News & Comment

Paleoanthropology Gets Physical

A hatful of new, high-tech methods of dating are stirring up the field on transforming our view of when—and where—anatomically modern human beings first evolved

SCIENCE IN THE '90s

Fourth in a series

ARCHEOLOGY HAS BEEN INVADED by several tribes of newcomers—physicists, molecular biologists, and computer specialists. They have moved in on what were once the paleontologists' exclusive hunting grounds, bringing with them new gadgetry and fresh ideas for probing the ancient past. They believe their methods are "more scientific" and less subjective than traditional ones. Their equipment, they say, is permitting them to find archeological evidence that has been locked until now in bits of rock, tooth enamel, and egg shells.

Within little more than a decade their high-tech methods have brought about a revolution in how scholars understand the emergence of anatomically modern human beings. The older view was that *Homo erectus*, an ancestor of modern human beings, spread out of Africa several hundred thousand years ago, populating Europe and Asia. In these regions humans evolved slowly, in some areas passing through transitional forms before they took on forms characterized as fully human. In Europe, one such intermediate form was thought to be the Neanderthals, who in theory evolved into modern human beings perhaps 35,000 years ago.

But now the wizards of the new technology have turned this view around. Citing evidence about DNA mutation rates, they claim that the ancestors of all modern human beings lived in Africa. Then, citing dates obtained from accelerator studies and experiments in solid-state physics, they attempt to show that anatomically modern humans emerged first in Africa—and much earlier than anyone had thought—perhaps 90,000 to 100,000 years ago. In this view, the Neanderthals were not ancestors of modern humans, but competitors who were swept aside as our own forebears moved out of Africa to populate the globe.

Not everyone is ready to endorse this scenario or even to acknowledge the value of the methods that have yielded the new dates. The chief skeptics are paleontologists who prefer to trace evolution in the changing shapes of bones and fossils. Some argue that this approach is a more reliable yardstick than clocks derived from quantum electron theory or molecular biology. But such arguments have an air of desperation, for the new high-technology dating techniques seem to be gaining ground.

Three techniques—all still in debate—lie at the heart of this revolution. They are electron-spin resonance (ESR), thermoluminescence (TL), and mitochondrial DNA (mtDNA) studies. ESR and TL are new, solid-state physics methods that measure time by testing for minute, radiation-induced changes in crystal. They have been crucial in providing the oldest dates for anatomically modern human beings in the Near East and Africa.

O. Bar-Yosef

End of the line? *A Neanderthal found buried in Kebara Cave may represent a prehuman type without progeny.*

The advantage of TL and ESR is that—in theory at least—they provide absolute dates for a period that cannot be read by the two main standard methods. One, carbon-14 dating, reaches only 40,000 years into the past; the second, potassium-argon dating, begins counting at about 300,000 years ago. Yet in that chronological gap lie issues that are critical to the debate over modern man's origin.

MtDNA methods, which are still the most controversial of all the new methods, have provided the genetic data for the argument that the ancestry of all modern human beings can be traced to a single population—perhaps even to a single woman—who lived in Africa some 200,000 years ago.

The "out of Africa" (or "Mother of Us All") hypothesis was developed by Alan Wilson and Mark Stoneking of the University of California at Berkeley and Rebecca Cann at the University of Hawaii. They examined the rate of variation in modern species' mitochondrial DNA to estimate when major species diverged in the distant past. Mitochondrial DNA is found in the cell's mitochondria, not the nucleus, and is inherited only from the mother, remaining unaffected by sexual reproduction. MtDNA is thought to be largely independent of natural selection pressures too. On this basis, the researchers assumed a constant mutation rate of 2 to 4% per million years and projected back to a point and time of convergence: Africa 200,000 years ago.

