SURVIVAL OF THE ADAPTABLE

"WHEN I FIRST EXCAVATED IN THE RIFT VALLEY, IT WAS COMMON KNOWLEDGE THAT human ancestors emerged on the dry African plains," wrote Rick Potts about his work on Olorgesailie in Kenya. "Yet scrambling up even a single gully, I couldn't help but notice the evidence of vast change over time in the layers of that eroded landscape. Above the white silts of an ancient lake was the brown soil of a dry environment, covered by a gray ash violently spewed from a nearby volcano; then the lake returned, followed by a hard white line when the waters dried up completely. Was it the constant survival challenge of the savanna—or was change itself the more potent force behind the defining qualities of our species?"

The living world is a display of astonishing adaptations. These adaptations embrace all the structures and behaviors that have favored the survival and reproduction of organisms in the times and places in which they evolved. Powerful claws and a long, sticky tongue do a lot to assist an anteater in digging up and capturing ants. The short "flippers" of penguins are useless for flight, but along with the birds' insulated, bullet-shaped bodies, they help them catch fish in icy Antarctic water. The idea of adaptation extends also to behavior and interactions with other species. The African honeyguide, for example, possesses a keen instinct for finding bee nests; while the honey badger, following the bird, is capable of ripping open the nests to get to the honey, which both honeyguide and badger feed upon.

Over time, a population of organisms evolves in response to the challenges and opportunities of its environment. As grasslands expanded across Africa, prehistoric antelopes evolved teeth that could efficiently chew tough blades of grass that grew on the plains. As the grazing herds expanded, flesh-eating cats became fast, effective killers, and hyenas evolved powerful jaws to crack open the nutritious marrow bones that no other carnivore could break.

Our bipedal cousins were no different. In the lineage of *Paranthropus boisei* the molar and premolar teeth became larger over time, and powerful jaw muscles focused the force on these teeth in a way that favored chewing tough

Opposite: *Molten lava fills the sky above a volcano in Iceland. Violent natural events, now as over millions of years past, signal our planet's dynamic nature and remind us that human evolution occurred in conjunction with ever changing environments.*

A Nile crocodile attacks a wildebeest crossing a river in Kenya. Our ancestors were vulnerable to many of the same dangers as other creatures were.

and abrasive foods. Considerably later, the short extremities and broad bodies of *Homo neanderthalensis* helped conserve heat and served as adaptations to the cold conditions of Europe in which this species initially evolved.

One of the basic principles of biology, therefore, is that adaptations emerge as organisms face the ongoing tests of survival in their surroundings—finding food, avoiding predators, attracting mates, warding off the cold, and locating shelter.

ADAPTIVE CHALLENGES

Our species, *Homo sapiens,* is recent on the evolutionary scene, having first appeared only about 200,000 years ago. Although all earlier hominins are now extinct, many of their adaptations for survival—an appetite for a varied diet, making tools to gather food, caring for each other, and using fire for heat and cooking—make up the foundation of our modern survival mechanisms and are among the defining characteristics of our species.

Life was not easy for our ancestors. Without claws or canines, the earliest hominins were physically more or less defenseless. Like other primates, they could probably toss rocks, wave sticks, and create a big fuss when threatened. They probably slept in trees at night or, at a minimum, huddled together in groups on the ground.

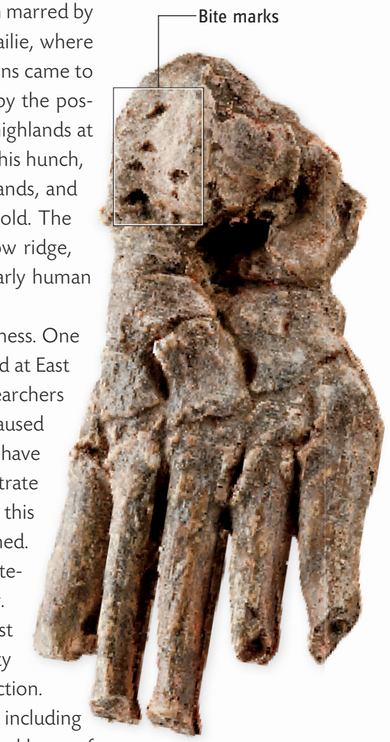
The hunting and scavenging efforts of later hominins, including the first to make stone tools, brought them close to animals that could injure them. They were meals for crocodiles and hyenas, as well as for big cats. Flash floods, volcanic eruptions, droughts, and other natural disasters added to their tribulations.

