CHAPTER 20

THE GREAT AGES OF OUR PLANET

Geologists can easily distinguish various types of land by its characteristics, such as whether or not it was created by fire and melted (lava) or by the gradual settling and compaction of sand in a large body of water (sedimentary rock). Perhaps not so surprisingly, they also recognize characteristics of land that have been determined by life. The most obvious change is the sudden appearance of large amounts of organic carbon, producing black soils, beginning between 500 and 350 million years ago. See page 222 for the definition of "organic". Very simply, prior to that time there was not a large mass of living organisms leaving their traces on the earth. Beyond that startling change, other forms of land can be identified by the presence of huge amounts of the shells of shellfish (such as the limestone cliffs of the English side of the English Channel—the famous "white cliffs of Dover"), or remnants of ferns and other plants (the large coal beds of the world). Within these larger categories, the types of shells and other remnants are identifiable and distinguishable. For instance, in some soils and rocks we can clearly identify the fossil bones of various types of amphibia and insects, but no reptiles, birds, or mammals. In others, there are far more reptiles than amphibia, but no birds or mammals. In yet others, there are some but not many reptiles and amphibia, and many birds and mammals. These different layers of rock are found worldwide and in soils of different types, but are so consistent that the fossils served as the first means of comparing the soils and rocks of one country to those of another. For instance, they served as the basis for determining the probability of finding oil or other minerals. The characteristic types were given names that served to identify a specific era in the history of the earth. The names were derived from Latin and were either basically descriptive (Carboniferous = coal-bearing) or were chosen from the first or most prominent region from which the era was standardized (Devonian = from the region of Devonshire, England; Cambrian = from Wales [Cambria in Latin]; Jurassic = from the Jura region of Switzerland; Mississippian and Pennsylvanian, for formations found in these regions of the continental United States, etc. In a more fanciful fashion, sometimes names were given to commemorate ancient tribes believed to have inhabited the land [Ordovician, Silurian]). Using Steno's rule, that in sedimentary deposits the deepest deposit is the oldest, geologists assembled the geological strata, or eras, into a sequence, though, of course, the actual timing remained in question. The sequence indicated a striking series of events. In the oldest strata of the earth, there appeared to be no life. (This interpretation has been revised, as is described on page 281.) Then, suddenly, at a point known as the Cambrian, life proliferated. This era was characterized by many animals and plants, but was most spectacularly identifiable by the presence of fossils of amphibia and primitive fish. After several variants on this theme, the Age of Amphibians was superseded by an era characterized by predominantly reptiles, some of gigantic size. Some but not all of the giants were the dinosaurs. In the most recent layers, the giant reptiles were gone, but mammals and birds had joined the fossil record. These eras were then given Greek names to define them: The Age of Amphibians was the Paleozoic ("old animals"); the Age of Reptiles was the Mesozoic ("middle animals") and the Age of Mammals, our current age, is the Cenozoic ("new animals"). Of course there were characteristic plants for each era—the ferns of the late Paleozoic are the coal fields of the Carboniferous (a subdivision of the Paleozoic), while flowering plants did not appear until the Cenozoic—but since we are animals, we tend to emphasize the animal names. A list of the primary geologic eras, their characteristics, and the translation of their names, is given in Table 19.1 and the eras themselves in Table 19.2.

The various types of strata had been recognized by Nicolas Steno at the end of the 17th Century, when he demonstrated that strata were similar over extensive areas of Europe and could therefore be easily compared. In the 18th Century Abraham Werner refined Steno's observations by dividing the categories of the earth's crust into four groups, appropriately if simply named Primary, Secondary, Tertiary, and Quaternary types of rocks, going from the oldest (deepest) toward the youngest. Alexandre Brogniart and Georges Cuvier in France and William Smith in England were using fossils to subdivide the major categories, recognizing as well that these subdivisions based on biology were valid for France, Italy, Germany, England, and Wales (the latter being an area from which many ancient rocks were taken.) Ultimately the generalization was extended to the New World, where, it could be seen, similar strata were easily identifiable. By 1850—before Darwin published *Origin of the Species*—the major subdivisions of the eras (periods) were defined, with the names of the periods (including "Mississippian" and "Pennsylvanian") reflecting the consensus that the geological patterns, including their fossils, represented changing conditions on a worldwide basis. The timing, however, was a matter of speculation. A river might dig through the rock where it is flowing fast and deposit the sediment slowly in a more slowly-moving stretch, but in a single major flood it might deposit a foot of sediment. A volcanic eruption might deposit anything from a dusting to ten feet of ash, or lava flows of equally broad range. Thus it is impossible to read dates from the order of layering alone. It is plausible to say that currently, the river extends the delta by an inch a year, so that a delta one mile long is approximately 65,000 years old (there are 63,360 inches in a mile). It is however equally plausible to argue that the delta was almost entirely created by Noah's flood approximately 6000 years ago and has variably expanded since that time. It was not possible to establish accurate time scales until measurements could be made of radioisotopes (Chapter 8), which are formed by mechanisms that are not affected by temperature, concentration, or presence of other chemicals. However, there were many ways to try, and many scientists set about to make the assessment. These methods are described in Chapter 9, page 114.