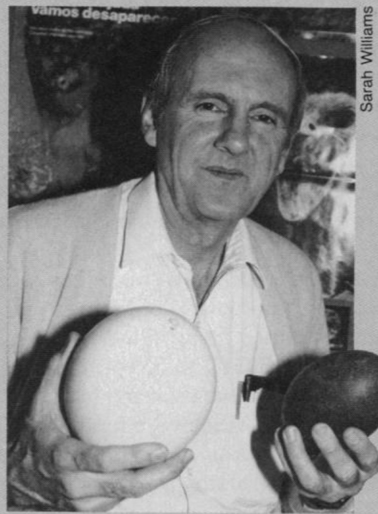
One of the most vocal critics of the "out of Africa" hypothesis, Millard Wolpoff, a paleoanthropologist at the University of Michigan, rejects all this. He says unequivocally: "There is no mitochondrial clock." Wolpoff argues that the rate of

Racemization Dating: Great Expectations

Like everything else in life, archeological dating methods have their moments of glory and their disasters. The record of a technique called amino acid racemization (AAR) shows how much a method's credibility can wax and wane in a single generation. It also shows how important attention to detail can be in getting a concept to work.

Fifteen years ago, enthusiastic users held out the hope that AAR could be used to determine the age of objects that could not be dated by other means. Today, in striking contrast to those early expectations, many people regard AAR as "some kind of joke," in the harsh judgment of paleoanthropologist Milford Wolpoff.

However, some AAR practitioners are still quite optimistic about it, having worked quietly for years to hone its accuracy. P. Edward Hare of the Carnegie Geophysical Lab in Washington, D.C., argues that the technique got a bad reputation through misuse in the 1970s and that refinements since then have made AAR quite accurate. He and others, including Gifford Miller at the University of Colorado at Boulder, have developed a way to elicit precise dates from ostrich egg shells, which are often found at archeological sites in Africa. They find that AAR dates correlate closely with carbon-14 dates. They hope to expand the application and have already gotten promising results with blackbird, crane, owl, and emu egg shells.



Sarah Williams

New technology. *Ostrich and emu eggs preserve amino acids over millennia, according to Edward Hare.*

The phenomenon proposed as a clock in AAR dating came to light in the 1950s when Philip Abelson, then at the Carnegie Institution and now a science adviser to the American Association for the Advancement of Science, found that amino acids made by organisms during life do not disappear immediately at death. In the case of mollusk and egg shells, the acids may be locked in a mineral matrix that preserves them for millennia, as they undergo a gradual change (racemization) from one isomeric form (L, type) to another (D type).

Abelson and Hare looked for ways to use AAR as a biological clock and discovered that by measuring the ratio of D to L acids in shells, it was possible to estimate dates as old as 100,000 years ago—suggesting that this might be a way to go beyond the carbon-14 barrier of 40,000 years. However, because the AAR process is strongly affected by temperature and moisture, the technique seemed most likely to work in cold climates, where racemization proceeds slowly and without big fluctuations in its rate. Hare warned at the outset that one must have a reliable temperature history of the sample to reach a credible date. Not everyone listened.

In the 1970s, Jeffrey Bada, a researcher at the Scripps Oceanographic Institution in La Jolla, California, began using AAR to get the age of human and animal bones that had been unearthed in California. His results were sensational. The human remains he found were breaking age records for North America; he reported that they were more than 50,000 years old. Others using AAR also began making spectacular finds, and AAR data were being "widely cited in the 1970s," according to Richard Klein, a paleoanthropologist at the University of Chicago.

But the bubble soon burst. Hare published a critical review in 1974 noting many inconsistencies in the new dates and hammering away at the point that bones are not reliable material for AAR testing, particularly if they come from a warm environment.

The debate went unresolved until the 1980s, Hare says, when radiocarbon dating became sophisticated enough to test small samples. When ^{14}C accelerator-mass spectrometry dating was applied to some of the California bones, Hare says, it turned out that "what [Bada] was calling 50,000 to 60,000 years old was in fact only 5,000 or 6,000 years old."

Hare thinks the problem of using AAR to test bones looks "almost insurmountable."

AAR dating fell out of favor in the 1980s, Klein has written, and "few paleoanthropologists today accept racemization dates at face value. . . . "

While Hare believes he has been vindicated, he regrets that there had to be a battle. "What it's done essentially is to damn the whole process," he says. "We've had trouble convincing people that [AAR] works in mollusks and ostrich eggs, because all they can picture is that nonsense with bones."

However, AAR may get a second chance at celebrity soon, when Miller's studies of African ostrich egg fragments are published. Miller has been looking at samples collected from the Border Cave on the east coast of South Africa, where extremely old remains of an unquestionably modern human have been found. Fixing the age precisely could be important, for if the bones are as old as Miller suspects—in the range of 100,000 years—this would provide an additional bit of independent evidence for the theory that modern humans came from Africa.

