MAMMOTH TRUMPET

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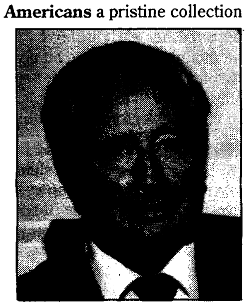
GEOLOGIST GIVES DATA ON OLD SITES

Byron Sharp Donates Maps, Artifacts for CSFA Study

Byron Sharp, recipient of the 1993 H. Marie Wormington 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 field work 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 Wormington Award, given each year to individuals who have made an exceptional contribution to the field of First American Studies.



Byron Sharp.

Robson 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 instruments 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

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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 cation-ratio 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 "^{14}C" 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.

–DAH

MASS SPECTROMETRY ENHANCES URANIUM-THORIUM COUNTING

Team Makes New Analysis of Zhoukoudian

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 Zhoukoudian (Choukoutien) southwest of Beijing, China. Some scientists believe the uranium-series dating process, using a new technique involving mass spectrometry, could revolutionize the dating science of archaeometry 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 600,000 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 Zhoukoudian project, is Associate Professor in the College of Oceanic and Atmospheric Sciences at Oregon State University. His pilot study costing $11,285 is backed by a $5,796 grant from the L. S. B. Leakey Foundation. Guanjun 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 that frequently produces more dissension 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 Zhoukoudian. 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 frequented caves. 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 Zhoukoudian, 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

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INSIDE

Geologist's Gift

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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 coming across flakes and tools constantly. I talked with Dee Simpson down at Calico [Calico Early Man Site near Barstow, in California's Mojave Desert] and told her 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, with me who wanted to come along and help—truly a fun 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 them." I came the other way and said: "Well, nature can't do this." I contacted a few people, like Marie Wormington, and sent some samples. This was in the 1970s, and I was really getting into it.

I knew these flakes couldn't come from nature.

MT Are you still mapping?
BS Yes. There are a couple areas I want to expand—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 buddies 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.

Though prospecting for uranium, Salt Lake City geologist Byron Sharp discovered many lithic artifacts, which he has donated, along with site maps, to the CSFA for study. Three from the northern Great Basin, left, are approximately 10 cm long; among obsidian pieces from another location, below, the unusual crescent creation is about 5 cm long.

PHOTOS: WORDS & PICTURES UNLIMITED

MT How many tools have you gathered?
BS Well, the best ones I gave to Rob and the CSFA. I imagine I sent about 450 of the best ones, the ones 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 Paleoindian site south of Fallon, Nev. Only the Lake Mojave people were there—no one else. And some of the tools were from the Hawthorne 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 your collection?
BS One of the geologists I worked with, Wayne Roberts, went to Maine when the **Center** was there and gave Rob some of the publications that we were working on. Then Rob 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 I 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 made that book showing the photographs of the artifacts from what I thought was oldest to youngest, and Rob 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.

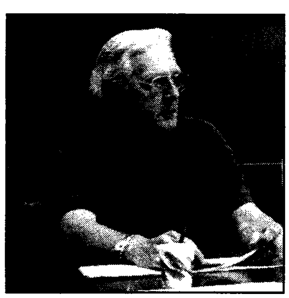
MT How does it feel to be a Wormington Award recipient?
BS I feel *very* flattered about that. Like I say, I contacted her early in my career and even though she thought I was a little bit crazy, it doesn't matter. I wrote her a couple of letters, and she sent my samples around to a few people, and it 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 Rob. I will be available for any students who want to see these sites—and for consulting purposes.

–Rebecca Foster

Long Cited for Dedication to Prehistory

Everett J. Long, entrepreneur, machinist 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 Wormington Award at the **CSFA**'s spring Advisory Board meeting in Corvallis, Ore.



Everett J. Long

Long, founder and president of Everett/Charles, Inc., which designs and builds specialized automatic assembly 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 devotion 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. Wormington did not hesitate to work with non-academic people in her quest for answers about early American 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 machining 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 Wormington 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. Wormington, director emeritus of the Denver Natural History Museum, and a leader in the study of America's earliest prehistory.

