

In our human origins toolbox, the paleoanthropology of 30 years ago has been augmented by 30 year's worth of new discoveries and the invention of more elegant ways of examining the fossil record. The single-gene genetics of 30 years ago is replaced by genomics, in which we are able to consider entire genomes, i.e., all an organism's DNA (deoxyribonucleic acid), or very large portions of them, at the same time. And the older evolutionary theory has been refined, tested, and revised to yield a more coherent body of knowledge with new analytical tools.

#### THE PALEOANTHROPOLOGICAL TOOLS

The study of human fossils goes back over 150 years, but paleoanthropology as we know it today is only as old as our fathers' toolboxes—less than half a century. Before the middle of the 20th century, most of those who studied human fossils were human anatomists, but in the 1960s, Louis and Mary Leakey assembled a group of specialists to help them study not only the human fossils they had found at Tanzania's Olduvai Gorge, but their age and environmental and archaeological contexts as well.

Thus was born paleoanthropology as an essentially collaborative enterprise, with specialists of many kinds contributing to the understanding of the fossils that make up the documentary core of human evolutionary history. Nowadays it is rare for an expedition aimed at discovering human fossils to go into the field without a whole array of members with widely differing expertise. Indeed, paleoanthropologists these days are frequently part-time, in the sense that their day jobs may well be as stratigraphers, anatomists, isotopic chemists, geochronologists, taphonomists, or many other professions. This means that while many paleoanthropologists are highly specialized, the toolbox available to paleoanthropology as a whole is amazingly broad.

Paleoanthropologists look for and collect human fossils, but they also look at how the remains of dead animals may have been preserved from destruction to become fossils. They look at the rocks that contain the fossils, and they study what those rocks can tell us about the environments in which our ancient precursors lived. They use a variety of ingenious techniques for dating those rocks, and thus for knowing when the fossil remains they collect were living, breathing animals on the landscape. They study the fossils themselves, and they do this from a whole host of perspectives. Some paleoanthropologists are most interested in identifying the species the fossils represent, so that they can proceed to figure out what parts those species played in the evolutionary story, and which other animals they were related to. Others specialize in studying how extinct human species functioned in life, what they ate, and even how they may have behaved in the social setting.

One unique feature of humans is that, since the invention of stone tools some 2.5 million years ago, they have left us a material record of their existence that extends far beyond fossils. This is the province of the archaeologists. As we'll see, the record of early human activities is very indirect and incomplete, but it has given us an amazing insight into the behavioral history of our predecessors. Like the more biological and geological areas of paleoanthropology, Stone Age archaeology itself is becoming increasingly subdivided into specialties.

But paleoanthropology doesn't stop there. It borrows from its sister sciences more liberally than any other specialty. Neurologists, demographers, physiologists, ethnographers, primatologists, ethnologists, philosophers, and a host of other kinds of scientists and scholars find their work freely appropriated by paleoanthropologists, who, after all, seek

to understand both humanity and the background from which we emerged in all of their many dimensions. Even parasitologists have lately become involved, for the good reason that virtually any aspect of biology finds an expression of some kind in the species *Homo sapiens* and its precursors. This makes paleoanthropology both intrinsically among the most exciting of the sciences, and perhaps the trickiest to characterize. We'll look more closely at the sheer diversity of paleoanthropology in the next chapter.

#### THE GENOMICS TOOLS

If one wants to follow the history of modern humans, or of any living organism for that matter, genes are a valid way to go. As we will discuss in later chapters, genes are the hereditary units of organisms. Genes are made up of a substance called deoxyribonucleic acid, or DNA. Because of DNA's unique structure it is an ideal molecule for carrying information. And because DNA can be copied readily and, for the most part, faithfully, it is also well-suited for transmitting information from one generation to the next.

Each species has a more or less set number of genes that are arranged in groups on large structures called chromosomes. The Indian muntjac, (a tiny barking deer), has the fewest chromosomes of any mammal (three chromosomes that pair to make six in most cells of the body), and all of its genes (probably more than 25,000 of them) are packed onto these three chromosomes. Humans have 23 pairs of chromosomes into which all of our 25,000 genes are packed. Almost every cell in our bodies has these 23 chromosome pairs in it, so that our bodies are a collection of millions and millions of sets of 23 pairs of chromosomes. All of these 23 chromosome pairs together make up what we call the human genome. Understanding how these 23 pairs of chromosomes are inherited can help geneticists and human biologists understand the history of human populations and of human origins.

