CHAPTER 1

Humankind Emerges: Tools and Toolmakers

Scholars customarily draw a sharp distinction between *prehistory* and *history.* Prehistory is taken to be the long era from the biological beginnings of humankind over 2 million years ago to the origins of civilization about 5,000 years ago in the first urban centers of the Near East. The transition to civilization and the advent of written records traditionally mark the commencement of history proper.

Prehistory, because of the exclusively material nature of its artifacts, mainly in the form of stone, bone, or ceramic products, has inescapably become the province of the archaeologist, while the historical era, with its documentary records, is the domain of the historian. However, the single label "prehistory" obscures two distinctly different substages: the *Paleolithic,* or Old Stone Age, which held sway for around 2 million years, is marked by rudimentary stone tools designed for collecting and processing wild food sources, while the succeeding *Neolithic,* or New Stone Age, which first took hold in the Near East around 12,000 years ago, entailed substantially more complex stone implements adapted to the requirements of an economy of low-intensity food production in the form of gardening or herding.

The technologies of both the Paleolithic and Neolithic eras have left a rich legacy of material artifacts. In contrast, only a feeble record exists of any scientific interests in these preliterate societies, mainly in the form of astronomically oriented structures. Thus, at the very outset, the evidence indicates that science and technology followed separate trajectories during 2,000 millennia of prehistory. Technology—the crafts—formed an essential element of both the nomadic food-collecting economy of Paleolithic societies and the food-producing activities in Neolithic villages, while science, as an abstract and systematic interest in nature, was essentially nonexistent, or, at any rate, has left little trace.

The Arrival of Handyman

By most accounts human beings appeared on Earth only recently, as measured on the scales of cosmic, geologic, or evolutionary time. As scientists now believe, the cosmos itself originated with the "Big Bang" some 12 to 15 billion years ago. Around 4 billion years ago the earth took shape as the third in a string of companion planets to an ordinary star near the edge of an ordinary galaxy; soon the self-replicating chemistry of life began. Biological evolution then unfolded over the next millions and billions of years. In the popular imagination the age of the dinosaurs exemplifies the fantastic history of life in past ages, and the catastrophic event—probably a comet or an asteroid colliding with the earth—that ended the dinosaur age 65 million years ago illustrates the vicissitudes life suffered in its tortuous evolution. The period that followed is known as the age of mammals because these animals flourished and diversified in the niche vacated by the dinosaurian reptiles. By about 4 million years ago a line of "ape-men" arose in Africa—the australopithecines—our now-extinct ancestral stock.

Figure 1.1 depicts the several sorts of human and prehuman species that have arisen over the last 4 million years. Experts debate the precise evolutionary paths that join them, and each new fossil discovery readjusts the details of the story; yet its broad outlines are not in dispute.

The figure shows that anatomically modern humans, *Homo sapiens sapiens,* or the "wise" variety of "wise Man," evolved from a series of human and prehuman ancestors. Archaic versions of modern humans made their appearance after about 500,000 years ago, with the Neanderthals being an extinct race of humans that existed mainly in the cold of Europe between 135,000 and 35,000 years ago. Scholars differ over the modernity of Neanderthals and whether one would or would not stand out in a crowd or in a supermarket. Many scientists look upon them as so similar to ourselves as to form only an extinct variety or race of our own species, and so label them *Homo sapiens neanderthalensis.* Others think Neanderthals more "brutish" than anatomically modern humans and therefore regard them as a separate species, *Homo neanderthalensis.*

Preceding *Homo sapiens,* the highly successful species known as *Homo erectus* arose around 2 million years ago and spread throughout the Old World (the continents of Africa, Europe, and Asia). Before that, the first species of human being, *Homo habilis,* coexisted with at least two other species of upright hominids, the robust and the gracile forms of the species *Paranthropus.* At the beginning of the sequence stood the ancestral genus *Australopithecus* (or "Southern Ape") that includes *Australopithecus afarensis*—represented by the fossil "Lucy."

This sequence highlights several points of note. First is the fact of human evolution, that we arose from more primitive forebears. Among the more significant indicators of this evolution is a progression in brain

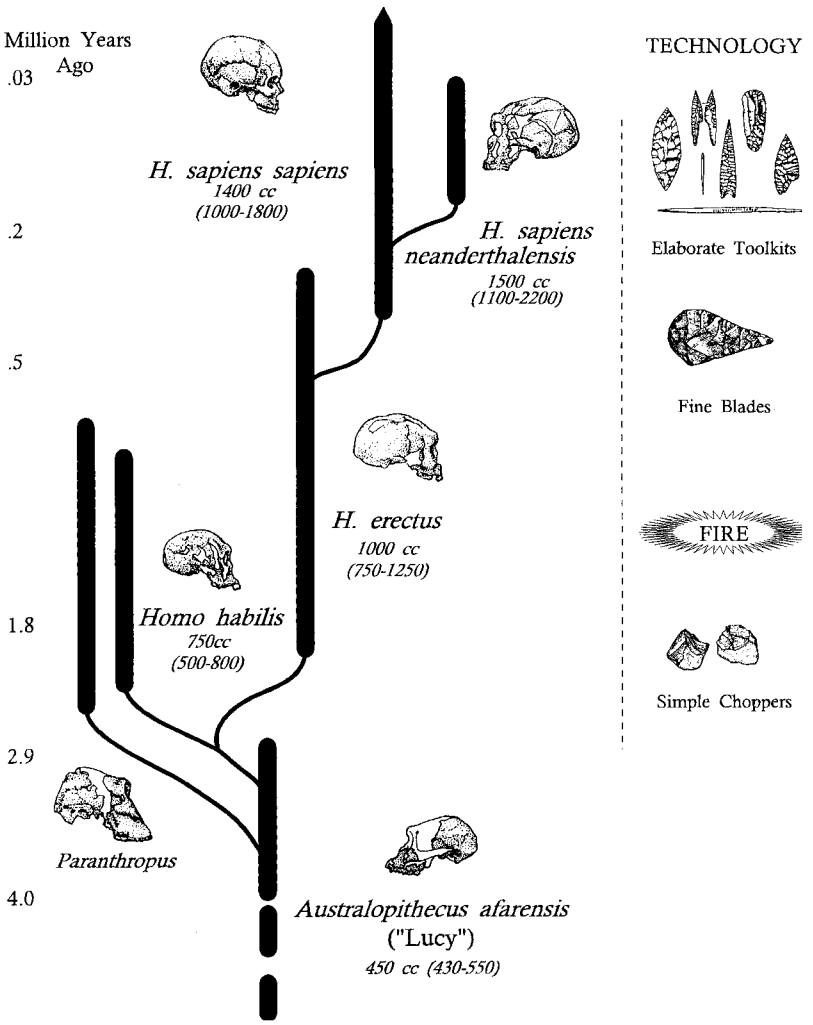


Fig. 1.1. Human evolution. Modern humans (*Homo sapiens sapiens*) evolved from earlier, now extinct, human and prehuman ancestors. (Plants and animals are classified according to the binomial nomenclature of genus and species: genus being general groups of related species, and species being specific interbreeding populations of individuals. Thus, *Homo* is the genus, and *sapiens* the species; the third name indicates a subspecies.) In general, brain size and technological sophistication increased over time, but there is no strict correlation between species and technologies. For example, *Paranthropus* and *Homo habilis* may both have used simple choppers; *H. erectus* and archaic *H. sapiens* cannot be distinguished by their respective fine-blade tool kits. Aspects of this picture are matters of debate, notably the relationship of Neanderthals to modern humans. New findings regularly shed new light on the details of human biological and cultural evolution.

size, from around 450 cubic centimeters (cc) in the case of prehuman Lucy, only slightly larger than the brain of a modern chimpanzee, through an average of 750 cc for *Homo habilis,* 1000 cc for *Homo erectus,* to around 1400 cc for humanity today. An as-yet-unexplained irony of this "progression" is that Neanderthals had slightly larger brains than today's humans.

Bipedality—or walking upright on two feet—represents another defining feature of this evolutionary sequence. Experts debate whether Lucy and her kin were fully bipedal, but her successors certainly were. An upright stance allows the hand and arm to become a multipurpose utensil for grasping and carrying items. Lucy and her type had probably adopted male-female cooperation, at least temporary pair-bonding, and a "family" structure for raising offspring.

