NAME: ______________________________ Per: ________ DATE: ______________

Evolution Coloring Packet

EARTH HISTORY. PRECAMBRIAN: EVOLUTION OF EARLY LIFE

The geological timetable divides earth history into five eras. Choose five colors for these eras and continue to use them for the next three plates. This plate focuses on the first two eras: the Archean and the Proterozoic, together known as the Precambrian, which account for over 90 percent of all earth history. Color the title for each era as discussed in the text. For each era, color the corresponding section of the time scale and the date to the left of the scale. Color the conditions of the atmosphere and the important events for each time period to the right of the time scale. Use a light color for G.

Approximately *4,500 million years ago (mya),* at the beginning of the *Archean* era, the *earth* began to *form* by condensation of dust particles into a molten mass. As this mass began to cool, a rock *crust* formed on the surface. The oldest rocks known on earth were formed about *3,800 mya.* A primitive atmosphere was formed by gases escaping from the molten rock, composed primarily of hydrogen, carbon dioxide, ammonia, and water vapor. There was *no free oxygen* (O_2) for the first third of earth history.

As the earth continued to cool, the dense layer of water vapor began to condense, flooding the planet with rains, which formed the oceans. In these waters, *biochemical evolution* began as organic molecules (carbon-rich acids, alcohols, and simple carbohydrates) were created by chemical reactions between inorganic molecules. These organic molecules were the essential building blocks needed for the emergence of *earliest life,* about *3,500 mya.*

Early life forms were single-celled *prokaryotes,* cells without a nucleus, similar to modern-day *bacteria.* The earliest *prokaryotes* fed on the "organic soup" of the ancient seas.

The early *prokaryotes* eventually began to deplete the supply of organic molecules upon which they fed. Those organisms that could synthesize their own energy source survived. About *3,000 mya* autotrophic (self-feeding) *prokaryotes,* like *blue-green algae,* evolved. These single-celled organisms evolved *photosynthesis,* a metabolic process using the energy of the sun to combine carbon dioxide and water to form simple sugars for energy storage. The early atmosphere was rich in carbon dioxide, but as a by-product of *photosynthesis, free oxygen* began to accumulate in the atmosphere.

Early in the *Proterozoic,* the era of "proto-life," the *prokaryotes diversified* into many types, shown here by a variety of single-celled life forms. Although it is difficult to tell from the fossil record, *eukaryotic organisms* may have first appeared as early as *1,200 mya. Eukaryotes,* which package their hereditary material in a cell nucleus (see Plate 19), evolved new methods for cellular division and the passage of hereditary information from one generation to the next. Soon after the evolution of *eukaryotes,* the *plant and animal* phyla diverged. Although this divergence cannot be seen in the fossil record, evidence from the study of proteins (see Plate 28) points to a split in the *Proterozoic.*

The next major evolutionary event was the development of *sexual reproduction.* Up to this point, *prokaryotes* and *eukaryotes* had reproduced asexually, with each cell duplicating its genetic material and passing on a complete copy to two identical daughter cells. *Sexual reproduction* probably evolved around *1,000 mya.* In this new reproductive process, two individuals rather than one contribute hereditary material to form a new organism. The combination of hereditary information from two different parent organisms created more diversity and enhanced the rate of *plant and animal* differentiation in the late *Proterozoic.*

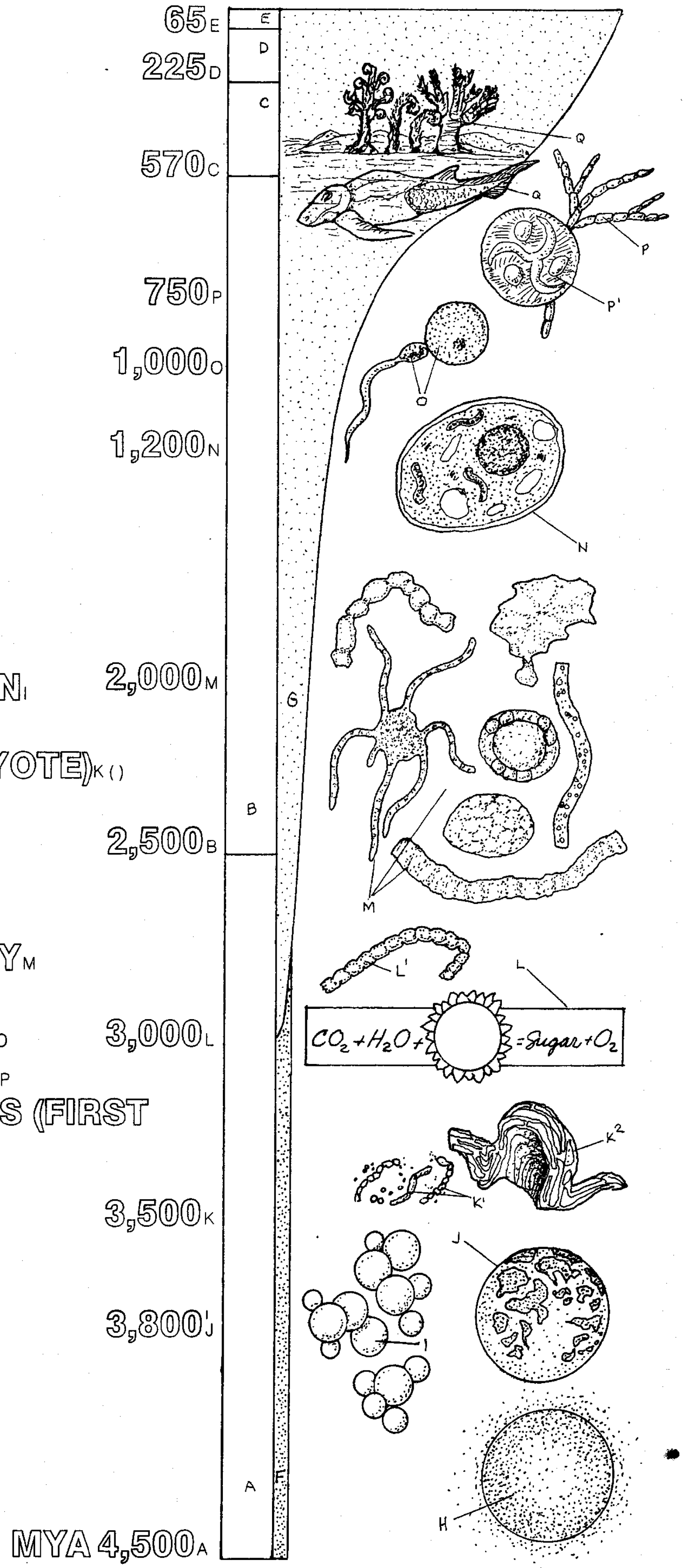
Multicellular plants and animals first appear in the fossil record about *750 mya.* These organisms developed tissue systems of specialized cells and structurally complex body forms. The early soft-bodied animals did not preserve well in the fossil record. *Plant and animal expansion* continues into the *Mesozoic* and *Cenozoic.*

EVOLUTION OF EARLY LIFE.★

ERAS•
ARCHEAN A
PROTEROZOIC B
PALEOZOIC C
MESOZOIC D
CENOZOIC E

ATMOSPHERE•
NO FREE OXYGEN (O_2) F
FREE OXYGEN ACCUMULATES G

IMPORTANT EVENTS•
EARTH FORMATION H
BIOCHEMICAL EVOLUTION I
EARTH'S CRUST J
EARLIEST LIFE (PROKARYOTE) K ()
BACTERIA K'
STROMATOLITES K²
PHOTOSYNTHESIS L
BLUE-GREEN ALGAE L'
PROKARYOTES DIVERSIFY M
EUKARYOTES APPEAR N
SEXUAL REPRODUCTION O
MULTICELLULAR PLANTS P
MULTICELLULAR ANIMALS (FIRST INVERTEBRATES) P'
PLANT AND ANIMAL EXPANSION Q



EARTH HISTORY. PALEOZOIC: LIFE LEAVES THE SEA

The accumulation of free oxygen in the atmosphere had two important consequences. First, an abundant supply of oxygen created the conditions necessary for the development of multicellular animals, as their metabolism requires oxygen for the efficient extraction of energy from carbohydrates. Second, oxygen accumulating in the upper reaches of the atmosphere created an ozone layer, which filters out the radiation destructive to DNA, the hereditary material in every life form.