Early humans ultimately developed ways to cope with such dangers, but predators and scavengers always lurked. The lower jaws and limb bones of ancestors who lived between 4.4 million and 3 million years ago are often marred by the gnawing of dangerous carnivores. At the later site of Olorgesailie, where handaxes were left behind by the thousands, no early human remains came to light despite decades of searching. Then researchers were struck by the possibility that early humans at this site may have found safety in the highlands at night, when predators typically prowl near water holes. Acting on this hunch, the research team began to dig in the upper margins of the lowlands, and right away found a fossil human cranium that was 900,000 years old. The only pieces that remained were bits of the braincase and the brow ridge, which bore puncture marks from the teeth of a carnivore. This early human never made it home.

Fossil human remains evince clues to other dangers, including illness. One example is a *Homo erectus* adult female whose skeletal remains, found at East Turkana, Kenya, were covered in a layer of abnormal bone. Researchers diagnosed a painful condition in which her bones essentially bled, caused by a disease associated with an overdose of vitamin A. How could this have happened? It turns out that the livers of carnivorous animals concentrate this vitamin at a level extremely toxic to humans, who fall victim to this terrible condition when the liver of a predator is accidentally consumed. Eating meat and even killing carnivore competitors were survival strategies of our ancestors, but in this case, a small mistake proved deadly.

Without medicine, even minor infirmities could be fatal. The robust appearance of the Kabwe cranium from Zambia belies the possibility that this *Homo heidelbergensis* individual died from a small but fatal infection. This individual is one of the oldest known to have had tooth cavities, including ten that invaded the upper teeth. A small perforation in the temporal bone of the skull leads to a larger pit on the interior and shows that either dental disease or a chronic ear infection was the cause of death.

What about fossil evidence of murder or even warfare? Wooden spears about 400,000 years old are preserved, and stone spheroids that could have been thrown date back nearly 2 million years. However, there is no evidence that multiple hominins ever died at the sites where they have been found. The earliest known death from a sharp stone point occurred in one of several Neanderthal individuals buried during thousands of years in the Shanidar Cave of northern Iraq, dated between about 45,000 and 35,000 years old. A severe wound to one of this individual's ribs resulted from a forceful thrust of a stone tip from the left side. Before this, there is no sign of intentional injury in the fossil record. Multiple



Bite marks similar in shape to those made by the teeth of living crocodiles remain in the ankle bone of a partial foot, suggesting the fate of a 1.8-million-year-old Homo habilis.

deaths in one place as the result of warfare occurred only more recently and are associated exclusively with our own species.

