NEO TESTS 1-66 READING PASSAGES

Contents

1.1: Was There Water on Ancient Mars?

Despite Mars's bleak, cold climate today, there is abundant geologic evidence that liquid water once flowed on the Martian surface (and even recent evidence that some water still periodically flows today). The evidence of past flows includes river channels, now dry, that were once carved by powerful floods; valley networks of branching streams and tributaries indicating precipitation falling over wide areas; river deltas and layered sediments suggesting flow into standing bodies of liquid water; and salt and other minerals that dissolved in liquid water and were left behind when water evaporated. When that ancient wet period existed and when it ended is difficult to say.

The best method for dating a surface uses radioactivity, the process by which certain elements decay over time. One collects rocks from the surface and measures their radioactive elements to see how much of the decay products have accumulated in the rock since it formed. Transferring this age to the age of the surface can be tricky unless one knows where the rock came from. And one needs to collect the samples and bring them to a well-equipped laboratory.

The other way to date a planetary surface, which is used when rock samples are unavailable, is by counting craters. The longer a surface has been exposed to meteorite bombardment, the more craters it will have. This gives the relative age and allows one to determine which surfaces are older and which surfaces are younger. To get the actual age, one needs a standard. This was established for the Moon when lunar samples were returned to Earth as part of the United States Apollo program. The crater counts of the areas of the Moon from which the samples came were carefully noted. The samples were dated in terrestrial laboratories using radioactive decay, and the relation between absolute age in years and crater density--numbers per unit area-was determined. This relation is valid for the Moon, and it is possible that it is valid for Mars as well. Then counting craters on a Martian surface should yield its actual age. It is possible, however, that the number of impacting objects is different for Mars. The problem has been carefully studied, and adjustments have been made, but the general conclusion is that a wet period occurred early in Mars's 4.5 billion-year history.

This causes a problem for Mars's climate science because the Sun was supposed to be fainter, perhaps by 20 or 30 percent, during Mars's wet period. Yet a watery Mars arguably would have required relatively warm temperatures. The power output of the Sun-its luminosity over time-is based on models of its interior and evolution. The models are well-tested and agree with the luminosities of stars like the Sun, whose ages are known. The same problem exists for Earth, which appears to have been warmer billions of years ago than it is today. Geologists have called this the "faint young Sun paradox." The solution to the paradox probably lies in climate science and not in the theory of stellar evolution, but the issue has not been entirely settled.

If Mars was wet billions of years ago, was it also warm? There could have been catastrophic floods released from underground aquifers (layers of rocks that can contain water) where the top surface of the water froze like the top of a Hawailan lava flow. The solid crust forms an insulating layer, trapping the heat of the liquid and allowing it to flow for great distances without freezing. Lava tubes on Hawalil are empty channels where lava once flowed in this way. Thus, the climate of Mars could have been wet but not warm, with the water flowing entirely under the ice. Ice sheets and glaciers on Earth today have extensive plumbing systems that allow water to flow and then drain away. Liquid water at the base of glaciers acts as a temporary lubricant and allows them to surge and slide downhill. Flood channels, river deltas, and standing bodies of liquid water all could have existed on Mars under thick layers of ice. The wet-but-not-warm hypothesis has the most trouble with areas that imply sources like precipitation over a wide area rather than the bursting of an underground aquifer. Further study of Mars's geology will clarify these issues.

1.1: Guam and the Brown Tree Snake

Guam is the largest island of Micronesia and, like many islands, once provided a home to a fantastic assemblage of native birds, reptiles, and mammals. The vast majority of these species are now extinct, and the remaining ones are threatened with extinction. Although many factors contributed to the loss of species, the principal cause is the invasive brown tree snake.

During the Second World War, the United States Navy established a large naval base on Guam. With the end of the war in 1945, the base proved useful for recovering abandoned war materials from the region, in particular, vehicles, aircraft, and other supplies from New Guinea, where these items may have sat unused for some time. The brown tree snake is native to New Guinea and other regions of Australasia. It is typically nocturnal and, during the day, rests within crevices and holes that provide good cover. It is commonly found in wheel wells on airplanes, under the hoods of cars, and in boxes of cargo, and most biologists think the brown tree snake was a hitchhiker within surplus Navy equipment brought to Guam from New Guinea in the postwar years of 1945-1950.

The brown tree snake was first noticed along Guam's southern shore near Apra Harbor. It then spread, somewhat slowly, until it occupied the entire island by 1970. Guam has no native snakes and no native predators that could have controlled tree snake numbers. Instead, the native vertebrates were all small species vulnerable to predation by the generalist tree snakes. The decline of most native forest animals was immediate and dramatic. Guam's Division of Aquatic and Wildlife Resources discontinued surveys of native birds and bats in the 1970s, as there were so few individuals of these species to count. The three native birds and mammals that persisted the longest were the Mariana fruit bat, Guam rail, and island swiftlet. The fruit bat and rail were relatively long-lived species that likely persisted simply because some individuals escaped predation and lived out the remainder of their lives; however, neither species had any reproductive success in the presence of the tree snake. The island swiftlet persists to this day but is confined to one cave on Guam. The swiftlet builds nests on the walls of caves using its own saliva and mud to adhere the nest to the cave wall. Despite this unusual habit, swiftlets are still vulnerable to tree snake predation, as tree snakes can easily capture prey in total darkness and climb most surfaces. The one cave where swiftlet persists is unique in that the cave walls are not textured enough for snakes to support themselves. This does not inhibit the swiftlet's ability to build nests, but it does prohibit tree snakes from reaching those nests.

There have been many other losses of native forest animals on Guam. Consequently, the food web of Guam's forests (the dominant native habitat) has shifted dramatically. The most striking change is the reorganization of the web to one in which most components are non-native. Beyond the brown tree snake, the Polynesian rat, Philippine turtledove, and the house mouse, among other non-native species, have been successively established. Three native lizards survive in Guam's forests. All the lizards are small and active during daylight. One would assume that, with the destruction of the native food web, the brown tree snake would suffer from a lack of food resources, but the available pool of invasive prey and native lizards maintains tree snake densities. Consequently, native species went extinct with no corresponding negative effect on the tree snake. The tree snake even seems to be adapting to the diurnal habits of the remaining native lizards since biologists have documented a shift in the tree snake's previously nocturnal activity pattern to one that Increasingly includes activity during daylight hours.

The reduction in the complexity of the Guam food web has had consequences beyond the loss of native animals. The loss of mammalian and avian insectivores presumably increased insect abundance at some cost to agricultural crops and crop production. And newly introduced non-native species may find it easy to invade Guam, given the many "open niches" left by the loss of native species.

2.1: The Most Common Bird on Earth

The red-billed quelea is a small, mostly brown bird found in the annual grasslands of Africa. Other than ornithologists and the people who see the bird in its native habitat, almost no one has ever heard of the little quelea, although, with a population estimated at 10 billion, it may be the most common bird on Earth.

Given the seemingly stressful conditions in the environments where the birds are found, it is surprising that the red-billed quelea survives at all, much less that it is so remarkably successful. Queleas feed on native annual grasses. Any animal that feeds primarily on the seeds of annual grasses has a potentially major problem-its food supply periodically appears and then disappears. A wide range of adaptations allow annual-seed eaters to survive. For example, rodents in annual grasslands often store their extra seeds to survive lean times, an adaptation that was taken up by human populations once they domesticated and became dependent on annual grasses, such as barley and wheat. If they are to survive, queleas must also cope with the challenging feast-or-famine situation of attending annual-grass feeders. One might expect such species to be regularly wiped out (at least locally) when fluctuations in the growing season result in seed failures of their food. The red-billed quelea copes well enough to be the world's most common bird.

Part of the quelea's success arises from its life-history adjustments to its environment. Over the African dry season, the species has to subsist on the ever-diminishing supply of seeds produced by the annual grasses at the end of the last wet season. As food becomes scarcer, the species feeds actively and gains sufficient weight reserves to be able to migrate to more auspicious areas. With the onset of rains in the African wet season, the seeds that queleas eat germinate (develop) and so are no longer available for food. The resulting severe food shortage lasts six to eight weeks. The birds are forced to migrate to better situations (if they can find them). For red-billed queleas, the savannas in which they live are an ever-shifting mosaic of patches of varying suitability depending on their recent rainfall history; some areas have dry seeds; others have immature grasses, mature grasses with abundant green seeds, or old grasses with no seed. By moving over distances of 30 to 120 miles (50 to 200 km), the birds subsist in an inhospitable universe by moving from one patch of habitat with suitable food to another.

The so-called early-rains migration ends when queleas return to formerly abandoned locations. By this time, the rains have come, and grass seeds have germinated. The new grasses mature, and eventually, fresh green seeds become available, ending the local food shortage. Then, queleas establish communal breeding colonies in appropriate locations. They typically nest in thorny acacia trees. Their breeding colonies can contain several million pairs of breeding birds and can cover tens of hectares. The entire breeding cycle, from nesting colony, to independent-fledged young, requires six weeks-an exceptionally short interval for birds. The biological synchrony found among the birds in a breeding colony can be remarkable. Millions of eggs in millions of nests hatch on the same day. The fall of eggshells from the subsequent dropping of the shells from the nests after these synchronous hatchings have been likened to a snowstorm. Sometimes the dry season comes early, and the breeding areas dry out prematurely. In such times, the breeding colonies are abandoned. In other instances, the rains may sustain a prolonged green period, and several episodes of breeding can occur in the same general area.

Since red-billed queleas feed on the seeds of annual grasses, they are preadapted to be effective feeders on the seeds of domesticated annual grasses as well. As human agriculture has planted more and more cereal grains across Africa, the number of quelea have exploded in response to the abundance of suitable food. The quelea's magnitude as a pest animal has increased correspondingly. Although the numbers may be overestimated, the species is certainly capable of destroying 10 to 20 percent of the production of large farms and the entire crop of small, independent farmers. The red-billed quelea is not only the most abundant bird; it can also be described as the most destructive pest bird on Earth.

2.2: Iron in Ancient Africa

Metal-production technologies (metallurgy) have had a profound influence on the course of human history. Aside from gold, used for jewelry and ornamentation, the first metal to be widely used was copper, with smelting (the process of extracting metal from ore by heating) beginning by 5000 B.C.E. in modern-day Serbia. Production of bronze from copper and tin began by 2800 B.C.E. in Anatolia, in what is modern-day Turkey. Next was iron, with smelting starting around 1500 B.C.E. in Anatolia and spreading to Europe by 1100 B.C.E. Although iron production was difficult and complex, this metal's greater hardness made tools and weapons far superior to those made from copper and bronze.

For a long time, scholars believed that iron production came to sub-Saharan Africa from Anatolia. One reason for this is that iron smelting requires considerable knowledge and experience, yet there was no evidence of previous metals technology in Africa. In particular, there seemed to have been no copper metallurgy, a likely precursor to iron production. Since Anatolia did possess the necessary knowledge and skill, it seemed to be a plausible source.

Some of the first evidence for African iron production was found in Meroe and dated to around 500 B.C.E.: iron tools and weapons, the remains of furnaces, and a large number of heaps of slag (waste left behind after processing metallic ores). This was significant because the kingdom of Meroe had close contact with Egypt to the north, where iron production had been imported from Anatolia and was known by 670 B.C.E. Therefore, it seemed logical that iron technology had diffused southward through Egypt to Meroe and from Meroe to sub-Saharan Africa. Some archaeologists have proposed a different source: Carthage, a North African city on the Mediterranean coast founded around 800 B.C.E. by the Phoenicians, whose homeland was close to Anatolia. However, no direct archaeological evidence for iron smelting has been found in Carthage, and it is not easy to explain how such knowledge and skill could have crossed the Sahara desert to reach the sub-Saharan regions. Also, it appears that the earliest iron production south of the desert predates Carthage's founding.

Although it seems clear that iron technology reached Meroe from Anatolia via Egypt, recent research shows that the rest of Africa developed the technology independently. There is evidence of iron working as early as 1000 B.C.E. in Central Africa, and iron smelters were in use in the Great Lakes region of East Africa around 900 B.C., both earlier than would have been possible if the technologies had diffused from Anatolia through Egypt. Iron production was widespread in West and East Africa as early as 600 B.C.E., and it reached southern Africa a few hundred years later. Not only do such dates precede those of Meroe's iron production, but the design of the smelters differs significantly from that of the smelters at Merod. Also, there are recent indications that sub-Saharan Africa had copper technology in place as early as 2200B.C.E., long before iron production began. Aside from the knowledge gained from copper technology, some experience may have come from pottery production. Since around 4000 B.C.E., crushed iron ore was used to coat pottery in Egypt, and the temperatures necessary for this were almost as high as those needed for iron smelting.

The diffusion of iron technology through Africa was relatively slow, possibly as a result of the scarcity of iron ore. It also did not have the immediate impact of other technologies (such as steam power in the modem era), but iron tools made hunting easier and facilitated tasks such as shaping wood, building houses, and digging wells. Iron technology certainly helped farmers and so accelerated the spread of agricultural communities in West Africa after 400 B.C.E., such as those of the upper Niger River, where farming settlements began to form clusters of villages that specialized in rice, cotton, or dried fish, and eventually developed into large market towns. However, the rarity of major iron deposits meant that iron tools, weapons, and other goods had to be transported over long distances. Along with the difficulty of iron production, this probably gave iron workers an honored place in the community.

3.1: Vasari, Art, and the Renaissance

The Italian artist, architect, and author Giorgio Vasari was an important influence on the modern Western conception of art. In his Lives of the Most Eminent Painters, Sculptors and Architects, a series of biographies of artists published in 1550, Vasari coins a word to describe the art made by the genius Michelangelo Buonarotti (1475-1564) and other painters, sculptors, and architects only slightly less talented than Buonarotti: Renaissance (rinascita, or "rebirth," in Italian). Although the artists Vasari discussed were not the first to take great interest in the art of ancient Greece and Rome-writers and thinkers of the fourteenth and early fifteenth centuries, such as Petrarch (1304-1374) and Lorenzo Valla (1407-1457), had already seen themselves as reinvigorators of the Greek and Roman past-Vasari thought the rebirth of the late fifteenth century had gone beyond the original. In Vasari's eyes, Buonarotti and his contemporaries were not simply skilled and highly trained artisans, but "rare men of genius" who should sign their names to and take full credit for their work. (Traditionally, artists did not sign their names to artworks.) This notion of the artist as creative genius did not apply to all branches of art but to those in Vasari's title-painting, sculpture, and architecture-which were subsequently judged to be the major arts. Other types of art, such as needlework, porcelain manufacture, goldsmithing, and furniture making, were minor arts, decorative arts, or crafts, and the names of those who made them were not considered important.

Along with inventing the term "Renaissance," Vasari influenced how Westerners understood other aspects of art and culture. He is often regarded as the first art historian, and his categories continue to shape the way that art history is taught and museums are arranged. Vasari's term "Renaissance" came to be used for a whole era and not simply its art. Because it derived from broad cultural changes and not specific events, the Renaissance happened at different times in different parts of Europe. "Renaissance" is used to describe fifteenth-century Italian paintings, sixteenth-century English literature, and seventeenth-century Scandinavian architecture. Some scholars see the Renaissance as the beginning of the modern era, while others see it as a sort of transition between medieval and modern.

Vasari's distinction between art (works made by "rare men of genius") and craft(works made by everyone else) has been extended to other cultural realms in Europe: certain forms of writing, such as poetry, history, and epics, came to be defined as literature, while other types of writing, such as letters and diaries, were excluded from this category; certain forms of music became classical, while everything else was popular or folk; instruction that occurred in institutional settings was education, while that going on in the family or workshop was training or tradition. Scholars traced a growing split between professional and amateur, and, to a lesser degree, between learned and popular culture.

Research into all aspects of cultural life over the last several decades, however, has pointed out that the divisions between art and craft and learned and popular are more pronounced in hindsight than they were at the time. Vasari may have prized painting, sculpture, and architecture, but patrons carefully ordered and paid enormous amounts for candlesticks, silver and gold tableware enamel or jewel-encrusted dishes, embroidery (cloth with decorative needlework), and enormous tapestries, along with paintings and statues. Embroiderers as well as painters experimented with perspective (the representation of three-dimensional space on a two-dimensional plane), paid great attention to proportion, shadowing, and naturalistic representation, and took their subjects from Greek and Roman antiquity. Writers paid as much, or even more, attention to literary conventions (standard practices) in their letters than in their poetry or drama. Folktales told orally for centuries became part of literary works in many countries, and people telling stories increasingly included those that someone had read in a book. Highly learned individuals participated in festivities involving all kinds of people that poked fun at their own intellectual pretensions and satirized various forms of power and status. Educated individuals did form a community among themselves with concerns different from the vast majority of the population, but they also shared many values and traditions with their neighbors who lacked extensive formal education.

3.2: Life in an Estuary

An estuary is the wide part of a river where it flows into the sea. It is affected by both marine influences (tides, waves, and the influx of saline water) and riverine influences (flows of fresh water and sediment) and is, therefore, not a perfectly stable environment. As a result, an estuary contains fewer resident species than the nearby marine or freshwater ecosystems, resulting in less competition for food and space. Because there is less competition, many estuarine species tend to be generalists; that is, they are able to consume a variety of foods, depending on what is available. Species that can tolerate the salinity and temperature changes in estuaries can exploit the area's high productivity, grow rapidly, and multiply into enormous populations.

Many marine animals have body fluids that contain about the same concentration of salts as seawater and that are essentially isosmotic to the surrounding water; that is, the pressure of their body fluids is equal to the pressure of the seawater, and they neither gain nor lose water. Because the marine environment remains relatively constant, they do not have a problem maintaining water balance. Animals that live in estuaries, however, must have some physiological mechanism for dealing with the varying salinity; otherwise, their tissues and cells would absorb water and lose salts as they encounter an environment with lower salinity than the sea. Thus, estuarine animals are either osmoconformers, which survive by having tissues and cells that tolerate the loss of salts through dilution, or osmoregulators, which maintain an optimal salt concentration in their tissues regardless of the salt content of their environment.

Animals such as jellyfish are unable to actively adjust the amount of water in their tissues. When their environment becomes less saline, their body fluid gains water and loses ions until it is isosmotic to the surroundings. These organisms are examples of osmoconformers. The ability of osmoconformers to inhabit estuaries is limited by their tolerance for changes in their body fluid. In contrast to osmoconformers, osmoregulators employ a variety of strategies to maintain a constant salt concentration in their bodies. Osmoregulators that live in estuarine waters concentrate salts in their body fluids when the concentration of salts in the surrounding water decreases. For instance, some crabs and fish regulate their salt content in less-saline water by actively absorbing salt ions through the gills to compensate for salt ions lost from their body. This helps them to maintain a relatively constant body fluid. Some animals can either concentrate salts when their environment is less saline or excrete salts when the environment is extremely salty. The latter are generally animals that live partly on land or in areas such as salt marshes and mangrove swamps that occasionally receive large amounts of rain. Other animals, such as the blue crab, are osmorcgulators at lower environmental salinity and osmoconformers at higher environmental salinity. Many fish species are osmoregulators that can adjust to both high-salt and low-salt environments.

Some estuarine organisms wall themselves off from their external environment to decrease water and salt exchange with their surroundings. Many estuarine animals have body surfaces that are less permeable than those of purely marine forms. This decreased permeability can be the result of increased amounts of calcium in the exoskeleton (outer skeleton) or increased numbers of mucous glands in the skin.

In addition to changes in salinity, the problem of remaining stationary in a changing environment affects the distribution of organisms in estuaries. The more or less constant movement of water in an estuary makes it difficult for some organisms to remain stationary long enough to feed and carry on other vital functions. Because of this, survival favors organisms that are benthic - those that live at the bottom. Marine plants and algae in estuaries have substantial root systems or holdfasts, to prevent moving water from pulling them up and carrying them out to sea. Animals live attached to the bottom, either in the available spaces around other sedentary animals and plants or buried in the small crevices between sediment particles.

4.1: Evidence for Continental Drift

Continental drift refers to the idea that the present continents once formed a single, giant continent called Pangaea, and since that time, has been slowly drifting apart. In 1915, the originator of this idea, the German meteorologist Alfred Wegener, was impressed by the close resemblance of coastlines of continents on opposite sides of the Atlantic Ocean, particularly South America and Africa. However, the configuration of the coastlines results from erosional and depositional processes and therefore is constantly being modified, so even if Wegener was right and the continents had separated in the distant past, it is not likely that the coastlines would fit exactly. But decades later, it was shown that the continents fit together well along the continental slope (the broad underwater shelf on the edges of continents), where erosion is minimal, and recent studies have confirmed the close fit between continents when they are reassembled to form Pangaea.

If the continents were at one time joined, then the rocks and mountain ranges of the same age in adjoining locations on opposite continents should closely match. Such is the case for the continents thought to have together formed the southern supercontinent Gondwana, when Pangaea broke up into a northern and a southern supercontinent, mostly during the Jurassic period (200-146 million years ago), Antarctica, South America, Africa, Australia-New Guinea, and India comprised Gondwana. Marine, nonmarine, and glacial rock sequences of the Pennsylvanian epoch (325-299 million years ago) to the Jurassic period are almost identical for all five Gondwana continents, strongly indicating that they were joined at one time. The trends of several major mountain ranges also support the hypothesis of continental drift. The folded Appalachian Mountains of North America, for example, trend northeastward through the eastern United States and Canada and terminate abruptly at the Newfoundland coastline. Mountain ranges of the same age and deformational style occur in eastern Greenland, Ireland, Great Britain, and Norway. Even though these mountain ranges are currently separated by the Atlantic Ocean, they form an essentially continuous mountain range when the continents are positioned next to each other.

During the later part of the Paleozoic era (544-255 million years ago), massive glaciers covered large continental areas of the Southern Hemisphere, leaving behind layers of till (sediment deposited by glaciers) and striations (scratch marks) in the bedrock beneath the till. Fossils and sedimentary rocks of the same age from the Northern Hemisphere, however, give no indication of glaciation. Fossil plants found in coals indicate that the Northern Hemisphere had a tropical climate during the time that the Southern Hemisphere was glaciated.

All the Gondwana continents except Antarctica are currently located near the equator in subtropical to tropical climates. Mapping of glacial striations in bedrock in Australia, India, and South America indicates that the glaciers moved from the areas of present-day oceans onto land. This would be highly unlikely because large continental glaciers (such as occurred on the Gondwana continents during the late Paleozoic era) flow outward from their central area of accumulation toward the sea. If the continents had not moved in the past, one would have to explain how glaciers moved from the oceans onto land and how large-scale continental glaciers formed near the equator. But if the continents are reassembled as a single landmass with South Africa located at the South Pole, the direction of movement of late Paleozoic continental glaciers makes sense. Furthermore, this geographic arrangement places the northern continents nearer the tropics, which is consistent with the fossil and climatologic evidence.

Finally, some of the most compelling evidence for continental drift comes from the fossil record. For example, fossils of Glossopteris, a group of woody shrubs, are found in equivalent Pennsylvanian and Permian coal deposits (299-251 million years ago) on all five Gondwana continents. Glassopteris shrubs produced seeds too large to have been carried by winds, and even if the seeds had floated across the ocean, they would not have remained viable for any length of time in salt water. The present-day-climates of the southern continents range from tropical to polar and are much too diverse to support the type of plants in the Glossopteris flora. These continents must once have been joined so that these widely separated localities were all in the same latitudinal climatic belt.

4.2: Han Dynasty Tomb Sculpture

Stone sculpture was something of a latecomer to Chinese art, starting a thousand years after figures were being made in jade and bronze. Under the first period of the Han dynasty, known as the Western Han (206 B.C.E. 9 B.C.E.), it was used mainly for the tombs (burial chambers) of emperors or local rulers, but by the Eastern Han (25 C.E. - 220 B.C.E.), the second period of Han rule, it had spread more widely. This change was largely the result of the increased importance of the tomb in the political philosophy of the time. The early Western Han emperors, faced with the problem of forging a unified empire threatened by uprisings on the part of ambitious rival kingdoms, had retained many of the first emperor's policies based on military force and harsh laws. But by the middle of the first century B.C.E., these were being replaced by an adaptation of the ideas of the fifth-century B.C.E. philosopher Confucius, whose philosophy emphasized personal and governmental morality, to the conditions of a united empire. Believing that in the long run, stability depended on an acceptance of the legitimacy of the ruler (and dynasty) rather than on military force, Han intellectuals and officials adopted a moral philosophy based on the belief that humans are perfectible through education and that a hierarchical society consists of a network of reciprocal duties and obligations: the subject's duty to obey the ruler was matched by the ruler's obligation to care for his subjects.

The increased emphasis on civic duty and order encouraged stability, loyalty, and obedience to the state, reinforcing central power. At the same time, the insistence on the value of education attracted intellectuals into state service, providing a well-qualified administration. In an age of rising standards of living with the growth of upwardly mobile merchant and artisan classes, the importance of filial piety (respect for parents and ancestors), one of the greatest of Confucian virtues, led to competitive tomb building. The imperial mausoleums (aboveground, free-standing tombs constructed as memorials) set the example, and their extravagance was copied downwards. But why was there such an urgent building of mausoleums?

A change in ritual had increased both the importance of the tomb and the scope for display. The ancestral rites previously held in city or palace temples were transferred to the tomb itself, making it necessary to build a hall south of the grave mound where the sacrifices could be performed. To emphasize the importance of the site, the approach was lined with an avenue of stone monuments known as the spirit road" since it was along this road that the deceased would travel to the grave. This innovation became popular in Han society. It spread from the emperor to other parts of Han society, eventually crossing into neighboring lands such as Korea and Vietnam. The result was a manifold expansion in the use of stone statuary. No longer the prerogative of a few, it was now open to citizens anxious to display their piety and wealth by erecting free-standing stone statues on their fathers' graves. The use of statuary spread so rapidly that, in order to prevent a complete devaluation of its status, it was controlled by imperial decree, and henceforth, the number and subject matter of spirit road statues were regulated according to the social rank of the deceased.

More tomb statuary has survived than any other form of Han statuary, and the easiest way to see the development of sculpture during the first and second centuries is to use the tomb as a starting place. During the first century B.C.E., there appears to have been a remarkable increase in the use of stone in connection with the tomb. While free-standing statues and monuments were placed on the tomb above ground, the interior of stone and brick tomb chambers below were adorned with carvings of figures on walls and engravings on walls and doors. Features previously made in wood, such as coffins and steles (vertical markers placed in the ground to memorialize the dead), were now carved in stone. Above and below ground, tomb layout and ornamentation followed a coordinated plan. The same images and themes reappear in different places, and the tasks of the tomb are clearly allocated between different media. The result is an unparalleled picture of contemporary life and thought.

5.1: Aztec Artisans

Most of the material objects produced by the Aztec people of central Mexico during the Late Postclassic period (1350-1521) were manufactured in household settings by household members. Craft skills and knowledge, from weaving to metalwork, were passed from parent to child. Some objects were produced in small amounts strictly for household consumption, but many goods were produced in larger quantities and destined for market exchange. Specialization in the production of goods reached a high level of diversity and intensity during these times. In part, this was possible because of the food surpluses created by increasingly intense systems of agriculture, complemented by an abundance of nonagricultural resources. These surpluses released some persons, either partially or fully, from food-getting activities, allowing them to concentrate their time and energy on pursuing other production activities. High levels of craft production were also related somewhat to the population surge in the Late Postclassic period, providing large groups of producers and consumers of goods. And also, in part, these specializations were stimulated and maintained by the increasing commercialization of the Late Postclassic period, facilitating relatively efficient and effective flows of raw materials and finished goods on local, regional, and extra-regional levels.

Where artisans produced their crafts reflected, to some extent, their organization and sociopolitical context. Artisans were either "attached" or "independent." The former were situated in or near palaces, suggesting elite economic, social, and/or political relationships. This particularly applied to some luxury artisans who enjoyed the patronage (support) of the local ruler. These artisans were assured access to raw materials as well as guaranteed consumers. For instance, the Tenochtitlan-Tlate featherworkers attached to the Tenochtitlan ruler's palace enjoyed access to the ruler's aviary and stored tributes and were specifically employed to produce ornate featherwork for the ruler's fine attire, for exquisite gifts for the ruler's diplomatic guests, and to adorn the god Huitzilopochtli. It appears that these highly esteemed artisans were resettled in or near the palace, yet it also seems that the household structure of production was maintained. That is, it is likely that entire households were relocated, allowing for the household's division of labor to be maintained. Other artisans attached to the royal palace in Tenochtitlan included gold workers and silversmiths, coppersmiths, painters, cutters of stones, greenstone mosaic workers, and woodcarvers, all of whom worked at or near the totocalli, or birdhouse.

Artisans continued to be attached to native nobles even after the Spanish conquest of the Aztec empire. Don Juan de Guzman, a native governor of Coyoacan (an area near Tenochtitlan) who was appointed by the Spanish in the mid-sixteenth century, enjoyed the privilege of having "all the artisans and craftsmen be attached to the royal house to do what is needed." Ten carpenters and ten stonemasons were also attached to Don Juan, but we know little about them beyond that he was having a house built, and "they are to do what is needed." Prior to the Spanish conquest, when king Motecuhzoma Xocoyotzin employed sculptors to carve a statue of him, he paid them handsomely for their work. Perhaps these were independent artisans, although the payment could as well represent compensation to attached artisans. While royal or elite sponsorship provided attached artisans with a predictable livelihood, it perhaps offered them less opportunity for creativity than the independent luxury artisans working beyond the reach of the palace and selling their finery in the markets.

Some of these independent artisans, producing both luxury and utilitarian goods, were concentrated in specific neighborhoods, or calpolli. Independent artisans could not necessarily depend on the generosity of the state in obtaining raw materials for their crafts. They relied on merchants and markets for access to raw materials and as outlets for their finished products. The Tlatelolco feather workers maintained especially close relations with their equally exclusive neighbors, the entrepreneurial pochteca (professional merchants), who provided them with the shimmering tropical feathers essential in their craft. While undocumented, it is likely that similarly close relations existed between luxury artisans and merchants in other city-states.

Whether attached to elite palaces or living in exclusive neighborhoods, specialized artisans required enduring and predictable links to several other areas of Aztec life: they gained status through participation in society-wide ceremonies, served royal and other noble palaces, dealt with long-distance merchants, and were consistent fixtures in any major marketplace.

5.2: Why Water Bugs Practice Parental Care of Eggs

Although paternal care of young (fathers caring for their young) is common among fishes, the trait is rare among other animals, vertebrates, and invertebrates alike. Among the few paternal insects are giant water bugs. In Lethocerus water bugs, males guard and moisten clutches of eggs (eggs deposited during a single episode of laying) that females glue onto the stems of aquatic vegetation located above the waterline. Other kinds of male water bugs (e.g., Abedus and Belostoma) permit their mates to lay eggs directly on their backs, after which the male assumes responsibility for their welfare. A male Abedus caring for its eggs spends hours perched near the water's surface, pumping his body up and down to keep well-aerated water moving over the eggs. Clutches of Abedus eggs that are experimentally separated from a male attendant do not develop, demonstrating that male parental care is essential for offspring survival in this case.

Bob Smith has explored both the history and the adaptive value of these unusual paternal behaviors. Since the closest relatives of the family that contains the paternal water bugs are the Nepidae, a family of insects without male parental care, we can be confident that the brooding species (species caring for eggs) evolved from nonpaternal ancestors. Whether out-of-water brooding and back brooding evolved independently or whether one preceded the other is not known, although some evidence suggests that back brooding came later. In particular, female Lethocerus sometimes lay their eggs on the backs of other individuals, male or female, when they cannot find suitable vegetation for that purpose. This unusual behavior indicates how the transition from out-of-water brooding to back brooding might have occurred. Females with the tendency to lay their eggs on the backs of their mates could have reproduced in temporary ponds and pools where aquatic vegetation sticking out of the water was scarce or absent.

But why do the eggs of water bugs require brooding? Huge numbers of aquatic insects lay eggs that do perfectly well without a caretaker of either sex. However, Smith notes that the eggs of giant water bugs are much larger than the standard aquatic insect egg, with a correspondingly large requirement for oxygen, which is needed to sustain the high metabolic rates underlying embryonic development. But the relatively low surface-to-volume ratio of a large aquatic egg leads to an oxygen deficit inside the egg. Since oxygen diffuses through the air much more easily than through water, laying eggs out of water can solve that problem. But this solution creates another problem, which is the risk of drying out that the eggs face when they are high and dry. The solution, brooding by males that moisten the eggs repeatedly, sets the stage for the evolutionary transition to back brooding at the air-water interface.

Wouldn't things be simpler if water bugs providing parental care simply laid small eggs with large surface-to-volume ratios? To explain why some water bugs produce eggs so large that they need to be brooded, Smith points out that water bugs are among the world's largest insects, almost certainly because they specialize in grasping and stabbing large vertebrates, including fish, frogs, and tadpoles. Water bugs, like all other insects, grow in size only during the immature stages. After the final molt (loss of outer covering layer) to adulthood, no additional growth occurs. As an immature insect loses its outer covering as it grows from one stage to the next, it acquires a new flexible outer covering that permits an expansion of size, but no immature insect grows more than 50 or 60 percent per molt. One way for an insect to grow large, therefore, would be to increase the number of molts before making the final transition to adulthood. However, no giant water bug molts more than six times. This observation suggests that these insects are locked into a five-or six-molt sequence, just as the bird species, the spotted sandpiper, evidently cannot lay more than four eggs per clutch. If a water bug is to grow large enough to kill a frog in just five or six molts, then the immature insect that hatches from the egg must be large because it will get to undergo only five or so 50-percent expansions.

6.1: Imitation in Monkeys and Apes

Almost all animals learn novel tasks more easily if they can observe a knowledgeable demonstrator Biologist Tom Langen trained individual magpie jays to pry open a door on a box that contained food. Subsequently, birds whose social groups included a demonstrator learned how to open doors much more rapidly than birds whose groups did not. Indeed, birds in groups that lacked a demonstrator did not even realize that there was food in the boxes. Similarly, in captivity, many monkeys can learn to use rudimentary tools to obtain food, and they do so more quickly and accurately in the presence of a demonstrator. If monkeys learned as humans do, it would be safe to assume that the monkeys learn to perform the tasks by watching the demonstrator and imitating his actions. This would imply that the monkeys understand the demonstrator's intentions and goals. But this does not seem to be the case.

Most animal species show very little evidence of purposeful copying by imitation. In the laboratory, monkeys are attracted to tools and often begin experimenting with them after observing another monkey do so, suggesting that social companions enhance and facilitate tool use. But learning about a tool's use through "social facilitation" typically requires extensive practice through trial and error. As a result, different individuals adopt different idiosyncratic styles, and the spread of the skill is very slow. Although many monkey species can learn to use tools in captivity, there are very few examples of tool use in the wild. Capuchin monkeys, which inhabit Central and South America, are the only monkeys that regularly use sticks or stones to pry into trees or break open nuts under natural conditions. Capuchins also have comparatively large brains compared to other monkeys. The relative lack of spontaneous tool use in monkey species suggests that monkeys have difficulty recognizing the relation between actions and objects.

In the wild, baboon monkeys seem to use tools only in aggressive contexts. When displaying, male baboons occasionally wave or throw sticks in the direction of their rivals. Whether they recognize the potential function of these weapons, though, seems doubtful. When one group of baboons in Namibia dislodged stones from a cliff when they were disturbed by humans, they did so not only when people were under the cliff but also when they were too far away to be struck. At Gombe, where chimpanzees compete with baboons for food, chimpanzees throw branches at baboons. Baboons, however, never throw objects at chimpanzees.

Chimpanzees and orangutans are different. In captivity, these animals, which are apes rather than monkeys, attend closely to a demonstrator when learning to use tools to open boxes, and they require very few trials to learn to copy his actions. They seem to recognize the intentions and goals of the demonstrator, and they rapidly learn a tool's function from attending to his behavior. Although they do not copy the demonstrator's exact motor patterns as closely as children do, they do tend to conform to his technique.

Under natural conditions, chimpanzees and orangutans also use a variety of tools for different purposes. In fact, different populations of chimpanzees and orangutans use different kinds of tools for different purposes, and the use of specific tool types appears to be socially transmitted. Two points about tool use in chimpanzees and orangutans seem relevant. First, in marked contrast to monkeys, no population of chimpanzees has been reported not to use tools. Second, unlike monkeys, chimpanzees and orangutans often show foresight and planning in selecting and modifying tools in advance of their use. Before fishing for termites, chimpanzees often search some distance from the termite mound to find an appropriate prodding stick and strip the bark from it. Similarly, when preparing to crack open nuts, chimpanzees must carry both stones and nuts to suitable hard surfaces. Often, this means that a chimpanzee will carry both nuts and stones over considerable distances before beginning a nut-cracking session.

In their ability to plan, understand a tool's function, and appreciate a demonstrator's goals, then, apes are strikingly different from most monkeys. This is not to say, however, that tool use and manufacture are unique to apes or that monkeys are completely incapable of imitation.

6.2: Roman and Chinese Metalworking

Chinese steel was highly valued in the Roman Empire (which controlled much of the Western world between 27 B.C.E. and 476 A.D.) since Roman workshops could not mass-produce metals with comparable strength and sharpness. Steel is a metal alloy (mixture)manufactured by heating iron ore (raw iron) to high temperatures, then combining the molten(melted) metal with carbon or other strengthening elements. The quality of steel produced by these techniques depends on the sustained temperature of the furnace and the quantity and condition of the added compounds. Good-quality steel is harder than iron and has much greater flexibility and strength. Blades made from steel, therefore, maintain a sharper edge for a longer time and have a greater resistance to rust than their equivalent in iron. Western civilizations did not have sufficient knowledge of the carbon compounds that needed to be added to molten iron to produce reliable steel. Instead, the Romans produced wrought iron (iron with very low carbon content) by first heating iron ore in a furnace (oven) to separate metal from impurities in a process known as smelting. This technique was used throughout the Roman Empire to make tools and bladed weapons. The resultant iron also acquired a trace of strengthening carbon from the charcoal fueling the furnaces.

The situation was different in the Chinese Han Empire (206 B.C.E to 220 A.D.), where metalworkers using more advanced furnaces had identified the natural compounds that created better-quality iron during the smelting process. Through continual practice, they refined the measurements needed to ensure that the compounds added to iron ore introduced sufficient carbon to create a reliable quality of steel. The Chinese had developed large enclosed furnaces that included bamboo nozzles (round openings) to produce steady streams of air. This made it easier to keep the fire at a steady heat and control reactions within the furnace. Chinese furnaces also burned compressed coal, which further increased temperatures and reduced fuel costs. This was significant because mass-produced cast iron (iron with carbon content greater than 2 percent) could be transformed into steel by applying blasts of cool air that provided oxygen to the molten metal (the "Hundred Refinings Method"). The Chinese also knew how to turn wrought iron into steel. Blades were wrapped in fruit skins rich in carbon, containing a small amount of impurities. These packages were then sealed in clay containers and heated at high temperatures over a sustained period (up to twenty-four hours) until the metal absorbed the necessary carbon and strengthening elements. In China, these techniques were used to mass-manufacture a variety of tools, including knives, hammers, and cooking pots.

This important development allowed the Han regime to mass-manufacture high-quality metal, including armor-piercing weapons. The Han understood that steel manufacturing techniques provided Chinese troops with superior armor and weaponry. Consequently, the regime tried to restrict the spread of this technology to foreign peoples and prevent the export of Chinese steel supplies to neighboring nations. However, there were strong incentives for Chinese merchants to break the embargoes (restrictions) and offer steel at high prices to foreign traders. Smuggling became a problem, and the warlike Xiongnu people of Mongolia were able to capture Han metalworkers when they raided Chinese territory. From these prisoners, the Xiongnu learned how to produce supplies of their own steel weaponry, which they offered for exchange with other people. In this way, supplies of superior eastern steel reached the Parthian Empire in Iran.

The superiority of this steel weaponry was demonstrated on the battlefield of Carrhae in 53 B.C.E. when a Roman army encountered Parthians from eastern Iran. The steel-tipped arrows carried by the Parthians easily punched through Roman shields and armor. The early Roman Empire possessed no weapons or armor comparable to that of the Parthians. Consequently, Roman authorities did not fully understand the significance of the metal used by their Iranian rivals. It was assumed that Parthian steel was the product of unique iron ores that could only be found in the distant east, and no initiative was taken to determine how these metals could be produced. This explanation seemed reasonable when the Romans considered how geography and climate provided the distant East with better fabrics, more precious stones, and more potent flavorings in the form of spices.

7.1: Early Chinese Silk Production

China is justly famous for its silk production, which probably began more than 6,000 years ago. Excavations of Neolithic sites have revealed clay artifacts with impressions made apparently by silk cloth, as well as stone ornaments carved in the shape of silkworms. The earliest find of silk itself, dated to around 2800 B.C., is from Zhejiang province, where a fragment of cloth was preserved in damp conditions inside a bamboo box. Zhejiang province, in southeast China, has always been an important silk-producing area and was probably also the center of one of the major prehistoric cultures.

Later writers attributed a well-organized system of production to the Western Zhou dynasty (1050-771 B.C.). A text compiled or revised in the Han period (206 B.C.-A.D. 220) describes a silk supervisor, a hemp supervisor, dyers, and weavers working in the women's section of the palace. Although one silkworm, making its cocoon, spins a pair of filaments that may be up to one kilometer in length, because of the fineness of these filaments, thousands of silkworms are required to produce enough silk to weave a length of cloth. From an early date in China, it was found best to carry out the manufacture of silk cloth on a large scale, with a division of labor according to the various tasks: picking the mulberry leaves to feed the silkworms, reeling the filaments from the cocoons, weaving, etc. In the eighteenth and nineteenth centuries, this highly organized and subdivided industry fascinated Westerners, who collected sets of illustrations of the different stages. Silk production has traditionally been associated with women in China, and in imperial days the empress would perform an annual mulberry-leaf-picking ceremony outside the Hall of Sericulture in Beijing.

By the Han dynasty, the silk industry was already highly specialized, producing in addition to plain cloth, self-patterned monochrome cloth figured gauzes, and thicker, multicolored cloth. The last was highly valued, costing up to fifteen times as much as plain silk. Chain stitch embroidery also became widespread at this time and was used to decorate clothes, wall hangings, pillows, and horse trappings. Elaborate examples have been found in Han dynasty tombs in Hubei and Hunan provinces, where waterlogged land has preserved much organic material.

Although produced in large quantities, silk remained an expensive luxury. Both woven silk and raw silk were used as tribute to the emperor and as offerings to foreign tribes, such as the Xiongnu on the northwestern borders of China. From here, Chinese silk must have been traded along the Silk Route through Central Asia and the Middle East as far as Europe. Most early examples of silk cloth in the West appear to have been woven locally but from cultivated silk fiber of the Bombyx mori worm. The fact that China was the origin of this fiber was acknowledged by the ancient Greeks and Romans, who referred to silk as serica, literally, "Chinese. "By the end of the Han period, silk cultivation and knowledge of silk processing must have begun to spread westward and by the fifth or sixth century, had reached the Mediterranean area. But Western silk production throughout the Middle Ages (fifth to fourteenth centuries A.D.) was never sufficient to satisfy demand from

Europe and Mediterranean areas, and imported Chinese silk remained very important.

Trade along the Silk Route was at its most vigorous during China's Tang dynasty (A.D. 618-906), and travelers record the bazaars of the Middle East as being full of Chinese patterned cloth and embroideries. Simultaneously, we are told that the Tang capital of Chang'an was populated by large numbers of Iranian craftsmen. A silk weave now known as weft-faced compound twill appears among Chinese textiles for a few centuries from about A.D. 700. This may well have been a technique introduced by foreign weavers, as it seems to have developed originally in Iran. In the West, it was particularly associated with repeating designs of roundels(circles) enclosing paired or single animals, with flower heads or rosettes between the roundels. The paired animals, rosettes, and the ring of pearl-like dots that often made up the roundel frame all passed into Chinese design.

Indeed, trade in textiles or other items may have carried the motif of the pearl roundel to China before any transfer of technology since it first appears in China as early as the fifth century A.D. on stone carvings at Buddhist cave temples.

7.2: Murals, Frescoes, and Easel Paintings

Murals are pictures on walls or ceilings that become a part of the building's architectural decoration. Archaeologists have excavated and saved mural paintings from Pompeii and Herculaneum, cities that were buried by an eruption of Mount Vesuvius in 79 C.E. Unfortunately, outdoor painting of any kind has little chance of surviving the effects of the environment for very long Richard Haas's famous mural Homage to Cincinnatus, which was painted in 1983 and is displayed on the Brotherhood Building in Cincinnati in the United States, has faded considerably. Indoors, where walls can be kept dry, murals have traditionally done much better when they were painted in fresco. The Italian word fresco means "fresh." Michelangelo's Sistine Chapel ceiling, painted in the sixteenth century, is a perfect example of fresco painting. In true fresco, water-based paints are applied to fresh, wet plaster so that the pigment (color) soaks into the plaster. The paint actually becomes part of the wall. The lime of the plaster, changing to calcium carbonate when it dries, binds the pigments permanently in the wall. The colors are matte, not glossy. They stay bright for hundreds of years, and as long as the wall lasts, the fresco lasts.

Paint applied to the wall when it is dry is not very permanent. Since some pigments will not combine properly in fresco, they have to be applied by the artist. The blue pigment that Giotto used in The Nativity, a fresco portraying the birth of Jesus Christ, would not mix with the lime in plaster, so he had to paint it on the dry plaster. As a consequence, the blue of the sky and the blue of Mary's robe have almost all flaked off. Since true fresco must be painted on wet plaster, an artist can work on only a small portion of the wall where the plaster was freshly applied beforehand. A normal area for a day's work might be about one or two square yards, although the size depends on the complexity of the painting. Some days, a fresco painter might complete only a head. In Giotto's fresco The Nativity, the breaks between one day's work and the next are visible on close inspection.

Fresco painting takes a lot of preparation because artists have to have the entire composition worked out before they get started on an individual patch of plaster. In addition to the usual preliminary drawings, the fresco painter also makes cartoons on paper in the same scale as the mural-so that the essential lines of the composition can be traced and transferred to the wall.

Most artists produce easel paintings-painting that are painted on a portable wooden support-that are intended to be hung on a wall. Bernardo Daddi painted the three-part Madonna and Child (Jesus Christ and mother) for use during private prayer. Originally, it may have rested on a table. After their prayers, the artwork owners could have folded the sides together to store it or carry it to another location.

When Daddi and other European artists in the fourteenth century wanted to create an easel painting, they usually worked on carefully prepared wooden panels. Wooden panels assembled from several planks and as large as ten to twelve feet high were common in that era. The wood had to be dried, aged, and sealed so that it would become an acceptable painting surface, as smooth as polished marble. Daddi mixed his pigments with egg yolk, a medium that is called egg tempera. If the panel received decent treatment over the years, a 650-year-old egg tempera such as Madonna and Child will have colors that are still preserved and fresh. Egg tempera is quite a permanent medium.

Egg tempera paint dries as fast as egg yolk dries on a breakfast plate and is just as stubborn to remove. An artist applies it in short strokes because of the rapid drying time, and by the time the artist comes back to the panel with the next brushstroke, the preceding one has already dried. Little blending is possible, and the only way to remove a mistake is by scraping it off. Every stroke has to be meticulously placed with small brushes.

8.1: Recognizing Social Play in Animals

Many animals engage in some type of social play-that is, playing with others, including chasing and fighting. Three functions of social play have been proposed: Social play may (1) lead to the forging of long-lasting social bonds, (2) help develop much-needed physical skills, such as those relating to fighting, hunting, and mating, and (3) aid in the development of cognitive skills. One cognitively related benefit of the social play revolves around the idea of self-assessment. Here, animals use social play as a means to monitor their developmental progress as compared to others. For example, in infant sable antelope (Hippotragus niger), individuals prefer same-age-play partners. While this preference could be due to numerous factors, Kaci Thompson has hypothesized that it is primarily a function of infants attempting to choose play partners that provide them with a reasonable comparison from which to gauge their own development.

Since many of the behavior patterns seen during play are also common in other contexts-hunting, mating, dangerous aggressive contests-how do animals know they are playing and not engaged in the real activity? And even more to the point, how do they communicate this information to each other? Bekoff has proposed three possible solutions to this important but often overlooked question. One way that animals may distinguish play from related activities is that the order and frequency of behavioral components of play are often quite different from that of the real activity. That is, when play behavior is compared with the adult functional behavior that it resembles, behavioral patterns during play are often exaggerated and misplaced. If young animals are able to distinguish these exaggerations and misorderings of behavioral patterns by, for example, observing adults that are not involved in playing, a relatively simple explanation exists for how animals know they are playing.

A second, somewhat related, means by which animals may be able to distinguish play from other activities is by the placement of play markers. These are also known as play signals and can serve both to initiate play and indicate the desire to continue playing, and to warn adults that the young are playing and not in danger of injury. In canids (the animal group that includes dogs and wolves), for example, biting and shaking are usually performed during dangerous activities such as fighting and predation. Yet, biting and shaking are also play behaviors of young canids. Bekoff found that play markers such as a bow (lowering the head) would precede biting and rapid side-to-side shaking of the head to indicate that they were not dangerous behaviors. The bow would communicate that this action should be viewed in a new context-that of play. Another play marker might be a particular kind of vocalization-for example, chirping in a rat, whistling in a mongoose, panting in a wolf, or a chimpanzee before or during a play interaction. Or there might be a distinctive smell that indicated that the animals were engaged in play.

Play markers have also been found in primates such as the juvenile lowland gorilla. Juvenile lowland gorillas play with each other often, and play ranges from what Elisabetta Palagi and her colleagues call gentle play to rough play. Palagi's team discovered that when juvenile gorillas-particularly males-were involved with rough play, the play was often preceded by a facial gesture they call the play face. This facial gesture, which is not seen in other contexts, includes slightly lowered eyebrows and an open mouth. In addition to using this facial gesture during rough play, juvenile gorillas also displayed it when a play session was in a place that made escape (leaving) difficult -another context in which it may be important to signal to others that what is about to occur is playing.

Yet another way by which young animals may be able to distinguish play from related behaviors is by role reversal, or self-handicapping, on the part of any older playmates they may have. In role reversal and self-handicapping, older individuals either allow subordinate younger animals to act as if they are dominant during play or the older animals perform some act (for example, an aggressive act) at a level clearly below that of which they are capable. Either of these provides younger playmates with the opportunity to recognize that they are involved in a play encounter.

8.2: Mesozoic Seed Dispersal

Many plants rely on wind to disperse (spread) their seeds. However, because seeds often fall into the wrong places, wind dispersal seems wasteful; it can work only in plants that produce great numbers of seeds. Wind-dispersed seeds must be light and small, so they cannot carry much energy for seedling growth. They have to germinate (grow from seed) in relatively well-lit areas, where they can obtain energy from sunlight. Alternatively, a plant could have its seeds carried away by an animal and dropped into a good place for growth. Many animals can carry larger seeds, which can successfully germinate in darker places. Some animals visit plants to feed on pollen or nectar, and others eat parts of the plants. Others simply walk by the plant, brushing it as they pass. Small seeds may be picked up accidentally during such visits, especially if the seed has special hooks, burrs, or glues to help attach it to a hairy or feathery visitor.

However, seed dispersal by animals is not cost-free. Many dispersers eat the seeds, passing only a few undamaged through their internal organs. So there is a significant wastage of seeds, depending on a delicate balance between the seed coat and the teeth and stomach of the disperser. Too strong a seed coat, and the disperser will turn to easier food, or germination will be too difficult; too weak a seed coat, and too many seeds will be destroyed. Some plants' seeds germinate well only if they are eaten by a particular disperser.

Scientists believe animals first began dispersing seeds sometime during the Mesozoic era (252-65 million years ago). Seed dispersal by animals surely evolved after insect pollination. Insects of the Jurassic period (206-145 million years ago) may have become good pollinators, but they were too small to have been large-scale seed transporters. Jurassic reptiles (including dinosaurs) were large enough, but often had low food-processing rates, so any seeds they swallowed were exposed to digestive juices for a long time. Reptiles do not even have fur in which seeds can be entangled (though feathered therapod dinosaurs might have). Seeds were undoubtedly dispersed by dinosaurs to some extent since the huge vegetarian dinosaurs ate great quantities of vegetation. But in spite of the size of the deposits of fertilizer (in the form of waste) that must have surrounded seeds passing through dinosaurs, browsing dinosaurs (ones that eat grass, leaves, and shrubs) probably damaged and trampled plants more than they helped them. It is unlikely that any Mesozoic plant would have encouraged dinosaur browsing.

Transport over a long distance can take a seed beyond the range of its normal predators and diseases and can allow a plant to become very widespread, provided that there are pollinators in its new habitat. As flowering plants adapted to seed dispersal by animals, they probably dispersed into new habitats much faster than other plants did. Other things being equal, we might expect a dramatic increase in the number of flowering plants found in the fossil record as they adapted toward seed dispersal by animals rather than by wind.

There were few effective animal seed transporters in the Jurassic period, and dinosaurs are unlikely candidates in the Cretaceous period (the last period of the Mesozoic era). The biologist Philip Regal suggested that birds and mammals prompted the distribution of flowering plants by aiding them in seed dispersal. Birds and mammals have feathers and fur in which seeds easily become entangled; seeds pass quickly through their small bodies with their high food-processing rates and are likely to be unharmed unless they have been deliberately chewed. Flowering plant seeds would have been especially suited to transport by vertebrate (back-boned) animals because of their extra protective coating. In contrast, the seeds of conifers (plants with needle-like leaves) are usually small and light, designed to blow in the wind, and conifers depend on close clusters for pollination. Isolated conifers are likely to be unsuccessful reproducers, and additional transport would make little difference to their long-term success. However, many new types of flowering plants appeared in the Early and Middle Cretaceous periods when mammals and birds were still minor members of the ecosystem. So, many scientists are unconvinced by this explanation of flowering plants' early success.