Continue using the same five colors for the geological eras. Color the era titles and the corresponding section of the time scale on the bottom left of the page. Choose six light colors for the periods of the Paleozoic. Color the Cambrian section of the large Paleozoic time scale, then color over the Cambrian vignette at the bottom of the page. Work upward, reading about events occurring in each period as you color.

During the *Cambrian,* life remained confined to the seas. Green algae — the probable ancestor of the land plants — appeared, and many kinds of soft-bodied invertebrates flourished. This period marks the appearance of the shelled arthropods, ancestral to modern insects, spiders, lobsters, and crabs. The most common arthropods during the *Paleozoic* were the trilobites, a diverse group, now extinct.

Numerous predators including the cephalopods, represented here by the ancient squid, evolved during the *Ordovician.* The first vertebrates appeared. These were jawless, armored fish whose internal skeleton provided support for their nervous systems, musculature, and gut organs without sacrificing flexibility and mobility. Their external armor protected them from predators.

The *Silurian* period provides our earliest evidence for life on land. The fossil record contains impressions of vascular plants with an internal transport system for moving nutrients between roots and leaves and a waxy cuticle layer to protect leaves and stems from drying out. These early plants were confined to swampy areas so that they could reproduce in water. In the seas, armored placoderms (fish) evolved an upper and lower jaw from the first gill arch of the jawless ancestors, setting an important precedent for new herbivorous and carnivorous lifestyles. Placoderms had paired fins that set the stage for vertebrate invasion of the land.

All forms of fish proliferated during the *Devonian.* The most important event in the seas was the evolution of the bony fish. True bone provided greater rigidity in the internal skeleton, and descendants of the bony fish were soon to begin moving around on dry land. Taking advantage of new food sources provided by abundant land plants, the earliest amphibians were able to utilize two further adaptations for land dwelling. First, lobed fins with bony internal skeletons allowed the earliest amphibians to move from pond to pond. Second, some bony fish had adapted to life in stagnant ponds, where oxygen levels in the water were insufficient. Many fish had an internal air balloon, known as a swim bladder, that evolved into a primitive lung and allowed some fish to come to the surface to gulp air. Amphibians evolved from these "lunged fish."

The *Carboniferous* was a period of increasing dryness. Gymnosperms ("naked seed"), such as conifers (nonflowering, seed-bearing plants), evolved and replaced seedless plants. The first reptiles evolved from amphibian ancestors. Their innovations for land dwelling included a hard-shelled egg and dry scaly skin, which retains the body's moisture. Thus, both seed plants and reptiles evolved mechanisms that alleviated their restriction to water environments for reproduction.

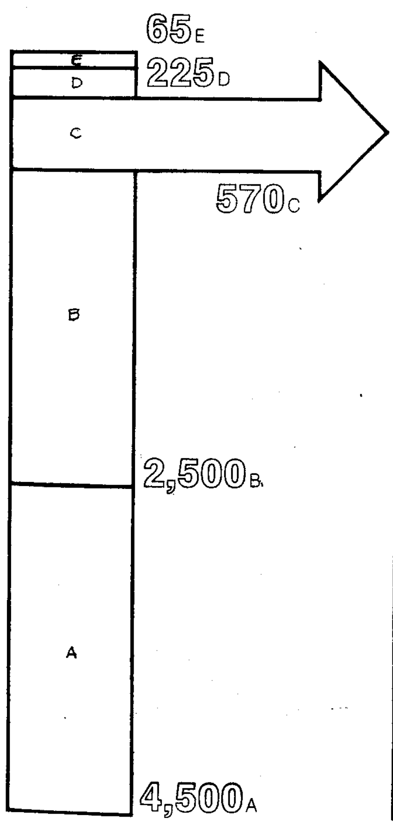
During the *Permian,* the swampy primitive forests of giant ferns were replaced by gymnosperm forests. While the amphibians and insects flourished, the reptiles diversified, and from this geological period comes the oldest reptilian fossil egg. The emerging reptiles include *Dimetrodon,* the sail-backed lizard (shown here), one of the mammallike reptiles that marks the branch of the evolutionary tree leading to early mammals, primates, and, still millions of years in the future, humankind.

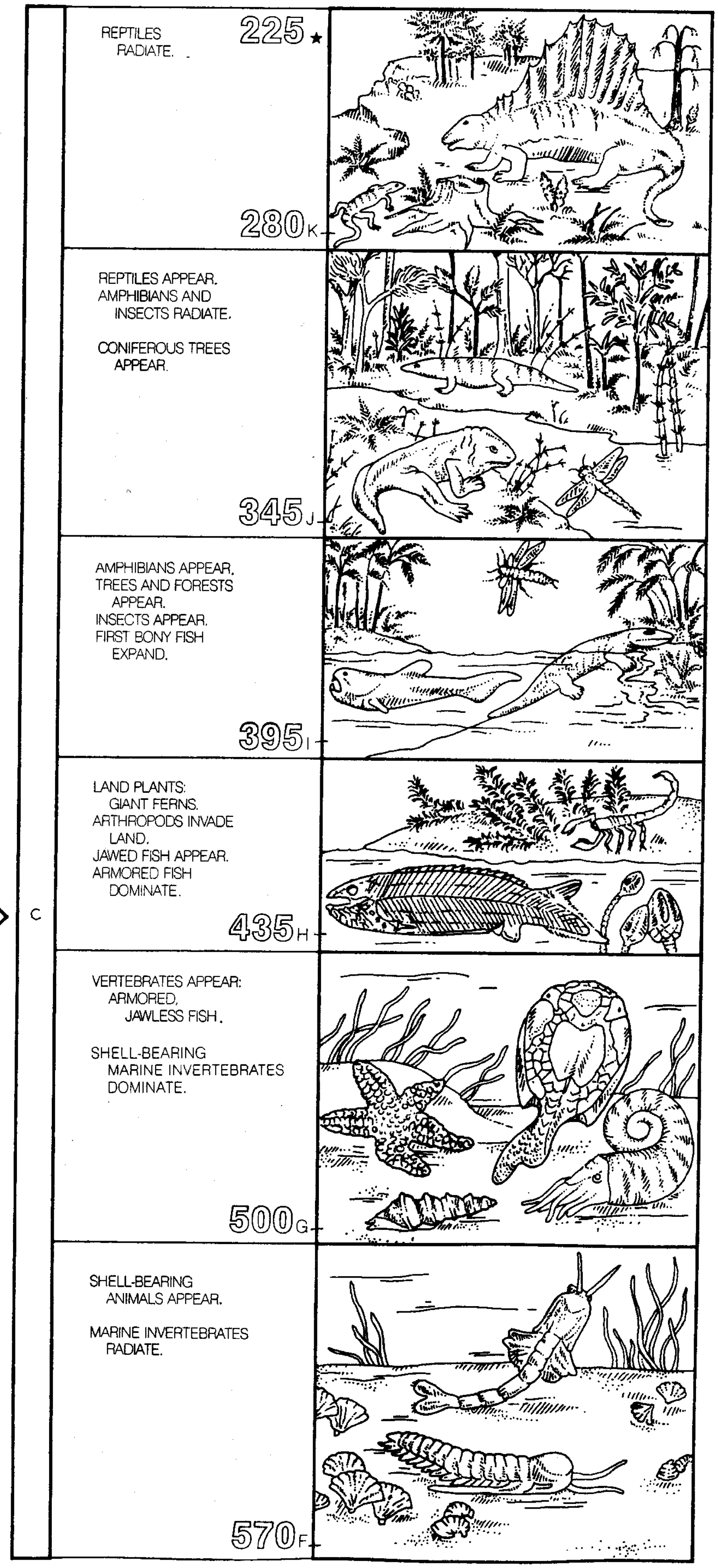
LIFE LEAVES THE SEA★

ERAS●
PRECAMBRIAN★
- ARCHEAN A
- PROTEROZOIC B

PALEOZOIC C
MESOZOIC D
CENOZOIC E

PALEOZOIC C
- CAMBRIAN F
- ORDOVICIAN G
- SILURIAN H
- DEVONIAN I
- CARBONIFEROUS J
- PERMIAN K





EARTH HISTORY. MESOZOIC: MAMMALS EMERGE, REPTILES REIGN

The *Mesozoic* ("middle life") era spans 160 million years and is divided into three periods: *Triassic, Jurassic,* and *Cretaceous.* This era is called "the age of the reptiles" because they were the dominant land vertebrates. Birds, mammals, flowering plants, and many modern insects appeared for the first time. Broadleaf flowering trees like elm, oak, and maple became common. Ammonites came to dominate the seas but were extinct by the end of the era. Lands and seas changed; new mountain ranges developed. The flowering plants spread, pollinated by insects, providing mammals with plant and insect food.