Prior to the 1970s, genetics in the study of human origins used mostly blood-group analysis. Everyone today should know his or her ABO blood type, because blood type is critical for the success of blood transfusions. The ABO blood-type system is controlled by a gene that determines the structure of blood cell surface molecules that can vary from human to human. Researchers in human origins would collect blood samples from a wide variety of people, determine the various blood types, and use the blood-type frequencies as a proxy for understanding the underlying genetic changes. While this information was important, and molded some of the first hypotheses tested about human genetics, the technique could only obtain information on a small portion of the human genome – either one gene or a very few genes.

Later, a way of looking at proteins not associated with red blood cells was developed, but even these protein techniques could only process a few or at most tens of genes for examination. Things changed drastically with the development of modern molecular biology, and of high throughput DNA-sequencing techniques that allow us to characterize the DNA itself. The genomic revolution began in the 1980s, when a group of scientists began suggesting that the entire human genome, that is, all of the genetic information in the chromosomes of a human, could be "read" using biochemical methods that we will describe later. In the early 1990s, the technological advances that were needed to automate the deciphering of the bits of information in a genome (called bases or nucleotides) were invented. The first genome of a living organism was sequenced in 1996. The organism was *Haemophilus influenzae* or plain old "H flu." The completion of

H flu was followed by completion of the baker's yeast genome, followed by a nematode (a worm) genome and the fruit fly genome. In 2000, the National Human Genome Research Institute at the National Institutes of Health (NIH), in coordination with a company called Celera Genomics, announced the finishing of the first draft of the human genome. Nearly all of the 3 billion bits of information in the human genome had simultaneously been deciphered by both NIH and Celera in this first-draft preparation. Shortly after this announcement, the mouse genome and some plant genomes were finished, and in the last half of 2005, scientists at NIH announced the completion of the second full primate genome—the chimpanzee's—a subject that we will touch upon later.

While the sequencing of whole genomes opens up enormous potential for understanding the workings of the human genome, the techniques that were developed to sequence the human genome can be used to examine large numbers of humans for large numbers of genes. These new techniques have revolutionized the ways human genes are interpreted in the context of human origins and human movement.

### THE EVOLUTION TOOLS

Evolutionary biology did not become a fully fledged discipline until scientists figured out a way to meld the ideas of descent with modification and natural selection with the mechanisms of genetic transmission. The basic rules of genetics were published by the Czech cleric Gregor Mendel in 1866, but it was not until after they were rediscovered in 1900 that the melding of evolution and genetics began. Experimental, theoretical, and mathematical approaches to evolution followed, and ultimately a notion of evolutionary biology called "the Modern Synthesis" came about, wherein population genetics and evolution were integrated, essentially by reducing evolutionary phenomena to generation-by-generation changes in gene frequencies within populations, under the guiding hand of natural selection.

Along the way, though, evolutionary biologists discovered that in addition to natural selection, several other factors could influence changes over time—among them small population sizes, large amounts of mutation, inbreeding, and large amounts of migration.

Of these four new influences one—small populations—is widely considered one of the most important in evolutionary biology in general, and in human origins in particular. This is because only in small populations can random chance radically alter the frequency of genes. To understand this, try flipping a coin 200 times straight and counting the numbers of heads and tails. When you are finished, your totals of heads and tails will almost always be about 100 heads and 100 tails. Now try flipping the coin four times. Chances are pretty high that you might flip heads all four times. If you don't get four heads (or four tails) the first time, try it again and again; we guarantee that you won't have to do this many times before you get all heads or all tails.

Now think back to genes in human populations. What might happen if a population fell to very low numbers due to disease or a natural disaster? The answer is that the same randomness of the results that you find when you only flip your coin a few times takes over. The phenomenon with the coin is called "sampling error"; in humans (and other organisms) it is called "bottlenecking." Another way to make human populations prone to sampling error is to separate off a very small part of the population through emigration. In this case, the people who move are called "founders," and the skewing of gene frequencies in the next generation produced by those founders is called the "founder effect."

