are not. The result is that only uranium isotopes are in ground water that seeps into limestone caves such as those at Zhoubouidian. But as water creates travertine deposits on cave walls and floors, the uranium decays to create daughter elements that are trapped and the radioactive time clock begins ticking.

The process is highly significant for the study of early humans because some frequently caved. Suppose, for example, that archaeologists find deposits of travertine above and below, or surrounding human remains or artifacts. The travertine layer below the archaeological deposits should be older than the human material, and the layer above should be younger. Thus uranium-series analysis would bracket the human material with maximum and minimum dates. This process is important for study of Zhoubouidian, where caves discovered in 1921 have yielded considerable information on the study of human evolution, being most closely associated with a population that came to be known as "Peking man."

Typical representatives Homo erectus. However, research at the site has not provided generally accepted absolute dates—only relative ages based... continued on page 8

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the U.S. Atomic Energy Commission. He still lives in Salt Lake City.

MT How did you become interested in archaeology?
BS This was very simple. I went to work for the Atomic Energy Commission as an exploration geologist. Most of the uranium deposits are in Tertiary formations. As I looked at the Tertiary formations, I was seeing flakes and tools constantly. I talked with Dee Simpson down at Calico [Calico Early Man Site near Barstow, in California's Mojave Desert]. She told me what I had. She was very interested. I started picking them up and looking at them, because I was seeing them everywhere. That's what got me going. After I retired, I thought I'd map the places I had noted. I figured out a way to estimate the number per 1,000 square feet. I had a couple of geologist friends, W.A. Roberts and W.O. Warner, who wanted to come along and help—truly a fan project.

I kind of came in the back door. Being a geologist, I knew what was not nature. As soon as I saw these flakes, I knew they couldn't come from nature. I'm not like the archaeologist, who comes in and says: "That's the way man made the them." I came the other way and said: "Well, nature can't do this." I contacted a few people, like Marie Worthington, and we sent some samples. This was in the 1970s, and I was really getting into it.

MT Are you still mapping?
BS Yes. There are a couple areas I want to expand on—Mountain City and Charleston Reservoir—and some new areas I want to look at—one at Brady Hot Springs, Nev., and one near Lusk, Wyo. My two bobbies and I are still on the job.

MT Have you published any of your discoveries?
BS Yes. [See Suggested Readings.]

MT When did you start collecting?
BS In 1963. I was in Wyoming mapping Shirley Basin for uranium favorability. I had my son with me and I said, "Go out and look for artifacts." So he was out picking up these things and bringing them back to me, and I was saying, boy, these sure don't look Indian to me! So I started looking into it, and looking for artifacts myself. I found out there was this controversy about the old stuff. So, I really started in 1963, but after I retired in 1976 I started mapping seriously.

MT How many tools have you gathered?
BS Well, the best ones I gave to Bob and the CSFA. I imagine I sent about 450 of the best ones, and I thought would be accepted by the archaeological community. I probably have about 100 or so of the more atypical tools here at home. They can be used for future studies by students if they want them.

Some of the tools I sent to the Center were from a Paleo-Indian site south of Fallon, Nev. Only the Lake Mojave people were there—no one else. And some of the tools were from the Haworth area; those were Paleoindian and early Indian. So, I didn't just send all older things.

MT How did you become aware of the Center for the Study of the First Americans, and what prompted you to donate the geologist who worked with, Wayne Roberts, went to Maine when the Center was there and gave Bob some of the publications that we were working on. When he gave me a call, he was going to be at the Salt Lake airport for a bit, so I went and got him and showed him what he had. He was very interested in taking it to the Center for research, because that's what you guys do. So that's how that came about.

I sent my book showing the photographs of the artifacts from what I thought was oldest to youngest, and Bob wanted to study the artifacts. I hoped that the Center could run all kinds of tests on these artifacts and also the dwelling sites that might yield a more accurate age than my estimates.

MT How does it feel to be a Worthington Award recipient?
BS I feel very flattered about that. Like I say, I contacted her early in my career and even thought she was a little bit crazy, it doesn't matter. I wrote her a couple of letters, and she sent me a sample to a few people, and it was very nice. I'm very flattered to receive this award.

MT What are your plans for the future?
BS I plan to do a lot of skiing! After I turned 70, they let me ski for nothing at the area resorts. So I have been skiing two or three times a week, and that's been three seasons now. Another thing I'm going to do is work on expanding my mapping projects, and start some new projects. If I get something interesting, I'll contact Bob. I will be available for any students who want to see these sites—and for consulting purposes.

-Rebecca Foster

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Long Cited for Dedication to Prehistory

Everett J. Long, entrepreneur, rachnacite and toolmaker, was recently recognized by the Center for the Study of the First Americans for his achievements in furthering the study of early American prehistory. Long was announced as the 1994 winner of the H. Marie Worthington Award at the CSFA's spring Advisory Board meeting in Corvallis, Ore. Long, founder and president of Everett/Charles, Inc., which designs and builds specialized robotic equipment and test equipment, has been a staunch supporter of the Center since it was established. A resident of Fontana, Calif., Long served as chairman of the Advisory Board at a critical time in the development of the Center, and he was one of those responsible for finding the Center a home at Oregon State University. His dedication to anthropology and archaeology are evident in his enthusiasm for the Center's future. He recently agreed to rejoin the Center's Advisory Board.