Continue to use your five colors for the eras and color those first. Then proceed to the Triassic, Jurassic, and Cretaceous periods, using light colors and the coloring plan of Plate 2.

During the *Triassic,* reptiles became more successful due to biological innovations such as the protected eggshell and advanced body structure. Mammallike reptiles were diverse and abundant until the end of the *Triassic,* when dinosaurs first appeared. The alligatorlike phytosaur pictured here is a relative of the dinosaurs. Pine, fir, and cedar arose in the *Triassic,* forming great forests. Today's redwood forest is the closest approximation of the great conifer-cycad forests of the *Triassic* and *Jurassic.* At the *Triassic-Jurassic* border, mammals began to appear. They were quite small, with shrew-sized jaws and teeth. Their fossil remains are found in the western United States, Europe, and South Africa.

During the *Jurassic,* which began *180 mya,* reptiles ruled the air, land, and sea. Winged reptiles ranged in size from those smaller than a sparrow to those with 1.25 meter wingspans. The brontosaurus shown here is one of three groups of dinosaurs, the land reptiles. Streamlined marine carnivores, including ichthyosaurs ("fish reptiles") and plesiosaurs ("near reptiles") dominated the seas. The oldest known bird, *Archeopteryx,* had feathers like modern birds but had reptilian teeth and a reptilian skeleton and short wings relative to body length.

Conifer-cycad-gingko forests were widespread at that time and ferns were common. There were several kinds of primitive mammals, known as *Mesozoic* mammals, the largest the size of a cat. They fed on plants and insects, and they did not constitute an abundant or important part of animal life on land.

The *Cretaceous* ("chalky," for its characteristic deposits), began *135 mya* and lasted for seventy million years. During this period, the Andes and Rocky Mountains were uplifted. Dinosaurs continued to be widespread on every continent, and there were many varieties, like the horned dinosaur pictured here. The carnivorous *Tyrannosaurus rex* stood 6 meters high, with a skull 1 meter long. There were giant turtles and sea-going mosasaurs. Large flying reptiles such as the *Pteranodon* still abounded, and there were diving birds and strong fliers.

Mammals were still small and did not dominate the land. Two distinct groups emerged, the marsupials (opossumlike pouched creatures), and the placentals (mostly insectivores). Living representatives of these groups are distinguished from each other by their type of reproduction. Marsupials lack a placenta, are born very immature, and develop in a pouch. Placentals (named for the cake-shaped uterine structure by which a fetus is nourished) have a longer period of development in the uterus and so emerge more mature. In fossils of this age, the two groups can only be distinguished by their teeth.

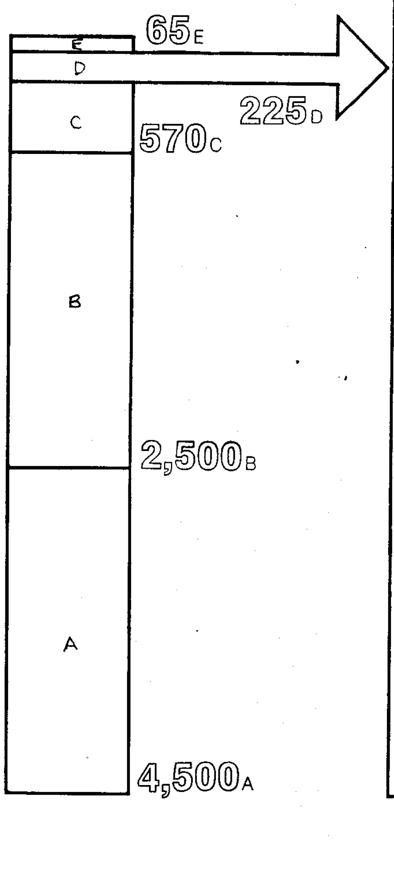
The most important new arrivals in this era were the flowering (seed-bearing) plants, the angiosperms ("covered seeds"). (Today 96 percent of vascular plants are angiosperms.) The enclosed seed permits the development of fleshy, edible fruit, sought after by birds and animals, which ate the fruit and dispersed the seeds. Earlier plants, the gymnosperms, had relied on the wind to carry pollen from plant to plant. As birds and mammals guaranteed dispersal of plant seeds, the nutrition provided by angiosperm fruit, seeds, flowers, shoots, and leaves, made it possible for birds and mammals to become increasingly successful. Later, primates exploited these foods, too.

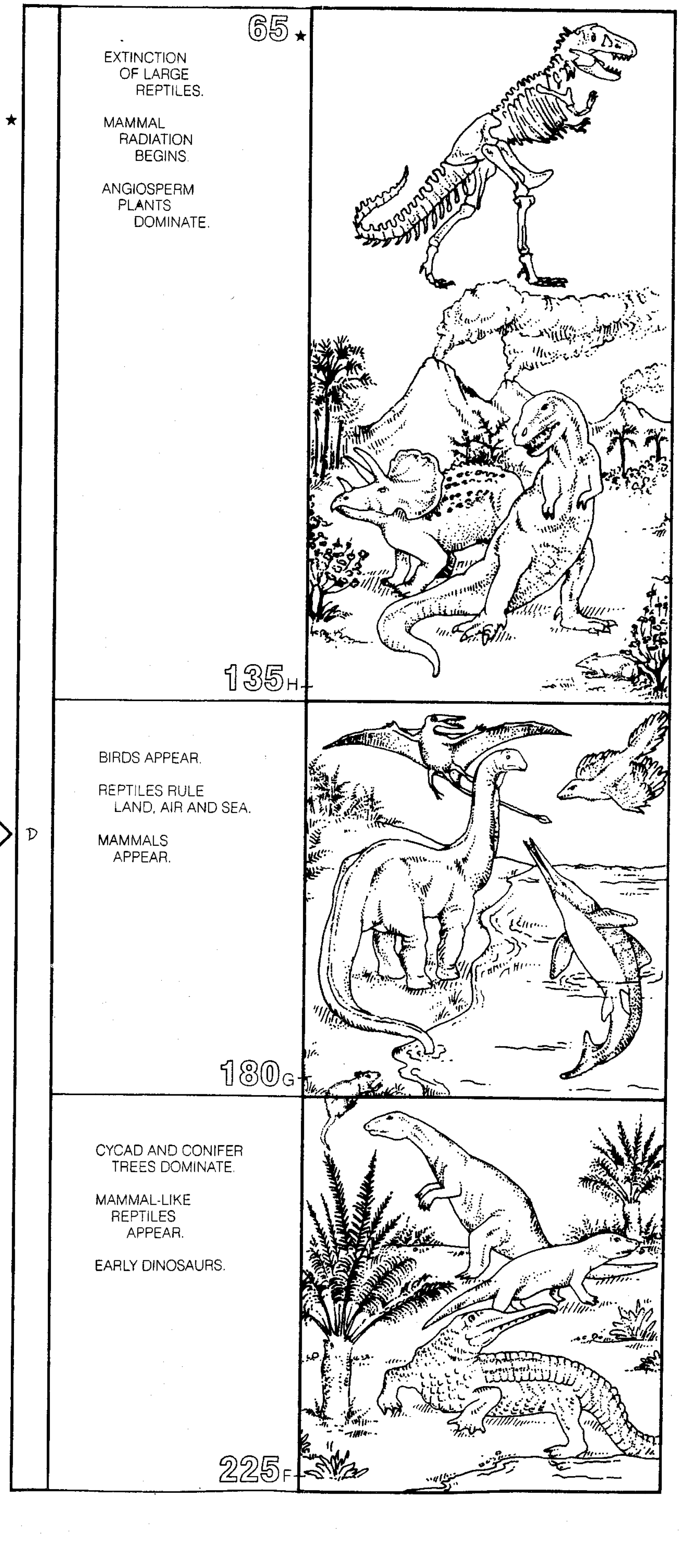
At the close of the *Cretaceous,* there was widespread extinction of many reptiles and of all the ammonites and dinosaurs.