From the point of view of the history of technology, however, the most important lesson to be drawn from figure 1.1 concerns tool use among our ancestors. It used to be thought that tool use—technology—

is an exclusively human characteristic; the oldest fossil of the human genus, *Homo habilis,* received its name ("handy man") both because of its "human" skeletal features and because it was discovered along with simple stone choppers. However, the older notion can no longer be maintained. Indeed, the origin of technology is rooted in biology. Some nonhuman animals create and use tools, and technology as a cultural process transmitted from generation to generation arises occasionally among monkey and ape communities. Chimpanzees in the wild sometimes "fish" for termites by carefully preparing a twig, inserting it into a termite nest, and licking off the insects that cling to it. Since the activity is not instinctive but is instead taught to juveniles by their mothers, it must be regarded as cultural, unlike, say, the instinct of bees to build hives. Reportedly, chimpanzees have also culturally transmitted knowledge of medicinal plants, so it may be possible to identify the origins of medical technology outside of the human genus, too. Perhaps the best documented feats of technical innovation and cultural transmission in the animal world concern a single female, Imo, the "monkey genius" of a colony of Japanese macaques. Incredibly, Imo made two separate technical discoveries. First she discovered that to remove sand from potatoes thrown on the beach she could wash them in the sea rather than pick off the sand with her fingers. Then, in an even more remarkable display of ingenuity, Imo found that to separate *rice* from sand she did not have to pick out the individual grains; the mixture can be dropped into water where the sand will sink, and the rice will float and can be easily recovered. Both techniques were adopted by younger members of the troop as well as by older females and passed on to the next generation.

Claims have been made that not only *Homo habilis* but also species of *Paranthropus* probably made stone implements and may have used fire. Furthermore, little correlation exists between species type and different types of toolkits. For example, Neanderthal tools varied little from the precedents set by *Homo erectus*. The record reveals only a weak correlation between biological species and the toolkit used.

That said, however, making and using tools and the cultural transmission of technology became essential to the human mode of existence and was practiced in all human societies. Moreover, humans seem to be the only creatures who fashion tools to make other tools. Without tools humans are a fairly frail species, and no human society has ever survived without technology. Humankind owes its evolutionary success in large measure to mastery and transmission of toolmaking and -using, and thus human evolutionary history is grounded in the history of technology.

Control of fire represented a key new technology for humankind. Fire provided warmth. Fire made human migration into colder climes possible, opening up huge and otherwise inhospitable areas of the globe for human habitation. The technology of fire also supplied arti-

ficial light, thus extending human activity after dark and into dark places, such as caves. Fire offered protection against wild animals. Fire permitted foods to be cooked, which lessened the time and effort required to eat and digest meals. Fire-hardened wooden tools became possible. And fire no doubt served as a hearth and a hub for human social and cultural relations for a million years. Their practical knowledge of fire gave early humans a greater degree of control over nature. *Homo erectus* was an exceptionally successful animal, at least as measured by its spread across the Old World from Africa to Europe, Asia, Southeast Asia, and archipelagoes beyond. That success in large measure depended on mastering fire.

The grasping hand constitutes one human "tool" that evolved through natural selection; speech is another. Speech seems to be a relatively recent acquisition, although paleontologists have not yet reached agreement on how or when it first appeared. Speech may have evolved from animal songs or calls; novel brain wiring may have been involved. But, once acquired, the ability to convey information and communicate in words and sentences must have been an empowering technology that produced dramatic social and cultural consequences for humanity.

A turning point occurred around 40,000 years ago. Previously, Neanderthals and anatomically modern humans had coexisted for tens of thousands of years in the Middle East and in Europe. Around 35,000 years ago Neanderthals became extinct, possibly exterminated through conflict with a new population, or they may have interbred and become absorbed into the modern human gene pool. A cultural discontinuity manifested itself around the same time. Whereas Neanderthals had produced simple, generalized, multipurpose tools from local materials, we—*Homo sapiens sapiens*—began to produce a great assortment of tools, many of which were specialized, from stone, bone, and antler: needles and sewn clothing, rope and nets, lamps, musical instruments, barbed weapons, bows and arrows, fish hooks, spear throwers, and more elaborate houses and shelters with fireplaces. Humans began to conduct long-distance trade of shells and flints through exchange over hundreds of miles, and they produced art, tracked the moon, and buried their dead. And yet, in terms of their basic social and economic way of life, they continued along the same path—they remained nomadic food-collectors.

Foraging for a Living

Prehistorians classify the period from 2 million years ago to the end of the last Ice Age at about 12,000 years ago as a single era. They label it the Paleolithic (from the Greek, *paleo,* "ancient"; *lithos,* "stone") or Old Stone Age. Food-collecting is its essential attribute, codified in the term *hunter-gatherer* society. Paleolithic tools aided in hunting or scavenging animals and for collecting and processing plant and animal food,

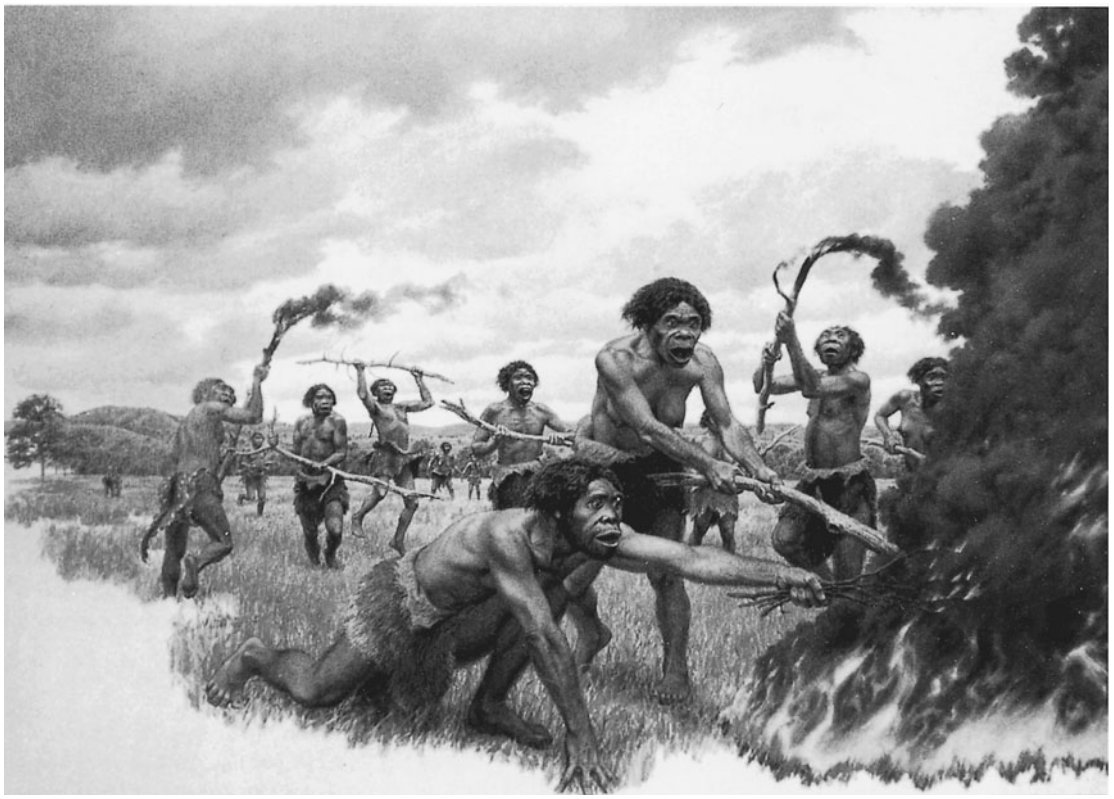


Fig. 1.2. "*H. erectus* Utilizing a Prairie Fire," by Jay H. Matternes. Control of fire became a fundamental technology in the human odyssey. Undoubtedly, members of the genus *Homo* first used wildfires before learning to control them.

and it is now understood that Paleolithic technology developed in the service of a basic food-collecting economy.