Robson Bonnichsen, CSFA director, and Anne Stanaway, chair of the Advisory Board, both praised Long for his dedication to First Americans Studies, and they expressed delight that he has returned to active duty with the Center. In announcing the award to Long, Bonnichsen reminded Advisory Board members that Dr. Worthington did not hesitate to work with non-academic people in her quest for answers about early Ameri- can prehistory. Long's avocational interest in anthropology, archaeology and world history has supplemented a meritorious mechanical and technical career, which involved him with the intricacies of making and matching parts for atomic bombs of the World War II era, and continued with key roles in designing and building highly technical equipment. His employers have included Los Alamos Scientific Laboratories, Bendix Aviation Co., and Consolidated Electrodynamics Corp.

Long says he became involved with the CSFA because of its commitment to science. "I wanted to be part of this kind of intellectual atmosphere," he told Bonnichsen and Center board members. As the Advisory Board met in April to formulate policies for current and future CSFA projects, Long voiced insistence on planning "for greatness." The most recent previous recipient of the Worthington Award was Byron Sharp, the retired geologist who presented a priceless collection of data on Paleoindian sites in the Great Basin to the Center (see related article). The award was initiated by the CSFA to recognize the achievements of Dr. Worthington, director emeritus of the Denver Natural History Museum, and a leader in the study of America's earliest prehistory.

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Measuring Energy Stored in Trapped Electrons

Three Related Techniques Calculate Elapsed Time

By Stefan C. Radosevich

A 10 percent error margin was possible (at the one-standard-deviation confidence level). Thermoluminescence trapped electron dating is now being used to date pottery and burnt fill. It is now being used to date all US sites. However, because exposure to sunlight prevents the same zeroing event to light-sensitive traps as heating doses to pottery. (Not all traps are light-sensitive; daytime empties light-sensitive traps, heating releases all trapped electrons.) One must prove, of course, that the layer in question had not been subsequently reheated or re-exposed to optical energies. After sediments are buried, ionizing radiations fill the empty traps.

Age Determination

To estimate the age of a sample in the laboratory the electron traps are re-emitted by either heating (thermoluminescence) or stimulation by light (optically stimulated luminescence). This provides the luminescence signal of our sample; but to obtain a date, we must determine two additional variables: the ratio of the natural luminescence signal to the luminescence signal produced in the sample by a known laboratory radiation dose, and the rate or speed at which the natural dose was deposited. The former is determined by comparison with what was released during initial heating; when the latter is the same, equal reconstructions of the dwell time the sample received during burial. In the laboratory, concentrations in the samples of the radioactive elements uranium and thorium may be found by such analytical techniques as neutron-activation analysis, a costly and time-consuming method. The third important radioactive element, potassium, can be determined quickly by commercial geochemical laboratories. Alternatively, direct measurement of dose rate can be done at the archaeological site. Two basic approaches are to bury sensitive radiation do- simeters in the deposits for a year or so, or to employ a portable gamma spectrometer, which provides immediate results. The small cosmic-ray contribution is estimated based on a model of overlying sediments, elevation, and latitude.

The age (A) can then be determined by dividing

Luther S. Cressman Dies; NW Prehistory Pioneer

Anthropologist Luther S. Cressman, whose archaeological discoveries revolutionized theories about the peopling of the Pacific Northwest, died April 4 at his home in Eugene, Ore. He was 96. Dr. Cressman was one of the first recipients of the H. Marie Wormington award, a recognition of his research on the prehistoric origins of the first Americans. He was known for his work on the early peopling of the northern Great Basin.

Cressman's research was recognized by the 1986 discovery of sandals, carefully woven of sedge and grasses, in a cave in the base of Fort Rock, a remnant cinder cone eroded by a Pleistocene lake in southeastern Oregon. This discovery was the first of its kind in the Pacific Northwest. Cressman was a member of the Oregon Anthropology department in 1933 and contributed to its early archaeological surveys in 1940. He organized the Oregon State Museum of Natural History and was founding director of the Oregon State Museum of Anthropology.
difficulty [when] applied to sediments older than 50,000–60,000 years. However, Huntley and others have reported in the journal Geology (see Suggested Readings) that they have recently obtained ages up to 900,000 years using feldspar micro-inclusions within quartz grains from known-age dune sands in Australia.

An additional problem for both thermoluminescence and optically stimulated luminescence, and related to dating saturated and underground deposits, is that intergranular water absorbs ionizing radiation. An assumption must be made of an equilibrium in the dose rate of uranium and thorium over time. If the water table has varied over time, this background figure for the average dose rate will vary as well. Determining the present dose rate, even averaged over a year, does not necessarily reflect the dose rate over the last 100,000 years if there is any possibility the water table or average rainfall has changed substantially.