MAMMOTH TRUMPET

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Measuring Energy Stored in Trapped Electrons

Three Related Techniques Calculate Elapsed Time

By Stefan C. Radosevich

THIS SUMMARY of three forms of trapped-electron dating presents information from experts of newly and quickly evolving specialties vital to understanding the rates and modes of human evolution. The three techniques described have one common attribute: they provide a way of measuring the energy held by electrons or charges trapped in crystalline minerals. This trapped energy was accumulated over long periods of time by the decay of radioactive isotopes and by bombardment with cosmic rays. Materials that can be tested are varied and include fired pottery, tempered stone tools, loess deposits, and tooth enamel.

The three trapped electron dating techniques are thermoluminescence (TL), optically stimulated luminescence (OSL), and electron spin resonance (ESR). One great advantage of this group of dating techniques is the large variety of materials that can be dated. Because archaeological sites are notorious for their differential preservation of biological and cultural remains (caves versus open-air sites, for example) this advantage cannot be overstated. Perhaps just as important, these techniques have age ranges extending beyond that of radiocarbon dating. They also allow cross-checking of dates determined by other methods.

In all three techniques, the number of trapped charges—expressed in a measure called the "signal"—is proportional to the time that has elapsed since some "zeroing" event. A zeroing event is one in which previous electron accumulations from radioactive decay have been released. This release is analogous to the zeroing in potassium-argon dating from the heating of rocks to form magmas, an event that releases the captured argon, effectively turning the atomic clock back to zero. In trapped-electron dating, as new electron accumulations occur within the crystal lattice, the "clock begins ticking." With thermoluminescence the signal to be dated is from the release of trapped electrons by heating to 250–400 degrees C, while with optically stimulated luminescence, release of trapped charges by light is the signal that is dated. Electron spin resonance spectroscopy is also a measure of the number of trapped charges, but none is released during measurement; only their response to being "tickled" with a strong electromagnetic field is detected. A good target for ESR dating is teeth, in which a charge is accumulated as a result of radiation from the surrounding sediments.

In thermoluminescence and optically stimulated luminescence, our ticking clock is a buildup of trapped electrons from exposure to radiation from radioactive elements such as thorium, uranium, and potassium in the surrounding sediments and within the object itself. A small additional dose comes from cosmic radiation. Alpha and beta radiation from within the sample, and gamma radiation from sediments within a radius of 30 cm of the dating object, are the major contributors to the signal to be measured.

Thermoluminescence dating was conceived by Farrington Daniels (University of Wisconsin) in 1953 as a way of dating pottery. By the late 1960s a methodology had been devised by which dates with a 10 percent error margin were possible (at the one-standard-deviation confidence level). Thermoluminescence dating has been used to date pottery and burnt flint. It is now being used to date eolian deposits (loess) because exposure to sunlight performs the same zeroing event to light-sensitive traps as heating does to pottery. (Not all traps are light-sensitive; daylight 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-emptied 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 radiation dose grows in the ground around the sample. The signal from each sample must be compared with a radiation dose of known amount. The artificial signal will then be compared with what was released during initial heating; when the two quantities are equal we have recreated the dose the sample must have received in antiquity—the "paleodose." Then it will remain to find the dose rate that 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 cheaply 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 dosimeters 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 thickness of overlying sediments, elevation, and latitude.

The age (A) can then be determined by dividing the paleodose (P), by the dose rate (Dr). As Aitken, Stringer and Mellars explain in their book (**Suggested Readings**), "The age so obtained is directly in calendar years and it is independent of any other chronological technique."

There are, however, significant problems with thermoluminescence, some of which have been worked out. For example, before values of the variables can be put in the equation many subtle parameters need to be determined in the laboratory. Other problems include the "effectiveness of natural zeroing of thermoluminescence signals by insolation . . . and erratic thermoluminescence age underestimations older than 80,000–100,000 years," as Glenn W. Berger writes in a paper being published in the journal *Geoscience Canada* (See **Suggested Readings**). Dr. Berger now operates the Luminescence Dating Laboratory at the Quaternary Sciences Center of the Desert Research Institute in Reno.

Accurate thermoluminescence ages seem to be derived from a great variety of materials (loess, buried "A" soil horizons, tephra, lacustrine deposits) from as recently as 200 years ago to more than 100,000 years ago. Verifications of dates in excess of this range (to 800,000 years) are of varying success, but progress is rapidly being made, according to Berger's *Geoscience Canada* article. Berger notes, however, that overestimations can also result from partially zeroed sediments and soils. In general, ages determined by both thermoluminescence and optically stimulated luminescence of more than 100,000 years need to be verified either by repeated testing or other techniques (such as uranium-series disequilibrium dating).