9.1: Challenges of Mesopotamian Agriculture

One of the world's first civilizations began in the area between the Tigris and Euphrates Rivers known as Mesopotamia (modern Iraq), where much of the fertile land was under cultivation by 4500 B.C. Sumer, in southern Mesopotamia, was dominated by eight major cities, including the city of Uruk, which had 50,000 inhabitants by 3000 B.C. But the irrigation that nourished Mesopotamian fields carried a hidden risk. Groundwater in semiarid regions usually contains a lot of dissolved salt. Where the water table is near the ground surface, as it is in river valleys and deltas, groundwater is moved up into the soil, where it evaporates, leaving the salt behind in the ground. When evaporation rates are high, sustained irrigation can generate enough salt to eventually poison crops. While irrigation dramatically increases agricultural output, turning sunbaked floodplains into lush fields can sacrifice long-term crop yields for short-term harvests.

Preventing the buildup of salt in semiarid soils requires either irrigating in moderation or periodically leaving fields fallow (unplanted). In Mesopotamia, centuries of high productivity from irrigated land led to increased population density, which fueled the demand for more intensive irrigation. Eventually, enough salt crystallized in the soil that further increases in agricultural production was not enough to feed the growing population.

The key problem for Sumerian agriculture was that the timing of river runoff did not coincide with the growing season for crops. Flow in the Tigris and Euphrates peaked in the spring when the rivers filled with snowmelt from the mountains to the north. Discharge was lowest in the late summer and early fall when new crops needed water and the most intensive agriculture required storing water through soaring summer temperatures. A lot of the water applied to the fields simply evaporated, pushing that much more salt into the soil.

Salinization was not the only hazard facing early agricultural societies. Keeping the irrigation ditches from becoming blocked by silt (mud) was a chief concern, as extensive erosion from upland farming in the Armenian hills poured dirt into the Tigris and Euphrates Rivers. Conquered people were put to work pulling mud from the all-important ditches. Sacked and rebuilt repeatedly, Babylon was finally abandoned only when its fields became too difficult to water. Thousands of years later, piles of silt more than thirty feet high still line ancient irrigation ditches. On average, silt pouring out of the rivers into the Persian Gulf has created over a hundred feet of new land a year since Sumerian time. The ruins of the city of Uruk, a once thriving seaport, now stand a hundred and fifty miles inland.

As Sumer prospered, fields lay fallow for shorter periods because of the growing demand for food. By one estimate, almost two-thirds of the thirty-five thousand square miles of arable land (land suitable for farming) in Mesopotamia were irrigated when the population peaked at around twenty million. The combination of a high load of dissolved salt in irrigation water, high temperatures during the irrigation season, and increasingly intensive cultivation pumped ever more salt into the soil.

Temple records from the Sumerian city-states inadvertently recorded agricultural deterioration as salt gradually poisoned the ground. Wheat, one of the major Sumerian crops, is quite sensitive to the concentration of salt in the soil. The earliest harvest records, dating from about 3000 B.C., report equal amounts of wheat and barley in the region over time; the proportion of wheat recorded in Sumerian harvests fell, and the proportion of barley rose. Around 2500 B.C., wheat accounted for less than a fifth of the harvest. After another five hundred years, wheat no longer grew in southern Mesopotamia.

Wheat production ended not long after all the region's arable land came under production. Previously, Sumerians irrigated new land to offset shrinking harvests from salty fields. Once there was no new land to cultivate, Sumerian crop yields fell precipitously because increasing salinization meant that each year fewer crops could be grown on the shrinking amount of land that remained in production. By 2000 B.C., crop yields were down by half. Clay tablets tell of the Earth turning white in places where the rising layer of salt reached the surface.

9.2: Extinction Trends

In general, the diversity of life on Earth has been constant or increasing slightly over the past 200 million or 300 million years. The geologic record shows new species emerging and old ones dying away, resulting in a broad range of forms over geologic time. On closer inspection, the geologic record also shows distinct short-term increases in the rate of extinction termed extinction events. One such event occurred 65 million years ago and marked the end of the Mesozoic Era, the age of reptiles. For years, the cause of this event puzzled scientists. However, in the 1980s, a thin layer of unique sediment containing the element iridium was discovered in sedimentary bedrock whose age coincided with this event. Research showed that this sediment was created by an explosion on Earth's surface, probably caused by an asteroid impact. The explosion threw a huge mass of debris into the atmosphere, which, scientists reason reduced incoming solar radiation and cooled Earth. Plants declined and the food sources for many herbivores (plant-eating animals) apparently disappeared, followed, shortly thereafter, by a sequence of extinctions among predators.

Many other extinction events are also identifiable in the geologic record. Some occur at 26-million-year intervals, and scientists speculate that they may be associated with extraterrestrial impacts similar to the one at the end of the Mesozoic Era. Between these events, many smaller episodes of extinction are also apparent. The influence of humans on extinction patterns, however, does not appear until about 10.000 to 15.000 years ago.

The last glaciation on Earth reached its maximum 15,000 to 20.000 years ago. At this time, the northern half of North America was covered with great sheets of glacial ice. A similarly large mass of ice covered a large part of northern Eurasia. Humans lived in the zone south of the ice border, where they survived by hunting and gathering. Among the animals hunted were large mammals such as mammoths and mastodons, which are now extinct. The extinction process appears to have taken place over several thousand years in the presence of humans as the ice sheets were melting and the bioclimatic environment was undergoing change. By 8,000 to 10,000 years ago, dozens of mammal species had disappeared. Scientists debate whether the extinctions were driven mainly by changing climate or mainly by human exploitation. No doubt these animals were under stress from a changing environment, but the evidence for population reduction by early hunters is also compelling. On balance, it appears certain that humans had a hand in the process. At the very least, hunting hastened the extinction process.

The next wave of extinction began about 10,000 years ago with the spread of agriculture and the growth of human populations. Before A.D. 1500 or so, much of the area taken up by sedentary agriculture in Europe and Asia was in subtropical and midlatitude environments. Many species were undoubtedly eliminated in these environments, but for most, there is little or no record of their existence, especially for plants, insects, and smaller organisms. In the Mediterranean basin, on the other hand, where the early historical record is most complete, there is sound evidence of widespread mammal extinction associated with the spread of early agriculture. Though less widely cultivated than the subtropics, the wet tropics were not exempt from early agriculture. Large areas of monsoon forest and rainforest were destroyed in Asia and Africa by both crop farmers and herders. In the Americas, tropical rainforests and wetlands were also lost to agriculture. Recent evidence indicates that considerable areas of rainforest were cleared by the Aztec and Mayan civilizations in Central America. All told, the first several thousand years of agriculture undoubtedly forced the extinction of thousands of organisms, most of which we can never know about because they left no measurable record of their existence.

After A.D. 1500 and European colonization of the Americas and Africa, the rate of global extinction increased again. In North America, most of the mid-latitude forests were eradicated. In the tropics, plantation agriculture, mining, and expanding subsistence farming (farming provides for the basic needs of the farmer) further reduced the tropical rainforest. Before the twentieth century, however, forest eradication was relatively minor by today's standards; beginning around 1950, rainforest destruction became a crisis that, by 1975, had reached epidemic proportions.

10.1: Chemical and Biological Weathering of Rocks

Rocks can be broken into smaller pieces by a natural process known as weathering. Weathering refers to the chemical alteration and physical disintegration of rocks by the actions of air, water, and organisms. Two principal types of weathering are chemical weathering and biological weathering.

The minerals that rocks are made of are subject to alteration by chemical weathering. Some minerals, such as quartz, resist this alteration quite successfully, but others, such as the calcium carbonate of limestone, dissolve easily. In any rock made up of a combination of minerals, the chemical breakdown of one set of mineral grains leads to the disintegration of the whole mass. In granite (made chiefly of the minerals quartz and feldspar), the quartz resists chemical decay much more effectively than does the feldspar, which is chemically more reactive and weathers to become clay. Often, granite surfaces are heavily pitted (marked with many small holes or depressions). In such cases, the feldspar grains are likely to have been weathered to clay and blown or washed away. The quartz grains still remain, but they may eventually be loosened too. So even rock as hard as granite cannot withstand the weathering process forever.

Three kinds of mineral alteration dominate in chemical weathering: hydrolysis, oxidation, and carbonation. When minerals are moistened, hydrolysis occurs, producing only a chemical alteration but an expansion in volume as well. This expansion can contribute to the breakdown of rocks. Hydrolysis, it should be noted, is not simply a matter of moistening; it is a true chemical alteration, and minerals are transformed into other mineral compounds in the process. For example, feldspar hydrolysis yields a clay mineral (silica) solution (that is, dissolved in water) and a carbonate or bicarbonate of potassium, sodium, or calcium in solution. The new minerals tend to be softer and weaker than their predecessors. In granite boulders, hydrolysis combines with other processes to cause the outer shells to flake off.

When minerals in rocks react with oxygen in the air, the chemical process is known as oxidation. We have plenty of evidence of this process in the reddish color of soils in many parts of the world and in the reddish-brown hue of layers exposed in such places as the Grand Canyon. The products of oxidation are compounds of iron and aluminum, which account for the reddish colors seen in so many rocks and soils. In tropical areas, oxidation is the dominant chemical-weathering process.

Various circumstances may convert water into a mild acid solution, thereby increasing its effectiveness as a weathering agent. With a small amount of carbon dioxide, for instance, water forms carbonic acid, which in turn, reacts with carbonate minerals such as limestone and dolomite (a harder relative of limestone). This form of chemical weathering, carbonation, is especially vigorous in humid areas, where limestone and dolomite formations are often deeply pitted and grooved, and where the evidence of solution and decay is prominent. This process even attacks limestone underground, contributing to the formation of caves and subterranean corridors. In arid areas, however, limestone and dolomite resist weathering much better, although they may show some evidence of carbonation at the surface.

Biological weathering is the breakdown of rock caused by the actions of living organisms. This kind of weathering plays an important role in the formation of soils. It is through the breakdown of rocks and the accumulation of a layer of minerals that plants can grow-plants whose roots and other parts, in turn, contribute to the weathering processes. But it is likely that the role of plant roots in weathering is somewhat overestimated. The roots follow paths of least resistance and adapt to every small irregularity in the rock. Roots certainly keep cracks open once they have been formed. More importantly, however, are as of roots tend to collect decaying organic material that is involved in chemical-weathering processes.

One of the most important aspects of biological weathering is the mixing of soil by burrowing animals and worms. Another interesting aspect is the action of lichens, a combination of algae and fungi that live on bare rock. Lichens draw minerals from the rock through an absorption process. The swelling and contraction of lichens as they alternately get wet and dry, may also cause small particles of rock to fall off.

10.2: The Professionalization of Painting in Europe

Before the eleventh century, most painters in Europe were monks (members of a religious group that lived in seclusion), and their work was exclusively religious. Such artists worked in a variety of art forms, including metalwork and manuscript illumination (the art of illustrating handwritten books), and they did not sign their work, as art was considered an opportunity for religious meditation, not self-advancement. Between the eleventh and the fourteenth centuries, however, painting began being practiced by lay professionals who had no connection to religious institutions. Inevitably, this had consequences both for working practices and for the art that was produced. These new painters followed a trade like any other. Like the woodworker, the potter, the baker, and the weaver, the lay painter offered his technical proficiency for a fee. He was by no means above asking the baker for the use of his ovens to make charcoal, employed as a black pigment. Nor would the artist sneer at the cook, with whom he had many skills in common.

One of the consequences of this transition from monk to artisan was increasing specialization. Painters were painters, not to be confused with illuminators, dyers, or workers in wood and metal. Such distinctions were rigidly enforced by the guilds-powerful associations of workers within specific trades-that developed to safeguard the employment of tradespeople against competition and economic uncertainty, so that it would have been unthinkable for a painter to be called in to illuminate a book page. There were even fine distinctions drawn among painters. In fifteenth-century Spain, one could find specialists in altarpiece painting (the painting of images for placement behind the altar of a church), fabric painting, and interior decorating. Associated with these divisions was a hierarchy of trades in which status tended to reflect the value of the materials. Goldsmiths were the most prestigious and powerful artisans, painters more humble, and woodworkers still more so. Guild restrictions prohibited the use of the most valuable pigments (coloring substances), such as ultramarine, for lowly purposes such as the painting of playing cards, carts, or parrot perches. Thus, these valuable pigments played a role in establishing the social standing of painters: it was in their interest to use fine materials.

Yet the art of painting was still regarded as a mechanical process. There was good and bad, to be sure, but the task of the painter was to meet the specifications of a contract, not to give free expression to artistic inspiration. It was the employer-the patron-who made the decisions. Initially, the patrons of lay painters, when not church-affiliated, tended to be royal or aristocratic, and the painter could find himself affiliated with a court. But as a prosperous middle class emerged during the fourteenth and later centuries, the base of patronage broadened, and artists could find commissions (orders for artworks)among merchants.

Membership in a guild was attained by apprenticeship. Aspiring painters would serve a training period of typically between four and eight years in a workshop operated by a master craftsman, beginning as all apprentices do with the most menial of jobs, such as grinding pigments and making glue. Pigment grinding was a particularly arduous and time-consuming job, and painters might need to allow several days for this alone in their scheduling for a commission. To qualify as a "master painter" ready to accept contracts, an apprentice would present a "master piece" to the guild for approval. Strange, then, that this term has come to refer to an artist's most accomplished piece of work rather than his or her first attempt to gain recognition.

A workshop undertook a commission as a group, much as a band of builders would (and still does) perform a job collectively. The master was responsible for the overall execution of the work, but the application of paint to the surface was as much, if not more, the responsibility of his apprentices. Thus the signatures that appear on fourteenth-and fifteenth-century art are simply trade stamps, denoting the name of the workshop's master. This traditional training placed little value on personal talent or inspiration: a person became a painter simply through hard work, dedication, and adherence to the master's demands. Skill was the product of diligence.

11.1: The Economics of Academic Tenure

In some countries, many universities use an employment system for teachers known as tenure. After a lengthy trial period, a faculty member whose performance meets with the approval of the senior members of the department and the administration of the institution may be awarded tenure. A tenured faculty member enjoys considerable job security for the rest of his or her working life and can only be fired for reasons of "moral turpitude" (bad or evil behavior) or "gross incompetence" or if the financial stability of the institution requires the elimination of an entire department or program.

The high degree of job security enjoyed by tenured faculty members has been the source of complaints about the tenure system. One issue that has been raised by many, including legislators evaluating the finances and managerial practices of state universities in the United States, is that tenure shelters faculty from accountability for poor performance. Another argument is that tenure makes the university inefficient in responding to changing instructional demands. It is difficult to substitute computer engineering faculty for civil engineering faculty if most of the latter have tenure. In 1988, the Education Reform Act significantly softened the tenure system in the United Kingdom, making it easier to fire individual faculty members for financial reasons. More recently, some universities in the United States have taken steps to give university administrators more control over tenured professors, and, in general, American institutions of higher learning have ended up increasing the use of part-time and nontenured instructors over time. In 1992, just 48 percent of all instructors who had tenure, were in a position that was expected to lead to tenure.

The traditional argument in favor of tenure is based on academic freedom, the freedom to investigate and teach any area of knowledge without restriction or interference. In this view, tenure protects faculty members from retaliation for voicing unpopular views. For example, a labor economist might not present a complete examination of the costs and benefits of worker unions. He or she feared that a rabidly anti-union university leader might seek to have the economist fired for speaking of the positive aspects of unions. In fact, the American Association of University Professors (AAUP), a group dedicated to protecting academic freedom, got its start in the wake of a 1901 decision by Stanford University to fire economics instructor Edward Ross at the insistence of the university's co-founder, Jane Stanford, who objected to his views on economics and other matters.

Going beyond academic freedom, the economics literature has recently turned to an emphasis on tenure as a labor-market institution that may have a positive payoff to universities through the incentives (motivation) it provides. For example, economist Lorne Carmichael's model of an academic department treats tenure as the means of providing incentives for incumbent (current) faculty to participate in identifying the best candidates for new positions. If incumbent faculty had to worry that more-able new additions to the department might replace them one day, they would be less inclined to make hiring decisions that were in the best interests of the university. Incumbents are much better positioned to judge the talents of potential new hires than the university administration. Moreover, the long-term job security they gain through tenure gives incumbents an incentive to hire new faculty who might be more productive than the existing faculty in a department.

The economists Michael McPherson and Morton Shapiro have also emphasized the notion that tenure has a positive payoff for the university by aligning the self-interest of individual faculty members with the long-run interests of the institution. They see two valuable economic benefits from the tenure system beyond the incentive to hire and mentor more productive new faculty. First, job security allows tenured faculty the independence to perform credibly objective evaluations of students and other faculty. People outside the university who rely on the information provided by student grades or faculty reviews of papers or proposals can have greater confidence that these evaluations have not been colored by the faculty member's concern about job security. Second, tenure allows faculty to make long-run strategic decisions about educational policy and research, even if these are in conflict with the short-run career interests of administrators. The fact that tenured faculty often are viewed as obstacles to change by ambitious administrators looking to enhance their records for their next career move might well be a good thing for the long-run interests of the university.

11.2: Programming Computers to Play Games

Backgammon is the oldest board game in the world. It was first played in ancient Mesopotamia, starting around 3000 B.C. The rules of Backgammon were codified in the seventeenth century, and the game has changed little since. The same can't be said about the players of the game. One of the best backgammon players in the world is now a software program. In the early 1990s, Gerald Tesauro, a computer programmer at IBM, began developing a new kind of artificial intelligence (AI). At the time, most AI programs relied on the brute computational power of microchips. This was the approach used by Deep Blue, the powerful set of IBM mainframes that managed to defeat chess grandmaster Garry Kasparov in 1997. Deep Blue was capable of analyzing more than two hundred million possible chess moves per second, allowing it to consistently select the optimal chess strategy. (Kasparov's brain, on the other hand, evaluated only about five moves per second.) But all this strategic firepower consumed a lot of energy, while playing chess. Deep Blue was a fire hazard and required specialized heat-dissipating equipment so that it didn't burst into flames. Kasparov, meanwhile, barely broke a sweat. That's because the human brain is a model of efficiency: even when it's deep in thought, the cortex consumes less energy than a lightbulb.

While the popular press was celebrating Deep Blue's stunning achievement-a machine had outwitted the greatest chess player in the world!-Tesauro was puzzled by its limitations. Here was a machine capable of thinking millions of times faster than its human opponent, and yet it had barely won the match. Tesauro realized that the problem with all conventional AI programs, even brilliant ones like Deep Blue's, was their rigidity. Most of Deep Blue's intelligence was derived from other chess grandmasters, whose wisdom was painstakingly programmed into the machine. (IBM programmers also studied Kasparov's previous chess matches and engineered the software to exploit his recurring strategic mistakes.) But the machine itself was incapable of learning. Instead, it made decisions by predicting the probable outcomes of several million different chess moves. The move with the highest predicted value was what the computer ended up executing. For Deep Blue, the game of chess was just an endless series of math problems.

Of course, this sort of artificial intelligence isn't an accurate model of human cognition. Kasparov managed to compete on the same level as Deep Blue even though his mind had far less computational power. Tesauro's surprising insight was that Kasparov's neurons were effective because they had trained themselves. They had been refined by decades of experience to detect subtle spatial patterns on the chessboard. Unlike Deep Blue, which analyzed every possible move, Kasparov was able to instantly isolate his best options and focus his mental energies on evaluating only the most useful strategic alternatives.

Tesauro set out to create an AI program that acted like Garry Kasparov. He chose Backgammon as his model and named the program TD-Gammon. (The TD stands for temporal difference.) Deep Blue had been preprogrammed with chess acumen, but

Tesauro's software began with absolutely zero knowledge. At first, its backgammon moves were entirely random. It lost every match and made stupid mistakes. But the computer didn't remain a novice for long; TD-Gammon was designed to learn from its own experience. Day and night, the software played Backgammon against itself, patiently learning which moves were most effective. After a few hundred thousand games of Backgammon, TD-Gammon was able to defeat the best human players in the world.

How did the machine turn itself into an expert? Although the mathematical details of Tesauro's software are numbingly complex, the basic approach is simple. TD-Gammon generates a set of predictions about how the backgammon game will unfold. Unlike Deep Blue, the computer program doesn't investigate every possible permutation. Instead, it acts like Garry Kasparov and generates its predictions from its previous experiences. The software compares these predictions to what actually happens during the backgammon game. The ensuing discrepancies provide the substance of its education, and the software strives to continually decrease this error signal. As a result, its predictions constantly increase in accuracy, which means that its strategic decisions get more and more effective and intelligent.

12.1: Chondrites

Meteorites are the keys to understanding how Earth and the solar system formed because, although superficially, many meteorites do not look significantly different from most Earth rocks, close study shows that they are very different, with those differences holding clues to their distant origin. The most common type of meteorite-known collectively as the "chondrites," contains clues about the kinds of material that went into the construction of our planet.

The chondrites are just one of a variety of meteorite types, all ancient, but each with a different history-and, each containing clues about how Earth and other planets formed and evolved. For example, the members of one group, the iron meteorites, are made up of solid iron metal, alloyed (or mixed) with a modest amount of nickel. All the evidence indicates that these meteorites are similar to the metallic cores that inhabit the interiors of planets.

In contrast to the iron meteorites, the chondrites are made up of a jumble of mineral grains, many of them familiar constituents of rocks on Earth, but also including pure iron metal-which does not occur in rocks on Earth-and small marble-like spherical objects called "chondrules" (it is from these that the chondrites take their name). The chaotic texture of chondrites indicates that they were formed in a process that randomly swept together their different components and cemented them together. The texture is also an instant clue to one of their most important characteristics: they have never been melted. Furthermore, mineral grains in the chondrites have provided the oldest ages ever measured by radiometric dating; they date from the very earliest days of the solar system. These two properties have led the geochemists who work on these intriguing objects to conclude that chondrites bring us something we cannot find on Earth or among other meteorite varieties: an unprocessed sample of the original material from which Earth and our neighboring planets were made. They appear to be unaltered samples of the solid matter that was floating around in the solar system just as Earth was being born; there is strong evidence that they come from small asteroids that never grew big enough to heat up and melt, as larger objects did.

The primitive nature of the chondrites has made them very important for information about Earth's overall chemical composition. You might wonder why these rare rocks from space should play such a key role when the whole Earth Is right below our feet, ready for us to analyze. The answer, in brief, is that if we want to understand how Earth got to its present state, we have to know something about its initial, overall composition. But we only have access to rocks from our planet's thin outermost skin-which is very different from the inaccessible interior. However, by using information from the chondrites as a reference point and integrating that data with direct measurements on surface rocks and information about the interior obtained using remote sensing methods, geochemists have been able to work out models for Earth's overall composition that satisfy already obtained independent evidence such as the density of our planet.

An important concept in formulating these models is that the composition of Earth and the other "terrestrial planets" (the solar system inner, rocky planets, Mercury, Venus, and Mars) depends on the proportions of the main minerals found in the chondrites that each planet incorporated. A good example is iron, which is so abundant and so heavy that the well-known density variations among the terrestrial planets can almost entirely be attributed to differences in their iron contents. Grains of iron metal are abundant in the chondrites, but different chondrites contain different amounts. The reason Earth is much denser than Mars, according to the models, is that its chondrite-like building blocks happened to contain more iron. Similarly, other differences among the terrestrial planets can be understood in terms of different planets incorporating different amounts of the various constituents of chondrites. This is undoubtedly an overly simplistic description of what actually happened, but that does not invalidate the chondrites as a good starting point for understanding the composition of Earth and other planets.

12. 2: Greek Art in the Classical Age

Greek art is thought to have reached its peak during the Classical period in the fifth century B.C.E. Leading up to this period, the most common type of sculpture was the kouroi, which were life-size or larger marble statues of nude males that stood on sacred sites, often as grave markers but also as offerings to the gods. With very stiff, straight poses (they evidently were modeled after Egyptian statues), it is clear that kouroi were not intended to look like real people. However, by the early fifth century, the style of Greek artwork changed. The transition is usually symbolized by the Kritios Boy, a marble statue found in the center of ancient Athens and attributed to Kritios, a sculptor active in Athens around 490-460 B.C.E. It is dated by experts to just before 480 B.C.E. and represents Callias, a victor in the boys' footrace in athletic competition. The changes from the traditional kouros are slight, but the boy is standing as a boy might actually stand, the right leg forward of the left, which bears the weight of the body so that the right can relax slightly, not how artistic convention decrees a hero should pose. Yet this naturalness is achieved without the loss of an idealization (representation as perfect) of the human body. Here is, in the words of the art historian Kenneth Clark "the first beautiful nude in art. " As John Boardman, an authority on Greek art, puts it: "This is a vital novelty in the history of ancient art-life deliberately observed, understood, and copied. After this, all becomes possible."

There are a few clues as to why this revolution in art, from the stylized to the observed, took place. One is that bronze was becoming the most popular medium in which statues were being created, (It has been suggested that the Kritios Boy is a copy of a bronze original now lost.) The technical problems involved in casting and assembling bronze statues had been solved by the end of the sixth century B.C.E., as the earliest examples show. From the Classical period on, bronze predominated in Greek sculpture, but as almost every statue was later melted down so its metals could be reused, it is hard to guess this today. The few bronzes to survive (the Riace warriors, the Delphi charioteer, and the majestic Zeus found in a shipwreck off Cape Artemisium foremost among them) simply highlight what has been lost in quantity and quality. Bronze allows far greater flexibility. Modeling the process of building up a figure in bronze is totally different from cutting into marble. As a wonderful exhibition at the Royal Academy in London in 2012, Bronze, also showed, bronze can be burnished (smoothed and shined) to produce a wide variety of aesthetic effects that pure white marble lacks.

The revolution also suggests a preoccupation with the human form. While earlier Greek artists were focused on those few human beings who had become heroes, they now seemed concerned with the physical beauty of human beings as an end in itself. It is hard to see the Riace warriors without being aware of their intense sensuality. Yet within a few years, this sensuality fades and is replaced by a greater concentration on the nature of the human body as an ideal. It was the sculptor Polycleitos, probably a native of Argos working from the fifth into the fourth century B.C.E., who allied aesthetics with mathematics when he suggested that the perfect human body was perfect precisely because it reflected ideal mathematical proportions that were capable of being discovered. One of his statues, the Doryphoros, or "spear bearer" (originally in bronze, but now known only through Roman copies in marble), was supposed to represent this ideal. If this approach was followed to its extreme, all statues would have had the same, perfect proportions, but the Greeks could not close their eyes to the variety of human experience. There always remained a tension in the art of the period between the abstract ideal of the human body and a particular body copied by the artist. This may be one reason for its aesthetic appeal.

13.1: Trade and Herring in Dutch Society

Although the people of the Netherlands were at war with their Spanish rulers, the Dutch economy prospered between 1588 and 1648, and trade was at the heart of this prosperity. The expansion of trade, directly and indirectly, brought increased employment opportunities: toward the middle of the seventeenth century, the fleet of trading ships employed almost 30,000 people, and the handling of cargoes in the ports provided work for large numbers of people. In addition, there were those involved in the internal transport system, moving goods and people along the rivers and canals. Another important source of employment was provided by artisan production of various kinds; manufacturing was still labor-intensive-- literally handwork - with very limited inputs of nonanimal energy, with the exception of the large-scale use of wind power for sawmills. Also, the fisheries and secondary industries were important sources of employment. Although the import and re-export of goods through the staple market (the market for bulk commodities, especially raw materials) were paramount to the success of the trading economy, manufacturing and fisheries supplied valuable export products for foreign trade.

Herring are edible ocean fish, and the herring fishery was important as a source of employment because it provided a crucial export item, as well as helping to feed the Dutch population. In terms of the numbers of boats and people employed, most if not all of the growth of the fishery seems to have already taken place before the revolt against Spanish rule began in 1568, with subsequent developments consisting chiefly of improvements in organization and coordination between the various branches of the industry. Dutch success in the fisheries was by no means certain ahead of time; the movement of the best herring fishing grounds to the North Sea gave them the opportunity, but they were geographically no better placed to exploit this than many potential rivals, indeed less so than the Scots and the English. What, then, accounts for the greater success of the Dutch?

Over the course of the fifteenth and sixteenth centuries, northern Netherlands fishing fleets introduced a number of key innovations, which gave them a decisive edge. Specialized fishing boats came into use, and mother ships (supply ships) began to sail with the fleet to enable these boats to stay on the fishing grounds longer. Also, a new method of preserving herring was found in the fifteenth century, and curing began to take place at sea to improve the quality of the product. The high quality was indeed the key to the success of the Dutch herring business, and concern to maintain this advantage over their competitors led to the use of the finest salt that could be found and to careful monitoring of the barreling storage process. It seems to have been agreed by contemporaries that Dutch herring was the best, which provided the Dutch with a market even in Scandinavia with its own sources of fish. In fact, herring made a significant contribution to the development of the Baltic trade providing an export item with a ready market there.

There may have been as many as 500 specialized boats employed at the peak of the herring fishery in the early seventeenth century. This in itself must have provided employment for 6,000 to 7,000 people, though only for part of the year, as the herring fishing was seasonal, starting in late June and ending in December or early January. However, if herring packers and the workers making the barrels in which the fish were packed are included, then the work provided directly by the fishery rises considerably. Moreover, the indirect boost to shipbuilding and sail and rope making is impossible to calculate but must have been significant, and if the transport to various markets by barge boat is taken into consideration, then the overall impact of the fishery on employment opportunities rises again.

There were other sea fisheries, especially cod, but the biggest growth in the early seventeenth century came in Arctic whaling, which rose from practically nothing to an important if not always thriving, business. Initially, this was open sea whaling, but from about the 1640s onward, certain whales became increasingly difficult to find in open waters, which meant that whaling had to turn to the construction of specially strengthened ships that could follow the whales into the pack ice. The real expansion of Dutch whaling, however, belongs to the second half of the century.

13.2: Increasing Jellyfish Populations

Scientists have had a tough time trying to discover whether recent increases in jellyfish populations are really worth worrying about. On one hand, jellyfish are known to proliferate rapidly in response to positive changes in prey abundance or environmental conditions such as water temperature and sunlight. The size of these "blooms" can vary from year to year. On the other hand, these population explosions are occurring in many places on a scale now widely viewed as unprecedented. In the Sea of Japan, for instance, Nomura's jellyfish are known to have drifted in from the south in large numbers three times during the twentieth century: in 1920, 1958, and 1995. Beginning in 2002, however, they have turned up every summer but one, and in astonishingly high numbers. In 2005, one of the worst years, up to 500 million Nomura's jellyfish were reported to be drifting into the sea each day.

Several factors have now been identified as possible contributions to the increased success of jellyfish worldwide. One of the leading suspects is the human exploitation of fish and other marine resources, something that has intensified in recent decades partly because of advances in large-scale seafood harvesting and processing techniques. Only a handful of species are thought to prey directly on jellyfish, and most of these predators-including giant sea turtles-are becoming increasingly rare. The main impact of overfishing, though, may stem from the reduction of filter-feeding fish, such as sardines and anchovies, which eat the same food as jellyfish. In the southern Atlantic waters off Namibia, where overharvesting has resulted in the complete collapse of a once-thriving sardine fishery, unusually large numbers of jellyfish are now a permanent feature of the near-shore marine ecosystem.

At the same time, jellyfish seem to thrive under conditions that are becoming increasingly widespread because of human-associated activities. Although the theory is highly speculative and still under debate, global warming and acidification of the oceans as a result of more carbon dioxide dissolving in the water may be two such factors. Jellyfish love warm water, for one thing. And at least one study from the North Sea has reported finding a connection between greater jellyfish abundance and higher acid levels.

Another environmental change, and one that is more firmly linked to expanding jellyfish populations, is eutrophication, the process by which water becomes enriched with dissolved nutrients, resulting in more aquatic plant life and, subsequently, reduced levels of oxygen. Eutrophication occurs in near-shore ocean waters close to large human population centers and the mouths of large rivers. A strong correlation exists between blooms of algae and other plankton caused by excessive nutrients from sewage and fertilizer runoff and jellyfish eruptions. One example is the waters off the southern United States coast. Nutrient-enriched waters from the Mississippi River have created, in the Gulf of Mexico, a massive dead zone (ocean area with low oxygen levels).

While fish and other aquatic life forms are finding survival increasingly challenging, jellyfish such as moon jellyfish and sea nettles are becoming increasingly numerous. This is not really surprising. A checklist of jellyfish traits-good survival rates during periods of starvation, rapid reproduction, diverse diet, ability to feed in murky water, and capacity for surviving under low oxygen conditions typical of dead zones-reveals that these seemingly fragile organisms are actually tough life forms, ideally suited to survive in disturbed environments. According to the National Science Foundation, the main science-funding agency in the United States, there are currently 400 known ocean dead zones where almost nothing lives except jellyfish.

Finally, like many other marine invasive species, jellyfish have benefited from the globalization of human trade. Many species are hardy enough to survive in the ballast water of ships, and jellyfish polyps can attach themselves to their hulls. Because of this, jellyfish species are being inadvertently introduced into new aquatic habitats. One of the best examples involves the warty comb jelly (Mnemiopsis leidyi), a species that likely made its way into the Black Sea for the first time in 1982. Since then, this highly adaptable organism has been thriving; its original nonnative range has expanded to include not just the Black Sea but also the Caspian, Baltic, and North Seas.

14.1: Northwest Coast Art

The Pacific Northwest of North America produced stable Native American cultures. This was in great measure due to the abundance of resources and temperate climate, which figured prominently in the social and cultural fabric of the people. Fishing, hunting, and foraging produced ample means of sustenance, and therefore, the people of this region had no reason to cultivate crops or domesticate animals. Their cultures tended to share certain features, probably because they traded and warred with one another. Artistic motifs (recurring artistic elements) were alike, and they shared a common religion-shamanism (ancient belief systems centered on shamans, individuals who communicate with invisible forces or spirits). Although their gods and myths differed, the Northwest peoples all acknowledged the power of shamans to contact the spirits of the forest and waters, to heal the sick, and to predict the future.

The rich forests of the area provided Native American artists with a wealth of materials for sculpting. Huge spruce and cedar trees abounded for many centuries, and when steel knives were obtained from fur traders and used as tools, Northwest-coast artists excelled in producing magnificent totem poles, carved posts for wooden dwellings, masks, rattles, and other objects. Carved wooden house posts not only supported the roof but also gave additional decoration to the interior. When living closer to the sea, artists had access to abalone shells that were used as inlays to give luster to their sculpted works.

Although many art objects from the area, such as masks, concern themselves with shamanistic religious rituals, a fair amount of art was secular. Like some African art, it was used to maintain the social fabric and bolster a ruler's power. For example, in the Tlingit group-a people who lived in the islands and bays of the upper reaches of the Pacific Northwest-communities were made up of a number of families, each of which had its own chief who inherited his rank from his mother. Carefully devised social customs obliged both men and women to marry outside their own clan. In this way, a balance was established in which no one family achieved dominance. Nonetheless, chiefs competed fiercely with each other in displays of riches. Totem poles formed a part of this ostentation, proclaiming prestige and family pride through genealogy-much like the coats of arms of the European aristocracy. Totem poles were carved from single tree trunks and often reached a height of 90 feet (27.4 meters). Probably originating as funerary (burial) monuments, by the nineteenth century, they had become fixtures adorning the exteriors of chiefs' houses.

Eagles, beavers, and whales appear on the totem poles, in essence, as symbolic crests that a chief inherited from his ancestors. The Tlingit did not worship these figures or have any supernatural relationship with them. They are governed by traditional artistic principles. One of these is that of bilateral symmetry-the designs on either side of the central axis are identical. Another specifies the transition from one motif to another. Each design must appear to grow from the one below. Thus, not only the overall vertical form of the totem pole but also the design of its interior parts leads the eye upward along its central axis.

As historical documents that record the wealth, social position, and relative importance of the person who paid for them, totem poles are quite similar to sculptural records from other cultures. The ultimate function of such art was probably to act as a gift. As the anthropologist Frederick J. Dockstader claimed, "The life goal of many ... involved the belief that the greatest value was to give away all of one's possessions." The actual working out of such a philosophy created some interesting scenarios. The more one gave away, the greater one's prestige. In turn, one's rival was more or less obliged to give back the same or more material wealth in order to prove greater disdain for possessions. As a result, totems and other goods were often burned, thrown into the sea, or otherwise destroyed.

14.2: Examining the Problem of Bycatch

A topic of increasing relevance to the conservation of marine life is bycatch-fish and other animals that are unintentionally caught in the process of fishing for a targeted population of fish. Bycatch is a common occurrence in longline fishing, which utilizes a long heavy fishing line with baited hooks placed at intervals, and in trawling, which utilizes a fishing net (trawl) that is dragged along the ocean floor or through the mid-ocean waters. Few fisheries employ gear that can catch one species to the exclusion of all others. Dolphins, whales, and turtles are frequently captured in nets set for tunas and billfishes, and seabirds and turtles are caught in longline sets. Because bycatch often goes unreported, it is difficult to accurately estimate its extent. Available data indicate that discarded biomass (organic matter from living things) amounts to 25-30 percent of the official catch, or about 30 million metric tons.

The bycatch problem is particularly acute when trawl nets with small mesh sizes (smaller-than-average holes in the net material) are dragged along the bottom of the ocean in pursuit of groundfish or shrimp. Because of the small mesh size of the shrimp trawl nets, most of the fishes captured are either juveniles (young), smaller than legal size limits, or undesirable small species. Even larger mesh sizes do not prevent bycatch because once the net begins to fill with fish or shrimp, small individuals caught subsequently are trapped without ever encountering the mesh. In any case, these incidental captures are unmarketable and are usually shoveled back over the side of the vessel, dead or dying.

The bycatch problem is complicated economically and ecologically. Bycatch is a liability to shrimp fishers, clogging the nets and increasing fuel costs because of increased drag (resistance) on the vessel. Sorting the catch requires time, leading to spoilage of harvested shrimp and reduced time for fishing. Ecologically, high mortality rates among juvenile fishes could contribute to population declines of recreational and commercial species. Evidence of this effect exists for Gulf of Mexico red snapper and Atlantic Coast weakfish. Because the near-shore areas where shrimp concentrate are also important nursery grounds for many fish species, shrimp trawling could have a profound impact on stock size.

Once the dead or dying bycatch is returned to the ecosystem, it is consumed by predators, detritivores (organisms that eat dead plant and animal matter), and decomposers (organisms that break down dead or decaying organic matter), which could have a positive effect on sport fish, seabird, crab, and even shrimp populations. Available evidence indicates that 40-60 percent of the 30 metric tons of catch discarded annually by commercial fishing vessels, and even more of the non-catch waste (organisms killed but never brought to the surface), does not lie unused on the bottom of the sea. It becomes available to midwater and ocean-bottom scavengers, transferring material into their food web and making energy available to foragers (organisms that search for food) that are normally tied up in ocean-bottom, deep-ocean, midwater, and open-ocean species.

Overfishing and overdiscarding may thus contribute to a syndrome known as "fishing down of food webs," whereby we eliminate apex (top) predators and large species while transforming the ocean into a simplified system increasingly dominated by microbes, jellyfish, ocean-bottom invertebrates, plankton, and planktivores. The strongest evidence for the fishing down phenomenon exists in global catch statistics that show alarming shifts in species composition from high-value, near-bottom species to lower-value, open-ocean species. In the last three decades of the twentieth century, the global fishing fleet doubled in size, and technology advanced immeasurably. Despite increased effort and technology, total catch stabilized, but landing rates (rates at which species are caught) of the most valuable species fell by 25 percent.

Conservation organizations have condemned the obvious and extreme waste associated with bycatch. Public concern over the high mortality rates of endangered marine turtles captured in shrimp trawls led to the development of turtle exclusion devices (TEDs) in the 1980s. TEDs were incorporated into the shrimp net design with the purpose of directing turtles out of nets without unacceptably reducing shrimp catches. Marine engineers and fishers also developed shrimp net designs that incorporate bycatch reduction devices (BRDs), taking advantage of behavioral differences between shrimp and fish or between different fishes in order to separate fishes.

15.1: Challenge of Dendrochronology

Dendrochronology is the technique of counting tree rings to determine a tree's age and measuring the width of these rings to determine characteristics of past climates. This might seem simple: each ring represents one year, and wider rings generally mean better growing conditions-plentiful rainfall, moderate temperatures, and so forth. But the seasonal growth of a particular tree is affected by factors other than the weather. Trees vary, one from another, just like people do. The genetic makeup of each individual tree is unique, so one particular tree may grow a bit more quickly than another. Highly local conditions can also change over time. It is easy enough to see that if part of the soil near a tree has been eroded, this will impact the tree's root system and limit its growth, at least until the situation stabilizes. Then again, an infestation of insects may affect a tree in one valley more than the same type of tree ten miles away, or one tree may suddenly start to get a lot more sunlight when an old, big tree in the neighborhood finally falls. These kinds of factors produce significant variations among individual specimens, and that fact means that researchers need to average together samples from many specimens of a single tree species in one region over the same time period. Some dendrochronologists think that measuring an average of twenty-five to thirty tree-ring records in a locale is an essential first step in getting around the problem of individual variability. While it may be easy enough to find thirty samples in some locations for particular periods, it obviously becomes less and less likely the more ancient the wood samples are.

Another issue is more general. Trees that are fortunate enough to live on good soil and near local sources of groundwater often grow at steady rates. Such growth translates into attractive trees that are tall and well-formed; they also have rings that are wide and quite uniform in thickness, but their uniform growth rings make them entirely useless when it comes to inferring anything about past weather patterns. That is why, instead of looking at superb botanical specimens, dendrochronologists focus their work on wood from trees that are living a tough life due to poor soil, steep slopes, the absence of local groundwater, or some other challenge. It is these "tortured" trees that are the most likely to grow very little during years of scarce rains or do poorly after a harsh winter and a late spring. What this means, of course, is that few trees in the woods are likely to be good samples for the scientist. Indeed, it may be quite a small fraction that yields useful ring patterns. Again, this increases the challenge of finding enough good samples to say with much certainty what past conditions were like.

Another factor of dendrochronology relates to the wood itself. In the spring, a tree grows rapidly, creating new cells on the outside of its trunk and branches, just under the bark. These cells, called "earlywood" or "springwood," are large and have thin cell walls; both these factors contribute to making the wood relatively lightweight for its volume. In the summer, growth slows. Denser "latewood" is formed, creating a band that is relatively dark when you look at the end of a piece of lumber. But occasionally, the sequence of a perfect pair of springwood and latewood does not hold up. If conditions-weather or disease-severely test a tree one year, it will not grow over all its surfaces. That may mean that a particular sample of wood taken by the dendrochronologist will have a missing ring in it, which will result in the scientist's inferences being off base by a year.

A few trees also may trip up scientists by revealing a "false ring" made of latewood that's in the middle of springwood. These features, sometimes known as double rings, usually can be distinguished from true rings because the unusual dark ring is likely to change gradually rather than more abruptly into the springwood that lies on either side of the false latewood. It is not clear what creates such double rings, although people have speculated that unusual conditions during the middle of the growing season or even highly local issues might be the cause.

15.2: The Problem with Microplastics

Scientists think that about 10 percent of all plastic, which includes plastic bags and bottles, ends up in the ocean. The attributes that make plastic a useful material for a large number of products are its light weight and the strong chemical bonds in its internal structure, which make the material durable. Because plastic by itself is less dense than water, it floats along the ocean surface, where it is continuously exposed to ultraviolet light from the Sun, which has the effect of loosening its chemical bonds. Ocean waves smash these weakened pieces of plastic against each other, and they are broken down into smaller and smaller pieces, eventually creating vast numbers of microplastics (pieces less than 5 millimeters across) that disperse throughout the water.

Due to the widespread increase in plastic production, there is six times as much plastic in the oceans as there was 40 years ago. Based on the amount of manufactured plastic, scientists have estimated that there are many trillion pieces of plastic in the ocean. To obtain a more precise idea about the amount, scientists conducted a study in 2010-2011 that involved sampling the ocean surface at 141 locations. After six months, they concluded that only 7,000 to 35,000 tons of plastic were present on the ocean surface. It is widely believed, however, that tens of millions of tons of plastics have entered ocean waters. Moreover, the scientists primarily found larger pieces of plastic, which means that the number of microplastics found diverged from expectations to an even greater degree.

Scientists have attempted to explain the apparent disappearance of vast amounts of plastic from the surface of the ocean. Plastic is hydrophobic-it repels water, like oil does-which by itself contributes to its buoyancy (ability to float). However, this hydrophobic quality attracts single-celled organisms, such as diatoms and bacteria, which attach themselves to the plastic's surface and replicate. Over time, the resulting biofilm (layer of organisms) alters the density of the plastic and reduces its degree of hydrophobia, increasing its chances of sinking. Organisms residing in the biofilm release certain chemicals that attract other organisms, including barnacles, aquatic insects, and algae, which make their homes on the plastic. This adds to the plastic's weight and further increases its chances of sinking. In one experiment, scientists submerged plastic food bags for three weeks, measuring the amount of biofilm and buoyancy of the bags each week. The bags sank deeper during each week of the experiment. Severe coastal storms and vertical movement of water associated with differences in temperature or salinity may be another reason why microplastics move into deeper waters. Scientists have found as many as 40 pieces of microplastic per 50 milliliters of sediment in locations sampled along the ocean floor.

Some of the microplastics are likely ingested (eaten) by ocean organisms. Many marine invertebrates (animals lacking a backbone) are filter feeders-they draw water into their bodies and ingest tiny bits of food contained within it. These animals do not discriminate among food items and can easily take in plastics along with the rest of their meal. Thus, scientists have found microplastics in the bodies of marine organisms, including zooplankton, crabs, fish, and marine worms. Although the plastic by itself can remain in or pass through the animals' bodies without significantly affecting them, many plastics come with pollutants left over from the manufacturing process or picked up as the plastics travel through the oceans, and these chemicals are often harmful to the animals.

Copepods-tiny, free-swimming organisms that eat algae-are among the filter feeders that have been found to ingest microplastics. But then, in an apparent attempt to avoid taking in even more of these materials, copepods switch to feeding on smaller algae, ones that are even tinier than microplastics. As a result of this diet change, copepods' energy intake can drop by as much as 40 percent. These copepods lay smaller eggs that are unable to hatch successfully. Microplastics may also get stuck in the antennae of copepods and other zooplankton, where they interfere with the organisms' ability to sense food in the surrounding waters and also in copepods' joints, limiting their ability to move and catch prey.

16.1: The Rise of the Maya

A hundred and fifty years of painstaking archaeological inquiry allows us today to understand how the Maya emerged to transform the rain forest of Central America into a scene of urban civilization. By 1000 B.C., the Maya were settled agriculturalists growing a variety of crops in clearings in the forest, which they turned into villages. They appear to have lived in a society of equals, without clear rulers or ceremonial centers. Then between 800 and 500 B.C., signs of a ruling elite within Maya society start to emerge in the form of elaborate burial monuments. At Los Mangales in the Salama Valley of highland Mexico, a chief was buried on a special mortuary platform accompanied by rich grave goods of jade and shell. Slightly later, the ceremonial center at El Portón was built, involving the construction of earth terraces and platforms, on which were located altars and standing stones; one with a brief written inscription, although too damaged to be read today.

In the lowlands of Guatemala and the Yucatán Peninsula of Mexico, vast ceremonial centers appeared quite suddenly after 600 B.C. At Nakbe in northern Guatemala, the site was swiftly transformed from a modest village into a city with a major monumental structure at its heart. A massive platform was constructed on the ruins of the original settlement, on top of which were a series of terraced buildings up to 60 feet tall. Without any doubt, we can see here the development of a more complex society. From 400 B.C. to Ad A.D. 250, major ceremonial centers developed in all parts of the Maya area, many carved out of the tropical rain forest that covered the southern lowlands of Guatemala. , Belize, and Mexico. These cities were dominated by enormous terraced platforms, some forming giant temple- pyramids. Vast palaces of limestone masonry with vaulted rooms were constructed. , set within architectural layouts that emphasized the most important buildings of a city, arranged around plazas with rows of standing stones lined up in front of them. A highly sophisticated art style emerged, seen in bas-reliefs, wall paintings, and beautiful pottery with multicolored fired decorations. Hieroglyphic writing became widespread, and inscriptions can be dated using the Maya Long Count, an elaborate but incredibly accurate calendarical system.

Earlier generations of archaeologists considered the great Maya cities to be purely ceremonial centers. In this view, the cities were occupied only by their peace-loving priestly rulers and their attendants except at great festivals. The British Mayanist Sir Eric Thompson, working at the Field Museum of Chicago, suggested that the Maya character encouraged the development of religious authority, and that their devoutness, discipline, and respect for authority would have facilitated the emergence of a theocracy.

This was not, however, an age of peace ruled over by unworldly priests living in solitude among the temples. In the last 25 years, a succession of remarkable breakthroughs has enabled us to read the Maya's hieroglyphic language. Whereas Thompson and others assumed that inscriptions outside temples concerned complex matters of astronomy and calendric systems that fascinated the priests, the translations now available show beyond any doubt that the cities were ruled by an aristocracy that was firmly secular (not based on religion) and indeed warlike in outlook. Hieroglyphic writing on monuments was mainly used to record the achievements of Maya rulers, especially in war. Victory stones were erected outside the temples, bearing the names of famous captives. Great monuments were liberally marked with the names and faces of the rulers who commissioned them.

Excavation has also played its part in overturning the established picture of Maya cities. Vital evidence that the cities were not just ceremonial centers has now been found at many lowland sites. On the outskirts of cities such as El Mirador are groups of low, rectangular mounds of earth and stone long ignored, but which archaeological investigations have now shown were occupied by small wooden houses, raised above the level of the summer flooding-humble dwellings that housed the ordinary inhabitants who served the aristocrats living in palaces at the heart of the city.

16.2: The Agricultural Revolution

During a relatively warm climatic period between 8000 and 6000 B.C., humans on the fringes of Mesopotamia began to shift from a hunting-gathering existence and started to control the animals and plants they would eat, thus initiating the Agricultural or Neolithic Revolution. That it was a revolution, there can be no dispute. It transformed the way human beings lived and shattered a tradition over two million years old. However, why the Agricultural Revolution occurred at this precise time is still largely a matter of conjecture. Why, for instance, did it not occur during one of the earlier interglacial periods (intervals of relatively warm climate that occurred periodically between ice ages over millions of years) when, presumably, the same conditions prevailed? It is difficult to find any uniformly satisfying answers. We know that agriculture developed more or less simultaneously in many different parts of the globe, so it is unlikely that it resulted from any single cause, such as climatic change or population growth, although both have been offered as explanations. We also know that the move to agriculture was not always permanently successful. In some places, it was tried for a while and then abandoned. It is even possible that certain plants and animals were domesticated more than once and by different people.

Most modern explanations of the origins of agriculture tend to emphasize the role of microenvironments and long-standing human-plant and human-animal relationships. Such factors as changing climatic conditions, the presence of animals and plants that offered good potential for domestication, and the cultural and technological levels of achievement of the human populations present undoubtedly played important roles in the development of agriculture.

The key to understanding agriculture is the process known as domestication. Domestication was the essential technological breakthrough that allowed human beings to escape the age-old system of hunting and gathering and to control the production of food rather than being at the mercy of what sustenance the terrain might offer at any given moment.

Domestication can be defined as a primitive form of genetic engineering in which certain plants and animals are brought under human control, their objectionable characteristics eliminated, their favorable ones enhanced, and in the case of animals, inducing them to reproduce in captivity. If wild animals cannot be induced to breed in captivity, they cannot be domesticated. Modern domesticated cattle, sheep, and pigs, for example, look only remotely like their leaner, meaner, and faster-moving ancestors. Domestication is best viewed as the creation of an artificial environment in which the chosen plants or animals come to exist exclusively. Left alone, domesticated species either die or revert to their original wild forms. Because herds, farms, orchards, and gardens are permanent, static entities, once they came into being, the old hunting-gathering forms of social organization had to be replaced.

Hunter-gatherers place a low value on possessions and a high value on mobility. Always on the move, they carry only a few tools and weapons with them. Agriculture reverses this way of life. It cannot be practiced without a commitment to permanence and the accumulation of large amounts of material goods. Homes, villages, and storage facilities must be constructed, fields cleared, divided, and fenced; herds built up and maintained; and tools fabricated. Constant effort is required to maintain all of these. Once settled, farmers may not move again for generations. Pastoralists (animal herders) are equally committed to their flocks and herds.

For practical purposes, hunting-gathering bands always remained small, in the range of 30 to 50 people. Larger groups would have been difficult to sustain in most environments; smaller groups could not reproduce themselves. Agriculture, by contrast, knew no limits as far as population growth was concerned. Thus, where hunting-gathering bands restricted their numbers, agricultural communities tended to expand them. People could be put to work in the fields or gardens at an early age and at harvest time when it was essential to maximize the number of people who could be mobilized. Overpopulation was solved by emigrating and opening up new land for cultivation. By about 6000 B.C., villages with populations in the thousands were common throughout the Middle East.

17.1: Christian Thomsen and Danish Artifacts

In 1807, the Danish Royal Commission for the Preservation and Collection of Antiquities was established. It began to gather together a collection of antiquities (objects from the ancient past) from all over Denmark that soon became one of the largest and most representative in Europe. In 1816, the commission invited the scholar Christian Thomsen to classify and prepare this collection for exhibition. The main problem that Thomsen faced was how the diverse assortment of prehistoric material in the collection could be exhibited most effectively. He decided to proceed chronologically by subdividing the prehistoric period into successive ages of stone, bronze, and iron. The notion of successive ages of stone, bronze, and iron was not merely speculation but a hypothesis for which there was already some evidence.

In attempting to sort the prehistoric material in the collection into three successive technological stages or eras, Thomsen faced a daunting task. He recognized that even for the stone and metal objects, automatic classification would not work. Bronze and stone artifacts had continued to be made in the Iron Age, just as stone tools had been used in the Bronze Age. The challenge was, therefore, to distinguish bronze artifacts made during the Iron Age from those made during the Bronze Age and to differentiate which stone tools had been made in each era. There also was the problem of assigning objects made of gold, silver, glass, and other substances to each period. Individual artifacts were no help in beginning this work. Yet the Danish national collection contained sets of artifacts that had been found in the same grave, collection, or other contexts and that could safely be assumed to have been buried at the same time. Thomsen called these "closed finds" and believed that, by comparing the various items from each such discovery and noting which types of artifacts occurred together and which never did, it would be possible for him to determine the sorts of artifacts that were characteristic of different periods.