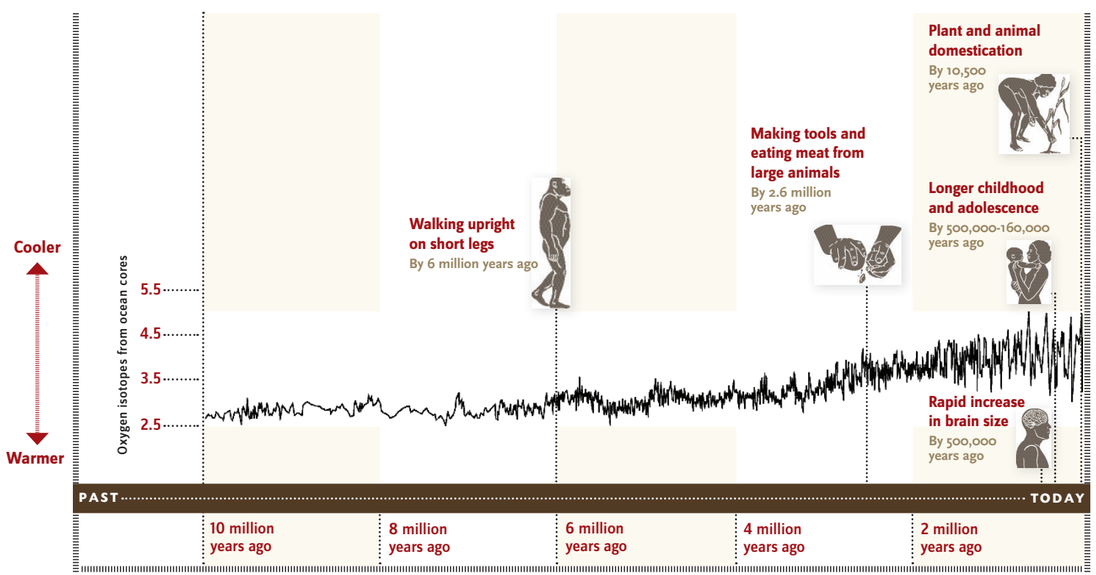
APPROACHES TO SURVIVAL

With all the signs of injury, disease, and death, one might wonder how our early ancestors survived at all. But this gives the wrong picture. Although early hominins may have been relatively defenseless from a physical standpoint, part of their primate heritage included impressive defenses against predators, including being social and vocal. Primates in social groups keep watch over each other. Together, they can stay aware of predators and may gang up to scare them away. Many primates have warning calls as well; some are specific to attacks from birds, snakes, and leopards. Social and vocal behaviors like these may have made it reasonably safe for our ancestors to venture away from the trees in the first place.

Throwing stones and using weapons were important additions to self- and group defense. There is also clear evidence that by about 800,000 years ago some hominins had controlled fire and built well-defined hearths. Most animals have an innate fear of fire and would be likely to have kept their distance from a campfire. The light from the campfire would also have helped our ancestors avoid surprise attacks. Between 800,000 and 400,000 years ago, when we see strong evidence for building both shelters and hearths, the level of human social cooperation had reached a crucial milestone.

Earth's Changing Climate and Human Evolution

Earth's climate has fluctuated between warm and cool over the past ten million years. The ratio of two oxygen isotopes, as measured in cores drilled from the ocean bottom, ranges from about 2.5 to 5.0 parts per million. This measure reflects both worldwide ocean temperature and the amount of glacial ice. Particularly dramatic fluctuations marked the six-million-year period of human evolution.



Possibly the ultimate evidence that social support had become an essential part of the human survival package is purposeful burial. Instead of leaving the dead where they lay, Neanderthals and modern humans buried their dead. It could be argued that this was simply a sanitary measure, but there is evidence that suggests far more was going on. We can see this at Shanidar Cave, where an adult male Neanderthal was carefully placed on his side in a shallow grave in a fetal position. There is good evidence that colorful flowers and evergreen boughs were intentionally placed in the burial with him.

Since the physical remains of the deceased do not benefit from burial goods or rituals, did mortuary practices develop mainly as an advantage to the living? The significance of the earliest burials, at least 100,000 years ago, may be twofold. First, rituals reinforce social bonds and may have helped earlier human groups cope with life's difficulties by allowing grieving. Second, burials show that humans were able to conceive of something other than the immediacy and harsh realities of their daily lives. Perhaps they imagined an afterlife for their departed loved ones. Or perhaps a better future for themselves.

A dried-up Texas lake bed may resemble the remnants of African Rift Valley lakes that disappeared during prolonged droughts.

ADAPTATIONS AND ADAPTABILITY

The causes of death offer clues to the events of natural selection that helped shape our human ancestors' adaptations. But there was another, equally pervasive influence on evolution—the uncertainties of climate change. While predation and disease exerted an ever present risk, uncertainties in the supply of food and other necessities also posed an incessant challenge to survival.

What happened as early humans tried to adjust to weather variations from one season to another or to wider swings in rainfall and temperature over time? And what about the misfortunes visited upon them by monsoons, intense droughts, or massive volcanic eruptions?

A species depends not only on the particular way of life that best matches its surroundings but also on keeping certain options open and adjusting to whatever trials or opportunities occur as things change. The process of evolution not only shapes adaptations to specific habitats but also shapes ways of life that confer a certain degree of *adaptability.* Since individual species may persist for hundreds of thousands, sometimes millions, of years, the capacity to adjust to novel situations is an important outcome of evolution, offering resilience and an ability to recover from difficult times.

This idea of adaptability has now become a pillar in the understanding of human origins. One reason is that our own species, *Homo sapiens,* may well be the most adaptable mammalian species ever to evolve on Earth. Just look at all the places on the planet where humans live today, at our capacity to alter our surroundings to suit our tastes, and at our propensity to seek out completely novel and challenging places to visit, even outer space.