In Border Cave, Miller finds that his use of AAR time dating is running head-to-head against electron-spin resonance dating carried out by Rainer Grün of Cambridge University, regarded as the world's most skilled practitioner. Thus far, Miller and Grün have not been able to get comparable results. AAR produces an age of 80,000 to 100,000 years for the egg shell taken from the layer where the human bones were found, and ESR shows 60,000 years.

Unlike ESR, which gives dates in absolute terms, AAR provides a relative index that must be anchored in some way, usually to a carbon-14 number. In Border Cave, Miller anchors his numbers to a layer of debris that has been dated repeatedly by ^{14}C at 36,000 to 39,000 years. Grün gets around 27,000 years for the same layer, a discrepancy he cannot explain at present, but which accounts for the clashing results.

Miller is nevertheless excited about the future. "We're still stuck with the problem that AAR is more sensitive to temperature than ESR or TL," he says. But he claims that it is more precise than those methods in nailing down exact dates within a layered deposit, so long as reference dates are available.

Dating egg shells with AAR "didn't really get cooking until about 3 or 4 years ago," Miller says, and "when I started talking to archeologists, I learned that the damn stuff's everywhere" but that people were in the habit of tossing it aside as uninteresting. Now, he says, "they're getting keyed in and saving it." ■ **E.M.**

mtDNA mutation must have been affected by population extinctions in the past, moving quickly in some periods and perhaps not at all in others. So if the molecular clock appears to be right from time to time, he says, "it's only because any stopped clock is right twice a day."

Criticism of this kind is familiar to Wilson, a pioneer in mtDNA research, but he is not impressed. He says he has taken "a lot of flak" from the paleontologists for narrow, professional reasons as much as for substantive disagreement. Wilson's own view that "you can dispense with the bones" by looking at DNA keeps the flak flying.

If mtDNA methods have been at the heart of the "out of Africa" controversy, TL and ESR have had central roles in the debate over how Neanderthals and anatomically modern human beings are related. Anthropologists once thought Neanderthals were the ancestors of modern Europeans. Data from TL and ESR studies in the last 3 years suggest a more complex reality. In the Middle East, at least, modern humans seem to have been on the scene *before* Neanderthals.

This puzzle is evident in a group of caves in northern Israel—Qafzeh, Kebara, Tabun, and Skhul—where archeologist Ofaer Bar-Yosef of Harvard and his colleagues dug out a series of surprises in the 1980s. At Kebara, for example, on the side of Mount Carmel facing the Mediterranean Sea, they found a well-preserved skeleton of a Neanderthal, apparently buried in a grave. In 1987 Helene Valladas of the National Research Center at Gif sur Yvette, France, used TL to test 38 burned flints and showed that they were set down 60,000 to 48,000 years ago, suggesting that the Neanderthal died during that period.

This was not surprising in itself, because traditional paleontology had dated the Neanderthals' golden age to this time. The big surprise came in results from Qafzeh Cave, 35 kilometers to the east. TL testing on 20 burned flints recovered from a level within the cave where remains of anatomically modern humans were found suggest that modern man was present very early in the Middle East: about 92,000 years ago—considerably before the Neanderthal. Similar studies using ESR on tooth enamel and sediment, run by Rainer Grün at Cambridge University, support these dates.

The findings suggest several striking possibilities, says Bar-Yosef. One is that the modern humans from Africa first pushed north, then retreated again as the glaciers of the last ice age spread through Europe, driving the Neanderthals southward. Then, thousands of years later, the tide of modern humans may have swept northward again, this time for good. And these moderns may never have mixed with Neanderthals. Another possibility is that the two types occasionally encountered and perhaps fought, even bred.

Many paleontologists, including Richard Klein, find the scenario of Neanderthal and modern humans living side by side in the Middle East difficult to accept. Klein points out that classic evolutionary biology rules out the notion that two types could share such a small territory. As a result, he says, "I don't know what to make of the TL and ESR dates."