We now have an accurate assessment of these eras and periods, and our astonishment remains: each of the great eras represents a very different type of life on the planet, and the transition from one era to the next was, in geological terms, rather sudden. Why was life so different at each stage, and what caused the sudden and dramatic changes? In order to examine these questions, we need to understand at least in broad terms what the eras were, and how they differed.

THE PRECAMBRIAN

Until approximately 40 years ago, the Precambrian period (from 4 billion up to approximately 2.5 billion years ago) was considered to be a period without life, during which chemical reactions produced organic molecules (Chapter 15, page 222) and in general the earth, having cooled to a point where life was possible, awaited the appearance of the first living organisms, which burst forth in huge variety as the world entered the Cambrian era. There was much evidence for this occurrence, as indeed there was a sudden and startling increase in living organisms (Chapter 19, page 277). In fact, it was argued that the late appearance of life on this earth (570 million years of 4 billion years, or in the last 12% of the earth's history) was evidence in support of the complexity and enormous difficulty of life's appearing on a planet. Such arguments were presented to defend the proposition that the creation of life was an extremely difficult task and consequently extremely rare in the universe. More current interpretations are that life arose quite early and is not likely to be so rare in the universe. Thus the original argument has been turned on its head. How could such a change occur? As always in science, evidence trumps theory, and ultimately new evidence forced the re-interpretation.

First there was the logic. The logic consisted of two parts, one intellectual and one practical. From the intellectual standpoint, there was the problem that at the beginning of the Cambrian era, most of the major types of life—vertebrates, arthropods, mollusks, starfish, to address only the animals—were already present. Where did they come from? Did they not evolve from other, simpler, organisms? How could it be that so many different types of plants and animals appeared suddenly and in profusion? This intellectual question led to the realization of an extremely practical problem: that fossils might have existed, but not be found or recognized. Darwin and later scientists had recognized that the formation of a fossil was likely to be a chancy affair. An organism would have to die and sink into a muddy environment to protect it from bacterial destruction or crushing, in one scenario; it would have to have sufficient rigidity to hold its shape in the mud, or a skeleton or shell that would survive; the mud would ultimately have to solidify into rock that would be buried and remain undisturbed by earthquake, volcano, or erosion, until one of these processes brought the rock back to the surface again, to be found and identified by limited number of appropriately skilled people during the last two hundred years of our existence. A slug or an earthworm would probably decay before being fossilized, or otherwise produce an unidentifiable record.

What happened in the mid-twentieth century was the realization that the latter situation was in fact likely for early organisms. The Cambrian animals had large shells, clearly used for aggression or defense, thus bespeaking a highly competitive environment. But the first life appearing on earth was by definition not competing against other organisms, and therefore was unlikely to have been selected for bulky, metabolically expensive armor. Early life was not likely to have been shelled. Furthermore, if living organisms developed from non-living emulsions or coacervates (Chapter 17, page 251), there was no reason to assume that these organisms would necessarily be large enough to see with the naked eye, or macroscopic. Perhaps early life was microscopic and soft. It would therefore be necessary to search not for fossils but for signs of life.

There are many potential signs of life, including some of the following:

- Organic molecules can be formed in "left-handed" and "right-handed" forms. The difference is that molecules can have the same number of atoms arranged in the same way, except that their relationship is that of a left glove compared to a right glove. Chemical reactions produce equal numbers of both kinds, but living organisms vastly prefer one kind, such as the left-handed version of amino acids that are the basis of proteins. Organic molecules are found in various soils and rocks. If the left- and right-hand forms are equally common, they were most likely formed by strictly chemical processes. If one type predominates, they were most likely formed by living organisms.
- Although the differences between water (H_2O) and heavy water (also H_2O, but with each hydrogen containing an extra neutron) are extremely small, living organisms can discriminate between the two. Heavy water exists naturally in nature but in very low amounts. Water is often incorporated into molecules being made by living things. If these molecules contain less heavy water than occurs naturally, they probably were made by living organisms.
- Although many organic molecules can be formed by strictly chemical means, some, such as molecules like cholesterol, are not spontaneously formed by any non-living process known. Thus, if some of these molecules are identified in the sediment, the sediment probably contained living organisms.
- In all known plausible reactions other than photosynthesis, free oxygen is consumed rather than produced. If oxygen increases in the atmosphere, its origin is most likely from photosynthesis.
- Tiny droplets in emulsions or coacervates come in a range of sizes, whereas living organisms such as bacteria are uniform in size. If microscopic droplet type structures in rocks are very uniform in size, and particularly if they contain carbon, or if they form more oval or elongate shapes rather than spheres, they may have been produced by bacteria.

- Large constructions may be formed by microorganisms. For instance, certain types of bacteria found along seashores tend to accumulate in large piles, and by secreting calcium salts into the water, produce large stone-like structures called stromatoliths. Characteristic structures such as these can be identified in fossil-bearing rock. (See Chapter 18, page 257)

Once these issues and characteristics were fully understood, and radioisotope dating (Chapter 8, page 104) was recognized as sufficiently accurate to identify the ages of rocks dating to before the Cambrian era, a new search of these rocks was undertaken, by electron microscopy and other techniques. Electron microscopy can enlarge images to over 200,000 times, and thus provide detailed pictures of objects far smaller than can be seen using even the best light microscope. (Because of the limit of resolution of the human eye and the physical characteristics of visible light, the theoretical limit of resolution is approximately 2,000X or 1/10,000 of one millimeter. The theoretical limit is not easily obtained, and the best one can often do is to obtain an image of a dot or a small rod that represents a bacterium, but with no internal detail.) Various groups also analyzed the types of molecules found in carbon-bearing rocks, as well as the distribution of isotopes such as deuterium, the basis of heavy water. As the data from these types of analyses came in, two major themes emerged: first, there was considerable evidence for life well before the Cambrian era; and second, that a few previously known old rocks, such as some in Greenland, China, and Canada (the Burgess Shale in Canada, which was first recognized as fossil-bearing rock by Charles Walcott in 1909) unequivocally dated from an era prior to the Cambrian era.

As is discussed below, these fossils were quite remarkable in many ways, but they also raised many questions. First, if the various data were to be believed, life first appeared much earlier in the earth's history, so early in fact that it could be interpreted as a rather easy or probable event. In this case it might be very likely that some form of life might be found on an appropriate planet elsewhere in the universe. Thus interplanetary probes and landers such as the Mars Lander explore for chemical and microscopic signatures such as those mentioned above. The other issue was the conversion of the question, "Why did it take so long for life to arise?" to "If the earth is 4.5 billion years old, and took a few hundred million years to cool to a temperature at which life could exist, and life appeared as early as 4 billion years ago, what delayed the proliferation of many varieties of large, complex animals and plants for 3½ billion years?" We have many theories, based mostly on logic but with some evidence (drawn from extrapolating backwards from the relationships of animals and plants) to support the theories. As is explained in Chapters 17–20, the primary theories include:

1. The invention of homeotic genes, allowing animals (but not plants, which use different mechanisms) to develop complex structures with head and tail and back and belly, and appearance of oxygen in the atmosphere.
2. Available oxygen rendered possible oxidative metabolism, which was capable of yielding far more energy than fermentation and most importantly blocked the brutal UV that bombarded the planet and made it possible for living organisms

to move onto land. Thus, the theory goes, for almost four billion years life consisted of bacteria, algae, and similar forms, living in the seas and at most along shorelines that were usually below the tideline.

The end of the Precambrian

Then, approximately 600,000 years ago, the world began to change. And what a change it was! What happened was originally most clearly illustrated in the Burgess Shale. Shale is mud hardened into rock, often splitting into sheets because the mud accumulates at different times, for instance during big floods, and other material accumulates on the mud between the floods. The Burgess Shale, now in the Rocky Mountains of western Canada, was once a muddy flat subjected to such flooding. The floods and mudslides buried what shore life was living there, encasing the creatures in the mud that eventually hardened into the shale. If one cracks apart the shale, there are many strange forms found in it. The forms are clearly biological in origin, as we know of no chemical or physical process that could produce them. Although none truly resemble anything found on earth today, some are similar enough to animals known today, or to later fossils that are themselves similar to modern creatures, that we can classify them. For instance, there are shells that are related to the shells of the fossil trilobites, which are tolerably similar to today's horseshoe crabs. Thus there is no reason to assume that these fossils are not primitive shellfish. Others can be compared to sea urchins and starfish, or to some modern marine worms. Still others look like no creature seen or imagined by humans. In fact, scientists who tried to identify them christened one with the name Hallucigenia! One has three eyes. Another is a bunch of feathery fronds—gills—that do not seem to connect to anything. Another is, perhaps, a walking worm with spines along its back (Fig. 20.1). The shale formation is now reliably dated as being approximately 505 million years old.

