Paleontology
Templeton Science and Religion Series

In our fast-paced and high-tech era, when visual information seems so dominant, the need for short and compelling books has increased. This conciseness and convenience is the goal of the Templeton Science and Religion Series. We have commissioned scientists in a range of fields to distill their experience and knowledge into a brief tour of their specialties. They are writing for a general audience, readers with interests in the sciences or the humanities, which includes religion and theology. The relationship between science and religion has been likened to four types of doorways. The first two enter a realm of “conflict” or “separation” between these two views of life and the world. The next two doorways, however, open to a world of “interaction” or “harmony” between science and religion. We have asked our authors to enter these latter doorways to judge the possibilities. They begin with their sciences and, in aiming to address religion, return with a wide variety of critical viewpoints. We hope these short books open intellectual doors of every kind to readers of all backgrounds.

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With appreciation to the professors/friends who taught me paleontology (but who might not agree with everything in this book):

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Paleontology
Introduction

We human beings are the inheritors of a vast and almost unimaginably diverse world that has had a long and tumultuous history. We can infer many of the events of that history by looking around us at nature as we see it today, and at how the luxuriant diversity of living things is structured. But for the details of how things came to be the way they are—and for the drama, for drama there was, aplenty—we have to turn to the always fascinating but often tantalizingly incomplete fossil record.

The physical story of the planet is told principally in the rocks that form the Earth’s thin skin, while the history of life on this finite globe is recounted by the fossils that some of those rocks fortunately enclose. The contemplation of the fossil record can be a humbling experience, reminding us that *Homo sapiens* is but one species among many millions that have existed, and how tiny a speck we are in the immensity of time. On the other hand, it is possible also to take comfort in the knowledge that *Homo sapiens* is not alone, that we are part of a much larger whole that will continue on its own majestic course long after our species is gone. This short book espouses the latter perspective: it is about the glorious diversity of the world, about our own place in it, and about how both it and we got to be where we are today. The book is also about how we understand this story: about how we acquire and process information about our past and that of the ecosystems from which, like it or not, we are inseparable.

The study of past life is the realm of paleontology. Paleontology
is a branch of science, and science is a sector of human knowledge that differs most especially from all others in being founded on questioning and doubt. Contrary to popular belief, science does not seek to prove anything: “scientific proof” is one of the great myths of our age. Rather, science tries to home in on an ever-more-accurate picture of nature by proposing new ideas about it and eliminating false ones. Science is most emphatically not about ultimate causation, which is properly the province of philosophers and theologians. Instead, scientists strive to understand the proximate causes for natural phenomena: those processes that we can observe at work in the world, and about which we are able to form testable hypotheses.

The process of hypothesis testing renders science a system of provisional, rather than absolute, knowledge; it is no denigration of any scientific hypothesis to label it “only a theory.” Indeed, we dignify as theories those hypotheses that have proven so resistant to attack that we can sufficiently depend on their accuracy to base further explanations upon them. So an important part of what makes science truly different from other ways of seeking knowledge is simply the limitations it imposes on the kinds of questions it asks about how nature works. If you can’t test your hypothesis somehow, or if it cannot be based on testable propositions that have resisted falsification, then your question lies outside the scope of scientific inquiry.

Scientific hypotheses are usually tested by experimentation; but paleontology is a rather unusual branch of science in that it is historical. Since paleontologists are unable to rerun the tape of history, they are obliged to look at the results of experiments already made by Nature, and to reconstruct as best they can the processes that produced them. How did the riotous diversity of the living world come to be? Well, we know of only one natural process that predicts the kind of diversity-within-similarity that we see in the biota around us. That process is evolution. The repeated divergence of new species from common ancestral forms that lies at the core of
evolution inevitably results in the pattern of sets-within-sets that we actually observe. What’s more, people have for a very long time been making this observation, and drawing conclusions from it— independent of their religious, philosophical, or scientific beliefs. The physicist and science historian Jim al-Khalili has, for example, recently quoted the following from The Book of Animals by a ninth-century Arab intellectual, abu Uthman al-Jahith (781–869):

Animals engage in a struggle for existence; for resources, to avoid being eaten and to breed. Environmental factors influence organisms to develop new characteristics to ensure survival, thus transforming into new species. Animals that survive to breed can pass on their successful characteristics to their offspring.