Optically stimulated luminescence has some advantages over thermoluminescence; it is a technique requiring light-stimulation, not heat, and it is non-destructive. OSL dating is much more rapid because the signals are bleached out of the traps very quickly and completely. This enhanced sensitivity makes possible the dating of very young sediments (down to only a few hundred years), as well as deposits that were exposed for only a short time. According to Rose, optically stimulated luminescence should be viewed presently as a complemenary technique to thermoluminescence, not a replacement for it.

Electron spin resonance has emerged as a new trapped-electron dating technique of great potential for dating tooth enamel, a ubiquitous occurrence at most archaeological sites. Tooth enamel is largely a crystalline mineral (hydroxyapatite) and its four significant requirements for electron spin resonance:

1. the material to be dated is free of all iron and other elements that affect the electron spin resonance signal of other materials;
2. the lifetime of trapped electron is great—more than 100 million years;
3. the material is found at most archaeological sites, and;
4. the material was formed close to the time of site occupation (or has been zeroed).

Electron spin resonance differs from thermoluminescence and optically stimulated luminescence in that it quantifies the number of trapped electrons by marking the intensity characteristic of a point in an energy spectrum. It is the same as the other two methods in that the objective is to determine a ratio of the number of trapped charges to their rate of trapping during burial in the ground.

Two problems present themselves with electron spin resonance in the form of additional constraints placed on the basic equation. The dose rate changes owing to uptake of uranium by the tooth since it was buried; second, uranium-series lighter isotopes increase the actual radioactivity through time. The uptake of uranium in the samples at each site through the specified time must be accounted for and included in the final calculation. General samples from the same tooth are used to average these effects.

Significance

Perhaps the most significant advances in dating human evolution, particularly mid- to late-Placocene sites in Europe (Mapuera, in Spain, for example) and the Near East, Nahal, in Israel, for example), have been furnished by thermoluminescence, optically stimulated luminescence, and electron spin resonance because their ranges lie beyond the range of carbon-14 (which is about 40,000–50,000 years except for accelerator mass spectrometry, but inside the low range of potassium-argon (or argon-40/argon-39), which is less than 100,000 years. Unlike these established dating techniques, the trapped-charged or trapped-electron dating techniques do not record the presence of volcanoes as the potassium-argon methods do, nor uncontaminated organic material. Especially useful is the capability of dating stalagmites in conjunction with uranium-series dating ("Mass Spectrometry" article in this issue). Many of the later hominid sites that remain undated are from the period of 40,000–300,000 years or are not near volcanoes. The fact that these techniques can give us the age of the objects themselves, instead of merely dating strata above and below it, as with the potassium-argon technique, is a great advantage. The variety of sedimentary source and biological remains that can be investigated also contributes to the usefulness of trapped-electron dating techniques. With the previously mentioned caveats kept in mind, the method seems to produce fairly reliable (repeatable) dates from samples younger than 50 years—those particularly applicable to the study of early humans in the Americas.

One weakness (presumably correctable) is the moderate-to-large imprecise volume estimates for the values dated from all the trapped electron dating processes. While the reliability of these newer techniques seems established, the precision (plus or minus error) remains in the range of 5–20 percent. By comparison, the more refined techniques of carbon-14 and potassium-argon can approach the 1 percent error level (at one-standard-deviation confidence level). As Chen Tienei, Yanq Quan, and Wu En recently described in the journal Nature, published dates in excess of 100,000 years are often in conflict with uranium-series dates and do not conform to the upper limit dates from carbon-14, though it is likely that carbon dates are at fault in the latter instance.

Sampling

I am unaware of any laboratory doing thermoluminescence, optically stimulated luminescence or electron spin resonance on a commercial basis, though at the Desert Research Institute in Las Vegas, Dr. Rodgers does perform contract work. Academic contractors can probably be found for these techniques at other universities, or for people who do thermoluminescence, optically stimulated luminescence, or electron spin resonance analysis may be found (mainly in England). They include Doreen Stoneham at the University of Oxford, England, who is known for her OSL dating on flint and pottery. I have no information on the costs of such studies, but a long time is required to determine the date of a site, especially if a year is required to get back a background radiation reading from a dosimeter planted at the site.

Because very special sampling procedures are required for these techniques, a field archaeologist should contact an expert before attempting any sampling. Aitken's 1985 book (see Suggested Readings) provides a good summary of methods for sampling, but the special care and diligence is something that is necessary for any project. A field archaeologist should consult with an expert for any site, and is advised to work with a specialist for all forms of trapped electron dating.

Dr. Rodosavich is a hominid paleontologist and geoarchaeologist with the University of Oregon's Department of Anthropology. He is highly regarded as an expert in geochronology, and will be describing the techniques in the September Mammoth Trumpet. He notes that writing this article gave him the opportunity to catch up on new developments in fields about which he is not proficient.
Magnetism Can Chronicle Time

Earth's magnetic field can be helpful in determining the age of archaeological materials. Geomagnetism, the force that enables us to find our way with a compass, leaves a permanent mark on different kinds of rocks, and because Earth's magnetic orientation changes, the fixed record of natural magnetism can accurately chronicle the passage of time. Paleomagnetism is the study of past magnetic fields through examination of the direction and intensity of that residual, natural magnetization fixed in rock.

