Doubts Over Spectacular Dates

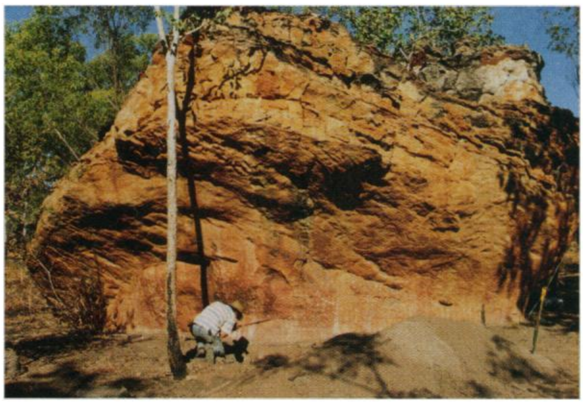
A dating technique based on a faint glow from sediments long hidden from light has yielded some of the most startling—and fiercely disputed—dates in archaeology

In the remote Northern Territory of Australia, a huge sandstone boulder marks the spot where, according to aboriginal lore, a spirit named Jinmium turned herself to stone to escape her pursuer. This rock shelter has long been a magical place where ancient people camped, painted ochre figures, and carved holes in the walls. Archaeologists have been eager to know how far back its history extends, and last year, they got an answer that even the leader of the dating team called "pretty outrageous": between 116,000 and 176,000 years. The date implies, among other things, that humans have been in Australia two to three times longer than previously thought, and it makes Jinmium the oldest known rock art site in the world. Admits Richard Fullagar, the Australian Museum archaeologist who led the team, "We worried about the date."

But the team published the results anyway, along with a few caveats. Appearing in the journal *Antiquity* in December 1996, the report drew worldwide attention—and intense scrutiny. "When I first heard about those dates, I didn't believe them," says Rhys Jones, an archaeologist at Australian National University in Canberra who is a member of the team now redating the site. "I doubt that the date will be confirmed." Even Fullagar isn't sure of the date he published. He jokes: "I'm sticking to my guns. We're still uncertain."

If the date falls—and there are early signs that Jinmium's real age may be as little as 10,000 years—it will eliminate a major challenge to the conventional view of Australian prehistory. But it will also deal a blow to the credibility of the experimental dating method used at the site: determining the age of sediments by measuring a tiny luminescence signal that builds up while the rock or sand grains are hidden from sunlight. The method is a potential boon to archaeology, offering a way to put a time scale on sites that can't be dated by any other method. Indeed, over the past decade, luminescence techniques have yielded a series of spectacularly early dates, which have put people in Siberia more than 260,000 years ago, modern humans in South Africa 260,000 years ago and in Australia 60,000 years ago (at sites other than Jinmium), and remarkably sophisticated toolmakers in central Africa 90,000 years ago.

But several of these dates are already in question, and the techniques that produced them are still being tested and refined. As a result, many archaeologists and anthropologists are wary of published luminescence dates. "From the perspective of a consumer, like myself, it can be very difficult to know in any given instance whether a date is reliable or not," complains Stanford University paleoanthropologist Richard Klein. Such doubts have discouraged many archaeologists, especially in the United States, from adopting the techniques.



R. ROBERTS/LA TROBE UNIVERSITY

Coy about its age. The rock shelter at Jinmium, Australia.

While luminescence dating has proved its value in dating pottery and burnt artifacts, dating experts agree that it has sometimes been applied too hastily to ordinary sediments. "There seems to be a great deal of danger of people taking a new technique and applying it without testing it adequately," says David Huntley, a physicist at Simon Fraser University in Burnaby, Canada, who pioneered sediment-dating techniques. Yet the methods can be powerful, they say, when applied carefully, by researchers who understand the geology of the site and use state-of-the-art techniques in the lab. "I trust the reliability of a sediment date by optical dating more than a radiocarbon date—when it's well applied," says Nigel Spooner, a physicist at Australian National University.

Light industry

The idea of using the light signal emitted by minerals in soil or ancient pottery to date these materials was proposed almost half a century ago. But it wasn't until the 1960s that it was put to work in dating pottery, and less than 20 years ago when it was first applied to sediments. Luminescence dating relies on a clock driven by natural radiation in common minerals like quartz or feldspar. The radiation bumps electrons from their normal positions in the minerals' crystal latticework into traps, or defects, at a rate that is roughly constant over time. Exposure to sunlight or heat from a fire at a site of human occupation empties many of the traps, setting the clock to zero. When the site is abandoned, the clock starts ticking again. As long as the mineral grains remain in the dark, the traps refill with electrons at a regular rate.