MAMMALS EMERGE, REPTILES REIGN★

ERAS•
PRECAMBRIAN★
ARCHEAN A
PROTEROZOIC B
PALEOZOIC C
MESOZOIC D
CENOZOIC E

MESOZOIC D
TRIASSIC F
JURASSIC G
CRETACEOUS H





EARTH HISTORY. CENOZOIC: RADIATION OF THE PRIMATES

The extinction of the ruling reptiles and the expansion of the angiosperms at the close of the *Mesozoic* left a variety of habitats available for exploitation by mammals. Even before the last of the dinosaurs had disappeared, several orders of mammals, including the primates, had appeared.

The early mammals were generally small in body size and had relatively small brains. Their longish snouts attest to the importance of smell in finding food and mates. Radiating during the *Cenozoic* from a small Cretaceous ancestor, the mammals quickly took to the sea and to the air, and dominated the land as well, like the reptiles before them. Ancestral whales, bats, elephants, hoofed animals, and carnivores originated and spread during this era, "the age of mammals." This plate focuses on the radiation of primates, the order of mammals to which the species *Homo sapiens* belongs.

Again, use your five original colors for the five eras and color those first. Then color over the events of the Tertiary period, which includes the Paleocene, Eocene, Oligocene, Miocene, and Pliocene epochs, as they are discussed in the text.

The oldest evidence of fossil primates consists of jaws and teeth from the very late Cretaceous in the Rocky Mountains and the early *Paleocene* of the western United States. These early primates were small, insect eating, and possibly ground living. In the *Paleocene,* we begin to see a diversity of primates, including some that took to the trees and supplemented their diet of insects with seeds, nuts, fruits, and leaves (Plate 69).

More solid evidence appears during the *Eocene* that primates were tree dwelling (arboreal; arbor = tree) animals. The *Eocene* primates had evolved grasping hands and feet, with opposable thumbs and great toes. Claws evolved into nails with fleshy tactile pads beneath them, which allowed better grasping of branches and gathering of small food items. Early primates had slightly longer lower limbs for power in jumping from branch to branch. Their eye sockets were directed toward the front of the skull, indicating development of stereoscopic vision and depth perception which contributed to skill in leaping among tree branches.

Prosimians were abundant in the tropical *Eocene* forests, but decreased in number during the *Oligocene.* At this time the primates developed completely enclosed bony eye sockets and a shorter snout, suggesting changes in the senses, with less reliance on smell and greater reliance on eyesight.

During the *Miocene,* there was increasing seasonality of climates and development of savannas around the world. In Africa, we find the earliest evidence of apes, the dryopithecines, and the closely related ramapithecines, which, by the middle of late *Miocene,* are found over Europe, Africa, and Asia (Plates 83 and 84). These early apes had teeth similar to modern apes, but their limbs resembled living Old World monkeys.

Around 5 mya, at the beginning of the *Pliocene,* the earliest hominids, direct human ancestors, stepped into the picture. They were adapted for bipedal, erect walking, but with small brains, similar to their ape ancestors, and obtained their food using tools made of wood on the African savannas. Bipedal locomotion for walking and carrying, tool using and regular food sharing are the main ingredients of this early savanna way of life.

Complete the plate by coloring the events of the Quaternary period, which includes the Pleistocene and Holocene epochs.

In the *Pleistocene,* the human fossil record is supplemented with evidence of human activities: first with the appearance of stone tools, found later with food remains.

The beginning of the *Holocene,* or recent epoch, marks the first human "revolution" with the domestication of plants and animals around 10,000 years ago. Cultivation of plants and the keeping of animal herds allowed humans to establish a greater degree of control over food sources. Though our species continues to evolve biologically (Plates 41 and 42), the remainder of our story of human evolution is primarily a cultural one, told by archeologists, historians, and storytellers through the ages.

Turn your attention again to the bar graph of all earth history on the bottom left of the plate. You can now see what an incredibly small proportion (five million years) of our evolutionary heritage is "uniquely human." For almost 3,500 million years, other life forms preceded us on this earth.