Earth's magnetic poles reverse themselves episodically. Rocks containing magnetic markers oriented toward the north pole are said to have "normal" polarity, while those oriented toward the south pole are of "reversed" polarity. Although the most recent major reversal occurred about 780,000 years ago, paleomagnetic dating is not exclusively for materials from very ancient sites. A lesser-known application of the technique utilizes two phenomena, the gradual wandering of the magnetic poles and the property of heated rocks or clay to acquire new magnetic orientation as they cool.

Paul R. Renne, director of the geochronology center at the Institute of Human Origins in Berkeley, Calif., operates the Institute's new paleomagnetism laboratory. He and colleagues have been instrumental in establishing the antiquity of widely reported human fossils and very primitive stone tools in the Hadar region of Ethiopia. In a recent telephone interview, Dr. Renne, who has been with the Institute, founded by Donald Johanson, since 1990, observed that episodic reversals of Earth's magnetic poles are not useful to historical investigations because the most recent major reversal was 780,000 years ago. Past orientations of the magnetic field, however, can be used for sites in the range of 2,000 to 10,000 years.

Because the geomagnetic field is continually changing in orientation and intensity, the difference, known as secular variation, can leave its mark on materials that have registered the magnetic orientation at a particular time. Heartsh, potholes or kilns, Renne explains, may represent materials such as soil, clay or rocks that have been heated sufficiently to have acquired a new, permanent record of magnetization. The materials' internal compasses will have been locked onto the location of the magnetic pole at the time of heating. By carefully analyzing that direction and comparing it with a standard curve of magnetic variations, investigators can determine when the heating occurred. "When you hear the term "archaeomagnetism," Renne said, "what people usually are talking about is a comparison of directions with a geomagnetic reference."

"Secular variation has been applied to phenomena as young as several thousand years." As an example, he cited research on cave sediments associated with Middle Stone Age artifacts in Albania, and studies of lava flows in Hawaii between 2,000 and 10,000 years old. "Of course there are no artifacts associated with those, but they can help serve as a reference data base that people can use for comparison elsewhere." To determine the age by the secular variation of Earth's magnetic pole, researchers have to make sure the materials they examine have not been disturbed. Renne said that a number of tests can be performed to ascertain the internal consistency of a site. "If you want to work with a hearth, you would want to analyze pieces of physically different material and see if you got the same answer." Lack of consistency probably indicates that components have been moved by humans or animals, but undisturbed rocks associated with a hearth might well contain the locked-in memory of an ancient magnetic orientation that will reveal the time of the last hot fire. (Renne says temperatures need to be more than 200°C to reset a material's internal compass.)

Studies of early humans and their hominid and primate ancestors and relatives involve time depth that makes geologic time spans useful in determining ages. While there is no regular pattern to the major reversals in Earth's polarity, worldwide reversals are useful to scientists.

These techniques have age ranges extending beyond those of radiocarbon dating.

Though Not Fully Understood, Reversals Are Useful to Science

A time scale based on reversals of Earth's magnetic polarity was first published in 1968, and the scale has been frequently recalibrated as new data become available. Paleomagnetism has produced a time scale that spans the entire Cenozoic Era to 65 million years ago, and research continues to extend it beyond, far into the Mesozoic. Though it is one of the youngest disciplines in the geosciences, its applications are better understood than the underlying reasons for episodic reversals of Earth's magnetic polarity.

Electrical currents in our planet's iron-rich liquid core are in constant motion, and those movements are responsible for the magnetic field. "All the variations that we see in the magnetic field can be traced to features of that convecting liquid," geochronologist Paul R. Renne explains. He suggests that the likely explanations for reversals in polarity may be found within these convolutions of the liquid outer core.

"Reversals or secondary variations are caused by variations in the pattern of convection," Dr. Renne emphasizes. "Polarity is not periodic; "You can't predict when a field would be reversed or normal."

As paleomagnetism has been subject to more research, it has become clear that there have been many reversals in polarity in the last several million years, not merely long-standing ones that have come to be known as polarity epochs. The most recent four earthquakes and calibration are establishing an ever more accurate time scale. However, Renne notes that paleomagnetism analysis will always need to be used along with other methods to determine antiquity. "It's never going to be calibrated to the point that you can just measure the magnetic polarity and say how old it is," he said.

"You have to have some dataset point that lets you tie into the time scale. If you do that you're in business." As an example, Renne cited some of his field work in Ethiopia, where he has been working with Rutgers University archaeologists Selash Semaw and Jack Harris in the investigation of some very primitive stone tools in the upper part of what is known as the Hadar Formation. "There's been quite a lot of uncertainty about the age of those sediments." But by analyzing the stratigraphy above and below the artifacts and obtaining dates from volcanic layers through the argon-40/argon-39 method, he was able to determine the site's position in the geomagnetic reversal time scale. Having established that datum, geomagnetic reversals above and below provide absolute time horizons from the known scale of reversals.

