CHAPTER 10^8: THE LAST FEW HUNDRED-MILLION YEARS (30 – 300 MILLION YEARS AGO)

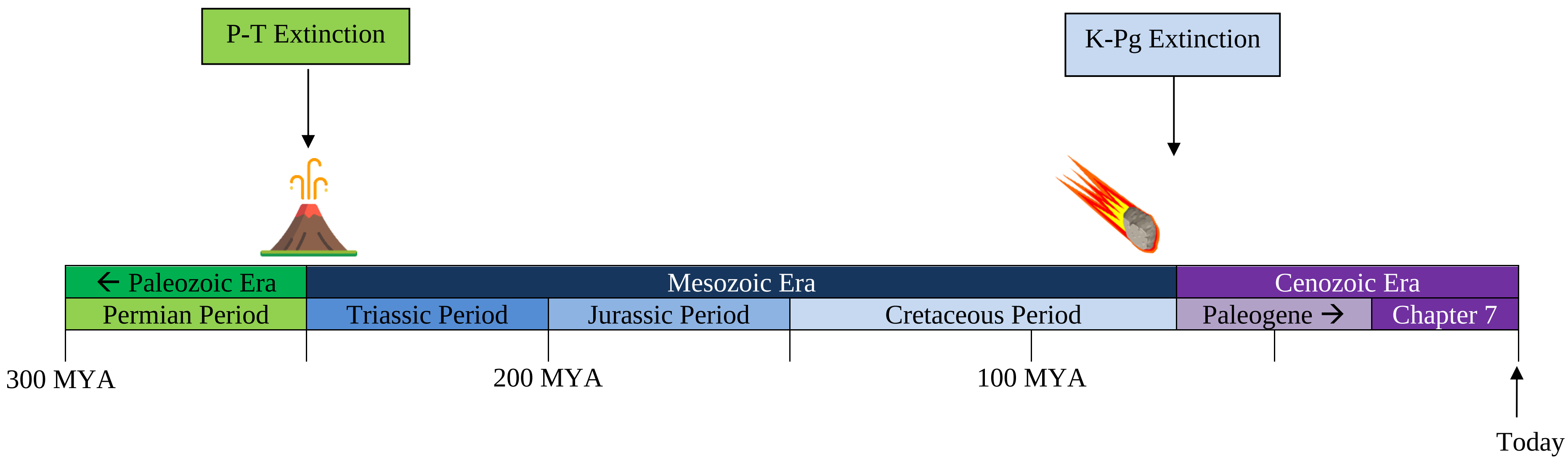
Contents

I. Introduction And Geological Time

Our identity does not begin or end with being human. Our nature is that of an animal, a mammal, a primate, and more. Chapter 8 could be characterized as "The Life and Times of Mammals". The timeline below shows the three eras of the last few hundred million years. Each era is divided into periods. This chapter mostly belongs to what geologists call the ***Mesozoic*** or "Middle Life" era, the time of the first mammals as well as dinosaurs.

Section II is a global overview of the Mesozoic Era. This era was dramatically bookended by two major mass extinctions. The mass extinction that ended the Paleozoic era, called the Permian-Triassic or simply the ***P-T*** event, was the most severe mass extinction in world history. The Cretaceous-Paleogene or ***K-Pg*** event is even more famous because it was the demise of the dinosaurs. Both of these mass extinctions had significant influence on the evolution of our ancestors. The P-T event was an evolutionary bottleneck, narrowing down the gene pool and leaving only a lucky minority of species to repopulate the Earth.

Dinosaurs' disappearance cleared the way for mammals to flourish in a variety of niches. Section III takes a closer look at mammals, our biological class. By the end of this time scale, our ancestors were primates who were already beginning to show signs of social and neurological sophistication. Although they still didn't look much like us, at least they were becoming cute and cuddly.