Paleolithic food-collecting bespeaks a subsistence economy and a communal society. Seasonal and migratory food-collecting produced little surplus and thus permitted little social ranking or dominance and no coercive institutions (or, indeed, any institutions) of the kind needed in stratified societies to store, tax, and redistribute surplus food. The record indicates that Paleolithic societies were essentially egalitarian, although grades of power and status may have existed within groups. People lived in small bands or groups of families, generally numbering fewer than 100. Much circumstantial evidence suggests that a division of labor based on gender governed the pattern of food collection. Although one has to allow for sexually ambiguous roles and individual exceptions, males generally attended to hunting and scavenging animals, while females most likely went about gleaning plants, seeds, and eggs as food and medicines. Men and women together contributed to the survival of the group, with women's work often providing the majority of calories. *Homo sapiens sapiens* lived longer than Neanderthals, it would seem; more true elders thus added experience and knowledge in those groups. Paleolithic bands may have converged seasonally into larger clans or macrobands for celebrations, acquiring mates, or other collective activities, and they probably ingested hallu-

cinatory plants. Except as located in a handful of favored spots where year-round hunting or fishing might have been possible, Paleolithic food-collectors were nomadic, following the migrations of animals and the seasonal growth of plants. In some instances Paleolithic groups engaged in great seasonal moves to the sea or mountains. In the Upper Paleolithic (around 30,000 years ago) spear-throwers and the bow and arrow entered the weapons arsenal, and the dog (wolf) became domesticated, possibly as an aid in hunting.

Ice Age art is the most heralded example of the cultural flowering produced after anatomically modern humans appeared on the scene. Earlier human groups may have made beautified objects of perishable materials, but several late Upper Paleolithic cultures in Europe (30,000 to 10,000 years ago) produced enduring and justly renowned paintings and sculptures in hundreds of sites, often in hard-to-reach galleries and recesses of caves. Artists and artisans also created jewelry and portable adornments, and decorated small objects with animal motifs and other embellishments. No one has yet fully decoded what purposes cave paintings fulfilled; anthropologists have suggested hunting rituals, initiations, magical beliefs, and sexual symbolism. The many "Venus" statuettes with exaggerated feminine features, characteristic of the Paleolithic, have been interpreted in terms of fertility rituals and divination of one sort or another. By the same token, they may represent ideals of feminine beauty. But we should not overlook the technical dimension of Ice Age art, from pigments and painting techniques to ladders and scaffolding. The great cave paintings of Europe are the better known, but literally and figuratively Paleolithic peoples the world over left their artistic handprints.

Neanderthals had already begun to care for their old and invalid, and by 100,000 years ago they ceremonially buried some of their dead. Centers of mortuary and burial activity may have existed, and one can speak of a "cult of the dead" beginning in the Middle Paleolithic (100,000–50,000 years ago). Intentionally burying the dead is a distinctly human activity, and burials represent a major cultural landmark in human prehistory. They bespeak self-consciousness and effective social and group cohesion, and they suggest the beginning of symbolic thought.

It may be enlightening to speculate about the mental or spiritual world of Paleolithic peoples. What we have already seen and said of Paleolithic burials and cave art strongly suggests that Paleolithic populations, at least toward the end of the era, developed what we would call religious or spiritual attitudes. They may well have believed the natural world was filled with various gods or deities or that objects and places, such as stones or groves, were themselves alive. Religious beliefs and practices—however we might conceive them—formed a social technology, as it were, that knitted communities together and strengthened their effectiveness.

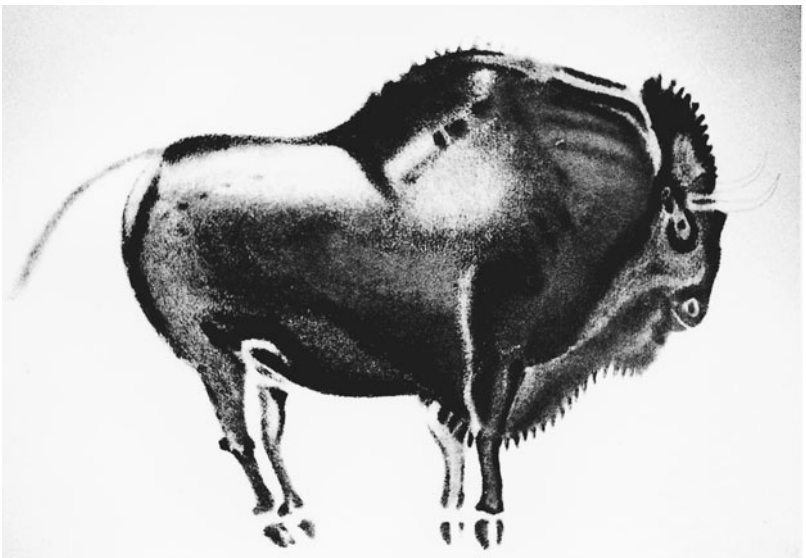


Fig. 1.3. Paleolithic art. In the late Paleolithic era food-collecting populations of *Homo sapiens* began to create art in many parts of the world. In southwestern Europe they adorned the walls of caves with naturalistic representations of animals.

For anatomically modern humans the Paleolithic way of life continued unabated and essentially unchanged for 30,000 years, a phenomenally long and stable cultural era, especially compared to the rapid pace of change in the periods that followed. Paleolithic peoples doubtless lived relatively unchanging lives involving great continuity with their own past. Well fed on a varied diet that included significant amounts of meat, not having to work too hard, cozy in fur and hide, comfortable by a warm fire, who can deny that our Paleolithic ancestors often enjoyed the good life?

Over the entire 2 million years of the Paleolithic, beginning with the first species of *Homo,* population density remained astonishingly low, perhaps no more than one person per square mile, and the rate of population increase, even in the late (or Upper) Paleolithic, may have been only one-five-hundredth of what it has been for modern populations over the past few centuries. The very low rate of population increase derives from several factors acting singly or in combination to restrict fertility rates: late weaning of infants (since nursing has somewhat of a contraceptive effect), low body fat, a mobile lifestyle, and infanticide. Nevertheless, humankind slowly but surely fanned out over the earth and, as long as suitable food-collecting habitats could be found, humanity had no need to alter its basic lifestyle. Food-collecting groups simply budded off from parent populations and founded new communities. Paleolithic peoples spread through Africa, Asia, Europe, and Australia, while waves of hunters and gatherers reached North America by at least 12,000 years ago, if not well before, ultimately spreading the Paleolithic mode of existence to the southernmost tip of South America. After many millennia of slow expansion, Paleolithic humans "filled up" the world with food-collectors. Only then, it seems, did population pressure against collectible resources trigger a revolutionary

change from food-collecting to food-producing in the form of horticulture or herding.

Is Knowledge Science?

The extraordinary endurance of Paleolithic society and mode of existence depended on human mastery of an interlocked set of technologies and practices. It is sometimes said that Paleolithic peoples needed and possessed "science" as a source of the knowledge that underpinned their practical activities. It is all too easy to assume that in making and using fire, for example, Stone Age peoples practiced at least a rude form of "chemistry." In fact, however, while both science and technology involve "knowledge systems," the knowledge possessed by food-collectors cannot reasonably be considered theoretical or derivative of science or theories of nature. Although evidence of something akin to science appears in late Paleolithic "astronomy," it evidently played no role in the practice of Paleolithic crafts. To discover the origins and character of that science we need to understand why it did not impact technology.

Practical knowledge embodied in the crafts is different from knowledge deriving from some abstract understanding of a phenomenon. To change a car tire, one needs direct instruction or hands-on experience, not any special knowledge of mechanics or the strength of materials. By rubbing sticks together or sparking flint into dry kindling, a scout can build a fire without knowing the oxygen theory (or any other theory) of combustion. And conversely, knowledge of theory alone does not enable one to make a fire. It seems fair to say that Paleolithic peoples applied practical skills rather than any theoretical or scientific knowledge to practice their crafts. More than that, Paleolithic peoples may have had explanations for fire without it being meaningful to speak about Paleolithic "chemistry"—for example, if they somehow thought they were invoking a fire god or a spirit of fire in their actions. A major conclusion about Paleolithic technology follows from all this: to whatever small extent we may be able to speak about "science" in the Paleolithic, Paleolithic technologies clearly were prior to and independent of any such knowledge.