For optically stimulated luminescence dating, Berger notes that "the accurate isolation of a thermally stable signal from the total signal remains a

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Inspecting Cores Anne Stanaway, chair of the CSFA Advisory Board, examines one of the scores of lithic cores being studied in the Center's labs at Oregon State University. With her is geologist Joanne Turner, the Board's secretary. All the cores are from the Mammoth Meadow archaeological site in southwestern Montana, where another field season is scheduled to begin June 18. Earthwatch volunteers and CSFA members will take part in three 2-week field sessions. The second will begin July 6, and the third July 23. For information about becoming a member of this year's research team, you may phone the Center at 503-737-4595. The CSFA Advisory Board met at OSU in early April.

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 the **Center for the Study of the First Americans** created to recognize outstanding efforts in the study of the earliest American prehistory. The award in 1989 cited Cressman for his long career in the study of the early peopling of the northern Great Basin.

Cressman is best known for the 1938 discovery of sandals, carefully woven of sagebrush bark and grasses, in a cave in the base of Fort Rock, a remnant cinder cone eroded by a Pleistocene lake in south-central Oregon. At the time, anthropologists believed people came to Oregon only about 4,000 years ago, but the artifacts proved to be 9,000 years old. Cressman established the University of Oregon's anthropology department in 1935 and initiated Oregon's first archaeological survey in 1950. He organized the University of Oregon's 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)** they have recently obtained accurate ages up to 400,000 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 underwater deposits, is that intergranular water absorbs ionizing radiations. 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 nondestructive. OSL zeroing is much more rapid because the signals are bleached out of the traps very quickly and more extensively. 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 Berger, optically stimulated luminescence should be viewed presently as a complementary 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 fits four significant requirements for electron spin resonance:

1. the material to be dated is free of all iron and manganese (their electron spin resonance signals interfere with other signals);
2. the lifetime of trapped electrons 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 daughter isotopes increase the actual radioactivity through time. Uptake of uranium in the samples at each site through the specified time must be accounted for and included in the final computation. Several samples from the same tooth are used to average these effects.

Estimating Antiquity

Method	Material	Procedure	Typical Age Range
Carbon-14	Organic (wood, charcoal, bone, shell)	Calibration of radioactive decay	300 to 50,000 yrs.
Uranium-Thorium	Calcite deposits	Calibration of radioactive decay	To 600,000 yrs.
Thermoluminescence	Lake deposits, loess, tephra, pottery, burned flint	Measure electrons trapped after significant heating	200 to 100,000 yrs. (depends on material)
Optically stimulated luminescence	Sediments, soil, minerals	Measure electrons trapped after sediment burial	To 50,000 yrs.
Electron spin resonance	Tooth enamel, cave deposits	Measure trapped electrons	Limits unknown
Archaeomagnetism	Pottery, hearths, kilns	Calibrate polarity	2,000 to 10,000 yrs.
Paleomagnetism	Lava, sediments	Calibrate polarity	From about 700,000 yrs. back through Cenozoic Era

Significance

Perhaps the most significant advances in dating human evolution, particularly mid- to late-Pleistocene sites in Europe (Atapuerca, in Spain, for example) and the Near East (Qafzeh, 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 lower range of potassium-argon (or argon-40/argon-39), which is less than 100,000 years. Unlike these established dating techniques, the trapped-charge or trapped-electron dating techniques do not require 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 object strata themselves, instead of merely dating strata above and below it, as with the potassium-argon technique, is a great advantage. The variety of sediments, soil, 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 50,000 years—those particularly applicable to the study of early humans in the Americas.

One weakness (presumably correctable) is the moderate-to-large imprecision values for the estimated dates 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 often approach the 1 percent error level (at one-standard-deviation confidence level). As Chen Tiemei, Yank 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 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 Reno, Dr. Berger does perform contract work. Academic contractors can probably be found for these techniques at other universities. Other people who do thermoluminescence, optically stimulated luminescence, or electron spin resonance analysis may be found (mainly in England). These include Doreen Stoneham at Oxford, England, who is involved with 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 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 circumstances endemic to each archaeological site demand the involvement of a specialist for all forms of trapped electron dating.