Scientific research shows now that the period of human evolution has been one of the most volatile eras of environmental change in our planet's history.

Evidence of vast swings between wet and dry, and between warm and cold, casts our own survival story in a new light.

ERRATIC ENVIRONMENT

Some time ago, any question concerning the environment in which humans evolved seemed entirely resolved: Early humans were adapted to the African savanna. Walking upright on two legs and making implements were critical to the survival of ancestors who ventured onto the dry, dangerous plains. As grasslands spread, hunting and eating meat proved advantageous. The control of fire staved off predators. With the expansion of early humans into Asia and Europe, the challenges of the Ice Age helped hone the capacity for social cooperation. Speaking to one another helped pass on the traditions of toolmaking. Eventually, language allowed technological innovations to catch on and creative endeavors, including art, to blossom. All the way back to the earliest bipedal predecessors, one survival skill led to another, which spurred on still newer adaptations—all against the backdrop of the arid equatorial savanna and the frigid northern landscape.

This notion of a straight line trending toward a drier, colder climate has now been replaced, however, by evidence that past climate fluctuation looked more like a rambunctious zigzag. The survival conditions of human evolution were continually revised as climate oscillated between arid and moist and between cold and warm. Scientists now speak of the *environments* of human evolution, with emphasis on variability. And they consider the instability of environments, not merely the expansion of grasslands or glaciers, as having shaped the evolved characteristics of human beings.

This relatively new theme in the story of human origins is still a matter of hypothesis—an overall explanation that is tested again and again as new details come to light. One of the exciting challenges in the field of paleoanthropology is to better understand how our own ancestors may have evolved adaptations to *change*—to what researchers call *environmental dynamics*—rather than to any single setting or environmental trend.

Evidence about past climates is, naturally, an inspiration for this environmental variability hypothesis. An important record of global climate change comes from oxygen measurements in ocean microorganisms called foraminifera. Forams, as they are also known, use oxygen in their immediate surroundings to build their tiny calcareous skeletons. As the planet has cooled and warmed, the levels of different forms, or isotopes, of oxygen have changed. Because the lighter isotope more easily evaporates than the heavier one, it was extracted from the oceans and incorporated into the expanding ice sheets on land. When these glaciers melted, the water composed of lighter oxygen flowed back into the ocean. Oxygen measurements of the forams obtained from the deep-ocean floor document these fluctuations in Earth's temperature and ice volume over time.

How do we know about climate history?

Researchers have many different methods to interpret Earth's climate history.

Drilling sediment layers from lake and ocean floors produces long cylinders called cores. Drill cores are also collected from the thick ice layers of glaciers and ice sheets. The depths (or lengths) of cores correspond to time, with the most recent layers near the top. By studying trapped gas, pollen, charcoal, and microorganisms deposited in each layer, scientists can infer changes in past climate.

Tree rings and coral are proxies for climate because their periodic growth rates are affected by environmental conditions.

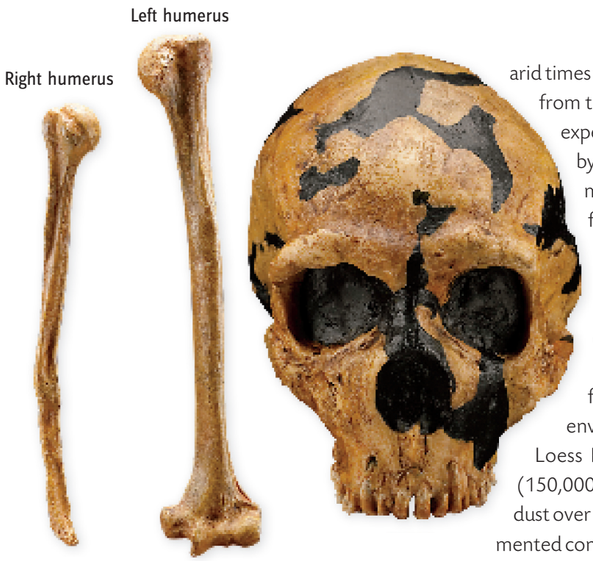
Cave formations provide useful information because they accumulate more or less rapidly in relation to how wet or arid, respectively, the environment is.