What we have learned from this formation, as well as from similar formations in Greenland, Australia, and China, is three things:

1. There was considerable life well before the Cambrian.
2. Nevertheless, the varieties and numbers of creatures (the total living mass of the earth) began to increase rapidly in the later pre-Paleozoic period. Without living creatures, the element carbon is found mostly as the gas carbon dioxide and as its equivalent after reaction with other atoms, such as carbonates. (Chalk is calcium carbonate, and many semi-precious stones are other types of carbonates.) When living creatures die, their organic molecules ultimately deteriorate to pure carbon. There is a substantial increase in the amount of carbon in soils during this period, so much so that the transition line is quite distinct, with dark, carbon-bearing rocks overlying less carbon-rich rocks. (Fig. 20.2)
3. Many of the creatures of this period are heavily shelled, bear spines, or are heavily armored. As noted above, there will be no selection for bulky structures that take considerable investment in energy to build unless the structure offers some advantage to its bearer. Thus the appearance of shells bears witness to

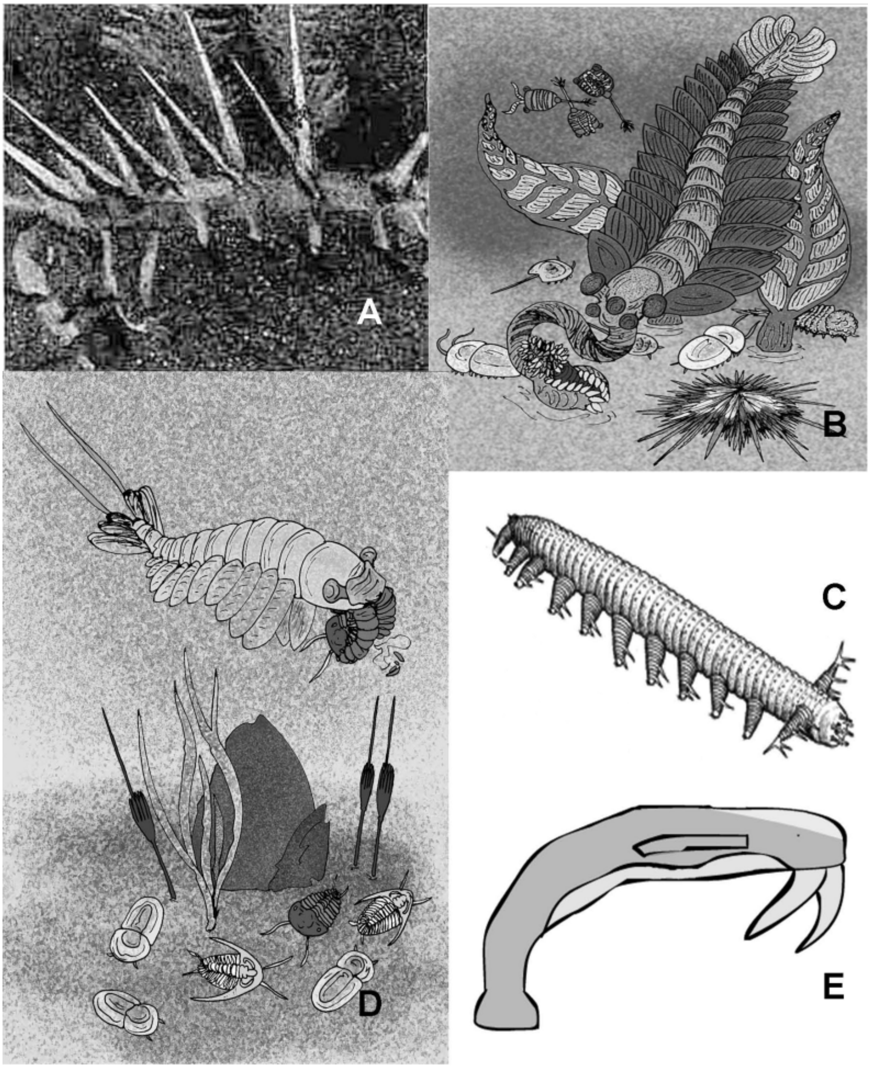

Figure 20.1. Precambrian animals. A. Hallucigenia. For a long while it was not certain which end of this animal was up and which was down, but it now is considered to a bit like a velvet worm (See Fig. 5.5) but with spines. B. An artist's reconstruction of a creature not known to be related to any modern form, Opabinia, eating a sea worm. The other creatures are apparently related to modern arthropods, sponges, and sea anemones. C. Another velvet worm-like creature, Ashyia. D. Artist's reconstruction of the rather large preCambrian arthropod-like animal Anomalocaris feeding on trilobites E. Artist's reconstruction of the mysterious soft-bodied creature named Amiskwia. It has no known descendents. Credits: Wikipedia.org

Figure 20.2. Cambrian-precambrian transition. The sudden appearance of black in the rocks indicates a substantial increase in carbon dioxide converted to organic molecules, as the amount of life suddenly escalated. The later disappearance of the carbon reflects the increase in shellfish in the rocks. Credits: http://wwwalt.uni-wuerzburg.de/palaeontologie/Stuff/ campics/n02.jpg–Wikipedia

predation and competition among animals. It also creates a situation in which fossils will be much easier to recognize.

4. Although we can describe a lineage from some of the creatures to creatures that we know today, many are completely foreign to us. They are not only extinct, but the entire group of animals that they represent is extinct. In fact, they do not seem to have survived much into the Paleozoic period. Thus, we can suggest, as did Steven Jay Gould, that this period was one in which many varieties of life appeared. It was, in his words, a period of enormous "biological experimentation". Of all these fantastic creatures, only a few proved to be sufficiently successful and adaptable to survive into the present. The ones that did are the ancestors of the handful of groups, or phyla, that we know today. Phyla, as defined in Chapter 5, are groups such as mollusks, arthropods, and chordates (the true vertebrates and their close relatives). In other words, the period was one of considerable competition, variation, selection, and survival or elimination—evolution in its most dramatic and rapid form. As is discussed in Chapters 17–19, although many of the phyla remain predominantly in the oceans, the families or major subdivisions of the phyla, such as fish, amphibians, reptiles, birds, and mammals among the chordates; crustacea and insects among