Thomsen sorted and classified his artifacts into various use categories, such as knives, adzes, cooking vessels, safety pins, and necklaces. He further refined each category by distinguishing the artifacts according to the material from which they were made and their various shapes. Having, in this way, established a set of informal artifact types, he began to examine closed finds in order to determine which types did and did not occur together. He also examined the decorations on artifacts and found that these, too, varied consistently from one closed find to another. On the basis of shape and decoration, it became possible for Thomsen to distinguish types of bronze artifacts that never occurred together with iron artifacts from ones that did occur with them. He also was able to demonstrate that large flint knives and spear points that had similar shapes to bronze ones had been made at the same time as bronze artifacts. Eventually, he succeeded in dividing the prehistoric artifacts in the collection into five distinct groups. Once these groups were established, he could assign single artifacts to each group on the basis of similarities in outward form and structure. Thomsen also studied the contexts in which artifacts had been found and discovered that these varied consistently from one group to another.

Thomsen then proceeded to order his groups into a historical sequence. He identified the simplest assemblages, which contained only chipped stone artifacts, as the remains of an early Stone Age. This material came invariably from small, simple sites. Next was a later Stone Age, which he described as the period when polished as well as chipped stone tools were manufactured, and the first use was made of metal. At this time, the dead were buried, uncremated, in prehistoric tombs, accompanied by crude pottery vessels with incised decoration. In the full Bronze Age, both weapons and cutting tools were made of bronze, the dead were cremated and buried in urns under small tumulimounds), and artifacts were decorated with ring patterns. In the Iron Age, tools and weapons were made of tempered iron, whereas bronze continued to be used to manufacture ornaments and luxury goods. Thomsen divided the Iron Age into two stages, the earlier characterized by curvilinear serpent motifs and the later by more elaborate dragons and other fantastic animals.

17.2: Early Astronomy

As surviving records and artifacts make abundantly clear, many early cultures took a keen interest in the changing nighttime sky. But unlike today, the major driving force behind the development of astronomy in those early societies was probably neither scientific nor religious. Instead, it was decidedly practical. Seafarers needed to navigate their vessels, and farmers had to know when to plant their crops. In a real sense, then, human survival depended on knowledge of the heavens. The ability to predict the arrival of the seasons, as well as other astronomical events, was undoubtedly a highly prized, perhaps jealously guarded skill.

The human brain's ability to perceive patterns in the stars led to the "invention" of constellations as convenient means of labeling regions of the nighttime sky. The realization that these patterns returned to the night sky at the same time each year met the need for a practical means of tracking the seasons. Widely separated cultures all over the world built elaborate structures to serve, at least in part, as primitive calendars, but often early experts on astronomy enshrined their knowledge in myth and ritual, sometimes turning sites used for astronomical observation into places for religious ceremonies.

Perhaps the best-known such site is Stonehenge, located on Salisbury Plain in England. This ancient monument, which today is one of the most popular tourist attractions in Britain, dates from the Stone Age. Researchers believe it was an early astronomical observatory of sorts-not in the modern sense of the term (a place for making new observations and discoveries pertaining to the heavens)--but rather a kind of three-dimensional calendar or almanac, enabling its builders and their descendants to identify important dates by means of specific astronomical events. Its construction apparently spanned a period of about 17 centuries, beginning around 2800 B.C. Additions and modifications continued until about 1100 B.C., indicating its ongoing importance to the Stone Age and, later, Bronze Age people who built, maintained, and used Stonehenge. The largest stones weighed up to 50 tons and were transported from many miles away.

Many of the stones are aligned so that they point toward important astronomical events. For example, the line joining the center of the inner circle to the so-called heel stone set off some distance from the rest of the structure, points in the direction of the rising Sun on the summer solstice (the longest day of the year). Other alignments are related to the rising and setting of the Sun and the Moon at other times of the year. The accurate alignments (within a degree or so) of the stones at Stonehenge were first noted in the eighteenth century, but it was only relatively recently-- in the second half of the twentieth century, in fact--that the scientific community began to credit Stone Age technology with the ability to carry out such a precise feat of engineering. While some of Stonehenge's purposes remain uncertain and controversial, the site's astronomical function seems well-established. Although Stonehenge is the most impressive and the best preserved, other stone circles found all over Europe are believed to have performed similar functions.

The early Chinese also observed the heavens. Their beliefs attached particular importance to omens" such as comets, which are seen in the night sky only occasionally, and "guest stars"-stars that appeared suddenly in the sky and then slowly faded away-and they kept careful and extensive records of such events. Twentieth-century astronomers still turn to Chinese records to obtain observational data recorded during the Dark Ages (roughly from the fifth to the tenth century A.D.), when turmoil in Europe largely halted the progress of Western science. Perhaps the best-known guest star was one that appeared in A.D. 1054 and was visible in the daytime sky for many months. We now know that the event was actually a supernova-the explosion of a giant star-which scattered most of its mass into space. It left behind a remnant that is still detectable today, nine centuries later. The Chinese data are a prime source of historical information for supernova research.

18. 1: The Switch to coal

In the United States and Great Britain, coal was not widely utilized until more easily available energy resources, such as wood, were on the point of exhaustion. The shift to fossil fuels and the corresponding rise in energy consumption is illustrated by the transformation of the shipping industry in the nineteenth century. Until the mid-nineteenth century, the world's ships had been powered by wind and human power. The first river steamboats came into use around 1810-they first crossed the English Channel in 1821 and by 1839 had crossed the Atlantic. Technological developments, such as the introduction of iron and steel hulls (watertight bodies of ships) in the 1850s and 1860s, increased the effectiveness of sailing ships, and the largest could still compete with the early, inefficient, and expensive steam-powered ships that operated from the 1840s. It was the development of the high-pressure steam boiler made from steel that transformed the situation. By the late 1860s, steamships could bring three times as much cargo from China to Europe in half the time taken by sailing ships. The amount of steam-powered shipping in the world rose from just 32,000 metric tons in 1831 to over three million metric tons by the mid-1870s and then rose exponentially as sailing ships gradually died out and the steamship took over the world's merchant and naval fleets. Britain built a chain of coaling stations across the globe to sustain the worldwide deployment of the Royal Navy. Not only had the amounts of shipping in the world increased dramatically, but its energy demands had also increased even more.

The growing use of coal led to the rise of an important byproduct-the use of the waste gases to provide the first non-natural source of lighting. Coal gas was first used to light a factory in Great Britain in 1807 and, six years later, a cotton mill in the United States. The advantage for the factory owners was that artificial lighting enabled far longer hours to be worked. Coal gas was cheap to use for street lighting once the high installation costs (laying gas pipes, known as mains, and installing new street lights) had been paid. It was cheaper than whale oil and available in much greater quantities. Street lighting could therefore spread on a much greater scale. By 1816, the first districts in London were lit by gas supplied from a central coal-burning plant through underground mains. By the late 1820s, gas lighting had been adopted in Boston, New York (which depended on imported British coal), and Berlin. The use of coal gas to light streets and houses and eventually for cooking spread through the industrialized world in the nineteenth century.

The peak of the world's dependence on coal for its energy came up in the first decades of the twentieth century. Coal's share of world energy consumption then fell from about 90 percent in 1900 to less than 25 percent in the early twenty-first century. However, coal production continued to increase from about 760 million metric tons in 1900 to just over 5,000 million metric tons in 2000. The decline in the importance of coal occurred first in the United States because of its large oil reserves. In Europe, the change came much later. In 1950, coal still provided over 80 percent of the continent's energy. Yet by 1970, the proportion had fallen to less than a third, as cheap imported oil replaced coal. Until the 1950s, Europe's railways still depended on coal-fired steam engines, as they had over a century earlier. Then, in the space of a couple of decades, they were replaced by diesel-powered locomotives and electrified systems. In 1900, Britain was the second-largest coal producer in the world, and the industry employed about 1,200,000 men. By the end of the twentieth century, output was at 10 percent of the level of a century earlier, and there were only 10.000 coal miners. The production also shifted from deep mines to open-pit mining, which was much more destructive environmentally but cheaper. In the United States, two-thirds of coal production now comes from open-pit mines. However, coal is still the second-most-important energy source in the world. About 40 percent of the world's electricity still comes from coal-fired plants, and in many countries of the world, it remains the primary fuel.

18.2: Why Did Agriculture Begin?

Transitions from a glacial to an interglacial world occurred many times during the last two million years. Through all but the most recent glaciation, people moved in response to environmental changes rather than staying put and adapting to a new ecosystem. Then, after living on the move for more than a million years, they started to settle down and become farmers. What was so different when the glaciers melted this last time that caused people to adopt a new lifestyle?

Several explanations have been offered to account for this radical change. Some argue that the shift from a cool, wet glacial climate to less hospitable conditions put an environmental squeeze on early people in the Middle East. In this view, hunters began growing plants in order to survive when the climate warmed and herds of wild game dwindled. Others argue that agriculture evolved in response to an inevitable process of cultural evolution without any specific environmental pressure. Whatever the reasons, agriculture developed independently in Mesopotamia, northern China, and Mesoamerica.

For much of the last century, theories for the origin of agriculture emphasized the competing oasis and cultural evolution hypotheses. The oasis hypothesis held that the postglacial drying of the Middle East restricted edible plants, people, and other animals to well-watered flood plains. This forced proximity promoted social bonds, which eventually led to domestication. In contrast, the cultural evolution hypothesis holds that regional environmental change was unimportant in the gradual adoption of agriculture through an inevitable progression of social development. Unfortunately, neither hypothesis provides satisfying answers for why agriculture arose when and where it did.

A fundamental problem with the oasis theory is that the wild ancestors of our modern grains came to the Middle East from northern Africa at the end of the last glaciation. This means that the variety of food resources available to people in the Middle East was expanding at the time that agriculture arose-the opposite of the oasis theory. So the story cannot be as simple as the idea that people, plants, and animals crowded into shrinking oases as the countryside dried. And because only certain people in the Middle East adopted agriculture, the cultural evolution hypothesis falls short. Agriculture was not simply an inevitable stage on the road from hunting and gathering to more advanced societies.

The transition to an agricultural society was a remarkable and puzzling behavioral adaptation. After the peak of the last glaciation, people herded gazelles in Syria and Israel. Subsisting on these herds required less effort than planting, weeding, and tending domesticated crops. Similarly, in Central America, several hours spent gathering wild corn could provide food for a week. If agriculture was more difficult and time-consuming than hunting and gathering, why did people take it up in the first place?

Increasing population density provides an attractive explanation for the origin and spread of agriculture. When hunting and gathering groups grew beyond the capacity of their territory to support them, part of the group would split off and move to a new territory. Once there was no more productive territory to colonize, growing populations developed more intensive (and time-consuming) ways to extract a living from their environment. Such pressures favored groups that could produce food themselves to get more out of the land. In this view, agriculture can be understood as a natural behavioral response to the increasing population.

Modern studies have shown that wild strains of wheat and barley can be readily cultivated with simple methods. Although this ease of cultivation suggests that agriculture could have originated many times in many places, genetic analyses show that modern strains of wheat, peas, and lentils all came from a small sample of wild varieties. Domestication of plants fundamental to our modern diet occurred in just a few places and times when people began to more intensively exploit what had until then been secondary resources.

19.1: Causes of Amphibian Declines

A striking feature of amphibian population declines, and what sets them apart from the general biodiversity crisis, is that they have occurred in some of the best-protected natural areas. For example, Sierra Nevada Yellow-legged Frogs have disappeared from wilderness areas high in the United States mountain range known as the Sierra Nevada. While remote locations such as these have escaped obvious habitat alteration and destruction, they are still being affected by human activities. Scientists have investigated five possible causes for the mysterious rapid amphibian declines that have occurred in such remote locations: (1) introduced nonnative species, (2) increased ultraviolet radiation, (3) disease, (4) climate change, and (5) toxic contaminants, such as pesticides.

People introduce non-native species for a variety of reasons, including recreational fishing, human food, and for biological control of pests. For example, as early as the 1800s, fish stocking of high-elevation lakes in the Sierra Nevada was done by horseback. Today, trout are raised in hatcheries and dropped by airplane into remote sites in mountain ranges throughout the West. Trout are heavy predators and will eat both tadpoles and adult frogs, so they could easily be the cause behind some declines. While introduced species such as trout have significant negative impacts on certain amphibian species, scientists are concluding that they are not the predominant cause of rapid declines.

Increased ultraviolet radiation was long thought to play a role in declines, and it has received much scientific attention. The release of ozone-destroying chemicals such as chlorofluorocarbons (CFCs), formerly used in refrigerators, has resulted in increased ultraviolet radiation reaching Earth's surface. Ultraviolet radiation can cause DNA damage and affect animal immune systems. However, the largest number of rapid declines has occurred in tropical mountain-slope forests where amphibians are sheltered from sunlight by the forest canopy. Thus, ultraviolet radiation is unlikely to be a primary cause of these declines.

In 1998, scientists discovered a previously unknown fungus that was associated with frog die-off in both Australia and Panama. The fungus, Batrachochytrium dendrobatidis, is in the chytrid family of fungi and is the only member known to be a pathogen (cause of disease) to vertebrates. The discovery of the chytrid fungus proved to be a turning point, and now disease, particularly that caused by the chytrid fungus, has emerged as the leading explanation for rapid amphibian population declines. Chytrid fungus has now been found in more than 400 amphibian species and has been associated with population die-offs in North, Central, and South America, as well as in Africa, Europe, Australia, and New Zealand. While it is clear that chytrid fungus is the immediate cause of many rapid amphibian-population declines, there is still much debate about the disease. Is chytrid fungus a newly emerging disease, spreading and attacking defenseless amphibian hosts? Or have recent environmental changes facilitated disease outbreaks by a pathogen that has long been widespread?

Global climate change, especially warming trends, could be contributing to chytrid fungus outbreaks. Unusually hot spells may stress amphibians, which would weaken their immune systems and make them more susceptible to disease. Another possibility is that temperature shifts caused by climate change may create environments more favorable for the growth of chytrid fungus. In addition, climate change may cause drier conditions, forcing amphibians to congregate in smaller bodies of water, facilitating the transmission of disease. All these factors point to a possible connection between climate change and disease, but to date, the necessary research has not been done to determine if any of these inks are actually operating.

Pesticides and other contaminants may facilitate disease also. Such chemicals can be carried long distances from where they are applied and often wind up in remote ecosystems. Studies have shown that contaminants can suppress immune systems in many organisms, including amphibians, which may lead to disease outbreaks. In California, researchers have found a strong association between the geographic pattern of population declines of a number of frog species and the pattern of pesticide applications. However, as with climate change, few studies have been conducted to establish a clear link between contaminants, disease, and amphibian declines. More research is clearly needed.

19.2: The Price Revolution

Unprecedented inflation, or the price revolution, swept through Europe in the sixteenth century. The main cause of the price revolution was the population growth during the late fifteenth and sixteenth centuries. The population of Europe almost doubled between 1460 and 1620. Until the middle of the seventeenth century, the number of mouths to feed outran the capacity of agriculture to supply basic foodstuffs, causing the vast majority of people to live close to subsistence (the minimum food necessary to live). Until food production could catch up with the increasing population, prices, especially those of the staple food bread, continued to rise.

The other principal cause of the price revolution was probably the silver that flowed into Europe from the Americas via Spain, beginning in 1552. At some point, the influx of silver may have exceeded the necessary expansion of the money supply and may have begun contributing to inflation. A key factor in the price revolution, then, was too many people with too much money chasing too few goods. The effects of the price revolution were momentous.

The price revolution had its greatest effect on farming. Food prices, which rose roughly twice as much as the prices of other goods, spurred ambitious farmers to take advantage of the situation and to produce for the expanding market; the opportunity for profit drove some farmers to work harder and manage their land better.

All over Europe, landlords held their properties in the form of manors. A particular type of rural society and economy had evolved in these manors in the fourteenth and fifteenth centuries. By the fifteenth century, much manor land was held by peasant tenants according to the terms of a tenure (relationship between tenants and landlords) known in England as copyhold. The tenants had certain hereditary rights to the land in return for the performance of certain services and the payment of certain fees to the landlord. Principal among these rights was the use of the commons-the pasture, wood, and pond. For the copyholder, access to the commons often made the difference between subsistence and real want because the land tilled on the manor might not produce enough to support a family. Arable land was worked according to ancient custom. The land was divided into strips, and each peasant of the manor was traditionally assigned a certain number of strips. This whole pattern of peasant tillage and rights in the commons was known as the open-field system. After changing little for centuries, it was met head-on by the incentives generated by the price revolution.

In England, landlords aggressively pursued the possibilities for profit resulting from the inflation of farm prices. This pursuit required far-reaching changes in ancient manorial agriculture, changes that are called enclosure. The open-field system was geared toward providing subsistence for the local village and, as such, prevented large-scale farming for a distant market. In the open-field system, the commons could not be diverted to the production of crops for sale. Moreover, the division of the arable land into strips reserved for each peasant made it difficult to engage in profitable commercial agriculture.

English landlords in the sixteenth century launched a two-pronged attack against the open-field system in an effort to transform their holdings into market-oriented, commercial ventures. First, they denied their tenant peasantry the use of the commons, depriving poor tenants of critically-needed products; then they changed the conditions of tenure from copyhold to leasehold. Whereas copyhold was heritable and fixed, leasehold was not. When a lease came up for renewal, the landlord could raise the rent beyond the tenant's capacity to pay. Both acts of the landlord forced peasants off the manor or into the landlord's employ as farm laborers. With tenants gone, fields could be incorporated into larger, more productive units. Landlords could hire labor at bargain prices because of the swelling population and the large supply of peasants forced off the land by enclosure. Subsistence farming gave way to commercial agriculture: the growing of a surplus for the marketplace. But rural poverty increased because of the mass evictions of tenant farmers.

20.1: Grinding Grain

It now seems that humans began to grind grain into flour earlier than was originally thought. Grinding stones have been found at African and Asian sites dating from 200,000-50,000 years ago. It was presumed at first that these stones were used primarily to grind plant and animal materials, or minerals, to make pigments, rather than for the preparation of foodstuffs. However, new findings from the Middle East raise the intriguing possibility that some human groups may have been using grinding stones to process cereal grains, such as wheat, and maybe other types of edible plants, as early as the Middle Paleolithic Era (i.e. 50,000 years ago and earlier). But why is it such an advantage to grind cereal grains before eating them? The main reason is that grinding breaks down the hard, fibrous cereal grain to release the easily digestible starch granules contained within This served two purposes. Firstly, it enabled people to save enormously on the wear and tear of their teeth, compared to eating raw unprocessed grains. Unlike the teeth of grazing animals, human teeth do not continue to grow after childhood. Tooth wear due to a diet high in fiber and raw plants can result in the substantial erosion of molars (back teeth by early adulthood). People with worn or absent teeth faced starvation unless they could find alternative types of food that did not require chewing. Alternatively, they could try to find another way of grinding the fibrous plant material before eating it. Perhaps it was one of these incentives that led to the use of stone-grinding tools for seed processing.

The development of grinding technology would have been socially advantageous to a human group. People would tend to keep their teeth for much longer, and thus older, more experienced individuals could have lived longer, despite the ultimate loss of their teeth. Such people could then serve their clan either as "grandparent" childcare givers or by acting as instruments for the innovation and transmission of oral culture. The latter role was a key adaptation in preliterate societies (societies without a writing system), particularly in relation to strategies for food acquisition and technology in an era of considerable climatic flux. The remembered knowledge of how their grandparents dealt with the last arid period, including alternative food acquisition strategies, would have enabled such surviving elders to greatly enhance the ability of their clan to deal with such difficult situations.

Unfortunately, grinding seeds to make flour could be a mixed blessing. Depending on the type of stone used, the prolonged and laborious process of grinding cereal grains would produce small chips of stone that could get into the flour. People eating the products of such flour every day would be repeatedly exposed to stone chips as they chewed their food, and eventually, their teeth might become chipped and worn. This problem was partially alleviated many millennia later by the invention of pottery, which enabled porridge to be made from grains mixed with water and boiled without grinding.

The second, and more immediate, reason for grinding cereal grains is that it enables us to produce a more attractive, sweeter tasting, more nutritious, and calorie-rich foodstuff. Rather than a hard, dry, indigestible, tooth-destroying- cereal grain, people could enjoy foods such as seed cakes, biscuits, and all the various forms of bread that we still relish so much today. Cereal grains that have been ground and processed into flour can be much more easily digested due to the higher surface area that is available for digestive enzymes (molecules that break down food). This means that not only the plentiful starches but also the grain proteins and the much less abundant micronutrients are more easily absorbed from processed cereals. In the cold, dry climate of the Last Glacial Maximum, plants of the grass family, such as cereals, would have been a more reliable source of food than woodland plants (e.g. nuts and berries). Many of these woodland plants would have died out as the weather worsened, and edible animals would have also become increasingly unavailable as they migrated to warmer climates, leaving cereals as one of the few remaining options for the people who chose, or were obliged to remain in the Middle East.

20.2: Machines and Manufacturing

The tremendous growth in European industry in the eighteenth and nineteenth centuries was the result of a number of changes, technology foremost among them. The accumulation and diffusion of technical knowledge necessary for manufacturing began in the countryside, where handicraft operations were gradually enlarged and mechanized. Often, it was small-and medium-sized producers, and the occasional amateur experimenter in a barn, who were the inventors and innovators. Numerous small inventions, applied and diffused on both sides of the Atlantic, gradually built up a stock of technical knowledge and practice that was widely available.

The most famous of these inventors was James Watt (1739-1819) of Scotland, who succeeded in making steam engines more efficient. Steam engines burned coal to boil water, which condensed into steam that was used to drive mechanized devices. Watt devised a way to separate steam condensers from piston cylinders so that pistons could be kept hot, and therefore, running constantly. This set the stage for a fuel-efficient engine. Early prototypes of Watt's engine were used to pump water out of mines. After moving to Birmingham in 1774, Watt joined forces with the industrialist Matthew Boulton (1728-1809), who marketed the steam engine won an extension of the patent for another twenty-five years, and set up a special laboratory for Watt so that he could refine his device. Thus, technical exploration joined forces with the interests of business: collaboration between inventors and entrepreneurs was a sign of the times. Moreover, perhaps the most important aspect of Watt's engineering feat was that it was subject to a stream of improvement and adaptation, not just from Boulton and Company, but from its competitors as well.

The steam engine, driven by burning coal, provided vastly increased power and sparked a revolution in transportation. Steam-powered ships and railroads, once inventors were able to construct lighter engines that required less coal to run, slashed the time and cost of long-distance travel. Steam power's diffusion accelerated when iron-making improved, allowing for the production of railroad tracks and cables used to hang suspension bridges. The first public rail line opened in 1830 in England, between Manchester and Liverpool. During the next twenty years, railway mileage increased from less than 100 to almost 25,000 in England, France, Russia, and the German-speaking countries. Steamships appeared in the 1780s in France, Britain, and the United States. and in 1807, Robert Fulton inaugurated the first commercially successful route between New York City and Albany on the Hudson River. A century of toying with boilers and pistons culminated in the radical reduction of distances. Moreover, steam-powered engines also improved sugar refining, pottery making, and many other industrial processes. Mechanizing processes that would have taken much longer and been subject to human error if done by hand, enabled manufacturers to make more products at cheaper costs.

Textile production was one of the areas that benefited from both technical changes and the consolidation of different stages of the work in a factory. With new machinery, a single textile operator could handle many looms and spindles at once and could produce bolts of cloth with stunning efficiency. Gone were the hand tools, the family traditions, and the loosely organized and dispersed systems of households producing cloth in their homes for local merchants to carry to markets. The material was also stronger, finer, and more uniform. Thanks to such innovations, British cotton output increased tenfold between 1770 and 1790, leading to a 90 percent decline in the price of cloth between 1782 and 1812.

Most raw cotton for the British cloth industry had come from colonial India until 1793, when the American inventor Eli Whitney (1765-1825) patented a device called a "cotton gin" that separated cottonseeds from the fiber. Cotton farming quickly spread through the southern states-from South Carolina into Georgia, Alabama, Mississippi, and Louisiana-as the United States came to produce more than 80 percent of the world's cotton supply by the 1850s, thus the American South became a supplier of raw cotton to Britain.

21.1: The British Economy in the Eighteenth Century

The British economy expanded significantly in the eighteenth century, particularly with the development of factory manufacturing. By the middle of the century, it had begun to alter the northern English landscape. "From the Establishment of Manufacturers, we see Hamlets swell into Villages, and Villages into Towns," exclaimed one gentleman in the 1770s. The production of manufactured goods doubled in the second half of the century. Cotton manufacturing led the way: from 1750 to 1770, British cotton exports doubled. The production of iron followed in importance, along with wool and woolen fabrics, linen, silk, copper, paper, cutlery, and the booming building trades. Coal was substituted for wood as fuel.

Despite its relatively small size, Britain had significant economic advantages over the other nations of Europe, helping to explain why the manufacturing revolution began in Britain. Unlike the German or Italian states, Britain was unified politically. People living in England spoke basically the same language. France and the Italian and German states still had internal tariffs that made trade more costly, whereas, in Britain, there were no internal tariffs once the union between England and Scotland had been achieved in 1707, creating Great Britain. The system of weights and measures in Britain had largely been standardized. Indeed, Great Britain was by far the wealthiest nation in the world. Colonies in faraway parts of the world provided raw materials for manufacturing and markets for goods produced in Britain; for example, the amount of raw cotton imported from India increased by twenty times from 1750 to 1800.

England's stable banking and credit arrangements also contributed to England's advantage by facilitating the reinvestment of agricultural and commercial profits in manufacturing. London's banks, particularly the giant Bank of England, were profitable and respected. Merchants and manufacturers accepted paper money and written orders for payment or bills of exchange with confidence. Gentry, or those who owned land, invested in overseas trade expeditions and in manufacturing without the reticence of landowners on the European continent. London's financial market could provide information twice a week on what investments were worth in Amsterdam and Paris. Joint-stock companies, which had begun in the late seventeenth century, offered investors shares in their businesses together with limited personal liability, which meant that in the case of a company's financial disaster, individual investors would be liable only to the extent of their investments.

Expanded demand for manufactured goods led to a dramatic improvement in Britain's transportation systems. A new process of road surfacing-using small pieces of stone mixed with tar-improved travel on the main routes. Major roads were extended and improved, as investors formed turnpike trusts, repairing the highways and turning a profit by charging a toll to travelers using them. In 1700, it took 50 hours to travel the 180 kilometers from Norwich to London by coach: by 1800, the journey could be achieved in 19 hours. Moreover, England's water transportation was unmatched in Europe, a gift of nature. Rich sources of coal and iron ore lay near waterways and could be transported with relative ease along the coast. No part of England stands more than 70 miles from the sea. Navigable rivers and canals built in the middle decades of the century also facilitated the transportation of raw materials and manufactured goods.

Finally, the British government offered business people more assistance than any continental rivals could anticipate from their own governments. The powerful Royal Navy protected the merchant fleet, which tripled during the first three-quarters of the century. Laws forced foreign merchants to ship export goods to Britain in British ships, bowing to pressure from woolens producers. The British government in 1700 imposed protective tariffs on imported silk and calico (printed cotton fabric). Agreements with the Dutch Republic and France in the late 1780s reduced trade tariffs with those states, which helped British exports. Furthermore, the political influence of business people kept taxes low.

Yet the British government rarely interfered in the operations of the economy in ways that businesses might have considered intrusive. Adam Smith (1723-1790), who emerged as the most important economic theorist of the time, rejected prevailing theories that prescribed more government control of the economy, instead extolling economic liberalism-that is, relatively little government intervention.

21.2: Characteristics of Sixteenth-Century European Towns

Size, legal status, or presence of fortifications (walls or other defensive barriers) might seem natural criteria in defining the distinction between town and village in sixteenth-century Europe. Ultimately, however, it was none of these, but rather "urban" functions, that distinguished even the smallest towns from villages. Some villages could be relatively large. Some had their own walls. On the other hand, many towns were unfortified and lacked legal status as a town.

Early modern towns were multifunctional. Whether they were large or small, this was what they shared, and this, in turn, is what distinguished them most from rural settlements. Not all of these functions were economic, but the economic functions were the foundations upon which all others were constructed. Only newly established military towns, such as Palmanova in northeastern Italy or Neuf-Brisach on the Franco-Imperial border, and the occasional ecclesiastical center were an exception to this pattern. Without the money and demographic momentum generated by economic activity, towns were not selected as the location for administrative centers, law courts, capital cities, colleges, and universities, Cathedrals, or the sites for religious orders. They might be transformed in the process, as were Madrid when it was chosen definitively by Philip II in 1561 as the capital of Spain, and Weilburg in Hesse, which was reconstructed for a similar purpose in the late seventeenth century by Count Johann Ernst of Nassau, but the preconditions for growth were already there.

Five economic functions distinguished towns from the countryside: their location as centers for exchange; the presence of artisans; occupational diversity; regular links with other centers of exchange; and influence over a hinterland or rural area far from any town. These distinguishing characteristics were then reinforced by social and cultural indicators, such as more complex forms of government, the presence of a stratified society with an identifiable elite, the presence of professionals, such as lawyers or schoolteachers, and religious orders and educational establishments. As time passed, new cultural indicators were added, such as discussion groups and charitable societies.

By using these urban characteristics and indicators, it is possible to suggest that centers of all sizes in Western Europe shared a common urban identity. Consider two Italian urban centers: Venice and the Sicilian town of Gangi, which, while not quite at the opposite ends of the urban spectrum, are usually considered to belong to totally different spheres. Gangi had a population of some 4,000 in the mid-sixteenth century. Two-thirds of its inhabitants were engaged in agriculture. The others were artisans, shopkeepers, merchants, servants, rentiers (people whose earnings are derived from rent on properties), and members of religious orders. At the height of its prosperity at the end of the sixteenth century, on the other hand, Venice had a population of 190,000. It was a major international trading center, supported by a substantial industrial sector, and was the capital of an extensive maritime and land-based empire. It had a significant number of merchants, renters, and professionals among its permanent population. As a point of departure for pilgrims and a point of arrival for tourists, it also functioned as a center of hospitality. Servants and others engaged in the business of food, drink, and hotels swelled the already large numbers who worked in the households of the permanent residents. In spite of these substantial contrasts, both Gangi and Venice shared the basic economic functions and the social and cultural indicators that have already been discussed. Both functioned, above all, as centers of exchange, which linked their rural hinterlands to long-distance trading networks. Gangi lay on the old Roman road between Palermo and Messina and was an important center for the export of livestock and wine. Venice's strategic location at the head of the Adriatic Sea enabled it to link the eastern and western Mediterranean with the producers and consumers of central Europe. It was also a center of exchange for goods emanating from northern Italy. Each town had its important public buildings and churches, a central square, and large houses belonging to an elite. Each had its cultural identity. Comparisons of similar kinds could be made from any region of Europe.

22.1: Origins of Earth's Salty Oceans

Scientists have long been interested in discovering the origin of Earth's water and establishing why Earth's oceans are so salty. There has been speculation that the earliest Earth was so hot that no liquid water existed, and all light elements (such as hydrogen and oxygen) were rapidly stripped away from Earth by the solar wind (a stream of charged particles emitted by the Sun). If this were true, then the elements needed to form water on Earth would not have been freely available. As a consequence, it was proposed that collisions with icy comets or similar gas-and water-rich materials brought water to Earth after the planet had sufficiently cooled to retain it. This concept was supported by comparisons of the gas compositions of meteorites with those of rocks from beneath the Earth's surface, notably using krypton and xenon, nonmetallic gases that do not react with other materials. There certainly is enough ice in space to have supplied our water (and atmosphere) in this manner.

In July 2015, the space probe Philae, which landed on comet Churi, discovered not only ice and dust but also 16 types of organic compounds, present not in a loose distribution but in discrete clumps. Suddenly, the idea gained lots of traction that comets brought not only water but also the ingredients for life, even in ready-made clumps. Intriguingly, in October 2015, it was reported that-as this comet slowly thaws-molecular oxygen (02) escapes in a constant and high proportion (1% to 10%) relative to water, which suggests that the comet also contains a surprising amount of primordial (ancient) oxygen, which was incorporated during the comet's formation.

Other work favors an alternative explanation. This work found that the hydrogen isotope ratio (the proportion of different forms of hydrogen) of ice in comets may be different from that of water on Earth. It instead emphasizes that the chemical composition of water on Earth resembles that of the small percentage of water contained within rocky meteorites and, thus, in asteroids, which are essentially very large meteorites. Thus, a theory was developed that the asteroids planetesimals and protoplanets that clumped together to form Earth had carried enough water in their rock minerals to explain our oceans. It would have escaped from the planet's interior as steam, which in turn would have condensed into water at the surface and in the early atmosphere. Calculations indicate that this mechanism can also provide plenty of water to explain Earth's observed water content.

We have a complete understanding of the origin of salt in our oceans. It represents an accumulation of dissolved minerals over tens of millions to hundreds of millions of years. These minerals were broken up and dissolved during chemical weathering. We are all familiar with this process from limestone buildings that become pitted or smoothed by the action of water, wind, and weather; this is where the term weathering comes from. The key process at work is one of the chemical reactions between the rock and the water, with an important role for gases that are dissolved in water, such as carbon dioxide or sulfur dioxide, since these make the water more corrosive. The chemical weathering reactions break up rock minerals into charged atoms or molecules, called ions, which are removed in solution by river water and groundwater. This is exactly what happens when you dissolve table salt in water: the mineral salt breaks down into sodium and chloride ions that are held in a solution.

The early atmosphere contained high levels of carbon dioxide, or CO2. This gas is easily dissolved in water, forming a mildly acidic solution. In the Co2-rich early atmosphere, this resulted in corrosive acid rain that was highly effective at chemically weathering rocks, and fresh volcanic rocks are especially easily weathered. The intense weathering released dissolved minerals in the form of ions into river water and groundwater. From early times onward, river and groundwater flow transported the dissolved minerals to their final collection point, the ocean basins. Given the extremely slow input and removal of salts, it becomes clear that the oceans' vast store of salt has accumulated because the oceans have, for ages, been the end station for salt transport. Meanwhile, water itself continually evaporates from the oceans-concentrating its salts, and the evaporated fresh water continues the weathering cycle.

22.2: Latin America in the Nineteenth Century

A series of wars that took place between 1808 and 1826 brought independence to most former colonies of Spain and Portugal in Latin America. After winning their independence, the new Latin American states began a long, uphill struggle to achieve economic and political stability. They faced immense obstacles, for independence was not accompanied by economic and social changes that could spur rapid progress. Large estates, generally operated using primitive methods and highly exploited labor, continued to dominate economic life. Far from diminishing, the influence of the landed aristocracy (established upper social class) actually increased. This was the result of the leading military role it had played in the wars of independence and the passing of Spanish authority.

Economic life stagnated, for the anticipated large-scale influx of foreign capital did not materialize, and the European demand for Latin American staples remained far below expectations. Free trade brought increased commercial activity to the coasts, but this increase was offset by the near destruction of some local craft industries by cheap, factory-made European goods. The sluggish pace of economic activity and the relative absence of interregional trade and true national markets encouraged local self-sufficiency, isolation, political instability, and even chaos.

As a result of these adverse factors, the period from about 1820 to about 1870 was, for many Latin American countries, an age of violence and alternate dictatorship and revolution. Its symbol was the caudillo (strongman), whose power was always based on force, no matter what kind of constitution the country had. Usually, the caudillo ruled with the aid of a coalition of lesser caudillos, each supreme in his region. Whatever their methods, the caudillos generally displayed some regard for republican (representative government) ideology and institutions. Political parties, bearing such labels as "conservative" and "liberal," were active in most of the new states. Conservatism drew most of its support from the great landowners and their urban allies. Liberalism typically attracted provincial landowners, professional people, and other groups that had enjoyed little power in the past and were dissatisfied with the existing order. As a rule, conservatives sought to retain many of the social arrangements of the colonial era and favored a highly centralized government. Liberals usually advocated a federal form of government (in which power is distributed between a central government and regional authorities), guarantees of individual rights, lay (nonreligious) control of education, and an end to special privileges for the clergy and military. Neither party displayed much interest in the problems of the native peasantry and other lower-class groups.

Beginning in about 1870, the accelerating tempo of the Industrial Revolution in Europe stimulated more rapid change in the Latin American economy and politics. European capital flowed into the area and was used to create the facilities needed to expand and modernize production and trade. The pace and degree of economic progress of the various countries were very uneven and depended largely on their geographic position and natural resources.

Extreme one-sidedness was a feature of the new economic order in which one or two products became the basis of each country's prosperity, making these commodities highly vulnerable to fluctuations in world demand and price while other sectors of the economy remained stagnant.

The late nineteenth-century expansion was accompanied by a steady growth of foreign control over the natural and human-made resources of the region. Thus, by 1900, a new structure of dependency, or Colonialism, had arisen, called neocolonialism, with Great Britain and, later, the United States replacing Spain and Portugal as the dominant powers in the area.

The new economic order demanded peace and continuity in government, and after 1870, political conditions in Latin America did, in fact, grow more stable. Old party lines dissolved as conservatives adopted the dogma of science and progress, while liberals abandoned their concern with constitutional methods and civil liberties (protections for individuals against unjust government interference) in favor of an interest in material prosperity. The cycle of dictatorship and revolution continued in many lands, but the revolutions became less frequent and less devastating.

These major trends in the political and economic history of Latin America in the period extending from about 1820 to 1900 were accompanied by other changes in the Latin American way of life and culture-notably, the development of a powerful literature that often sought not only to mirror Latin American society but to change it.

23.1: The Meaning of Upper Paleolithic Art

The period beginning 40,000 years ago (the Upper Paleolithic) witnessed a marked increase in human artistic and symbolic expression. At about this time, a large number of statues carved from bone or stone began to appear in the archaeological record, as do magnificent paintings of animals that were hunted and animals that were not, as well as other images on cave walls and ceilings. It is difficult for modern viewers to remain unmoved by these images, but what did these works mean to their creators, and why did they create them?

Some researchers regard Paleolithic artwork as part of a system of communication of ideas-a system that uses animals and geometric patterns as symbols, the specific meaning of which may be lost forever. Anthropologist Meg Conkey views the 1,200 bones engraved with abstract geometric patterns at Altamira Cave, Spain, as the identifying symbols-the "flags"-of different groups of people who came together at the cave during certain periods. Archaeologist Michael Joachim views the cave paintings of northern Spain and southern France (the so-called Franco-Cantabrian region) as symbols marking territory. Social stresses that accompanied the population influx into the region during the period beginning 25,000 years ago may have resulted in the need to mark territory with symbols of ownership. Painting animals-probably the most important resources of a territory-within a sacred place in the territory, like a cave, might have served to announce to intruders the rightful ownership of the surrounding lands. Archaeologist Clive Gamble views the small stone statues of female figures, known as Venus figurines, as a symbolic social glue, helping to maintain social connections between geographically distant groups through a common religion and art style.

More recently, researchers Patricia Rice and Ann Paterson have returned to a more economic perspective. Their statistical analysis of the numbers and kinds of animals seen on cave walls in the European Upper Paleolithic shows interesting correlations with the collections of animal remains found at habitation sites in Spain and France. Small, non-aggressive animals such as reindeer and red deer were important in the diet of the cave painters and seem to have been depicted on cave walls in proportion to their economic importance. In addition, animals whose remains are found less often at archaeological sites, but that were impressive, dangerous, and produced large quantities of meat when they were successfully hunted, were commonly included in the artwork as well. So it would appear that cave painters wanted to depict animals that were important food sources. However, the relatively recently discovered Chauvet Cave contradicts this pattern, with its stunning depictions of animals not known to have been exploited for food by Paleolithic Europeans, including carnivores like lions, bears, and panthers, as well as woolly rhinoceroses.

A neuron-psychological approach has been applied by researchers J. D. Lewis-Williams and T. A. Dowson to explain at least some of the less naturalistic cave art. They note that there are six basic geometric forms that people who are placed into an altered state of consciousness (for example, through hypnosis) under experimental conditions report seeing: dots, wavy lines, zigzags, cross-hatching or grids, Concentric circles or U-shaped lines, and parallel lines. Interestingly, these geometric forms are precisely those seen in some ancient cave art dating to more than 30,000 years ago.

Lewis-Williams and Dowson's approach is cross-cultural. In other words, they surveyed a wide variety of historical and archaeological cultures, finding common images in artwork all over the world. Lewis-Williams and Dowson point out ethnographic records of shamans (priests) who, in an attempt to communicate with spirits or see into other worlds, fall into a trance-like state by fasting, dancing, hyperventilating, going into isolation in absolute darkness, undergoing sleep deprivation, or even ingesting natural hallucinogens. When these shamans produce an artistic representation of what they have seen in their trances, they often include geometric shapes that are also seen in Upper Paleolithic artwork. These images from trances are not culturally controlled but result, in part, from the structure of the optic system itself and are, therefore, universal. Perhaps through sleep deprivation, staring at a flickering fire, or the ingestion of drugs, ancient shamans or priests produced these images in their own optic systems. They then translated these images to cave walls as part of religious rituals.

23.2: The Roots of Economic Transformation in England

England was the first nation in Europe to develop a social structure that strongly supported the innovation and economic growth we associate with modern times. England's advantages were many, some of them deeply rooted in geography and history. This comparatively small realm contained an excellent balance of resources. The plain to the south and east, where traditional centers of English settlement concentrated, was fertile and productive. The uplands to the north and west possessed rich deposits of coal and iron, and their streams had powered flour mills for hundreds of years. Proximity to the sea was another natural advantage. No part of the island kingdom was distant from the coast. At a time when water transport offered the sole economic means for moving bulky commodities, the sea brought coal close to iron, raw materials close to factories, and products close to markets. Above all, the sea gave Britain's merchants access to the much wider world beyond their shores.

The efficiency of transport was critical in setting the size of markets. During the eighteenth century, Britain witnessed a boom in the building of canals and turnpikes (roads that could be traveled for a fee). By 1815, the country possessed some 2,600 miles of canals linking rivers, ports, and other towns. In addition, few institutional obstructions to the movement of goods existed. United under a strong monarchy, Britain was free of internal tariffs (payments for goods transported across a border), unlike prerevolutionary France, Germany, or Italy. English merchants everywhere counted in the same money, measured their goods by the same standards, and conducted their affairs under the protection of the common law. By contrast, in France, local regions differed in their legal codes and in weights and measures, which complicated and slowed exchange. As the writer Voltaire sarcastically remarked, the traveler crossing France by coach changed laws as frequently as horses.

The English probably had the highest standard of living in Europe and generated strong consumer demand for manufactured goods. English society was less stratified (divided into groups based on status) than elsewhere in Europe, and the aristocracy was powerful but much smaller. Primogeniture-the right of the eldest son to inherit the family's land-was the rule both among the aristocratic members of the House of Lords and among the other land-owning classes. Left without lands, younger sons had to seek careers in other walks of life, and some turned toward commerce. They frequently obtained capital for their ventures from their landed fathers and elder brothers. English religious minorities, chiefly Calvinists and Quakers, formed another pool of potential businessmen; denied careers in government because of their religion, many turned their energies to business enterprises.

A high rate of reinvestment is very important to industrialization; reinvestment, in turn, depends on the skillful management of money by both individuals and public institutions. Here again, Britain enjoyed advantages. Early industrial enterprises could rely on Britain's growing banking system to meet their capital needs, a system which in the seventeenth century was taken over by the goldsmiths of London, who accepted and guarded deposits, extended loans, and provided other financial services. In the eighteenth century, banking services became available beyond London; the number of regional banks rose from 300 in 1780 to more than 700 by 1810. English businessmen were familiar with banknotes and other forms of commercial papers, and their confidence in paper money facilitated the recruitment and flow of capital.

The founding of the Bank of England in 1694 marked a distinctive period in the history of European finance. The bank took responsibility for managing England's public debt, sold shares to the public, and faithfully met the interest payments due to the shareholders with the help of government revenue, such as the customs duties efficiently collected on Britain's extensive foreign trade. When the government needed to borrow, it could turn to the Bank of England for assistance. This stability in government finances ensured a measure of stability for the entire money market and, most importantly, held down interest rates in both the public and private sectors. In general, since the late seventeenth century, England's government was sensitive to the interests of the business classes, who, in turn, had confidence in the government. Such close ties between money and power facilitated economic investment.

24.1: Understanding Insects through Fossils

Although it has been estimated that insects account for roughly one-third of all animal species alive today, insects are, on the whole, poorly represented in the available fossil record, where many species are known from just a single specimen, and a high proportion of fossil insects come from exceptional fossil deposits that are sporadically distributed in time and space. Nonetheless, about 40,000 species of insects have been described as fossils, with many more awaiting description. Foremost among insect-rich deposits are ambers in which complete external preservation of insects is routine. Amber is the fossilized resin of a few particular kinds of trees. Oozing out of the bark, this resin had the ability to trap and surround insects, as well as other small animals, protecting them from the normal processes of organic decay as it hardened into transparent, yellow or orange amber. The chemical process of "amberization" could take up to 10 million years. During this time, it was common for amber initially buried in the soil to be washed out by rivers and redeposited in the sea.

Although the oldest amber comes from the Carboniferous period (360-290 million years ago), the great majority of amber deposits were formed between the start of the Cretaceous period（146 million years ago）and the present. They provide priceless windows on the insects and other small animals living at the time in the forests where amber-producing trees grew. Elsewhere in the fossil record, insects can be found in fine-grained sedimentary rocks, such as clays and silts deposited in freshwater lakes and sluggish rivers. Unlike the insects in amber, these fossils generally comprise only fragments, particularly of wings or wing cases, although more complete examples can be found, such as the dragonflies of the famous Jurassic Solnhofen Limestone of Bavaria.

The fossil record describes a multiplicity of insects that scientists have grouped according to their features. The most basic categorization of insects is into a primitive group without wings, called the Apterygota, and the winged Pterygota. Surviving apterygotes include springtails and silverfish. They are now relatively rare, comprising less than 1 percent of all insect species. Pterygotes are divided into those with wings that cannot be folded, which are called the Palaeoptera, and a larger, more advanced group, the Neoptera, capable of folding their wings close to the body. Mayflies, dragonflies, and damselflies are all palaeopteran insects, while the neopterans include locusts, butterflies, and wasps.

In spite of its imperfection, the fossil record holds a lot of useful information about the times of origination of insect groups that are alive today. Primitive wingless insects -the apterygotes- appear to have undergone an initial diversification during the Devonian period(416-359 million years ago), possibly even the Silurian period（444-416 million years ago). Unfortunately, however, relatively few fossil insects of this age are known and there is a great need for further discoveries. The oldest known fossil insect is currently Rhyniognatha hirsti from the early Devonian fossils in Scotland. However, this species, preserved in sinter (mineral sediment) from an ancient hot water spring that was active between 400 and 412 million years ago, exhibits some advanced characteristics, implying that there are more primitive, older insects still to be discovered.

Fossil insects with preserved wings (Pterygota) first occur in the mid-Carboniferous. The evolution of wings was accompanied by an increase in maximum body size. A remarkable dragonfly called Meganeura with a wingspan approaching 70 cm has been described from the late Carboniferous. This inhabitant of the forests is one of the largest insects ever to have lived. The huge size of Meganeura has led to speculations about the composition of the atmosphere at the time, the powered flight of such a large insect perhaps demanding an atmosphere containing higher levels of oxygen than that of the present day. Unfortunately, the fragmentary insect fossil record sheds little light on the origin of flight, as the oldest winged insects already had fully formed wings.

24.2: Interplanetary Seeding

Some scientists believe that microbial life may be distributed across terrestrial planets by interplanetary rocks. Rocks are capable of carrying microbes from the surface of one planet, across hundreds of millions of miles of space, to neighboring planets. Each year, Earth is impacted by half a dozen half-kilogram or larger rocks from Mars. These rocks were blasted off Mars by large impacts and found their way to orbits that cross Earth's path, where they eventually collided with Earth as meteorites. Nearly 10 percent of the rocks blasted into space from Mars end up on Earth. All planets are impacted by interplanetary objects large and small over their entire lifetimes, and the larger impacts actually eject rocks into space and into orbit about the Sun.

A glance at the full Moon with binoculars shows long streaks, or rays, radiating from the crater Tycho, located near the bottom of the Moon as seen by observers in the Northern Hemisphere. The rays are produced by the fallback of impact debris (impact material) ejected from the crater, which is 100 kilometers in diameter. The rays can be traced nearly across the full observable side of the Moon, and such long "airborne" flight is evidence that some ejecta （ejected materials） were accelerated to near-orbital speed. Debris ejected at speeds higher than the escape speed（2.2 kilometers per second）did not fall back but flew into space. It has long been appreciated that material could be ejected from the Moon by impacts, but only in the relatively recent past have we realized that whole rocks greater than 10 kilograms in mass could be ejected from terrestrial planets and not be severely modified by the process. It was formerly believed that the launch process would shock-melt or at least severely heat the ejected material. There was little expectation that rocks capable of carrying living microbes from planet to planet would survive the great violence of the launch. The discovery of lunar（Moon）rocks in Antarctica showed that this is possible.

There is also a rare class of meteorites called SNCs, or Martian meteorites, that is widely believed to be from Mars. The first suggestion that these odd meteorites might be Martian was greeted with considerable skepticism. The discovery of lunar meteorites changed this by proving that there actually was an adequate natural launch mechanism. The lunar meteorites could be positively identified, because rocks retrieved by the Apollo program, which brought astronauts to the Moon, showed that lunar samples have distinctive properties that distinguish them from terrestrial rocks and normal meteorites derived from asteroids （rocky objects that orbit the Sun and are smaller than planets). Positive linking of the SNC meteorites with a Martian origin was a more complex process. It included showing that gas trapped in glass in the meteorite matched the composition of the Martian atmosphere, as measured by the Viking spacecraft that landed on Mars in 1976. The general properties of the SNC meteorites revealed that they were basalts （dark-colored volcanic rocks） formed on a large, geologically active body that was definitely neither Earth nor the Moon. Because the atmosphere of Venus is too thick and its surface too young, Venus was also ruled out as a source.

The astounding discovery that meteorites from the Moon and Mars reach Earth has profound implications for the transport of life from one planet to another. Over Earth's lifetime, billions of football-size Martian rocks have landed on its surface. Some were sterilized by the heat of launch or by their long transit time in space, but some were not. Some Martian ejecta are only gently heated and reach Earth in only a few months. This interplanetary transporter is capable of carrying microbial life from planet to planet. Like plants releasing seeds into the wind, or palms dropping coconuts into the ocean, planets with life could seed their neighbors. Perhaps, then, nearby terrestrial planets might contain microbial life with common origins. The seeding process would be most efficient for planets that have small velocities of escape（the minimum speed needed for an object to break free from a planet's gravitational attraction） and thin atmospheres. In this regard, Mars would be a more likely source than Earth or Venus.

25.1: Development of Mass Transportation in the United States

Before the development of cheap, reliable urban transportation in the United States (U.S.), city size had been limited by the distance people could comfortably walk to work. In such "walking cities," the radius rarely extended beyond a few miles, and people of all classes lived and worked close to one another. By the end of the nineteenth century, the walking city had metamorphosed into a sprawling, segmented city. Economic function and income divided the city roughly into a concentric pattern. A central business district, or downtown core, where few lived, was ringed by a manufacturing and wholesaling district, where immigrants and the working lower-income classes jammed into tenements and subdivided old houses. Beyond them was a stretch of lower-middle-class to middle-class row houses or apartment buildings, where skilled, clerical, and some factory workers resided. Then came the fringes of the city, where professionals, managers, and businessmen retreated to their spacious homes, leading comfortable lives and tending their manicured lawns and shrubs away from the stench, noise, dirt, and push-and-shove of the city.

New means of transportation made possible the new urban geography of economic integration and social segregation. As early as the 1820s and 1830s, such eastern cities as Boston, New York, and Philadelphia had operated horse-dray public carriers called omnibuses. Omnibus systems Spread rapidly through the 1850s, but the slow, heavy vehicles accommodated few passengers, and high fares limited ridership. By the mid-century, steam-powered commuter railroads were pushing city boundaries outward for the affluent. The New York Harlem Railroad connected the suburban village of Harlem with New York, and the Chicago & Milwaukee Railroad linked communities such as Evanston, Wilmette, and Lake Forest with Chicago.

At the same time, many cities had switched to horse-drawn streetcars. Rails smoothed the ride, compared to the bouncing of omnibus wheels over cobblestones, and they made possible larger conveyances and more rapid movement. By establishing fixed routes, the horse railways promised riders predictability. They also broadened the compass of the city to five miles or more. With lower fares, the horse car systems attracted a middle-class clientele, who commuted to work downtown from newly developed residential areas, or suburbs, on city borderlands. By the 1880s, horse-drawn streetcars were carrying almost 190 million passengers annually in the United States. Horse cars, however, were not as clean, cheap, or reliable as needed. Technology soon replaced the horse cars with cable cars, pulled by steam-driven, underground wire rope clamped to the car. Introduced in San Francisco in 1873, cable cars proved especially effective there and in such other hilly cities as Pittsburgh and Washington, D.C.

The most important advance in urban transit was the electric trolley. In 1888, on a twelve-mile track in hilly Richmond, Virginia, Frank J. Sprague, a naval engineer and former associate of Thomas Edison, demonstrated the practicality of powering streetcars with electrical currents transferred from overhead wires to the Vehicle by a four-wheeled spring device, or troller. A frenzy of construction and conversion to electricity followed, as city governments awarded generous trolley franchises to transit entrepreneurs. Trolleys rolled along at twice the speed of horse cars, and the US system of flat-fee fares (the same fare no matter how long the trip) with free transfers encouraged mass ridership. For ten cents, one could escape the soot and smells of the city on a daily commute or, for the poor, on a Sunday outing.

Mass ridership encouraged construction. In 1890, the nation had 5,700 miles of horse-drawn track and only 1,260 miles of electrified track; twelve years later, just 250 miles of horse-drawn track remained in service, while the total length of electrified track had grown to 22,000 miles. Transit companies tried to increase ridership by developing areas surrounding cities. By the 1890s, the Peoples Railroad trolley in St. Louis ran out to Grand Boulevard, a dirt road amid cornfields that the transit company was transforming into an avenue worthy of its name. The company laid out private streets with fountains, and it planted shade trees and shrubs to lure prospective home builders and buyers. Everywhere in the urban United States, transit companies invested heavily in such suburban real estate development, thereby encouraging population dispersal.