P-T Extinction
K-Pg Extinction
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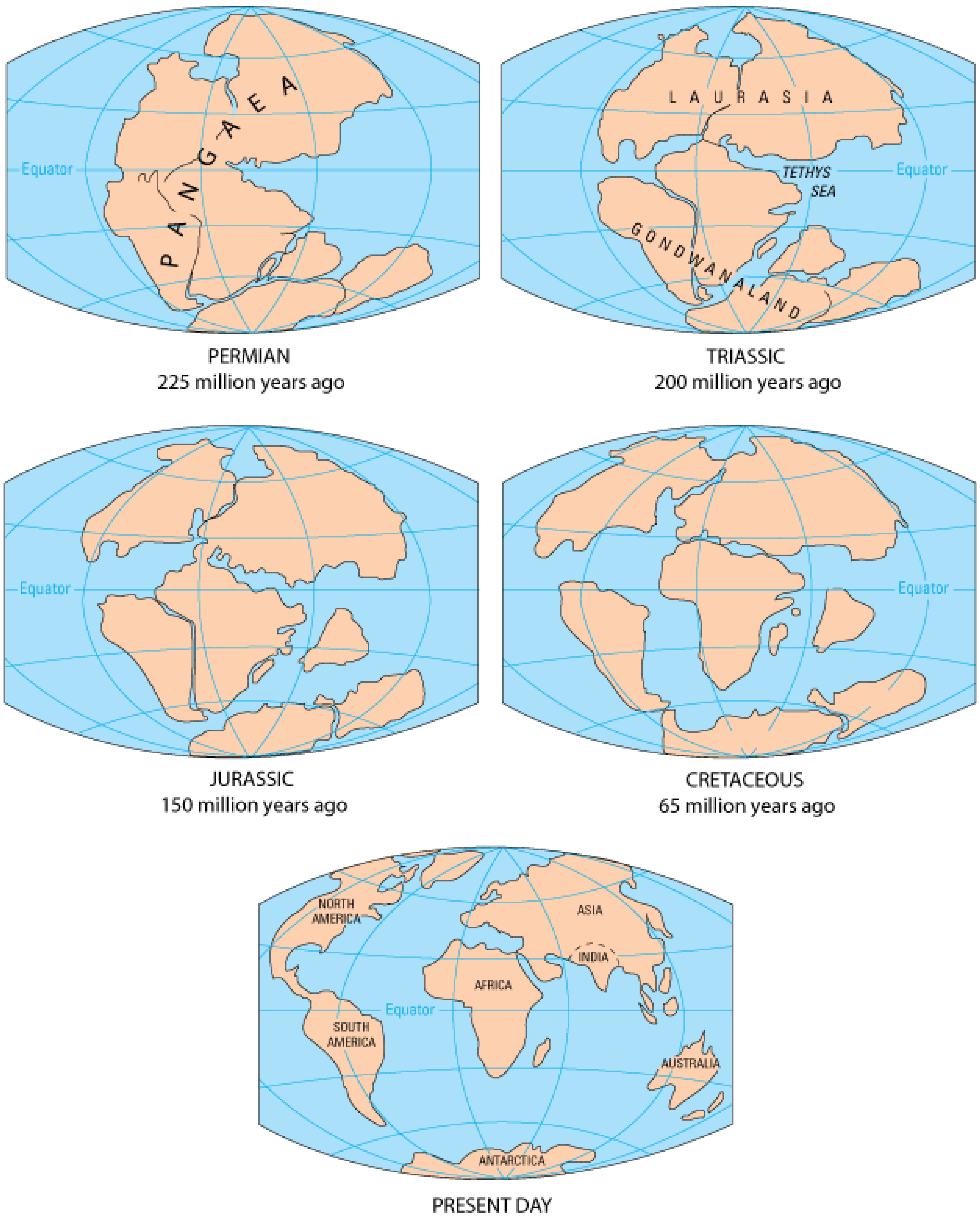
II. The Mesozoic World

A. Pangaea and the Modern Continents

About 300 million years ago, the continents just happened to coincide in one single land mass. That supercontinent is now called ***Pangaea*** (all-land). It was centered roughly at what is now the middle of the Atlantic Ocean, extending from pole to pole. The rest of the world was the single ocean, ***Panthalassa*** (all-sea), with a few major island arcs to the east of Pangaea. Evidence of the formation of Pangaea can still be found in the mountains created by continental collisions. The Ural Mountains were formed when Europe joined Asia. [1] The Appalachian Mountains of North America were part of the same orogeny as the Anti-Atlas Mountains of Africa. They recorded the joinder of two continents that are now an ocean apart.

Pangaea remained intact for most of the Mesozoic Era. Around 200 million years ago, the North American plate began drifting westward from the rest of the landmass, opening a waterway that would widen to become the North Atlantic Ocean. The South Atlantic Ocean formed another 100 million years later between South America and Africa. Meanwhile, Australia and India separated from Antarctica and drifted northward. By 30 million years ago, the continents were mostly recognizable as they appear today, with the exception that Eurasia was still under formation. The Atlantic Ocean is still widening while the Panthalassa / Pacific Ocean narrows at the rate of a few centimeters per year. Antarctica has been essentially parked at the South Pole the whole time. The sequence is roughly illustrated below. [2]



The assembly, consolidation, and breakup of Pangaea all had important consequences for life. Recall that plants and animals came ashore gradually 300 – 500 MYA. This was when bygone continents were converging to form Pangaea. All terrestrial life forms were then in a position to conquer the same landmass. If continents had been widely separated at that time, some of them might have remained lifeless.

A world with one supercontinent and one super ocean had distinct climate patterns. Pangaean coasts were probably buffeted by monsoons. [3] Monsoons occur in tropical coastal zones such as today's Indian Ocean. The continental interior was arid with extensive deserts. The ocean acts as an "insulator" because it does not change temperature quickly. On a large continent with a deep uninsulated interior, desert temperatures fluctuated from low to high extremes on a daily basis. Additionally, there was no way for warm ocean currents to circle the equator. The land mass diverted those currents toward the poles. This contributed to a climate that was more globally uniform than today. There were no ice caps during the Mesozoic, and even Antarctica thrived with life.