The record (or rather the absence of one) indicates that Paleolithic peoples did not self-consciously pursue "science" or deliberate inquiries into nature. Does the Paleolithic period nevertheless offer anything of note for the history of science? On the most rudimentary level one can recognize the extensive "knowledge of nature" possessed by Paleolithic peoples and gained directly from experience. They had to be keen observers since their very existence depended on what they knew of the plant and animal worlds around them. And, like surviving food-collectors observed by anthropologists, they may have developed taxonomies and natural histories to categorize and comprehend their observations.

Even more noteworthy, the archaeological record for the late Pale-

olithic era, beginning around 40,000 years ago, offers striking evidence of activities that look a lot like science. That evidence appears in the form of thousands of engraved fragments of reindeer and mammoth bones that seem to have recorded observations of the moon. An "unbroken line" of such artifacts stretches over tens of thousands of years. The engraved mammoth tusk from Gontzi in Ukraine is an example of such lunar records, which may have been kept at all major habitation sites. Pictured in figure 1.4, it dates from around 15,000 years ago.

We can only speculate, of course, but, as Paleolithic peoples lived close to nature, the waxing and waning moon would naturally present itself as a significant object of interest with its obvious rhythms and periods. One can easily imagine our intelligent forebears following those rhythms and beginning to record in one fashion or another the sequence and intervals of full and new moon. Moreover, the Gontzi bone and others like it could have served as a means of reckoning time. Although we cannot go so far as to say that Paleolithic peoples possessed a calendar, we can surmise that knowledge of the moon's periods would be useful in time-reckoning. For example, dispersed groups might have come together seasonally and would have needed to keep track of the intervening months. We need not envision a continuous tradition of such lunar records, for the process may have been invented and reinvented hundreds of times over: a simple counter fashioned over the course of a few months and discarded. The artifacts in question evidence the active observation and recording of natural phenomena over time. That activity indicates only a rudimentary approach to theoretical knowledge, but its results seem more abstract than knowledge gained from direct experience and different from what Paleolithic peoples otherwise embodied in their crafts.

Leaving the Garden

This picture of humankind's childhood, which has emerged from the research of archaeologists, paleoanthropologists, and prehistorians, raises several puzzling questions about the dynamics of social change. How can we explain the steadfast durability of a food-collecting social system for 2 million years including more than 200,000 years populated by our own species? How can the relative lack of technological innovation be accounted for? Why, after anatomically modern humans flourished culturally in the Paleolithic 40,000 to 30,000 years ago, did they continue to live as food-collectors, making stone tools and following a nomadic way of life? And why did the pace of change accelerate 15,000 years ago, as food-collecting finally gave way to food-producing, first in the form of gardening (horticulture) and animal husbandry in the Neolithic era and later, after another technological revolution in

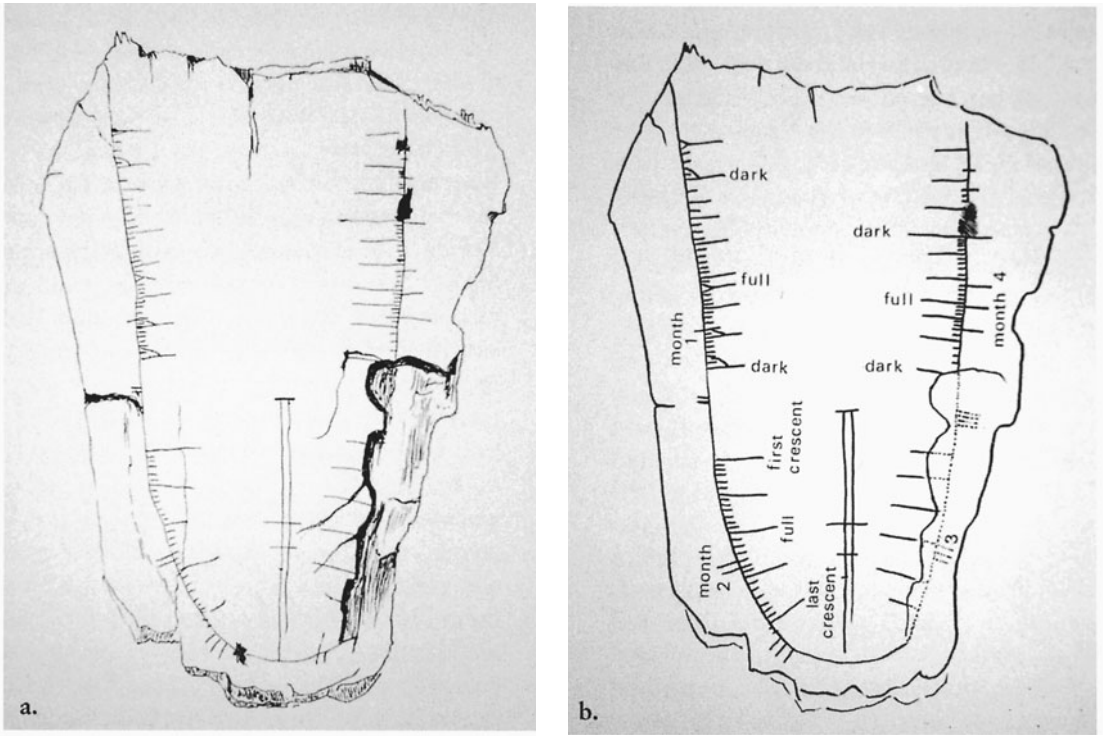


Fig. 1.4. Paleolithic lunar observations. a) An engraved mammoth tusk from Gontzi, Ukraine, that has been interpreted as a record of lunar cycles. Thousands of these artifacts have been found stretching back 30,000 years. This one dates from approximately 15,000 years ago. b) A diagrammatic rendition of the artifact showing cycles of four lunar months aligned with the engraved markings.

the form of intensified farming (agriculture) under the control and management of the political state?

Different explanations have been offered to explain the social and economic transformations that occurred at the end of the Paleolithic. It may have been set in motion by climate change and the retreat of the glaciers at the end of the last Ice Age about 10,000–12,000 years ago. The extinction of many large-bodied animals occurred then, restricting the food supply, and other animal-migration patterns shifted northward, probably leaving some human groups behind. Humans themselves probably overhunted large game, self-destructively changing their living conditions. Another line of argument that has recently gained credibility postulates that the food-collecting mode of life persisted as long as the population of hunters and gatherers remained small enough to exploit the resources of their habitats with reasonable ease. Since population increased slowly and since suitable habitats were numerous on a global scale, 2 million years passed before hunter-gatherers reached the "carrying capacities" of accessible environments through the increase of their own numbers and a resulting broadening of foraging activity. This account also explains the low rate of technological innovation prior to the late Paleolithic era: small populations blessed with ample resources were served well by their techniques and refined skills. Although Paleolithic peoples would have known that seeds grow and that gardening is possible (and occasionally practiced

it), they had no compelling incentive to revolutionize their way of life. Only when increasing population density that could no longer be readily relieved by migration finally upset the balance between needs and resources were plant and animal husbandry taken up as a new way of life.

Our ancestors did not give up their Paleolithic existence willingly. By abandoning, under pressure of ecological degradation, a nomadic lifestyle of food-collecting, and adopting a mode of food-producing—by "progressing" from hunting and gathering to gardening and stock-raising—only then did humankind reluctantly fall out of the Garden of Eden into the Neolithic era.

CHAPTER 2

The Reign of the Farmer

At the end of the last Ice Age, around 12,000 years ago, the Neolithic revolution began to unfold. This revolution, first and foremost a socioeconomic and technological transformation, involved a shift from food-gathering to food-producing. It originated in a few regions before eventually spreading around the globe. In habitats suitable only as pasture it led to pastoral nomadism or herding animal flocks; in others it led to farming and settled village life. Thus arose the Neolithic or New Stone Age.