As al-Khalili points out, these words have an eerie resemblance to those Charles Darwin would use a thousand years later in summarizing his theory of evolution by natural selection.

Closer to home, a century before Darwin published his theory, Carl Linnaeus (1707–1778), the originator of the system of naming living things that scientists use today, classified human beings in the species Homo sapiens, within the genus Homo, of the order Primates. To the conventionally religious Linnaeus it was evident, purely on the basis of our anatomical structure, that we group first with the apes (which he also placed in Homo), all of us together forming a single larger group with the monkeys and the lemurs, in contrast to all other warm-blooded, hairy mammals. This “nested” structure is repeated throughout nature (hooded crows are a kind of crow, which is a kind of perching bird, which is a kind of bird, which is a kind of backboned animal, and so forth) and it was taken for granted in folk taxonomies long before scientists came along to make a profession out of the job. Consequently, as an explanation for why we see what we see in the living world around us, the notion of evolution is as strongly supported as any hypothesis in
science. Like all science, though, evolutionary biology is a work in progress, and evolutionary biologists are constantly seeking to refine their understanding of how things got to be the way they are. Science is a process rather than a product; and as it slowly inches in toward an ever-more-accurate description of nature, it is complementary to, rather than in conflict with, the many other ways of human knowing.

Look on this book, then, as a sort of progress report rather than as a repository of fixed knowledge. Paleontology is a particularly fast-moving branch of science since it advances not simply through new analyses and new ways of extracting data from what is already known, but through new fossil finds that are constantly enlarging our base of knowledge. The fossil record is vast and constantly growing, so there is no way a short volume can do more than scratch the surface by sketching the larger picture and fleshing it out with a few carefully chosen examples. On one level my aim is to help the reader come away with an appreciation of what the record can and cannot tell us, and with a general understanding of the biological background from which modern biota and our own peculiar species emerged. More viscerally, though, I hope that the reader will gain some sense of the fun and excitement of paleontology, and of the process of discovering where we human beings fit into the natural world.
Whether or not living forms exist elsewhere in the cosmos, for all practical purposes life as we know it was born here on Earth, several billion years ago. An awful lot has happened since then, and it is in the rocks composing the surface of our planet that we find the fossils that document the long history of living things. So it seems appropriate to start this book on paleontology, the science that studies those fossils, with a few words about the planet that we take so much for granted.

The geologist Preston Cloud once neatly described our Earth as an “Oasis in Space,” which is, I think, about as apt a short description as it’s possible to achieve. Our planet today really is an extraordinary place, with an oxygen-rich atmosphere, abundant water, a hospitable range of surface temperatures, and all the other necessities for the maintenance of life as it is familiar to us today. This amazing and comfortable environment exists, moreover, in the midst of a vast, hostile emptiness. Yet life itself came into being under very different—and very much more extreme—conditions.

The matter of origins goes back in an infinite recession, to a point that lies beyond the bounds of today’s science. But scientists know the general outlines of how the Earth first began to form, some 4.5 billion years ago, out of a roiling cloud of hot dust and gases that eventually condensed to form our solar system. In early days the Earth’s surface was an inferno, assailed from below by raging radioactive heat and from above by a constant bombardment of
The publication in 1859 of Charles Darwin’s book *On the Origin of Species by Means of Natural Selection* caused an immediate social furor. But it did not burst in upon an intellectual milieu totally unprepared for evolutionary ideas. French scientists studying the newly recognized phenomenon of fossils around the turn of the nineteenth century had already entertained ideas of change, or at least of replacement, in ancient “antediluvian” faunas. In 1844 the Scottish encyclopedist Robert Chambers had (anonymously) published his theory that life had changed over time according to a principle of “progressive development.” And in Germany, too, many proponents of *Naturphilosophie* were willing to accept some inner impetus toward development among organisms.