Dr. Radosevich is a hominid paleontologist and geoarchaeologist with the University of Oregon's Department of Anthropology. Though he has firsthand knowledge of tephrochronology (and will be describing that dating technique 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.*

COMING CONFERENCES

June 19–22 13th American Quaternary Association 13th Biennial Meeting, University of Minnesota, Minneapolis.
Field trips June 17–19 to Archaeological Sites in Minnesota dating from Paleoindian to European contact. Contact: Linda C. K. Shane, Limnological Research Center, 310 Pillsbury Drive S.E., Minneapolis, MN 55455-0219. 612-626-7889 Fax: 612-625-3819.

July 5–9 Seventh International Specialist Seminar on Thermoluminescence and Electron Spin Resonance Dating, Krems an der Donau, Austria.
Contact: Norbert Vana, Atominstitut, Schuttelstrasse 115, A-1020, Vienna, Austria.

Aug. 15–19 15th International Radiocarbon Conference, Glasgow.
Contact: The Secretariat, c/o M. Smith, Department of Statistics, University of Glasgow, Glasgow, G128QW, Scotland. 44-41-339-8855 x5024. Fax:44-41-330-5094. E-mail: gata24@uk.ac.glasgow.vme.

Aug. 25–Sept. 2 45th Arctic Science Conference, Anchorage, Alaska, and Vladivostok, Russia.
Themes include Natural Resources and Environmental Changes, Recent Discoveries about Beringia, Development and Adaptation of People and Culture, and Communication and Information Exchange. Contact: Dr. Gunter Weller, Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800, E-mail: gunter@dino.gi.alaska.edu; Fax: 907-474-7290.

Sept. 5–9 Arctic Margins International Meeting, Magadan, Russia.
Contact: Kirill Simakov, North East Scientific Centre, 16 Portovaya St., Magadan, 685000, Russia. U.S. Phone: 907-474-7219

Sept. 26–Oct.2 Seventh Congress of the International Council for Archaeozoology, Constance, Germany.
Contact: Dr. M. Kokabi, Landesdenkmalamt Baden-Wurttemberg, Fischersteig 9, 78343 Gaienhofen-Hemmenhofen, Germany, or S. J. Miller (see below.)

Sept. 26–Oct.1 Eighth Meeting of Working Group No. 1, Bone Expediency Tools/Taphonomy, (in conjunction with ICAZ) Constance, Germany.
Contact: S. J. Miller, Idaho National Engineering Laboratory, P.O. Box 1625, MS 2091, Idaho Falls ID 83402. 208-525-0062. Fax: 208-525-0071. Deadline for registration, June 30.

Oct. 14-16 Science and Archaeology: A Multi-Disciplinary Approach sponsored by Society for Archaeological Sciences, Cambridge, Mass.
Contact: Robert H. Tykot, Archaeometry Laboratories, Harvard University, Cambridge, MA 02138. 617-496-8991; Fax: 617-495-8925.

Oct. 18–22 Rewriting the Pacific: Culture, Frontiers and the Migration of Metaphors, Davis, CA.
Contact: Kay Flavell, Critical Theory, University of California, Davis, CA 95616. Fax: 916-752-8630.

November International Symposium on Pleistocene/Holocene Boundary, Mendoza, Argentina.
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Nov. 13–18 Annual Meeting, Soil Science Society of America, Seattle.
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March 15–19 1995 Annual Meeting, Association of American Geographers, Chicago.
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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 many 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 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 most archaeological investigations because the most recent major reversal was 780,000

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

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. Hearths, potsherds or kilns, Renne explains, may represent materials such as soil, clay or rocks that have been heated sufficiently that they acquire 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 'archaeomagnetic,'" 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 ages 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 geomagnetic reversals useful in determining ages. While there is no regular pattern to the major reversals in Earth's polarity, worldwide research 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.