Growing Your Own

A surprising but grand fact of prehistory: Neolithic communities based on domesticated plants and animals arose independently several times in different parts of the world after 10,000 BCE (before the common era)—the Near East, India, Africa, North Asia, Southeast Asia, and Central and South America. The physical separation of the world's hemispheres—the Old World and the New World—decisively argues against simple diffusion of Neolithic techniques, as do the separate domestications of wheat, rice, corn, and potatoes in different regions. On the time scale of prehistory the transformation appears to have been relatively abrupt, but in fact the process occurred gradually. Nonetheless, the Neolithic revolution radically altered the lives of the peoples affected and, indirectly, the conditions of their habitats. Although different interpretations exist concerning the origin of the Neolithic, no one disputes its world-transforming effects.

The Neolithic was the outcome of a cascading series of events and processes. In the case of gardening—low-intensity farming—we now know that in various locales around the world human groups settled down in permanent villages, yet continued to practice hunting, gathering, and a Paleolithic economy before the full transition to a Neolithic mode of production. These settled groups lived by complex foraging in

limited territories, intensified plant collection, and exploitation of a broad spectrum of secondary or tertiary food sources, such as nuts and seafood. They also lived in houses, and in this sense early sedentary humans were themselves a domesticated species. (The English word "domestic" derives from the Latin word *domus,* meaning "house." Humans thus domesticated themselves as they domesticated plants or animals!) But the inexorable pressure of population against dwindling collectible resources, along with the greater nutritional value of wild and domesticated cereal grains, ultimately led to increasing dependence on farming and a more complete food-producing way of life.

In most places in the world people continued a Paleolithic existence after the appearance of Neolithic settlements 12,000 years ago. They were blissfully unpressured to take up a new Neolithic mode of food-producing, and as a cultural and economic mode of existence even today a few surviving groups follow a Paleolithic lifestyle. As a period in prehistory, the Neolithic has an arc of its own that covers developments from the first simple horticulturists and pastoralists to complex late Neolithic groups living in "towns." In retrospect, especially compared to the extreme length of the Paleolithic period, the Neolithic of prehistory lasted just a moment before civilization in Mesopotamia and Egypt began to usher in further transformations around 5,000 years ago. But even in its diminished time frame the Neolithic spread geographically and persisted in particular locales over thousands of years from roughly 12,000 to 5,000 years ago, when the Neolithic first gave way to civilization in the Near East. To those experiencing it, Neolithic life must have proceeded over generations at a leisurely seasonal pace.

Two alternative paths toward food production led out of the Paleolithic: one from gathering to cereal horticulture (gardening), and then to plow agriculture; the other from hunting to herding and pastoral nomadism. A distinct geography governed these Neolithic alternatives: in climates with sufficient atmospheric or surface water, horticulture and settled villages arose; in grasslands too arid for farming, nomadic people and herds of animals retained a nomadic way of life. Of these very different paths, one led historically to nomadic societies such as the Mongols and the Bedouins. The other, especially in the form that combined farming and domestication of animals, led to the great agrarian civilizations and eventually to industrialization.

Opportunistic and even systematic hunting and gathering persisted alongside food-producing, but where Neolithic settlements arose the basic economy shifted to raising crops on small cleared plots. Gardening contrasts with intensified agriculture using irrigation, plows, and draft animals which later developed in the first civilizations in the Near East. Early Neolithic peoples did not use the plow but, where necessary, cleared land using large stone axes and adzes; they cultivated their plots using hoes or digging sticks. In many areas of the world, espe-

cially tropical and subtropical ones, swidden, or "slash and burn," agriculture developed where plots were cultivated for a few years and then abandoned to replenish themselves before being cultivated again. The Neolithic toolkit continued to contain small chipped stones, used in sickles, for example, but was augmented by larger, often polished implements such as axes, grinding stones, and mortars and pestles found at all Neolithic sites. Animal antlers also proved useful as picks and digging sticks. And grain had to be collected, threshed, winnowed, stored, and ground, all of which required an elaborate set of technologies and social practices.

Human populations around the world independently domesticated and began cultivating a variety of plants: several wheats, barleys, rye, peas, lentils, and flax in Southwest Asia; millet and sorghum in Africa; millet and soybeans in North China; rice and beans in Southeast Asia; maize (corn) in Mesoamerica; potatoes, quinoa, beans, and manioc in South America. Domestication constitutes a process (not an act) that involves taming, breeding, genetic selection, and occasionally introducing plants into new ecological settings. In the case of wheat, for example, wild wheat is brittle, with seeds easily scattered by the wind and animals, a trait that enables the plant to survive under natural conditions. Domesticated wheat retains its seeds, which simplifies harvesting but which leaves the plant dependent on the farmer for its propagation. Humans changed the plant's genes; the plant changed humanity. And, with humans raising the grain, the rat, the mouse, and the house sparrow "self-domesticated" and joined the Neolithic ark.

The domestication of animals developed out of intimate and longstanding human contact with wild species. Logically, at least, there is a clear succession from hunting and following herds to corralling, herding, taming, and breeding. The living example of the Sami (Lapp) people who follow and exploit semiwild reindeer herds illustrates how the shift from hunting to husbandry and pastoral nomadism may have occurred. As with plant culture, the domestication of animals involved human selection from wild types, selective slaughtering, selective breeding, and what Darwin later called "unconscious selection" from among flocks and herds. Humans in the Old World domesticated cattle, goats, sheep, pigs, chickens, and, later, horses. In the New World Andean communities domesticated only llamas and the guinea pig; peoples in the Americas thus experienced a comparative deficiency of animal protein in the diet.

Animals are valuable to humans in diverse ways. Some of them convert inedible plants to meat, and meat contains more complex proteins than plants. Animals provide food on the hoof, food that keeps from spoiling until needed. Animals produce valuable secondary products that were increasingly exploited as the Neolithic unfolded in the Old World. Cattle, sheep, pigs, and the rest are "animal factories" that produce more cattle, sheep, and pigs. Chickens lay eggs, and cows, sheep,

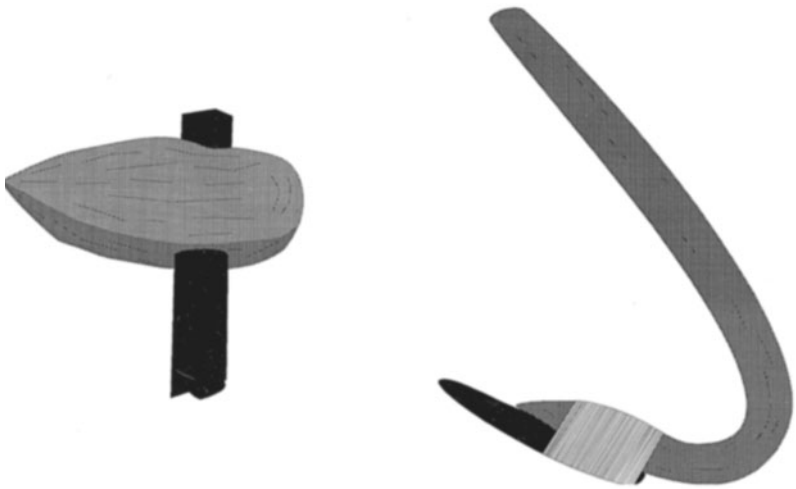


Fig. 2.1. Neolithic tools. Neolithic horticulture required larger tools for clearing and cultivating plots and for harvesting and processing grains.

goats, and horses produce milk. Treated and storable milk products in yogurts, cheeses, and brewed beverages sustained the great herding societies of Asia and pastoralists everywhere. Manure later became another valuable animal product as fertilizer and fuel. Animal hides provided raw material for leather and a variety of products, and sheep, of course, produced fleece. (Wool was first woven into fabric on Neolithic looms.) Animals provided traction and transportation. The Neolithic maintained the close dependence on plants and animals that humankind had developed over the previous 2 million years. But the technologies of exploiting them and the social system sustained by those technologies had changed radically.

After a few thousand years of the Neolithic in the Near East, mixed economies that combined the technologies of horticulture and animal husbandry made their appearance. Late Neolithic groups in the Old World apparently kept animals for traction and used wheeled carts on roads and pathways that have been favorably compared to those of medieval Europe. The historical route to intensified agriculture and to civilization was through this mixed Neolithic farming. If biology and evolution were partly responsible for the character of our first mode of existence in the Paleolithic, then the Neolithic revolution represents a change of historical direction initiated by humans themselves in response to their changing environment.