Not only has our capacity to understand how genes behave in populations advanced, but the tools available for the reconstruction of historical events have also expanded. Think back to the figure we mentioned in Darwin's *Origin of Species*. It was a tree, and through the development of genomics we now have available tree-building techniques that can analyze DNA sequence information. These are particularly useful because some DNA sequences evolve faster than outward appearances do. This means that variation at the DNA sequence level is almost always higher than the variation at the morphological level, which in turn allows us insights that we could not get purely from morphology. New techniques for dealing with the onslaught of DNA sequence information in evolution and tree building, as well as the development of large-scale computational tools for building trees, have also become a large part of the basic toolbox of evolutionary biology.

Along with an understanding of what is going on in populations at the level of the genes, and of how new features are incorporated into genomes and gene pools, huge advances have also been made in the way we view larger evolutionary patterns. In reducing the evolutionary process largely to a matter of slowly changing gene frequencies under natural selection, the Modern Synthesis produced an expectation that evolutionary change as seen in the fossil record would be a gradual affair, with species changing slowly over time as they adapted to new conditions or became fine-tuned to their old ones. Any discontinuities seen in the fossil record were attributed to that record's famous "gaps"—and there's certainly no argument with the fact that known fossils represent only the tiniest fraction of all organisms that ever lived.

Yet, as we'll explain, we can see now that there is much more to evolution than that: Evolutionary processes operate at many levels, all the way up from the genes and individual organisms to local populations, species, and even entire ecological communities. What's more, evolutionary change seems most often not to be continuous, but to happen in spurts; and the mechanisms underlying the appearance of new species and new morphologies are not the same. Indeed, it seems to be inaccurate to speak of *the* evolutionary process; in the long history of life many different processes have intervened, all of which have left their mark on its evolutionary outcome.

## Why All of This is Important

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As we were writing this chapter, yet another challenge to the teaching of evolution and natural origins in United States classrooms loomed just a couple hundred miles from our offices in New York City. Ironically, on the 80th anniversary of the Scopes trial, at which the renowned lawyer Clarence Darrow and the populist leader William Jennings Bryan argued the evolutionist schoolteacher John Scopes' fate in a Dayton, Tennessee, courtroom, the judicial system in Dover, Pennsylvania, faced a similar challenge. But this time, it came in the guise of a newly coiffed, dressed-up and manicured name for creationism: "intelligent design." In Dover, the U.S. District Court for the Middle District of Pennsylvania was hearing a challenge to the way evolution is taught in the town's public high school. A lawsuit (*Kitzmiller et al. vs. Dover Area School District et al.*), brought by a group of parents, contested a policy implemented by the city of Dover's school board requiring that a disclaimer be read in science classrooms calling attention to alleged failings in evolutionary theory and suggesting that alternatives be examined in the form of a so-

called "new" way of looking at the problem of origins called "intelligent design." [Figure 7] By a 6-3 vote, the Dover school board approved the following resolution:

Students will be made aware of gaps/problems in Darwin's theory and of other theories of evolution including, but not limited to, intelligent design.

At the time of the imposition of the disclaimer, the Dover school board was led by conservative Christian members of the community, and the parents who filed the suit were angry that what they considered a nonscientific idea (intelligent design), was to be taught as science in their classrooms. Here is what the disclaimer said:

The Pennsylvania Academic Standards require students to learn about Darwin's Theory of Evolution and eventually to take a standardized test of which evolution is a part. Because Darwin's Theory is a theory, it continues to be tested as new evidence is discovered. The Theory is not a fact. Gaps in the Theory exist for which there is no evidence. A theory is defined as a well-tested explanation that unifies a broad range of observations. Intelligent Design is an explanation of the origin of life that differs from Darwin's view. The reference book, *Of Pandas and People*, is available for students who might be interested in gaining an understanding of what Intelligent Design actually involves. With respect to any theory, students are encouraged to keep an open mind. The school leaves the discussion of the Origins of Life to individual students and their families. As a Standards-driven district, class instruction focuses upon preparing students to achieve proficiency on Standards-based assessments.

For six weeks, testimony from many experts on both sides ensued. The testimony focused on whether intelligent design (ID) is, in fact, scientific. Two aspects of this matter were examined in the trial. First was the question of whether intelligent design meets the criteria to be called science. The second and more practical question was whether publications on intelligent design are properly peer-reviewed, as is routine in science. While we were finishing this chapter, the decision came down from Judge John E. Jones III. His 139-page opinion is stunning enough for us to look at it in some detail.