RADIATION OF THE PRIMATES ★

ERAS •

PRECAMBRIAN ★

ARCHEAN A

PROTEROZOIC B

PALEOZOIC C

MESOZOIC D

CENOZOIC E

TERTIARY F

PALEOCENE G

EOCENE H

OLIGOCENE I

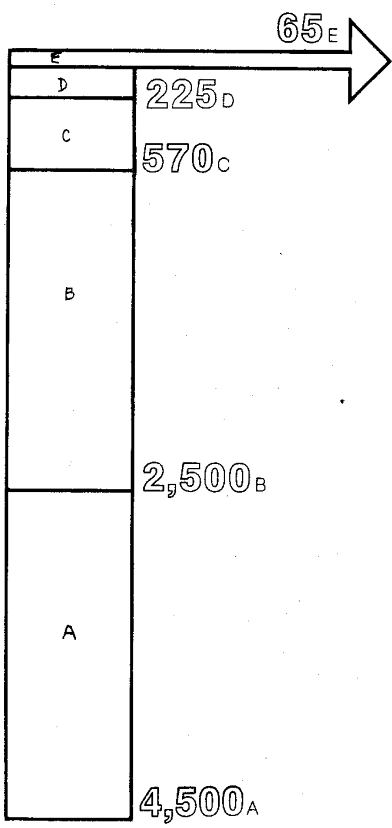
MIOCENE J

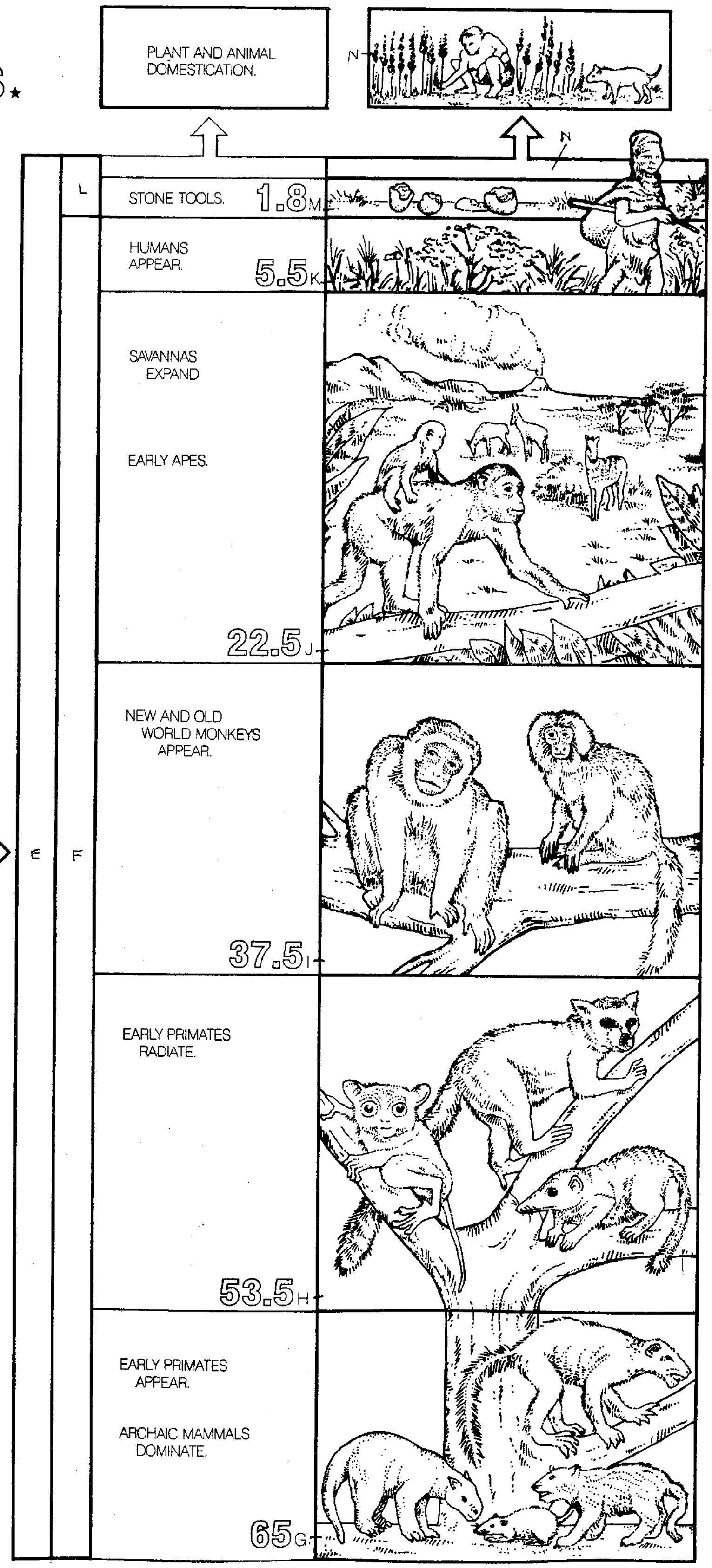
PLIOCENE K

QUATERNARY L

PLEISTOCENE M

HOLOCENE N





ADAPTIVE RADIATION: MAMMALIAN FORELIMBS

The variety of mammalian forelimbs—the bat's wings, the seal's flippers, the elephant's huge supportive columns, the human's arms and hands—provides a lesson in the process of evolution. Comparative anatomy of homologous structures like the forelimbs, together with comparative embryology, provided early clues that evolutionary processes have created all these different mammals. Despite the obvious differences in shape, all mammalian forelimbs are composed of similar bones arranged in a comparable pattern. These homologies testify to a common evolutionary history. They also illustrate the phenomenon known as adaptive radiation. The external shape of the forelimb varies with its function, primarily with the animal's mode of locomotion. By adapting to environments as different as forest, plains, air, water, and underground, mammals have been able to radiate (like the sun's rays) into an incredible range of habitat milieus and ways of life.

Color the opossum scapula in the center of the page. Color the scapulae on all the surrounding species: the mole, bat, wolf, and around to the human. Continue to color in this manner first the opposum, then all other species.

The opossum represents the generalized ancestral mammalian forelimb pattern. The surrounding pictures show specializations of the forelimb for uses in different environments. The forelimb consists of the *scapula* (shoulder blade), which connects the rest of the forelimb to the trunk; *humerus* (upper arm bone); *radius* and *ulna* (lower arm); *carpal* (wrist) bones; *metacarpals* (hand bones of humans); and *phalanges* (finger bones of humans).

When you have colored all the individual bones, color the opossum's shadowed forelimb gray.

The opossum is much like the early (marsupial) mammals that originated more than 100 million years ago; so its forelimb is the kind from which all others were derived. The opossum is small bodied, moves easily on the ground or in trees, and has a flexible forelimb for these functions.

Turn now to the mole, which lives underground in moist soil and eats insects. Its forelimbs are short, close to the body, with large broad paws well suited for digging or "swimming" through the soil medium in which it lives. Its *scapula* is long and slender and anchors the forelimb against the trunk—a unique pattern, as you can see by comparison with the others. Its *ulna* is relatively long and robust, the *radius* somewhat reduced. The shovel-like paw constitutes almost half the length of the limb, and the elbows are rotated so that the palms face backward. The short, robust *metacarpals* and *phalanges*, with an extra bone (the falciform) make the short, broad paw an effective digging implement.

The bat's forelimb has been modified into a wing for flying. Its *humerus* is short relative to the long, slender *radius*, and the *ulna* is reduced—a pattern the reverse of that found in the mole. Remarkably long *metacarpals* and *phalanges* stretch out the skin like a sail. The broad wings are wider than the length of the bat's body.

The wolf is a swift runner, the better to pursue its prey. Its *humerus*, *radius*, and *ulna* are relatively long, providing a lengthy stride. The *metacarpals* are closely packed together for bearing weight—in marked contrast to those of the bat. The wolf walks somewhat up on its toes, on bent *phalanges*.

For its life in a predominantly watery environment, the sea lion has evolved a relatively short forelimb. It has a broad paw, modified into a paddle, with robust *metacarpals* and *phalanges* that stretch out the skin in a manner similar to the bat. The robusticity of the bones is necessary for supporting the sea lion's weight when it hauls out on land.

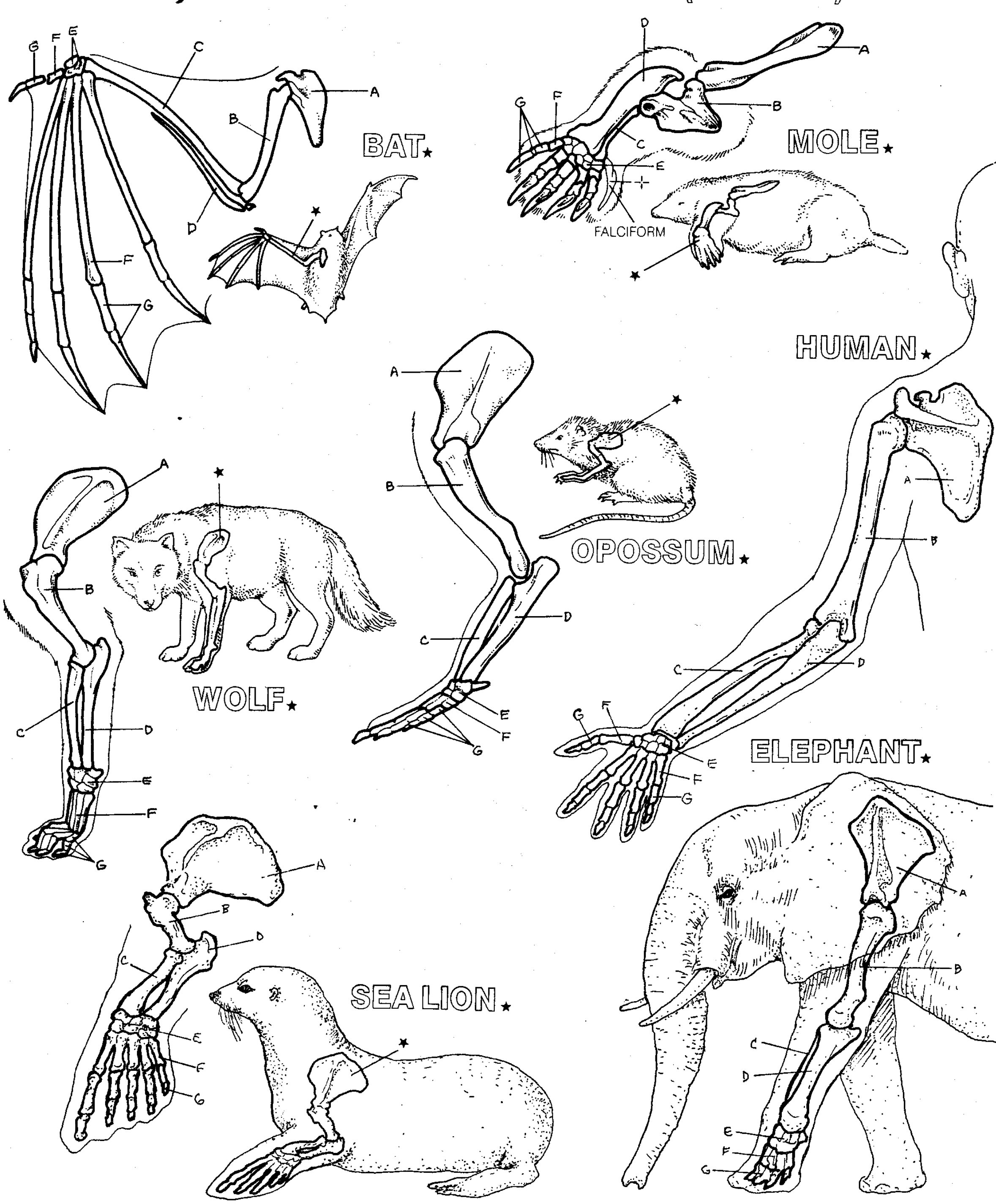
This evolution for support of a bulky mass is taken to the extreme in the 5-ton elephant. The bones are not only robust, but are arranged like an architectural column, from the *scapula* down to the *phalanges*.