Doesn't a hiatus in the geological record spoil the magnetic dating system? Not necessarily, but you can't be sure if you don't take into account a few things.

Major polarity "epochs" are called chronos. The four most recent have been named for prominent scientists in geomagnetism. Within each of these four chronos are shorter periods of polarity reversals called "subchrons." Epochs, or "chrons," have been named for geomagnetism researchers—Bruhns, Matuyama, Gauss, and Gilbert. During each chron, there have been "subchrons," when polarity reversed.

What determines the duration between reversals? And what causes switches in the polarity of what is, in effect, a bar magnet at the center of our planet? While the physical details are not well understood, it seems apparent that the dynamo mechanism in the convecting liquid of Earth's outer core varies with time and occasionally the electrical currents halt. When the currents resume, there's an even chance that the direction will change, thus redirecting the magnetic field. Scientists have not found a regular pattern associated with the changes, but there has been considerable speculation about it.

Renne suggests that a periodic pattern may yet be discovered. He notes that as more data are obtained there are indications that brief "blips" observed in the magnetic record indicate short-term reversals in polarity or "excursions" in its direction. Such data necessarily come from studying rapid geologic deposits such as sequences of lava flows or lake-bed sediments that provide high-fidelity definition of the magnetic record at times of change. Renne cites a hypothesis put forth about 10 years ago linking polarity reversals with Milankovitch climatic cycles. "It was hypothesized that during periods of cooler climate, a significant... continued on next page..."
have to know it is there and account for it. Renne explains that if there is no stratum that reveals a particular reversal of stratigraphy, the researcher loses some resolution in the time scale. If two reversals were missing from the record, however, a researcher might be led astray. Renne emphasizes the desirability of having as many inter-comparisons as possible with other dating systems.

"You need to have a pattern and be able to compare that with the global time scale. Because it is a binary system—it's either black or white, up or down—it is always going to be comparatively different than methods like argon/argon or carbon-14." That difference doesn't mean that paleomagnetism is not a precise method of determining the age of archaeological or paleontological sites. "It is not comparable to carbon-14 in terms of precision and probably never will be," says Renne. But when calibrated on an astronomical time scale, the geomagnetic time scale has a theoretical resolution of from 1,000,000 to 2,000,000 years. Provided that it is tested and calibrated by other methods, Renne says, "paleomagnetic scale is probably going to be the most accurate time scale up to 5 to 4 million years ago. But its usefulness depends on finding magnetic reversals.

"You can't necessarily date any arbitrary horizon you find. You can only date the places where the reversals occur."

Renne explained some of his field techniques involved in gathering data for testing paleomagnetism. The most basic necessity is to preserve the geographical orientation of the sample so its magnetic alignment can be referred back to the coordinates of the site. Compass measurements must be marked on the sample. Hard rock, either sediments or lava, is the easiest to deal with, and most field workers gather samples with a gasoline-powered drill that takes cylindrical cores from the rock.

"That's the ideal situation," Renne explained. "You get nice, coherent material. But when you're working with sediments, which is usually what you're working with in the archaeological context, you have material that may be very poorly consolidated, so it is a lot more difficult."

Renne has devised a method of creating cores of sorts from unconsolidated material that can be removed without disruption. He carves a block of the material that is to be tested into a little pedestal and then pours a special ceramic compound similar to plaster of paris around it. Once the compound has solidified, he can remove the sample without having it disrupted. The technique can be used in sand, "It's tricky, but with a little thought, generally it can be done."

Samples must be protected from high-intensity electromagnetic fields. Renne keeps samples away from propeller-driven airplane engines and automatic motors. When possible, he hand-carries samples through airport security. "Sometimes that's a chore, because they can weigh quite a bit." Hot weather isn't a problem, but samples should be subjected to a drying oven, for example, with temperatures in excess of 100° C.

Renne's lab at IHO recently installed an instrument known as an automated cryogenic magnetometer for analyzing magnetic samples. The instrument employs liquid helium to maintain superconductivity—the disappearance of electrical resistance. Employing liquid helium to maintain superconducting temperatures, the new instrument measures the orientation and strength of magnetic samples. It was installed in a specially shielded room. Renne's colleague Carl Swisher has been active in helping set up the lab; Dr. Swisher will be a major user of the facility. "We welcome collaborative research in which somebody needs the kind of data we produce. Generally we ask that collaborators cover the costs."

As of mid-April, he still wasn't sure what the center's costs would be. "I'll be working this out in the next few months. The main cost will be technicians' time to make the measurements." Renne says that use of work-study students will keep the costs low—perhaps $500 for an "average" project.

Renne was introduced to paleomagnetism by working on the tectonic question of whether part of the Klamath Mountains was terrain accreted to the North American continent. That research also included potassium/argon dating. After getting a Ph.D. in 1987 from the University of California at Berkeley, he did post-doctoral work at Princeton employing both paleomagnetism and argon/argon dating on other tectonic applications. But he became particularly interested in magnetostriatigraphy. He has been director of geochronology at IHO since 1991.