25.2: Spider Web Decorations

An evolutionary puzzle is provided by orb-weaving spiders (weavers of round webs) that incorporate impressive zigzag lines of white ultraviolet silk into their webs, which would seem to make the trap more obvious to the prey that the spider needs to catch. Given that many insects can see ultraviolet light, one wonders how orb weavers could gain by alerting potential victims to the danger posed by their webs. But perhaps these web additions actually attract ultraviolet-reflecting bees that specialize in taking nectar from ultraviolet-reflecting flowers. The fact that bees constitute the large majority of prey for some spiders with ornamented webs supports this hypothesis.

On the other hand, it could be that spiders that have been catching many preys, simply because their webs are in a good spot, are the spiders that tend to add decorations to their webs. If this is true, then the correlation between web decorations and higher rates of prey capture need not mean that the decorations cause the increase in prey capture. Instead, perhaps high feeding rates provide the extra energy that the spiders need to spin their web decorations, which they do for some purpose other than prey attraction. This hypothesis can be evaluated by testing the prediction that spiders, given an abundance of food, should invest more in web decorations than spiders deprived of food. Indeed, in two species of orb-weaving spiders, females that received more food made significantly larger decorations, and in one species, well-fed females were more likely to add decorations to their webs than were food-deprived individuals.

If one places an orb-weaving spider in a wooden frame and lets it build a web there, so that the web can be moved to a site chosen by the experimenter, then one can put two such webs side by side in a field. In this way, one can compare the rate of prey capture in an ornamented web with that in another web in the same spot whose decorations have been removed--something that can be easily accomplished by cutting out the two web lines that support the decoration (two web lines are also cut from the other web, but not those that hold the decoration). Such an experiment controls for the effects of site productivity. Under these conditions, the decorated web catches about a third less prey than the undecorated one. Thus, web decorations involve a cost to foraging (obtaining food), not a benefit, under some conditions.

If it is true that decorating one's web carries a cost in lost calories, what counterbalancing benefit exists for this behavior? One possibility is that when passing birds see the bright decorations, they swerve to avoid colliding with the web and getting covered in sticky silk. If this is true, then in the experiment above, webs with decorations should have been less often damaged by birds than webs without any "keep away" signals. And in fact, the actual results from the experiment matched the predicted ones, with decorated webs damaged by birds 45 percent less often than undecorated ones.

Another benefit of web decorations might come from having the added silk camouflage (hide) the body of the web builder, making the spider less vulnerable to attack from its predators. Evidence in support of this explanation comes from a set of spiders whose females regularly incorporate a silky egg sac into their webs. The spider perches (sits) on this moderately conspicuous vertical tube of silk, eggs, and debris in ways that make her much less visible to human observers, especially because the spider's color pattern matches that of the egg sac so closely. Moreover, when the egg sac is experimentally removed, the spider replaces it with a vertical strip composed entirely of silk, on which she perches as if it were an egg sac. Given that the egg sac seems to be used as a concealment aid, its replacement can be assumed to serve the same function.

More data on this point come from a study in which orb-weaving spiders that had built webs with or without extra silk decorations in an enclosed area were exposed to wasps, which hunt spiders and feed them to their offspring. In one experiment, only 32 percent of the spiders with web decorations were captured, as opposed to 68 percent of those without.

26.1: The Beginning of Planet Formation

The four innermost planets of our solar system-Mercury, Venus, Earth, and Mars-are terrestrial, or rocky planets. The beginning of their creation process occurred when the cloud of leftover material from the formation of the Sun settled into a disc around the young star. Most of the material in the cloud, like the material of the Sun itself, was in the form of hydrogen and helium. But there was a trace of dust, no more than 2 percent of the original material, in the form of particles as fine as the particles in smoke. The heat from the young Sun blew much of the gas away, but the rotation of the original cloud ensured that the dust settled into a disc around the young Sun-a protoplanetary disc like the ones seen around young stars today.

Within the disc, all the particles were moving in the same direction around the Sun, like runners going round a track. This meant that when they bumped into one another, they did so relatively gently, not in head-on collisions, giving the particles a chance to stick to one another. The tendency to stick may have been helped by electric forces produced by particles rubbing against one another, in the same way that you can make a child's balloon stick to the ceiling after rubbing it on a woolen sweater. Another important factor was turbulence in the gas, creating swirling structures like whirlwinds that gathered pieces of material together and gave them a chance to interact. Computer simulations show how objects as big as Ceres can form in this way-provided the particles can stick together.

Something else may also have helped the particles to stick together-something else that is special about the solar system. Studies of pieces of rock from meteorites show that the dusty disc around the young Sun contained tiny globules of material, known as chondrules, formed by melting at temperatures between 1,200 degrees Centigrade and 1,600 degrees Centigrade. Molten, or partly molten, blobs would be more sticky and encourage the buildup of larger lumps of stuff in the disc. But how did they get so hot? The most likely explanation is that the heat was released by radioactive elements that had been sprayed by a nearby star in the process of dying into the gas cloud from which the planets formed. One possibility is that a supernova occurred close to the cloud that became the Sun just before the Sun formed; it is even possible that the blast wave from this explosion triggered the collapse of the gas cloud that became the Sun and solar system. Supporting evidence for this idea comes from measurements of the proportions of various isotopes (different forms of an element) found in meteorites. Radioactive aluminum-26 seems to have been present in the proto-solar system from the beginning, but a pulse of iron-60 arrived about million years later. This matches what we know about the fate of a very large star, with more than 30 times as much mass as the Sun. In the late stages of its life, the star first blows away much of the outer layers of material, which by then is relatively rich in aluminium-26, in a wind easily strong enough to cause any nearby gas cloud to collapse. The star only explodes at the very end of its life, showering the neighborhood with elements including iron-60.

There is a rival idea, developed in Barcelona by Josep Trigo Rodriguez and colleagues, which suggests that the radioactive material was fed into the solar system as it was forming from a much less massive star which came much closer to the Sun. The right proportion of isotopes could have come in the wind of material being blown away from a star with only six times as much mass as our Sun in the last stages of its life. But the star would have to be very close to the Sun for this to happen -closer than 10 light-years- which makes such an event unlikely, statistically speaking.

26.2: Species Competition

Interspecific competition occurs when two or more species seek the same limited resource. In the 1930s, Russian biologist G. F. Gause devised a set of elegant laboratory experiments that provide the basis for our formal understanding of competition. Gause grew two different species of the single-celled Paramecium—P.aurelia and P. caudatum --separately and together. Populations of both species always increased more rapidly when they were grown alone. When grown together, populations of both species grew more slowly. Eventually, P. aurelia totally displaced P. caudatum. The results of his experiments with Paramecium species, along with similar experiments he performed on other organisms, led Gause to form this postulate: two species that directly compete for essential resources cannot coexist; one species will eventually displace the other. This postulate has come to be known as the competitive exclusion principle.

An acre of tropical forest may include over 100 species of trees, all of which depend on the same soil, water, and nutrients. Freshwater lakes may have dozens of species of fish, all of which feed on the planktonic algae and animals suspended in the water. Indeed, two or more species of Paramecium may be found in the same lake. These and many other examples from ecological communities in nature seem to contradict Gause's principle. If two competing species cannot coexist in the laboratory, how are they able to coexist in natural settings? This question has been the basis for hundreds of ecological studies.

Ecologist G. Evelyn Hutchinson provided one of the most important explanations for the coexistence of competing organisms. He proposed that each species has a fundamental niche, the complete range of environmental conditions, such as requirements for temperature, food, and water, over which the species might possibly exist. Hutchinson noted, however, that few species actually grow and reproduce in all parts of this theoretical range. Rather, species usually exist only where they are able to compete effectively against other species. Hutchinson used the term realized niche to describe the range of conditions where a species actually occurs given the constraints of competition. Species whose fundamental niches overlap significantly are potential competitors. Hutchinson suggested that these potential competitors are able to coexist because they divide up the fundamental niche. Hutchinson called this division of resources niche differentiation.

Niche differentiation occurs among many different kinds of organisms. For example, five different species of warblers, small insect-eating birds, occur together in the evergreen forests of the United States. During nesting season, the primary food of all the warblers is caterpillars. Careful studies of the birds' feeding behavior reveal that each species competes most effectively in a different part of the forest's highest layer, and that is where each species can be found. The diverse grasses and herbs that grow in native prairies provide another example of niche differentiation. Above ground, these plants appear to be vying for the same space and resources. However, careful mapping of root systems shows that different species are adapted to exploiting different portions of the soil. In addition, some species compete most effectively when growing in bright light, whereas others compete effectively when growing in the shade of taller plants.

Some of Gause's experiments support Hutchinson's niche differentiation hypothesis. Under any specific set of conditions-the same temperature, water availability, food source, etc., Gause's principle holds true. But if conditions change, competition among species may produce different winners and losers. Indeed, if waste products are periodically removed, the outcome of the competition between P. aurelia and P. caudatum is reversed and P. caudatum wins. Thus, in a complex environment where waste materials are collected in some places and not in others, these two species could coexist.

Time is required for one species to competitively displace another, and the competitive exclusion principle presumes that environmental conditions remain constant during that time. In nature, however, environments change from season to season and from year to year, so conditions that are favorable to a particular species may not persist and environments that are constantly changing may allow competing species to coexist.

27.1: Origins of the Industrial Revolution

The Industrial Revolution, the wave of technological, economic, and social changes that helped produce what we know as modern Europe, arose among back-country English cottage craftspeople in the early 1700s and fundamentally restructured industry. First, human hands were replaced by machines in the fashioning of finished products, rendering the word manufacturing (made by hand technically obsolete). No longer would the weaver sit at a handloom and painstakingly produce each piece of cloth. Instead, large mechanical looms were invented to do the job faster and more economically. Second, human power gave way to various forms of inanimate power. The machines were driven by water power, the burning of fossil fuels, and later by hydroelectricity and the energy of the atom. Men and women, once the proud producers of fine handmade goods, became tenders of machines. Within a century and a half of its beginnings, this economic revolution had greatly altered industrial activity.

The initial breakthrough came in the secondary, or manufacturing sector. More exactly, it occurred in the British cotton textile industry, centered at that time in the district of Lancashire in western England. At first, the changes were modest and on a small scale. Mechanical looms were invented, and flowing water, long used as a source of power by local grain millers, was harnessed to drive the looms. During this stage, manufacturing industries remained largely rural, diffusing to sites where rushing streams could be found, especially waterfalls and rapids. Later in the eighteenth century, the invention of the steam engine provided a better source of power, and a shift away from water-powered machines occurred. In the United States, too, the first factories were textile plants.

Metallurgy was also affected. Traditionally, metal industries had been small-scale, rural enterprises, carried on in small forges (fireplaces where metals were heated and shaped) situated near ore deposits. Forests provided charcoal for the smelting process in which ores were melted and fused. The chemical changes that occurred in the making of steel remained mysterious even to the people who made steel, and much ritual superstition and ceremony were associated with steelmaking. Techniques had changed little in 2, 500 years. The Industrial Revolution radically altered all this. In the eighteenth century, a series of inventions by iron makers allowed the old traditions, techniques, and rituals of steelmaking to be swept away and replaced with scientific, large-scale industry. Coke, nearly pure carbon derived from high-grade coal, was substituted for charcoal in the smelting process. Large blast furnaces replaced the forge, and efficient rolling mills took the place of hammers and anvils. Mass production of steel resulted, and the new industrial order was built of steel. Other manufacturing industries made similar transitions and entirely new types arose, such as machine-making.

Primary industries-those that gather or extract raw materials-were also revolutionized. The first to feel the effects of the new technology was coal mining. The adoption of the steam engine necessitated huge amounts of coal to fire the boilers and the conversion to coke in the smelting process further increased the demand for coal. Fortunately, Great

Britain had large coal deposits. New mining techniques and tools were invented so that coal mining became a large-scale, mechanized activity. Coal, heavy and bulky, was difficult to transport. As a result, manufacturing industries began flocking to the coalfields in order to be near the supply. Similar modernization occurred in the mining of iron ore, copper, and other metals needed by rapidly growing industries.

The Industrial Revolution also affected the tertiary(service) sector, most notably in the form of rapid bulk transportation. The traditional wooden sailing ships gave way to steel vessels driven by steam engines, canals were built, and the British-invented railroad came on the scene. The principal stimulus that led to these transportation breakthroughs was the need to move raw materials and finished products from one place to another, both cheaply and quickly. The impact of the Industrial Revolution would have been minimized had not the distribution of goods and services also been improved. It is no accident that the British, creators of the Industrial Revolution, also invented the railroad, initiated the first large-scale canal construction, and revolutionized the shipbuilding industry.

27.2: The Heavy Bombardment and Life on Earth

It is estimated that Earth formed around 4.5 billion years ago, yet life-even the simplest sort of microscopic life that must have started things off-did not begin right away. Until about 3.9 billion years ago, Earth was subject to an intense barrage of large objects from space, a time called the "heavy bombardment." Radiometric dating of Moon rocks shows that most of the Moon's visible impact craters, or holes formed on its surface from impacts, must have formed during this early period of the solar system's history. This is not surprising: According to our modern theory of solar system formation, the planets were built as larger and larger chunks of rock (sometimes mixed with metal or ice), or planetesimals, collided with one another. When a colliding planetesimal stuck to a growing planet, the planet got larger, increasing its gravity and allowing it to draw in even more planetesimals. Even after the planets had reached essentially their current sizes, there must still have been many planetesimals floating around; some of them still remain today, as the objects we call asteroids and comets. Those planetesimals that had orbits intersecting the orbits of the planets were doomed to eventual collisions, and most of those collisions must have occurred early in the solar system's history, when the number of planetesimals was still large. In other words, the heavy bombardment was the period of time during which impacts were most common, and the evidence from the Moon tells us that this period ended by about 3.9 billion years ago.

Some of the planetesimals were quite big. We have good reason to think that the Moon itself was created when a planetesimal the size of the planet Mars struck the young Earth within just 20 to 30 million years after Earth's formation. This "giant impact" is thought to have blasted rock from Earth's outer layers into space, where some of it settled into Earth's orbit and then was collected together by gravity to make the Moon.

Once the Moon formed, it became a record of the continuing impacts, not only telling us when the heavy bombardment occurred but also telling us about the sizes of the impacting objects from the sizes of the craters they left. Because human spaceflight missions visited and brought back rocks from only six sites on the Moon, we have only incomplete data about lunar cratering. Nevertheless, these data point to two key ideas: First, while there were no more Mars-size impacts (fortunately!), the Moon continued to be pelted by objects tens of miles to a couple of hundred miles across. Second, some of the largest impacts occurred as the heavy bombardment was ending, marking what many scientists now call the "late heavy bombardment." These large impacts created the smooth lunar maria (large, flat surface areas), that you can see easily with a pair of binoculars.

Because the heavy bombardment was a phenomenon of the solar system, it cannot have been unique to the Moon. This explains why we see craters on so many other planets' arid moons. Earth, too, must have been frequently scarred by large impacts during the heavy bombardment. In fact, Earth should have been hit even more than the Moon, because our planet presents a bigger target and Earth's stronger gravity would have drawn in more objects and accelerated them to higher speeds by the time they hit the ground. The only reason we do not see the craters from these impacts on Earth is that they were erased long ago by volcanic eruptions, erosion, and other geological processes that occur here but not on the Moon.

What does all this have to do with the origin of life? Calculations suggest that some of the larger impacts would have had a devastating effect on life. For example, the impact of an object larger than about 225 miles across would have released enough energy to completely vaporize the oceans and raise the global temperature to more than 3,000F. Such an impact probably would have sterilized our planet, wiping out any life that existed when it occurred. Somewhat smaller impacts would have vaporized all but the deepest ocean water, killing off any life that was not either living near the ocean bottom or in rock deep underground. This means that life on Earth probably could not have begun until after this stage.

28.1: Planetary Formation

According to the condensation theory of planet formation, planets form out of a spinning disk of gas that surrounds a newborn star known as a protoplanetary disk. The disk and star both originate in a rotating, collapsing cloud of material, and this process of collapse produces different abundances of materials in the disk at different distances from the star. In the higher temperature regions, comparable to the region around the planet Mercury in our solar system, the only kinds of material that can condense from the gas to the solid state (in this case, microscopic dust grains) are metals. Farther out, about where Venus, Earth, and Mars are now, the gas temperatures are lower. At these distances and temperatures, rocky materials such as silicates can also begin to form dust grains. Even farther out, the temperature gets low enough for water ice to form, and even farther from the star, ices of other compounds such as ammonia and methane can condense. But how do young planetary systems go from making dust grains to making planets?

"The answer to that question," explains astronomer David Jewitt, "is a process called binary accretion, where collisions between pairs of objects let larger and larger structures get put together. " Collisions between grains, which are small and sticky, quickly lead to the construction of pebbles. Collisions between pebbles lead to rocks. Collisions between rocks lead to boulders. Collisions between boulders lead to planetesimals, rocky bodies the size of asteroids (bodies that orbit between Mars and Jupiter and range in size up to about 1,000 kilometers). If this accretion process happens far enough from the star, significant quantities of ice will be included in the planetesimals. This is the likely origin of comets. Eventually, the objects are large enough for gravity to begin compressing and heating the planetesimal interiors. As planetesimals grow even larger, gravity pulls them into a spherical shape, and the heaviest elements sink to the center of the body. Iron and nickel will, in this way, form the dense metallic cores of the young planets. Eventually, full-sized terrestrial planets, the rocky cores of gas giants (such as Jupiter and Saturn), and moons are formed through the accretion process.

The timescale for the accretion process depends on the density of gas and dust in the protoplanetary disk, because higher densities mean more frequent collisions. In the inner part of our pre-solar system disk, the density was high, and it took only 100 million years to build the terrestrial planets. The formation of the outer planets is a more complicated story, and scientists are still not sure how the gas and ice giants formed. "There are basically two models for the formation of giant planets like Jupiter, " says Jewitt. In the first model, an icy terrestrial planet grows by binary accretion up to a mass about 5-10 times that of Earth, at which point a new process begins. "When that small core planet reaches the critical mass, "Jewitt explains, "it has enough gravity to start pulling in gas from the surrounding disk. You get a very rapid flow of gas onto this core, taking the planet all the way up to Jupiter's or Saturn's mass." This idea is called the core accretion model. According to Jewitt among most solar system astronomers the core accretion model is the preferred idea for the formation of the large gas planets Jupiter and Saturn. The problem with the core accretion theory for these particular planets is that building up the rocky center takes an exceedingly long time. Near the end of the accretion phase, the disk begins losing its gas content when radiation from the Sun causes it to disperse. If the gas disperses before the core has a chance to reach its critical mass, the idea cannot work. That is why astronomers have developed a second theory, called the hydrodynamic instability model. This begins with an enormous disk of gas that collapses in on itself due to the influence of its own gravity. Just as the star and its disk were formed from a gravitationally unstable cloud, some astronomers claim that planets form from the gravitational collapse of gas within the disk itself. "Parts of the disk would just contract under their own gravity, " says Jewitt. The planets would form directly without needing a core.

28.2: The Columbian Exchange

When Christopher Columbus and his men became the first Europeans to arrive in the Americas in 1492, they set in motion a process of cultural, economic, and environmental exchange that had profound effects on the whole world. For the "old," Afro-Eurasian world, an important transformation included the addition of valuable new food items into the diets of people in such widely separated regions as Ireland, China, and sub-Saharan Africa. For the "new" American world, the most significant transformation involved the deadly effects of Afro-Eurasian diseases among its peoples, which in turn, helped pave the way for imperial conquest by Europeans. After two centuries of what is now known as the Columbian Exchange, both Old and New Worlds were transformed.

About 12,000 years ago, the land bridge linking the Americas with Afro-Eurasia across the Bering Strait disappeared as a result of rising sea levels. As a result, the people of the Americas were almost completely separated from Old World people until the Spaniards arrived in 1492. In other words, for twelve millennia, the people as well as the plants and animals of the Americas developed in isolation from Afro-Eurasia according to the specific environmental conditions of the Americas.

Some human developments were similar: for example, agriculture and writing developed in the Americas just as they had done in Afro-Eurasia, as did the birth of hierarchical societies and patriarchies -societies headed by the eldest male. In other ways, however, developments in the Americas followed a different course from those of the Old World. For example, plant species such as corn, potatoes, and tobacco were unique to the Americas, and thus, American people had a different set of choices regarding possible domesticated crops. Just as importantly, not long after humans arrived in the Americas, all of the large mammals that existed there became extinct. As a result, when humans in the Americas began to turn to settled agriculture, they did not have the choice to domesticate large mammals such as cattle or horses. Because of this, American societies did not develop innovations like the wheel, which proved unnecessary without large animals to pull carts or push plows. Furthermore, other animals familiar across much of Afro-Eurasia-including sheep, pigs, chickens, and goats-were nonexistent in the Americas. In fact, the only animals that could be domesticated available to American peoples were the dog, the turkey (in North America), the llama/alpaca and guinea pig (in the Andes region of South America), and the Muscovy duck (in the South American tropics).

The absence of animals that could be domesticated is critical because, in the Old World, the domestication of animals such as sheep, chickens, goats, and cattle contributed greatly to the development of serious diseases such as influenza, smallpox, measles, and pertussis. In fact, many of these serious diseases resulted from microbes that were first present in herds of domesticated animals and then made the jump from their animal hosts to human hosts. The jump was made much easier because early Afro-Eurasian communities that relied on domesticated animals for food and labor tended to live in close proximity to their herds- even keeping them inside their houses for protection or warmth. Over time, a number of these microbial jumps occurred between domesticated animals and humans. In addition, because of the land connections across much of Afro-Eurasian, these diseases were able to spread to many Old World populations. While these diseases continued to be serious for the peoples of Afro-Eurasia, the human populations that survived them over the generations tended to pass on an acquired partial immunity to their offspring.

Without many animals that could be domesticated and living in enforced separation from Old World people, the people of the Americas remained freer from the type of contagious diseases that so often plagued the Old World. Some contagious diseases did exist, to be sure, and included dysentery, pneumonia, and possibly syphilis. But the "crowd" diseases of the Old World that flourished in crowds of large, centralized populations of humans did not exist, which meant that American people—when exposed to them—had no immunity whatsoever. Therefore, when Europeans carrying these diseases inadvertently spread them among American people, sickness spread rapidly, resulting in many deaths.

29.1: Echinoderm Evolution

The echinoderms are a phylum of invertebrate animals that includes starfish, sea urchins, and sand dollars. One feature that distinguishes echinoderms from other groups of organisms is their system of locomotion-the bottoms of echinoderms are covered with a number of tiny tube feet, which aid the echinoderm in feeding and slow movement on the ocean floor. Like other invertebrates, echinoderms lack a backbone and have a fairly primitive nervous system. Unlike many invertebrates, the soft bodies of which are often poorly preserved as fossils, echinoderms have hard internal skeletons made of calcite. For this reason, echinoderms are well-represented in the fossil record. In spite of their generally good preservation as fossils, there are several puzzles surrounding the evolution of echinoderms.

One major mystery surrounding echinoderms is how they originated. The first clearly recognizable echinoderms appeared around 540 million years ago during the Cambrian period; however, these first echinoderms were already fairly complex. Paleontologists have been unable to conclusively identify a simpler organism that could have been the ancestor of the echinoderms. One fossil that has been tentatively suggested as an ancestral echinoderm is Tribrachidium, which dates to the Ediacaran period, just before the Cambrian. Tribrachidium is a round, flat, disc-shaped fossil that was discovered in 1959. Some paleontologists have suggested that Tribrachidium could have been a primitive echinoderm, as it shares the radial body plan of modern echinoderms. A radial body plan is one in which an organism's body is composed of parts that are arranged symmetrically around the center, like the petals of a flower. Since most known echinoderms have radial body plans, the radial symmetry of Tribrachidium has been viewed as suggestive of an evolutionary relationship. However, Tribrachidium has now been discounted as an ancestral echinoderm since it has triradial (three-point) symmetry instead of the pentaradial (five-point) symmetry found in adult echinoderms. In 1985, Tribrachidium was placed in its own phylum, Trilobozoa, a group with no known living descendants.

Another puzzle related to echinoderm evolution is how and why these organisms acquired their distinctive radial body plan. Among animals, all but the most primitive have bilateral symmetry-the left sides of their bodies are roughly mirror images of the right sides. Two main groups of animals have radial symmetry instead. One of these groups is jellyfish, which are extremely primitive and are assumed never to have evolved bilateral symmetry. The other radially symmetrical group is the echinoderms, which are fairly sophisticated. In fact, biologists know that the echinoderms did once have bilateral symmetry because the free-swimming larvae (young) of echinoderms are bilaterally symmetrical. Once the larvae settle down on the ocean floor, they develop the radial symmetry of adult echinoderms. It is not clear why echinoderms do not retain bilateral symmetry as adults.

Paleontologists are always attempting to determine evolutionary relationships among organisms. One widely accepted hypothesis is that echinoderms are closely related to vertebrates-the group of animals that includes fish, reptiles, and mammals. Although adult echinoderms do not resemble vertebrates, biologists have based this conclusion on DNA comparisons and embryological evidence. In most non-echinoderm invertebrates, the mouth forms from the first opening in the embryo (an early stage of development), whereas in both echinoderm and vertebrate embryos, the mouth develops from a secondary opening.

A group of animals called carpoids, which are only known through the fossil record, have been considered to be intermediate between echinoderms and chordates, a group that includes all vertebrates. Carpoids share several characteristics with vertebrates, including gill slits and a complex nervous system. In fact, some experts have placed them near or at the beginning of chordate evolution. However, carpoids possess a skeleton of calcite plates identical to that of echinoderms. Calcite skeleton is not present in any chordates. Furthermore, no ancestral genes for calcite skeleton development have been identified in any present-day chordates, which indicates that chordates and echinoderms most likely followed their own evolutionary paths and that carpoids are echinoderms. In 2012, scientists reported the discovery in southern Europe of fossils from the early middle Cambrian period; these fossils show adult echinoderms with a fully bilateral body plan. The animals represented by these fossils may be the earliest echinoderms from which all other echinoderms evolved.

29.2: Ancient Mapmaking

Claudius Ptolemy, who lived from approximately 85 to 168 AD, was an ancient mapmaker whose works were rediscovered in Europe after being lost until the fifteenth century. He lived in Alexandria, Egypt, where he used Alexandria's famous library to compile existing knowledge of astronomy, geography, and astrology into three treatises. The astronomy and geography treatises had a long-lasting influence, but they both presented serious errors that went uncorrected for about 1,300 years. Ptolemy's astronomy treatise, Almagest, rejected the theory earlier proposed by Aristarchus (approximately 230 BC) that Earth revolves around the Sun. Ptolemy's geocentric idea-that Earth was the center of the universe -accepted the ideas of Aristotle and formed the main thesis of his treatise. When Ptolemy's works resurfaced in the fifteenth century, they were accepted as gems of ancient wisdom, and few had the nerve or the authority to challenge them. Likewise, any sixteenth-century maps that altered the Ptolemy map were regarded with suspicion.

In his other influential treatise, Geographia, Ptolemy rejected the nearly correct computation of the distance around Earth-Earth's circumference-made by Eratosthenes in approximately 240 BC. Rather, he chose an erroneous and much smaller distance (about 75 percent of the actual size). Ptolemy did not make any measurements himself, as Eratosthenes had done, but selectively compiled other information that was known at the time. The estimate he chose came from the Greek astronomer Poseidonius. Subsequently, however, his choices became known as Ptolemaic ideas and were considered irrefutable. Also, Ptolemy assumed that the known world's land surface covered 180 degrees of longitude, ranging from the Canary Islands in the west to the easternmost part of Asia (about 20 degrees of longitude). This error on his map showed the Atlantic Ocean much too narrow and connecting Western Europe and East Asia without the American continents in between. This remained the understanding of the world for 1,300 years.

The combination of these two errors -Earth's circumference too small and land area too large- encouraged mariners of the fifteenth century to assume that a relatively short voyage across the Atlantic Ocean would take them to Asia. Columbus was the first to promote an expedition on the basis of these errors. When Columbus reached land, he had traveled as far as he expected to travel to reach Asia and logically assumed that he had succeeded.

To his credit, Ptolemy's map introduced some excellent standards to mapmaking, despite the errors. Though he was not the first to use the idea of a gridded coordinate system, his method of showing attitude and longitude became a standard for future maps. Also, Ptolemy insisted that maps should be drawn to scale. Many maps of his time were distorted by enlarging the better-known places in order to include all the known information. Unfortunately, many mapmakers of his time failed to adopt his practical approach to scale and location.

Maps began to proliferate in the sixteenth century. Each voyage of exploration and discovery provided new information that had to be mapped. In 1507, a German mapmaker, Martin Waldseemoler, produced a map of the world, Universalis Cosmographia, which was the first to show Columbus's discovery as a separate continent. But he cautiously made the new continent very narrow-just a long, skinny island -rather than contradict Ptolemy's erroneous circumference of Earth. By the middle of the sixteenth century, enough voyages had been made, including Magelan's trip around the world, that most mapmakers recognized that Earth's circumference, as shown on Ptolemy's map, was wrong.

In 1569, the Flemish mapmaker, Gerardus Mercator, made a map of the world showing all the known lands using his now famous innovative grid system of latitude and longitude. In 1570, Abraham Ortelus, a Belgian mapmaker, made the first known atlas of the world in an effort to compile rapidly accumulating geographic knowledge. Although these maps still had some remaining traits of the Ptolemy map, they showed great improvements in detail and accuracy. A major feature retained from the Ptolemy map was the presence of a very large continent in the Antarctic-large enough to counterbalance the weight of the Northern Hemisphere land. This belief was based on the Greek concept of symmetry, as well as the idea that the Earth needed to be balanced to turn smoothly.

30.1: The Difference Threshold and Signal-detection Theory

How much weight must be added to or subtracted from a stack of books for the carrier to sense that the load is heavier or lighter? The just-noticeable difference (JND) is the smallest change in sensation that a person is able to detect 50 percent of the time. The difference threshold is a measure of the smallest increase or decrease in a physical stimulus that is required to produce the JND. A person holding a 5-pound load would notice the addition of a single pound, but a person already holding 100 pounds would not be able to sense an additional pound. More than 150 years ago, researcher Ernst Weber (1795-1878) observed that the JND for all the senses depends on a proportion or percent of change rather than a fixed amount of change. This observation became known as Weber's law. A weight being held must increase or decrease by 2 percent for the difference to be noticed. According to Weber's law, the greater the original stimulus, the more it must be increased or decreased for the difference to be noticeable.

The difference threshold is not the same for all the senses. A very large (20 percent) difference is necessary for some changes in taste to be detected, for instance. In contrast, a difference is noticeable if a musical tone becomes slightly higher or lower in pitch by only about 0.33 percent. Nor are the difference thresholds for the various senses the same for all people. In fact, there are great individual differences, often arising from experience or expertise. Professional food tasters know if a particular item or batch is a little too sweet, even if its sweetness varies by only a fraction of the 20 percent usually necessary to detect changes in taste. Furthermore, people who have lost one sensory ability often gain greater sensitivity to the other sensory abilities. Actually, Weber's law best fits people with average sensitivities and sensory stimuli that are neither very strong nor very weak, for example, not as loud as thunder or as quiet as a faint whisper.

The classic methods in psychophysics for measuring difference thresholds focus exclusively on the physical stimulus-how strong or weak it is or how much the stimulus must change for the difference to be noticed. But even within the same individual, sensory capabilities are sharper and duller from time to time and under different conditions. Factors that affect a person's ability to detect a sensory signal are, in addition to the strength of the stimulus, the motivation to detect it, previous experience, an expectation that it will occur, and alertness or level of fatigue.

In another approach, these factors are taken into account. According to signal-detection theory, the detection of a sensory stimulus involves discriminating that stimulus from background noise (all the other stimuli present in the environment) and deciding whether the stimulus is actually present. But deciding that a stimulus is present in the first place depends partly on the probability that the stimulus will occur and partly on the potential gain or loss associated with deciding that it is present or absent. Suppose you were given the description of a cousin you had never seen before and were asked to pick her up at the airport. Your task would be to scan a sea of faces for someone fitting the description and then to decide which of the several people who fit the description was actually your cousin. All the other faces and objects in your field of vision would be considered background noise. How sure you would have to be before you approached someone would depend on several factors-among them, the embarrassment you might feel approaching the wrong person as opposed to the distress you would feel if you failed to find your cousin.

Signal-detection theory has special relevance to people in many occupations: air-traffic controllers, police officers, military personnel on guard duty, medical professionals, and poultry inspectors, to name a few. Whether these professionals detect certain stimuli can have important consequences for the health and welfare of vast numbers of people.

30.2: Bird Songs and Calls

Birds use song both in courtship and to define areas of territory. Both of these are communicative purposes: the bird is passing specific messages to other members of its species. Birds communicate for other reasons as well: a blackbird, for instance, will make a sharp "pink-pink" sound when there is a cat nearby, which warns other birds in the neighborhood of the danger.

William Thorpe (1961) studied the behavior of gannets in a colony containing many thousands of birds. Thorpe found that when a bird was returning to its nest, it would drift on an updraft of air from the bottom of the cliff upwards, calling as it went. When the bird on the nest heard its mate calling, it would call in reply, showing that each bird's call could act as an identification signal. Thorpe also calculated that a bird might have as many as fifteen or sixteen different kinds of calls, each serving a different function.

J. R. Krebs (1976) investigated how birds seem to sing more intensively in the early morning--"the dawn chorus." By investigating what the birds actually did during each day and how much time they spent on each activity, Krebs found that the dawn chorus serves a largely territorial function. The early morning is not a particularly good time for gathering food, because it is dark, so visibility is lower, and it is also cold, so many insects are still inactive. On the other hand, at this time, many birds move around looking for living space, so establishing and defending a territory is necessary. Birdsong is not just territorial, of course. A bird's song can serve a dual purpose: it can be used to defend a territory, and by indicating to a prospective mate that the singer has a territory to defend, it can also attract a female bird.

P. J. B. Slater (1981) suggested that bird calls and birdsong are partly learned from other birds. He found that chaffinches which had been hand-reared and had not heard other wild birds made an entirely different kind of "chink" call from that of wild birds. In one case, Slater observed a laboratory chaffinch in a duet with a wild sparrow outside the window of the laboratory. The chaffinch imitated the sparrow's "cheep" whenever the sparrow produced it. Slater concluded that learning through copying is an important part of the way in which birds acquire their songs. Slater also found that individual chaffinches can have up to five different types of songs. Some of these are personal, sung by that bird alone. Others are shared by several birds. In some cases, too, Slater observed chaffinches singing songs which were almost identical to those sung by others, but with just a note or two different-possibly because the bird had made an error in copying the song from another.

Slater studied a population of 40 chaffinches on the Orkney Islands and found that among them, they had seventeen different song types. So it was not a matter of each bird having its own individual songs--there was a considerable amount of sharing. Slater found that this sharing related to geographical distribution, but that the boundaries were not distinct enough for it to be accurately described as a dialect or regional variety of a song. Instead, there was considerable overlap between the songs sung in one area and those sung in an adjoining one, but gradually the overlap would become less, until birds a long distance away from one another would be singing entirely different songs.

In 1970, Peter Marler proposed that birdsong and speech were directly comparable in certain key respects and that the study of birdsong might provide psychologists with some useful indicators as to the nature and development of speech in human beings. One of the parallels which Marler identified was the way that both humans and birds show a strong genetic predisposition to pick up and imitate certain sounds rather than others. Marler showed that young birds will learn the songs of their own species if they are played to them when young, but they will ignore the songs of birds from other species. Similarly, young human beings are surrounded by all kinds of sounds and noises, but it is the human voice to which they listen most closely and human speech which they imitate.

31.1: Mass Production under China's First Emperor

Attempts to optimize the function, value, and appearance of mass-produced goods-goals associated with modern industrial design-date to as early as China's first emperor, Qin Shi Huang, who harnessed the power of design and mass production in the name of conquest. He is remembered for unifying by force China's warring states in 221 B.C. into the most powerful country the world had ever seen. He was also responsible for building the Great Wall of China to protect his new nation's borders from raiding Mongolian invaders. He is even better known, certainly in archaeological circles, for the Terracotta Army that was made to honor him and to protect him in the afterlife. This collection of ceramic funeral sculptures depicting the emperor's army is estimated to have included 8,000 life-sized statues of soldiers and 670 horses, as well as depictions of other members of his vast following, from officials and servants to musicians, singers, and acrobats. Although this army should probably be considered collections of statues rather than expressions of manufacturing design, the figures were essentially factory-pro, using systemized methods of production similar to those used to make serially manufactured functional objects. The figures were also buried with weapons, and around 40,000 bronze spears, swords, crossbows, halberds, and staffs have been recovered by archaeologists so far.

As with the manufacture of the terracotta warriors themselves, the production of their accompanying weapons reveals that Emperor Qin's workforce was organized into highly efficient production teams that used standardization measures and quality-control procedures. The technical knowledge of these Chinese weapon-makers, however, was not confined to equipping the Terracotta Army with weapons, far from it. Recent research has revealed that some of the burial material was actually used in battle and bears the scars to prove it. Emperor Qin's craft workers perfected the art of bronze-making to such an extent that they were able to produce swords that are now considered some of the finest bronze weapons ever made. Because their raw material was of such a high grade, the emperor's craft workers could manufacture swords that were significantly longer than any that had gone before, which gave Qin's soldiers the enormous benefit of 30 percent greater reach and cutting power. Thus, the development of better-quality materials enabled the production of better-performing designs, which gave the first Chinese emperor's forces a decisive advantage; this is a recurring theme throughout the story of design-as more advanced materials are invented or discovered, their unique benefits are employed by designers to improve existing designs, thereby creating superior products.

Another reason that Qin was able to achieve his epic conquest of the warring states was that his workers produced weaponry to such precise specifications that their parts were completely interchangeable. If, for example, a section of a crossbow broke in battle, it could be replaced easily with an exactly replicated piece. Similarly, the arrows used by his soldiers had interchangeable shafts so that their arrowheads could be reused even if the shaft had broken. A high degree of manufacturing efficiency and standardization was bolstered by a culture of manufacturing accountability, with workers' output overseen by supervisors to ensure that no defective workmanship was ever allowed to creep into the production system-and if it did, the consequences were severe. Precision manufacturing and an exacting quality-control system were used not only for weaponry but also for weights and measures during Qin's reign, and this system of standardized production formed the basis upon which Chinese design and manufacturing would flourish over the succeeding centuries.

Over the next thousand years, Chinese craft workers used methods similar to these to design and manufacture ceramics and bronze wares that were technically far superior to their European equivalents. The delicate blue-and-white porcelain crockery imported from China into Europe in increasing quantities during the 1700s must have seemed the finest example of refinement and modernity when compared to the heavy and rather primitive earthenware pottery produced in Europe. A capacity for the precise replication of designs is still a defining characteristic of Chinese production, and it can surely be traced back to the first emperor's innovative implementation of rigorous design standards, which became incorporated into the nation's manufacturing culture.

31.2: Changes in the Art Market During the Late Nineteenth Century

Today's market for European art has its roots in the nineteenth century. In 1882, the passage of the Settled Land Act reformed inheritance law in Britain. As a consequence of industrialization and the availability in Europe of large quantities of cheap American wheat, the fortunes of British landowners were in decline. After bankruptcies began to mount, the inheritance laws were changed, making it possible for landowners to support their landholdings by selling their art treasures. Until 1882, estates were strictly settled, meaning that the head of the family did not actually own the land and estate goods, but rather was entrusted to preserve and protect the family property. This was meant to hinder large estates from being sold off in sections. The Settled Land Act made it possible to sell individual portions of an estate, such as works of art, in order to save the real estate (land and buildings). The art treasures of the British nobility began to flow into London auction houses, shoring up their dominant position in the art market.

Besides the passage of this law, the early 1880s marked the public acknowledgment of French Impressionism, a revolutionary art movement that emphasized subjects from everyday life and the accurate depiction of light and its changing qualities. Prior to this, Impressionist artists had been regarded as radical, immoral individuals who had declared war on beauty. Impressionist paintings were not accepted by the Salon de L'Academie des Beaux-Arts in Paris, which had been, since 1830, the most important exhibition forum in the world and was historically the guardian of traditional standards of French painting. In reaction to the conservative tendencies of this institution, a group of Impressionist artists in Paris organized their own exhibition in 1874. Reviews of the exhibition were mixed. But in 1881, the Impressionist painter Edouard Manet was named a knight of the Legion of Honor; in 1882, Paul Cezanne was allowed to exhibit his work for the first time at the Salon.

With the advent of Impressionism, the modern art market was born. Since most collectors rejected the Impressionists, especially early on, the usual paths for distribution were closed to these artists, and they had to find other ways to sell their pictures. The rejection, however, meant that the artists were not dependent on the tastes of potential patrons (wealthy supporters), and hence, they began to see themselves as autonomous masters. This new approach also awakened a newfound respect for the art dealer, since the dealer had access to artistic genius and could open up the path to new art and explain it to potential buyers. In the early twentieth century, the Cubist style (abstract art based on geometric forms) arose, and representational art- art that represented objects and people realistically- became less significant. This development also strengthened the notion of the artist’s genius, as well as that of the art dealer as a go-between. On the one hand, the content of art became more complex, and on the other, it also became more difficult to understand and communicate.

Of course, artworks by the so-called old masters continued to be sold. The most successful dealer of such art was probably Joseph Duveen, who arrived in New York City at the age of seventeen in 1886. After a brief apprenticeship under his uncle, the art dealer Henry Duveen, Joseph opened a gallery (a privately owned establishment for displaying and selling artwork) in proximity to the Waldorf-Astoria Hotel, which was already the meeting place for the city's elite. Duveen's business strategy entailed the purchase of complete art collections from their owners. In this way, a buyer would be unable to calculate Duveen's wholesale price for an individual artwork and hence, the percentage that he kept for himself. If he made purchases at auctions where the price he paid would be public knowledge, he did not shrink from paying record prices, since this practice brought him a reputation and also raised the value of the pieces already in his inventory. He also stirred up enthusiasm for collecting among many American industrialists; these millionaires regarded the acquisition of European masterpieces as an opportunity to ensure the immortality of their names.

32.1: Ocean and Atmosphere on Early Earth

Where did Earth's ocean water come from? Scientists agree that a large amount of water must have arrived during planet accretion, which is the process of collision and sticking together of the material in orbit around the Sun by which Earth and the other planets in the solar system formed 4.6 billion years ago. Perhaps significant volumes were added during the period of heavy bombardment, during which Earth was being hit by a large number of comets (whose nuclei are composed mostly of ice) and other objects left over from the formation of the planets. The volume of water eventually found on Earth may be related to the formation of Earth's core (innermost layer). When the iron- and nickel-rich core formed, most of the water in the forming planet was consumed in oxidation processes whereby the oxygen component of water was used to make iron and nickel oxides. It is the residual water that makes up the oceans. Perhaps that residual quantity was significantly enhanced by water carried by comets after Earth's initial formation, perhaps not. In either case, the oceans reached approximately their present volume 3.8 billion years ago. But this does not mean they were in their present area. Geologist Don Lowe has estimated that before 3 billion years ago, less than 5 percent of Earth's surface was land. Earth's atmosphere was also very different from that of today. There was no oxygen, and there was a great more carbon dioxide (Co2)—perhaps 100 to 1,000 times as much as today.

Earth's surface temperature was higher than it is now because more heat was emanating from the interior and because of the warming generated by the extensive CO2 and other greenhouse gases in the atmosphere. Greenhouse gases trap heat near the surface through the so-called greenhouse effect. Earth's internal generation of heat was an important factor; the Sun at this time was much fainter, delivering perhaps a third less energy than at the present time.

What would have happened if Earth had stayed a water world? Probably global temperatures would have remained high or even increased. For animal life to form, the temperature had to drop from the levels acknowledged to have been characteristic of Archaean time (about 4 to 2.5 billion years ago). A drop in global temperature while the Sun was getting hotter required a drastic reduction of atmospheric CO2--a reduction of the greenhouse effect. Thus, there had to be some means of removing CO2. The most effective way to do this is through the formation of limestone, which uses CO2 as one of its building blocks and thus removes it from the atmosphere. But significant volumes of limestone form today only in shallow water; the most effective limestone formation occurs in a depth of less than 20 feet (6 meters). In deeper water, high concentrations of dissolved CO2 slow or inhibit the chemical reactions that lead to limestone formation. There is evidence of deep-water, inorganic limestone formation in very old rocks on Earth, as demonstrated by geologist Jo. Grominger and his team. These studies show that early Earth's ocean may have been saturated in the compounds that can produce limestone and thus could have formed solid limestone in deeper water at that time, removing carbon dioxide from the atmosphere as a consequence. However, Grominger points out that occurrences of carbonate rocks such as limestone during the early Archaean--roughly the first billion years of Earth's existence—are rare. And this is only partly due to the rarity of rocks of this age. It looks as though the central mode of removing carbon dioxide from the atmosphere-the formation of carbonate rocks—seldom occurred.

To form limestone in significant volumes, then, shallow water is needed, but on a planet without continents, shallow water is in short supply. On Earth, from perhaps 2.7 to 2.5 billion years ago, there occurred a rapid buildup of continental areas, resulting in an increase in the land surface from perhaps 5 percent to about 30 percent. Larger continents meant larger shallow-water regions, for the emergence of continents created shallow areas near the continents as well as large inland seas and lakes.

32.2: Zebra Stripes

Zebras, horse-like animals native to the grasslands of Africa, are known for their distinctive black and white stripes. Historically many scientists thought zebras' stripes served to camouflage (hide) them from predators, such as lions and hyenas. This assumption was based on the observation that other animals, such as tigers, have similar stripes that make them less visible. However, in recent years, scientists have noted that zebras' environment and behavior are not well suited to camouflage by stripes. Tigers often inhabit heavily-forested areas in which their vertical stripes help them blend in with the surrounding trees, but zebras typically inhabit open grasslands. Unlike tigers, who use stealth to stalk their prey, zebras are herbivores that rarely hold still when threatened by predators; instead, they rely on their good eyesight to spot predators at a distance and flee at any signal of danger.

A zebra's stripes may help to protect it in other ways. Stripes may help zebras blend in with each other, rather than blend in with their environment. Zebras live in large herds, and they flee as a group when threatened. The dense pattern of moving zebra stripes may appear as a mass of confusing images, making it difficult for predators to target individual zebras. Catching a fleeing zebra requires a precisely timed final leap, and a zebra's stripes may interfere with predators' perception of distance. Because zebras have some ability to defend themselves by using their hind legs to kick at pursuing predators, at times powerfully enough to cause serious injury, a zebra's distinctive stripes may also serve as a Warning that encourages predators to seek less dangerous prey. However, none of these explanations is strongly supported by observation. Zebras are killed by lions about as frequently as other unstriped prey animals.

More recently, scientists have suggested that the primary purpose of stripes is to protect zebras from biting flies. The grasslands of Africa are home to a number of species of flies that feed on the blood of large mammals and can cause considerable damage through blood loss and the transmission of diseases. Laboratory tests have shown that biting flies are less likely to land on objects covered in black and white stripes than on solid black on white surfaces. It is not yet known why biting flies would avoid striped objects, but scientists have suggested that the explanation lies in the mechanisms of flies' vision, which is simple and apparently confused by stripes. The stripes may make it difficult for flies to detect the outline of a zebra's body or cause the flies to confuse a zebra for a collection of thin, vertical objects that do not resemble potential victims. Scientists have analyzed the stomach contents of wild biting flies and have found relatively little zebra blood.

If stripes are an effective means of protection against biting flies, then why have other animals not evolved stripes as well? One theory is that zebras are particularly vulnerable to flies because of their unusually short hair and developed stripes as an alternative protective measure. Horses, which are closely related to zebras, are indeed extremely susceptible to biting flies when imported to Africa. They are frequently infected by fly-borne parasitic infections, which are often fatal even when veterinary treatment is provided. Horses do not develop immunity to the parasites and so can be repeatedly re-infected.

Other puzzles remain. For instance, biting flies seem to be most discouraged by horizontal stripes, but the stripes on zebras are mostly vertical. More mysteriously, not all zebras are covered in stripes: the quagga, an extinct subspecies of zebra, had fainter stripes that were present only on the front half of its body. If stripes protect from flies, why would the quagga lack protection on half of its body? This cannot be explained by environmental factors, because quaggas' range overlapped with that of fully striped zebras. One possible explanation is that if they only have stripes on half of their body, quaggas can more easily distinguish between their own and other species of zebra, making it easier for them to follow the solid-colored hindquarters when fleeing from predators. This behavioral hypothesis is unfortunately impossible to test, because scientists can only study the quagga through preserved museum specimens and a handful of nineteenth-century photographs.

33.1: The Behavior of Magma

Why do some volcanoes explode violently while others erupt gently? Why do some kinds of magma (molten rock) solidify within Earth to form hard rocks, and others rise all the way to the surface to erupt from volcanoes as lava? To answer these questions, we must consider the properties and behavior of magma. Once magma forms, it rises toward Earth's surface because it is less dense than surrounding rock. As it rises, two changes occur. First, it cools as it enters shallower and cooler levels of Earth. Second, pressure drops because the weight of the overlying rock decreases. Cooling and decreasing pressure have opposite effects on magma: Cooling tends to solidify it, but decreasing pressure tends to keep it liquid.

Whether magma solidifies or remains liquid as it rises toward Earth's surface depends on the type of magma. Basaltic magma commonly rises to the surface to erupt from a volcano. In contrast, granitic magma usually solidifies within Earth's crust (outer layer). Granitic magma contains about 70 percent silica, whereas the silica content of basaltic magma is only about 50 percent. In addition, granitic magma generally contains up to 10 percent water, whereas basaltic magma contains only 1 to 2 percent water.

As in silicate minerals, silicate tetrahedral (four-faced solids, similar to triangular pyramids) in magma link together to form chains, sheets, and framework structures. They form long chains if silica is abundant in the magma but shorter chains if less silica is present. Because of its higher silica content, granitic magma contains longer chains than basaltic magma. In granitic magma, the long chains become tangled, making the magma stiff or viscous. It rises slowly because of its viscosity and has ample time to solidify within the crust before reaching the surface. In contrast, basaltic magma, with its shorter silicate chains, is less viscous and flows easily. Because of its fluidity, it rises rapidly to erupt at Earth's surface.

A second difference is that granitic magma contains more water than basaltic magma. Water lowers the temperature at which magma solidifies. Thus, if dry granitic magma solidifies at 700C, magma with 10 percent water may remain liquid until its temperature drops below 600C. Water tends to escape as steam from hot magma, but deep in Earth's crust, where granitic magma forms, high pressure prevents the water from escaping. As magma rises, pressure decreases, and Water escapes. Because the magma loses water, its solidification temperature rises, causing it to become hard rock. Thus, water loss causes rising granitic magma to solidify within the crust. For this reason, most granitic magmas solidify at depths of 5 to 20 kilometers beneath the Earth's surface. Because basaltic magmas have only 1 to 2 percent water to begin with, water loss is relatively unimportant. As a result of its comparatively low viscosity, rapidly rising basaltic magma remains liquid on the way to the Earth's surface, and basal volcanoes are common.

In most cases, granitic magma solidifies within Earth's crust to form a rocky mass called a pluton. Many granite plutons are large, measuring tens of kilometers in diameter. To form a large pluton, a huge volume of granitic magma must rise through the continental crust. But how can such a large mass of magma rise through solid rock? If you place oil and water in a jar, screw the lid on, and shake the jar, oil droplets disperse throughout the water. When you set the jar down, the droplets coalesce to form larger bubbles, which rise toward the surface, easily displacing the water as they ascend. Granitic magma rises in a similar way. It forms near the base of the continental crust, where surrounding rock is soft and flexible and behaves plastically. It flows and deforms without fracturing because it is hot. As the magma rises, it shoulders aside the hot, plastic rock, which then slowly flows back to fill in behind the rising bubble. After a pluton forms, forces in the crust may push it upward, and erosion may expose parts of it at Earth's surface.

33.2: Transport of Food to Rome

During the reign of Emperor Augustus (63 B.C-14 A.D.), the city of ancient Rome may have had as many as 1,200,000 inhabitants. With so many residents, the city needed an extremely large food supply, necessitating the development of an improved system for shipping food. Transportation of bulk goods by land was prohibitively expensive and slow. It simply was not practical to haul a wagonload of wheat very far, for example, since the animals needed to pull the wagon would quickly eat an amount of food equal to the relatively limited amount that could be carried in the wagon itself. The solution to this problem was to move goods by sea. Scholars have estimated that the cost of shipping grain from one end of the Mediterranean to the other was cheaper than hauling the same amount of grain 120 kilometers overland. It was perhaps 40 times more expensive to transport goods by land rather than by sea, and while it was somewhat more costly to move goods along a river than over the open ocean, river transport was still many times more efficient than land transport.

Since Italian resources were not sufficient to feed Rome, Romans naturally looked to the Roman-controlled areas that were closest to Rome, and that had access to the sea. The first provinces that had surplus grain collected from them and transported to the city of Rome in large quantities were, logically enough, the nearby islands of Sicily and Sardinia. Once Rome had conquered the coast of North Africa, the foods from this region were rounded up and routed toward the city of Rome as well. By the first century A.D., Egypt and the coastal areas of Spain and Gaul had been added to this list. Despite its distance from Rome, Egypt, in particular, was an important source of grain. The safe arrival of the Egyptian grain fleet off the Coast of Italy was a major cause for celebration.

While necessary as the only practical way to transport enough food to Rome, this maritime traffic could also be problematic. Particularly during the winter, the Mediterranean Sea can produce violent storms that would have sunk ancient ships. Thus, the prime sailing season was restricted to only three or four months during the summer since most of the supplies for the city had to reach Rome's ports during this narrow window of opportunity or else face greatly multiplied chances of being caught in a storm and sinking. Natural dangers were not the only threat to shipping, however. Piracy in the ancient Mediterranean was rampant, and despite sporadic attempts at suppression, pirates had nearly free reign to prey upon merchant ships. The Romans were aware of challenges that had to be overcome to keep the city fed. The Roman historian Tacitus commented, "Italy relies upon external supplies, and the life of the Roman people is daily at the uncertain mercies of sea and storm" (Annals 3.54). The scale of the food and other supplies pouring into Rome demanded an appropriate infrastructure, both administrative and physical.