the arthropods; or mosses, ferns, evergreens, and broad-leafed flowering plants among the plants, represent adaptations to life on land.

THE PALEOZOIC

Beginning a bit less than 600 million years ago, the world that we can recognize began to take shape, with a vast increase in the number of living organisms on earth as well as representatives of today's organisms. During this period, which lasted a little less than 300 million years, there appeared fish, corals, primitive land plants, insects. The middle of the period saw the appearance of amphibia, flying insects, and the first plants that could truly stand erect on land (the vascular plants, including mosses and ferns). By the end of this period, slightly less than 300 million years ago, the ferns were giant (tree ferns) and so numerous that their remnants gave rise to the eponymous Carboniferous period, the fossils that created the great coal fields of the Americas and elsewhere. We have already addressed the issue of why the Cambrian was such a fertile period, and we will speculate in Chapter 23 why it finally closed, giving rise to the Mesozoic. We also need to ask what the world was like and how we can tell what it was like.

As will be discussed in Chapter 22, there is substantial evidence that the continents were not in their present locations and that the present configuration of mountain ranges, deserts, rain forests, and plains was probably not present. There are several means of determining that the climate was warm and moist. To take the simplest and most obvious, ferns today are found only in moist locations. They are not hardened to retain water like a cactus, and their means of reproduction requires that the gametes (the technical equivalent of eggs and sperm) find each other in water. Furthermore, ferns undergo what is known as a two-stage life cycle, in which one stage is a small, inconspicuous organism that would quickly shrivel up and die if left in a dry situation. Fossil ferns appear to have reproduced the same way. The presence of amphibia, which reproduce almost exclusively in water, and of ferns, which likewise require water for reproduction, indicates that wherever we find such fossils, the land was at least damp. Today we find ferns mostly in damp locations, tree ferns in tropical rainforests, and by far the largest number of amphibia in rainy areas. We have no reason to assume that they lived otherwise in earlier times. Also, with the exception of one frog, the crab-eating frog, which has very special adaptations, frogs, toads, salamanders, and newts cannot survive salt water and are consequently very rarely found on islands. Although the sea was once less salty, the presence of amphibians on all continents argues for land bridges connecting the continents during this time.