Protoevolutionary currents were thus already stirring widely by the middle of the nineteenth century, and Darwin had mulled privately over his evolutionary ideas for almost a quarter of a century before he went public with them. Indeed, he procrastinated for so long that he was almost preempted, entirely independently, by his younger colleague Alfred Russel Wallace, whom we now honor as the codiscoverer of evolution by natural selection. Given the huge initial public fuss over Darwin’s book, it is perhaps remarkable how quickly the idea was absorbed that life had evolved—that all living organisms were related by common ancestry. This acceptance came partly because Darwin’s argument for “descent with modification” was made in exquisite detail. But it was also because the mechanism he proposed for evolution—natural selection—was such a
compelling one. Indeed, in retrospect many found this mechanism to be entirely self-evident, which is why Darwin’s colleague and supporter Thomas Henry Huxley famously berated himself with the exclamation, “How very stupid not to have thought of that!”

**Evolution by Natural Selection**

Darwin’s idea was elegantly simple. It was based, among other things, on his practical experiences as a pigeon fancier. As breeders of animals and plants had known from time immemorial, in every generation individuals vary among themselves in heritable features. Equally undeniably, more are born than survive to reproduce. Darwin’s point was that the reproductively victorious are those whose inherited characteristics make them better adapted to the environmental circumstances in which they live, while the less fit reproduce less successfully. Just as cattle breeders can change the appearance of their cows remarkably quickly by selecting those individuals that are allowed to reproduce, Nature exerts a constant pressure on the population as a whole to become better adapted. Thus, Darwin proposed, over the generations the cumulative effect of such natural selection is to physically transform each lineage of animals—eventually into new species and beyond.

Species are, of course, the basic *kinds* of organisms that we recognize in the living world, although their exact nature continues to be hotly debated. It is generally agreed that they are the largest populations of organisms within which individuals successfully interbreed with each other, but beyond this all bets are off. This is largely because speciation, the means by which new species come into existence, is not a unitary mechanism. Instead, reproductive discontinuity may come about for wildly varying reasons, from anatomical incongruity, through failures in fertilization or development of the embryo, all the way to behavioral differences. Speciation is simply a result that we observe in retrospect. Once it has taken place, though, it is typical for any successful new species
Chapter 3
The Tree of Life

“How did life get to be the way it is?” is the most basic of questions, but for paleontologists it has to be asked with two important caveats. First, evolutionary events happened in the moment, unaware of the future. Second, we need to avoid judging the past by standards of our own time, even though the best way of interpreting past forms is often to compare them with living ones.

Fortunately, today’s biota captures past diversity quite extensively, not least through living fossils, extant forms that have not changed much over time. Because of the branching nature of evolution, the history of life can be represented by a tree-like diagram, in which every species, living and extinct, takes its place at the tip of a peripheral twig. Those twigs are in turn assembled into ever-larger branches that reflect the descent of increasingly inclusive groups from ever-more-remote common ancestors.

Diagrams of this kind do not have to take the form of a typical slender tree, with a central trunk soaring toward its highest tip. Indeed, they should not. It turns out that one of the most economical ways of representing an evolutionary tree is in the form of a circle, as in Figure 3.1, which shows the relationships between the great subdivisions of life as they are understood today. Here the hypothetical ancestor lies in the center, and the individual branch tips are all of equal importance—emphasizing that, while evolution promotes diversity, it does not inexorably lead toward more complex states, and certainly not at uniform rates.
The question, “What is life?” seems pretty straightforward; the answer is less so. Modern living things are all membrane-bound entities that metabolize (convert energy) and reproduce by means of self-replicating nucleic acids. But the first organisms were probably completely unlike even their simplest descendants today.