Humans have long, mobile upper limbs that, unlike those of the other animals shown, are used primarily to manipulate objects rather than for weight bearing and locomotion. In common with the apes, the ball and socket joint of the *humerus* in the *scapula* allows the arm a 360° range of motion.

The similarity of a bat's wing and an elephant's leg may not be readily apparent until we examine homologous bone structures in all mammalian forelimbs. It then becomes clear that a common basic design has been modified by evolutionary processes into the particular pattern of each species.

ADAPTIVE RADIATION: MAMMALIAN FORELIMBS★

SCAPULA A
HUMERUS B
RADIUS C
ULNA D
CARPALS (WRIST) E
METACARPALS (HAND) F
PHALANGES (FINGERS) G



CONVERGENCE: THE SWIMMING NICHE

Just as there are differences among closely related animals, there are similarities among distantly related animals. Why does this happen? The phenomenon called convergence occurs because the environment is an important shaping force in evolution. The environment presents the opportunities and the challenges to organisms, which then respond by changing or by becoming extinct. Species of animals, even though distantly related, come to resemble each other when they live in a similar habitat or environment. Paleontologist George Gaylord Simpson pointed out that the expansion of life follows the opportunities presented rather than a preset plan.

Numerous examples of convergence exist, for example, between animals living in the tropical rainforests of West Africa and South America or among animals living in the grasslands of North America, South America, Africa, and even Australia. In this plate, animals of the ocean provide an excellent example of convergence in which the major groups of vertebrates are represented: fish, reptile, bird, and mammal.

Color the body shapes of the four animals.

The bodies of these animals are so streamlined that they appear not to have a neck; they all have fins or flippers and some form of tail. This *body shape* moves easily through the water with minimal resistance.

Color the forelimbs, first on the drawing of the individual animal, then on the enlargement on the right.

The shape on all four animals is very similar—elongated and flexible to act as a powerful paddle. The internal structures among the four animals are different. The similarity in external shape reflects the similarity in function; the differences in the internal structure reflect their different genetics and divergent evolutionary histories. Compare this to forelimb adaptive radiation on Plate 14.

Color the name of the animal and the internal structure of the forelimb.

The *shark,* which represents the fishes here, has no true bone; the supporting structure of its *forelimb* is cartilage, which is flattened and expanded into a fin. *Sharks* come in all sizes and are major predators in the oceans around the world. They have been in existence since Devonian times, over 350 million years ago.

The swimming reptile is represented here by an *ichthyosaur,* a highly specialized marine reptile that appeared in the Triassic, flourished during the Jurassic, then became extinct. It was up to 3 meters long and had a streamlined body, legs modified into paddles, and a well-developed tail. The bones in its *forelimbs* were relatively inflexible. It looked like a big fish, but we know it is a reptile because of details in its morphology.

Although we think of birds as flying through the air, some birds, like the *penguin,* are adept at swimming. The wings of its ancestors were modified into flattened and fused bones, forming a compact and powerful fin *(forelimb). Penguin* feet are placed far back and webbed for swimming but also provide support on land, where their eggs are laid. *Penguins* live mainly in the oceans of the southern hemisphere and evolved from flying birds over 60 million years ago.

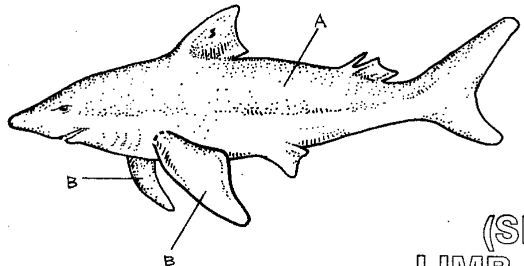
The mammal represented here is a *dolphin,* a member of the Cetaceans, which includes the whales and porpoises. This group successfully invaded the oceans more than 60 million years ago, evolving from a land-dwelling animal. The humerus, radius, and ulna are distinguishable and are homologous with those of other mammals on Plate 14. Most modification has taken place in the carpals, metacarpals, and phalanges to form a broad paddle. Although the *dolphin* looks like a fish, it is warm-blooded, as are other mammals. One young at a time grows within the mother's body. After birth, it is nourished by its mother's milk. A thick layer of blubber keeps *dolphins* warm.

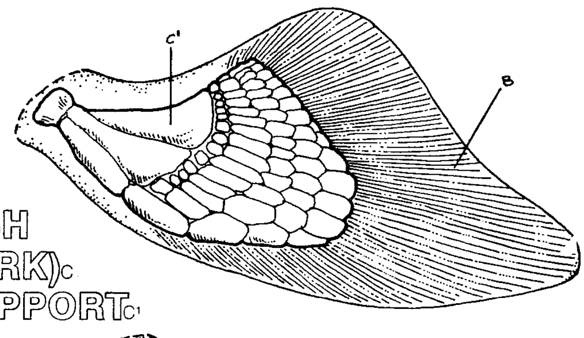
Although the *shark, ichthyosaur, penguin,* and *dolphin* are only distantly related, they have converged by developing similar methods of locomotion and of obtaining food, both of which involve moving rapidly through water. Therefore, the modification of *body shape* and *forelimbs* in the four animal groups serve similar functions. Such marked similarities of ocean-living vertebrates suggests that there are a limited number of ways animals can effectively exploit the oceans and thus emphasizes the importance of the environment in shaping the course of evolution.

CONVERGENCE: THE SWIMMING NICHE*

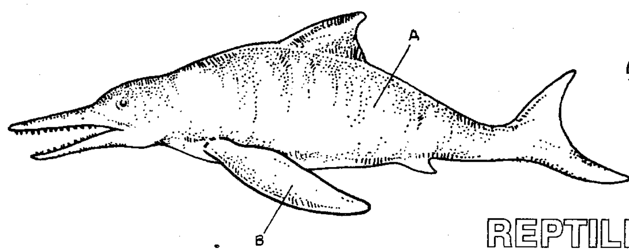
BODY SHAPE A

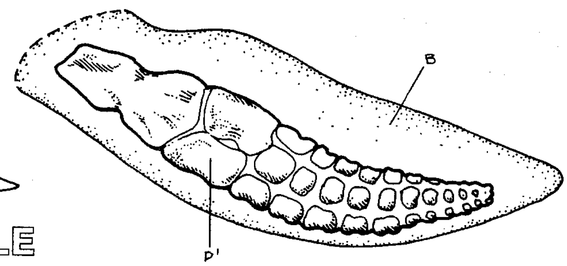
FORELIMB B



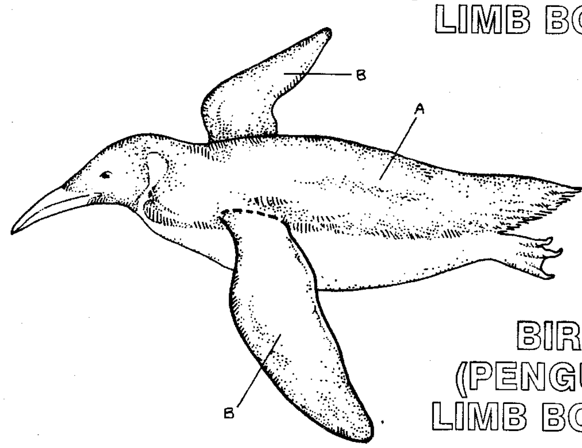


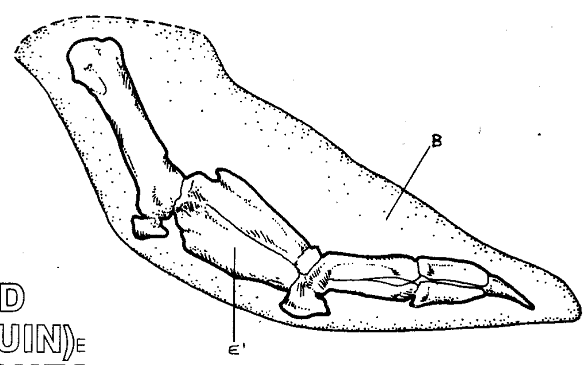
FISH
(SHARK) C
LIMB SUPPORT C'