In the Institute of Human Origins' geochronology laboratory, Paul Renne, center, IHO director of geochronology, confers with Bill Gorce, left, and Bill Goodman as they prepare to install new equipment. Gorce and Goodman are of 2-G Enterprises, builder of the lab hardware.

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Radiocarbon Remains the Standard for Determining Archaeological Age

Radiocarbon Dating is a dating technique that has been highly accurate and reliable. Its accuracy and reliability are due to the relationship between atmospheric carbon-14 and the carbon-12 found in all living organisms. Chronometric measurements using carbon-14 are independent of all archaeological data. Dates can be obtained on a wide range of materials including bone, tooth, shell, bone, discolored carbon, and carbonates on a worldwide basis.

The first carbon-14 dates were announced in 1949 by Willard F. Libby at the University of Chicago. The discovery earned him the Nobel Prize in Chemistry. Since then, radiocarbon laboratories have grown in number, size, and sophistication. Radiocarbon testing is so far the most popular method used by researchers to determine the antiquity of relevant materials. One commercial laboratory alone, Beta Analytic in Miami, Fla., performs 15,000 carbon-14 tests a year. The turnaround times for tests are now weeks instead of years, as they once were. Beta Analytic’s principal users are geologists (80 percent of the tests), archaeologists (15 percent) and oceanographers and geophysicists (5 percent). Basic tests cost about $225 each.

If you analyze a sample of charcoal from your fireplace, you will find that it consists of three isotopes: carbon-12 will constitute 98.9 percent of the sample, carbon-13 1.1 percent, and carbon-14 only 0.00001 percent. While the carbon-12 and -13 isotopes are stable, carbon-14 decays into nonradioactive nitrogen-14. Radiocarbon has a half-life now calculated at 5,730 years (originally its half-life was measured at 5,568 years). In time, carbon-14 will disappear through decay unless it has a source of replenishment.

And it does—the source is literally cosmic. Earth’s atmosphere is continually bombarded by cosmic rays, generated outside the solar system. A component of these rays is the proton, the positive charges of hydrogen nuclei. These protons interact with atmospheric nuclei, ejecting neutrons from them. As a neutron so created caroms off of neighboring atoms and molecules, it loses energy. If at this point this "thermal" neutron collides with a nitrogen-14 nucleus, a proton is expelled and a carbon-14 atom is created. This atom is rapidly oxidized to carbon dioxide. While the ocean absorbs most of the carbon dioxide, a very small amount enters the biosphere. Because of the rapid cycling of carbonates in marine waters and in the metabolism of living organisms, carbon-14 levels maintain an approximate steady state in the biosphere.

As long as an organism is alive, it continues to acquire carbon-14 to replace the carbon-14 that decays. At its death, carbon-14 intake stops and the amount of carbon-14 in the remains of the organism begins to decrease. After death the carbon-14 activity measured in a sample is thus a measure of its age. A model has been developed that this directly correlates carbon-14 activity and half life to carbon-14 age. "Radiocarbon dating is interesting," observes R. Ervin Taylor, director of the Radiocarbon Laboratory at the University of California, Riverside, a researcher widely respected for his experience with carbon dating. "One shouldn’t doubt what the radiocarbon dates do. Nature isn’t usually this good to us. It’s one of the few dating methods where the model and physical reality coincide so well," he said in a recent telephone interview.

Because a beta particle (electron) is emitted when a carbon-14 atom decays, one method of measuring the carbon-14 activity is counting beta particles emitted in a sample in a given time. The difficulties of this method—counting decay—are:

1. the weakness of the radiation being measured;
2. the minute amounts of carbon-14 to be detected;
3. no assurance of background radiation.

Even with heavy shielding, background counts can be registered from environmental radiation. To reduce the background, a sample is measured in its own sample and its counter. Then if any one of the ring counters registers within a few microseconds of the sample counter, the count can be ignored as background, and only sample counts will be recorded.

In early work, carbon-14 was measured with the sample in the form of solid carbon. This was inefficient, and in present practice the carbon of the sample is converted either to a hydrocarbon gas, such as methane, or to carbon dioxide. If carbon dioxide is used, it must be prepared with great care, as even minute traces of halogens, such as chlorine, can cause difficulty in counting. The maximum age limit of current gas methods is 40,000 to 60,000 years.

Search for more sensitive and accurate dating methods led in the late 1950s to the development of the scintillation technique. In this method, the carbon of the sample is converted to benzene and a compound is added that causes the carbon-14 disintegrations to appear as minute flashes of light in the liquid, which can be counted by sensitive photo-multiplier tubes. As in gas-counting methods, purity of the benzene on the parts-per-million level is a necessity. The maximum age limits are comparable to gas counting methods.