Years later, scientists who have protected specimens from light while collecting them can empty those traps again in the lab. They do so by heating the sample—a technique called thermoluminescence dating (TL)—or tickling it with light from a lamp or laser, in optically stimulated luminescence (OSL). The freed electrons often generate a faint glow. The more intense this luminescence, the more time has elapsed since the clock was reset. If scientists can figure out how fast the clock ticks, for example by measuring natural radiation at the archaeological site, they can calculate when the mineral was last heated or exposed to light.

One appeal of the technique is its ability to see at least 100,000 years back in time, and sometimes as much as 800,000 years—much farther than the better known radiocarbon dating method, which cannot date sites older than 40,000 years or so. And unlike radiocarbon dating, which requires organic material such as charcoal, or argon-argon and other dating methods, which require volcanic materials, luminescence dating can be put to work almost anywhere. "Quartz and feldspar are ubiquitous—they're in the sediments at practically every site," explains James Feathers, an archaeologist at the University of Washington's luminescence dating lab in Seattle. "So you can often do luminescence where you can't do something else."

The technique has already established a solid reputation for dating pottery and other artifacts that were fired or burned in antiquity. These artifacts are often so opaque that feldspar, quartz, and other datable minerals in their interior layers have been well-protected from light—even if the relics themselves lay exposed on the ground. The record of believable dates for artifacts ranges from the terra-cotta army figures in Xi'an, China (dated to 2200 years) to burned tools and flint found with the remains of Neandertals and modern humans in the Levant (dated to about 90,000 years). Says

Feathers, "TL dating on pottery and burned artifacts is almost routine."

Bleach job

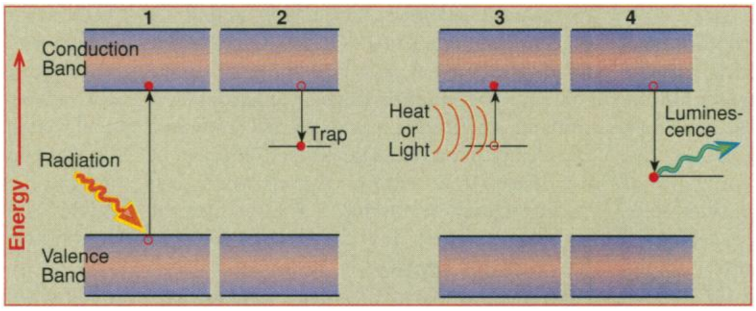
Luminescence dating is breaking new ground, however, in studies of ordinary sediments from archaeological sites. In place of the heat that sets the clock to zero in pottery or burnt stones, these studies assume that sunlight does the job—and that the sediment last saw daylight just before the art, tools, or other traces of human presence were buried. The burning issue for every scientist using TL or newer OSL methods on sediments is whether the light completely emptied the electron traps—zeroing the clock—when the sediment layer formed.

While some electrons require only a few minutes of sunlight to be bleached, or freed from their traps (the easy-to-bleach signal), others need hours or even days of ultraviolet light (the hard-to-bleach signal). If soil was blown into the site by the wind, the minerals probably did see enough light to be entirely bleached, says Huntley. But sediment deposited by a river or glacial outflow may not have been thoroughly bleached. As a result, the luminescence age it yields will be misleadingly old.

This is the chief concern at the site called Katanda in what is now the Democratic Republic of Congo, where George Washington University archaeologist Alison Brooks and her team uncovered a finely crafted barbed bone point and other tools from a cliff bank above the Semliki River in 1988. The textbook view has been that humans capable of making such sophisticated tools first appeared in Europe about 40,000 years ago. But luminescence dating of the tool-bearing sediments, together with another experimental dating method, called electron spin resonance (ESR), suggested that the tools were made at least 75,000 years ago, pushing back the onset of modern behavior (*Science*, 28 April 1995, pp. 495, 548, 553).

The ESR date came from hippopotamus teeth in the tool layer, which could have washed in from older deposits, says McMaster University geologist Henry Schwarcz, who dated the teeth. And Seattle's Feathers, who was a postdoc in the lab of retired University of Maryland physicist William Hornyak, where the luminescence dating was done, is equally uncertain about the sediment results. The date rested entirely on TL of the hard-to-bleach signal, which may not have been zeroed completely by sunlight when the soil was deposited at the site.

"The trouble with the site is the date that was published was based on the assumption that the quartz got fully bleached," says Feathers, who is working to correct the problems with the OSL dating, which is better than TL at measuring the more reliable, easy-to-bleach signal. Hornyak, however, has said he is "very confident" of the TL dates because repeated tests on the sediments have yielded the same results.