THE MESOZOIC

As is discussed in Chapters 22 and 23, mountain building creates many more environments, or niches, in which individual animal and plant species can survive, and it also creates regions of much more highly variable temperatures and levels of humidity. This resource produces great potential for any creature that can exploit the opportunity, but to exploit the opportunity means acquiring the several physiological features needed to survive on land. These include skeletons capable of supporting animals or plants erect on land; means of motility on land; means of protecting sperm (pollen), eggs, or both for reproduction protected from the drying effects of air; skins capable of minimizing water loss; respiratory structures adapted for air rather than water; and excretory systems (kidneys and rectums) capable of reabsorbing water. These adaptations were first completely achieved by reptiles and the plants that became the pines, spruces, and similar evergreens (described, significantly, as Gymnosperms, or plants with hidden seeds). Unlike the frogs, toads, and salamanders, the reptiles have dry skins; they have internal fertilization, meaning that the male implants sperm into the female rather than spreading it over eggs already in water; they have eggs with hard shells, impermeable to water; their legs and shoulders lift them farther off the ground than the legs and shoulders of frogs or salamanders; and they process urine and feces in such a manner that very little water is lost. Insects have similar adaptations. For animals and plants such as these, the land was a paradise waiting to be exploited, more so than the fabled El Dorado ("The gold-covered land" that the Spanish sought in South America). The reptiles moved into the land, expanding to fill every possible slot for life, in what can be described as "adaptive radiation" or development of forms to occupy every position from herbivores to carnivores, from lowly creeping creatures to turtles to rhinoceros-like creatures to the powerful and fast raptors beloved of children. (Unfortunately, judging from the skeletons—see Chapter 2, page 28, and Chapter 3—it certainly would NOT have been fun to meet a real raptor.) Some took to the air to become the first flying vertebrates, and others returned to the sea as porpoise-like animals (see Fig. 3.4.) This is what we really mean by adaptive radiation. Each particular role on the planet—large, fast-moving aquatic carnivore, small, mouse-like creature eating seeds and any dead animal or plant material, large leaf-eating herbivore—is called a niche, from the French for nest, and if no creature currently occupies the niche, something will evolve to do so. Thus in the absence of porpoises there were pleisiosaurs.

The age of the Middle Animals, the Mesozoic, had begun. It was quite a successful period, lasting for 180 million years, three times as long as the current modern era, the age of mammals, has lasted. Again, judging from the types of plants and animals that we can recognize, the climate was tolerably mild and moist. Almost every variation on animals and plants appeared among the reptiles and the plants, with some exceptions. There were no true flowering plants, fertilized by insects. Some of the reptiles must have been warm-blooded in the sense that they were usually much warmer than the environment, and a few had begun to develop feathers, presumably as insulation; but feathers and control of body temperature were probably not common. Finally, they laid eggs, and eggs were vulnerable to predation or to sudden changes in climate. Nevertheless, the Mesozoic persisted for almost 200 million years before rapidly collapsing approximately 65 million years ago. The cause of its demise is a matter of considerable curiosity and speculation, as is described in