Rome is not located directly on the Mediterranean Sea but is about 22 kilometers inland on the Tiber River. The mouth of the Tiber lacked a natural harbor where ships could be safely unloaded. The smallest ships could have traveled upriver directly to Rome, but medium or large freighters had to be off-loaded somewhere else. During the republic (509 to about 29 B.C.), many ships (including the huge Egyptian grain freighters) docked at the good harbor at Puteoli on the Bay of Naples. From here, their cargo had to be either shifted to smaller watercraft for their trip to Rome or else hauled overland. At the mouth of the Tiber was located the port city of Ostia. The harbor facilities at Ostia remained rudimentary through the republic, and larger ships that docked there simply had to anchor offshore and have their cargo transferred onto barges or small craft for the trip upriver. As Rome continued to grow and traffic increased, these harbor arrangements were clearly unacceptable, and in A.D. 42, the emperor Claudius tackled this problem and began to construct substantial harbor works at Ostia. Just north of the city, he excavated out of the coastline an artificial harbor known as Portus, although it was not a wholly successful project. Rome at last got a first-rate harbor when the emperor Trajan rebuilt Portus and added an inner harbor where ships could be completely safe.

34.1: Water and Life on Mars

The question of life on Mars depends heavily on the characteristics of its air and water. Mars has a relatively thin and dry atmosphere, with a high percentage of carbon dioxide compared to Earth's atmosphere. Mars tilts about 25°, which leads to seasons like those on Earth. Carbon dioxide freezes into the polar caps during the winter and evaporates into the air in the summer. This causes a fluctuation in the density of the atmosphere of up to 25 percent over the year; with so little atmosphere, the planet experiences a wide range of temperatures, heating up during the day and rapidly cooling at night. Temperatures on Mars have been measured between 225 F and 95°.

Scientists remain fascinated by the possibility of liquid water on Mars. Life as we know it requires water, so it should be a good marker for habitability. Current conditions on Mars suggest that liquid water could not occur on the surface. The low pressure and low temperature mean that ice would sublime-go straight from solid to gas-rather than melt. Water may be hiding in subsurface reservoirs, however, and stream forth for limited periods. In 2002, the Mars Odyssey orbiter detected large quantities of water ice near the surface of the southern hemisphere. Channels on the surface suggest the presence of moving water in large quantities. In 2006, Mars Global Surveyor provided pictures of gullies (channels) on the surface that could only have been produced by liquid water flowing within the past seven years. Theories exist for how climate and erosion may reveal underground ice and cause sudden floods, but specific details are still a mystery. The water probably represents flash floods that quickly evaporate and may not provide an adequate medium for the development of life. If life arose in the distant past, though, the surface floods may have been enough to maintain organisms adapted to such environments.

Astrobiologists continue to investigate whether the current situation-frozen water with occasional flash floods-was always the situation on Mars. Some surface channels on Mars could not have been produced by flash floods or geologic activity. The Opportunity rover, which landed on Mars in 2004, made two interesting discoveries in several craters on Mars. Rock layers on the sides of the craters look like the patterns inside sedimentary rocks on Earth. Sedimentary rocks form gradually at the bottom of bodies of water as particles settle down to the bottom. Sedimentary rocks on Mars would imply that a body of water was present for hundreds of years at some point in the past. In addition, Opportunity has found countless tiny spheres of the mineral hematite (a mineral composed of iron and oxygen) on the surface. These tiny spheres, or "blueberries" as they have come to be called, strongly resemble accretions (accumulations) found on Earth in highly acidic stream beds. Together with rippling patterns in the stone of the surface, the layers and blueberries make a compelling argument. Acidic, salty, flowing water must once have covered large regions of the plain where Opportunity landed. The Sun has been very slowly cooling off for the past few billion of years. A warmer Sun in the past means a warmer Mars. Planetary scientists do not think the difference was enough to bring Mars up to Earth-like temperatures, but it may have been enough to support liquid water in the warmer regions of the planet.

Overall, Mars looks like a good candidate for past life. Water, carbon, and energy were all present in useful amounts. If life arises quickly wherever resources allow, then Mars probably had life once. Unfortunately, we have no way to assess how common the origin of life might be. This is one of the questions scientists were asking when they explored Mars in the first place.

Another important question to ask in the exploration of Mars has to disagree about evidence for life in the first billion years of Earth's history. Mars' history must be even more contentious. The most unambiguous evidence of life on Earth comes in the form of structural fossils, which probably did not start forming on Earth until life had been around for at least a billion years. If life did arise on Mars, it may not have been around long enough to leave that kind of evidence.

34.2: Jomon Pottery

The oldest known pottery in the world comes from Japan, and is known as Jomon, which means "cord marks", after its typical decorations made by impressing cords into the wet clay. The earliest Jomon pottery is dated to around 14,000 B.C., considerably earlier than any pottery produced in Europe and western Asia, the earliest of which dates to approximately 8,000 B.C.

Why should the Jomon people have been so inventive? Why were they making pottery so much earlier than anywhere else in the world? Only pottery from China comes remotely close to it in date, and there it is explained by the requirements of rice cultivation. Melvin Aikens, an authority on the Jomon period, believes that Japanese pottery was invented to cook and store the produce of the thick broad-leaved woodlands that had already covered Kyushu, Japan's southernmost main island, by 13,000 B.C. The relationship is evident, he argues, from the simultaneous spread of broad-leaved woodlands and pottery into the northern islands of Japan, both appearing on the northernmost island of Hokkaido at around 7,000 B.C.

There are ,however, two problems with this idea. First, there is no necessity for hunter-gatherers to have pottery when living in wooded environments-the inhabitants of other villages of this era, such as Ain Mallaha in western Asia at 12,500 B.C. and Star Carr in northern Europe at 9, 500 B.C., flourished by relying entirely on vessels made from bark, skins, wood, and stone. Pottery no doubt made life easier for those who did the cooking in the woodlands of Kyushu, and we know from food residues that pottery vessels had indeed been used to make vegetable, meat, and fish stews, but people could have easily survived without such vessels.

A second problem for Aikens' theory arose in 1999, when a new sample of pottery was found in northern Honshu (Japan's largest island). Radiocarbon dates on the residues stuck to the interior of the pot dated to 14,500 B.C., pushing back the origin of pottery by at least another thousand years. At this date, Honshu would have had no more than a sparse covering of pine trees. And so the theory that Japanese pottery was invented to store and cook the produce of broad-leaved woodlands cannot be correct.

An archaeologist, Brian Hayden, has proposed an alternative explanation. It provides another example of his belief in social competition as the driving force of social change that he applied in explaining the origin of squash cultivation in Mexico. Hayden suggests that ceramic vessels have a number of important qualities that make them prestigious objects to own and ideal containers for serving food to guests. At the outset, the potter's art would have been difficult to master; clay had to be carefully selected, tempers (materials added to clay to reduce its plasticity), prepared, and construction and firing techniques explored, practiced, and refined. Neighbors and other visitors would have been struck with the amount of labor and skill required to produce a pottery vessel. The display of novel forms with fancy decoration would have impressed them even more. Most striking of all might have been the dramatic smashing of vessels during feasts as an ostentatious display of wealth.

Theatrical smashing of pots may have occurred in the later Jomon period, as immense piles of broken pottery have been found. And as they come in astonishingly elaborate forms, there can be no doubt that many later Jomon vessels were primarily for display. They have spectacular rims modeled as licking flames or serpents winding around the vessel. Sometimes the decoration is so top-heavy that the pots can hardly stand alone. Lacquered (glossy) objects must have been very striking. But we must be cautious about applying such interpretations to the earliest and rather dull specimens of pottery. We currently know too little about the very earliest pottery makers of Japan to decide whether they had been more concerned with impressing their visitors or devising a means to cook vegetable stew. We do know, however, that by 9,500B.C., many were living sedentary lives in permanent settlements. Although pottery had already been invented, the sedentary lifestyle must have been crucial in enabling ceramic technology to flourish.

35.1: The Origins of the Arctic Fox

The arctic fox lives in the far northern Arctic region with other well-known arctic animals like the caribou, musk ox, and polar bear. Scientists aren't sure exactly when the arctic fox first evolved. Arctic fox bone fragments from the Pleistocene epoch (2.6 million-11,700 years ago) are rare, and the ones that do exist are difficult to date with any degree of accuracy. The oldest confirmed arctic fox bone is believed to be 200,000 years old. There are other bones that may be 400,000 years old, but whether they belonged to an arctic fox or some other fox remains under debate. "It's still an open question, "says Love Dalen, a Swedish biologist who has been using genetics in an attempt to understand the evolution of the arctic fox. "Right now, the best estimate is that arctic foxes emerged somewhere between 200,000 and 400,000 years ago, presumably during one of the ice Ages."

For many years, researchers believed the species arose in Europe, basing this conclusion on the location of those 2000-year-old fossils. Since the early 1980s, however, genetic comparisons between different fox species have revealed some surprising results. For example, research done by Robert Wayne at the University of California at Los Angeles has found that the arctic fox, despite its unique appearance and adaptations, is actually much more closely related to other foxes than had previously been thought. Its closest living relative, according to genetic studies, is the North American swift fox.

The result suggests one of two scenarios. One is that arctic foxes gave rise to swift foxes, an evolutionary sequence that would depend on the arctic fox being much older than the fossil record currently indicates. The second possibility is that swift foxes gave rise to arctic foxes, likely during the height of a period of glaciation when tundra forming to the south of the ice sheets may have met the grassland habitat of the swift fox.

On the one hand, the latter scenario could hardly seem more implausible. Swift foxes, after all, live on the arid, sun-baked prairies and open desert, where temperatures can top 120°F (49°C). It's hard to imagine a greater environmental leap from this environment to the frozen tundra. To have acquired over the course of a few hundred thousand years, all the adaptations necessary for survival in such an extreme environment suggests a rapid rate of evolution. And for the early species to have so rapidly conquered such a large territory in a polar region seems equally mystifying.

In other ways, however, this scenario works. As one of the smallest foxes, the swift fox can survive on very little food, a trait that would have helped its ancestors gradually stray farther and farther into the biologically barren tundra. And being a nocturnal hunter that seeks shelter in a den during the day, the swift fox is not overly adapted for life at high temperatures. Indeed, in the northern parts of their range, modern swift foxes have faced winter temperatures every bit as severe as those encountered in the Arctic.

From what researchers know about the evolution of other polar species, there seems to be a pattern of evolution in which species living in the biologically rich temperate zones give rise to animals that are more specialized for survival in the more extreme Arctic. Polar bears, for instance, are thought to have evolved from a northern population of brown bears that learned to hunt seals out on the sea ice. As for the rapid evolution and widespread dispersal, one must remember that the arctic fox is no ordinary species when it comes to both reproductive efficiency and migratory tendency; rapid genetic change and rapid migration would both appear to be well within the species' capabilities.

According to Love Dalen, most of the arctic species evolved during the Quaternary Period (the last 2.6 million years), and they all seem to have evolved from temperate species. In evolutionary terms, arctic species are quite young, including, presumably, the arctic fox. Dalen adds that if that is true, then the arctic fox would have evolved in North America, though he notes that there is no solid proof either way.

35.2: Deriving Scientific Facts from Theories

In science, a theory is an idea that, once confirmed by experiment or meticulous observation as certainty, becomes a scientific law. Facts are generally obtained through empirical research (through observation or experiment). Occasionally, however, facts that are not easy to obtain directly are deduced from theory. A good example is the work done in the 1840s on Saturn's rings by the great Scottish physicist James Clerk Maxwell. At the time, astronomers had observed three concentric rings about Saturn, all in the same plane. They knew that at least some regions of the rings must be quite thin since, in some areas, the planet behind could be plainly seen. Aside from that, their structure was an intriguing mystery. Maxwell carried out a careful theoretical and highly mathematical treatment and concluded that the rings could not be single solid or liquid units, since mechanical forces acting upon rings of such immense size would break them up. He suggested instead that the rings must be composed of vast numbers of individual solid particles rotating in separate concentric orbits at different speeds. He even drew some conclusions about how large the particles would be and how fast they would move.

For many decades, there was no way of testing Maxwell's conclusion, but in the latter years of the twentieth century, observations-particularly those from Voyager spacecraft-confirmed Maxwell's conclusions. The particles are composed of window-impure ice, or at least are ice covered. Radar observations have even confirmed the range of masses and speeds predicted by Maxwell. This was a remarkable achievement on Maxwell's part of the basis of a theory; he had arrived at factual information that could not be directly obtained for almost a century and a half.

Scientific work is best done with a theory in mind. It does not matter if the theory is proved wrong: it will nevertheless guide the initial experiments, which may lead to the correct theory. Paradoxically, people occasionally do much better with the wrong theory than with the right one, and there is one rather striking example of this. By the year 1900, physicists had become aware of the properties of radio waves, which they knew to be of the same character as light but with much longer wavelengths. Experiments had shown that radio waves (unlike light) would pass through walls because of the long wavelengths, and that, like light, they travel in straight lines.

One of the people working on radio waves at the time was the Italian Guglielmo Marconi. Unlike almost everyone else working on them, he knew hardly any physics. (Hence, the award to him of the 1909 Nobel Prize for physics amazed and horrified most physicists.) He did not really understand the properties of electromagnetic waves and did not even realize that radio waves were of that type. He said that his waves were Marconi waves, and that, instead of traveling in straight lines, they could be controlled by him to go to any point he chose. This was nonsense, but his ignorance of physics led him to try to send a signal across the Atlantic Ocean. No other physicist thought this was a reasonable thing to try -how could a wave, which has to travel in a straight line, possibly travel so far over the curved surface of the Atlantic? On December 12, 1901, Marconi's assistant sent signals across the Atlantic Ocean, from Cornwall, England, to St. John's, Newfoundland, where Marconi was apparently just able to receive them.

Physicists were quite correct in thinking that radio waves go in straight lines. How, then, can a radio signal go across the Atlantic, in view of Earth's curved surface? The most plausible answer is that they are reflected in some way. In 1902, the British physicist Oliver Heaviside and the American physicist Arthur Edwin Kennelly postulated the existence of a layer in the upper atmosphere in which they thought that molecules would be ionized, meaning they would carry electric charges. Such a layer would reflect the waves from the upper atmosphere and allow them to travel great distances over Earth's surface.

36.1: Industrial Activities in Britannia

As the Roman Empire expanded throughout Europe, it brought profound changes to newly conquered lands. One of the later territories to be absorbed as a province was Britain, in the first century A.D. There, with the arrival of the Roman army and its-relatively speaking- very rapid advance north, a number of new, or at least improved, technologies were introduced. Although ceramics had been made in Britain for several millennia, new kiln (furnace) technology allowed far-better-quality vessels to be made. Furthermore, Iron Age Britain had developed a specialized and highly artistic metalworking industry; with Roman technologies came the ability to mass-produce items. Consequently, while Iron Age communities had mastered many crafts and industries, what the Empire brought was the apparatus and the will to exploit these activities, with the initial impetus coming from the army.

It has long been recognized that the army was responsible for many industrial activities early on in the life of the new province of Britannia, and this conformed to the well-established pattern of conquest and Romanization. While undertaking and controlling industrial production had obvious fiscal, political, and even social benefits, it is unlikely that these were the initial motives for the role the army took in manufacturing. First and foremost, the army was the largest consumer of goods in early Roman Britain, and what the legions required had to either be produced locally or more expensively imported from abroad. Consequently, it made far more sense for the army to produce as many of its own goods as possible, on one hand, saving limited financial resources but also ensuring a controlled supply of items that were vital to the day-to-day existence of the legions.

Not only did the active role of the army in industrial production make strategic sense, but it was an ideal way to promote the spread of new technologies. While it is well recognized that legions themselves were made up of people from all over the Empire, what is more often overlooked is that the army consisted of individuals with diverse skills drawn from across most of the known world. Glassmaking, among other expertises, was not originally native to Britain or any of her immediate neighbors, but with the arrival of the army, practiced experts were immediately placed at the heart of Britannia. It was, therefore, inevitable, rather than just a matter of chance, that glassmaking became so quickly established in the first century A.D.

This association of the army with industrial processes can be seen archaeologically, with many production sites being associated with forts. A typical example can be seen at Temple borough, South Yorkshire, where excavations just prior to the First World War revealed the remains of a small glass furnace in the vicus, or attached settlement, of the fort. Obviously, glassmaking was not the only industrial activity undertaken by the army, and it is, therefore, no surprise that furnaces have been found in areas of more general and mixed industrial production. Perhaps the best example of this can be seen just beyond the confines of the fort at Mancetter in Warwickshire. A glass furnace dating to the second half of the second century, with associated working waste, was found to be operating among a group of pottery kilns. This pattern of mixed industrial quarters in close association with forts is mirrored at other sites across the Western Empire.

However, what is clear is that glassmaking was not being undertaken only at military sites. Indeed, there is probably more evidence from Britain of glassmaking being practiced in civilian settlements, and, more specifically, in towns. The growing urban populations of the first- and second-century provinces were a clear market for any products. And the possibility of furnaces as close as possible to these populations inevitably reduced transportation costs and the possibility of accidental breakage through carriage. The main difference with urban-centered production was that it was less likely to have been undertaken by the army directly, although since many towns were closely associated with forts, they still remained likely consumers.

36.2: Iridium and the Terminal Cretaceous Event

There have been a number of natural catastrophes in Earth's past that wiped out huge numbers of plant and animal species--in effect, "resetting the clock" and requiring a new start for much of life on Earth. One such catastrophe took place at the end of the Permian era, some 251 million years ago. But perhaps the most famous one occurred about 65 million years ago at the end of the Cretaceous, causing the dinosaurs to go extinct (except for a small number that evolved into modern birds). Evidence that the terminal Cretaceous event was triggered by the impact of an asteroid with Earth began to emerge in the early 1980s, when Luis and Walter Alvarez discovered a thin layer of iridium in rock strata (layers) 65 million years old at widely separated sites around the world. Iridium is very rare on Earth's surface but is much more common in some kinds of meteorites. The two scientists calculated that the impact of such an object, about 10 kilometers across, could have spread the right amount of iridium around the globe in the cloud of debris (fragments) blasted out by the impact. The idea was greeted with skepticism at first, but more traces of debris from an impact occurring at the time of the death of the dinosaurs began to turn up as geologists searched for evidence for or against the hypothesis. To most people, the most decisive evidence came in the early 1990s, when a geological feature at Chicxulub in the Yucatan Peninsula of Mexico was identified as the remains of an impact crater in exactly the right place and with exactly the right age to connect it to the terminal Cretaceous event.

There remained one doubt. Iridium does exist within Earth, and it is brought to the surface by volcanic eruptions. It still seemed just possible that volcanic eruptions on a truly massive scale could have put the iridium layer in place, and such eruptions would, of course, be bad news for life on Earth. There was even a known volcanic event that could have been responsible. Huge eruptions at roughly the right time spread vast amounts of lava across what is now west-central India, forming a structure known as the Deccan Traps. This is one of the largest volcanic features on Earth, more than two kilometers thick and covering an area of more than a million square kilometers. But, it is not a unique feature. The Siberian Traps were produced in one of the largest known volcanic events since the start of the Cambrian, which lasted for a million years and spanned the Permian-Triassic boundary about 250 million years ago. This coincided with the terminal Permian extinction event, which killed some 90 percent of the species existing at the time; in fact, the eruption of the Siberian Traps almost certainly caused this extinction.

So it is reasonable to implicate the formation of the Deccan Traps with the extinction at the end of the Cretaceous, and it is certain that such events have played a part in the history of life on Earth. And it also seems possible that life at the end of the Cretaceous was already under stress because of the environmental changes associated with the formation of the Deccan Traps when the meteorite struck. All of these possibilities encouraged a great deal of work over the best part of the next two decades, culminating in a meeting of 41 geologists, paleontologists, and other researchers who reviewed all the data and published their conclusions in the journal Science in 2010. They found that the volcanic activity lasted for about 1.5 million years, much longer than the time span over which the famous iridium layer was deposited, and that the eruptions began about half a million years before the terminal Cretaceous event. During that time, ecosystems did not change dramatically, but they suddenly collapsed at the time of the Chicxulub event. In light of all the data, the team concluded that a large asteroid impact 65 million years ago in modern-day Mexico was the major cause of the mass extinctions.

37.1: The Evolution of Plant Roots

Roots are essential to the development of large plants because they provide a means of anchoring and maintaining an upright position. Most land plants are literally rooted to the spot. Roots also play a key role in water and nutrient acquisition. More significantly still, roots have a tremendous impact on the environment. They can break up rock, bind loose particles together, and provide a conduit for the movement of water and dissolved minerals, all of which are essential to the development of soils.

In piecing together a fossil plant to form a conceptual whole, it is usually the rooting system that remains the final piece in the puzzle. It is often the case that roots are poorly studied or completely unknown. Although the fossil record of roots is, therefore, less complete than that of other plant organ systems, it is possible to discern some general trends. The earliest land plants, like modern mosses and liverworts, did not have well-developed root systems. These plants simply bore absorbing hairlike cells on stems and leaves that grew flat along the ground. From their fossils, some very early plants are known to have borne branches that appear to be specially modified for rooting. In other cases, roots were able to form from dormant buds on aerial stems. Fungi are also known to have played a key role in these early rooting systems, as they do in modern plants. Fungal symbionts—fungi that live in mutually beneficial relationships with another organism-have been recorded in the petrified plants of the 400million-year-old Rhynie Chert fossil site in Scotland, demonstrating a link with mycorrhizal fungi that goes back to the dawn of the land flora. These tiny, shallow rooting systems were adequate for small plants (30-50 centimeters tall), but larger organisms required something more substantial.

By the Late Devonian and Early Carboniferous eras (385 to 300 million years ago), an enormous variety of rooting structures had evolved. The evolution of large erect plants, and in particular, trees, placed increasing demands upon the anchoring and supply functions of roots. These problems were solved mainly through the development of more extensive underground systems. The evolution of the cambium, the layer of living cells between wood and bark, enabled continuous perennial growth and long-term survival of roots in soils.

One important consequence of all this was that there was a progressive and massive increase in root biomass during the Devonian, which had an enormous impact on the development of soils. Prior to the Devonian, soils, if developed at all, were thought to have been predominantly thin and of microbial origin. By the Middle Devonian, soil penetration depths of roots were still shallow (less than 20 centimeters), but this increased to 1 meter or more as forests spread. The diversity of soils also increased. This change was brought about by root-induced weathering and mixing. By the end of the Devonian, there was an increase in soil clay content, structure, and differentiation into distinct layers—a development that correlated with increases in the depth of root penetration. Soils with modern profiles (series of layers) are recognizable at this time.

The impact of roots on the environment extends beyond their immediate effects on the development of soils. The presence of roots in soils increases the natural weathering of calcium and magnesium silicate minerals. This apparently mundane fact turns out to have extremely important consequences for climate and temperature globally. Under natural circumstances, calcium and magnesium silicates react chemically with a dissolved form of the gas carbon dioxide (a process referred to as weathering), which comes from the atmosphere. This produces calcium and magnesium carbonates, which are transferred through the groundwater system to rivers and ultimately to the oceans, where they accumulate in the form of limestone and dolomite rock. Across the surface of the Earth, these chemical reactions occur on a vast scale, removing carbon dioxide gas from the atmosphere and locking it up as carbonate in rock formations. This reduces the so-called greenhouse effect, which leads to lower global temperatures. In other words, the widespread development of roots in land plants affected the chemistry of the atmosphere and the oceans, which, summed over millions of years, added up to changes in climate on a global scale.

37.2: Herbivores on the Serengeti Plain

Herbivores (plant-eating animals) living in the same environment often compete for food plants. But in some cases, herbivores may cooperate in the harvesting of plant matter. The grazing system of large herbivores on the Serengeti Plain of East Africa is an excellent illustration of how these animals may interact over their food supply. The Serengeti Plain contains the most spectacular concentration of large mammals found anywhere in the world. Approximately 1,000,000 wildebeests, 600,000 Thomson's gazelles, 200,000 zebras, and 65,000 buffalo occupy an area of 23,000 square kilometers (9,000 square miles), along with undetermined numbers of 20 other species of grazing animals.

The dominant grazers of the Serengeti Plain are migratory and respond to the growth of the grasses in a fixed sequence. First, zebras enter the long-grass communities and remove many of the longer stems. Zebras are followed by wildebeests, which migrate in very large herds and graze and trample upon the grasses until they are close to the ground. Wildebeests are, in turn, followed by Thomson's gazelles, which feed on the short grass during the dry season.

The various grazing species in the Serengeti system do not each select different species of grasses but instead select different parts of the grass plant during different seasons. Zebras eat mostly grass stems and sheaths, and almost no grass leaves. Wildebeests eat more sheaths and leaves, and Thomson's gazelles eat grass sheaths and a large fraction of herbs not touched by the other two herbivores. These feeding differences have significant consequences for grazing species because grass stems are very low in protein and high in lignin, an organic substance that strengthens the cell walls of some plants. Grass leaves, on the other hand, are relatively high in protein and low in lignin, which means leaves provide more energy per gram of dry weight than stems. Herb leaves typically contain even more protein and energy than grass leaves. So zebras seem to have the worst diet and Thomson's gazelles the best.

How can zebras cope with grass stems as the major part of their diet during the dry season? Most of the grazing animals in the Serengeti are ruminants, animals that have a specialized stomach containing bacteria and protozoa that break down the cellulose in the cell walls of plants. But the zebra is not a ruminant and is similar to the horse in having a simple stomach. Zebras survive by processing a much larger volume of plant material through their gut than ruminants do, perhaps roughly twice as much. So even though a zebra cannot extract all the protein and energy from the grass stems, it eats more, and thus, compensates by volume. Zebras also have the advantage of being larger than wildebeests and Thomson's gazelles, and larger animals need less energy and less protein per unit of weight than smaller animals do.

It would seem that competition for food would occur between wildebeests and Thomson's gazelles because they eat the same parts of the grass. Wildebeests have what appears to be a devastating effect on the grassland as they pass through in migration. Green biomass was reduced by 85 percent and average plant height by 56 percent on sample plots. By establishing fenced areas as grazing enclosures, one researcher was able to follow the subsequent changes both in grassland areas subject to wildebeest grazing and in areas protected from all grazing. Grazed areas recovered after the wildebeest migration had passed and produced a short, dense lawn of green grass leaves. As gazelles entered the area during the dry season, they concentrated their feeding on areas where wildebeests had previously grazed, and they avoided areas of grassland that the wildebeest herd had missed.

Grass production was reduced by both wildebeests and gazelles, but no signs of competition were found. The Serengeti grazing populations instead show evidence of grazing facilitation, in which the feeding activity of herbivore species improves the food supply available to a second species. Heavy grazing by wildebeests prepares the grass community for subsequent exploitation by Thomson's gazelles in the same general way that zebra feeding improves wildebeest grazing.

38.1: British Agriculture

England was one of the first nations in the modern period to increase the efficiency of its agricultural production, making it possible to produce the same or more while using fewer workers. By the end of the seventeenth century, England was already in advance of most of continental Europe in agricultural productivity, with only about 60 percent of its workers involved primarily in food production. Although the actual number of workers in agriculture continued to grow until the middle of the nineteenth century, the proportion declined steadily to about 36 percent at the beginning of the nineteenth century, to about 22 percent in the mid-nineteenth century (when the absolute number was at its maximum), and to less than 10 percent at the beginning of the twentieth century.

The means by which England increased its agricultural productivity owed much to trial-and-error experimentation with new crops and new crop rotations. Turnips, clover, and other fodder crops (plants used to feed livestock) were introduced from the Netherlands in the sixteenth century and became widely diffused in the seventeenth. Probably the most important agricultural innovation before scientific agriculture was introduced in the nineteenth century was the development of so-called convertible husbandry, involving the alternation of field crops with temporary pastures in place of permanent cultivated fields and pastures. This had the double advantage of restoring the fertility of the soil through improved rotation, including leguminous crops, and of maintaining a larger number of livestock, thus producing more manure for fertilizer as well as more meat, dairy produce, and wool. Many landowners and farmers also experimented with selective breeding of livestock.

An important condition for both the improved rotations and selective breeding was the enclosure (the conversion of common land into private plots) and consolidation of the fields. Under the traditional open field system, it was difficult, if not impossible, to obtain agreement among the many participants on the introduction of new crops or rotation; and with livestock grazing in common herds, it was equally difficult to manage selective breeding. The most famous enclosures were those carried out by acts of Parliament (the British governing body) between 1760 and 1815. Enclosure by private agreement, however, had been going on almost continually since the late Middle Ages; it was especially active in the late seventeenth and the first six decades of the eighteenth centuries. By that time, more than half of England's arable land (land that can be farmed productively) had been enclosed.

The new agricultural landscape that emerged to replace villages surrounded by their open fields consisted of fields that were compact, consolidated, and closed in by walls, fences, or hedges. Along with the processes of enclosure and technological improvement, a gradual tendency toward larger farms emerged, further boosting productivity. By 1851, about one-third of the cultivated acreage was in farms larger than 300 acres; farms smaller than 100 acres accounted for only 22 percent of the land. Even so, the occupants of the small farms outnumbered those of the others almost two to one. The reason for this is that the small farmers were owner-occupiers who farmed the land with the help of family labor; the larger farmers rented pieces of their property to others and hired landless agricultural workers. It used to be thought that the enclosures led to a loss of population in the countryside, but in fact, the new techniques of cultivation associated with them actually increased the demand for labor. Not until the second half of the nineteenth century, with the introduction of such farm machinery as threshers, harvesters, and steam plows, did the absolute size of the agricultural labor force begin to decrease.

In the meantime, the increasing productivity of English agriculture enabled it to feed a burgeoning population at steadily rising standards of nutrition. For about a century, from 1660 to 1760, English farmers produced a surplus for export; after that period, the rate of population growth overtook the rate of increase in productivity. The relatively prosperous rural population provided a ready market for manufacturing goods, ranging from agricultural implements to such consumer products as clothing, pewter-ware, and porcelain.

38.2: The Documentary Film in the United States

In the United States, the nonfiction film was primarily defined and sustained by the travelogue, which was filmed in foreign lands and shown at lectures and sideshows to introduce audiences to different cultures and exotic locations. In 1904, at the St. Louis Exposition, George C. Hale's Tours and Scenes of the World was particularly successful but did not reach the mythic proportions of the film made from President Teddy Roosevelt's African safaris or Robert Scott's expedition to the South Pole. These kinds of travelogues appealed to the American public because they demonstrated a spirit of enterprise and adventure. This outlook underpins the Romantic tradition of filmmaking that begins with travelogues of the American West and comes to its fullest expression in the films of Robert Flaherty. It is he who most embodies the development of the documentary form as an objective tool of ethnography- -the scientific study of other cultures from a position "within" the community- -and anthropology.

His film Nanook of the North (1922), a study of Inuits of northern Canada, is acknowledged as one of the most influential films within the genre. It perhaps provides us with all the clues we require to define both the documentary and its acceptable limits. Flaherty's films, which have been called “authored" films, are made with a specific intent: not merely to record the lives of the Inuits but to recall and restage a former, more “primitive" era of Inuit life. This nostalgic intent only serves to mythologize Inuit life and, to some extent, remove it from its real context, thus calling into question some of the inherent principles that we may assume are crucial in determining documentary “truth."

Although Flaherty was an advocate of the use of lenses that could view the subject from a long distance so as not to affect unduly the behavior of the natives, and he filmed long, uninterrupted scenes at one time without stopping the camera instead of using complex editing, it is his intervention in the material that is most problematic when evaluating Nanook as a key documentary. Flaherty was not content merely to record events; he wanted to dramatize actuality by filming aspects of Inuit culture that he knew of from his earlier travels into the Hudson Bay area between 1910 and 1916. For example, he rebuilt igloos to accommodate camera equipment and organized parts of the Inuit lifestyle to suit the technical requirements of filming under these conditions. In another of his documentaries, Moana (1926), Flaherty staged a ritual tattooing ceremony among the Samoan Islanders, recalling a practice that had not been carried out for many years. In Man of Aran (1935), shark hunts were also staged and did not characterize the contemporary existence of the Aran Islanders.

John Grierson, the British documentary maker, argues that Flaherty becomes intimate with the subject matter before he records it and thus, “He lives with his people till the story is told 'out of himself' and this enables him to 'make the primary distinction between a method which describes only the surface value of a subject and a method that more explosively reveals the reality of it." This seems to legitimize Flaherty's approach because Nanook, Moana, and Man of Aran all succeed in revealing the practices of more “primitive” cultures- cultures which in Flaherty's view embody a certain kind of simple and romanticized social perfection.

Clearly then, Flaherty essentially uses actuality to illustrate dominant themes and interests that he is eager to explore. In some ways, Flaherty ignores the real social and political dimensions informing his subjects' lives and, indeed, does not engage with the darker side of human sensibility, preferring instead to prioritize larger, more mythic, and universal topics. There is almost a nostalgic yearning in Flaherty's work to return to a simpler, more physical, preindustrial world, where humankind could pit itself against the natural world, slowly but surely harnessing its forces to positive ends. Families and communities are seen as stoic and noble in their endeavors, often surviving against terrible odds. Flaherty obviously manipulates his material and sums up one of the apparent ironies in creating documentary “truth" by suggesting that “Sometimes you have to lie. One often has to distort a thing to catch its true spirit."

39.1: The Decline of the Arctic Fox in Scandinavia

The arctic fox has lived in the Scandinavian countries of Norway, Finland, and Sweden since the last Ice Age, which ended more than 10,000 years ago. Today, however, the Arctic fox in Scandinavia is in severe trouble. Despite intense conservation efforts, its numbers have been radically declining. Why this most resourceful of species has been unable to rebound since hunting it was prohibited is not altogether clear.

One possibility is that the animals have gone through what biologists refer to as a population bottleneck. Such bottlenecks occur when the number of animals in a given population is reduced to the point where inbreeding enables the enhanced proliferation of genes that may be detrimental to a species' overall fitness (ability to survive). A related hypothesis is that the arctic foxes had lost their genetic advantage owing to the spread of genes from selectively bred foxes that escaped from farms. Captive-raised foxes are known to have escaped, and recent genetic studies from Norway have shown that such interbreeding between farm-bred foxes and foxes in the wild has indeed taken place. While these results are being viewed as potential future trouble, there is still no indication that they explain past difficulties. The number of crossover genes detected in the Norwegian study was small, suggesting that mixing between wild and escaped foxes is a recent occurrence.

Among changes in the environment that might be to blame, one of the earliest ideas relates to the absence of wolves, animals that, for thousands of years, filled the role of top predator throughout Scandinavia but that disappeared from most of Norway and Sweden during the twentieth century after hundreds of years of persecution. There is no winter sea ice along the coastlines of Norway and western Russia, as there is throughout the Canadian Arctic and off the coast of Siberia, meaning the arctic foxes in this part of the world have no access to remains of polar bears' prey, an important source of food for arctic foxes. What they do have access to is reindeer. Since wolves are the only predator of reindeer in Scandinavia, it has been argued that the elimination of the wolf has led to a decline in the availability of a necessary winter food supply.

Scientists, however, have been unable to uncover any strong evidence to support the claim that arctic foxes are suffering because of the absence of large predators. One study even suggests arctic foxes do better in the absence of large predators because when animals such as reindeer die of natural causes, the foxes have the large carcasses all to themselves. Also casting doubt on the wolf's culpability is the fact that it had been hunted out of many alpine regions of Scandinavia during the mid-nineteenth century, long before the arctic fox entered into its decline. What's now known about wolf biology suggests the amount of meat and entrails (internal organs) left behind by these animals may not be sufficient to have a noticeable impact on the arctic fox population.

Today, there is little enthusiasm among Arctic fox scientists for the idea that a lack of wolves is to blame. Instead, most now believe the trouble stems from the increased presence of another canine carnivore- one that, in the eyes of the arctic fox at least, is far more ferocious: the red fox. The red fox is one of the most successful carnivores anywhere. It has evolved a repertoire of instincts that has enabled it to thrive in a world increasingly dominated by humans and human-altered landscapes.

For the most part, arctic foxes and red foxes occupy different environmental niches. Generally, the arctic fox keeps to the tundra, while the red fox is at home in a wide range of habitats throughout the northern hemisphere. In recent decades, however, there is evidence that red foxes are increasingly encroaching on what previously had been territory inhabited only by arctic foxes. During the nineteenth century, there were occasional red fox sightings on southern Baffin Island in Canada, but none of the animals were known to settle down and breed. In the last half of the twentieth century, however, they returned and became a permanent population there.

39.2: The Cooling of Early Earth

Earth formed just under 4.6 billion years ago, and for its first 50 to 100 million years, it was a boiling ball of liquid rock without a permanent crust (hard outermost layer). An important event in Earth's earliest phase is known as the differentiation event, which completely changed the initially uniform composition of the planet. It happened around 4.5 billion years ago when the planet had grown large enough for the pressure to drive temperatures in the interior above 1,000℃ (degrees Celsius), the point at which rocks melt. Then, denser (metal-rich) materials sank to the center of the planet, and less dense (rocky) materials rose toward the surface. The sinking dense materials formed Earth's nickel-iron core, the planet's inner 3,500 kilometers or so. The lighter materials that rose up formed the less-dense rocky mantle, the planet's outer 2,900 kilometers.

The formation of Earth's core transformed conditions on Earth's surface. This is because it created the right conditions for the development of the planet's magnetic field, which originates from movements in the outer layers of Earth's core. It had been known for a while that the magnetic field was already operational by about 3.5 billion years ago, and very recent research has brought that back to before 4 billion years ago. The magnetic field is Earth's only real protection against the solar wind (charged particles from the Sun), which was stripping gases from the earliest atmosphere before the magnetic field had started up. Thus, the differentiation event is thought to have been critical for reducing the loss of light elements from the atmosphere to space. Without it, Earth might have ended up without hydrogen, and, thus, without water. And over time, many heavier gases would also have been stripped off by the solar wind. Mars is thought to have started out with a magnetic field but—being much smaller than Earth—to have cooled enough for its magnetic field to die around 4 billion years ago. It subsequently lost almost all of its atmosphere and surface water. While this often-used explanation for retaining an atmosphere by the presence of a magnetic field sounds plausible, some further thought suggests that things may be a little more complicated. Venus has no magnetic field and is closer to the Sun, yet it has a very well-developed atmosphere. Venus and Earth have similar sizes and masses, while Mars is much smaller—hence, gravity may have been equally or more important for retaining an atmosphere than a magnetic field, especially when the gases concerned are heavier gases, like the dominant CO2 (carbon dioxide) on Venus.

At Earth's position in the earliest solar system, temperatures of 250°C to 350°C would be expected, but the energy from the intense early impacting by objects from space had pushed temperatures up well above the melting temperature of rocks. Still, research has demonstrated that as early as about 4.4 billion years ago, Earth's surface had not only cooled sufficiently to form an early crust (likely below 1,000°C) but even enough to allow for the presence of liquid water, which at modern atmospheric pressure would mean that temperatures had dropped below 100°C. However, at higher pressures, this value is higher, and we don't really know how dense the early atmosphere was. So 100°C is a lower estimate; true temperatures may have been double that value if the early atmosphere was very dense.

Now that clouds and rain had appeared on the scene, oceans began to develop. Large portions of the planet were covered with water by about 4 billion years ago. This is somewhat unexpected because, at this time, Earth's fiery birth phase had rapidly settled down, and the Sun was only about 70 percent as strong as it is today. After their first bright ignition, stars like the Sun shine more weakly and then grow gradually more intense with age; we refer to this as the "faint young Sun." With only 70 percent of the modern energy coming in from the Sun, early Earth should have been covered by ice, not water. Somehow, Earth's early atmosphere must have retained heat more effectively than the modern atmosphere. Indeed, reconstructions of the early atmosphere's composition suggest high levels of CO_2, water vapor, and methane, which would have caused efficient heat retention.

40.1: The Commercialization of Agriculture in the United States

Thomas Jefferson, a Founding Father of the United States, believed that farmers were the foundation of American democracy. To execute his plan for democracy, Jefferson proposed the United States Rectangular Land Survey- -familiarly known as the grid. Under the plan, surveyors were first sent to eastern Ohio with instructions to divide the land into boxes that would measure six miles square. Then they were instructed to divide these larger boxes into smaller ones, one-mile square, which were divided yet again into quarter sections measuring 160 acres each, which was considered to be the appropriate size for a single farm. In 1785, Congress passed the grid into law, and from that point on, the same checkerboard pattern was etched across the West- -one of the most far-reaching attempts at rationalizing a landscape in world history.

The grid was the outward expression of a culture wedded not simply to democracy but to markets and exchange as well. It would aid in the rapid settlement of the country, turning millions of Americans into independent landowners, while at the same time transforming the land itself- its varied topography, soil, and water conditions- into a commodity, a uniform set of boxes easily bought and sold. But the grid was only the first step in the commercialization of Western farmlands.

Once farmers purchased land, they needed to plow up the existing vegetation. The grasses that thrived on the organically rich, deep soil laid down by the glaciers thousands of years earlier were at first a challenge to cut. Wooden plows with edges made of iron proved virtually useless. The development and spread of the steel plow-invented in 1837 by John Deere, an Illinois blacksmith- -made plowing successful. In place of the native vegetation, farmers planted corn and wheat, domesticated species of grass that grow best in a monocultural environment, that is, in fields by themselves. These crops tend to grow quickly, storing carbohydrates in their seeds. With bread constituting a major component of the American diet, wheat would eventually emerge as the West's major cash crop; acres and acres of some of the world's best agricultural land in states such as Ohio, Indiana, Illinois, Iowa, and Kansas were plowed up and given over to the plant.

In the early years of settlement, farmers grew a variety of grains, including wheat, corn, oats, rye, and barley. Increasingly, however, farmers became more specialized, as commercial agriculture, aided by improved railroad transportation, proceeded apace. Much of the grain ended up in the Northeast, where, by the 1840s, population growth had outstripped the local farm economy's ability to provide. In effect, the West's surplus of soil wealth underwrote the industrial development farther east.

The railroads not only delivered the products of the rich soils of the Western grasslands into the stomachs of Easterners, but they also changed the meaning of the crops themselves. With waterborne transportation, farmers put their grain into sacks so they could easily be loaded into the irregularly shaped holds of steamboats. The advent of the railroads and steam-powered grain elevators (first developed in 1842) spurred farmers to eliminate the sack altogether. Now grain would move like a stream of water, making its journey to market with the aid of a mechanical device that loaded all the wheat from a particular area into one large grain car. Sacks had preserved the identity of each load of grain. With the new technology, however, grain from different farms was mixed together and sorted by grade. The Chicago Board of Trade (established in 1848) divided wheat into three categories- spring, white winter, and red winter- -applying quality standards to each type. Wheat was turned into an abstract commodity, with ownership over the grain diverging from the physical product itself. By the 1860s, a future market in grain had even emerged in Chicago. It was now possible to enter into a contract to purchase or sell grain at a particular price. What was being marketed here was not the physical grain itself so much as an abstraction, the right to trade something that may not even have been grown yet.

40.2: The Angiosperm Revolution

Of all the kinds of modern land plants, one group dominates: the angiosperms, or flowering plants. With over 250,000 living species, they are the majority of plants in most habitats- except marine environments, which are still habitats for the more primitive algae. But angiosperms were a comparatively recent development in plant evolution. They arose in the mid-Mesozoic (approximately 200 million years ago to 145 million years ago), but by about 100 million years ago, they had pushed the conifers (plants having cone-shaped reproductive structures rather than flowers for reproduction) into the background. Even earlier types of plants, such as ferns, are now restricted to certain wet habitats, and many of the dominant gymnosperms (plants with exposed seeds, such as conifers) of the early Mesozoic have now been largely replaced by angiosperms; the formerly dominant gymnosperms that did not become completely extinct now survive in comparatively few places.

Why were the angiosperms so successful? A major advantage they have over more primitive plants is their efficient mode of reproduction- -the flower and all of its complex reproductive mechanisms that ensure success. Instead of the inefficient wind-pollinated gymnosperm seed, which wastes a huge amount of pollen and is dependent on random breezes, angiosperms have evolved flowers specifically as devices to attract pollinators--mainly insects (especially moths, butterflies, and bees) but also birds, bats, and other flying creatures. The pollinators ensure that the pollen is carried directly from one flower of the same species to another, which is more efficient than relying on the wind. This process of delivery is called cross-pollination. The reproductive cycle is highly modified: the ovules (egg-producing organs) are fully enclosed within protective covers called carpels, which form the core of the flower. The carpel protects the ovule from drying out, from fungal infection, and from predation by plant-eating insects. Pollen-producing organs called stamens are surrounded by petals (which serve to attract the pollinator and guide it to the ovules in many cases) and an outer covering of sepals for protection. Typically, a pollinator gets pollen stuck onto it as it climbs into a flower, seeking the nectar that is generated to lure it. The ovule is usually pollinated by the sperm carried from a different flower, thus minimizing self-fertilization (but angiosperms can also self-fertilize if cross-pollination is not possible).

Once the pollen has been delivered, a pollen tube transports the sperm to the ovules. Here, angiosperms have another advantage: double fertilization. The pollen carries two sperm nuclei, one of which fuses with the egg nucleus to form the embryo, the other of which fuses with two other nuclei to form a food supply for the embryo. This means that angiosperms don't need to invest a lot of energy in creating food stores for each seed until it is fertilized (unlike gymnosperms, which create food even for infertile seeds).

The entire process of fertilization and producing an embryo takes place in only a few weeks or days, so angiosperms can sprout, flower, reproduce, and die in a single season if necessary. By contrast, most gymnosperms are slow to grow and reproduce (usually taking at least eighteen months between reproductive cycles) and cannot accomplish the entire process in a single season. For gymnosperms such as evergreen conifers to live in highly seasonal, cold-winter climates, they must be able to survive the cold and shut down much of their physiological systems during winter. Many angiosperms, on the other hand, are annuals- sprouting in the spring, flowering, and producing seeds that can survive until the next winter while the rest of the plant dies. This rapid reproduction enables them to quickly exploit habitats that other plants cannot.

Finally, angiosperms are known not only for their rapid growth rates but for their ability to grow back quickly after they have been munched by animals. Think of how quickly the grass grows back after you mow it (or an animal grazes it). By contrast, ferns cannot grow back so quickly after they have been heavily eaten, and often die if the damage is too great (such as when an animal eats the growing tip of the plant)- whereas many angiosperms can be eaten right down to their roots but grow back again.

41.1: Formation of the Solar System

Where did the solar system come from? This question has tantalized astronomers for centuries. While we do not yet have a wholly complete answer, a consensus has arisen about the most likely series of events that led to the present-day system of the Sun and planets.

A key piece of evidence about the origin of the solar system is that all the planets orbit the Sun in the same direction and in nearly the same plane. As long ago as the eighteenth century, German philosopher Immanuel Kant and French scientist Pierre-Simon D.E. Laplace independently suggested that this state of affairs could not be a coincidence. They proposed that our entire solar system-the Sun, as well as all of the planets, satellites, asteroids, and comets-formed from a vast, rotating cloud of gas and dust called the solar nebula. In the modern version of their theory, the solar nebula is thought to have had a mass somewhat greater than that of our present-day Sun.

Each part of the nebula exerted a gravitational attraction on the other parts, and these mutual gravitational pulls tended to make the nebula contract. As it contracted, the greatest concentration of matter occurred at the center of the nebula, forming a relatively dense region called the protosun, which eventually developed into the Sun. The planets formed from the much lesser amount of material in the outer regions of the solar nebula. Indeed, the mass of all the planets together is only 0.1 percent of the mass of the Sun.

When you drop a ball, the gravitational attraction of Earth makes the ball travel faster and faster as it falls; in the same way, material falling inward toward the protosun would have gained speed. As this fast-moving material ran into the protosun, the energy of the collision was converted into thermal energy, causing the temperature deep inside the solar nebula to climb. While the protosun's surface temperature stayed roughly constant, the temperature inside the protosun increased even more by means of further contraction. Eventually, after perhaps 100 million years had passed since the solar nebula first began to contract, the central temperature of the protosun reached a few million degrees, and nuclear reactions began in its interior. When this happened, the contraction stopped, and a true star (the Sun) was born. Nuclear reactions in the interior of the present-day Sun are the source of all the energy that the Sun radiates into space.

If the solar nebula had not been rotating at all, everything would have fallen directly into the protosun, leaving nothing behind to form the planets. Instead, the solar nebula must have had an overall slight rotation, which caused its evolution to follow a different path. As the slowly rotating nebula collapsed inward, it would naturally have tended to rotate faster. Figure skaters use this same phenomenon; when a spinning figure skater pulls her arms and legs inward, close to her body, the rate at which she spins automatically increases. As the solar nebula began to rotate more rapidly, it also tended to flatten out, just as a spinning ball of dough flattens out when it is spun rapidly by a pizza chef. The eventual result was a structure with a rotating flattened disk surrounding a newly formed

Sun. The planets formed later from this disk, which explains why their orbits all lie in essentially the same plane and why they all orbit the Sun in the same direction.

Naturally, there were no humans to observe these processes taking place during the formation of our solar system. But astronomers have seen disks of material surrounding other stars that formed only recently. These are called protoplanetary disks, or proplyds, because it is thought that planets can eventually form from these disks around other stars. By studying these proplyds, astronomers are able to examine what our solar nebula may have been like some 5 billion years ago.

41.2: El Nino and the Southern Oscillation

Between the ocean surface and the atmosphere, there is an exchange of heat and moisture that depends, in part, on temperature differences between water and air. Even a relatively small change in surface ocean temperatures could modify atmospheric circulations and have far-reaching effects on global weather patterns.

Along the west coast of South America, where the cool Peru Current sweeps northward, southerly winds promote upwelling (rising to the surface and flowing outward) of cold, nutrient-rich water that gives rise to large fish populations, especially anchovies. The abundance of fish supports a large population of seabirds whose droppings (ale guano) produce huge phosphate-rich deposits that support the fertilizer industry. Near the end of the calendar year, a warm current of nutrient-poor tropical water often moves southward, replacing the cold, nutrient-rich surface water.

In most years, the warming lasts for only a few weeks to a month or more, after which weather patterns usually return to normal and fishing improves. However, when conditions last for many months and a more extensive ocean warming occurs, the economic results can be catastrophic. This extremely warm episode, which occurs at irregular intervals of two to seven years and covers a large area of the tropical Pacific Ocean, is now referred to as a major El Nino event, or simply El Nino.

During a major El Nino event, large numbers of fish and marine plants may die. Dead fish and birds may litter the water and beaches of Peru; their decomposing bodies reduce the water's oxygen supply, which leads to the bacterial production of huge amounts of hydrogen sulfide. The El Nino of 1972-1973 reduced the annual Peruvian anchovy catch from 10.3 million metric tons in 1971 to 4.6 million metric tons in 1972. Since much of the harvest of this fish is converted into fish meal and exported for use in feeding livestock and poultry, the world's meal production in 1972 was greatly reduced. Countries such as the United States that rely on meals for animal feed had to use soybeans as an alternative. This raised poultry prices in the United States by more than 40 percent.

Why does the ocean become so warm over the eastern tropical Pacific? Normally in the tropical Pacific Ocean, there are the trades-persistent winds that blow westward from a region of higher pressure over the eastern Pacific toward a region of lower pressure centered near Indonesia. The trades create upwelling that brings cold water to the surface. As this water moves westward, it is heated by sunlight and the atmosphere. Consequently, in the Pacific Ocean, surface water along the equator usually is cool in the east and warm in the west. In addition, the dragging of surface water by the trades raises the sea level in the western Pacific and lowers it in the eastern Pacific, which produces a thick layer of warm water over the tropical western Pacific Ocean and a weak ocean current (called the counter current) that flows slowly eastward toward South America.

Every few years, the surface atmospheric pressure patterns break down as air pressure rises over the region of the western Pacific and falls over the eastern Pacific. This change in pressure weakens the trades, and, during strong pressure reversals, east winds are replaced by west winds. The west winds strengthen the counter current, causing warm water to head eastward toward South America over broad areas of the tropical Pacific. Toward the end of the warming period, which may last between one and two years, atmospheric pressure over the eastern Pacific reverses and begins to rise, whereas, over the western Pacific, it falls. This seesaw pattern of reversing surface air pressure at opposite ends of the Pacific Ocean is called the Southern Oscillation. Because the pressure reversals and ocean warming are more or less simultaneous, scientists call this phenomenon the El Nino/Southern Oscillation, or ENSO for short. Although most ENSO episodes follow similar evolution, each event has its own personality, differing in both strength and behavior.

42.1: Beaks of Darwin' Finches

In 1835, before he had developed his theory of evolution, Charles Darwin collected specimens of 13 previously unknown species of finches from the isolated Galapagos Islands. The Galapagos finches closely resembled a species of finches living on the mainland of South America, but each of the Galapagos species of finches had a differently shaped beak unique to it. His observations led Darwin to speculate that "from an original paucity of birds in this archipelago [the Galapagos Islands], one species has been taken and modified for different ends." This is the essence of Darwin's theory of evolution by natural selection: Birds with a particular beak shape survived and reproduced because their beak made them well-adapted to using a particular food source. In this way, one original species that came to Galapagos from the mainland ultimately evolved into 13 new species.

The correspondence between the beaks of the 13 finch species and their food source immediately suggested to Darwin that evolution had shaped them. If his suggestion that the beak of an ancestral finch had been shaped by evolution is correct, then it ought to be possible to see the different species of finches acting out their evolutionary roles, each using their beaks to acquire their particular food specialty. The four species that crush seeds within their beaks, for example, should feed on different seeds, those with stouter beaks specializing in harder-to-crush seeds.

Many biologists visited the Galapagos after Darwin, but it was 100 years before anyone tried this key test of his hypothesis when the great naturalist David Lack finally set out to do this in 1938. observing the birds closely for a full five months, his observations seemed to contradict Darwin's proposal. Lack often observed many different species of finch feeding together on the same seeds. We now know that it was Lack's misfortune to study the birds during a wet year when food was plentiful. The finch's beak is of little importance in such flush times; small seeds are so abundant that birds of all species are able to get enough to eat.