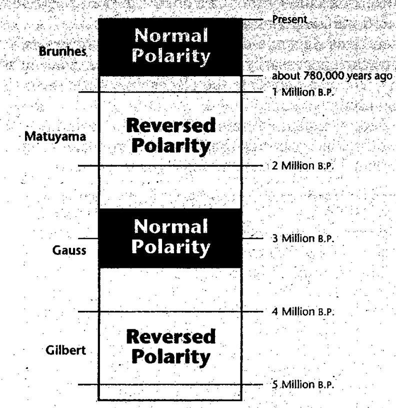
"You have to have some datum point that lets you tie into the time scale. If you do that you're in business." As an example, Renne cited some of his field work in Ethiopia, where he has been working with Rutgers University archaeologists Selshi Semaw and Jack Harris in the investigation of some very 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

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 convections of the liquid outer core. "Reversals or secondary variations are caused by variations in the pattern of convection." Dr. Renne emphasizes that changes in polarity are 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



Major polarity "epochs" are called chrons. The four most recent have been named for prominent scientists in geomagnetism. Within each of these four chrons are shorter periods of polarity reversals called "subchrons."

epochs, or "chrons," have been named for geomagnetism researchers—Brunhes, 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 altogether. 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 ten years ago linking polarity reversals with Milankovitch climatic cycles. "It was hypothesized that during periods of cooler climate, a significant

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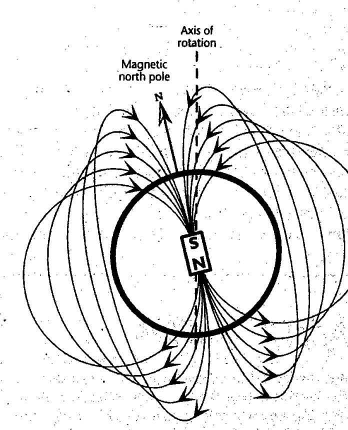

Earth's dynamo mechanism makes electric currents that create a magnetic field as if there were a bar magnet near the center of the planet with its "south" pole beneath Earth's magnetic north pole. This hypothetical magnet's lines of force represent the direction a magnetic compass tries to point.

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 intrinsically 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's 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 to 2,000 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 6 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."

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

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 out of 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."

Heating locks a material's internal compass onto the location of the magnetic pole.

Samples must be protected from high-intensity electromagnetic fields. Renne keeps samples away from propeller-driven airplane engines and automobile 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 magnetostratigraphy. He has been director of geochronology at IHO since 1991.

-DAH

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amount of the hydrosphere gets tied up at the poles as the ice caps build up, and that redistributes the mass of Earth enough that a certain rotational torque is applied on the core." As a result of the changing rotation, according to this theory, reversals are triggered. Most geologists now believe that climate cycles are periodic. "And we don't see those same cycles in the reversal record."

In 1920 Serbian astronomer Milutin Milankovitch first proposed climatic cycles based on the eccentricity, obliquity and precession of Earth's orbit. Recently geologists have found variations in stratigraphy that reflect such cycles, and still more recently Renne and other geochronologists are finding that those stratigraphic records are useful in calibrating the geomagnetic polarity time scale. Just possibly, Renne suggests, it may yet turn out that polarity reversals are periodic and don't appear to have occurred at uniformly chronometric intervals because most of the changes were mere blips or excursions not well recorded in the geologic record. "I think that's going to be a very significant field of active research in paleomagnetism," Renne said in a recent telephone interview.

Discovery that the floor of the Atlantic Ocean spread gradually outward from a central ridge was responsible for what eventually turned out to be a useful, though indirect, system for calibrating the magnetic time scale. Research vessels towing magnetometers produced a record of the strength of the magnetic fields along traverses of the ocean floor. Igneous rock spreading outward from the mid-oceanic ridge took on the magnetic orientation of Earth at the time of its initial cooling. With assumptions of a uniform rate of sea-floor spreading tied to established calibration points at boundaries of polarity reversals, the result is a detailed record back through time.

As specialists discover absolute dates that calibrate the beginnings and endings of particular subchrons of the magnetic time scale, paleontologists and paleoanthropologists find the ages of well-known sites or faunal markers must change, too. But science thrives on change.

-DAH

Radiocarbon Remains the Standard for Determining Archaeological Age

RADIOCARBON DATING is a dating technique unique in its accuracy and breadth of application. Chronometric measurements using carbon-14 are independent of all archaeological data. Dates can be obtained on a wide range of materials including charcoal, wood, shell, bone, dissolved carbon dioxide 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 by far the most popular method used by researchers to determine the antiquity of relevant materials. One commercial laboratory alone, Beta Analytic of Miami, Fla., performs more than 10,000 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 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 10^{-10} percent. While the carbon-12 and -13 isotopes are stable, carbon-14 decays into non-radioactive nitrogen-14. Radiocarbon has a half-life now calculated at 5,730 years (originally its half-life was measured at about 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 is protons, the positive charges of hydrogen nuclei. These protons interact with atmospheric atoms, 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-14. While the oceans absorb most of the carbon dioxide-14, 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 directly relates 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-14 dating. "It shouldn't work as well as it does. 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—decay counting—are:

1. the weakness of the radiation being measured;
2. the minute amounts of carbon-14 to be detected;
3. the interference of background radiation.