In the 1920s it was suggested that complex organic (carbon-based) molecules might have been formed in an oxygen-free atmosphere such as that of primordial Earth, or alternatively in the “hot dilute soup” of the newly formed oceans. But in a breathtakingly prescient letter of 1871, Charles Darwin had already imagined a “warm little pond, with all sorts of ammonia and phosphoric salts, lights, heat, electricity etc. present,” in which “a protein compound was chemically formed ready to undergo still more complex changes.” In the 1950s, scientists duly generated amino acids, the building blocks of proteins, by sending electric charges through a “prebiotic soup” consisting of molecules of methane, hydrogen, and ammonia in water. Once it was established that the basic components of life could indeed be spontaneously engendered from simple and abundant inorganic precursors, the question became one of the medium in which the transformation occurred.

One leading candidate is the bottom of Earth’s late Hadean oceans. In this gloomy setting, warm, alkaline, mineral-rich underwater springs may have reacted with cooler seawater to precipitate out thin films of inorganic molecules consisting of silica, carbonates, clays, iron sulfides, and other minerals. Tower-like edifices of
this kind, composed mostly of carbonates, are known today around submarine vents that lie away from the mid-ocean ridges. Such vents furnish much less extreme environments than the scorchingly hot and highly acidic on-ridge black smokers that support “extremophile” life today. The cooler fluids they emit are well below boiling point, but in the early days the heat gradient would probably have provided enough energy to promote the production of larger, more complex organic molecules, and eventually of self-contained cells.

To be perfectly frank, we don’t know exactly how such organic chemicals began behaving like living organisms, or how they developed cellular complexity. Some scientists favor a “genes-first” notion whereby nucleic acids formed at the outset, while others prefer a “metabolism-first” scenario, in which simple metabolic pathways were initially established. However they formed, proto-organisms could have migrated into the sediments of the seabed, to initiate what has been called the “deep biosphere,” the mass of microbes that live beneath the sediments of the ocean floor. With the maturing of the Earth’s crust, some of these simple organisms would sooner or later have been upthrust into shallow waters, where the penetration of sunlight allowed them to build organic molecules based on carbon dioxide—and photosynthesis began.

This is, of course, just one scenario among several, though whatever the exact details, the basic ingredients for life were present very early on. Sadly, hardly any rocks survive from the Hadean to tell us what happened. The oldest known rocks, about 4.3 billion years old, simply confirm that crust formation began very early. Some 3.8-billion-year-old rocks in Greenland are claimed to contain the waste products of microbial metabolism, but they are pretty thoroughly altered by metamorphism and harbor an active population of cyanobacteria whose activities may have confused the picture. Thus, to begin the paleontological history of life, the history that is documented by physical remains of living things, we have to move beyond the Hadean and into the Precambrian, the period when the true sedimentary record begins. The first eon of this almost
The huge increase in animal diversity as the Paleozoic Era began appears to have been in large part a consequence of two major environmental drivers: the climatic changes that stressed the biota worldwide in the late Proterozoic and the major extension of shallow seas as Rodinia broke up. The first of these influences cleared the decks, as it were, and the second created new habitats in which the newly evolved hard-shelled bilaterans could flourish and diversify. But the Cambrian Explosion also hinged on a significant biological development: the three-layered bilateran embryo. The outer germ layer gave rise to the skin and sensory systems. The inner one generated the digestive tract and associated structures. From the middle layer the muscular and circulatory systems developed, plus a host of internal organs and, in deuterostomes, the internal support system. As body volumes grew, extra systems were needed, for the tissues could not be nourished simply by absorbing oxygen directly. Specialized circulatory and respiratory systems arose, requiring complex control that was provided by sensory organs at the head end. Here was an entirely new biology, as a result of which, by early in the Cambrian around 530 million years ago, the major groups of animals familiar in the modern biota were beginning to make their appearance.
Following the Great Dying the world was a very different place. The new Mesozoic Era of “middle life” was rapidly dominated by the diapsid dinosaurs, while the ancestors of mammals were marginalized to specialist niches.