The gas counting and scintillation methods use an inherently inefficient method of counting carbon-14 atoms, as only atoms that disintegrate get counted. Counting all carbon-14 atoms in a sample would be vastly more efficient. Sampling can be orders of magnitude smaller, and in theory maximum age limits expanded. For the tools to accomplish this, researchers have adopted the methods of experimental atomic physics.

The first such attempt used a conventional mass spectrometer. In this instrument, the sample is ionized, then the ions are accelerated and passed through a magnetic field, which separates the ions by mass. The ions strike a detector tuned to the mass of the ion and are counted. Because of the profusion of ion types in the beam, a high background noise obscures the faint carbon-14 signal. An accelerator is used in tandem with the mass spectrometer to "tune out" the background, so that the ultra-sensitive mass spectrometer can separate the carbon-14 and carbon-12 ions, so that carbon-14 ions alone can be counted. This method, usually called AMS (accelerator mass spectrometry), may eventually extend the carbon-14 method to 100,000 years. Another advantage of the great sensitivity of accelerator mass spectrometry is that very small samples may be used when dating ancient artifacts such as a Dead Sea Scroll. A disadvantage of the technique is the high cost, necessitated by the size and complexity of the instruments, and the requisite staff to maintain and run them. Price varies according to a sample’s characteristics, and Roelf Beukens, director of Carbon-14 Analytical Services at ISOTRACE Laboratory in Toronto suggests that AMS may not be substantially more expensive than conventional decay counting.

All carbon-14 analyses share one feature: the selection and chemical treatment of the sample are crucial. Charcoal is an ideal material, as it can be chemically treated to remove any other contaminating forms of carbon. A primary dating material such as bone is more difficult. If the collagen of the bone is well preserved, routine carbon-14 dating is possible. If the bone or protein is degraded, the carbon-14 may be hard to distinguish from contaminating organic materials. Materials such as chalcedony shell, in which carbonates continue to exchange in the environment, are usually unsuitable. However, shell samples are regularly dated by most labs, which have developed methodologies for allowing for confounding variables, including the fact that marine shell has built-in age that varies from place to place.

Reliability of carbon-14 dating is a function of two variables—precision and accuracy. Precision concerns the statistical spread in the age expression caused by the nature of the decay process. All radiocarbon dates, because of the random statistical nature of carbon-14 decay, are subject to errors, and laboratories report the degree of uncertainty. For example, a sample of charcoal taken from an archaeological site might be reported to be 12,000 ± 200 years. The 200 indicates the degree of precision assigned to the age value. Various personal computer calibration programs exist to convert radiocarbon years into actual years.

How accurate are radiocarbon dates? How close is a carbon-14 date to the actual age of a sample? Libby assumed that the ratio between carbon-12 and carbon-14 in the atmosphere has remained constant over the past 2,600 years. It was soon determined that carbon-14 dates of ancient Egyptian artifacts were several hundred years earlier than dates available through re-examined historical chronology. What was the error? Studies based on time scales produced by analysis of annual tree rings found in ancient wood eventually confirmed that production of atmospheric carbon-14 has varied over time. Careful study of wood from the bristlecone pines of California and European oaks and pines produced a dendrochronology record by which carbon-14 values can be correlated. The main trend of the carbon-14 variation has been plotted by this method back to almost 10,000 years ago, at which point the carbon-14 age has varied from 100 to over 10,000 years. Recently, comparison of carbon-14 ages with uranium-thorium ages taken from corals support dendrochronological controls. Uranium-thorium values are at present being used to examine carbon-14 deviations over the last 30,000 years. These will provide a basis for the conversion of carbon-14 dates to real dates for an extended period in the Pleistocene.

What are the practical problems for the archeologist determining the age of material by the radiocarbon method? Obviously, care must be taken not to contaminate samples with any fresh carbon in handling. Material from above a stratum being sampled must not be allowed to fall onto a sample. A towel could contaminate a sample. Sample containers can present problems. They should be of inert material, such as polyethylene, and should seal tightly. Radiocarbon dates are a lot of numbers that aren’t all that good,” Dr. Beukens of the ISOTRACE Laboratory said in a telephone interview. “People wrap samples in aluminum foil, and if the sample is slightly acidic the aluminum foil will dissolve, an inch at a time, so Beukens explained. If the aluminum foil is coated with oil, this can cause problems.

Most importantly, the archeologist must understand the stratigraphy of a site in detail and this knowledge involves the recognition that materials apparently in place in a section may be intrusions. ‘A big problem is roots,’ said Jerry Stipp of Beta Analytic. ‘If they char underground, when you do a cross section they look like they are in place, but will give you a modern carbon date. You can find a modern tree at your site.’ At the time of a recent telephone interview Dr. Stipp was preparing a paper for overseas researchers who likely had been deceived by a recent root. ‘They expected a date of 2,000...
Uranium-Thorium

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on archaeological methods such as biostratigraphy and geological correlation. Beginning in 1978, a team of Chinese scientists studied the Zhokhovkian, seeking absolute dates from the site's 13 strata. Ages indicated by a variety of techniques, including uranium-series dating, ranged from 207,000 years B.P. for the youngest layers to 700,000 years B.P. for the oldest. The accuracy of these dates, according to Dr. Huh, continues to be controversial.