Klein and several others, including Gifford Miller at the University of Colorado at Boulder, question whether the users of TL and ESR have as much control over confounding variables as they claim. Because the two techniques are related, they have common vulnerabilities.

Methods of Archeological Dating

Method	Carbon-14	Thermo-luminescence	Electron-spin resonance
Time span	to 40,000 yr	to 1 mill yr or more	to 1 mill yr or more
Min. cost of equip 1983	10,000	20,000	100,000
Minimum sample	1 to 20 g (conventional)	5x5 mg	5x50 mg
	0.5 to 5 mg (accelerator/mass spectrometer)		
Main interference	contamination by background carbon	recrystallization	

Menu of methods. *New ways of dating archeological finds differ in the range of costs and span of time coverage.*

Both TL and ESR are designed to measure radiation damage sites in the lattice of crystals by examining the behavior of electrons trapped in the sites. The number of sites increases with the age of the material, because ionizing radiation from natural sources such as uranium and thorium penetrates it and continuously punches "holes" in the structure. The older a sample is, the more holes it will have; and the more holes it has, the more electrons.

In the TL process, a sample is heated to excite the electrons, which give off a visible flash when they leave the crystal lattice. The intensity of the flash, which is proportional to the stored energy, can be detected using a photomultiplier. By experimenting on samples of a known age, TL practitioners have built up a scheme that correlates TL values with age.

ESR also measures radiation damage, but it does so by exciting the electrons within the lattice, not by driving them out. The sample is put in a magnetic field and bombarded by carefully tuned microwaves. A sensor detects a response whose intensity correlates to the age of the sample. The big advantage in this case is that a sample can be tested repeatedly by ESR and should yield the same result each time. (TL testing, by contrast, can only be done once because it sets the sample's "clock" back to zero.)

A weakness of both ESR and TL is that they assume that present-day estimates of radiation dose rates can be applied retroactively for tens of thousands of years. In reality, however, the rates change, and ESR practitioners must take care to compensate for these fluctuations. Two important confounding elements identified so far are natural uranium, which is water soluble and moves readily through the environment, and thorium, which is not so soluble. Bones absorb uranium. So when teeth are tested by ESR methods, an adjustment must be made to discount the long-term radiation.

The failure to adjust in this way skewed some results recently in Kansas. Because the influence of uranium seeping into bones found in sandbars in the Kansas River was not taken into account, the bones were initially dated at 100,000 years ago, long before most anthropologists believe the New World was populated. When the uranium absorption was taken into account, the age of the bones was corrected to about 17,000 years—still old, but within the range of the debate over the peopling of the Americas.

Grün, who has used ESR to examine teeth from caves in the Middle East and in South Africa where modern human remains were found, says he is well aware of the uranium problem and will not be blindsided by it. He uses two different models to calculate the possible rate of uranium uptake and assumes that these bracket the possible extremes. Because the best practitioners take such care, ESR is rapidly gaining acceptance among anthropologists.

Another novel technique that has begun to influence the debate on the relations between Neanderthals and modern humans is an updated version of the old carbon-14 method, which was itself regarded as the gold standard in archeology. New carbon-14 methods have been used by James Bischoff of the U.S. Geological Survey and others to show that the Neanderthal toolmaking culture underwent a rapid change in Spain—several thousand years earlier than previously assumed—beginning about 40,000 years ago.

The problem with ^{14}C dating has always been the difficulty of keeping samples pure. A small inclusion of debris from the wrong layer of the excavation site or a bit of dust from the laboratory can throw results way off when very old dates are being sought.

But great improvements in carbon-14 dating have come in the last decade through the use of high-energy accelerators and mass spectrometers to take a direct reading of the ratio of ^{14}C to ^{12}C atoms. This contrasts with the old, indirect approach of measuring radioactive emissions and inferring the number of carbon atoms from that signal. The advantages of the new technique are that smaller samples can be used and the process is faster.

A further refinement, developed by Thomas Stafford at the University of Colorado in Boulder, among others, attempts to solve a long-standing weakness of ^{14}C dating: its poor record in dating bones more than 10,000 years old. As bones age, they lose collagen, and with it, most of the carbon atoms whose decay could be observed. Meanwhile, they tend to absorb chemicals from the environment around them, including fresh carbon atoms, making the sample appear younger.