Complementing the many techniques and skills involved in farming and husbandry, several ancillary technologies arose as part of the shift to the Neolithic. First among these novelties was textiles, an innovation independently arrived at in various parts of the Old and New Worlds. Recent findings show that some Paleolithic groups occasionally practiced techniques of weaving, perhaps in basketry, but only in the Neolithic did the need for cloth and storage vessels expand to the point where textile technologies flourished. The production of textiles involves several interconnected sets of technologies: shearing sheep or

growing and harvesting flax or cotton, processing the raw material, spinning thread (an ever-present part of women's lives until the Industrial Revolution 10,000 years later), constructing looms, dyeing, and weaving the cloth. In considering the advent of textile production in the Neolithic, one cannot overlook design considerations and the symbolic and informational role of dress in all societies.

Pottery, which also originated independently in multiple centers around the world, is another new technology that formed a key part of the Neolithic revolution. If only inadvertently, Paleolithic peoples had produced fired-clay ceramics, but nothing in the Paleolithic economy called for a further development of the technique. Pottery almost certainly arose in response to the need for a storage technology: jars or vessels to store and carry the surplus products of the first agrarian societies. Neolithic communities used plasters and mortars in building construction, and pottery may have arisen out of plastering techniques applied to baskets. Eventually, "manufacturing centers" and small-scale transport of ceramics developed. Pottery is a "pyrotechnology," for the secret of pottery is that water is driven from the clay when it is "fired," turning it into an artificial stone. Neolithic kilns produced temperatures upwards of 900°C. Later, in the Bronze and Iron Ages, the Neolithic pyrotechnology of pottery made metallurgy possible.

In Neolithic settings, hundreds if not thousands of techniques and technologies large and small melded to produce the new mode of life. Neolithic peoples built permanent structures in wood, mud brick, and stone, all of which testify to expert craft skills. They twisted rope and practiced lapidary crafts, and Neolithic peoples even developed metallurgy of a sort, using naturally occurring raw copper. The technology of cold metalworking produced useful tools. The now-famous "Ice man," the extraordinary frozen mummy exposed in 1991 by a retreating glacier in the Alps, was first thought to belong to a Bronze Age culture because of the fine copper axe he was carrying when he perished. As it turns out, he lived in Europe around 3300 BCE, evidently a prosperous Neolithic farmer with a superior cold-forged metal tool.

The Neolithic was also a social revolution and produced a radical change in lifeways. Decentralized and self-sufficient settled villages, consisting of a dozen to two dozen houses, with several hundred inhabitants became the norm among Neolithic groups. Compared to the smaller bands of the Paleolithic, village life supported collections of families united into tribes. The Neolithic house doubtless became the center of social organization; production took place on a household basis. The imaginative suggestion has been made that living inside houses forced Neolithic peoples to deal in new ways with issues concerning public space, privacy, and hospitality. Neolithic peoples may have used hallucinatory drugs, and they began to experiment with fermented beverages. Although a sexual division of labor probably persisted in the Neolithic, horticultural societies, by deemphasizing hunt-

ing, may have embodied greater gender equality. A comparatively sedentary lifestyle, a diet higher in carbohydrates, and earlier weaning increased fertility, while freedom from the burden of carrying infants from camp to camp enabled women to bear and care for more children. And one suspects that the economic value of children—in tending animals or helping in the garden, for example—was greater in Neolithic times than in the Paleolithic. At least with regard to Europe, some archaeologists have made compelling claims for the existence of cults devoted to Neolithic goddesses and goddess worship. There were doubtless shamans, or medicine "men," some of whom may also have been women. Neolithic societies remained patriarchal, but males were not as dominant as they would become with the advent of civilization.

In the early Neolithic, little or no occupational specialization differentiated individuals who earned their bread solely through craft expertise. This circumstance changed by the later Neolithic, as greater food surpluses and increased exchange led to more complex and wealthier settlements with full-time potters, weavers, masons, toolmakers, priests, and chiefs. Social stratification kept pace with the growth of surplus production. By the late Neolithic low-level hierarchal societies, tribal chiefdoms, or what anthropologists call "big men" societies appeared. These societies were based on kinship, ranking, and the power to accumulate and redistribute goods sometimes in great redistributive feasts. Leaders now controlled the resources of 5,000 to 20,000 people. They were not yet kings, however, because they retained relatively little for themselves and because Neolithic societies were incapable of producing truly great wealth.

Compared to the Paleolithic economy and lifestyle, one could argue that the standard of living actually became depressed in the transition to the Neolithic in that low-intensity horticulture required more labor, produced a less varied and nutritious diet, and allowed less leisure than Paleolithic hunting and gathering in its heyday. But—and this was the primary advantage—Neolithic economies produced more food and could therefore support more people and larger population densities (estimated at a hundredfold more per square mile) than Paleolithic foraging.

Populations expanded and the Neolithic economy spread rapidly to fill niches suited for them. By 3000 BCE thousands of agrarian villages dotted the Near East, usually within a day's walk of one another. Wealthier and more complex social structures developed, regional crossroads and trading centers arose, and by the late Neolithic real towns had emerged. The classic example is the especially rich Neolithic town of Jericho, which by 7350 BCE already had become a well-watered, brick-walled city of 2,000 or more people tending flocks and plots in the surrounding hinterland. Jericho had a tower nine meters high and ten meters in diameter, and its celebrated walls were three meters thick, four meters high, and 700 meters in circumference. The walls were nec-

essary because the surplus stored behind them attracted raiders. Warlike clashes between Paleolithic peoples had undoubtedly occurred repeatedly over the millennia in disputes over territory, to capture females, or for cannibalistic or ritual purposes. But with the Neolithic, for the first time, humans produced surplus food and wealth worth stealing and hence worth protecting. Paleolithic groups were forced to adapt to the Neolithic economies burgeoning around them. Thieving was one alternative; joining in a settled way of life was another. In the long run, Neolithic peoples marginalized hunter-gatherers and drove them virtually to extinction. Idealized memories of the foraging lifestyle left their mark in "Garden of Eden" or "happy hunting grounds" legends in many societies.

Blessed or cursed with a new economic mode of living, humans gained greater control over nature and began to make more of an impact on their environments. The ecological consequences of the Neolithic dictated that the domestic replace the wild, and where it occurred the Neolithic revolution proved irreversible—a return to the Paleolithic was impossible because Paleolithic habitats had been transformed and the Paleolithic lifestyle was no longer sustainable.

Moonshine

The Neolithic revolution was a techno-economic process that occurred without the aid or input of any independent "science." In assessing the connection between technology and science in the Neolithic, pottery provides an example exactly analogous to making fire in the Paleolithic. Potters made pots simply because pots were needed and because they acquired the necessary craft knowledge and skills. Neolithic potters possessed practical knowledge of the behavior of clay and of fire, and, although they may have had explanations for the phenomena of their crafts, they toiled without any systematic science of materials or the self-conscious application of theory to practice. It would denigrate Neolithic crafts to suppose that they could have developed only with the aid of higher learning.

Can anything, then, be said of science in the Neolithic? In one area, with regard to what can be called Neolithic astronomy, we stand on strong ground in speaking about knowledge in a field of science. Indeed, considerable evidence makes plain that many, and probably most, Neolithic peoples systematically observed the heavens, particularly the patterns of motion of the sun and moon and that they regularly created astronomically aligned monuments that served as seasonal calendars. In the case of Neolithic astronomy, we are dealing not with the prehistory of science, but with science in prehistory.

The famous monument of Stonehenge on the Salisbury Plain in southwest England provides the most dramatic and best-understood case in point. Stonehenge, it has now been determined by radiocarbon

Fig. 2.2. Jericho. Neolithic farming produced a surplus that needed to be stored and defended. Even in its early phases, the Neolithic settlement of Jericho surrounded itself with massive walls and towers, as shown in this archaeological dig.

dating, was built intermittently in three major phases by different groups over a 1,600-year period from 3100 BCE to 1500 BCE, by which time the Bronze Age finally washed across the Salisbury Plain. The word "Stonehenge" means "hanging stone," and transporting, working, and erecting the huge stones represents a formidable technological achievement on the part of the Neolithic peoples of prehistoric Britain.