The problem, Dr. Shen said, was that several levels of travertine in the caves. The material provided what Shen said in a telephone interview was a rare opportunity to test uranium-thorium dating through mass spectrometry. A project to do that recently has gained archaeological attention. It has been used successfully in oceanography, environmental studies, and geology. The mass-spectrometry process relies on the same elements as does alpha spectrometry, but it differs by electronically measuring the mass of particular atoms rather than measuring their radioactive decay, which can be particularly difficult when dealing with a substance with an extremely low level of radioactivity.

Huh said in an interview that mass spectrometry has two distinct advantages over the alpha technique: a greater sensitivity allowing as little as 10 milligrams of material for accurate testing. (Ten milligrams is only about one-third the weight of a staple!) A paper stapler in a spectrometry also has an error margin that can be as low as 0.02 percent. By comparison, Huh said, alpha spectrometry requires 10 to 20 grams of material for testing, and error factors are considerably higher than those associated with mass spectrometry. The low error rates of mass spectrometry, for example, make it possible for an archaeologist to differentiate between something 350,000 years old and something 400,000 years old. Huh noted that such a distinction is impossible with alpha spectrometry.

Huh's initial studies of four samples collected by Shen from different strata at Zhokhovkian have produced ages ranging from 205,000 to 5,000 years old (2 percent uncertainty) to 450,000 years to 35,000 years old (less than 10 percent uncertainty). These dates have similarities and differences with ages established by the radiocarbon method at the 1979 Chinese studies. Huh explains that the reliability of these dates depends on the integrity of the samples and their relationship to the strata in which they were found. Both Shen and Huh agree that the problem is far from being resolved. More research, more money, and more tests, primarily on the integrity of samples, are needed, Huh says.

Shen's research is coordinated through the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing, part of the Chinese Academy of Science. "We have done a lot of work to do them. We have to test more samples," Shen said.

Huh said the team will need to selectively clean more calcium-carbonate samples to minimize contamination; take steps to assure more thorough calibration of thorium readings; and generally refine the process to achieve greater precision.

Uranium-series dating by mass spectrometry has a strong supporter in Curtis R. McKinney, a research associate with the Center for American Archaeology in Kampsville, Ill. Dr. McKinney used the

Radiocarbon Dating

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B.C. and we got 140 B.C. It's almost certain that it was a treatise that smoldered underground at the site.

Buttle most common errors in the field or lab are careless ones, such as incorrectly marking a sample bag or misreading an instrument. At all stages of history, the time that great care must be exercised to avoid these simple lapses to which the best researchers are not immune. Yet problems with radiocarbon dating are insignificant when compared with its values. As Dr. Taylor observed, "Nature isn't usually this good to us."

—Donald Unger

alpha-spectrometry process of uranium-thorium dating to produce a still-controversial, 11,600 to 800-year-age of a human skeleton found in 1953 near Midland, Texas (See Mammoth Trumpet 8:1, "Clavus Age Confirmed for Midland Woman").

"If I feel it's going to be the coming thing in our field," McKinney said of mass spectrometry. "I think it could put radiocarbon dating out of existence as a primary dating mechanism... That's because it simply involves the counting of atoms and not measuring radioactivity." In a telephone interview, he said mass spectrometry has the potential to make the calibration process more precise by a factor of 10. "You can use small amounts of material to obtain results, and you don't have to deal with all the calibration issues that you have to with carbon-14 dating."

But because scientists deal with such small amounts of material in mass spectrometry, they have to keep the material cleaner—particularly in the laboratory, McKinney noted, although field handling becomes less of a problem. "Theoretically," he said, "it would be possible to separate out the contaminants—to separate the grains of sand if you will—" to obtain a pure material for dating." One could, for example, analyze a single crystal of calcite—find a pure sample and get the best date possible. With alpha spectrometry, McKinney noted, one needs 50 grams of calcite to get enough uranium to measure radioactivity.

Although calcite-rich travertine is an ideal material for testing, fossil bones and teeth can be used. McKinney suggests that some effort be focused on dating tooth enamel with the mass-spectrometry process.

Setting up a mass-spectrometry laboratory to conduct the research is expensive—about $1 million or so compared with $20,000 or so for an alpha-spectrometry lab," said McKinney, so the process has not yet reached the commercial stage.

Meanwhile, Huh and his colleagues will continue to seek an absolute age on material from Zhokhovkian. They have applied for a National Science Foundation grant of up to $100,000 to keep their study alive. "We will wait for the money before we get more samples to test," he said.

George Wiseman

SUGGESTED READINGS

ON Geologist Gives Data


ON Mass Spectrometry Enhances


ON Trapped Electron-Dating


Michels, J. W. 1973 Dating Methods in Archaeology. Seminar Press, New York. (Out of date, but a good basic explanation of most chronometric dating methods pertinent to archaeology.)

ON Magnetism Can Chronicle Time


ON Radiocarbon Remains the Standard