Kenneth Miller of Brown University was the lead witness for the prosecution. Miller has written several biology textbooks, and he testified at length concerning the lack of scientific attributes in intelligent design. Robert Behe of Lehigh University in Pennsylvania was the star witness for intelligent design. Behe has applied the concept of irreducible complexity to only a few select systems: (1) the bacterial flagellum; (2) the blood-clotting cascade; and (3) the immune system. Behe's testimony was soundly refuted by Miller, as summarized in the following quote from the judge's decision:

Contrary to Professor Behe's assertions with respect to these few biochemical systems among the myriad existing in nature, however, Dr. Miller presented evidence, based upon peer-reviewed studies, that they are not in fact irreducibly complex.

In fact, there isn't a single peer-reviewed scientific article on intelligent design. More to the point, the judge addressed the scientific approach in intelligent design:

IN THE UNITED STATES DISTRICT COURT  
FOR THE MIDDLE DISTRICT OF PENNSYLVANIA

TAMMY KITZMILLER, <u>et al.</u>	:	Case No. 04cv2688
	:	
Plaintiffs	:	Judge Jones
	:	
v.	:	
	:	
DOVER AREA SCHOOL DISTRICT, <u>et al.</u>	:	
	:	
Defendants.	:	

MEMORANDUM OPINION

December 20, 2005

**INTRODUCTION:**

On October 18, 2004, the Defendant Dover Area School Board of Directors passed by a 6-3 vote the following resolution:

Students will be made aware of gaps/problems in  
Darwin's theory and of other theories of evolution  
including, but not limited to, intelligent design.  
Note: Origins of Life is not taught.

On November 19, 2004, the Defendant Dover Area School District announced by press release that, commencing in January 2005, teachers would be required to read the following statement to students in the ninth grade biology class at Dover High School:

The Pennsylvania Academic Standards require students  
to learn about Darwin's Theory of Evolution and

Accordingly, the purported positive argument for ID does not satisfy the ground rules of science which require testable hypotheses based upon natural explanations. ID is reliant upon forces acting outside of the natural world, forces that we cannot see, replicate, control or test, which have produced changes in this world. While we take no position on whether such forces exist, they are simply not testable by scientific means and therefore cannot qualify as part of the scientific process or as a scientific theory.

Judge Jones was extremely clear about the lack of any scientific approach in intelligent design, but he did not stop there. Because the entire problem with teaching intelligent design is one of separation of church and state, or one of maintaining the Establishment Clause of the U.S. Constitution, the judge had also to address this problem with respect to intelligent design and the Dover school board. What he concluded was amazing. First, he asked what, as it is not science, intelligent design actually is. His answer was as follows:

The facts of this case make it abundantly clear that the Board's ID Policy violates the Establishment Clause. In making this determination, we have addressed the seminal question of whether ID is science. We have concluded that it is not, and moreover that ID cannot uncouple itself from its creationist, and thus religious, antecedents. Both Defendants and many of the leading proponents of ID make a bedrock assumption which is utterly false. Their presupposition is that evolutionary theory is antithetical to a belief in the existence of a supreme being and to religion in general. Repeatedly in this trial, Plaintiffs' scientific experts testified that the theory of evolution represents good science, is overwhelmingly accepted by the scientific community, and that it in no way conflicts with, nor does it deny, the existence of a divine creator.

Intelligent design is thus nothing more or less than creationism in disguise, but Judge Jones didn't stop there. He also asked if the Dover school board was honest in its attempts to propose ID as a scientific approach to origins on this planet. If board members honestly thought that ID was scientific, but were misled or had misinterpreted ID as scientific, then the judge might have taken another tack. But he found that:

The citizens of the Dover area were poorly served by the members of the Board who voted for the ID Policy. It is ironic that several of these individuals, who so staunchly and proudly touted their religious convictions in public, would time and again lie to cover their tracks and disguise the real purpose behind the ID Policy.

Finally, in detailing all of this, Judge Jones ended his decision by filling a hole in the decision that is almost always raised in legal actions such as the Dover trial. Many judges are accused of being activists and not judges. This is because some judges can impose their own ideas on the public by their decisions, and, in essence, actively influence society rather than merely apply the law. Judge Jones makes it clear that he is not an activist:



Those who disagree with our holding will likely mark it as the product of an activist judge. If so, they will have erred as this is manifestly not an activist Court. Rather, this case came to us as the result of the activism of an ill-informed faction on a school board, aided by a national public interest law firm eager to find a constitutional test case on ID, who in combination drove the Board to adopt an imprudent and ultimately unconstitutional policy. The breathtaking inanity of the Board's decision is evident when considered against the factual backdrop which has now been fully revealed through this trial. The students, parents, and teachers of the Dover Area School District deserved better than to be dragged into this legal maelstrom, with its resulting utter waste of monetary and personal resources.