Even with heavy shielding, background counts can be registered from environmental radiation. To reduce the background, a ring of counters encircles the 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 efficient and sensitive counting 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 scintillating 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. Sample sizes 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.

"It's one of the few dating methods where the model and reality coincide so well."

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 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 precious articles such as a Dead Sea Scroll. A disadvantage of the technique is the higher 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 pretreatment 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 protein is degraded, the resulting peptides may be hard to distinguish from contaminating organic materials. Materials such as chalky shell, in which carbonates continue to exchange in the environment, are usually unsuitable. However, sound 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 relatively imprecise, and laboratories report the degree of uncertainty. For example, a sample of charcoal taken from an archaeological site might be reported to be 10,600 ± 120 years. The 120 indicates the degree of precision assigned to the age value. Various personal-computer calibration programs exist to convert radiocarbon years into actual years.

How about accuracy? 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 geologic time. It was soon determined that carbon-14 dates of ancient Egyptian artifacts were several hundred years earlier than dates available through recorded historical chronology. What was the error? Studies based on time scales produced by analysis of annual tree rings found in ancient wood ultimately 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 calibrated. 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 been found off by 800 to 1,000 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 time 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 trowel could contaminate a sample. Sample containers can present problems. They should be of inert material, such as polyethylene, and should seal tightly.

"There are a lot of practices 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." The sample is then contaminated, 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, because it's a root of 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 Zhoukoudian, 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 those dates, according to Dr. Huh, continues to be controversial.

Then in 1989, Dr. Shen found 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 process that only 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 from a standard office paper stapler.) Mass 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 not possible with alpha spectrometry.

Huh's initial studies of four samples collected by Shen from different strata at Zhoukoudian have produced ages ranging from 205,000 ± 5,000 years old (2 percent uncertainty) to 450,000 years ± 35,000 years old (less than 10 percent uncertainty). These dates have similarities and differences with ages established during the 1978 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 much work to do to verify 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 alpha-spectrometry process of uranium-thorium dating to produce a still-controversial 11,600 ± 800-year age of a human skeleton found in 1953 near Midland, Texas (See **Mammoth Trumpet** 8:1, "Clovis Age Confirmed for Midland Woman").

"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 can improve precision 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 also 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 Zhoukoudian. 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 Wisner

COUNTING ON CALCITE

Uranium-series dating has proven useful for determining dates in the period from 50,000 to 350,000 years ago. The principal archaeologically relevant material to be dated by uranium-series has been travertine, the finely crystalline deposits of calcium carbonate—calcite—formed by chemical precipitation from surface waters and ground waters in which there usually is uranium, but no thorium. Travertine, with its constituent calcite, forms around the mouth of springs, especially hot springs, and in limestone caves, where it can coat walls and form stalactites and stalagmites. (Calcite also is the chief constituent of limestone and most marble.) With time, uranium-234 in the calcite decays into thorium-230, which accumulates in the rock. Eventually an equilibrium is reached when the accumulating thorium has a decay rate equal to that of the uranium. The equilibrium point sets the upper limits for age estimation, and estimation grows more difficult the closer to the border one gets. For example, at 350,000 years, thorium-230 actually is within 4 percent of the equilibrium value. (See Aitken, 1990, in **Suggested Readings.**)

Alpha-spectrometry u-series dating relies on the measurement of the decay ratio between uranium isotopes such as the uranium-234 and their "daughter" elements such as the thorium-230. Because the isotopes decay at different rates, technicians can determine the age of the original material being tested; thus age estimates are based on the ratio of uranium-234 to thorium-230.

The name travertine is geographical in origin, coming from the Italian *tivertino*, the Roman name of Tivoli, a town near Rome where there is a considerable travertine deposit.

Radiocarbon Dating

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

But the 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 handling the sample, 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

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