Fossil plants and animals are used to reconstruct ancient environments and climates. Fossilized leaves, seeds, bark, roots, and pollen are also direct indicators of ancient climate. Drawing upon the habitat preferences of living animals may help us use animal fossils to infer past habitats.

When we look at the oxygen climate curve all the way back to 70 million years ago, we see that Earth has indeed cooled dramatically, especially over the past several million years. Important details come into focus when one examines the past ten million years. This shorter record, which includes the era of human evolution, shows that the cooling actually involved sharp fluctuations between warm and cool. The oscillations began to pick up around six million years ago, near the time the earliest human ancestors originated. The genus *Homo* evolved later, during a time of even greater climate fluctuation. And the immediate predecessors of our own species, *Homo sapiens,* evolved as climate instability maxed out with the widest oscillations.

An equally compelling climate record focuses on the moist-arid fluctuations in Africa. Cores drilled from the bottom of the Mediterranean Sea give us a long archive of black mud layers that alternate with lighter bands of silt. The two types of sediment are derived from the Nile River. The dark layers are evidence of strong monsoons that washed black mud, rich with organic material, from the huge Nile watershed into the Mediterranean, while the light bands indicate

Sediments at Olorgesailie, in Kenya, contain a wealth of information about climate change over the past 1.2 million years. White and beige sediments reflect the area's alternation between a large lake and dry land, respectively. Brown sediments represent deposits of a river that flowed through valleys eroded into the older lake beds.



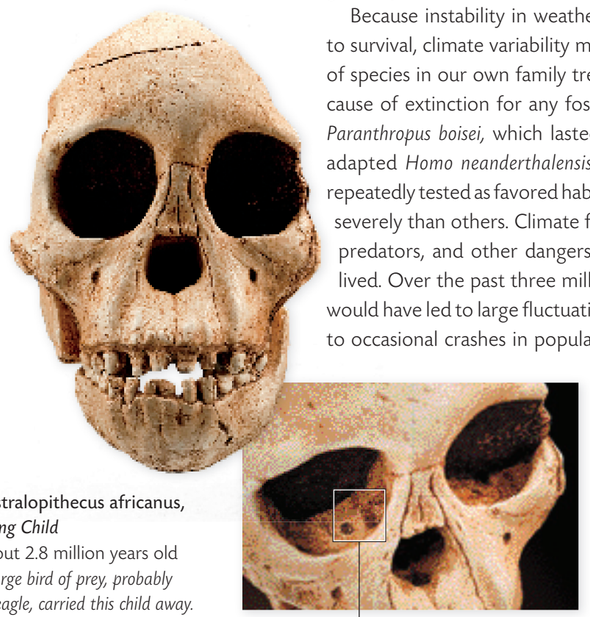
Homo neanderthalensis, *Shanidar 1*
About 45,000 to 35,000 years old
This Neanderthal survived a crushing blow to the left side of his head and had a withered right arm (left).

arid times when rainfall declined and vegetation shrank. The record from the past five million years shows that early human species experienced periods of relatively stable climate interrupted by even longer periods when strong shifts between arid and moist conditions took place. Each interval lasted from a few thousand to several hundreds of thousands of years. This long-term switching back and forth between high and low climate variability had a persistent influence on the survival and ways of life of early humans as they evolved in Africa.

Environmental records from all over the world confirm the magnitude of climate fluctuation. The longest environmental archive from any continent comes from the Loess Plateau of central China, a 400,000-square-kilometer (150,000-square-mile) region that has accumulated windblown dust over the past 21.5 million years. There, researchers have documented continuous shifting between arid periods, when loess blew in from the northern deserts, and moist times when rich vegetation converted the loess into soil. Each of these phases lasted as long as tens of thousands of years. Although the fluctuations have occurred over many millions of years, they were especially large during the past 2.6 million years, around the same time as the glacial cycles of the Northern Hemisphere began.