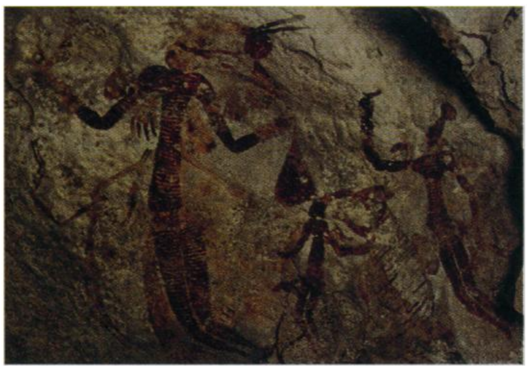


SOURCE: J. FEATHERS

Enlightening technique. Luminescence dating relies on natural radiation in minerals to knock electrons into "traps" (1 and 2); in the laboratory, heat or light empties the traps and stimulates a glow that indicates age (3 and 4).

Rubble trouble

A problem of a different sort is undermining the TL dates on sediments at the Jinmium rock shelter: pebbles of crumbly sandstone from the boulder wall or bedrock jumbled into the dated sediments. Because the rubble might not have been bleached at the same time as the sediments, it could have thrown off the dates. "Where there is rubble, there may be trouble," jokes Richard "Bert" Roberts, a geochronologist at La Trobe University in Bundoora, Australia, who has dated many of the earliest sites of human occupation in Australia.



R. ROBERTS/LA TROBE UNIV.

Quartz timing. Grains of the mineral from wasp nests are yielding dates for this Australian rock art panel.

Fullagar noted in his paper in *Antiquity* that although some of the layers he dated contained rubble, none was found in the layer with the oldest stone artifacts. Still, says Roberts, undetected grains from the wall of the rock shelter or from the bedrock below the sediment layer could have been mixed with the quartz that was dated. In a sample of 100 grains, he says, it would take just two 250,000-year-old flecks of quartz to give an overall date of 6000 years, even if the rest of the sample was just 1000 years old.

To address that concern, Roberts has now collected fresh samples of sediment from Jinmium to date with the newer luminescence method, OSL. OSL can tease a date from samples as small as a few tens of grains of sediment—and sometimes as small as a single grain—instead of the thousands of grains typically needed for a TL signal, says Roberts. He is now painstakingly dating the sample, grain by grain, to see if old grains are mixed with newer ones, and expects results by the end of the year. Meanwhile, Spooner has analyzed the published TL data and thinks that the site could be as little as 10,000 years old.

That's the kind of disagreement that has unnerved many archaeologists: "When I see wacky TL dates, I wait and set it aside until things settle down," says archaeologist David Meltzer of Southern Methodist University in Dallas, who studies early sites in the Americas. "My sense is that you need to prove it over each time you go into a new area and make sure it works there."

Dating experts like Huntley agree: "One really has to find sites with well-established ages that no one's going to argue with to test the technique, to see if you can get the right answers. There hasn't been enough of that done," he says.

As an example of the right way to apply these techniques, some dating experts point to two rock shelters in Northern Australia where Roberts's team has come up with luminescence dates of 50,000 to 60,000 years, making them the earliest sites of human occupation in Australia outside of Jinmium. The team checked younger luminescence dates against radiocarbon results to show that the two clocks were in synch. They also used both OSL and TL, and analyzed very small specimens. "Those dates look solid," says geochronologist Ann Wintle of the University of Wales in the United Kingdom, an expert on OSL and TL dating of sediments. "One has to compare with radiocarbon, where possible."

But such cross-checking isn't always possible. At one site in Siberia that has come under the luminescence spotlight, Diring Yuriakh, Russian scientists had come up with a TL date of over 1.6 million years for the sediments around a set of stone artifacts. That date was widely viewed as outlandish, and another team headed by Steve Forman, a geologist at the University of Illinois, Chicago, redated the sediments with TL to get a figure of at least 260,000 years (*Science*, 28 February, pp. 1268 and 1281). Yet the prevailing view is that humans didn't venture into subarctic regions until 30,000 years ago.

So the team that redated the site has looked for other methods. But Diring Yuriakh lacks the charcoal, volcanic materials, or teeth needed for other techniques, and Forman's attempts to use OSL failed, because the sediments had been buried too long and all the OSL electron traps had been filled long ago. "So you're left with nothing except TL," says Forman. "Yes, it's experimental. Yes, it's developing, but what else do you do?"

Buzz word

Caution is the best advice that Wintle and others can offer to archaeologists eager to use luminescence methods. They advise forming an interdisciplinary team that can scrutinize the geology of the site, such as how the sediments were laid down, particularly around the object being dated, and detect signs of trouble in the lab (such as poor bleaching or a signal that fades because the traps have leaked electrons before the sample was dated). "Above all, the ultimate test of a date is whether it can be reproduced by an independent lab with access to the original site, because reassessment of the geological context is critical," adds geologist Jack Rink of Canada's McMaster University.