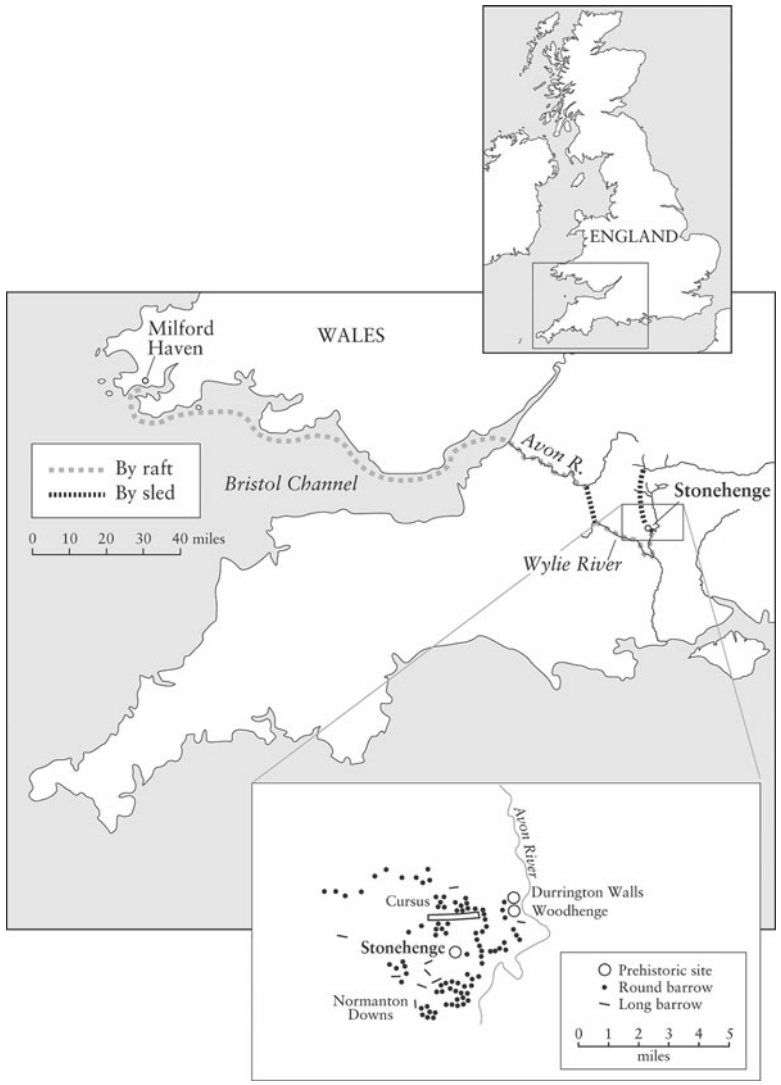
A huge amount of labor went into building Stonehenge—estimates range to 30 million man-hours, equivalent to an annual productive labor of 10,000 people. In order to create a circular ditch and an embankment 350 feet in diameter, 3,500 cubic yards of earth were excavated. Outside the sanctuary the first builders of Stonehenge erected the so-called Heel Stone, estimated to weigh 35 tons. Eighty-two "bluestones" weighing approximately five tons apiece were brought to the site (mostly over water) from Wales, an incredible 240 kilometers (150

miles) away. Each of the 30 uprights of the outer stone circle of Stonehenge weighed in the neighborhood of 25 tons, and the 30 lintels running around the top of the ring weighed seven tons apiece. More impressive still, inside the stone circle stood the five great trilithons or three-stone behemoths. The average trilithon upright weighs 30 tons and the largest probably weighs over 50 tons. (By contrast, the stones that went into building the pyramids in Egypt weighed on the order of five tons.) The great monoliths were transported 40 kilometers (25 miles) overland from Marlborough Downs, although the suggestion has been made that ancient glaciers may have been responsible for moving them at least part way to Stonehenge. The architects of Stonehenge appear to have laid out the monument on a true circle, and in so doing they may have used some practical geometry and a standard measure, the so-called megalithic yard.

The labor was probably seasonal, taking place over generations. A stored food surplus was required to feed workers, and some relatively centralized authority was needed to collect and distribute food and to supervise construction. Neolithic farming and ranching communities appeared on the Salisbury Plain by the fourth millennium BCE and evidently reached the required level of productivity. Although Neolithic farming never attained the levels of intensification later achieved by civilized societies, Stonehenge and the other megalithic ("large stone") structures show that even comparatively low-intensity agriculture can produce sufficient surpluses to account for monumental building.

Recognition that Stonehenge is an astronomical device has been confirmed only in our day. As literate peoples encountered Stonehenge over the centuries, any number of wild interpretations emerged as to who built it and why. Geoffrey of Monmouth in his twelfth-century *History of the Kings of Britain* has Merlin from King Arthur's court magically transporting the stones from Wales. Other authors have postulated that the Romans or the Danes built Stonehenge. A still-current fantasy holds that the Druids built and used Stonehenge as a ceremonial center. (In fact, the Celtic Iron Age Druids and their culture only appeared a thousand years after Stonehenge was completed.) Even in the 1950s, when

Fig. 2.3. Stonehenge. Neolithic and early Bronze Age tribes in Britain built and rebuilt the famous monument at Stonehenge as a regional ceremonial center and as an "observatory" to track the seasons of the year.



Map 2.1. The Salisbury plain. Stonehenge was set among a cluster of Neolithic sites, indicating the relative wealth and resources of the region. Some of the smaller stones that went into making Stonehenge were transported 150 miles by rollers and raft from Western Wales; some of the largest stones came from 25 miles north of the site.

the possibility became clear that Neolithic peoples from the Salisbury Plain themselves were responsible for Stonehenge, there was considerable resistance to the idea that "howling barbarians" might have been capable of building such an impressive monument, and some supposed that itinerant contractors from the Near East built it. All scholars now agree that Stonehenge was a major ceremonial center and cult site built by the people of the Salisbury Plain. Its astronomical uses indicate that it functioned as a Neolithic religious center for the worship of the sun and the moon and for establishing a regional calendar.

The English antiquarian William Stukeley (1687–1765) was the first modern to write about the solar alignment of Stonehenge in 1740. The sun rises every day at a different point on the horizon; that point moves back and forth along the horizon over the course of a year, and each year at midsummer the sun, viewed from the center of the sanctuary at

Stonehenge, rises at its most northern point, which is precisely where the builders placed the Heel Stone. The monument's primary astronomical orientation toward the midsummer sunrise is confirmed annually and has not been disputed since Stukeley.

In the 1960s, however, controversy erupted over claims for Stonehenge as a sophisticated Neolithic astronomical "observatory" and "computer." The matter remains disputed today, but wide agreement exists on at least some larger astronomical significance for Stonehenge, especially with regard to tracking cyclical movements of the sun and the moon. The monument seems to have been built to mark the extreme and mean points of seasonal movement of both heavenly bodies along the horizon as they rise and set. Thus, the monument at Stonehenge marks not only the sun's rise at the summer solstice, but the rise of the sun at winter solstice and at the fall and spring equinoxes. It also indicates the sun's settings at these times, and it tracks the more complicated movements of the moon back and forth along the horizon, marking four different extremes for lunar motion.