Geologists divide the Mesozoic Era into three successive periods: the Triassic (251 million–200 million years ago), the Jurassic (200 million–145 million years ago), and the Cretaceous (145 million–65.5 million years ago). In this time Earth’s geography changed hugely: at the end of the Triassic the Pangaeon supercontinent began to fragment, and by the close of the Cretaceous the world map was just beginning to take on its familiar form.

The Mesozoic was a time of major transformation in terrestrial floras worldwide. As the era opened, ferns, cycads, ginkgos, and so forth dominated. But quite early in the Triassic, coniferous seed plants began to diversify and to assume a recognizably modern aspect. As the interior Pangaeon deserts of the Triassic gave way to generally more humid environments with tectonic breakup into the great continents of Laurasia in the north and Gondwana in the south, lush forest formations spread across the landscape. These were dominated by the conifers, although cycads and ginkgo relatives were also common locally, and the ubiquitous seed fern Glossopteris became emblematic of the Gondwanan flora. Recently, some tiny Triassic droplets of amber, 220 million years old, were found in Italy. Formed in an ancient coniferous forest, they preserve an incredibly diverse microworld of bacteria, tiny fungi, and
protozoans. These organisms include very close relatives of living counterparts—implying an amazing lack of change in the microbiota since then.

By Cretaceous times the flora was changing again, as temperatures started rising after an initial brief cooling. Botanically, by far the most significant events of the period were the origin of the flowering plants (angiosperms) in the early Cretaceous and their subsequent diversification. By a little under 100 million years ago, many groups familiar today had appeared, and by the end of the Cretaceous the flowering plants had become dominant in most terrestrial floras.

In the seas corals flourished again, although initially sparse shallow waters limited reef development. Fish lineages rapidly diversified following the Permian extinction, providing sustenance for a burgeoning variety of marine diapsids, the most successful among these being the sauropterygians (“lizard flippers”). Sharing adaptations of the shoulder girdle that made them powerful foreflipper-propelled swimmers, the sauropterygians made their debut at the beginning of the Triassic, some 245 million years ago. Eventually some became the top marine predators of their day. The longest-lived sauropterygian group was the plesiosaurs (“near-lizards”), veterans of many a “Monster of the Lake” movie.

They were not without competition, sharing the oceans with the ichthyosaurs (“fish lizards”), formidable swimmers that appeared in the record equally early. Early Triassic ichthyosaurs looked rather lizard-like, but their descendants rapidly assumed the fish-like body proportions. Showing some remarkable convergences on marine mammals as well as fish, these marine predators probably swam at speeds of up to twenty-five miles per hour, propelled by powerful side-sweeping tails.

The flourishing of marine faunas was partly due to a rise in sea levels as the Mesozoic progressed. As Pangaea split apart during the Jurassic, high rates of seafloor spreading displaced water onto the expanding continental margins and greatly increased the area
With the demise of the dinosaurs the mammals proliferated on land, and soon in the seas, too, where fish diversified along with mollusks and corals. As the Cenozoic (“new life”) Era began some 65.5 million years ago, the Earth was relatively warm, though the subsequent tendency was toward cooling and increasing temperature contrast between equator and poles. The most notable break in this trend was the “Paleocene-Eocene Thermal Maximum” around 55 million years ago, when world temperatures sharply peaked.