New luminescence strategies may also help. Roberts and his colleagues, for example, have now dated some of the most spectacular rock art in Australia by extracting single grains of quartz from mud-wasp nests on the rock face (*Nature*, 12 June). Wasp nests are common at rock art sites in Australia and elsewhere, and the mineral grains they harbor should have been well bleached at the time the nests were built—and sealed off from light since then. And because the nests are often right on top of the pigment, and in some cases have been partially painted over, they can provide minimum and maximum dates for the art. In another advance, Spooner and the University of Wales's Geoff Duller are borrowing a tool from astronomers' telescopes for detecting the luminescence—a charge-coupled device, capable of detecting the dimmest signals.

In the end, high-profile controversies at sites like Jinmium may speed the transformation of luminescence sediment dating from showy upstart into a reliable standby. "My job is luminescence dating," says Roberts. "I can't afford to have the field look inept."

–Ann Gibbons

ASTRONOMY

Probing a Star's Heart of Crystal

Looking into a crystal ball is not what you'd expect an astronomer to do. But Don Winget and his colleagues will give it a try next year. Their hope is not to predict the future, but to unravel the past. And their crystal ball isn't on a magician's table; it is a pulsating white dwarf star at a distance of tens of light-years in the southern constellation Centaurus.

Winget and his colleagues have identified this star, called BPM 37093, as an ideal laboratory for studying how material inside white dwarfs—ancient stellar embers—crystallizes as they age. Depending on what the researchers find, "the ages of white dwarf stars in the disk of our galaxy might have to be revised upward, from 9 billion to 11 billion years or so," says Winget, who is at the University of Texas, Austin. That could spell trouble for cosmologists, who believe the universe as a whole is only about 11 billion years old.

Compact stars with a mass comparable to the sun, but a diameter not much larger than Earth's, white dwarfs are the remains of sunlike stars that shed their outer layers into space at the end of their lives. The cores, which no longer have any fuel left for nuclear fusion, slowly cool and fade. The coolest white dwarfs should thus be relics of the first stars to form in the galaxy.

Determining a white dwarf's age from its temperature isn't simple, however. In the early 1960s, theorists predicted that the atomic nuclei inside a cooling, compacting white dwarf would arrange themselves in a rigid lattice structure. The formation of this crystal ball, like the freezing of water, would release energy, slowing the cooling rate and making the star look younger than it really is.

Just how big an effect the crystallization has on the star's cooling rate depends on whether the carbon and oxygen nuclei that make up most of the white dwarf crystallize as an "alloy"—which would limit the effect—or separate into a core of pure oxygen and a carbon-oxygen mantle. "If [this] phase separation takes place," says white-dwarf specialist Gilles Fontaine of the University of Montreal, "you have additional energy release, and the cooling of the white dwarf is slowed down [further]." The delay would add 2 billion or 3 billion years to the age determined from temperature alone.

Astronomers have had a technique that could settle the question—but until now, no suitable star. The technique is asteroseismology: observing pulsations at a star's surface to deduce its internal structure, much as geologists study earthquakes to learn about the interior of our planet. Pulsating white dwarfs are scarce, however, and known pulsators are too hot to be crystallized.

HST/NASA

Birth of a white dwarf. Planetary nebulas like this one form when an aging star flings off its outer layers, exposing its hot, dense core.

In the 1 October issue of *The Astrophysical Journal*, Winget and his colleagues Mike Montgomery (also at the University of Texas) and Kepler de Souza Oliveira Filho, Antonio Kanaan, and Odilon Giovannini (at the Universidade Federal do Rio Grande do Sul in Brazil) identify BPM 37093 as an exception. They point out that this particular pulsating white dwarf is massive enough (about twice the mass of an average white dwarf) to have a crystallized interior, despite its relatively high surface temperature of over 11,000 degrees Celsius. Asteroseismology of this star "promises to provide us with the first empirical tests of the theory of crystallization," say the researchers.

In March 1998, Winget and his colleagues will begin studying the star's pulsations, observable as tiny brightness variations over periods of about 10 minutes, with the Whole Earth Telescope. WET is a collection of medium-sized telescopes all over the world, working in tandem to ensure that the star is never lost from sight. The observations will continue for nearly 2 weeks, yielding data that Winget hopes will settle the issue of whether phase separation takes place.

"That would be a fabulous achievement," says Huib Henrichs, a University of Amsterdam astronomer who uses asteroseismology to study giant stars. But Fontaine argues that poorly known features of the star such as its internal convection and the mass of the external hydrogen layer could make the results hard to interpret. Says Fontaine: "A lot of hard work will be necessary to untangle the various effects" that could mimic the signature of crystallization.

Winget agrees but says additional, ultraviolet (UV) observations of his crystal ball, to be made next year by the orbiting Hubble Space Telescope, will help sort out these effects. In the UV images, he says, it should be possible to distinguish the confounding effects from glimpses of a real crystal ball.

–Govert Schilling

Govert Schilling is an astronomy writer in Utrecht, the Netherlands.