In other words, thanks for wasting my time, your time, and your children's time, but it won't happen again on my watch. Judge Jones was, by the way, appointed to his first government job in Pennsylvania by Republican Gov. Tom Ridge and then to the federal Court by President George W. Bush. He has had a record of conservative decisions in both posts, so it's hard to argue that he had an ideological axe to grind here. But the story doesn't quite end even there. Four days after testimony in the trial ended, an eight-member slate of candidates opposing the Dover ID resolution was voted onto the Dover school board. Earlier members who had supported the resolution were resoundingly ousted from the board membership.

## Even More Important

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Evolution is much more than a theory that helps us answer questions about the origin of human beings and the ever-changing nature of life on Earth—topics that are typically the focus of debates on the subject. For while these debates are important in their own right, support for Darwin's theory is bolstered by demonstrating the impacts of evolution on our lives. Modern humans are, by and large, practical people, and the practical implications of evolutionary theory on our everyday lives also shed some light on why evolutionary theory is so important. Evolutionary principles, and the predictive value of studying evolution, influence our lives in at least three major ways—in human disease research, in bioterrorism preparedness, and in energy production. [Figure 8]

First, the Human Genome Project, the multibillion-dollar international effort to sequence, interpret, and exploit the human genetic code, illustrates the significance of evolutionary theory. The field of comparative genomics enables scientists to identify genes and their functions by comparing the DNA sequences of two or more species that share a common ancestor. This is why the sequencing of more than 1,000 nonhuman genomes—from mammals to bacteria to plants—has been such an integral part of genomics. This evolutionary information helps scientists and doctors develop innovative and effective diagnostics and treatments for diseases such as cancer, diabetes, and heart disease.

Evolutionary theory enhances our ability to understand pathogens that not only might occur naturally, but that also could be used in a bioterror attack. In the event of such an attack, the rapid identification of pathogen strains using a comparative evolutionary approach (similar to that used by the Human Genome Project) has the potential to be helpful in developing countermeasures and treatments.



Evolutionary principles are being used to decipher the genomes of microbes responsible for infectious diseases. Evolutionary biology has revealed the incredible abilities of microbes that cause everything from Severe Acute Respiratory Syndrome (SARS) to avian influenza to adapt to their environments and develop deadlier strains. An evolutionary perspective helps scientists and clinicians understand how both antibiotic resistance and changes in the genes of microbes can enhance a microbe's evolutionary success and thus threaten human health.

Finally, evolutionary biology has opened up opportunities to study Earth's microbes as a possible source of clean energy. It is no wonder that J. Craig Venter, who as president of Celera Genomics led its sequencing of the human genome, is now dedicating much of his research to using comparative evolutionary techniques to develop environmentally friendly microbial energy sources.

We are worried about the impact on our nation's or any nation's scientific, medical, and public health infrastructures were the Darwinian foundations of biology to be surrendered to an ideology of creationism. Ultimately, this is not a debate about science versus faith; faith and science do not need to be exclusive of one another. After all, faith coexists quite happily with other scientific fields like physics and chemistry. Instead of debate, scientists and supporters of evolution should educate, helping the public understand both the nature of science and the basic tenets of evolutionary theory as well as the important discoveries that are made possible by the application of evolution to biology.



**FIGURE 8.** Earth's microbial diversity and evolution. A Black Smoker, source of much extremophile microbial life.

If as a society we abandon the teaching of evolution and origins in our schools, we will not only leave our children behind, but we will devastate our scientific and public health infrastructures. This will halt progress and hope on humanity's scientific frontier—and that, no amount of faith would be able to restore.

We have digressed into this important area of the role of evolutionary thought in our everyday lives because it shows the importance of understanding origins. Origins are at the heart of understanding evolution and ultimately, we believe, at the heart of understanding the human condition. It is important to think back to all of the attempts by recent humans to grapple with the almost overwhelming subject of our origins, and to view current evolutionary thought and ideas about our human origins as yet another step in becoming more human. In the following chapters we will delve into the tools that help us take the scientific journey to an understanding of our origins.