Oceans are major distributors of heat around the globe, and climates worldwide were greatly influenced by continental repositioning as the remnants of Pangaea continued reconfiguring toward today’s familiar geography. When Australia separated from Antarctica around 34 million years ago there was significant general cooling, as the frigid new Arctic Circumpolar Current brought cold water to the surface and isolated Antarctica from the warmer waters to its north. A major ice sheet developed on the formerly forested Antarctica, and sinking cold water began a northward flow that affected ocean temperatures right into the northern Atlantic and Pacific: an event correlated with a major faunal replacement at higher latitudes that amounted to a minor mass extinction. Radical changes also occurred some 3 million years ago when the formation of the Isthmus of Panama rerouted the world’s major oceanic currents to create the “great conveyor” that dominates oceanic circulation today. Cooling temperatures and high precipitation thereafter combined to produce an ice cap
Chapter 8
Of Whales and Primates

The mammalian menu is a rich one, especially in the Cenozoic. It includes armadillos, otters, kangaroos, shrews, civets, water rats, bats, elephants, rabbits, colugos, and rhinos, and each has its own fascinating story. Since it’s impossible to cover this vast waterfront here, let’s look more closely at the evolution of one “extreme” mammal order, the whales, and our own group, the primates.

Whales

The ancestral mammal was a land dweller. Yet many mammal groups, including most notably the otters, the seals, and the dugongs, have returned to a mainly or entirely watery existence. But none of these secondarily aquatic forms has made this transition with quite the degree of commitment shown by the members of the order Cetacea: the baleen whales, plus the toothed whales and the dolphins and porpoises. Even the dugongs, which spend their entire lives grazing in warm, shallow waters near the shoreline, retain forelimbs that are still recognizably arms, albeit greatly modified; modern cetaceans, on the other hand, are at home in the deep ocean, with entirely flipper-like forelimbs and a whole host of other adaptations to a specialized aquatic existence.

Whale body shape is fusiform (spindle-shaped) and hydrodynamic; the tail is modified into a fluked and powerfully propulsive structure (which moves up and down, mirroring the axis of bending of the terrestrial mammal vertebral column and contrasting
with that of fish, which bends sideways); the hind limbs are so reduced as not to be apparent externally (something seen also in the dugongs); and there are extensive modifications to the respiratory, auditory, visual, and other body systems. The shift from a terrestrial to a fully aquatic lifestyle, with all of the physical and physiological accommodations involved, is as radical an ecological transition as any organism can make; fortunately, we have a truly remarkable fossil record showing how whales achieved it.

When dealing with a group as highly specialized as the whales, it is often difficult to find anatomical characteristics that will help identify that group’s closest relatives. Because of this, for many years the relationships of whales to other mammals were rather unclear. The favorite candidate for a cetacean stem group was the mesonychids, superficially wolf-like primitive hoofed predators that flourished on the northern continents during the Paleocene and the Eocene. These included such extraordinary forms as the Mongolian Eocene *Andrewsarchus*, possibly the largest mammalian terrestrial predator that ever lived. They were thought to be artiodactyl relatives, but they also had rather distinctive triangular teeth that vaguely resembled those of toothed cetaceans, which they also resembled in some points of ear structure.

Mesonychids were thus considered close to whale ancestry until some biologists began thinking that, on other structural grounds, the closest relatives of the cetaceans might be the artiodactyls themselves. The initial idea here was that the whales were the closest relatives of the artiodactyls as a group. Even this seemed a bit odd to some, implying as it did that cows were more closely related to whales than to the more structurally similar horses. But worse was to come.

Early molecular systematic findings supported a general relationship between the whales and artiodactyls, while casting doubt on the comfy cohesiveness of the artiodactyls as a group. The real stunner came later, though, when on a whole variety of genetic markers the cetaceans turned out to fall well within the Artiodac-
Look closely at a chimpanzee—preferably in its environment, not yours. Its psychological resemblance to you is almost frightening. When you look into its eyes, you know something complex is going on behind them. Almost all of you is there. But not everything. It’s frustrating not to know exactly what the missing ingredient is, but as you stare it seems so small, as if the chimpanzee were but a single short cognitive hop away from you.