The construction of Stonehenge required sustained observations of the sun and the moon over a period of decades and mastery of horizon astronomy. The monument embodied such observations, even in its earliest phases. The ruins testify to detailed knowledge of heavenly move-

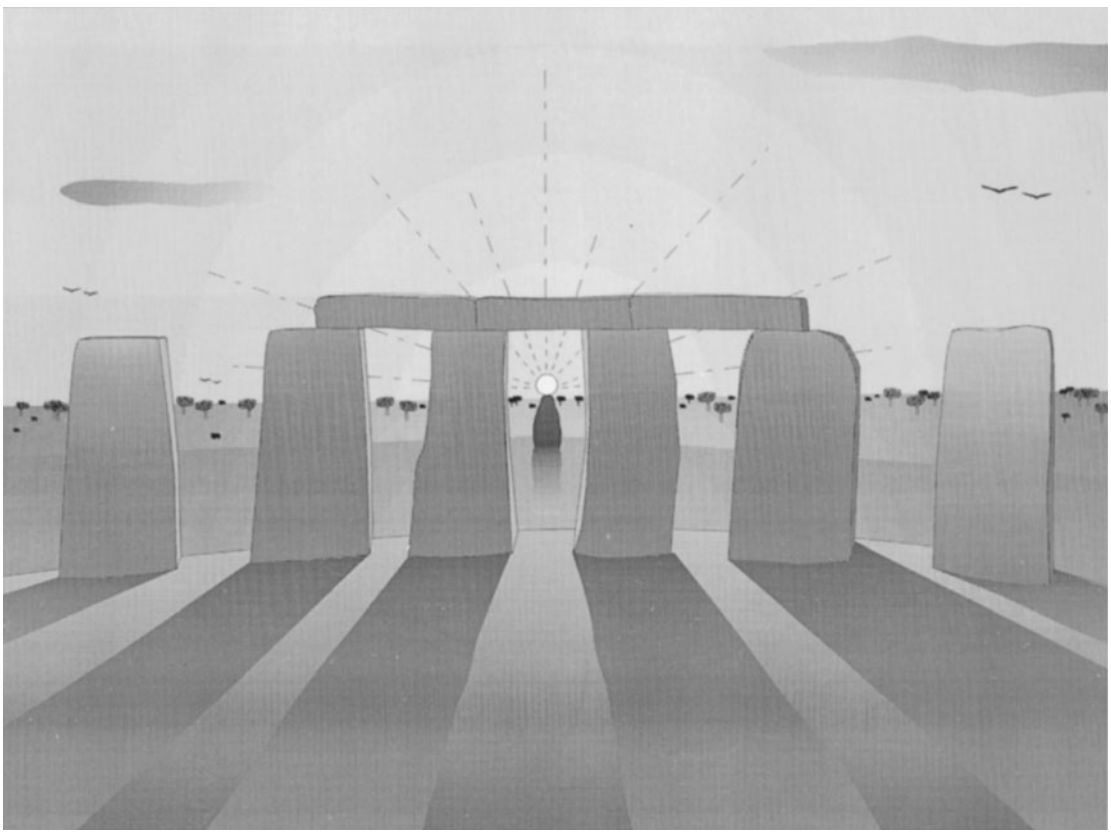


Fig. 2.4. Midsummer sunrise at Stonehenge. On the morning of the summer solstice (June 21) the sun rises along the main axis of Stonehenge and sits atop the Heel Stone.

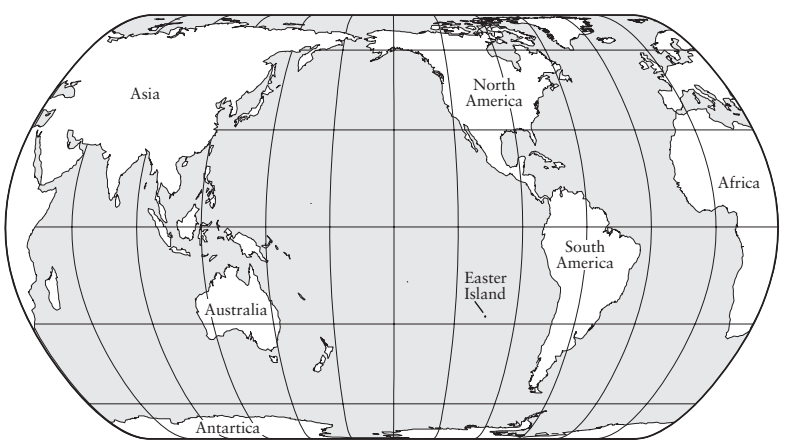
Fig. 2.5. Neolithic society on Easter Island. A society based on low-intensity agriculture flourished here for hundreds of years before it was extinguished by ecological ruin. During its heyday it produced megalithic sculptures called *moai* comparable in scale to Stonehenge and other monumental public works that are typical of Neolithic societies.

ments and to a widespread practice of "ritual astronomy." We have no access to what megalithic Europeans thought they were doing; their "theories" of the sun and the moon, if any, may have been utterly fantastic, and we would probably label their explanations more religious than naturalistic or scientific. Still, megalithic monuments embody a scientific approach in that they reflect understanding of regularities of celestial motions and they bespeak long-term systematic interest in and observations of nature. Although religious elders, hereditary experts, or priestly keepers of knowledge doubtless tended Stonehenge, it probably goes too far to suggest that megalithic monuments provide evidence for a class of professional astronomers or for astronomical research of the sort that later appeared in the first civilizations. Stonehenge may better be thought of as a celestial orrery or clock that kept track of the major motions of the major celestial bodies and possibly some stars. In addition, Stonehenge certainly functioned as a seasonal calendar, accurate and reliable down to a day. As a calendar, Stonehenge kept track of the solar year and, even more, harmonized the annual motion of the sun with the more complicated periodic motion of the moon. It may even have been used to predict eclipses, although that possibility seems unlikely. In these telling ways—systematically observing the heavens, mastering the clock-like movement of the sun and the moon, gaining intellectual control over the calendar—it is possible and even necessary to speak of Neolithic "astronomy" at Stonehenge. The further development of astronomy awaited the advent of writing and cohorts of full-time experts with the patronage of centralized bureaucratic governments. But long before those developments, Neolithic farmers systematically investigated the panorama of the heavens.

On the other side of the globe the remarkable giant statues of Easter

Island (also known as Rapa Nui) provide mute testimony to the same forces at play. Easter Island is small and very isolated: a 46-square-mile speck of land 1,400 miles west of South America and 900 miles from the nearest inhabited Pacific island. Polynesian peoples reached Easter Island by sea sometime after 300 of the common era (CE) and prospered through cultivating sweet potatoes, harvesting in a subtropical palm forest, and fishing in an abundant sea. The economy was that of settled Paleolithic or simple Neolithic societies, but local resources were rich, and even at slow growth rates over a millennium the founding population inevitably expanded, reaching 7,000 to 9,000 at the peak of the culture around 1200 to 1500 CE. (Some experts put the figure at over 20,000.)

Islanders carved and erected more than 250 of their monumental moai statues on giant ceremonial platforms facing the sea. Notably, the platforms possessed built-in astronomical orientations. Reminiscent of the works of the peoples of Stonehenge or the Olmecs of Central America, the average moai stood over 12 feet in height, weighed nearly 14 tons, and was transported up to six miles overland by gangs of 55 to 70 men; a few mammoth idols rose nearly 30 feet tall and weighed up to 90 tons. Hundreds more statues—some significantly larger still—remain unfinished in the quarry, where all activity seems to have stopped suddenly. Remote Easter Island became completely deforested because of the demand for firewood and construction material for seagoing canoes, without which islanders could not fish for their staple of porpoise and tuna. By 1500, with the elimination of the palm tree and the extinction of native bird populations, demographic pressures became devastatingly acute, and islanders intensified chicken-raising and resorted to cannibalism and eating rats. The population quickly crashed to perhaps one-tenth its former size, the sad remnant "discovered" by Europeans in 1722. Only 100 souls lived there in 1887. The wealth of the pristine island had provided rich resources where a human society evolved in a typically Neolithic (or settled Paleolithic) pattern. But



Map 2.2. Easter Island. This isolated speck of land in the South Pacific lies 1,400 miles off the coast of South America and 900 miles from the nearest inhabited island to the west. Polynesian seafarers, probably navigating by star charts and taking advantage of their knowledge of wind and current changes, arrived at Easter Island around CE 300. Europeans "discovered" the island in 1722.

human appetites and the island's narrow ecological limits doomed the continuation of the stone-working, heaven-gazing, and wood-burning culture that evolved there.

In general, through observation of the sun and the moon Neolithic peoples around the world established markers, usually horizon markers, that monitored the periodic motion of these bodies across the sky, tracked the year and the seasons, and provided information of great value to communities of farmers. In some cases the devices they created to reckon the year and predict the seasons became quite elaborate and costly and were possible only because of the surplus wealth produced in favored places.

Before Stonehenge and long before the settlement and ruination of Easter Island, in certain constricted environments growing populations pressed against even enlarged Neolithic resources, setting the stage in Egypt, Mesopotamia, and elsewhere for a great technological transformation of the human way of life—the advent of urban civilization.