CHAPTER TWO

# PALEO- ANTHROPOLOGY

32 HUMAN ORIGINS

# WE'VE ALREADY SEEN HOW PALEOANTHROPOLOGY IN ITS MODERN GUISE GOT ITS START AROUND 1960, WHEN LOUIS AND MARY LEAKEY CO-OPTED A

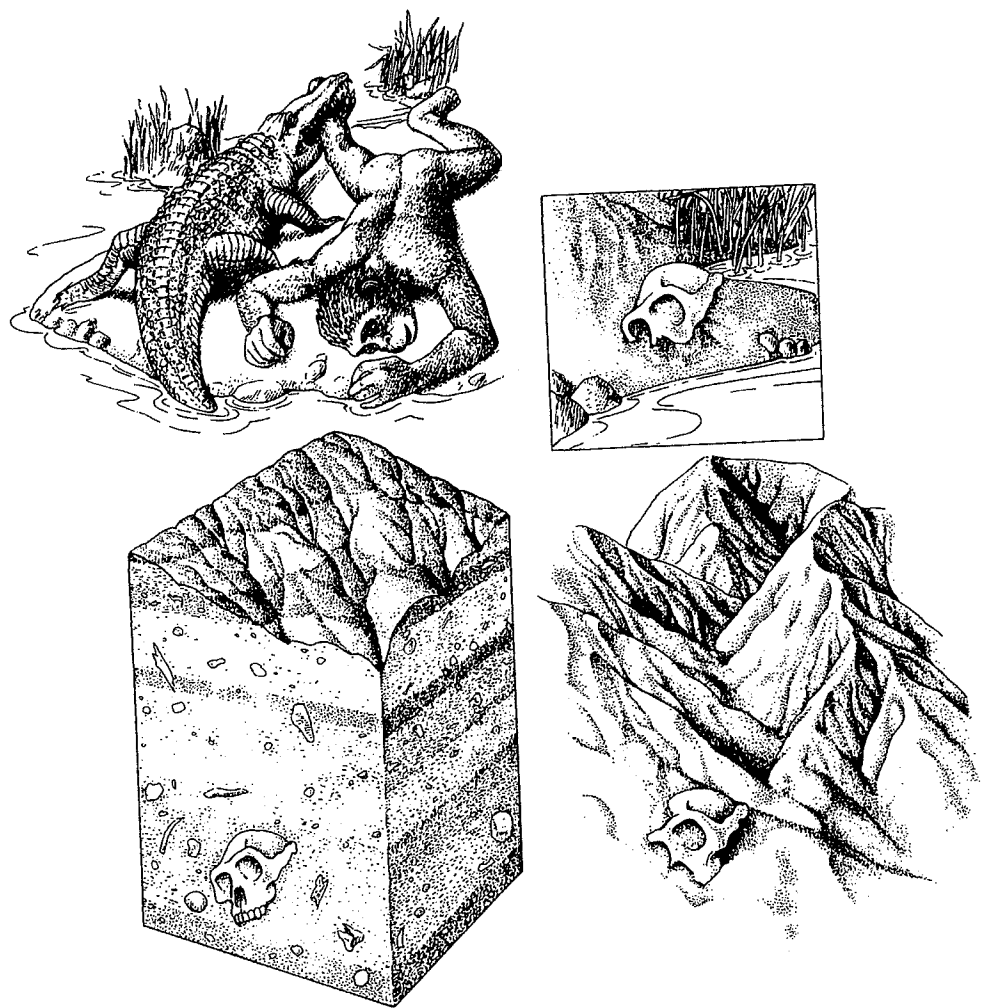
variety of specialists to work with them as they excavated the fossil human-containing deposits of Olduvai Gorge, in Tanzania. This was actually quite a turnaround for Louis, who up until then had been the personification of the "lone paleontologist." But the Leakeys had obviously hit on the wave of the future.

The collaborative theme was soon taken up on a larger scale by the American anthropologist Clark Howell, when he organized a series of field expeditions to the remote wastes of the Omo Basin in southern Ethiopia in the late 1960s. A Howell expedition could easily consist of a couple dozen members, including several Ph.D.s and, as likely as not, a helicopter, in addition to a fleet of Land Rovers. Since then, paleoanthropology has in many ways become Big Science, like genomics, and it often seems that no expedition is complete without a host of specialists in tow and often, given the wild and remote places in which human fossils are often found, a gaggle of armed guards.