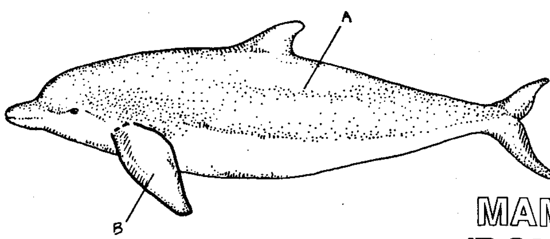


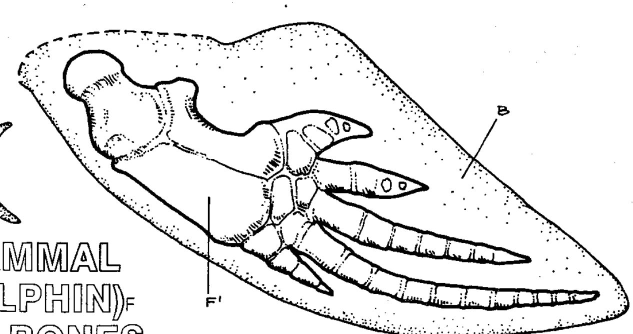
REPTILE
(ICHTHYOSAUR) D
LIMB BONES D'





BIRD
(PENGUIN) E
LIMB BONES E'





MAMMAL
(DOLPHIN) F
LIMB BONES F'

AUSTRALOPITHECUS: SKULL COMPARISON

Some of the earliest and latest trends in human evolution can be discerned by comparing the skull of a chimpanzee with those of the earliest hominid, *Australopithecus,* and the latest, *Homo sapiens. A. africanus* from Sterkfontein was chosen for this comparison. The skull of *A. afarensis* is even older and in some respects more chimpanzeelike.

Color cranial capacity, a measure of brain size. Next color the temporal regions in all three views.

The *cranial capacity* of *Australopithecus* is only marginally larger than the chimpanzee. The chimpanzee's entire braincase is covered by the temporal muscle; the hominid's slightly larger skull shows around the muscular attachment; and in the human the *temporal area,* though really the same size, appears much smaller because of the greatly enlarged cranium and can hardly be seen in the top view.

Color the nuchal (neck) area in the side and rear views.

The *nuchal area* lies toward the rear in the ape but more inferiorly in the early hominid and human as a result of different skull proportions. The chimpanzee has more massive neck muscles (to use its canines effectively) attaching to this area, and there is a nuchal crest and a protuberance where these muscles and the temporals meet. They do not meet in *Australopithecus;* the neck muscles are not as powerful, due to reduction of the *canines;* so the back of the skull is more rounded. These muscles are even less confluent in living humans, but occasionally a nuchal crest is seen in very muscular males.

Color the zygomatic arches in the side and top views.

Two slender bony processes form the *zygomatic arch,* one extending from the temporal bone, the other, from the maxilla. The masseter, a main chewing muscle, attaches to this *arch* and the temporal muscle passes under it, attaches to the mandible, and is also important in chewing. Therefore, the strength and size of the *zygomatic arch* provide clues, along with the dentition, as to an animal's diet—at least as to the need for stronger or weaker chewing muscles. The *arch* flares out from the skull more in *Australopithecus* than in the chimpanzee, meaning a bigger masseter and temporal muscle to go with its big grinding teeth. The teeth are more nearly underneath the *arch,* which is mechanically more efficient for chewing. Modern humans, because of tools for preparing food, do not have the big chewing muscles and big teeth, and the rather gracile *zygomatic arch* is dwarfed by the large braincase.

Color the brow ridges and notice the amount of face in front of them and braincase above them.

Even though *Australopithecus* has prominent *brow ridges,* rather like the chimpanzee's, there is considerably less face in front of them and considerably more cranium above them. Unlike the chimpanzee's, the early hominid's *brow ridge* cannot be seen from the rear. The *brow ridges* are much smaller in the modern human and can be seen from neither the top nor the rear. There is very little face forward of them and a great deal of brain above them.

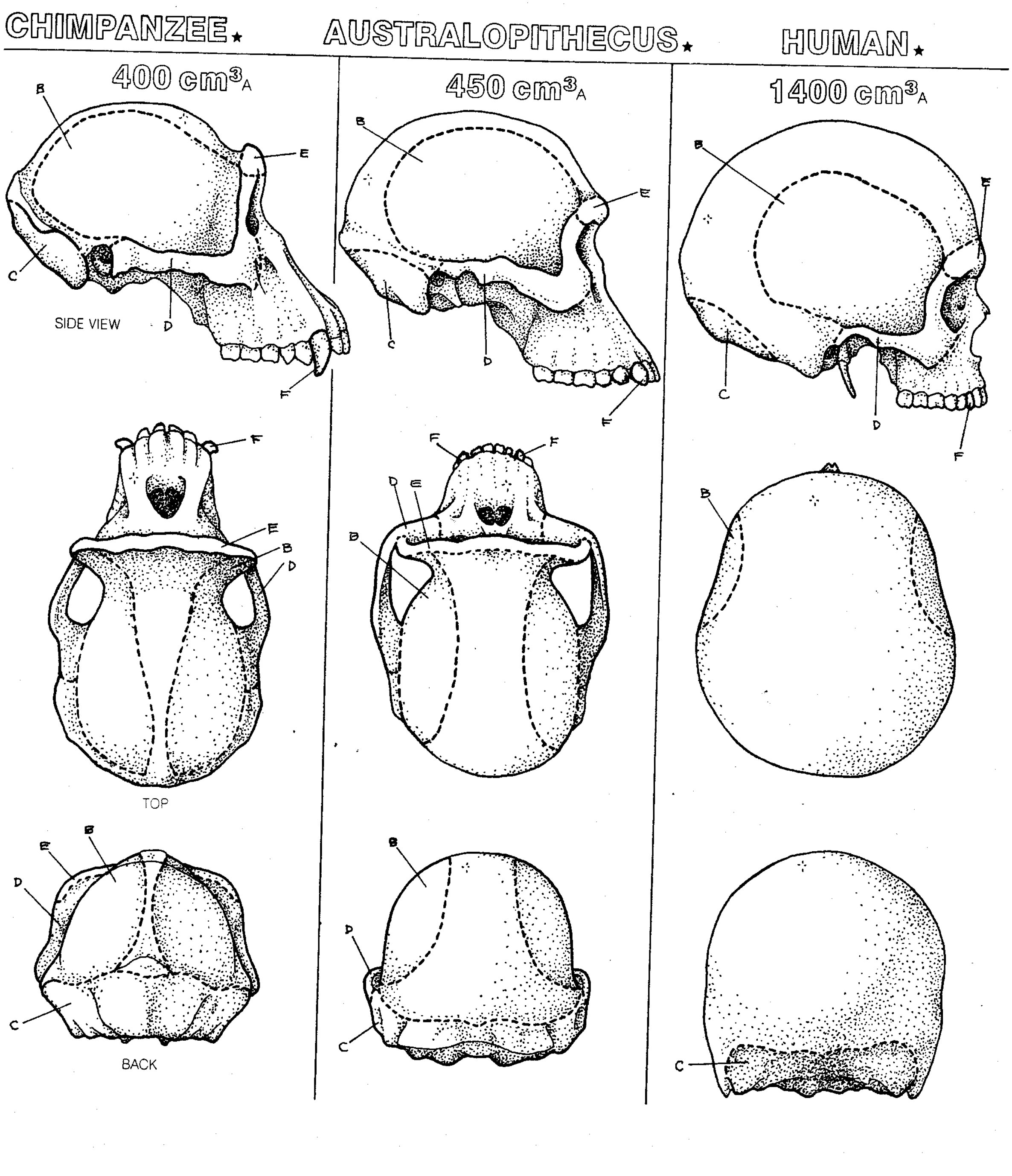
Color the canine teeth.