The key to successfully testing Darwin's proposal that the beaks of Galapagos finches are adaptations to different food sources, proved to be patience. Starting in 1973, Peter and Rosemary Grant of Princeton University and generations of their students have studied the medium ground finch Geospiza fortis on a tiny island in the center of the Galapagos called Daphne Major. These finches feed preferentially on small, tender seeds produced in abundance by plants in wet years. The birds resort to larger, drier seeds, which are harder to crush, only when small seeds become depleted during long periods of dry weather, and plants produce few seeds.

The Grants quantified beak shape among the medium ground finches of Daphne Major by carefully measuring beak depth (width of the beak, from top to bottom, at its base) on individual birds. Measuring many birds every year, they were able to assemble a detailed portrait of evolution in action. The Grants found that beak depth changed from one year to the next in a predictable fashion. During droughts, plants produced few seeds, and all available small seeds were quickly eaten, leaving large seeds as the remaining source of food. As a result, birds with large beaks survived better, because they were better able to break open these large seeds. Consequently, the average beak depth of birds in the population increased the next year, only to decrease again when wet seasons returned.

Could these changes in the beak dimension reflect the action of natural selection? An alternative possibility might be that the changes in beak depth do not reflect changes in gene frequencies, but rather are simply a response to diet- -perhaps during lean times, the birds become malnourished and then grow stouter beaks, for example. If this were the case, it would not be genetics but environment alone that influences beak size. To rule out this possibility, the Grants measured the relation of parent bill size to offspring beak size, examining many broods over several years. The depth of the beak was passed down faithfully from one generation to the next, regardless of environmental conditions, suggesting that the differences in beak size indeed reflected genetic differences.

42.2: Sequencing Ice Ages

Traditionally, climate scientists believed that Earth underwent four major periods of glaciation (being covered by ice sheets) with the warm interglacial in between. But climate research has now shown that over the past 800,000 years, Earth has seen a complex pattern of some twenty major climatic shifts, with temperatures alternating between very warm and intensely cold, featuring warm seas in northern Europe at one extreme and ice sheets covering vast areas of the globe at the other. The cause of these fluctuations lies in the complex relationship between Earth and the Sun. We are all familiar with the fact that Earth orbits the Sun and that it spins around its own axis, which is at an angle to the plane of its orbit. This causes some parts of Earth's surface to be nearer the Sun for periods of time, accounting for the differences between summer and winter. If all parts of this system were stable, Earth's climate would remain constant, but this is not so. First, Earth's orbit is not perfectly circular but is slightly elliptical, causing a variation on a 100,000-year cycle. Secondly, the axis of Earth Changes its tilt (angle by a fraction over a 41,000-year cycle); and thirdly, the planet has a slight wobble (shaking movement) about its axis as it spins, setting up changes over a cycle of 23,000 years. The combination of all these factors (known as the Milankovitch cycles) creates very small changes in the Sun-Earth relationship that determine the expansion or contraction of the polar ice cap and, thus, the sequence of fluctuating ice ages.

The complexity of these changes has taken some time to unravel. The earliest work was done on glaciers in the Alpine region, and it was here that the four major stages of glaciation were identified, providing a useful regional sequence. More recently, over the last fifty years or so, work on deep-sea cores has pioneered a new way to study the phenomenon globally. The principle is quite simple: Deep-sea cores provide stratified sequences of accumulations of calcium carbonate derived from the shells of dead organisms. The calcium carbonate in these layers contains two different oxygen isotopes (oxygen of different atomic weights), (16)O and (18)O, which the organisms extract from the atmosphere. Since it can be shown that cold conditions favor (18)O over (16)O, by assessing the ratio of the two, it is possible to arrive at a direct measurement relating to the temperature of the ocean at the time of deposition. From these measurements, a system of twenty phases, known as marine isotope stages, can be distinguished, reflecting changes in Earth's climate. The method was extremely valuable in providing a relative sequence, but it needed to be calibrated to give approximate dates for the phases.

The breakthrough came when, in one of the cores, it was possible to identify a point at which a major reversal had occurred in Earth's magnetic field, the time when the North and South Poles took up their present positions. This same reversal has been recorded in rocks, which could be dated to around 736,000 years ago using an absolute dating method. With this one point securely established and assuming that the deep-sea sediments had accumulated at a standard rate, it has been possible to assign dates to the entire sequence. Another valuable dating method, which has been developed over the last thirty years, is based on cores bored out of the Greenland ice cap. The largest core is 3,000 meters deep and represents the buildup of the ice over a 110,000-year period. From the cores, it is possible to measure annual increments, one year's winter ice being separated from the next year's by a fine dust layer formed during the summer melt. The temperatures prevailing at the time are estimated from the (16)O to (18)O ratios and from the proportions of the windblown chemical particles. The cores provide a very precise, dated sequence of climatic events extending back from the present.

43.1: The Roman Road System of Britain

During its occupation of Britain (A.D. 43-410), the Roman Empire built an extensive network of roads. The Roman government recognized four categories of roads ranging in order from the most important to the least: public roads funded by the state; military roads built at the army's expense but also used by the public; local roads on which less engineering effort was expended; and private roads that were built and maintained by their owners. The latter two categories encompassed roads and tracks of varying quality. Before the Romans built roads, the ancient trackways of Britain had followed the natural terrain, seeking the easiest ground to traverse. Such tracks often detoured around marshy areas, hills, or ravines. Romans did not like to waste effort building long, meandering roads, so they ignored the older routes, preferring instead to move in the straightest line possible except where major obstacles in the landscape left no choice. Since Roman roads usually connected such new places of military importance as forts, towns, and administrative centers, the old trackways often did not take the desired direction. There were a few exceptions. Silchester was one of the pre-Roman centers of British activity reused by the Romans. There, the old native roads connected to the new road system.

Laying roads, the shortest distance by going through obstacles, required a great investment of labor. If a hill stood in the way, the earth was hauled away until the land was leveled. If a wetland needed to be crossed, the earth was moved in to build a causeway (raised road). Construction was systematic. A dependable road requiring a solid foundation. Roman roads were constructed with thick layers of tightly packed stones and gravel sorted for size. The larger stones formed the bottom layer, while layers of progressively smaller gravel filled in and leveled the roadbed. The final result was well over 30 centimeters thick and resistant to the wear and tear of heavy traffic and severe weather. More important roads were elevated above the surrounding land surface and provided with ditches on both sides so that the road surface would never flood. Elevated roads were so well fabricated, they did not collapse or become rutted even in the worst rainy seasons. Upright curb stones buried in a line along the sides reinforced the road surface, keeping it stable. These elevated roadbeds formed the original highways of Britain and were much used until modern times.

Construction methods varied according to the official status of the planned road, but certain techniques were distinctly Roman. The careful layering and tight packing of selected gravels and other materials to form the roadbed is called metalling. Many different materials were used, depending on their availability and suitability to local subsoil conditions. Sand was added to keep the road from becoming too rigid and prone to cracking. In areas where iron ore was smelted into iron, the rock-hard chunks of slag, produced as a waste by-product during the smelting process, were added to the layering material. The iron content of the slag pieces had the added value of rusting over time. The rust would physically combine and harden with adjacent stones and sand to create an extremely solid, concrete-like mass. Heavily used roads were resurfaced from time to time. The final road metalling performed at the end of the fourth century sometimes resulted in a total road thickness of about a meter.

Roman roads in the fifth and sixth centuries continued to carry traffic, but roads did not choose their travelers. Historians speculate that the existing road system enabled a quick penetration of southeastern Britain by Germanic newcomers. The road system also allowed the entire population of Britain to move about in response to foreign threats and changing weather conditions. Townspeople left for the urban amenities of the European continent. Merchants sought markets and customers in safer jurisdictions, while farmers migrated to drier and warmer fields. The old Roman roads retained their importance in successive medieval centuries, too. Even where they did not remain in use as roads, the lines they imposed on the landscape often became boundaries for parishes and other significant administrative or private land units. The well-known Roman highway Watling Street in Northamptonshire now serves as the line for a number of modern administrative boundaries.

43.2: Group Foraging

Bluegill sunfish obtain food by flushing (forcing into the open) small aquatic insects from dense vegetation. Researcher Gary Mittelbach hypothesized that larger foraging (food searching) groups might flush out more prey and increase the average number of prey obtained per group member. He examined this hypothesis by experimentally manipulating the foraging group size of bluegill sunfish in a controlled laboratory setting. Mittelbach placed 300 small aquatic prey into a large aquarium containing juvenile bluegill sunfish. He examined the success of bluegills that were foraging alone, in pairs, and in groups (ranging from three to six bluegills). Mittelbach measured the number of prey captured per bluegill, and he found a positive relationship between foraging group size and individual foraging success (the larger the group, the greater the success) up to a group size of four fish. The increased feeding rate per individual was due to two factors. First, more prey were flushed when group size rose. Second, prey clumped together, so when one group member found prey, others swam over to this area and then often found food themselves.

While increased group size in bluegills does benefit each individual forager in its intake of food (its per capita of foraging success), there is no evidence to suggest that bluegill foragers hunt in any coordinated or cooperative fashion. The manner in which bluegills increase foraging efficiency in larger groups (that is, by flushing) is only one means of increased foraging efficiency through group living. For example, in a number of species, increased group size reduces the amount of time that any given individual needs to devote to antipredator activities-often, but not always, increasing per capita foraging success.

The general relationship between group size and foraging success uncovered by Mittelbach has been found over and over in animal studies. For example, Scott Creel ran an analysis on foraging success and group size in seven species that hunt in groups. Overall, Creel found a strong positive relationship between per capita foraging success and group size.

Individuals may cooperate with one another when hunting in groups. For example, when wild dogs hunt down an animal, it is a coordinated effort, with different members of the hunting pack playing different roles in the hunt: flushing the prey, making the initial attack, killing the prey, and so forth. In such cases, it is useful to separate the effects of cooperation from that of group size. To see how animal behaviorists disentangle such effects, let us examine hunting behavior in chimps. Cooperative hunting, or the lack of it, has been examined in chimp populations in the Gombe preserve in Tanzania, the Ma hale Mountains in Tanzania, and the Tai National Park in the Ivory Coast. The most comprehensive studies of cooperative hunting among chimps are those of Christophe and Hedwige Boesch, who compared hunting patterns across the Gombe and Tai chimp populations. Major differences in hunting strategies emerged between these populations.

In Tai chimps, a positive relationship was found between hunting success and group size in what is called a nonadditive fashion. That is, adding more hunters to a group did not simply increase the amount of food by a fixed amount for each new hunter added. Rather, with each new hunter, all group members received more additional food than they did when the last new hunter was added to the group (up to a limit). In addition to these group-size effects, Christophe Boesch found evidence of cooperation in Tai chimp hunting behavior. Very complex, but subtle, social rules exist that regulate access to meat and assure hunters—that is, those that actually cooperate during the hunt—-greater success than those who fail to join a hunt.

The situation was quite different with Gombe chimps—there was no positive relationship between group size and hunting success in chimps from this population. That is, no group-size effect was uncovered in the context of obtaining food. In addition, unlike in the Tai population, behavioral rules limiting a nonhunter's access to prey were absent, and such individuals received as much food as those that hunted cooperatively. Part of the difference in hunting behavior in Tai and Gombe chimps may be due to the fact that the success rate for Gombe solo hunters was quite high compared with the individual success rate for chimps in the Tai population.

44.1: Nutritional Changes in Human History

Although we now think of an optimal diet as one that promotes longevity (long life), historically, our optimal diet was whatever made us strong enough to have healthy children and then live long enough to help those children survive to do the same. The best measure of good nutrition is average height, which is about 80 percent genetic but is also strongly linked to childhood and adolescent calories and especially protein intake. Although big and strong people might out-hunt, out-gather, and even out-fight their smaller neighbors, they also need more calories. So people faced with chronic or recurrent food shortages are better off if they are short and lean. The small bodies of less-well-nourished humans are not only an effect of their lower intake of calories, protein, and calcium but also protection against the likelihood of even lower intakes in the future. By these metrics, our nomadic hunter-gatherer ancestors were remarkably well-nourished. Remains from the Paleolithic Stone Age (2.6 mya to 10,000 ya) show that men had an average height of about 179 cm (5 feet 10 inches) and an estimated weight of about 67 kg (148 pounds). The women were substantially smaller, averaging an estimated 157.5 cm (5 feet 2 inches) and 54 kg (119 pounds). After agriculture began about 10,000 years ago, in the Neolithic era, humans actually got smaller. Archaeological evidence suggests that the average Neolithic man was about 165 cm (5 feet 5 inches) tall and weighed 63 kg (139 pounds), while women were an average of 150 cm (4 feet 11 inches) and weighed 45 kg (99 pounds).

Paleolithic men were bigger than modern European men through the end of the nineteenth century and were as big as they are today. And when the Europeans came to North America, as supposedly well-nourished invaders from the most technologically advanced countries in the world, the indigenous hunter-gatherer population of the American plains was far taller than they were. Why would that be the case? It all came down to nutrition. The plains diet of the hunter-gatherers centered around grass-fed wild bison, whose meat was less fatty than meat from modern corn-fed animals. And the plains tribes ate pretty much the whole animal. By comparison, even when agriculturalists' crops provided enough calories to meet their energy requirements- -which probably were as high if not higher than those of hunter-gatherers because farmers often worked every day from dawn till dusk- they didn't provide as much protein or calcium as the hunter-gatherers' diets did. Even nuts generally have more protein per ounce than grains, especially domesticated grains. This is why agriculturists also looked to legumes- -beans, peas, and even peanuts- for their protein, much as modern vegetarians do. But it's a challenge to get enough protein from nonanimal sources, and it was even harder in the era before supermarkets.

Nutrition continues to correlate with human height today. The economist Richard Steckel compared the height of people living in Europe from the ninth through the nineteenth century by measuring the length of their thigh bones, or femurs, which account for about 25 percent of our height. He estimated that an average man in the early Middle Ages (5th-10th century A.D.) stood 174 cm (5 feet 8/z inches). But by the seventeenth and eighteenth centuries, when more people lived in cities, where there was less vitamin D (from exposure to sunlight) and fresh meat, the average man's height had declined to 167 cm (5 feet 5%4 inches)- a reduction of over 6 cm (2/z inches). And by the early twenty-first century, better nutrition explains why the average height of young men in affluent European countries increased to about 178 cm (5 feet 10 inches) on average.

In most societies, women are generally 10 to 13 cm (4 to 5 inches) shorter than men, regardless of the height of the men. In this context, the 21.5 cm (8%2 inch) difference in height between Paleolithic men and Paleolithic women was noticeably larger than the sex difference we've seen ever since. This large difference may have been because Paleolithic women didn't fully share in the protein bounty of the hunt, or perhaps became pregnant at a younger age, when they were still growing, and their growth was stunted by having to share their protein and calcium with a developing fetus.

44.2: Accounting for the High Density of Planet Mercury

Venus, Earth, and Mars are all thought to have formed from similar materials. Their iron cores take up similar fractions of the planets, and their silicate mantles- -the mantle is the layer of material between a planet's central core and its outer crust- -melt to produce similar kinds of volcanic rocks. By contrast, Mercury, the smallest and closest to the Sun of the four inner, or terrestrial planets, may have been formed from a different bulk composition, or it may have formed under different conditions than the other terrestrial planets. The planet has a huge iron core, indicating either that the planet contains at least twice the iron content of the other terrestrial planets or that virtually all the iron from the bulk composition was pulled into its core, leaving its mantle almost iron-free. At the same time, the planet shows no recent volcanic activity, and so, unlike Venus, Earth, and Mars, its interior can be assumed to be stationary. The lack of volcanic activity is usually taken to mean that the planet has largely finished losing its internal heat. Mercury, however, has a small magnetic field. Magnetic fields are generally accepted to be caused by fluid movements in the mantle caused by heat loss. Somehow, Mercury has created a balance that allows the generation of a magnetic field in the absence of mantle movements.

Mercury's average density is 341 pounds per cubic foot, just less than the densest planet, Earth, at 347 pounds per cubic foot. The planet's high density was first discovered by measuring the surprising acceleration of the Mariner mission toward Mercury in the grip of the planet's strangely strong gravity field. Earth is a much larger planet, and so its interior pressure is much higher, pressing the material into much denser forms. With the effects of pressure taken away, Mercury's density is actually much higher than Earth's, and it is, therefore, the densest planet in the solar system. The high density of the planet is thought to imply that it contains a lot of iron-more, by proportion, than any other planet. Iron is the most common dense inner solar system element, and it is likely to be responsible for the high density in Mercury. If Mercury's extra density is due to iron content, then Mercury has a core that is 60 percent or more by mass, the largest core relative to the planetary radius of any planet in the solar system. Mercury's core is probably 1,120 to 1,180 miles in radius, nearly 75 percent of the planet's diameter. This is at least twice the metal content of Venus, Earth, or Mars.

Current models for planetary formation suggest that any terrestrial planet should form with a large percentage of silicates, which would make up a thick mantle above the core, as they do on Venus, Earth, and Mars. Mercury may have lost most of its silicate mantle in some catastrophic event after its early formation. The simplest candidate for this event is a giant impact. If a large body struck Mercury more or less directly, then its iron would combine with Mercury's into an unusually large core, and much of Mercury's silicate mantle could have been lost to space. The impacting body may also have been made predominantly of metal, like an iron meteorite. In this scenario, the metal meteorite would combine with the early, small Mercury, creating a planet with an unusually large iron core. Alternatively, the silicate mantle could have been removed by vaporization in a burst of heat from the early Sun. A third possibility is that there may have been a strong compositional variation in the early solar system and that, in fact, Mercury formed with the iron-rich composition it now seems to possess. Finally, Mercury could have differentiated in a particularly oxygen-poor environment. Without oxygen, iron will preferentially form a metal and sink into the core rather than forming iron oxide and combining into silicate mantle materials. In this scenario, Mercury could have started with the same bulk composition and ended with its current structure without having endured a giant impact.

45.1: Polar Dinosaurs

Once there was an idea that dinosaurs were cold-blooded and only thrived in the swamps and wetlands of tropical climates. But the more we look, the more we realize dinosaurs were found in as many different kinds of habitats as birds and mammals are today. Polar dinosaurs, probably warm-blooded and feathery, were thriving roughly 70-100 million years ago in great polar forests, of which there is no modem equivalent. Fossils of such dinosaurs have been discovered in Siberia, specifically at the Kakanaut River on the Kamchatka Peninsula. The dinosaur remains found here over the years are mostly teeth, but also include some bones, and they reveal the presence of a variety of species. All of these remains are from the very end of the Cretaceous, 66- 68 million years ago, just before the mass extinction event that saw the extinction of the non-bird dinosaurs. "The material was fragmentary but showed that the Arctic dinosaurs were very diverse," says Pascal Godefroit, an expert on early birds and birdlike dinosaurs who has been involved in the work at the Kakanaut River.

The Kakanaut finds have been important in understanding the end-Cretaceous extinction event. This is in part because Kakanaut was within the Arctic Circle and just 1,600 kilometers from the North Pole at that time. Conditions then were warmer than today, but mean annual temperatures were still around 10 degrees Celsius, and there would have been frequent spells below freezing and many months of darkness. Dinosaur fossils found farther east across the Bering Sea in Alaska were left by creatures that endured similar climatic conditions, but some experts have argued that they migrated south in the winter to avoid the coldest months. At Kakanaut, researchers found fragments of eggshell from hadrosaur and theropod dinosaurs, which suggested that these animals were breeding in polar regions and living there year-round.

Many scientists argue that the dinosaurs went extinct as a result of Earth's collision with a massive asteroid or comet about 66 million years ago that created the Chicxulub Crater on Mexico's Yucatan Peninsula. Other scientists have claimed that falling global temperatures had led to a decline in dinosaurs around the world in the period before the impact (collision). However, the rich fauna (animal life) found by Godefroit and his colleagues suggests that not only had a diverse ecosystem of dinosaurs persisted in the Arctic in the late Cretaceous, but also that they were thriving in very cold conditions. The herbivores here must have fed on plants, such as conifers, that remained green year-round and also taken advantage during summer months of a profusion of nutritious fresh growth by plants bathing in light 24 hours a day.

"For the first time, we have firm evidence that these polar dinosaurs were able to reproduce and live in these relatively cold regions. There is no way of knowing for sure, but dinosaurs were probably warm-blooded just like modem birds, which are the direct descendants of dinosaurs," Godefroit told reporters when his findings were published in the German journal Naturwissenschaften in 2009. "The dinosaurs were incredibly diverse in polar regions- as diverse as they were in tropical regions. It was a big surprise for us."

Rather than dinosaurs slowly dying out due to climate change in the period before the impact, Godefroit believes that the discovery backs up the idea that dinosaurs were killed off in a rapid and brutal fashion by cataclysmic conditions that swept the world following the Chicxulub impact. Debris in the atmosphere may have blackened the skies for several years, killing off plants and destroying the food supply- -particularly as large herbivores (plant eaters), such as sauropod dinosaurs, required vast quantities of plant matter to fuel their massive bulk. Starved for meat, the flesh eaters would eventually have succumbed too, as herbivores disappeared.

It is likely that a combination of factors led to the demise of the non-bird dinosaurs, but the precise explanation remains a fascinating and enduring mystery. It had been thought that Siberia had a paucity of fossils in comparison to its southern neighbors, Mongolia and China, but recent discoveries suggest this may not be true.

45.1: Dating the Arrival of Humans in North America

Developed in the mid-twentieth century by Willard Libby and Jim Arnold, radiocarbon dating (used for dating organic materials) brought the chronology of North American prehistory into sharp focus. The method provided accurate ages for the deposits of organic material left behind by the last great ice sheets that covered the continent during the Pleistocene Ice Age, that began approximately 1.6 million years ago. One such deposit was determined to be 11,400 years old. Radiocarbon was also used to date the traces (indications of their presence) left by America's earliest human inhabitants, enabling scientists to map out the movements of people and glaciers and to investigate the interrelationships between the two. Libby's first attempts to analyze an ancient North American site included what archaeologists call the Folsom culture.

Folsom is a small town in northeastern New Mexico. In 1926-27, arrowhead-like stone points were found there, mixed together with bones from a now-extinct type of bison, a discovery that caused great excitement because it placed humans in New Mexico during the last glacial period, when bison were abundant. Beyond that general observation, however, there was no way to date the site. Eventually, additional "Folsom" sites were discovered in other regions, all characterized by the same distinctive stone points. A few of these were in places that could be correlated with specific glacial deposits, which, through a fairly weak line of reasoning, were thought to be between 10,000 and 25,000 years old. Most workers favored the older end of the range.

Arnold and Libby included a charcoal sample linked to the Folsom culture in their first published list of radiocarbon dates. The result was a surprise: 4,283 +/- 250 years B.P. (before the present). This was clearly much younger than any of the earlier estimates suggested, and if the date held up, it would mean that what appeared to be one of the oldest Native American cultures was actually quite recent. Although they were confident about their analysis procedures, Libby and Arnold were suspicious of the result and wondered if the sample had been contaminated with young carbon, or if there was some other difficulty they were unaware of. In the end, it turned out to be a classic case of improper sampling, and an example of the importance of careful field documentation. When the charcoal was collected in 1933 (it had been stored away from then until the analysis), it appeared to be lying within a soil layer that contained both animal bones and the distinctive Folsom stone points. But the unexpectedly young age prompted a reexamination of the site, and it was determined that the charcoal came from a channel that cut into and through the older layers. Although it appeared to be at the same level as the bones and stone points, it was actually much younger. Once this problem was recognized and new samples from this and other sites were analyzed, it became clear that the most reliable Folsom ages fell in the range of 10,000 to 11,000 B.P.

However, it was also discovered that Folsom sites are not the oldest evidence of humans in North America. At some localities, slightly different varieties of stone hunting points occur; initially, it was thought that these were simply regional variations, or perhaps weapons used for hunting different types of animals. But, in some places- notably at Clovis, New Mexico-they appear in layers that lie beneath the typical Folsom points. This indicated that they were older, and soon, archaeologists began to distinguish between Clovis and Folsom cultures. Obviously, Clovis sites became another target for radiocarbon dating, and the results confirmed their antiquity. Clovis sites consistently gave dates that were a few hundred years older than those characterized by the Folsom artifacts, and there seemed to be little or no overlap between the two cultures.

With these results, the radiocarbon dates of both glacial deposits and archaeological sites in North America seemed to be painting a consistent picture. As the last severe glaciation of the Pleistocene Ice Age lost strength, early people spread into the United States. Clovis people were the first widespread hunters, making distinctive stone points for their weapons and hunting large game such as mammoths. Within a few hundred years, however, a new culture appeared, making smaller and finer stone points and apparently taking over from its Clovis predecessors as the dominant hunters in North America.

46.1: Industrialized Moths

When most people think of evolution, they imagine slow, incremental changes in a population of plants or animals. But evolutionary changes can also appear suddenly. This is illustrated by the most famous example of natural selection at work- the changing coloration of the peppered moth (Biston betularia). The story of this population of light-colored moths that turned dark and then light again in response to environmental change is an elegant example of Darwinian evolution at work. What happened to the peppered moth reminds us how easily populations can adapt to new conditions in times of environmental stress.

The peppered moth, easily recognizable by its distinctive off-white wings peppered with black specks, is common in England, where its preferred daytime environment is light-grey, lichen-covered trees. The species, which includes a variety of color gradations from dark to light, has always been popular with insect collectors because it's easy to preserve and because the specimens generally maintain their color after death. Before 1850, most of the specimens netted by English collectors were a speckled light grey-roughly the color of the lichens (organisms that often cover the bark on trees). But then, the collectors noticed a change: increasingly, the moths they captured had dark wings, and many of them were almost totally black. British entomologists (scientists who study insects) were fascinated by this rapid change in the peppered moth population, especially when they realized that it was almost entirely restricted to polluted industrial areas. They began to realize that what they were seeing was the process of evolution through natural selection.

Because the light grey moths resembled the lichens on the trees, they were relatively safe from their main daytime predators, birds. But the darker moths were easy to see, and this disadvantage limited the percentage of genes for dark coloration in the peppered moth gene pool. When, in the mid-nineteenth century, industrial pollution in England began turning the lichen on the tree trunks black, the darker moths were suddenly protected while the light-colored moths became vulnerable. As more and more dark moths survived, the gene pool shifted toward darker coloration. Similar examples of industrial melanism, a darkening in color linked to a rise in industrialization, were identified in Europe, Japan, the United States, and Canada.

For about a century, dark-peppered moths continued to dominate the populations. Then, in the 1950s, scientists noticed that the gene pool was rapidly shifting back toward the lighter coloration. As a result of antipollution legislation, the air was cleaner, the lichen on the tree trunks was becoming lighter, and so were the moths. In fact, this second shift in the gene pool was so radical that many entomologists believe the genes for dark coloration may disappear completely, and that soon the dark-peppered moths will be extinct.

The story of peppered moth evolution is so simple that many evolutionary biologists and entomologists have wondered if it could possibly be true, and several of them have tested it. Although the results of their experiments have been reported in the popular press as falsifying Darwinian evolution, what they actually revealed both supports the main points of Darwinian evolution and emphasizes its complexity. The coloration of the peppered moth population definitely shifted in response to environmental factors, but almost every aspect of the process was more multifaceted than anyone thought. During the day, peppered moths rest on a number of locations besides tree trunks. Moths' survival is less dependent on their coloring than was originally assumed. It also turns out that the changes in the peppered moth gene pool didn't parallel the changes in pollution levels as closely as had been reported- -migration, as well as bird predation, also had an effect on the ratio of dark to light forms. In short, far from illustrating the elegant simplicity of natural selection, the story of the peppered moth highlights its elegant complexity, and reminds us that even simple evolutionary changes aren't easy to trace.

46.2: Brick Technology in Mesopotamia

One of the earliest civilizations was that of Mesopotamia (part of the present-day Middle East), including Sumer and Assyria. Some of its buildings survive to this day. Sun-dried bricks made of mud and straw were its main building materials, as river mud was found in abundance along the Tigris and Euphrates Rivers. Here, the scarcity of stone may have been an incentive to develop the technology of making oven-fired bricks to use as an alternative. To Strengthen walls made from sun-dried bricks, fired bricks began to be used as an outer protective skin for more important buildings like temples, palaces, city walls, and gates. Making fired bricks is an advanced pottery technique. Fired bricks are solid masses of clay heated in ovens to temperatures of between 950 and 1,150 degrees Celsius, and a well-made fired brick is an extremely durable object. Like sun-dried bricks, they were made in wooden molds, but for bricks with decorations, special molds had to be made. Unlike the river mud used for sun-dried bricks, the clay for proper bricks needed to be carefully prepared, and building an oven, finding suitable fuel, and controlling oven temperatures required a professional level of skill and know-how. This is perhaps the reason why the use of fired bricks came in gradually over time.

The technical complexities involved in making fired bricks may explain why one of the first recorded instances of pieces of fired clay, used as a protective covering for mud-brick walls at the Sumerian city of Uruk in southern Mesopotamia in 3600- 3200 B.C., did not involve bricks but small clay cones. Uruk was one of Mesopotamia's first cities and had an important temple complex at its center, known as the Eanna precinct. Here was found the Limestone Temple, which was connected to a second temple via a courtyard. In this courtyard was a terrace with massive pillars made of mud and bundled reeds. To protect them from weathering, thousands of nail-shaped ceramic cones were pushed into an outer bed of clay. The cones have flat tops and were painted red, white, or black and arranged in such a way that they formed geometric patterns. What is so significant about this is that here we find, perhaps for the first time, fired clay as a practical protection against the environmental effects of rain and wind, safeguarding the columns from deterioration as well as creating an ornamental surface decoration.

Over time, fired bricks also came to be used in Uruk as a building material and for decorative purposes. An example is the temple of Inanna, the goddess of fertility, built by King Karaindash at the end of the fourteenth century B.C. The exterior of the temple was constructed of fired bricks with alternating projections (structures extending from the temple) and recessions (hollow areas). In the recessions were brick statues of gods holding vessels from which flowed streams of water.

Assyrian kings used fired bricks for the construction of ziggurats (a series of rectangular terraces of decreasing size), palaces, and gateways. Some fine examples have survived from the city of Nimrud in northern Mesopotamia, where in the ninth century B.C., temples and palaces were decorated with fired bricks during the reigns of the Neo-Assyrian kings Ashumasirpal II (883- 859 B.C.) and Shalmaneser III (859- -840 B.C.). A glazed tile was found at Nimrud at one of the palaces, which shows a king attended by servants and bodyguards, and probably represents Ashumasirpal II, who rebuilt Nimrud during his reign. Similar compositions of Assyrian kings attended by their servants can also be found on stone-relief carvings of that time.

Bricks with cuneiform script provide important written information about the history of the period. Cuneiform is the oldest known form of writing and dates from around 3200 B.C. Text was imprinted with a small stick or reed pen into the soft clay, which was then left to harden in the sun, or sometimes fired to become a permanent record of the royal, religious, military, or economic history of the various Mesopotamian kingdoms. Cuneiform became the basis for all subsequent Sumerian, Akkadian, Assyrian, Babylonian, and Persian writing. It was frequently used to record royal deeds, as on the clay tablets excavated at the ziggurat attached to the temple of the god Ninurta, a prominent building in Nimrud.

47.1: The Early History of Jupiter

The Sun and all planets in the solar system formed from the same cloud of interstellar material known as the solar nebula. However, the size and composition of the four outer Jovian planets (Jupiter, Saturn, Uranus, and Neptune) radically differ from those of the four terrestrial planets, which are closest to the Sun (Mercury, Venus, Earth, and Mars). Whereas the inner planets are composed mainly of heavier elements, the Jovian planets are much larger and contain a much higher proportion of the light gases hydrogen and helium. Jupiter, with its mass of around 300 times that of Earth, is the largest planet in the solar system and is the closest Jovian planet to the Sun.

It is generally believed that Jupiter's formation began with the accretion (the coming together of material under the influence of gravitation) of a solid core. This core grew by collision and sticking of dust, ice, rocks, and larger bodies- -a process similar to the accretion of Earth. Jupiter, however, formed outside, or beyond, the “snow line," a special place in the solar system where water vapor condensed (solidified) to form ice grains, and the presence of “snow" in this region would enhance the density of solid matter and accelerate the accretion process. The mystery is why the proto-Jupiter (early Jupiter) grew so rapidly. Apparently, Jupiter grew to a mass of 15 Earths before Mars grew to 10 percent of an Earth mass. Planetary scientist David Stevenson has suggested that outward migration of water vapor and condensation at the “snow line" may have provided larger concentrations of solid matter at this location, thus speeding up the formation of the early Jupiter.

Jupiter's growth into a giant planet began when the rock-ice core mass reached 15 Earth masses. At this mass, the gravity of the core can pull in and hold hydrogen and helium, the light gases that account for 99 percent of the mass of the nebula. When this gas accretion process begins, it is very dramatic because the rate of accretion of gas is proportional to the square of the mass already accreted. In other words, the bigger it gets, the faster it grows. If gas could be continually fed to it, it would consume the Universe in a relatively short time! What actually happens is that Jovian planet formation depletes its feeding zone (the area from which a forming planet can accumulate material) of matter, which, in turn, truncates planet formation. And although the general properties of this process might be modeled, it just seems to have been by chance that our Jupiter formed as it did.

Because Jupiter's gravity efficiently scatters bodies that approach it, it cleans our solar system of dangerous Earth orbit-crossing asteroids and comets (objects orbiting the Sun that are smaller than planets), thus having a beneficial influence on life on Earth. However, it appears that we have been quite lucky that Jupiter in our solar system has maintained a stable orbit around the Sun. A Jupiter and a giant neighbor like Saturn (the second planet outside the “snow line" and the second largest in the solar system) are a potentially deadly couple that can lead to disastrous situations where a planetary system can literally be torn apart. Recently, it has become possible to use powerful computers to determine the stability of the orbits of Jupiter and Saturn over the lifetime of the planetary system. There are minor chaotic changes but no major changes, and the solar system, at least to a first approximation, is stable over its lifetime. However, this would not be the case if either Jupiter or Saturn were more massive or if the two were closer together. It would also be dangerous to have a third Jupiter-sized planet in a planetary system. In an unstable system, the results can be catastrophic.

Gravitational perturbations (destabilizing interactions) among the planets can radically change orbits, making them noncircular. Although instability might start with just two planets, the effects would spread to them all, and the resulting repeated changes in distance between a planet and the central star would prevent any of them from having the persistence of conditions required for a stable atmosphere, ocean, and complex life, such as plants and animals.

47.2: The Economic and Cultural Impact of Plant Diseases

Plant diseases have affected people for as long as humans have grown crops. The ancient Romans even had a god, Robigus, whom they needed to placate in hopes of preventing wheat rust, a disease caused by a fungus that affects wheat, barley, and rye stems, which can cause a significant decrease in crop yield. Probably the most famous example of a plant disease was the late blight of potatoes, which devastated the potato crop in Europe and especially Ireland in the mid-nineteenth century. A large proportion of the people in Ireland were completely dependent on potatoes for subsistence, and as a result of the blight, Ireland lost about a quarter of its population to famine and emigration. It is now known that plant diseases are caused by the same types of organisms, or pathogens, that cause human and animal diseases, including bacteria, fungi, and viruses.

The discovery of evidence that plant diseases are caused by microscopic organisms was contemporary to discoveries substantiating the theory that infectious animal diseases are caused by microbes. In 1878, fire blight, a disease of pears and apples, was determined to be caused by a bacterium, a discovery that came only two years after the German physician Robert Koch had confirmed that anthrax, a disease of livestock, is caused by a bacterium. The first evidence that infection with a virus, a pathogen smaller than bacteria, can result in disease came from an experiment with the tobacco mosaic virus, which can infect tobacco as well as tomato plants. The experiment, which was performed in the 1890s, showed that sap from a diseased tobacco plant was still infectious after having been passed through a filter with pore sizes small enough to prevent the passage of bacterial cells.

Some plant pathogens, such as the organism responsible for cedar-apple rust, must infect an intermediate, or alternate host before they can complete their life cycle on the economically important host (in this case, the apple). For this disease, the alternate host is red cedar, on which the fungus overwinters. Therefore, the elimination of red cedar trees was advocated to help reduce the incidence of the disease. These kinds of relationships with intermediate hosts are not unique to agents infecting plants. Both yellow fever and malaria require an incubation period of roughly ten days in the mosquitoes that transmit them before infection of new human hosts can occur.

Perhaps the most bizarre example of a plant disease affecting the economy of a country was the appearance of streaks or featherings of darker colors on a lighter-colored background in tulip flowers in Holland. These symptoms became known as color breaking. The bulbs of these tulips, which in reality were infected by a plant virus, became highly prized. Prices for these infected bulbs initially skyrocketed but then suddenly fell in 1637, resulting in the collapse of Holland's economy, which had become excessively dependent on tulip exports. The coffee rust outbreak and its aftermath in Ceylon (now Sri Lanka) in 1875 had a lasting cultural impact. Ceylon had come under British control about 50 years earlier, and most of the island consisted of coffee plantations. The coffee rust fungus destroyed the coffee plants, and the plantations switched to growing tea bushes.

As a result, drinking tea became an integral part of British culture.

Prevention of plant diseases is achieved by several methods, such as chemical treatment and altering the plants' genes to make them disease resistant. The first chemical treatment was discovered in the nineteenth century when botanist Pierre-Marie- Alexis Millardet was studying an outbreak of downy mildew, a devastating disease of grapes, in vineyards in the Bordeaux region of France. During his investigation, he noted that even in infected fields, vines closest to the road were not affected by mildew. He eventually learned that farmers had sprayed the vines near the road with a visible and bitter-tasting mixture of copper sulfate and lime so that passersby would not eat the grapes. Soon this mixture, known as the Bordeaux mixture, became a common means of preventing downy mildew.

48.1: Shoaling Behavior

A shoal is any group of fish that remain together for social reasons. A shoal may be a school (a coordinated group with synchronized movements) at some times and a less organized mass at others. Shoaling is of considerable interest because of its prevalence, and various hypotheses have been put forward to explain it: increased efficiency of movement in water (hydrodynamic efficiency), increased efficiency of food finding, reproductive success, and reduced risk of predation.

The idea that shoaling increases the efficiency of swimming applies mainly to schooling. This idea is very appealing, both because of the regular spacing that seems to characterize fish in schools and because fish in shoals tend to be uniform in size. To gain hydrodynamic advantages, however, each fish must maintain rather precise positioning within a school to use the hydrodynamic lift created by its neighbors. By and large, measurements of fish positions within schools in the laboratory have not found this to be true. Nevertheless, the regular spacing of fish in schools observed in the wild indicates that being in a school probably does have a hydrodynamic advantage- -at least for fish that are behind other fish. Some scientists argue that the leadership of a school is constantly changing, because while being immersed in a school incurs hydrodynamic advantages to individuals, leaders of schools are first to find food, which is also advantageous.

Schooling by predators increases the probability of their detecting a school of prey, just as shoaling in planktivores (fish that feed on plankton, the very small plants and animals in the water) increases the probability of detecting suitable patches of plankton. The reason for this is the presence of many searching eyes over a large area. Fish in shoals share information by monitoring each other's behavior. Feeding behavior in one fish quickly stimulates food-searching behavior in others. For planktivores, however, this advantage may be decreased by having to share the patch with many other fish: fish in the rear of a school are likely to encounter much lower densities of plankton than those in the front as well as higher concentrations of waste products from their schoolmates.

For fish that shoal throughout their lifetimes, little energy has to be expended in finding a mate when spawning time comes. Presumably, shoaling also allows fish to closely synchronize their reproductive cycles (through behavioral and hormonal cues). In addition, for fish that migrate long distances to breed, schooling may increase the accuracy of finding the way home, because the average direction sought by fish in a school is likely to be a better choice than that chosen by an individual migrating alone. For tunas, with habitual migration routes, this means that groups of individuals may stay together for long periods.

Shoaling reduces predation risk in two main interacting ways: by confusing predators and by providing safety in numbers. When predators attack, large shoals are particularly advantageous because of the reduced probability that any one individual will be eaten; in any given attack, a smaller percentage of a large shoal will be eaten compared to a small shoal. The confusion effect is based on the common observation that shoaling fish tend to get eaten mostly when they have been separated from the shoal; many attack strategies of predators can thus be best interpreted as efforts to break up shoals so that individuals can be picked off. Shoaling fish are the same size and silvery, so it is difficult for a visually oriented predator to pick an individual out of a mass of twisting, flashing fish and then have enough time to grab its prey before it disappears into the shoal. Shoaling fishes also are fairly uniform in size and appearance, a further factor confusing predators. Individuals that stand out (for example, because of heavy parasite infestations) are quickly picked off. Even when shoals are made of several species, individual fish are similar in size, although the species may remain segregated within the school. Thus, it has been noted that banded killifish, golden shiner, and white sucker shoal together, but that the killifish occupy the top of the shoal, the shiners the middle, and the suckers the bottom.

These shoal positions reflect the preferred feeding areas of the three species (surface, mid-water, and bottom, respectively).

48.2: Pleistocene Overkill

Around 11,000 years ago, near the end of the Pleistocene era (2.6 million to 11,700 years ago), most megafauna -large, mostly herbivorous (plant-eating) land animals- went extinct in North America. Their disappearance has been the topic of much debate, but considerable evidence supports a hypothesis known as “Pleistocene overkill." The idea is that, as humans spread across the continent, they preyed upon large herbivores, such as woolly mammoths, ground sloths, and tortoises, and wiped them out. As originally formulated by the American geoscientist Paul Martin, the large mammals were driven to extinction in a few hundred years in a massive, fast-moving event. A newer version of the hypothesis posits that the extinctions were more gradual, based on evidence that, in some areas, humans and large animals coexisted in the same habitats for long periods of time, despite hunting. However, the end result was the same: the extinction of the megafauna. Large animals are more vulnerable to extinction than smaller ones because they cannot hide easily from human predators and because they reproduce quite slowly. It is possible that the large animals were also relatively unafraid of human beings since they would have evolved for hundreds of thousands of years without humans present. In addition, there is some indication that a rapid shift in climate reduced the habitats of many of the giant herbivores, making them more vulnerable to human predation. Likewise, Australian biologist Tim Flannery suggests humans may have changed the environment through their actions, especially by increasing the frequency of fires.

Not unexpectedly, when the large herbivores disappeared, their natural predators, such as saber-toothed tigers and short-nosed bears, became extinct as well. The large scavenger birds, which had adapted to eating the remains of large animals, also followed them into extinction. The California condor may have held on because it had access to the carcasses of large marine mammals, such as whales and sea lions, which did not go extinct at this time. The loss of these giant animals also impacted the diversity of smaller animals. Because abundant large animals (such as mammoths and tapirs) alter plant communities by the way they graze (feed on plants), their disappearance would have caused a shift in the plant communities, resulting in the extinction of many smaller species that depended on the habitats maintained by the large grazers. In fact, there existed a grassland ecosystem in Alaska called the mammoth steppe that disappeared entirely once the woolly mammoth went extinct in that region.

The idea of the Pleistocene overkill is quite controversial, yet the principal alternative to explain the rapid loss of all these giant animals is a drastic climate change that occurred when the last ice age ended near the end of the Pleistocene. Recent fossil data and archeological discoveries increasingly support the idea that the early native people were responsible for the extinction of many species. One of the early groups (but not the first) to colonize North America was the Clovis people. At Clovis archeological sites, researchers have found distinctive, beautifully made stone spearheads that would have been well-suited to killing large herbivores. These same Clovis spearheads have been found embedded in the skeletons of large animals, which strongly suggests that these animals were hunted by the Clovis people. Clovis culture rapidly spread throughout North America, and then abruptly disappeared after about 300 years- -a disappearance that seems to coincide with the extinction of many (but not all) of the large animals of interior North America.

Additional support for the overkill idea comes from the growth rings of mammoth tusks at the time of the mammoths' extinction, which indicate that the animals were eating well and not experiencing the starvation that would normally accompany climate-driven extinction. Also, many of the extinct species of megafauna had already survived several other glacial climate cycles during the previous 100,000 years, and so presumably, they could have survived one more. It is worth noting that a similar event occurred in Australia, with early human societies apparently wiping out many species of giant marsupials, as well as on islands throughout the world. If we accept some version of the Pleistocene overkill hypothesis, then we also have to accept the idea that early hunter-gatherer societies were capable of having large and permanent effects on their environment.

49.1: The Absence of Snakes in Ireland

According to legend, Ireland in northern Europe has no snakes because a fifth-century monk named Patrick drove the island's snakes into the sea. In reality, Ireland has no snakes because of the interplay between organisms and their physical environment.

Snakes, like all reptiles and amphibians, are ectotherms (cold-blooded): their body temperature and functionality are dictated by the temperature of their external environment. Species diversity of reptiles decreases rapidly from the equator toward the higher latitudes. In North America, the number of lizard species is highest in the warm desert regions of the southwest and declines continuously as you move northward. The same pattern of species diversity is evident in Europe, where the number of reptile species declines markedly as you move from the warmer Mediterranean coast toward northern Europe and the British Isles. Although one snake species, the European adder (viper), is found above the Arctic Circle in Scandinavia, its unusually northern distribution comes at a cost. The adder has a very limited period of activity, often only three to four months a year. In addition, the species may take up to four years to attain sexual maturity, and females may breed only once every three or four years, using the intervening period to build up the fat reserves necessary to produce offspring.

The progressive decline in solar radiation and temperatures from the tropics to the poles not only reduces the abundance and diversity of reptiles but also has a direct influence on their body size. The reason for these patterns is that heat exchange occurs across the surface of a body, but warming usually occurs throughout the entire body's mass or volume. Large bodies, because of their low surface area to volume ratio, take longer to warm than smaller ones. This physical reality results in upper limits to the size of snakes (and other reptiles) depending on the distance of the snake's habitat from the tropics. All of the large snakes, such as the anaconda and python, are found within the tropic and subtropical regions. Other large reptiles- such as the iguanas, monitor lizards, and the crocodilians (alligators, caimans, and crocodiles)- -are likewise limited in their distribution to the warm, aseasonal environments of the subtropics and tropics. The maximum body size for ectotherms declines as you move north and south from the equator. This pattern is the exact opposite of that observed for endotherms (warm-blooded animals), where average body size increases from the tropics to the poles, a pattern referred to as Bergmann's rule. The environmental constraint on the upper limit of body size for ectotherms is at the very heart of the current debate over whether the dinosaurs were cold- or warm-blooded. The fossil record places the dinosaurs well into the northern latitudes, with specimens found in Alaska and Siberia.

As for snakes, the fossil record reveals that the diversity of reptiles and amphibians (terrestrial ectotherms) has always been low in northern Europe. During the Pleistocene epoch (from 2.6 million to 11,700 years ago), a time when the temperature of Earth was considerably lower than that now observed, much of the Northern Hemisphere was covered by glaciers. Although certain refugia (small pockets of land not covered by ice) existed, the massive ice sheet virtually obliterated all life in northern Europe, including Ireland and Britain. As temperatures rose and the glaciers retreated during the Holocene epoch (11,700 years to the present), the region was recolonized by plants and animals, but the cool temperatures of northern Europe proved inhospitable to most snakes. Nevertheless, the island of Britain, similar in climate to Ireland, ended up with three species of snakes that survive there to this day.

Three species of snakes is a paltry sum, but nonetheless, it is more than Ireland has. Why the difference? After the retreat of the continental glaciers at the end of the last ice age, Britain had a land bridge connecting it with the mainland of Europe, whereas Ireland did not. The limited diversity of snakes on the mainland meant that the pool of species available to recolonize both Britain and Ireland was small in the first place. However, Ireland's lack of a land bridge with continental Europe, coupled with the limited dispersal abilities of most snake species, have to date, prohibited their successful recolonization there.

49.2: Early European Tapestries

Tapestries, handwoven textiles made with different colored threads to produce designs or images, were highly popular in Western and northern Europe between the thirteenth and seventeenth centuries. The nobility at the time usually lived in big, austere, drafty castles, and tapestries provided comfort and warmth. They could be hung on cold walls or used to cover doors and windows. Noble families often did not have a permanent home, instead moving periodically among several locations. Tapestries, which were expensive, were usually packed and moved each time, bringing with them a sense of luxury and familiarity.

Some of the most famous tapestries were woven from wool in Flanders (modern Belgium), a region well-placed for tapestry production. Many of the plants that supplied dyes grew there. The leaves of the woad plant were used to make blue, and the madder root provided red. Yellow came from different materials, including onion skins and lemon peels, though most of these yellows faded quickly, thus also affecting the quality of green, which is a mixture of blue and yellow. High-quality wool was not produced in Flanders but was readily imported from nearby England.

Because of a long history of textile production, Flanders already boasted many skilled weavers and dyers when tapestry production began to increase, and this advantage grew in the late fifteenth century because of unrest in Flanders' southern neighbor, France. Originally, Paris had been a center of tapestry production, but the turmoil produced by the Hundred Years' War between England and France (1337- 1453) caused many textile workers to relocate to Flanders or to the city of Arras, which was then a part of the Duchy of Burgundy. Following the death of the Duke of Burgundy in 1477, the French king Louis XI conquered the territories around Arras. Its inhabitants, still loyal to Burgundy, then expelled all the French who had lived in the city. In retaliation, Louis attacked the town and, in turn, expelled the inhabitants loyal to Burgundy, including the textile workers, many of whom fled to Flanders. Paris regained some of its strength in tapestry production in the seventeenth century when Louis XIV established the famed Gobelins workshops there.

Tapestries were initially used mostly for warmth, but their visual aspect later gained importance. Tapestries often tell a story. Many early tapestries were hung in churches and cathedrals; these often featured biblical scenes and were used for teaching or religious devotion. However, the use of tapestries in churches later declined with the rise of Gothic architecture. Because this new style emphasized light, churches had many more windows than before, reducing the space for tapestries. In homes, tapestries were still prized; they tended to show complex, varied scenes in vivid colors and provided visual unity to rooms. Historical or mythical scenes were popular, including depictions of heroes and heroines from Greek mythology and figures from European legend. Among the most famous tapestries is a set of six called The Lady and the Unicorn, now in the Cluny Museum in Paris. These tapestries, done in the intricate millefleurs design (with a background of many small flowers), all show an elegant lady accompanied by a unicorn and a lion. Five of them likely represented the senses, but the meaning of the sixth, bearing an inscription sometimes translated as“my sole desire," is debatable.

Tapestries were often used as symbols of power and success. A nobleman would sometimes commission a tapestry showing historical or mythical scenes that lent his family legitimacy or commemorated a battle his family had won. Because these tapestry pieces declared status, they were often finer than other kinds of tapestries, sometimes made with gold or silver thread. One magnificent group of tapestries, called the Apocalypse of Angers, was commissioned by the Duke of Anjou (France) in 1375. In Christian narratives, the Apocalypse is the final battle between good and evil, which is symbolized in the tapestry by various images, like battles between angels and beasts. Some of the angels are holding flags showing the Cross of Anjou, a symbol of the duke's territory. The tapestries were probably designed to represent the duke's wealth as well as to reinforce his authority as a ruler.

50.1: Sexual Dimorphism in Lamprologus Callipterus

Lamprologus callipterus is one of over 300 species of cichlid (a freshwater fish) found only in Lake Tanganyika in Africa. Most African cichlids, including L.callipterus, exhibit sexual size dimorphism-the males are larger than the females. What is unusual about L.callipterus is the magnitude of the size difference. The key to understanding the sexual dimorphism of L.callipterus lies in the reproductive behavior of the species, particularly spawning (release of eggs by females and release of sperm by males) and brooding (protection of eggs). Female L.callipterus spawn and brood their eggs in empty snail shells on the lake bottom. In all other shell-brooding cichlids, both sexes enter the shell to spawn, and thus, both must be small enough to fit into the shells available on the lake bottom. In L.callipterus, however, only the females enter the shell to spawn and brood their eggs. The males remain outside, releasing their sperm only at the entrance to the shell. Consequently, female L.callipterus are small enough to fit into the shells, but the males, unconstrained by the need to enter shells, are much larger.

Spawning and brooding inside shells puts females in an evolutionary dilemma with respect to their body size. In cichlids, as in most fishes, the number of eggs spawned per batch (the fecundity) increases with female body size, and this favors females that grow large. In L.callipterus, the correlation between female length and the number of eggs spawned is as high as 0.95, which means that more than 90 percent of the variation in fecundity among females can be explained by differences in body length. Further, because fecundity is more a function of body volume than length, it increases disproportionally as body length increases. In one study, for example, an increase in female length from 3 centimeters to 4 centimeters was associated with an increase in fecundity from 59 to 134 eggs. In addition to this huge fecundity boost, larger females are able to exclude smaller females from access to the larger, preferred shells and so gain in the competition for spawning sites. All this suggests that female L.callipterus should be large, but this is where the dilemma comes in. No matter how beneficial the large size might be, the scarcity of large shells ultimately limits the size that females attain in a given population. In laboratory experiments, females actually adjust their growth rates so that their body size at maturity matches that of the available shells, and in the wild, the correlation between shell size and female size explains more than 98 percent of the variation in female size among populations. The ultimate size of female L.callipterus is thus a compromise between growing as large as possible to maximize fecundity and remaining small enough to be able to find suitable shells for spawning and brooding their young.

Finding shells large enough for brooding is so critical for female L.callipterus that, when they are ready to spawn, they generally pay more attention to choosing shells than to choosing mates. Males have adopted a unique strategy to exploit this female choosiness. Rather than trying to attract females from afar with flamboyant displays, male L.callipterus entice females to mate with them by assembling piles of empty snail shells. They set up small territories, less than a meter in diameter, and each territory is centered on a patch of shells. In most areas of the lake, these patches of shells are separated by stretches of sandy or rocky bottom devoid of shells. The males create this patchy distribution by picking up and carrying shells from as far away as 20 meters. In addition to clearing the surrounding area of abandoned shells, territorial males frequently steal shells from the shell piles of other males, sometimes with females and offspring inside. When this happens, the female and her offspring usually disappear, and the empty shell becomes available for a new female in the territory of the male relocating the shell. The effect of this remarkable shell transporting is to create artificial clumps of shells surrounded by unsuitable stretches of lake bottom. When females are ready to spawn, they have to visit the shell piles of territorial males to find suitable shells, thus creating spawning opportunities for males.