Diverse as paleoanthropology is, its hard core is still the human fossil record, and any description of the science has to start with fossils, which usually consist of petrified bones and teeth, the hardest tissues in the body. Still, it is not easy even for something as tough as a bone to become a fossil on a paleontologist's workbench. [Figure 9] First of all, an animal has to die in the right place, that is to say, somewhere that it will not only escape complete obliteration by scavenging beasts, but where it will be covered by protective sediments—mud from flooding rivers, say—before wind and weather complete the destruction process. Then, the remains have to escape annihilation underground by chemical action or earth movements. After that, they have to be exposed once more by erosion of the rocks above them, and be collected by paleontologists before the elements have a chance to destroy them—which is not a good bet, for rocks containing many kinds of fossils, especially fossils as rare as human ones, are hard to find.

Even where you have located promising rocks, paleontological fieldwork can be tough indeed, especially when carried out in rough and remote country. Frequently, it involves surveying vast areas of scorching desert on foot, searching the rubbly surface for the slightest hint of bone. Worse, it is often unrewarding. Unlike all of the technical advances that have taken place in genomics laboratories in the past two decades, paleontological fieldwork is still done the old, hard way, although technology has intruded to the extent that findspots can now be pinpointed by the Global Positioning System, and satellite images of Earth's surface are now beginning to be used to identify promising rock outcrops.

Once the fossils are back in the laboratory, you have to clean them of the matrix with which they may be covered, and prepare them for analysis. This is often not easy;



**FIGURE 9.** The life history of a fossil. After death, most vertebrates will be devoured by predators or scavengers (top left). What is left over will either weather away or become buried in accumulating sediments (top right). Under appropriate conditions such buried remains may become fossilized, their constituents replaced by minerals (bottom left). If erosion subsequently wears away the sediments above, the fossil will be exposed at the surface again (bottom right). It must then be collected before it is destroyed by the elements. Illustration by Diana Salles.

adhering matrix may be rock-hard and unwilling to come away from the bone, and the fossils themselves more often than not are fractured and crushed, their pieces needing to be restored to their original relationships with one another. This can be an exacting task, and sometimes risky for the fossils themselves.

Braincases pose a particular problem, because they may be filled with tough sediment that somehow has to be removed to reveal the internal anatomy of the skull; if it was not already cracked, the only way of doing this used to be by physically breaking



**FIGURE 10.** A CT scan ("virtual image") of the 2.5 million year-old *Australopithecus africanus* cranium Sts 5 from Sterkfontein, South Africa. The bone is shown in translucent gray, while the endocranial cavity (the space formally occupied by the brain) is shown in blue. Sascha Senck, Department of Anthropology, University of Vienna; courtesy of Gerhard Weber.

the braincase open, then laboriously removing the matrix from the interior using dental tools, vibrating needles, and other devices. However, one of the most exciting developments in recent years has been the development of a "virtual anthropology," using computerized tomography scanning, originally developed for clinical use. [Figure 10] CT images of fossil braincases and other bones are often made in hospitals, usually late at night when there are fewer patients to be imaged, because patients always get priority over even the most important fossils! The scanning procedure allows three-dimensional computer images of fossils to be generated and then manipulated at will. It is possible, for example, to "digitally subtract" the matrix without having to remove it physically.

In the case of a cranium, say, this will reveal the anatomy within that is not visible from the exterior, including sinuses inside the bone that cannot be reached by any physical means. It also allows accurate measurement of the

skull capacity (a proxy for brain size), even where the braincase is still clogged with sediment. Further yet, the CT images can allow the different bits of a fractured skull (or whatever) to be virtually separated out and reassembled to provide an accurate view of what the specimen looked like when it was fresh, unbroken, and undistorted. To cap it all, the computer image can then be converted to an accurate and tangible model of what the original skull looked like, using "3-D printing" techniques originally used to produce models of broken or anomalous bony structures to help surgeons plan corrective operations.

## Inferring Environments

Almost invariably, the ancient world that the fossils lived in was very different from the world in which they are discovered by paleoanthropologists; and there are whole sub-disciplines of paleoanthropology devoted to understanding how those ancient worlds can be reconstructed from the meager indications that the paleontologist finds. This can very often be a tricky business, because the fossil animals that a paleontologist finds in a particular place are normally not a typical sample of those that lived there in the remote past. For although the "death assemblages" that a paleontologist deals with are derived from a once-living fauna, they typically consist simply of those species and bony elements that are most likely to be preserved after an often rough ride. For example, bones that