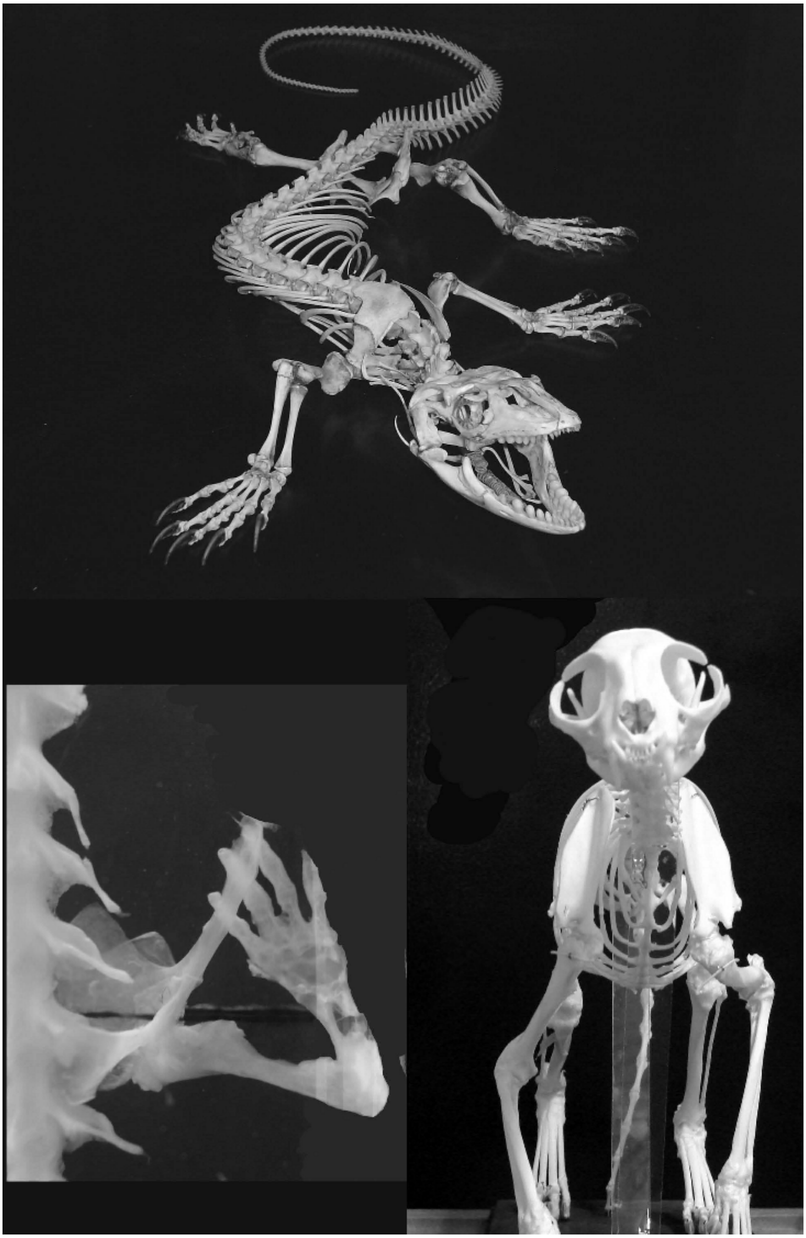

Figure 20.3. Reptilian vs mammalian leg position. The legs of a monitor lizard (upper left) or of a salamander (lower left) go to the sides of the body, providing stability but not much power for a forward motion. Thus, reptiles often run by moving their bodies from side to side. Those of a mammal (cat, lower right) align vertically relative to gravity, allowing an efficient forward-to-backward movement. Credits: Cat, salamander: Author's Photos; lizard:http:// bioweb.wku.edu/faculty/Huskey/default.html Skeleton articulated and photographed by Steve Huskey, Ph.D

Chapter 23, page 323. At this point we should simply note that the disappearance of most of the reptiles again created the opportunity for adaptive radiation.

THE CENOZOIC

The dinosaurs have not really disappeared. Modern-day birds are the descendents of one particular group of dinosaurs, judging from similarities in their skeletons, and the mammals are descendents of another large group of Mesozoan reptiles, again judging from the skeletons. One feature of the skeleton that is easy to see is the structure of the shoulder. Reptiles run with their limbs out to the sides, and they tend to waddle or creep along the ground. (The name "reptile" derives from a Latin word referring to the tendency of these animals to creep.) They can be very fast—you do not want to be in the position of trying to outrun a charging alligator—but mammals swing their legs alongside their bodies in what is physically a more efficient motion (Fig. 20.3) and lifts them higher off the ground. One group of reptiles, the therapsids, had developed this shoulder and hip structure, and mammals came from this group. This group also developed homeothermy, or the ability to maintain a constant warm body temperature, and the feathers-without-the-side-barbs that are modern hairs to insulate the body and limit both excess heat loss and excess heat absorption from the sun. Also, whereas some reptiles retain their eggs in the body of the mother until they hatch, mammals did away with the eggshell and the yolk altogether and invented an entirely different means of protecting the baby. They allow the baby to attach to the mother, through the placenta, as a sort of parasite, drawing its nutrition from the mother; and finally, after birth, to be nourished by a very protein-rich, highly nutritious form of sweat called milk, produced in the specialized mammary glands (for which mammals are named) or breasts.