50.2: Weather Forecasting

Because the many variables that affect weather are constantly changing, meteorologists have used high-speed computers to devise atmospheric models that describe the present state of the atmosphere. These are not physical models that paint a picture of a developing storm; they are, rather, mathematical models consisting of dozens of mathematical equations that describe how atmospheric pressure, winds, and moisture will change with time. Actually, the models do not fully represent the real atmosphere but are approximations formulated to retain the most important aspects of the atmosphere' s behavior.

Computer-generated forecast charts using these models to interpret recorded weather data are known as prognostic charts, or simply progs. At present, there are a variety of models, and hence progs, from which to choose. One model may work best in predicting the position of troughs (elongated areas of low barometric pressure) in the upper atmosphere. Another may forecast the position of surface lows quite well. And some models even forecast the state of the atmosphere 384 hours (16 days) into the future.

A good forecaster knows the idiosyncrasies of each model and carefully scrutinizes all the progs. The forecaster then makes a prediction based on the guidance of the computer. This prediction is a personalized practical interpretation of the weather situation given the local geographic features that influence the weather within the specific forecast area. Since the forecaster has access to hundreds of weather maps each day, why is it that forecasts are sometimes wrong?
Unfortunately, there are flaws inherent in computer models that limit the accuracy of weather forecasts. Computer-forecast models idealize the real atmosphere, meaning that each model makes certain assumptions about the atmosphere that may be accurate for some weather situations and be way off for others, so a forecaster who bases a prediction on an inaccurate prog may find a forecast of rain and wind turning out to be a day of clear and colder weather.

Another forecasting problem arises because the majority of models are not global in their coverage, and errors are able to creep in along a regional model's boundaries. A model that predicts the weather for North America may not accurately treat weather systems that move in along its boundary from the Pacific Ocean. Obviously, a good global model of similar sophistication would require an incredible number of computations.

Even though many thousands of weather observations are taken worldwide each day, there are still regions where observations are sparse, particularly over the oceans and at higher latitudes. Temperature data recorded by satellites have helped to alleviate this problem, as the newest satellites are able to provide a more accurate profile of temperature for computer models. Since the computer's forecast is only as good as the data fed into it and since observing stations may be so far apart that they miss certain weather features, a denser network of observations is needed, especially in remote areas, to ensure better forecasts in the future.

Another forecasting problem is that computer models cannot adequately interpret many of the factors that influence surface weather, such as the interactions of water, ice, and local terrain on weather systems. Some models do take large geographic features such as mountain chains and oceans into account, while ignoring smaller features such as hills and lakes. These smaller features can have a marked influence on the local weather. Given the effect of local terrain, as well as the impact of some of the other problems previously mentioned, computer forecasts presently do an inadequate job of predicting local weather conditions, such as surface temperatures, winds, and precipitation.

Even with a denser network of observing stations and near-perfect computer models, there are countless small, unpredictable atmospheric fluctuations that fall under the heading of chaos. These small disturbances, as well as small errors (uncertainties) in the data, generally amplify with time as the computer tries to project the weather further and further into the future. After a number of days, these initial imperfections (errors) tend to dominate, and the forecast shows little or no skill in predicting the behavior of the real atmosphere.

51.1: Class Structures in Postwar Europe

Rapid economic growth went a long way toward creating a new society in Europe after the Second World War. European society became more mobile and more democratic. Old class barriers relaxed, and class distinctions became fuzzier.

Changes in the structure of the middle class were particularly influential in the general drift toward a less rigid class structure. In the nineteenth and early twentieth centuries, the model for the middle class had been the independent, self-employed individual who owned a business or practiced a liberal profession such as law or medicine. Ownership of property- -very often inherited property- -and strong family ties had often been the keys to wealth and standing within the middle class. After 1945, this pattern declined drastically in Western Europe. A new breed of managers and experts replaced traditional property owners as the leaders of the middle class. The ability to serve the needs of a big organization largely replaced inherited property and family connections in determining an individual's social position in the middle and upper-middle classes. At the same time, the middle class grew massively and became harder to define.

There were several reasons for these developments. The rapid industrial and technological expansion created a powerful demand for technologists and managers in large corporations and government agencies. Moreover, the old propertied middle class lost control of many family-owned businesses, and many small businesses simply went out of existence as their former owners joined the ranks of salaried employees. Top managers and ranking civil servants, therefore, represented the model for a new middle class of salaried specialists. Well-paid and highly trained, often with backgrounds in engineering or accounting, these experts increasingly came from all social classes, even the working class. Pragmatic and realistic, they were primarily concerned with efficiency and practical solutions to concrete problems. Managers and technocrats, of whom a small but growing number were women, could pass on the opportunity for all-important advanced education to their children, but only in rare instances could they pass on the positions they had attained. Thus the new middle class, which was based largely on specialized skills and high levels of education, was more open, democratic, and insecure than the old propertied middle class.

The structure of the lower classes also became more flexible and open. There was a mass exodus from farms and the countryside, as one of the most traditional and least mobile groups in European society drastically declined. Meanwhile, the industrial working class ceased to expand, and job opportunities for white-collar and service employees grew rapidly. Such employees bore a greater resemblance to the new middle class of salaried specialists than to industrial workers, who were also better educated and more specialized.

European governments were reducing class tensions with a series of social security reforms. Many of these reforms -such as increased unemployment benefits and more extensive retirement pensions- simply strengthened social security measures first pioneered in Germany before the First World War. Other programs were new, such as comprehensive national health systems directed by the state. Most countries also introduced family allowances - direct government grants to parents to help them raise their children. These allowances helped many low-income families make ends meet. Most European governments also gave maternity grants and built inexpensive public housing for low-income families and individuals. These and other social reforms provided a humane level of well-being. Reforms also promoted greater equality because they were paid for in part by higher taxes on the rich.

The rising standard of living and the spread of standardized consumer goods also worked to level European society, as the percent of income spent on food and drink declined substantially. For example, the European automotive industry expanded phenomenally after lagging far behind the United States since the 1920s. In 1948, there were only 5 million cars in Western Europe, but in 1965, there were 44 million. Car ownership was democratized and came within the range of better-paid workers. Europeans took great pleasure in the products of the gadget revolution as well. Like Americans, Europeans filled their houses and apartments with washing machines, vacuum cleaners, refrigerators, dishwashers, radios, televisions, and stereos. The purchase of consumer goods was greatly facilitated by installment purchasing, which allowed people to buy on credit. With the expansion of social security safeguards, reducing the need to accumulate savings for hard times, ordinary people were increasingly willing to take on debt.

51.2: What Made Venetian Art Different

Venice was a major center for art in the Renaissance, yet it produced a style of art and architecture markedly different from that of other Italian cities like Rome or Florence. It owed this uniqueness to a thriving commercial empire: between the ninth and fifteenth centuries, Venice gained control over Mediterranean shipping and so became the most important market for goods from all over the known world. Because of the presence of traders and immigrants from far and wide and the experiences of its own merchants and diplomats, Venice benefitted from a huge range of cultural influences on its art and architecture.

Perhaps the biggest external influence on Venice was the East-Byzantium and the Islamic lands- seen especially in the architecture of its two most prominent buildings, Saint Mark's Basilica and the Doge's (Duke's) Palace. The basic interior plan of St. Mark's was derived from the sixth-century Church of the Apostles in Constantinople, and so, unlike most Italian churches of its time, it is in the form of a Greek cross, with four extensions or “arms" of equal length. The arrangement of domes above the arms is similar to that of Islamic architecture in Egypt. However, the architecture of St. Mark's is not a simple imitation of Eastern antecedents. Although the four arms of the church are of equal length, they vary in height and width, and the domes were raised and enlarged in the thirteenth century to make them more prominent in the city's skyline. The adjoining Doge's Palace, which was the political center of Renaissance Venice, is mostly an example of the Gothic style, which originated in northern Europe. Yet it, too, has Eastern elements. The details of its roof ornamentation, the patterns of its pink and white marble facing, and its pointed arches are reminiscent of major buildings in Egypt, one of Venice's most important trading partners.

St. Mark's interior has unusually fine examples of Byzantine ornamentation, especially its gold mosaics. Mosaics are decorations or images made up of small, colored pieces of glass, stone, or tile, called tesserae. Venetian tesserae were primarily made of glass, which was easily available from Venice's advanced glass workshops, like those on the island of Murano. An important effect of glass is that the color changes as the light in a room changes. This effect, combined with the curving surfaces of domes and vaults (arched ceilings) and the deliberate setting of tesserae at different angles to catch the light, produces a striking shimmering quality to St. Mark's. The heavy use of gold had long been established for religious images in Byzantium, but in Venice, it was extended beyond the mosaics of St. Mark's to other artistic media. Textiles were often produced with gold thread. Painters such as Giovanni Bellini (C. 1430-1516) used gold in their paintings, and artists came from other regions of Europe to learn the techniques for using powdered gold. The Ca' d'Oro, a famous Venetian palace whose name means “House of Gold," even had substantial areas of gold on its exterior.

Eastern influences were not all that made Venetian art special. The city's commercial connections resulted in its being among the first to adopt new techniques of oil painting that were developed in Flanders (modern Belgium) in the late fifteenth century. Venice went on to become famous for its great oil painters, such as Veronese (1528- 1588), Giorgione (1477/1478- 1510), and Titian (C. 1488/1490- 1576). These painters adopted some stylistic elements of northern European painting, including the conventions of portrait painting and the use of mountains and forests in landscapes that typified German painting. At about the same time that the Flemish were making advances in oil painting techniques, Johannes Gutenberg (1395- 1468) was perfecting the technology of movable type in Germany. Venice quickly became one of the most important cities for book manufacturing in Europe. It had already produced a limited number of prints, but now the resulting upsurge in publishing created a greater need for illustrations, so there were increased opportunities for artists to produce woodcuts and engravings for books.

52.1: The Age of Sailing in Europe

Sailing began long before ships were capable of crossing entire oceans. Phoenicians are known to have sailed from the area of present-day Lebanon and Israel to the Atlantic Ocean and down the west coast of Africa over two thousand years ago. But the Phoenicians' boats (as well as those of other early Mediterranean sailors) were primitive in design and difficult to sail. These early galley ships had one mast and a single square sail, which meant they could sail well only downwind. Early sailors also lacked any reliable means of navigation on open seas. Once out of sight of land, sailors had nothing but the stars to guide them home, and without accurate timepieces and navigational tools, navigating by the night sky was a daunting and uncertain prospect. At that time, almost all travel by sea was within a single biogeographic province: from one end of the Mediterranean Sea to the other, or around the Baltic Sea, or from one South Pacific island to the next.

“Blue water sailors"- -those willing to sail out of sight of land- -had to wait for several major developments in sailing technology before they could make open ocean voyages with any reasonable expectation of being able to return home. European sailors received an important tool when the compass (a Chinese invention) became available, probably in the tenth century A.D. Together with maps, the compass allowed sailors to break away from coastal routes and set out across the open ocean without losing track of where homes lay. But if they were to make long voyages safely and regularly, sailors also needed boats they could control in contrary winds. Single-masted boats with square sails hanging perpendicular to the boat cannot sail upwind efficiently because the sail cannot be adjusted over a wide range of angles to the wind. Technical improvements that began to address this problem included arranging the sail fore-and-aft (that is, with the sail parallel to the length of the ship) and using several sails on several masts or a triangular sail at the front of the boat. Replacement of the ancient steering oar at the rear of the ship with a much larger and more easily controllable rudder board also helped provide better control. Once these crucial innovations had been made around 1300 A.D., ship design evolved rapidly, and sailors began to set their sights on more distant shores.

But even with compasses and improved ships, sailors still needed a working knowledge of the wind patterns that would carry them across the oceans- and back home. Between the 1330s and the 1520s, Portuguese and Spanish sailors discovered and mapped broad circles of wind that provided reliable routes across the Atlantic and back. A Portuguese sailor found the Canary Islands off the northwest coast of Africa in 1336 by following the northeast trade winds southwest from the Iberian Peninsula. Luck and insight eventually led the Portuguese to discover that the easiest way back was not to sail slowly and painfully against the wind up the African coast, but to sail west out to sea until they hit the westerlies, another group of winds that carried them northeast back to Europe. Other Portuguese and Spanish sailors mapped most of the rest of the great circulatory patterns of winds by the end of the sixteenth century, making possible the first controlled movement of large numbers of people and cargo back and forth between Eurasia (the combined continental landmass of Europe and Asia) and the Americas.

Several elements conspired to make Europe the place where this long series of inventions and discoveries- -compasses and star charts, ships that could sail into the wind, and knowledge of wind patterns- came together to create a power that could sail around the world. Europe's physical position on the globe was as critical a factor in its transoceanic explorations as were its technologically advanced ships. Compared to the Pacific, the Atlantic was a manageably-sized ocean to cross on a regular basis, and the Americas (once discovered) was a much more profitable destination than the scattering of islands in the Pacific or the emptiness south of the Indian subcontinent. Perhaps even more important, the social and religious values that characterized many European cultures both impelled their transoceanic voyages and fueled the innovation that made these voyages possible.

52.2: Euglena: Ecosystem Engineers

In 1995, an extremophile, or an organism that thrives in extreme environments, was discovered in the United States in a lake outside of Butte, Montana. The body of water where it lives, known as the Berkeley Pit, is a former open-pit copper mine that is slowly filling with groundwater that dissolves heavy metals like arsenic, cadmium, zinc, and aluminum from the mine's 2,000-foot-deep surface; the dissolved metals mix with the water to form a toxic (poisonous) solution. The Berkeley Pit is the largest hazardous waste site targeted for cleanup in the United States. As 2.6 million gallons of groundwater seep into the pit every day, the toxic brew edges ever closer to spilling into the Clark Fork River, which makes its way to the Columbia River and out to the ocean, representing a massive-scale ecological threat to the fisheries and communities in these areas.

Though the water in the pit is as acidic as lemon juice and considered inhospitable to life, a novel species has emerged and is slowly but surely changing the lake's toxic brew to one more habitable. An analytic chemist studying the lake noticed a clump of green slime floating in the lake and brought a sample to Dr. Grant Mitman of Montana Tech. Mitman brought his colleagues Don and Andrea Sterile into the lab, and they identified the slime as a colony of Euglena mutabilis, a single-celled organism that forms algae-like mats. How Euglena came to grow in the Berkeley Pit is unknown, although some attribute its spread to a flock of 350 snow geese that landed (and subsequently died) in the lake several months prior to the discovery of the organism. The geese may have carried reproductive material of the Euglena in their feces (waste matter).

Euglena is among the oldest organisms in the world, having survived since the time when conditions on Earth were not too dissimilar to those found in the Berkeley Pit- -ancient acidic oceans were full of heavy metals and other free-floating elements. These unique creatures exhibit traits of both plants and animals: they can photosynthesize (produce their own food using sunlight), but they can also move around in search of food. Their ability to photosynthesize produces oxygen. As a result of this oxygen combining with the dissolved iron in the water and by other means, the organisms cause iron to separate from the watery solution in the form of a solid, thereby creating stable substrates (surfaces) for other organisms to inhabit. In other words, Euglenas are ecosystem engineers. They work to improve the environment for themselves and, in doing so, make their surroundings more habitable for other organisms. This type of bioengineering (engineering using biological organisms) fostered the development of all life on Earth, since the production of oxygen led to the proliferation of organisms that depend on oxygen, and over the course of billions of years, the stable iron-based substrates eventually contributed to the formation of landmasses out of what was once a planet covered by water. Species like Euglena manufactured the current configuration of air, water, and land that makes this planet so uniquely hospitable to life today.

In the Berkeley Pit, Euglenas are doing similar work. They thrive in the heavy-metal-laden waters of the lake and remove the iron, zinc, and cadmium from the solution, storing them in their bodies, and rendering the metals biologically inactive. When they die, their bodies and the metals they contain are deposited in the sediments at the bottom of the lake. The chemistry of the Berkeley Pit is changing slowly but surely, and research is underway to encourage the population increase of Euglena and similar organisms to biologically treat the water before it spills into critical waterways. Since the discovery of Euglena, more than forty species of similar microorganisms have been discovered in the lake, several of them new to science. Many of these have found suitable habitats because of the pioneering work of Euglena, and they also serve to neutralize and repair the pit's toxic water. Species like Euglena are fascinating from an evolutionary perspective because they exhibit traits that not only confer advantages to their own species but also create conditions that enable other types of life to thrive.

53.1: Plant and Animal Domestication

The domestication of plant and animal species in prehistoric times-the so-called Neolithic Revolution- was a vital innovation and has received a great deal of scrutiny. The domestication of a species ensured its reproductive success while providing humans with some type of necessity. Domesticated organisms are usually altered in various ways due to selective breeding, making them better adapted for interactions with humans.

Wild cereals have a very fragile stem, whereas domesticated ones have a tough stem. Under natural conditions, plants with fragile stems scatter their seed for themselves, whereas those with tough stems do not. When the grain stalks were harvested, their soft stems would shatter at the touch of a harvesting tool, and many of their seeds would be lost. Inevitably, though unintentionally, most of the seeds that people harvested would have been taken from the tough plants. Early domesticators probably also tended to select seeds from plants having few husks (outer seed coverings) or none at all - eventually breeding them out- because husking prior to pounding the grains into meal or flour required extra labor. Many of the distinguishing characteristics of domesticated plants can be seen in remains from archaeological sites. Paleobotanists can often tell the fossil of a wild plant species from a domesticated one by studying the shape and size of various plant structures.

Domestication also produced changes in the skeletal structure of some animals. The horns of wild goats and sheep differ from those of their domesticated counterparts, and some types of domesticated sheep lack horns altogether. Similarly, the size of an animal or its parts can vary with domestication, as seen in the smaller size of certain teeth of domesticated pigs compared to those of wild ones.

A study of age and sex ratios of animal remains at an archaeological site may indicate whether animal domestication was practiced. Investigators have determined that if the age and/or sex ratios at the site differ from those in wild herds, the imbalances are due to domestication. Archaeologists documented a sharp rise in the number of young male goats killed at 10,000-year-old sites in the Zagros Mountains of Iran. Evidently, people were killing the young males for food and saving the females for breeding. Although such herd management does not prove that the goats were fully domesticated, it does indicate a step in that direction. Similarly, archaeological sites in the Andean highlands dating to around 6,300 years ago contain evidence that lamas were placed in enclosures, indicating the beginning of domestication.

Although it is tempting to think that a sudden flash of insight about the human ability to control plants and animals might have led ancient people to domestication, the evidence points us in different directions. There are several false ideas about the motivation for becoming food producers. First, contemporary foragers (people who search for food) show us that food production probably did not come about from sudden, unforeseen discoveries, such as that seeds can be planted and grown into plants, since these food foragers are perfectly aware of the role of seeds in plant growth, that plants grow better under certain conditions than others, and so forth. Jared Diamond aptly describes contemporary food foragers as “walking encyclopedias of natural history with individual names for as many as a thousand or more plant and animal species, and with detailed knowledge of those species' biological characteristics, distribution, and potential uses." In addition, food foragers frequently apply their knowledge to actively manage the resources on which they depend. Indigenous people living in northern Australia deliberately alter the runoff channels of creeks to flood extensive tracts of land, converting them into fields of wild grain.

Second, the switch from food foraging to food production does not free people from hard work. In fact, available ethnographic data indicate just the opposite. They show that farmers, by and large, work far longer hours compared to most food foragers. Finally, food production is not necessarily a more secure means of subsistence than food foraging. Seed crops, in particular -of the sort originally domesticated in Southwest Asia, Central America, and the Andean highlands- are highly productive but not stable because of low species diversity. Without constant human attention, their productivity suffers.

53.2: The Atmospheric Greenhouse Effect

The atmospheric greenhouse effect is the result of electromagnetic energy from the Sun that is trapped in a planet's atmosphere. Atmospheric gases freely transmit visible- -short wavelength- solar energy, warming the planet's surface. The warmed surface tries to radiate the excess energy back into space, but because the planet is much colder than the Sun, it radiates at much longer infrared (IR) wavelengths. But carbon dioxide and water vapor strongly absorb IR radiation, converting it to thermal (heat) energy. They subsequently re-radiate this thermal energy in all directions; some of the thermal energy continues into space, but much of it returns to the ground. The planetary surface receives thermal energy both from the Sun and from the atmosphere, and consequently, it heats up.

Nowhere in the solar system is the atmospheric greenhouse effect more dramatic than on Venus. Its opaque cloud cover and massive atmosphere of carbon dioxide and sulfur compounds raise Venus's surface temperature by more than 400 K to about 740 K (870'F). At such high temperatures, any remaining water and most carbon dioxide locked up in surface rocks would long ago have been driven into the atmosphere, further enhancing the atmospheric greenhouse effect.

Why does the atmospheric greenhouse effect make the composition of Earth's atmosphere so different from that of Venus? The answer lies in Earth's location in the solar system. Consider early Earth and early Venus, each having about the same mass, but with Venus orbiting somewhat closer to the Sun than Earth does. Volcanoes and comet impacts poured out large amounts of carbon dioxide and water vapor to form early atmospheres on both planets. Most of Earth's water quickly rained out of the atmosphere to fill vast ocean basins, but Venus was closer to the Sun, and its surface temperature was higher than Earth's, so most of the rainwater on Venus immediately re-evaporated. Venus was left with a surface containing very little liquid water and an atmosphere filled with water vapor. The continuing buildup of both water vapor and carbon dioxide in the atmosphere of Venus then led to a runaway (out of control) atmospheric greenhouse effect that drove up the surface temperature of the planet. Ultimately, the surface of Venus became so hot that no liquid water could survive there.

This early difference between a watery Earth and an arid Venus forever changed the ways that the two planets' atmospheres and surfaces evolved. On Earth, water erosion caused by rain and rivers continually exposed fresh minerals, which then reacted chemically with atmospheric carbon dioxide to form solid carbonates (minerals containing metal combined with oxygen and carbon). This reaction removed some of the atmospheric carbon dioxide, burying it within Earth's crust as a component of a carbonate rock called limestone. Later, the development of life in Earth's saltwater oceans accelerated the removal of atmospheric carbon dioxide. Tiny sea creatures built their protective shells of carbonates, and as they died, they built up massive beds of limestone on the ocean floors. As a result of water erosion and the various chemical reactions related to living organisms, all but a trace of Earth's total inventory of carbon dioxide is now tied up in limestone beds. Earth's particular location in the solar system seems to have spared it from the runaway atmospheric greenhouse effect. But what if Earth had formed a bit closer to the Sun? If all the carbon dioxide now in limestone beds had not been locked up by these reactions, Earth's atmospheric composition would resemble that of Venus or Mars.

Some scientists think that Venus once had as much water as Earth-as liquid oceans or as more water vapor than is measured today. If that's true, what happened to all the water? One possibility is that water molecules high in Venus' atmosphere were broken apart into hydrogen and oxygen by solar ultraviolet radiation. Hydrogen atoms, being of very low mass, were quickly lost to space. Oxygen escaped more slowly, so some eventually migrated downward to the planet's surface, where it could have been removed from the atmosphere by combining with surface minerals. The Venus Express spacecraft has measured hydrogen, and some oxygen, escaping from the upper levels of Venus's atmosphere.

54.1: Megafauna Extinctions in Ancient Australia

In an effort to discover the connections in Australia's past between climate change, the vanishing of the large Ice Age animals (megafauna) there, and the arrival of humans, Gifford Miller turned to fossil eggshells he found in dune deposits along the ancient shoreline of a now vanished lake. The eggshells had been left by emus, ostrich-like flightless birds that still walk Australia's savannas and woodlands, and by Genyornis newtoni, an extinct bird species whose massive bones suggest each individual would have weighed about 550 pounds. Australia's acid soils and severe climate quickly leach all organic matter out of bone. But because eggshells have a different mineral structure than bone, the ancient shells retained traces of protein. This made it possible to date them using a technique called amino acid racemization. Results from a large set of samples- -1,200 dates collected from three different sites- -showed that the emu and Genyornis had coexisted for millennia. Then, about 45,000-50,000 years ago, Genyornis vanished.

The eggshells also offered clues to the big birds' diets. Grasses that thrive in hot habitats use a unique chemical pathway to capture the Sun's energy, a process that distorts the amount of the stable isotope carbon-13 they contain relative to most other plants. Miller and his colleagues compared the carbon isotope signatures of fossil emu and Genyornis eggshells. The results show that the two bird species relied on different food sources. Grass must have been abundant right before the extinction event, because the emu of that era ate little else. The doomed Genyornis ate both shrubs and grass.

Two large, flightless birds living in the same habitat would have to develop different survival strategies and different food sources or constantly clash with each other. The emu is now, as it was during the Pleistocene (1.8 million years ago-11,700 years ago), a flexible eater. If necessary, it ate only grass, but it could also make do with shrubs and herbs. Genyornis included shrubs in its menu but seems to have been unable to get by without grass. About 45,000 years ago, the vegetation changed throughout the Lake Eyre basin. Emus shifted their tactics and began eating lots of shrubs. Genyornis could not adapt, and the species died out. More recently, Miller has analyzed the carbon isotope signatures of teeth fossils of the wombat (a pouched mammal). Like the emu, the wombat survived the ecological shift that came 45,000 years ago because it fed on shrubs, making do without grass.

According to Miller, the arrival of people carrying fire sticks in their hands changed everything. The harsh landscape of interior Australia does not hold well-preserved deposits of ancient pollen that might precisely track the changing vegetation. Based on the shifting diets of the herbivores he has studied, however, Miller can envision how and why the balance tipped. “Before people came, there must have been a savanna mixed with open woodland, the kind of habitat where grasses are abundant in years of good rainfall, and the trees and shrubs sustain the animals when water is scarce," he explains. Frequent burning tends to favor grasses over shrubs and trees, yet at the moment of human arrival, emus and wombats stopped eating grass, and Genyornis simply vanished.

Miller argues that burning did promote one kind of grass growth, but that grass was spinifex, an unpleasant-tasting species that now dominate the region. Spinifex leaves are heavily loaded with silica and are nutrient-poor. No native mammal eats it, and introduced cattle will take only the freshest, youngest shoots that sprout up after a fire. And spinifex loves fire: it grows in hummocks (low mounds) where alive and dead blades intermix, laden with flammable resin, and it resprouts quickly after a burn. Australian plants had evolved with fire for millions of years. Before people came, the bush burned regularly at the end of the dry season, the time of many lightning strikes. But humans could light fires at any time of the year. In Miller's scenario, the increased frequency of fire wiped out many plants. Many ecosystems in the interior, he says, are adapted to burn every 20 to 50 years, the kind of frequency that occurs if lightning is the only ignition source. Torched frequently by Aboriginal people, such habitats would not have enough time to recover between burns.

54.2: The Port of Melaka

The port of Melaka, on the southwestern coast of the Malay Peninsula, was founded around the turn of the fourteenth century, and it continued the tradition of a previous regional power, Srivijaya, in ensuring the success of international trade. It owed its success to a number of factors. In the first place, it was generally able to guarantee the safety of its sea lanes. The rulers of Melaka, like those of Srivijaya, commanded the allegiance of various Orang Laut groups (nomadic sea peoples) who protected Melaka's clients and attacked ships going to rival ports. These safeguards (and the threat of attack for those who passed by Melaka) were an important element in the decision of traders to frequent the new settlement in preference to other ports in the region.

Secondly, Melaka was attractive to traders because of its commercial facilities. High priority was given to security within the town and to the protection of foreign merchants and their goods. For example, underground warehouses were constructed where stored goods would be less vulnerable to fire, damage, or theft. Such measures were necessary because departures, arrivals, and the exchange of goods were all governed by the monsoon winds (the seasonal wind of the Indian Ocean and southern Asia). Between December and March, the period of greatest activity, vessels reached Melaka from western Asia and the Far East; it was not until May, however, that ships from Java to the south and the eastern Indonesian archipelago (chain of islands) began to arrive. All traders, especially those from China and eastern Indonesia, had some time to wait before the change in monsoon winds made their homeward voyage possible. Secure storage facilities were, therefore, a significant factor in Melaka's ability to attract international clients.

Third and most important was Melaka's efficient legal and administrative machinery, which provided the predictability essential for the long-term plans of foreign traders. The Undang-Undang Melaka, the first code of laws in the Malay world, devotes considerable attention to the regulation of commercial matters. A separate codification of maritime laws concentrated specifically on matters concerned with sea-going trade, such as the collection of debts, shipboard crimes, and the duties of a captain and crew.

Melaka's administrative system also directly responded to the needs of a growing trading community. Four syahbandars, or harbor masters, were appointed, each one representing different ethnic groupings. Each syahbandar was required to oversee the affairs of his particular group; manage the marketplace and the warehouse; maintain a check on weights, measures, and coinage; and adjudicate in any disputes between ship captains and merchants. The ruler of Melaka was the final arbiter who settled all quarrels between the different trading communities. Whenever a ship arrived in port, the captain reported to his particular syahbandar, who in turn referred him to Melaka's principal minister, the bendahara. The syahbandar then supplied elephants for the captain to transport his cargo to a warehouse assigned for the temporary storage of his goods. Before trading could be conducted, customs duties were paid in accordance with the value of the merchandise and the area from which the trader came. In addition, it was necessary to present gifts to the ruler, the bendahara, and the temenggung (the Melaka official principally involved in the collection of import and export duties), as well as to the appropriate syahbandar.

Melaka's reputation for security, a well-ordered government, and a cosmopolitan and well-equipped marketplace all attest to the priority its rulers placed on creating the conditions for safe and profitable commerce. But these facilities alone would not have automatically attracted traders. The fundamental element in Melaka's success as a storage and distribution center was the dual role it played as the principal collecting point for spices such as cloves, nutmeg, and mace from islands to the east and as an important redistribution center for Indian textiles. Indian cloth was carried mainly by Malay traders from Melaka to various parts of the archipelago and exchanged for spices, aromatic woods, sea products, and other exotic items highly prized by traders from both East and West. Without the spices from the eastern islands and the Indian cloth, Melaka would have been simply one of a number of other ports in the area specializing in a few local products.

55.1: Cave Artists

The earliest surviving cave and rock art was created in the Paleolithic period (40,000-10,000 years ago) in locations that were not sites of human habitation. Some Paleolithic artwork was ephemeral—only six examples of open-air engravings survive—but the fine-art engravings and paintings that decorate caves were made to last and did last, in some cases for hundreds and even thousands of years, during which they were available for delight and use. Big cave galleries thus contained work done over a long period, available for comparison to people who had some notion of historical time and were developing a sense of their ancestry. The best Paleolithic art, especially the polychrome paintings, was the work of professionals.

We can say this with some confidence, for cave art at its best was difficult and expensive to produce. In the first place, it required lighting. Some 85 certain and 31 probable examples of Paleolithic lamps have survived, but less than one-third of them were found inside caves. The conjecture, therefore, is that artists usually worked by torchlight. Both lamps and torches consume animal fats in large quantities. Second, while it is true that some of the best cave paintings, especially at Altamira in Spain, were painted by artists standing up, or in some cases, lying down or squatting, others required elaborate scaffolding, no different in principle from that used by Renaissance artist Michelangelo when he painted the ceiling of the Sistine Chapel. Some of the paintings were done on a gigantic scale or at heights many feet above the cave floor. The sheer scale of the art is daunting. The big cave vault at Lascaux, known as the Picture Gallery, is over 100 feet long and 35 feet wide. Caves were specially chosen for their size as well as for their security. Niaux in the Pyrenees Mountains in Europe is over half a mile in length, and this is by no means unusual. The big cave art Rouffignac runs over 6 miles (more than 9 kilometers) into the mountain, and some of its huge collection of drawing engravings are nearly 7 feet (over 2 meters) long.

Professional cave artists, then, needed not only platforms and scaffolding, whose existence at Lascaux, for instance, is betrayed by sockets cut into the walls, but assistants. They mixed the paints, some of which had to be used quickly before they dried; filled the lamps or held the torches; put up and secured the scaffolding; and made the brushes from twigs, feathers, leaves, and animal hairs, to the satisfaction of the master. These assistants probably graduated as masters themselves. It is not going too far to speak of a studio system as the basis of Paleolithic cave art. After all, there is positive evidence that art studios, where important works were fabricated and artists trained, existed in Egypt at least as far back as 3000 B.C. That still leaves a gap of 7,000 years from the end of the Paleolithic period, but the quality and consistency of the best-painted work in caves, and the evidence of the time, expense, and skill required to produce them, do suggest that artists needed the collective support of something very like a studio. The probability is that the leading cave artists were important persons.

This brings us to quality. To modern eyes, accustomed to 5,000 years of continuous development in the depiction of living forms, the best of the Paleolithic paintings are magnificent. Indeed, seen in depth and in the total silence of the caves, the images are awesome. Human forms are rare and often quite unsophisticated, but the variety of animal forms is impressive. In the eight galleries of the great cave at Les Eyzies, there are multiple examples of mammoths, reindeer, horses, stags, bison, and wolves, as well as humanoids and abstractions or signs. These interlocking galleries, unfolding one by one, are meant to impress, and they do. The art is both detailed and monumental, oscillating designedly between simplification and elaboration, between stasis and extreme dynamism. Some Paleolithic artists clearly understood both the anatomy of the animals they depicted and their principles of motion, the result of intense observation over many years and of self-discipline in rendering that suggests a long apprenticeship and extensive study.

55.2: Breathing Inside an Egg

Tucked away inside its shell, a bird embryo has to breathe. But, rather than using lungs to draw air in and push carbon dioxide and water vapor out, a bird embryo relies on “diffusion"- -the natural movement of gases- -much as do insects (which also lack lungs). In fact, both insects and eggs use tiny pores, or holes, and pore canals that connect the outside with their interior. For birds, there are hundreds or thousands of tiny pores distributed all over the shell surface. The pores connect, via a narrow tube, the embryo's blood supply to the outside world. The number of pores per egg varies markedly between species, partly but not entirely related to the size of the egg. Since the pores are fairly straight and run vertically from the inner to the outer surface, their length is usually similar to the thickness of the shell. Generally, the number and size of pores determine how much and how fast oxygen diffuses into the egg. As well as taking away unwanted carbon dioxide, the pores allow water vapor to escape from the developing embryo. As the embryo grows, it generates water, referred to as metabolic water, produced as a result of the metabolism of food. Different foods generate different amounts of metabolic water. Fat, for example, yields comparatively high amounts of metabolic water.

Inside an egg, the developing chick generates plenty of metabolic water from the fat-rich yolk (yellow part of the egg) as it grows. This water has to be removed; otherwise, the embryo would drown in its own juices, so to speak, and it does this by allowing it to diffuse as water vapor through the pores in the shell. As a result, eggs lose weight during the course of incubation. What is remarkable is that, despite the huge variation across bird species in the size of eggs, the duration of incubation, and the relative size of the yolk, the loss of water between laying and hatching is always about 15 percent of the egg's initial weight. The water vapor lost during incubation ensures that the relative amount of water in the egg is the same in the chick at hatching as it was when the egg was laid. In other words, the composition of the newly laid egg has evolved through natural selection to ensure that the newly hatched chick has the right composition- -in terms of the amount of water in its tissues, too. This is achieved by adjusting-via natural selection- -the effective pore area such that all the metabolic water produced during development is eliminated before hatching. One consequence of this loss of water vapor is a space in the egg, roughly 15 percent of its volume, that becomes the air cell at the blunt, or the flat end of the egg, and provides the amount of air needed by the chick just before it hatches.

The air cell is formed between the inner and outer shell membranes when the egg is laid. As the egg cools and its contents contract after leaving the female's body, the air is drawn in through the pores and accumulates in a lens-shaped pocket at the blunt end of the egg. If you hold a hen's egg against a bright light, you can see the air cell. Furthermore, when you peel a hard-boiled egg to eat, the air cell's presence is revealed by the flattened area of white at the blunt end where the air cell has pressed down on the albumen (egg white). William Harvey, in the 1600s, was the first to think about the role of the air cell, dismissing the then-widespread belief that its position in the egg signaled the sex of the chick. As development proceeds, the air space increases in size, and it is for this reason that you can assess the age of an egg, or its stage of development, from how it floats in water: a very fresh egg with virtually no air cell sinks; an older egg floats.

Because gases behave differently under pressure, we might expect the size and number of pores to differ among birds breeding at different altitudes. Specifically, the loss of gases will be less at high altitudes. And this is confirmed by a comparison of birds breeding at different elevations: species breeding at high altitudes have fewer, smaller eggshell pores.

56.1: Polynesian Migration

Polynesia is a large grouping of islands scattered over the central and southern Pacific Ocean. The origins of the indigenous people of the Polynesian islands are the subject of some debate, as are the reasons for their migration from one island to another. In about 3000 B.C.E., people living in the Bismarck Archipelago (a chain of islands in the neighboring region of Melanesia) began making pottery, keeping domesticated dogs, pigs, and chickens, and growing vegetables. Their culture was known as the Lapita culture, and the people were likely ethnic Chinese. In about 1300 B.C.E., they began to spread eastward into Polynesia. Over the next 2,300 years, they brought their culture to several islands there, including New Zealand, where the Polynesian settlers became known as the Maori people. Their long voyages were made in canoes approximately 65 feet (20 meters) long. These canoes carried crews of at least five and up to 15, with a supply of vegetables, live chickens and pigs, and water stored in gourds that could be augmented by collecting rainwater in sailcloth.

Navigators memorized the routes to other islands and taught them to young men who were learning the skill of navigating, in the form of songs and drawings. Their method was based first on their knowledge of the direction and times of rising and setting of the most prominent stars and planets. Voyages began at dusk. The navigator set a course in relation to the direction of prominent landmarks that were still visible and of the stars, and during the night, he would steer by the stars. During the day, he would steer by the Sun. The condition of the sea and the direction of the wind also provided valuable information. In the tropical Pacific, the prevailing winds blow from the northeast to the north of the equator and from the southeast to the south of the equator. Because they blow for most of the time, the winds produce a large swell, with waves that all move in the same direction. Navigators could steer by the direction of their canoe in relation to the swell, and they would tow a length of rope in the water behind the canoe. If a sudden wave or gust of wind blew the canoe to one side, the rope would not be affected, and its line would record the direction they should steer. Small pennants (flags) tied to the canoe indicated the wind direction, which was also useful. In addition, Polynesian sailors knew the paths followed by migrating birds and whales. They were familiar with ocean currents, the cloud patterns that formed over distant islands, and they watched for floating plant debris that indicated land just over the horizon.

Polynesian navigation was remarkably skillful-but why were the Polynesians so restless? One possible clue can be found in the fact that despite living on islands surrounded by abundant stocks of fish, the people of the Cook Islands seldom eat fish. The seas around Rapa Nui support many species of edible fish, as well as lobsters and turtles. These have always been an important part of the Rapa Nui islanders' diet, and island traditions forbade fishing at certain times of the year, which prevented the overexploitation of stocks. As recently as the early twentieth century, however, the islanders believed that the fish living in deep water farther from shore were poisonous, and they refused to touch them.

In 2009, Teina Rongo, a Cook Island marine biologist, aroused considerable interest among historians when he proposed that from time to time, the fish on which Polynesians depended had turned poisonous, and the islanders had suffered from a type of food poisoning called ciguatera. Robbed of their food supply, they had no alternative but to move elsewhere. Ciguatera is caused by eating fish contaminated by a single-celled organism called Gambierdiscus toxicus. The poisoning is seldom fatal, although it can be; its symptoms include vomiting, blurred vision, a burning sensation in contact with a cold surface, and heartbeat irregularities. Common throughout the Tropics, this poisoning is most severe in people who have eaten carnivorous reef fish such as barracuda, snapper, and grouper. It may be that the waves of Polynesian migration were motivated by the need to find wholesome food.

56.2: The Ecological Roles of Birds

Birds provide numerous invaluable ecological services, and one of the most important is by scattering plant seeds. Seed dispersal enables plants to migrate into new territory and reduces competition with others of their own species, thereby increasing survival rates. In fact, if you enjoy spicy foods, you owe some appreciation to birds, who played a pivotal role in the evolution of chili peppers. In an example of evolutionary partnership, chili plants evolved in a way that offers birds a nutritious food source, while the plants benefited from the wide distribution of their seeds after passing through the birds' digestive systems. Capsaicin is the molecule in spicy peppers that creates the sensation of heat we feel when it binds to pain receptors in the mouth. On a human tongue, a solution of just ten parts per million creates a distinct sense of burning, but nerve receptors in birds do not register the heat of capsaicin even if they ingest as much as twenty thousand parts per million.

Bird digestive systems also do the seeds of the chili pepper no harm, because many birds with a fondness for them have a rather short, straight digestive pipe through which food transits quickly. Researchers have even found snails that had been eaten by a bird, passed through its digestive tract, cast out the other end, and were still alive. Moreover, chili peppers can be plucked readily from the stem only when they are ripe, which means only those seeds ready to germinate (begin growing from a seed into a plant) are swallowed by the bird. Catching the eye of birds helps pepper plants expand their range. If mammals ate chilies, they would digest and destroy them or deposit them fairly close to the plant. Birds, however, drop the undigested seeds in faraway places. The cradle of chili pepper civilization is in Brazil, in a lowland region dubbed “the nuclear area" because it has the largest number of wild varieties of chilies in the world. It is believed that the first wild chili peppers sprang to life here and were spread across much of the Western Hemisphere by birds.

Birds shape the plant world in myriad other fascinating ways. Some two thousand species inadvertently play the middleman in sexual relations between plants. White-winged doves that survive in the desert on cactus flower nectar carry pollen between saguaro cactus flowers, and hummingbirds seek out the nectar of a variety of wildflowers and domestic crops; some hummingbirds visit thousands of flowers in a day, and as they search for nectar, they carry millions of tiny grains of pollen stuck to their heads, beaks, and feathers, brushing flowers like flying paintbrushes.

There are places where birds and the pivotal roles they play have vanished. The extinction of the dodo, the three-foot-tall flightless bird of Mauritius, could well be the cause of the decline of the tambalacoque tree, also known as the dodo tree, which is highly valued for its timber (wood). Some plants have just a single animal partner that plays a key role in their life, and in the case of the peach-tree-like tambalacoque, the dodo's digestive tract may have been vital in paving the way for the tree's successful growth. As the seeds moved through the bird's system, fruit pulp was scrubbed off, reducing the risk that bacteria and fungi would kill the seeds before they germinated. These days, botanists growing tambalacoque trees pass their seeds through wild turkeys or even gem-polishing machines to roughen and clean them in preparation for planting.

Large enough flocks of birds can also be a factor in the weather. When millions of migratory seabirds arrive in the Arctic each summer, they bring a huge burst of guano (bird waste). As bacteria go to work on the guano and break it down, they emit ammonia. As sulfuric acid and water combine with the ammonia in the atmosphere, bigger particles are formed, which become the nuclei for cloud droplets and thus create cooling clouds. The number of cloud droplets near seabird colonies can be 50 percent more than in those areas without birds. Smaller droplets are also formed, which reflect sunlight and contribute to the cooling effect. When seabirds change their migratory patterns or disappear, experts believe they may contribute to changes in Arctic weather.

57.1: The Harappan Decline

The Harappan civilization flourished around the Indus River Valley on the western Indian subcontinent from about 2700 to 2000 B.C.E. The Harappans exploited the seasonal overflow from their rivers by capturing the water with dams and distributing it to crop-growing farms. They built cities of brick and traded widely, sending wood, fabrics, and other products to Mesopotamia, where other early civilizations thrived.

By around 1900 B.C. E., the Harappan civilization was in decline, a result likely related to environmental degradation. Intensive plant growth, water-saturated land, and hot, dry summer climates cause rapid surface evaporation over time, drawing salts in the Earth closer to the surface, where they slowly poison plant life through a process called salinization. Moreover, salt-permeated topsoil is easily blown away by passing winds, causing desertification (fertile land turning into desert). These conditions are further exacerbated where a hard layer of bedrock impervious to water lies not far beneath the surface, as is the case in the valley of the Indus. Such soil formations mean water tends, even more, to stay close to the surface (a high water table), where the process of evaporation is greatest. Salinization is particularly deadly in regions experiencing a period of decreasing local rainfall, as the drier the air, the faster the evaporation, and hence, the quicker the rise in salts to the surface. A shift eastward of seasonal rains may have been responsible for decreasing moisture on the western Indian subcontinent, encouraging a drying trend that became well established there and in Mesopotamia, where civilizations also began to decline around the same period.

Ironically, both the Harappan and Mesopotamian civilizations' management of their natural resources may have figured in this mutual decline. Much of the Harappan-Mesopotamian bulk trade was in Harappan wood. Harappan woodsmen may have stripped much of the Indus Valley of its local forests for this trade and to provide fuel for the ovens that dried the bricks used widely in Harappan construction. Mesopotamians had already deforested their lands, hence their need for outside suppliers of wood. The removal of forest cover, for any reason, increases flooding, because trees hold water in the soil. The making of burnt bricks and the trade in wood, combined with drought, was a prescription for disaster.

Dramatic earth movements have often altered the course of human history: earthquake-related tsunamis (large ocean waves) alone have eradicated cities from ancient Mycenae (Crete) to Port Royal (Jamaica) in the early modern period. The fate of Harappans was probably sealed by a series of earthquakes and other geologic events between 1900 and 1500 B.C.E. that uplifted land and shifted river beds so as to create an even greater pooling of water in a time of flood, further increasing salinization. Increasingly unproductive land and declining Mesopotamian trade would have made it harder to fix the damage done by floods and earthquakes. Cities show signs of a slow dissolution of civic cohesion, including the rise of slums (low-quality residential areas) and a decline in the quality of crafts.

Harappan cities along the Indus and Ghaggar-Hakra rivers may have been the first to perish, as their life-giving waters shifted or largely dried up by 1900 B.C.E. Other cities, such as the port at Lothal, may have survived for perhaps two centuries longer until river courses either shifted away from or flooded over them. In an effort to avoid annihilation, Harappans may have moved farther east and south in search of fertile land and reliable rainfall. Such a migration might explain the ancient Harappan-like dam structures and cultural fragments found along rivers in the Deccan Plateau in India.

Language offers further evidence of Harappan migration. In an isolated valley of what used to be the Harappans' region, the earliest form of language found (called Brahui) is related to the earliest form of the Dravidian language group, which is widely spoken in the southern regions of the Indian subcontinent but has few clear connections to other language groups. If the Brahui-speaking inhabitants of Harappan lands are the descendants of speakers of the ancient Harappan language, so also are speakers of Dravidian. The idea of such an ancient lineage is very popular among Dravidian speakers. It is challenged by many other linguists, however, who argue that Brahui speakers migrated to their present location from their original home in the Dravidian-speaking south.

57.2: Where Life Arose

Life could not have come into being on Earth until after about 4 billion years ago when bombardment by asteroids had subsided substantially. Even after Earth's surface had stabilized, certain conditions were required for the origin of life. Some researchers have concluded that precursor compounds, and ultimately life itself, arose in small bodies of water that were struck by lightning and turned into what is sometimes referred to as the "primordial soup "of organic compounds. The problem with that idea is that it would have required an atmosphere lacking oxygen because even a small amount of oxygen would have oxidized, and, thereby, destroyed chemical raw materials necessary for the production of essential organic compounds.

Knowing that photosynthesis produces the preponderance of oxygen in Earth's atmosphere today, scientists once assumed that the atmosphere lacked free oxygen before the origin of photosynthetic organisms. We now know, however, that ultraviolet light breaks down water vapor in Earth's upper atmosphere, slowly liberating oxygen, which spreads in small quantities throughout the atmosphere. This process would have contributed a small amount of oxygen to the ancient atmosphere-enough to destroy chemical compounds essential to life. Life must have originated not in a small body of water that was exposed to atmospheric oxygen but in some environment that was isolated from Earth's atmosphere. The most likely setting was a warm area beneath the seafloor in the vicinity of a mid-ocean ridge (submarine mountain range).

The heat that rises from Earth's mantle (the layer between the crust and the planet's central core) along mid-ocean ridges warms seawater that has percolated into the crust through pores and cracks. Because heating causes water to expand and so reduces its density, this water rises back to the ocean. In some areas, it flows from the seafloor through large vents as columns of very hot water. Bacteria of many kinds inhabit the warm water of ridge environments, occupying pores, cracks, and vents. They live in a variety of ways, but most of them derive energy from the chemicals that the hot water has dissolved while moving through the ridge system. Some of these bacteria live in water warmer than 100 degrees Celsius, which remains in a liquid state because of the great pressure applied by the ocean above. Others live in lukewarm water farther from ridge axes. In general, these high-temperature bacteria may be inhabiting the kind of setting where life originated.

The principle that most warm-adapted bacteria put into practice to obtain energy is quite simple: they harness the energy of naturally occurring chemical reactions. Many of the chemical compounds that emerge from deep within mid-ocean ridges are not stable after the rising water in which they are dissolved cools and mixes with seawater, so they will enter into chemical reactions. Many such reactions do not occur quickly, however, and the bacteria take advantage of this situation. The bacteria consume the chemical compounds and simply allow chemical reactions that would have occurred in seawater to take place inside their cells. These reactions release energy. The bacteria harness the energy for their metabolism and excrete the chemical products of the reactions.

Some warm-adapted bacteria actively carry out chemical synthesis, but unlike photosynthetic organisms, they do not use light as an energy source. Other kinds of bacteria get energy by combining hydrogen or sulfur with oxygen in the way that higher organisms obtain energy by oxidizing sugars.

There is evidence that the warm-adapted bacteria that live in the vicinity of mid-ocean ridges are actually the most primitive living bacteria. Biologists have compared the genetic material, DNA and RNA, of all kinds of bacteria to reconstruct their evolutionary relationships. Those features of DNA and RNA that are shared by many bacterial groups are regarded as primitive features inherited from very ancient ancestors. Traits shared by a few bacterial groups are regarded as indicating more recent branchings of the evolutionary tree. Using this method, it turns out that the most primitive living bacteria (Archaebacteria) are adapted to warm habitats. This finding suggests that bacteria evolved in such habitats, perhaps in the vicinity of mid-ocean ridges.

58.1: Porcelain in Seventeenth-and Eighteenth-Century England

Porcelain is a white ceramic that originated in China and that incorporates kaolin clay. When Asian porcelains first appeared in Europe, Europeans were delighted and mystified by their lightness, hardness, and translucence (allowing light to pass through). Starting in the seventeenth century, Britain's East India Company imported large quantities of goods from East Asia, with the volume of imported porcelain rising dramatically toward the end of that century and into the eighteenth. One reason for this increased importation of porcelain was the increasing popularity of hot beverages: coffee, chocolate, and tea. The earliest London coffeehouses date from the 1650s, and though the first known advertisement for tea appeared in 1656, it was not imported by the East India Company for resale in Britain until 1678. The rising popularity of coffee drinking and tea drinking in Britain, and the vastly increased importation of Far East ceramics, are thus both phenomena that had their origins in high-class British social life during the last quarter of the seventeenth century. Being heavy and not susceptible to water damage, porcelain was packed underneath the very much lighter cargoes of tea brought by the East India Company. The histories of the two are thus closely intertwined, and the links extended from the act of importation to its sale-as porcelain dealers very often sold tea, coffee, and chocolate in addition to ceramics and glass -right through the final act of consumption.

Porcelain was resistant to the thermal shock of contact with boiling water, but unlike silver (of which late-seventeenth-and early-eighteenth-century teapots continued to be made), it did not get uncomfortably hot. And being of Asian origin, it no doubt seemed the appropriate material from which to drink the teas imported by the East India Company. As importation increased, some of the mystery surrounding its production was dispelled. Indeed, its preparation was described in two letters by Pere D'Entrecolles, a Jesuit missionary resident at the great ceramic center of Jingdezhen, China, in 1712 and 1722. These letters were published in Paris in the 1720s and subsequently appeared in a work on China published in French and English editions in the 1730s.

Although Asian wares had much to recommend to seventeenth-and eighteenth-century Europeans, three characteristics, in particular, excited their admiration. Firstly, there were the physical qualities of the material itself, which was hard and white-bodied, and -most remarkable to Western eyes-could be translucent if thinly made. Secondly, the wares were technically superior to almost all seventeenth-and eighteenth-century European ceramics, not allowing liquids to pass through and resistant to wear and tear. Finally, they came embellished with painted patterns in blue, or with brightly enameled decoration, the subjects and scenes of which must have appeared fascinating to Western eyes.

The late-seventeenth-century taste for such exotic porcelain wares was part of a wider fashion that embraced Asian goods in other materials, including Chinese and Japanese lacquerware (household goods coated with a protective material made from tree resins), silks and fans, and printed cottons and embroideries from the Indian subcontinent. From the fact that such goods were brought to the West by European East India companies, imported decorative work of this type was frequently called "Indian" during the seventeenth and eighteenth centuries since the geography and cultural diversity of Asia were very little understood by the European consumers in these years. Like the Indian cotton cloth known as calico, the majority of Chinese porcelains that found their way to the West during the eighteenth century were specially made for the Western market, very often after prototypes or design specifications were supplied or laid down by European merchants. In the case of textiles, and to a lesser degree in ceramics, the designs with which they were embellished were also frequently based on Western reworkings of, or fantasies upon, Asian themes and decorative styles. The porcelain wares made to Western order and specifications were themselves copied and adapted in the ceramic factories of Europe, and some of these, in due course, made their way back to China, where they became the subject of further copying and variation.

58.2: Transitions in World Populations

Unless we know the size, density, age distribution, and reproductive capacity of a population, it is difficult to understand many aspects of its society, politics, and economy. In the contemporary world, most nations conduct periodic censuses to assess the present situation of their populations and to plan for the future. Before the mid-eighteenth century, when census-taking became a regular procedure, population estimates and counts were sporadic and usually inaccurate. Thus, arriving at estimates of populations from the past, especially for non-literate societies, is a highly speculative exercise in which archaeological evidence and estimates of the productive capacity of agricultural practices and technology are used. The earliest date for a population estimate with a margin of error of less than 20 percent is probably 1750.