Because instability in weather, food, and water inevitably posed challenges to survival, climate variability may ultimately help us make sense of the demise of species in our own family tree. Usually it's very difficult to pinpoint a single cause of extinction for any fossil species. Yet the habits of the large-toothed *Paranthropus boisei,* which lasted in Africa for a million years, or of the cold-adapted *Homo neanderthalensis,* which thrived in Eurasia for 200,000, were repeatedly tested as favored habitats expanded and contracted, sometimes more severely than others. Climate fluctuation also meant variation in the parasites, predators, and other dangers that challenged human ancestors where they lived. Over the past three million years in particular, powerful climate swings would have led to large fluctuations in supplies of crucial resources, contributing to occasional crashes in population size. All of these factors can influence the survival or extinction of species.

This leads to a curious finding in the study of human origins: Our closest evolutionary cousins—species that also walked upright, made tools, and had large brains—went extinct, even though these basic characteristics were at one time considered to be the hallmarks of evolutionary success in human beings. This finding brings us back to the question of adaptability.



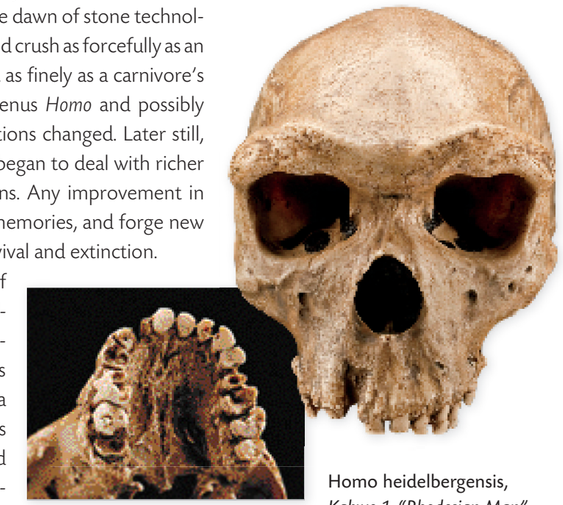
Australopithecus africanus, *Taung Child*
About 2.8 million years old
A large bird of prey, probably an eagle, carried this child away.

CLIMATE CHANGE AND EVOLUTION

The rapidly expanding data on past climate change have started to recast our ideas about the evolution of human adaptations. What benefits did those adaptations offer as our ancestors confronted shifting conditions? The advent of upright walking, for instance, did not mean that our oldest ancestors abandoned the trees entirely. Instead, they walked across open terrain *and* climbed trees in more wooded areas. But later, as African environments varied dramatically between moist and dry, the ability to walk long distances would pay off well in the diverse landscapes encountered by *Homo erectus.* Similarly, at the dawn of stone technology, the basic toolkit—including hammerstones that could crush as forcefully as an elephant's molar and sharp-edged flakes that could cut as finely as a carnivore's tooth—would enable the earliest toolmakers of the genus *Homo* and possibly late *Australopithecus* to eat new kinds of food as conditions changed. Later still, as conditions continued to change, our evolving brain began to deal with richer and more complex surroundings and social interactions. Any improvement in how quickly brains could process information, call up memories, and forge new thoughts could have made the difference between survival and extinction.

One of the most impressive and unusual aspects of humans today is the way in which we alter our surroundings. Creating stone implements, controlling fire, building shelters, growing and storing food: All represent ways of altering the immediate surroundings. Each made life a bit more predictable, furthering survival in surroundings that were prone to change. The entire package proved so successful that, eventually, the sole surviving hominin—*Homo sapiens*—was able to spread around the globe.

Certain abilities that evolved in earlier human species proved especially beneficial in times of change. Whether or not this variability hypothesis of human evolution stands up to all the tests of scientific data down the road, the drama of environmental change is now understood as a prominent backdrop to the story of our origins. In the end, it may offer new insights into the origin and current status of our own species.



Homo heidelbergensis, *Kabwe 1, "Rhodesian Man"*
About 300,000 to 125,000 years old
This Homo heidelbergensis *lived with severe cavities (left) and perhaps died from a bone infection.*

FAQ:
How does evolution occur?

Genetic variation is fundamental to evolution. A population's gene pool undergoes slight changes every generation because of mutation and the recombining of parents' DNA in their offspring.

To survive, living things adapt to their surroundings. Natural selection provides an important mechanism for change in a population's gene pool over time. A genetic variation occasionally gives a member of a species an edge. That individual passes the beneficial gene on to his or her descendants. More individuals with the new trait survive and pass it on to their descendants. If many beneficial traits arise over time, a new species—better equipped to meet the challenges of its environment—can evolve.