Mammals existed during the Mesozoic but were not very common or very conspicuous. They were small, rodent-like creatures, presumably capable of sneaking around at night, since they were warm-blooded, perhaps stealing eggs. (Since all chemical reactions increase 2, 3, or more times for each 18º F rise in temperature, an animal that gets cold at night cannot move quickly. This is why flies found by windows in the fall seem to be very "sleepy".) But they did not radiate, or expand, until niches occupied by the reptiles became available. Once they were, at the beginning of the Cenozoic (the "recent or new animals"), they quickly radiated. Today we have large and small carnivores and herbivores, flying mammals (bats), and mammals completely confined to the sea (whales and porpoises). Similarly, springtime in any part of the world can convince you of the importance of the flowering plants. Even plants that do not appear to have flowers, such as birch or oak trees, in fact have less visible flowers adapted to being pollinated by the wind rather than by insects. Thus the Cenozoic is the age of mammals, insects, and flowering plants. Essentially all the broad-leafed plants that you see today are members of this group, technically named the "tube-seeded" plants from the manner in which a pollen grain grows to meet the seed—again a reproductive adaptation to life on land. The major eras and their characteristics are outlined in Table 20.1, and the translation of their names is listed in Table 20.2. It is worth having some familiarity with these names, if only because the names are frequently used in many contexts.

Table 20.1. Geologic eras

GEOLOGIC TIME					
EON	ERA	PERIODS AND SYSTEMS	EPOCHS AND SERIES	BEGINNING OF INTERVAL*	BIOLOGICAL FORMS
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	
			Pleistocene	1.6	Earliest humans
		Tertiary	Pliocene	5	
			Miocene	24	Earliest hominids
			Oligocene	37	
			Eocene	58	Earliest grasses
			Paleocene	65	Earliest large mammals
	Cretaceous-Tertiary boundary (65 million years ago): extinction of dinosaurs				
	Mesozoic	Cretaceous	Upper	98	
			Lower	144	Earliest flowering plants; dinosaurs in ascendance
		Jurassic	208		Earliest birds & mammals
		Triassic	245		Age of Dinosaurs begins
	Permian-Triassic boundary (245 million years ago): Major extinction				
	Paleozoic	Permian		286	
		Carboniferous			
		Pennsylvanian		320	Earliest reptiles
		Mississippian		360	Earliest winged insects
		Devonian		408	Earliest vascular plants (as ferns & mosses) & amphibians
		Silurian		438	Earliest land plants & insects
		Ordovician		505	Earliest corals
		Cambrian		570	Earliest fish
Proterozoic	Precambrian			2500	Earliest colonial algae & soft-bodied invertebrates
Archean				4000	Life appears;earliest algae & primitive bacteria

* In millions of years before the present – from Merriamwebster.com

Table 20.2. Names and characteristics of geological eras

Era	Period or Epoch	Translation
Cenozoic		New or recent life
	Quaternary	Fourth period
	Holocene	Entirely recent
	Pleistocene	Most recent
	Miocene	Less recent
	Oligocene	Fewer recent (mammals)
	Eocene	Dawn [of the] new
	Paleocene	Older new
Mesozoic		Middle life or middle animals
	Cretaceous	Chalky era (period of White Cliffs of Dover)
	Jurassic	Like the limestone of the Jura Mountains (Switzerland)
	Triassic	Third period (of the Mesozoic)
Paleozoic		Old life or animals
	Permian	Like Perm, a former province in Russia
	Carboniferous	Carbon bearing (coal bearing)
	Pennsylvanian	Like the soils of Pennsylvania
	Mississippian	Like the soils of the Mississippi valley
	Devonian	Like the soils of Devon, England
	Silurian	Like the soils of the land of the Silures*
	Ordovician	Named after an ancient people of Wales
	Cambrian	Like the lands of Wales
Proterozoic		Before life
	Precambrian	Before the Cambrian
Archean		Ancient

* An ancient mythical people in England

REFERENCES

http://www.beyond.fr/history/geology.html (Description of geology, based on Provence, France, in English)

http://www.gpc.edu/˜pgore/geology/geo102/burgess/burgess.htm (Description of the Burgess Shale, from Georgia Perimeter College)

http://www.burgess-shale.bc.ca/ (Burgess Shale site)

STUDY QUESTIONS

1. What was the practical value of giving names to different geologic eras?
2. How sharp are the boundaries of the different eras?
3. What reasons can you give for why there should be boundaries between eras?
4. What evidence is there for when life began on earth? How reliable is this evidence?
5. How do interplanetary probes “search for life”? What do they look for? Why?

6. How do preCambrian creatures differ from those of the Cambrian era?
7. What happened to most of the preCambrian creatures?
8. How do fossils indicate climate?
9. What do we mean by the term “adaptive radiation”?
10. What do we mean by the term “niche”?