In comparison with the chimpanzee's, the *canines* of *Australopithecus* have been reduced nearly to human size, a change that has both dietary and social significance. The reduction implies less need for anterior teeth to procure food; when there is heavy chewing, big *canines* tend to get in the way. Male great apes have larger *canines* than females. Yet they eat the same diet; so the big *canines* must serve some social function, such as threat displays against other males. The small early hominid *canines* suggest two possibilities: they were using their hands more, and possibly tools as well, rather than their front teeth to procure food or the male–male aggression requiring large dimorphic *canines* was no longer such an important social interaction among them as it had been in their ape forebears.

Skulls, even long dead ones, tell many tales about the living ways of their vanished possessors.

SKULL COMPARISON★

CRANIAL CAPACITY A
TEMPORAL AREA B
NUCHAL AREA C
ZYGOMATIC ARCH D
BROW RIDGE E
CANINE F



HAND AND TOOLS

Humans have long been thought unique among animals in their ability to make and use *tools.* The gap between ourselves and our closest relatives, the apes, was believed so large that it was hard to imagine how it was crossed in the evolutionary process. New evidence from archeology and from field studies of *chimpanzees* has narrowed the gap to a crack.

Ancient *tools* of copper, bronze, and iron had long been known, but stone *tools* were first recognized as human artifacts in 1790 by Englishman John Frere (Mary Leakey's great great great grandfather), who found handaxes associated with extinct animal bones and described them as "fabricated and used by people who had not the use of metals," from a very ancient period.

In Europe and Africa, especially at Olduvai, stone *tools* are found in much greater abundance than *hominid* remains and were discovered much earlier.

Color the titles: chimpanzee, early hominid, and human, using light colors. Then color the corresponding hands.

Wrist and hand *bones* of *Australopithecus* and *Homo* are often not associated with teeth when discovered and so are difficult to identify as to species. Here a composite *early hominid* hand is compared with that of a *chimpanzee* and a modern *human.*

Color the thumb, finger, and wrist bones. Color the long flexor muscle tendons in the chimpanzee and the human.

The *early hominid thumb phalanges* and *finger phalanges* (in side view) are from Olduvai Bed I, analyzed by anatomist John Napier. These *finger bones* are more curved than in modern *humans* but less than in *chimpanzees.* The terminal *phalanx* of the thumb is intermediate in size between the *chimpanzee's* and the modern *human's.* It's breadth suggests strong muscles and a sturdy *tendon* of the *long flexor* going to the *thumb,* unlike the tiny one in the *chimpanzee*—again, an intermediate condition between *chimpanzee* and modern *human* that indicates *early hominid* hands were well equipped to use *tools.*

The skull provides more evidence, for in *Australopithecus* it appears that the cerebellum, important for skilled and coordinated hand movements, was larger than a *chimpanzee's.*

Complete the plate by coloring the hand grips (power and precision) and the objects in them.

Chimpanzees, like other apes and monkeys, have good hand control, but their *power grip* barely involves the *thumb* and their *precision grip* opposes the *thumb* to the proximal rather than the distal *phalanx* of the index *finger,* making these *grips* less flexible and effective than the *human* ones. The first stone *tools* were "choppers," made from pebbles, only a few flakes removed, which were also used as *tools* and must have required a well-muscled *thumb* for *precision* use (possibly to butcher animal carcasses or cut up plants). But these only appeared 2 mya, and we have *hominid* remains as old as 3.5 million years. How can we explain this seeming jump from no *tool* use to stone *tools*?

The answer lies in the bias of the fossil record. *Tools* made of wood or other organic materials, like those that *chimpanzees* make or the sticks, gourds, skins, bark, and vegetation used by contemporary gathering-hunting peoples, would not have survived in the fossil record. Yet it is very likely that our earliest ancestors depended heavily on such *tools* long before they systematically made ones of stone. It is also likely that the early pebble choppers were used to make organic ones.

Stone *tools* do mark a kind of technological "revolution," based on millions of years of perfecting organic *tools.* It has often been assumed that stone *tools* and evidence of butchering large animals indicate that *early hominids* were hunters, but weapons for hunting, such as spearheads suitable for hafting, have not been found; such unequivocal evidence appears only 150–200,000 years ago. Stone *tools* became increasingly varied and sophisticated within 0.5 million years of their first appearance, but metal *tools* emerged only several thousand years ago.

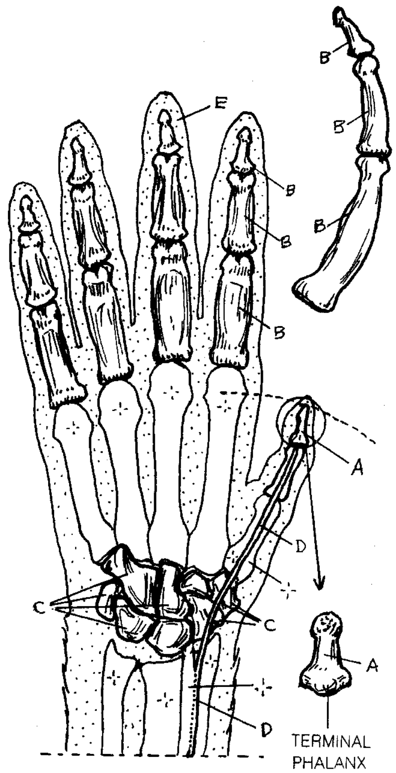
HAND AND TOOLS ★

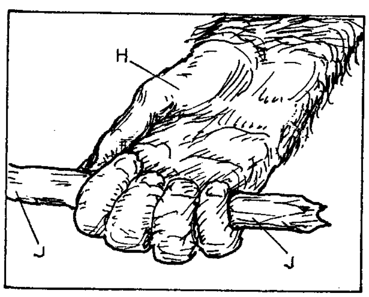
THUMB PHALANX A
FINGER PHALANX B
WRIST BONES C
LONG FLEXOR MUSCLE TENDON D

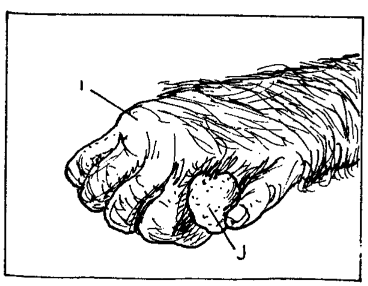
HAND GRIPS •
POWER H
PRECISION I

OBJECT/TOOL J

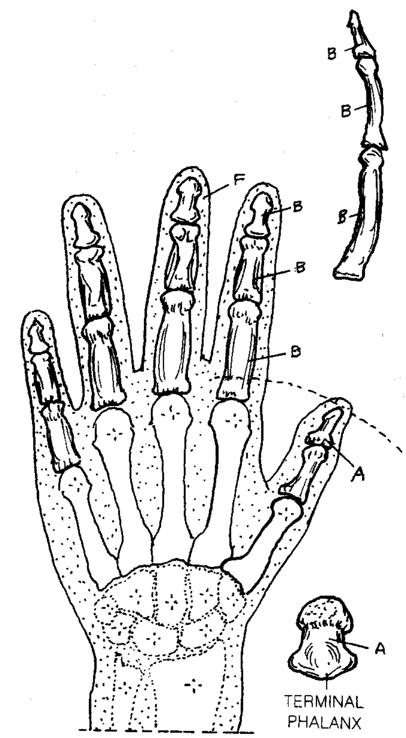
CHIMPANZEE E

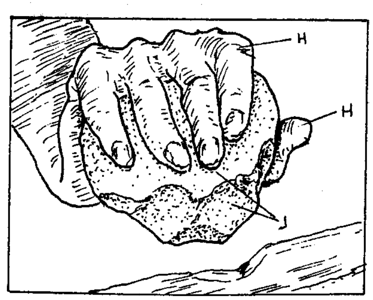


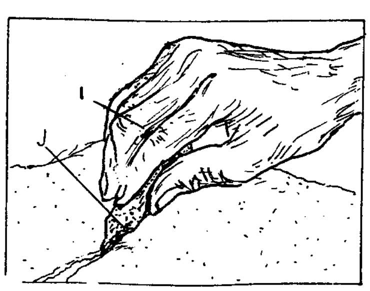




EARLY HOMINID F







HUMAN G