The history of human population can be divided into two basic periods: a long era-almost all of human history-of very slow growth, and a very short period-about 250 years from the mid-1700s to the present-of very rapid growth. Before agriculture was developed, the hunting-and-gathering economies of the world's populations supported 5 to 10 million people, if modern studies of such populations can be used as a guide. After about 8000 B.C.E., when plants and animals were domesticated, the world's population began to increase more rapidly but still at a modest level. Although agriculture provided a more secure and larger food supply, population concentration in villages and towns would have made people more susceptible to disease and thus reduced their numbers. Some historians also believe that the settled agricultural life also led to intensified warfare (because of the struggle for land and water) and increasing social stratification within societies.

Still, the Neolithic revolution, the shift from hunting-and-gathering to settled agricultural life, stimulated population growth. It was the first major transition in the history of world population. One estimate, based on Roman and Chinese population counts and some informed guesses about the rest of the world, is an annual growth rate of about 0.36 per million. By 1 C.E., the world population may have been about 300 million people. It increased between 1 C.E. and 1750 C. E. to about 500 million people. We should bear in mind that during this period of general increase, there were always areas that suffered a decline, sometimes drastic, because of wars, epidemics, or natural catastrophes, such as the disastrous decline of American Indian populations after contact with Europeans, caused by disease, conquest, and social disruption.

A second and extremely important transition took place between the mid-seventeenth and the mid-eighteenth centuries. Initially based on new food resources, this transition often is associated with the Industrial Revolution, when new sources of energy were harnessed. The growth rate greatly increased during this period in the countries most affected. Between 1750 and 1800, the world population grew at a rate of more than 4 percent a year to more than a billion people. By the mid-twentieth century, the world growth rate had tripled, and by 1990 the world population had risen to more than 5 billion.

This demographic transition took place first in Europe and is still more characteristic of the developed world. Most pre-modern agrarian economies were characterized by a balance between the annual number of births and deaths; both were high. Life expectancy usually was less than 35 years, and the high mortality was compensated by high fertility; that is, women had many children. Improvements in medicine, hygiene, diet, and the general standard of living contributed to a decrease in mortality in the eighteenth century. This allowed populations to begin to grow at a faster rate. By the nineteenth century, in most of Western Europe, the decline in mortality was followed by a decline in fertility. In some countries, such as France, these two transitions took place at about the same time, so population growth was limited. In much of Europe, however, the decline in fertility lagged behind the decrease in mortality, so there was a period of rapid population growth. Until the 1920s, population growth in Western Europe and the United States was higher than in the rest of the world, especially in the less industrialized countries. In recent times, that situation has been reversed.

59.1: The Jack Pine and Fire

The jack pine tree of Canada has several qualities that seem to equip it for life with fire. As in many conifer trees, the branches nearer the ground tend to die off as the tree grows taller, not least because they find themselves without light. In the jack pine, however, these dead branches simply fall off. If the dead branches were allowed to persist, they would provide a "ladder" for the fire from the ground to the top. The physics of fire is, in many ways, counterintuitive. Crucially, a hot fire that burns itself out quickly can be less damaging than one that's somewhat cooler but lasts longer. Jack pine needles are high in resin (a flammable organic substance secreted by trees) and often low in water, especially in the droughts of spring and summer when fires are likely, and so, they burn hot but quickly. On much the same principle, the jack pine's bark is flaky. It picks up surface fires but then burns swiftly and does little harm. The stringy bark of eucalyptus trees in Australia, hanging loosely from the smooth trunk beneath, is protective in much the same way. In both cases, the discarded bark prevents the fire from seriously harming the tree.

On the other hand, when jack pine bark accumulates on the ground (as it does if there is a long interval between fires), surface fires—particularly in spring and summer--can be very fierce. Then most trees of all kinds are killed. But the jack pine is typically the first to spring back, for a very hot fire in the summer burns both the leaf litter on the surface and the organic material in the soil itself, leaving a bare, mineral soil behind. Jack pines germinate well in such soil and, indeed, are inhibited by leaf litter. They like bright sunlight, too, and appreciate the open space.

By their fourth or fifth year, many of the young jack pines are producing their first cones-which by tree standards is markedly young. Why are they so precocious? Why not focus their precious energy on more growth rather than on reproduction? Forest fires often leave a lot of fuel behind, and sometimes a second fire quickly follows the first. It seems a good idea to scatter a few seeds before the possible subsequent fire.

But it is the cones and seeds of the jack pine that are adapted most impressively and specifically to fire. The cones are hard as iron, their scales tightly bound together with what could be called a "resinous glue." Many creatures attack cones, but only the American red squirrel will take on the jack pine cone, and even the red squirrel much prefers the easier, fleshier meat of spruce cones. The cones may persist on the trees for many years, and the seeds within them remain viable. In one study, more than half the seeds from cones that were more than twenty years old were able to germinate. The cones do not open until there is a fire: it takes the heat of 50C to melt the resin that locks the scales together. Then, they open like flowers. Thus the seeds are not released until the fire has cleared the ground of organic matter and of rivals and has created exactly the conditions they need. The output is prodigious. After a fire in the taiga (the northernmost forest, which then gives way to tundra), the burned ground may be scattered with twelve million jack pine trees per acre.

Although the cone responds to fire, and only to fire, it is remarkably fire resistant. It has been found that the seeds inside would survive for thirty seconds even when the cone was exposed to as much as 900C. It has also been shown that the cone does not respond simply to the presence of fire, like some crude unmonitored mechanical device: rather, as it is heated, it releases resin from within, which oozes to the surface and creates a gentle, lamp-like flame around the cone, which lasts for about a minute and a half. All in all, it seems that once ignited, the cone is programmed to provide a flame for the right amount of time to open the cone.

59.2: Ziggurats in Mesopotamia

Like the pyramids of Egypt, the towers called “ziggurats” built in ancient Mesopotamia were monumental symbols of a great civilization. Ziggurats consisted of several levels or platforms of diminishing sizes with exterior stairways or ramps leading to their summits. New platforms were built on top of older ones over many centuries, leaving earlier stages buried under later enlargements. The Egyptian pyramids, however, were never meant to be climbed, and new pyramids were not built over the remains of older ones.

Unlike in Egypt, there was no stone for building projects in Mesopotamia, but mud-available everywhere-was used to produce bricks. Despite the availability of this cheap building material, ziggurats were always considerably smaller than pyramids, possibly due to a lack of manpower and wealth. The central core of most ziggurats consisted of unbaked, sun-dried bricks covered with a thick outer shell of baked bricks. Water occasionally leaked into the interior of a ziggurat, causing its unbaked core to expand and crumble. All kings of Mesopotamia had to face the constant task of rebuilding mud-brick structures; ziggurats, as well as other structures, rarely lasted a century without a major renovation.

Why, then, were ziggurats not built entirely out of baked bricks instead of just their exterior walls? If they had been, they could have withstood the ravages of time, and their kings would not have been obliged to repair them every few years. As is so often the case, environmental factors may have dictated the number of burnt mud bricks used in large structures. There were very few trees in Mesopotamia, and the Mesopotamians lacked the necessary fuel to bake the millions of bricks required for large structures. Most of the wood and straw fuel available was used for cooking fires in private homes and could not be spared for brick-making. Another factor that contributed to the demise of ziggurats was the size of the bricks used to make them. Mud bricks are smaller and lighter than the great stones used in pyramid construction and, long after they were abandoned, peasants in search of easily available building material found ziggurats to be a convenient source of bricks for constructing houses and other domestic buildings.

The purpose of Egyptian pyramids is clear: they were tombs for their deceased kings. But if ziggurats were not tombs, then what was their purpose? Early explorers naively thought that they were used by Mesopotamian priests to escape the mosquitoes. Some maintain that the first small ziggurats were simply raised platforms where the village grain supply could be kept dry during the annual flood. As early as the fourth millennium B.C., temples were built on raised earth and mud-brick mounds, and ziggurats may have been a further development of this type of construction. The most widely accepted explanation is that ziggurats were meant to be climbed. Ziggurats always had several stairways leading to their summits, and it seems clear that their primary purpose was to elevate the priests closer to the realm of the gods in the heavens. In the city of Sippar, the ziggurat was called “The Staircase to Holy Heaven,” and offerings were made to the gods from a small temple at the summit of the ziggurat. In this way, ziggurats formed an important spiritual link between people on Earth and the sacred realm of the gods in the heavens.

In the early days of research on Mesopotamia, it was claimed that ziggurats were built as celestial observatories where astronomers could have studied the stars without city buildings obstructing their view. It is likely that on some occasions, celestial observers climbed to the top of ziggurats to observe the night sky, recite prayers to the gods of the night, and make offerings to the celestial gods. It should be kept in mind that, since the moon and planets would still appear to be the same size, climbing a few meters to the top of a ziggurat would not give an observer a significantly closer or better view of celestial objects. It is doubtful that ziggurats would have been of much use to astronomers and calendar-makers, but they would have elevated priests and celestial observers into the higher spiritual realm that was such an important element of their religious world.

60.1: Bat Diets

One of the most dramatic measures of the diversity of bats is the variety of food they consume. Although some 600 species eat insects as the main dietary staple, others live on fruit, nectar and pollen, fish, frogs, birds, small mammals, blood, and even other bats. Most of this diversity occurs in the tropics, although many bats from temperate regions vary their diets by eating a wide range of insects.

What any bat eats is determined by two important factors: the need for enough energy to keep the body going and the need for essential chemicals to maintain it. Just as an automobile requires fuel to move and lubricants to keep the engine running smoothly, animals require protein, carbohydrates, or fat for energy, along with vitamins and minerals to stay healthy. Since it is essential for bats to consume enough calories to make flight, reproduction, growth, and other bodily functions possible, it is easy to see why such variety is necessary in their diets. Species that feed mainly on plant products require protein, which can be obtained by eating animals (insects), pollen (which provides only moderate amounts of protein), or large quantities of fruit (a very limited source of protein). Bats feeding on insects appear to obtain a balanced diet from this source of nutrition.

To obtain the energy and chemicals they need, bats consume vast quantities of food. Small insectivorous species (species that eat mainly insects) eat at least 30 percent of their body weight each night they are active, and in nursing mothers, the amount may exceed 50 percent. These figures appear to apply to all bats, regardless of diet. It may not be impressive to learn that a little brown bat eats three grams of insects on a summer night, but to find 150 mosquitoes in its stomach certainly is, especially when you realize they are not an entire night's ration and the bat probably caught them in less than fifteen minutes. The most impressive statistic of insect consumption comes from Texas, where it is estimated that a local population of Mexican free-tailed bats eats slightly more than 6,000 tons of insects each summer.

The basic design of a bat imposes certain restrictions on the range of food available to it. Bats determine the direction and distance of objects in their environment by emitting high-pitched sounds and interpreting their echoes to find their location-the term for this is echolocation. Because they can echolocate, New World leaf-nosed bats that feed mainly on fruit are able to catch insects to supplement their diet with protein. Flying foxes (a species of bat found mainly in Indonesia and Malaysia) and their relatives, however, do not echolocate and must obtain their protein from something other than insects. Recent studies in the Ivory Coast by the Canadian biologist Donald Thomas suggest that several species of the herbivorous bat family pteropodidae get their protein from the fruit that composes the main part of their diet. The levels of protein in the fruit are low, but this is countered by the consumption of large quantities of fruit and by enzymes in the digestive tract that efficiently extract what little protein is available. Size is also a factor in determining the diet of a bat; a 3-gram butterfly bat has fewer prey species from which to choose than a 40-gram, large slit-faced bat. As a rule, smaller bats are almost entirely insectivorous, and larger species include larger prey in their diet, readily switching to small vertebrates such as fish, birds, and frogs. The smallest bats that feed on plant material are nectar and pollen feeders. Larger species more often feed on fruit but may also supplement their diet with nectar and pollen.

The food selected by bats also depends on where they feed. Flying bats chasing flying insects will not catch scorpions that do not fly, but they often snatch spiders ballooning on pieces of web. Bats feeding on stationary or terrestrial prey often catch resting insects that are able to fly. Bats concentrating their feeding activity over water catch more aquatic insects than those feeding high over the forest, and species hunting over water have opportunities to catch fish not available to high-flying species that visit the water only to drink.

60.2: Continuous Script and Oral Culture in Europe

Today people commonly read in silence and in private, but that was not the case in Europe during the periods of ancient Greece (800-146 B.C.E.), ancient Rome (753 B.C.E. -476 C.E.), and the centuries that followed. In ancient Greek times, reading was an oral (spoken) practice--one reflected in writing itself. Greek texts were written in a continuous script (without spaces between words) and with minimal punctuation; this both required and rewarded sounding them aloud. A continuous script could not have developed without the Greek introduction of letters for vowels, which allowed readers to identify syllables and hold them in memory as the eye moved across the text.

Though it seems awkward to us now, the continuous script was not a natural construction, but a choice, as demonstrated by the fact that the Romans discarded their own punctuation in the first century in favor of the Greek model. It established literacy (ability to read and write) as the domain of a cultured elite, who either studied from a young age to master the skills appropriate for reading each individual text or employed a professional reader, or lector, for the task. It also facilitated a culture of shared inquiry, in which challenging texts were read aloud in groups as an incentive for debate. In ancient Greece, literature was primarily a social activity, with audiences gathering for performances of epic poetry and drama. Epic poems bear the hallmarks of this orality: they rely on repetition, formulaic images, meter, and rhyme as mnemonic (memory) aids to the performer. The term used to describe performances of such works, rhapsody, means “to stitch together" -suggesting the extent to which oral composition relies on weaving familiar lines.

The great thinkers of ancient Greece, in fact, mistrusted writing as a technology that would destroy the oral arts of debate and storytelling on which they based their sense of the world, philosophy, and time and space. In Plato's dramatic play Phaedrus, the philosopher Socrates looks down on the written word for separating ideas from their source, citing Egyptian king Thamus as the first to voice this concern when he received the gift of writing from the god Thoth. Transcription (writing speech down), Socrates fears, is an aid that will both interfere with memory and trap philosophical thought in ambiguity, leaving interpretation in the hands of the reader. Texts, after all, can circulate without their author, thus preventing one from explaining or defending them. Despite these fears, the very writing Plato used to record his works proved instrumental in the development of ancient Greek oratory (the art of speech-making). As scholar Walter Ong points out in Orality and Literacy, his study of the ways writing technologies restructure consciousness, the written word enabled Greek scholars to transcribe and codify effective rhetorical (speaking) strategies. It also vastly increased human vocabulary, since we no longer had to rely on memory to hold all of the language for immediate use. Writing, in fact, allowed rhetoric to flourish.

For the kind of silent reading we now experience to take hold, reading would have to change its context and text its form. It would have to become a more private experience, which means literacy would have to extend beyond the elite and monastic (religious) communities. Texts, too, would need to become more legible, with standardized punctuation and word spaces so that the mumbling of readers sounding out text, common through the sixth century, could disappear. And libraries designed for quiet, contemplative reading could then develop to serve this new readership.

British scribes, like those who crafted the Book of Kells (around 800 C.E.), played a key role in making the text more accessible. They wrote in Latin, and because it was a second language, and one more challenging to sound out in continuous script, they introduced several changes to improve its legibility, including word separation (around 675 C.E.), additional punctuation, and simplified letterforms.

Still, it took nearly four hundred years for these small innovations to spread. The translation of Arabic scientific writing into Latin in tenth-century Europe likely played a vital role in solidifying word separation, since it was inherent in the language (because, unlike Greek and Latin, it is written in consonants). Translators kept Arabic word separation when rendering these texts in Latin, in part because it made the complex technical prose significantly more comprehensible.

61.1: Tern Hunting of Fish

Terns are a group of bird species that hunt fish close to the water's surface. Fish have adaptations to avoid being eaten, including cryptic coloration (most fish are dark along the back, even if they are silvery on the sides), habitually swimming at depths below those at which they are in danger from above, and taking evasive action if they see a bird diving toward them. Terns have their own cryptic coloration, most having white or light grey underparts so that they are difficult to see from below the surface, and they dive vertically toward the fish at the highest possible speeds.

Terns also have to learn to adjust for parallax: sunlight changes direction at the air-water interface, which makes fish always appear to be at shallower depths than they really are. This is an especially difficult problem when the water surface is wavy, which makes the image of the fish move around horizontally as well as vertically-as one can see by looking down from a bridge or dock into rippled water. Terns must learn by trial and error to compensate for parallax and dive accurately toward a target that appears to be moving unpredictably. It has been shown that terns' success in catching fish declines with increasing wind speed, presumably because increasing waviness of the surface makes the fish increasingly hard to locate. At the other extreme, terns' fishing success declines again at very low wind speeds, either because the terns have more difficulty hovering to locate the fish in still air, or because the fish can see the terns more easily when the surface is smooth. Except in the most favorable circumstances, terns' fishing success is usually quite low-typically only one fish caught for every three or four dives, with many attempts broken off even before the tern hits the water.

At most times and in most places, terns are unable to catch fish because the fish are swimming deeper below the surface than the terns can dive. Terns' ability to catch fish usually depends on factors that bring the fish toward the surface. Many fishes follow vertical movements of their invertebrate prey, or zooplankton (tiny water-based animals), but these prey habitually come to the surface at night when terns are usually unable to catch fish. Sand eels, one of the main prey species for terns, come to the surface to spawn (lay eggs), and several other fishes spawn in shallow water near the shore. These spawning events provide good opportunities for terns to catch fish, but they are usually localized and transitory. Fish larvae and juvenile fish are more likely to swim near the surface than adult fish, but these prey are often too small to be good food sources for terns.

An important factor that brings larger fish close to the surface is the vertical movements of the water caused by currents running over obstacles or through narrow passages. Terns regularly concentrate over tide “races" such as that at Dungeness, England, where currents running around narrow strips of land generate turbulent eddies (circular currents) that bring fish to the surface, or at gaps in barrier beaches such as those of the north Norfolk coast (also in England), where tidal currents running in and out twice each day produce similar eddies. Other sites suitable for tern feeding are where tidal currents run around islands or over shallow rocks, reefs, or sandbars, bringing fish close to the surface at predictable times of the tidal cycle. Roseate terns, in particular, feed regularly over such places, and in some areas, travel long distances to feed at sites where fish can be caught predictably.

The most widespread factor making fish come toward the surface, however, is predatory fish chasing them from below. In many coastal areas, flocks of terns gather over schools (groups) of predatory fish and follow them as they feed, diving frantically in the short intervals when the prey fish are forced close to the surface by the predators pursuing them from below. Many tropical terns habitually follow tuna, bonito, or other predatory fish that hunt in schools. The sooty tern is thought to be dependent for much of the year on tuna and the dolphins that accompany them, ranging widely over tropical oceans and coming together wherever the tuna come near the surface to feed.

61.2: Chaco Canyon

Archaeologists have discovered that the Anasazi civilization of present-day southwestern United States flourished even after environmental problems had reduced crop production and virtually eliminated timber supplies in Chaco Canyon, the center of the Anasazi population. Despite these problems, or because of the solutions the Anasazi found for them, the canyon's population continued to increase, particularly during a big spurt (sudden and brief increase) of construction that began in A.D. 1029. Such spurts went on, especially during wet decades when more rain meant more food, more people, and more need for buildings. A dense population is attested not only by the famous great houses (such as Pueblo Bonito) spaced about a mile apart on the north side of Chaco Canyon, but also by holes drilled into the northern cliff face to support roof beams, indicating a continuous line of residences at the base of the cliffs between the great houses, and by the remains of hundreds of small settlements on the south side of the canyon. The size of the canyon's total population remains unknown and much debated. Many archaeologists think that it was less than 5,000 and that those enormous buildings had few permanent occupants except priests and were just visited seasonally by peasants at the time of rituals. Other archaeologists note that Pueblo Bonito, which is just one of the large houses at Chaco Canyon, by itself was a building of 600 rooms and that all those post holes suggest dwellings for much of the length of the canyon, thus implying a population much greater than 5,000. Such debates about estimated population sizes arise frequently in archaeology.

Whatever the number, this dense population could no longer support itself but was subsidized by outlying satellite settlements constructed in similar architectural styles and joined to Chaco Canyon by a radiating regional network of hundreds of miles of roads that are still visible today. Those outliers had dams to catch rain, which fell unpredictably and very patchily; a thunderstorm might produce abundant rain in one desert area and no rain in another area just a mile away. The dams meant that when a particular area was fortunate enough to receive a rainstorm, much of the rainwater became stored behind the dam, and people living there could quickly plant crops, irrigate, and grow a huge surplus of food in that area in that year. The surplus could then feed people living at all the other outliers that did not happen to receive rain then.

Chaco Canyon became a black hole into which goods were imported but from which nothing tangible was exported. Into Chaco Canyon came tens of thousands of big trees for construction; pottery (all late-period pottery in Chaco Canyon was imported, probably because exhaustion of local firewood supplies precluded firing pots within the canyon itself); stone of good quality for making stone tools; turquoise from other areas of New Mexico for making ornaments; and macaws (parrots), shell jewelry, and copper bells from the Hohokam and from Mexico, as luxury goods. Even food had to be imported from places as far as 50 to 60 miles away, as shown by a recent study tracing the origins of corncobs excavated from Pueblo Bonito.

Chaco society turned into a mini-empire, divided between a well-fed elite living in luxury and a less well-fed peasantry doing the work and raising the food. The road system and the regional extent of standardized architecture testify to the large size of the area over which the economy and culture of Chaco and its outliers were regionally integrated.

Why would outlying settlements have supported the Chaco center, dutifully delivering timber, pottery, stone, turquoise, and food without receiving anything material in return? The answer is probably the same as the reason why outlying areas of Italy and Britain today support cities such as Rome and London, which also produce no timber or food but serve as political and religious centers. Like the modern Italians and British, Chacoans were now irreversibly committed to living in a complex, interdependent society. They could no longer revert to their original condition of self-supporting mobile little groups, because the trees in the canyon were gone, irrigation was impossible, and the growing population had filled up the region and left no unoccupied suitable areas to which to move.

62.1: Energy Distribution in Plants

Annuals are plants that go through their entire life cycle within a single year. Annuals begin their life cycles in the spring when seeds that survived the winter germinate (begin to grow). In regions with distinct dry and wet seasons, germination occurs with the onset of the rainy season. Because it has only one growing season, an annual has to distribute its photosynthates (energy-rich molecules) first to leaves. Leaves, in turn, become involved in photosynthesis, which replenishes the supply of photosynthates and increases overall plant biomass. At the time of flowering, the plant decreases the amount of energy distributed to leaves and diverts most of its photosynthate to reproduction. For example, in the sunflower, the biomass of leaves declines from approximately 60 percent of the total plant weight during the period of growth to 10 to 20 percent by the time the seeds are ripe. When in bloom, the sunflower distributes 90 percent of its photosynthate to the flower head and the remainder to the leaves, stem, and roots.

Perennial plants maintain a vegetative structure over several years. Once established, they distribute their energy in a very different manner from annuals. Before perennials expend any energy on reproduction, they divert photosynthate to the roots. This distribution to roots is in excess of that required for the development of roots for the uptake of nutrients and water from the soil. In some species, such as the skunk cabbage, the roots develop into large storage organs. Energy stored in the roots makes up a reserve upon which the plants draw when they begin growth the following growing season. When they are ready to flower, perennials divert energy from storage to the production of flowers and fruit. As the flowers fade and the fruits ripen, the plant once more sends photosynthate to the roots to build up the reserves it will need for the following spring.

Trees and woody shrubs live a long time, which greatly influences the manner in which they distribute energy. Early in life, leaves make up more than one-half of their biomass; however, as trees age, they accumulate more woody growth. Trunks and stems become thicker and heavier, and the ratio of leaves to woody tissue changes. Eventually, leaves account for only 1 to 5 percent of the total mass of the tree. The production system (the leaf mass) that supplies the energy is considerably less than the rest of the biomass it supports. Thus, as the woody plant grows, much of the energy goes into support and maintenance, which increases as the plant ages.

When deciduous trees (trees that lose their foliage in winter) produce leaves again in the spring, they expend up to one-third of their reserve energy on the growth and expansion of leaves. This expenditure is repaid as the leaves carry out photosynthesis during the spring and summer. After leaves, trees give preference to flowers; then tissues that transport nutrients and water, new leaf buds, deposits of starch in roots and bark, and finally, new flower buds.

Evergreen trees have a somewhat different approach. Many have fine, sharp-pointed leaves called “needles." Because the photosynthetic tissues in these needles can function year-round when temperature and moisture conditions permit, they do not need to draw on root reserves for new growth in the spring. They can afford to wait until later in the growing season to produce new growth. Then evergreens can draw upon energy built up earlier in the spring. For the same reason, new growth develops rapidly and matures within a few weeks.

Reproduction and vegetative growth compete for energy allotments. If photosynthesis is limited, vegetative growth gets the first claim. Because the energy that reproduction demands is high-up to 15 percent in pines, 20 percent in deciduous trees, and 35 percent or more in fruit trees-trees can afford an abundance of fruit only periodically, once every two to three years in deciduous trees and two to six years in evergreens.

The proportionate distribution of net production to above-ground and below-ground biomass tells much about different ecosystems. Low light conditions favor the distribution of energy to the production of leaves and stems at the expense of roots. A reduction in water or nutrient availability favors the distribution of energy to the roots.

62.2: The Early American Economy

In the sixteenth century, settlers from England, a part of Britain, began to colonize North America. These colonies remained under British control until the American Revolution, which occurred at the end of the eighteenth century. The economic theory of mercantilism that was dominant from the sixteenth to the eighteenth century, held that colonies should benefit the mother country by helping her become self-sufficient and wealthy. Beginning in the 1650s, the British Parliament passed a series of laws relating to the American colonies that were designed to advance those goals. Colonists were required to buy goods only from English merchants using English ships operated by English crews. The laws stated that certain products, such as tobacco, rice, and indigo, could be sold only in England and nowhere else. On the other hand, colonial agricultural products that competed with those produced by English farmers, such as wheat or meat, could not be sold in England.

The mercantile system was designed to profit the colonizers-not the colonies-and Americans grumbled about some aspects of it and evaded some of its regulations. But on balance, the colonies probably benefited from it. For one thing, it gave colonial producers of protected goods a monopoly in the British market, and English economic energy and strength maintained a vigorous resale trade in American commodities on the European continent. Also, the producers of some commodities received the inducement of a cash subsidy, called a bounty, that profited them immensely. Finally, all American trade benefited from a strong British commercial and financial infrastructure and from the physical protection provided by the powerful British navy, which controlled the North Atlantic. The British connection was especially helpful in the second third of the eighteenth century, when English and European prosperity and population growth led to increased demand for American products. The British even lowered their barriers to American foodstuffs, creating a new market for colonial farmers.

This prosperity had a generally positive, if uneven, effect on American standards of living. As productive people enjoying extensive use of a rich resource base and taking advantage of growing market opportunities, the colonists probably lived as well as any people anywhere. For the colonies as a whole, per capita wealth on the eve of the Revolution was only slightly lower than in England, and in some places—Pennsylvania, for example-was actually higher.

As a consequence, Americans were progressively better fed, clothed, and housed. They drank coffee, tea, and rum, flavored their food with sugar and spices, and wore clothes constructed from imported textiles. They enjoyed luxuries their parents and grandparents had been unable to acquire, such as glass windows, china, silver candlesticks, and lace. Especially attractive to colonial consumers were luxury foods for the table, an indication that they were entertaining guests and perhaps that women were playing an important role in purchasing decisions.

Prosperity fueled expectations among colonists and prospective colonists. Immigrants poured in to share the American bounty, not only from England but from Ireland, Scotland, and Germany. Farmers bought and cleared more land and hired labor. Planters went into debt for luxuries, assuming that the upward economic trend minimized their risk.

The problem with discussing broad trends in economies or the economic behavior of people in the aggregate is that it leads us to lose sight of important qualifications and distinctions. The first and perhaps the most important qualification that must be made involves farmers' behavior and intent. Virtually all colonial farmers-including even the most substantial planters-practiced a safety-first agriculture that was modified only slowly and incompletely by growing commercial opportunities. The essential goal of most farmers was not to fill a market demand but to provide sufficiency for their families and dependents. It was their first priority to feed their families from their own flocks and fields, clothe their families with thread spun and cloth woven at home, and warm their families from their own woodlots. Self-sufficiency is not the same as subsistence, however, and most farmers produced some sort of surplus for the market most of the time. Market involvement was necessary because few farmers could produce enough of everything their families consumed. Hence, one might sell surplus wheat to purchase another's surplus apples or to buy a cooking pot. Moreover, farmers needed a surplus to generate profits to pay taxes, and they wanted a surplus in order to buy those luxuries that would make their lives more attractive.

6

3.1: The Mycenaean Collapse

The Mycenaean culture of ancient Greece, with major centers at Mycenae and Pylos on the Greek mainland and Knossus on the island of Crete in the Aegean Sea, was at its height from 1400 B.C.E. to 1200 B.C.E., with growing cities, thriving trade, and a prosperous economy. Around 1200 B.C.E., however, the Mycenaean world showed signs of great trouble, and by 1100 B.C.E., it was gone. Its palaces were destroyed, many of its cities were abandoned, and its art, patterns of life, and system of writing were buried and forgotten.

What happened? Some recent scholars, noting evidence that the Aegean island of Thira (modern Santorini) suffered a massive volcanic explosion in the middle to late second millennium B.C.E., have suggested that this natural disaster was responsible. According to one version of the theory, the explosion occurred around 1400 B.C.E., blackening and poisoning the air for many miles around and sending a monstrous tidal wave that destroyed the great palace at Knossus and, with it, Minoan culture. According to another version, the explosion took place about 1200 B.C.E., destroying the Bronze Age culture throughout the Aegean Sea region. This second version conveniently accounts for the end of both the Mycenaean and Minoan civilizations in a single blow, but the evidence does not support it. The Mycenaean towns were not destroyed all at once; many fell around 1200 B.C.E., but some flourished for another century, and the Athens of the period was never destroyed or abandoned. No theory of natural disaster can account for this pattern, leaving us to seek less dramatic explanations for the end of Mycenaean civilization.

Some scholars have suggested that sea raiders destroyed Pylos and, perhaps, other sites on the mainland. The Greeks themselves believed in a legend that told of the Dorians, a rude people from the north who spoke a Greek dialect different from that of the Mycenaean peoples. According to the legend, the Dorians joined with one of the Greek tribes, the Heraclidae, in an attack on the southern Greek peninsula of Peloponnese, which was repulsed. One hundred years later, they returned and gained full control. Recent historians have identified this legend of the return of the Heraclidae with a Dorian invasion.

Archaeology has not provided material evidence of whether there was a single Dorian invasion or a series of them, and it is impossible to say yet with any certainty what happened at the end of the Bronze Age in the Aegean Sea region. The chances are good, however, that Mycenaean civilization ended gradually over the century between 1200 B.C.E. and 1100 B.C.E. Its end may have been the result of internal conflicts among the Mycenaean kings combined with continuous pressure from outsiders, who raided, infiltrated, and eventually dominated Greece and its neighboring islands. There is reason to believe that Mycenaean society suffered internal weaknesses because of its organization around the centralized control of military force and agricultural production. This rigid organization may have deprived it of flexibility and vitality, leaving it vulnerable to outside challengers.

The immediate effects of the Dorian invasion were disastrous for the inhabitants of the Mycenaean world. The palaces and the kings and bureaucrats who managed them were destroyed. The wealth and organization that had supported the artists and merchants were, likewise, swept away by a barbarous people who did not have the knowledge or social organization to maintain them. Many villages were abandoned and never resettled. Some of their inhabitants probably turned to a nomadic life, and many perished.

Another result of the invasion was the spread of Greek people eastward from the mainland to the Aegean islands and the coast of Asia Minor. The Dorians themselves, after occupying most of the Peloponnese, swept across the Aegean Sea region to occupy the southern islands and the southern part of the Anatolian coast. These migrations made the Aegean Sea a Greek lake. Trade with the old civilizations of the Near East, however, was virtually ended by the fall of the Minoan and Mycenaean civilizations, nor was there much internal trade among the different parts of Greece. The Greeks were forced to turn inward, and each community was left largely to maintain itself.

63.2: Examining the Diets of Prehistoric People

One of the most important pieces of information about prehistoric people is the nature of their diet. This information is especially relevant when trying to answer questions related to the origins and development of agriculture. Archaeologists can approach diet in a number of ways. They can study diet indirectly by figuring out what people might have eaten based on what was available in their natural environment. For example, deer, duck, turkey, and fish are known to have been available in what is now the northeastern United States for about 7,000 years. Hunting-and-gathering people in this area are likely to have used such resources at one time or another. The weakness of this method of reasoning is that we cannot know with certainty which of the available foods were most important in the diet.

On the other hand, archaeologists can approach the question of diet more directly if there has been good preservation. In many instances, food remains themselves are still present in archaeological sites. Archaeologists can study the fireplaces and garbage heaps of the people who lived at a site and recover food material if it has been preserved. Such remains as bone, seeds, and nuts are often fragile and fragmentary, however, making it difficult to get them out of the ground and back to the lab for identification and analysis. In many cases, an archaeologist takes the entire feature, including all soil, back to the laboratory, instead of attempting to separate the dry soil matrix from the fragile archaeological remains in the field. In the lab, through a number of different procedures collectively called flotation, the archaeologist uses liquid to do the job of separation, taking advantage of the fact that soil and rock will not float in some liquids, whereas organic remains will.

The next task in the reconstruction of a prehistoric diet is the identification of the species of plant or animal represented by the remains. This task can be difficult because of the fragmentary nature of such remains and the changes in them as they decay. In some cases, no precise identification can be made-the piece of bone is too small or the seed too broken up to tell what it is with any degree of confidence. But by comparing the fragment to items in a “library" of bones, nuts, and seeds, archaeologists can often identify many of the dietary remains found at a site.

The examination of the animal remains found at a site is called faunal analysis. Here, the species represented, their sex, ages at death, health, and physical characteristics are identified. Knowing the species of the remains as well as their age, sex, and health status, can provide insight into the hunting practices of prehistoric people. Were the people hunting large numbers of herd animals in group hunts, or were their prey solitary creatures that could be hunted by individual hunters? Were the ancient people able to kill large animals in their prime or only those that were very young, very old, or sick? Also, because many animals give birth to their young seasonally, knowing the age at death of a young animal helps determine the season of the hunt. For example, the North American white-tailed deer usually gives birth to its young in May or June. If the bones of a deer found at an archaeological site indicate an age of nine months, the animal must have been killed, and the site was most probably occupied, in February or March.

Information about diet can sometimes be gathered from an animal's teeth and bones. For example, in mammals, teeth provide clues to overall food sources. Carnivores such as dogs and cats, for example, have slicing teeth adapted to meat eating. Humans have a more generalized dentition, built for chewing a variety of foods. Certain wear patterns on the teeth, examined microscopically, can reveal whether the diet was made up of soft foods such as fruits or more abrasive foods such as roots and tubers. Prehistoric bones can be analyzed to determine what proportion of their chemical composition is strontium and calcium; this information can be used to determine whether plants or meat made up the bulk of the diet of certain populations.

64.1: The Development of Factories

One of the most enduring images of the eighteenth and nineteenth-century British Industrial Revolution is that of the large factory, filled with workers laboring amid massive machinery driven by either water or steam power. Mechanized factory production evolved out of forms of industry that had emerged only during the early modern period (1500-1750). In the Middle Ages, virtually all industry in Europe was undertaken by skilled craftsmen belonging to urban guilds, and these artisans, working either by themselves or with the assistance of apprentices or journeymen, produced everything from candlesticks and hats to oxcarts and beds. During the early modern period, the urban craftsman's shop gave way to two different types of industrial workplaces, the rural cottage and the large handicraft workshop. Both of these served as halfway houses, or transitional stages, to the large factory.

Beginning in the sixteenth century, entrepreneurs began employing families in the countryside to spin and weave cloth and make nails and cutlery. By locating industry in the countryside, the entrepreneurs were able to escape the regulations imposed by the guilds regarding employment and the price of finished products. They also paid lower wages, because the rural workers, who also received an income from farming, were willing to work for less than the residents of towns. Another attraction of rural industry was that all the members of the family, including children, participated in the process. In this “domestic system," a capitalist entrepreneur provided the workers with the raw materials and sometimes the tools they needed. He later paid them a fixed rate for each finished product. The entrepreneur was also responsible for having the finished cloth dyed and for marketing the commodities in regional towns.

The rural household industry was widespread not only in certain regions of Britain but also in most European countries. In the late eighteenth century, it gradually gave way to the factory system. The great attraction of factory production was mechanization, which became cost-efficient only when it was introduced in a central industrial workplace. In factories, moreover, the entrepreneur could reduce the cost of labor and transportation, exercise tighter control over the quality of goods, and increase productivity by concentrating workers in one location. Temporary labor shortages sometimes made the transition from rural industry to factory production imperative.

The second type of industrial workplace that emerged during the early modern period was the large handicraft workshop. Usually located in the towns and cities rather than in the countryside, these workshops employed relatively small numbers of people with different skills who worked collectively on the manufacture of a variety of items, such as pottery and munitions. The owner of the workshop supplied the raw materials, paid the workers' wages, and gained a profit from selling the finished products.

The large handicraft workshop made possible a division of labor- the assignment of one stage of production to each worker or group of workers. The effect of the division of labor on productivity was evident even in the manufacture of simple items such as buttons and pins. In The Wealth of Nations (1776), the economist Adam Smith (1723-1790) used a pin factory in London to illustrate how the division of labor could increase per capita productivity from no more than twenty pins a day to the astonishing total of 4,800.

Like the cottages engaged in rural industry, the large handicraft workshop eventually gave way to the mechanized factory. The main difference between the workshop and the factory was that the factory did not require a body of skilled workers. When production became mechanized, the worker's job was simply to tend to the machinery. The only skill factory workers needed was manual dexterity to operate the machinery. Only those workers who made industrial machinery remained craftsmen or skilled workers in the traditional sense of the word.

With the advent of mechanization, factory owners gained much tighter control over the entire production process. Indeed, they began to enforce unprecedented discipline among their workers, who had to accommodate themselves to the boredom of repetitive work and a timetable set by the machines. Craftsmen who had been accustomed to working at their own pace now had to adjust to an entirely new and demanding schedule.

64.2: Causes of Glacial Ages

Any theory that attempts to explain the causes of glacial ages must successfully address two basic questions. First, what causes the onset of glacial conditions? For ice sheets to have formed, average temperatures must have been somewhat lower than at present and perhaps substantially lower than throughout much of geologic time. For that reason, a successful explanation would have to account for the gradual cooling that finally leads to glacial conditions. The second question is: What caused the alternation of glacial and interglacial stages that have been documented for the Pleistocene epoch (1.6 million to 10,000 years ago)? Whereas the first question deals with long-term trends in temperature that occur on a scale of millions of years, this second question relates to much shorter-term changes.

Probably the most attractive proposal for explaining why extensive glaciations have occurred only a few times in the geologic past comes from the theory of plate tectonics. Not only does this theory provide geologists with explanations about many previously misunderstood processes and features, it also provides a possible explanation for some previously unexplainable climatic changes, including the onset of glacial conditions. Since glaciers can form only on land, we know that landmasses must exist somewhere in the higher latitudes before an ice age can commence. Many believe that ice ages have only occurred when Earth's shifting crustal plates carried the continents from tropical latitudes to more poleward positions.

Glacial features in present-day Africa, Australia, South America, and India indicate that these regions experienced an ice age near the end of the Paleozoic era, about 250 million years ago. For many years, this puzzled scientists. Was the climate in these relatively tropical latitudes once like it is today in Greenland and Antarctica? Why did glaciers not form in North America and Eurasia? Until the plate tectonics theory was formulated and proven, there was no reasonable explanation. Today, scientists realize that the areas containing these ancient glacial features were joined together as a single supercontinent called Pangaea, that was located at high latitudes far to the south of their present positions. Later, this landmass broke apart, and its pieces, each moving on a different plate, drifted toward their present locations. It is now believed that during the geologic past, plate movements accounted for many dramatic climatic changes as landmasses shifted in relation to one another and moved to different latitudinal positions. Changes in oceanic circulation also must have occurred, altering the transport of heat and moisture and, consequently, the climate as well. Since the rate of plate movement is very slow, on the order of a few centimeters per year, appreciable changes in the positions of the continents occur only over great spans of geologic time.

Since climatic changes brought about by moving plates are extremely gradual, the plate tectonics theory cannot explain the alternation of glacial and interglacial climates that occurred during the Pleistocene epoch. Therefore, we must look to some other triggering mechanism that may cause climatic change on a scale of thousands rather than millions of years. Today, many scientists believe, or strongly suspect, that the climatic oscillations that characterized the Pleistocene may be linked to variations in Earth's orbit. This hypothesis was first developed and advocated by the Yugoslavian scientist Milutin Milankovitch and is based on the premise that variation in incoming solar radiation is a principal factor in controlling Earth's climate. Milankovitch formulated a comprehensive mathematical model based on the following elements: variations in the shape (eccentricity) of Earth's orbit around the Sun; changes in obliquity, that is, changes in the angle that Earth's axis makes with the plane of Earth's orbit; and the unsteady wobbling of Earth's axis, called precession.

Using these three factors, Milankovitch calculated variations in the seasonal timing of the receipt of solar energy and the corresponding surface temperature of Earth over a long period of time in an attempt to correlate these changes with the climatic fluctuations of the Pleistocene. In explaining climatic changes that result from these three variables, it should be noted that they cause little or no variation in the total amount of solar energy annually reaching the ground. Instead, their impact is felt because they change the degree of contrast between seasons. Somewhat milder winters in the middle to high latitudes mean greater snowfall totals, while cooler summers would bring a reduction in snowmelt.

65.1: Imitation in Child Development

When does imitation become possible? How important is this ability in the learning of infants and children? Andrew Meltzoff and M. Keith Moore argue that even newborns and very young infants imitate a variety of responses, including tongue protrusion, mouth opening, and possibly even facial expressions portraying such emotions as happiness, sadness, and surprise. Although some investigators have been unable to replicate these results, many others, including the authors of one study involving infants from Nepal, report a high degree of imitative competence in newborns.

Even more controversial is what imitative behaviors mean. The influential Swiss psychologist Jean Piaget, for example, claimed infants younger than eight to twelve months could imitate someone else's behavior only when able to see themselves making these responses. Because babies do not ordinarily view their own faces, imitative facial gestures would be impossible, according to Piaget, until after about a year of age, when symbolic capacities (abilities to use a symbol, an object, or a word to stand for something) emerge. From this perspective, then, the facial gestures that infants younger than a year make in response to a model's facial expression are stereotyped, rigid responses set off by or linked to limited forms of stimulation rather than imitations of what the child has seen. For example, perhaps tongue protrusion by a model arouses the infant, which in turn promotes a sucking response that naturally invokes tongue protrusion from the infant. If this is the case, infants could be responding to just a few types of stimuli and producing a kind of reflexive (automatic) motor activity that is not really a form of imitation.

Meltzoff and Moore counter that very young infants imitate a variety of responses, modify their imitations to increasingly match the modeled behavior over time, and exhibit their imitations primarily to other people and not to inanimate objects. These arguments contradict the view that such behaviors are simply a fixed pattern of reflexive actions. They propose instead that infants imitate in order to prolong interaction with others. In fact, babies as young as six weeks will imitate the behaviors of a model up to twenty-four hours later. Such imitation is a way to continue the earlier imitative communication with the model. If this interpretation is correct, imitation has an important social-communicative function and is one of the earliest games babies play with other people.

Between six and twelve months of age, infants display far more frequent and precise imitations, matching a wide range of modeled behaviors. Piaget and others believed that deferred imitation, the ability to imitate well after some activity has been demonstrated, is not possible until about eighteen to twenty- four months of age. Piaget believed deferred imitation, along with pretend play and the emergence of language, marks an important transition from one stage of thinking to the next and provides one of the first major pieces of evidence for symbolic capacities. However, as we have already seen, Meltzoff and Moore claim infants as young as six weeks can reproduce a model's behavior a day after seeing it.

Deferred imitation involving actions associated with objects can also be observed far earlier than Piaget claimed. For example, six-month-olds will remove a mitten from a puppet's hand, shake it, and try to put it back on the puppet after observing this sequence of actions performed by a model twenty-four hours earlier. Moreover, toddlers as young as fourteen months who see a peer pulling, pushing, poking, and inserting toys in the laboratory or at a daycare center will reproduce the behaviors in their own homes as much as two days later when given the same toys. The capacity for deferred imitation, then, appears to exist much sooner than previously assumed. In fact, the results are consistent with research on memory, showing that infants younger than one year can recognize stimuli hours and even days later. The observances of imitation at very young ages are important from a social learning perspective, providing clear and compelling evidence that infants, as well as older children, learn many new behaviors by observing others.

65.2: Birds and Food Shortage

The term “food shortage" has been used for food that is inadequate in quantity, quality, or availability. Whatever the abundance of food in the environment, if it is for some reason unavailable, bird species in either inland or coastal areas may starve. Food sources like intertidal invertebrates retreat deeper in the mud in cold weather, putting them beyond the reach of shorebirds, while many soil-dwelling invertebrates move deeper into the ground during drought. Such behaviors illustrate the general points that only a proportion of potential food items may be accessible to birds at any one time, and that this proportion may change through time in response to other conditions. Secondly, if food is plentiful but of low nutrient content or digestibility, a bird may be unable to process enough each day to maintain its weight. This is particularly true of herbivores (plant eaters) eating fibrous, or coarse vegetation, and food shortage may arise partly from the structure of a bird's inner parts, or gut, which limits the rate at which food can be processed. In general, among birds, species differences in gut structure correspond with dietary differences, and in species whose diet changes seasonally, the gut structure may change accordingly. The need for change in gut structure can make some species vulnerable at times of rapid shift in diet, as when snowfall forces birds suddenly from one food type to another.

Many bird species cushion the effects of food shortage by storage, either of body fat or food itself. In small birds, fat stores are accumulated mainly for use overnight, and few species can last more than a day or two without feeding. Larger birds, with their relatively lower metabolic (energy) demands, can store relatively more energy per unit of body weight. As a result, larger birds can rely on internal reserves for longer than small ones, more than two weeks in large waterfowl. Many birds store some body fat and protein in preparation for breeding, extreme examples being Arctic-nesting geese, in which the females produce and incubate their eggs almost entirely on reserves accumulated in wintering or migration areas. For some weeks, then, they are protected against the need to feed on their breeding grounds. Most migratory birds accumulate body fat for the journey, the amount depending on the duration of the unbroken flight.

Species that store food items outside the body may retrieve them hours, days, or even months later, depending partly on the type of food. Some meat eaters cache (store) prey for consumption later in the day or in the following days, while some seed eaters may store food in autumn to last through the winter or even year-round. Long-term storage is frequent among various birds, such as tits, nuthatches, and woodpeckers, reaching its extreme in certain jays and nutcrackers. In some such species, stored food can provide more than 80 percent of the winter diet, and can also feed the adults into the next breeding season, influencing the numbers of young raised. In good seed years, huge amounts of seed can be stored. Crucial aspects of hoarding behavior are that individuals should guard their stores or should hide them (to reduce theft) and remember where they are. Some species store items individually, each in a separate place, and in experiments, have shown incredible feats of memory. But none of this behavior alters the dependence of such birds on their food supplies; it simply enables them to use their foods more effectively, taking advantage of temporary gluts (oversupply) to lessen later shortages. It does not prevent them from being limited by shortages in years of poor seed crops.

Yet other birds can cushion themselves against temporary food shortages by becoming torpid, meaning they achieve an inactive state in which body temperature and heart, respiratory, and metabolic rates are greatly depressed, thereby conserving energy. In some small species, this happens to some degree every night, but it is especially marked in some small hummingbirds, such as Anna's hummingbird of western North America. Some other species, such as the common swift, can remain torpid for several days at a time when cold weather renders their insect prey inactive, and at least one species, the common poorwill, can remain torpid for several weeks, in a state akin to hibernation in mammals. These adaptations help the species concerned to last through difficult periods, whether hours, days, or weeks, but they cannot eliminate altogether the risk of starvation.

66.1: Cotton Ginning and Interchangeable Parts: The Legacy of Eli Whitney

Cotton is a soft fiber that grows around the seeds of the cotton plant. It was first cultivated in the Indus Valley about 6,000 years ago and then spread to Egypt, Persia, China, and the Mediterranean. For thousands of years, the cultivation of cotton was very labor-intensive. Many steps were involved in preparing cotton to be used in a garment, and many machines were invented to make cotton more valuable as a general-purpose textile material.

The process of separating cotton fibers from seeds is called ginning, which is depicted as far back as the fifth century in paintings in the Ajanta Caves in India. Egyptian cotton has the longest fibers and is used to make premium fabrics. In the American South, the high-quality long-staple cotton can be grown only in a narrow band along the Carolina and Georgia coast and is called Sea Island cotton. The interior areas of the American South can only grow Upland short-staple cotton. The shorter-length fibers mean reduced yarn and cloth quality, and they have "fuzzy" seeds because the fibers are tightly attached to the entire seed surface. This strong attachment of fibers to seeds makes it difficult to remove the fibers without damage, which made the process expensive as it was time-consuming and labor-intensive. These time-consuming tasks were done by slaves in the American southern states during the 1800s.

The modern cotton gin was invented by the American Eli Whitney (1765-1825), who graduated from Yale University in 1789 and is known for two great inventions: the cotton gin, which transformed the southern economy, and interchangeable parts in machinery, which led to the mass-production method of manufacturing. When he graduated, he was short of funds and went to Georgia to seek his fortune in plantations. He was introduced to the problem of finding a better way to gin the Upland short-fiber cotton, which led him to invent the cotton gin in 1794. Whitney's cotton gin made the mechanical separation of fiber from seeds much more efficient. His machine had spiked sawteeth mounted on a revolving cylinder in a box, which was turned by a crank. The teeth pulled the cotton fiber through small slotted openings that were too small for the seeds to pass; thus, the lint was separated from the seeds. Then, a rotating brush removed the fibrous lint from the teeth, and the seeds fell into a hopper. Whitney's machine could separate up to 50 pounds of cleaned cotton daily, making cotton production profitable for the southern states.

Unfortunately for Whitney, his cotton gin was extremely simple and easy to copy, so he failed to profit from his invention. Soon after, imitations of his machine appeared, and his 1794 patent for the cotton gin could not be upheld in court until 1807. Instead, he decided to make money by going into the ginning business, and manufacturing and installing cotton gins throughout Georgia and the southern states. However, his ginning plants were resented by the planters, who thought that he charged too much, and hence, found ways to circumvent his patent.

In later years, Eli Whitney cultivated social and political connections through his status as a Yale alumnus and through his marriage. Although he had never made a gun in his life, through those connections, he won a contract from the War Department in 1798 to make and deliver 10,000 muskets (firearms used by soldiers before the invention of the rifle) for the army in 1800. Treasury Secretary Wolcott sent him a "foreign pamphlet" on arms manufacturing techniques, and Whitney began to talk about interchangeable parts. This concept was a departure from the usual method of having an individual master machinist make each part of the musket and fit them together, which is slow and painstaking. Whitney's method was to have many less-skilled machinists specialize in making only one part per person to highly specified dimensions, so that the parts would be interchangeable and could then be assembled. This is the heart of the mass-production method, later made more famous by Henry Ford in the manufacture of the Model T automobile. Whitney ultimately delivered on the army contract in 1809, and he spent the rest of his life promoting interchangeability.

66.2: Interpreting Prehistoric Cave Art

The Upper Paleolithic period began about 45,000 B.C. It is from this period, in several caves located in Europe, that archaeologists have discovered remarkable examples of prehistoric art. One of the early interpretations of cave art was that it was “art for the sake of art," much as we today might go to a museum to see the skills of artists. This is a Western-culture-centered interpretation, however, and some would argue that there might be other, context-specific interpretations that are more suitable. The location of this art deep within dark caves, in which small flickering lamps would only reveal small portions of painted walls, also does not seem to fit with an interpretation of prehistoric “art galleries."

Another early interpretation was based on the fact that most of the images are animals, and the majority of these, such as horses and bison, were hunted for food. This viewpoint became known as the "hunting magic" explanation. The drawing of the animals was interpreted as a way to magically ensure that an upcoming hunt would be successful. The hunting-magic interpretation has much appeal because we know that hunting was an important part of daily life during this period. And, in direct contrast to the art-for-art's-sake explanation, the practice of these “rituals" deep within caves suggests that not everyone participated. There are many nonhunting images in the caves, however, that do not support this explanation, such as geometric shapes and human figures.

In an effort to include all the types of images in Upper Paleolithic cave art in a comprehensive interpretation, some researchers turned to aspects of how the human mind works during altered states of consciousness and what images the mind “sees" during different phases of altered states. This explanation is called “entoptic phenomena," and it argues that all modern human brains experience the same sets of visual images in the same progression. For example, during the first stage, it is common to see geometric patterns; during the second stage, the brain begins to associate various geometric designs with real objects; and during the third stage, the brain sees actual animals, people, and monsters. Altered states can be achieved in many ways-drugs, intense dancing, sitting in absolute darkness as in a deep cave-and the entoptic phenomena interpretation argues that cave-art images represent the "visions" seen during these experiences.

Other explanations focus more on the use of cave art as a form of communication. That is, its presence and the types of images were used to establish social identities and perhaps as territorial markers. Communication, as an explanation, is based on identifying different styles that represent different groups of people and is a key element at aggregation sites, places where these people came together at certain times. Communication also is seen as adaptive because it enhances the survival of groups using social networks or alliances. The abundance of cave art in France and Spain, particularly during the Late Upper Paleolithic, is thought to be one outcome of the dense packing of people as they moved south to escape the harshest conditions of the extreme cold of the glacial maximum of the last ice age. Art was used to form alliances and thus resolve disputes about resources between groups who could not easily move away because of the close presence of many groups and the inhospitable nature of more northern areas in Europe.

In recent years, accumulating evidence suggests that Upper Paleolithic people created wall art not only in relatively inaccessible caves, but also in the rock shelters where they lived. Like Later Stone Age rock shelters in Africa, those of the Upper Paleolithic in Europe were exposed to sun, rain, and other weather, and most of the art present in these locales has long since disappeared. The traces we do have, however, suggest that wall art was a much more common feature of daily life than the art present deep in caves might suggest. And, if wall art was much more widespread and was typical of people's living sites, then single-cause explanations for wall art, especially those that are based, in part, on its inaccessibility in deep caves, seem less likely to be accurate models for all Upper Paleolithic wall art.