Chimpanzees have incredibly complex social lives. They love, they hate, they form alliances, they go to war. They hunt bushbabies with spears, and colobus monkeys in organized gangs. They use leaf sponges to soak up water, and they crack open nuts using stone anvils and hammers. They deliberately murder each other. All this and much more makes them eerily like us in so many cognitive ways—although physically, it’s maybe another matter. Chimpanzees are quadrupeds, with hands and wrists that are specialized for weight bearing, albeit in a clever way that allows them to retain slender digits with good manipulative abilities. And of course they are quite capable of walking around upright, although common chimpanzees don’t do this quite so much as their close cousins the bonobos—which, significantly, also copulate facing each other, as part of an impressive repertoire of such behaviors. Clever and adaptable as they are, though, chimpanzees and bonobos are essentially forest dwellers, with all the necessary physical equipment for life in the trees. Modern humans, on the other hand, with their tall, slender, bipedal bodies, are built for life out in the open, away from the shelter of the forest.
Chapter 10
A Cognitive Revolution

The African hominid record dwindles a bit between about 1.5 million and 1.0 million years ago, as hominids were spreading to other areas of the Old World. It contains few specimens with larger braincases than the Turkana Boy’s. Some, indeed, had smaller ones, and it is not at all evident how most of these fossils are best classified. Morphologies are quite diverse, and the picture only starts to clarify a lot later in time.

The First Cosmopolitan Hominid Species

In 1976, paleontologists found a distinctive thick-boned skull at Bodo in Ethiopia. Some 600,000 years old, it had a big, broad, and flattish face. Its brain capacity was estimated at about 1,250 cubic centimeters: not too far below the modern average. No postcranial bones were discovered along with it, but you’d guess that its skeleton had been very massively built. Most significantly, Bodo is the earliest known member of a hominid species found widely in the Old World. Similar African fossils come from Zambia and South Africa; European representatives of the same species were found in Germany, France, Greece, and maybe the United Kingdom; and a couple are known from China as well. The first of these specimens to be named was a mandible from Germany that was dubbed Homo heidelbergensis for the nearest city, and all such specimens now bear this name, regardless of where they were found. Many are poorly dated, but two European dates of around 500,000 and
400,000 years ago are probably quite reliable, and some specimens may be as little as about 200,000 years old.

It seems probable, then, that the highly distinctive *Homo heidelbergensis* originated in Africa at some time before about 600,000 years ago, and that within a hundred thousand years or so it had begun to spread to almost all parts of the Old World. This was the first truly cosmopolitan hominid species, though it seems clear that it did not completely replace all of the endemic hominids whose territories it invaded.

The earliest *Homo heidelbergensis* evidently made rather crude stone tools, but during the tenure of this species several very intriguing cultural developments occurred. The site of Terra Amata, in southern France, close to 400,000 years old, contains traces of the world’s earliest artificial shelters. One such structure was made of saplings stuck into the ground in a large oval and brought together at the top. The perimeter was reinforced with a ring of stones and, just within the entrance, a shallow scooped-out area containing blackened stones and bones indicated a hearth.

Although it doubtless represents a vitally important aspect of the lives of the Terra Amata hominids, this hearth is not the earliest one known. The most ancient well-documented claim of domestic fire use actually comes from Gesher Benot Ya’aqov in Israel, a 790,000-year-old site that lacks hominid fossils but where thick lenses of ash indicate that hominids had regularly used fire. Oddly, since this innovation must have made an enormous difference to hominid life, it is only from Terra Amata times onward that the remains of hearths become a regular feature of archaeological sites.

Evidence for early fabrication of shelters comes in only slowly, but the 350,000-year-old site of Bilzingsleben offers traces of structures, too. Also potentially (but not necessarily) the work of *Homo heidelbergensis* are some long and elegant wooden throwing spears, some 400,000 years old, found in a bog at Schoeningen in Germany. Because wood preserves only exceptionally, we have no