The process Stafford uses is designed to avoid contamination by isolating amino acids that remain in bone after most of the collagen has gone. After these acids have been isolated chemically (producing tiny samples that may weigh as little as 0.5 milligram), the carbon they contain is tested for age. In theory, this method should make ^{14}C dating available for many bones that have never been testable before.

Many of the new technologies that came to fruition in the 1980s are considered experimental even by those who use them, like Bar-Yosef. But those techniques have delivered an initial body of data and with it a potent message about the origin of mankind. That message constitutes a challenge to the established order in paleoanthropology. During the 1990s there will be further debate over these new techniques. Archeologists and anthropologists will determine to what extent they respect them and whether the information they yield is to be included in the established order that is passed along to the next generation of scholars.

■ ELIOT MARSHALL

Hearing on Lab Vandalism

In January, two University of Pennsylvania scientists became statistics in the criminal justice system's catalogue of victims. On 14 January, someone broke into the office of Adrian R. Morrison, a sleep researcher. They stole files, videotapes, slides, and computer disks, and scrawled "ALF—First Strike" on the walls. A few hours later someone claiming to represent the Animal Liberation Front called Morrison's lab and described the incident as "a gentle warning." Ten days later, a former lab technician claimed responsibility for stealing some rats used in research from the laboratory of psychologist Robert Rescorla.

In spite of the significant disruption of his work—and the threat to his future safety—it was not easy for Morrison to interest the Philadelphia police. It's hard to get local authorities excited about investigating "a ransacked office and a few stolen rats," he says. Morrison acknowledges that police in a big city like Philadelphia have a heavy burden already. But, he adds, they "don't understand what's at stake" when a research laboratory is vandalized.

Would federal authorities do better? The question arises because Congress is considering two measures that would make vandalism of animal research facilities a federal crime. The Senate version, passed in November, makes it a felony to break into a facility subject to the Animal Welfare Act; both government and corporate research facilities are covered. The maximum penalty would be imprisonment for up to 1 year or a fine of $5000. The U.S. Department of Agriculture would have the principal regulatory authority.

The House is considering a bill that is narrower in scope but carries a bigger stick. Introduced by Representative Henry Waxman (D–CA), the measure covers only federally funded health research facilities and primate centers. Conviction could carry a penalty of up to 5 years and fines. The Federal Bureau of Investigation would be enlisted to enforce it.

The Bush Administration has been silent on the Senate bill, but the House measure has provoked conflict within the Administration. The Justice Department opposes the measure on the grounds that prosecution is best left to local authorities. They have prevailed, and officially the Administration opposes the bill. The Department of Health and Human Services, on the other hand, recommended that the White House support the House measure, as deputy assistant secretary of health James Mason testified last week at a hearing before the House health and environment subcommittee, which Waxman chairs.

Recounting the attack on Morrison's lab, Mason said, his voice rising: "The people who broke into the lab are terrorists. The nation must not tolerate this kind of criminal activity."

To show the subcommittee the scope of the problem, Mason offered statistics from the National Association for Biomedical Research. According to the association, in the past 8 years there have been 71 incidents involving theft, firebombing, bomb threats, or arson against facilities connected with animal research. One in five entailed bomb (or other) threats, and one in ten involved actual or attempted arson, bombing, or firebombing.

Mason argues that such attacks are damaging research. In the past 2 years the number of published articles on drug addiction based on animal research fell by 62%, he testified. The Public Health Service, Mason says, has "anecdotal information indicating a link between this drop in research and threats by animal rights extremists."

But opinion remains divided over whether making lab vandalism a federal crime is the best solution. Staff aides from the House agriculture subcommittees, which are holding an oversight hearing February 28 on protection of animal research facilities, say critical data are lacking. Supporters of the House measure contend that local authorities are hampered in prosecutions because the people who carry out the breakins sometimes flee across state lines. But no one has figures on how often this occurs, leaving open the question of how much federal intervention would help.

Meanwhile, Mason pointed out to Waxman's subcommittee, some observers feel young researchers may choose not to go into biomedicine due to obstacles raised by animal activism. The "loss of bright and dedicated people to the field of biomedical research is a grave concern in the long run," Mason said. ■ MARJORIE SUN