Differing scientists have attributed both global cooling and global warming to Pangaea. It is true that temperatures fluctuated greatly while Pangaea formed and grew, but these changes can mostly be explained by atmospheric conditions. [4] High carbon-dioxide content causes a greenhouse effect and global warming. During high-oxygen periods, temperatures fall. The deepest cold spell was a late-Paleozoic ice age, which covered the southern continents with a large polar ice cap for 90 million years. This was the cooling period that played a role in the extinction of coal-producing forests.

Pangaean animals had an unlimited range of latitude, so they could spread out to ideal locations all across the supercontinent. During the Paleozoic ice age, animals could migrate toward the tropics. When the climate was hotter, they could retreat toward the poles. In fact, during most of the Mesozoic, equatorial Pangaea was too hot and dry for most living things.

What is remarkable is that all terrestrial animal life evolved together on the same landmass. The ancestors of today's amphibians, reptiles, mammals and birds originated in Pangaea, so they were all shaped by the same environmental constraints. Eventually, the full diversity of Pangaean life was carried by continental drift in all directions. By the Jurassic Period, oceans were large enough to almost completely isolate the continents from one another. From that time forward, life on the various continents diverged on different evolutionary paths.

B. The Worst Mass Extinction of All Time

1. Causes

Extinction is the rule, not the exception. 99.9% of species that have ever lived are now extinct, at least as defined by physical appearance. It is normal for a micro-percentage of all species to go extinct every year. [5] The exceptional episodes have been a number of mass extinctions, global events that either killed off a high number of life forms or hit some taxa particularly hard. Obviously, our ancestors survived them all. It might seem that a history of proto-human evolution could ignore the extinctions of foreign clades. But mass extinctions played an important role in shaping our lineage. By determining the course of who lived and who died, extinction events favored some animals over others. They exerted evolutionary pressures and opened up ecological opportunities when competing species failed. In other words, we are who we are because our ancestors had what it took to survive these extinctions – even when it was just dumb luck.

Since a mass extinction is global, it usually involves the atmosphere and / or ocean. The Earth is changing constantly, just like living things. Sometimes the environment changes too rapidly for life to adjust. It need not be instantaneous. Each species goes extinct over many generations, as young adults fail to have enough offspring to replace their numbers. A mass extinction can occur gradually over thousands or millions of years.

The most devastating mass extinction in world history was the end-Permian extinction, also known as the Permian-Triassic (P-T) Extinction. [*] Scientists are still unearthing the full story of this catastrophe, but it appears to be strongly associated with major ongoing volcanic activity. 250 million years ago, the ***Siberian Traps*** volcanoes released enough gas from within the Earth's mantle to change the entire atmosphere. [6] The main culprit was carbon dioxide, CO_2. CO_2 is a greenhouse gas that traps heat at the surface. An excess of CO_2 caused runaway global warming. Temperatures rose so high that the tropics became virtually uninhabitable. [7] Other gases caused acid rain, which killed plants and eroded soil. The ocean became acidic and lost most of its oxygen; this was exacerbated because ocean water could not circulate well around Pangaea.

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[*] There might have been arguably "larger" mass extinctions earlier in time, particularly the Great Oxygenation Event (when life was still prokaryotic) and a possible "Snowball Earth" in the age of protists and sponges. Direct evidence of the impact of those events is scant, and it is hard to compare extinctions across such different eons.

The P-T Extinction is of particular interest in the 21st century. Not only is this event on the frontier of geological research, but it serves as a warning about today's man-made carbon dioxide. The CO_2 levels of the Permian reached levels much higher than today. However, our current annual rate of carbon production is comparable to Permian accumulation. [8] If today's industrialization continued on track for millennia, it would likely have the same effect (though we'd probably run out of gas well before that).

2. Effects

The late Permian Period was the grand finale of Paleozoic "old life". Land and sea alike were rich with diverse communities of plants and animals. The crown jewels of shallow coastal waters were the coral reefs. Reefs sheltered familiar animals like shellfish, snails, sea urchins, shrimp, and lobsters. Bony fish and some marine reptiles now swam with rays, sharks, armored fish, and jawless fish. The seafloor was home to burrowing worms, sponges, and other *sessile* animals rooted in the ground. One of the most distinctive Paleozoic animals was the ***trilobite***, the three-lobed relative of the crab.

Reptiles ruled the continent. Many of them were moderately large (bear-sized) and are sometimes wrongly called dinosaurs. The most charismatic creatures, at the top of the food chain, included the sail backed *Dimetrodon* and the saber-toothed ***Gorgonopsian***. Amphibians were less dominant but still holding their own in wetlands. Terrestrial plants made a major breakthrough in the Permian Period as well, with the evolution of seed-bearing plants. Forests of conifer trees, like pines, covered vast areas.

After all that evolutionary success, the impact of the climate change is hard to believe. The P-T extinction killed off almost all forms of life, 90% of the species living throughout the world! Most species seem to have died out relatively suddenly, maybe within 100,000 years, concurrently with the lava flows that created the Siberian Traps. Panthalassa was impacted worse than Pangaea. Marine invertebrates took the hardest hit of all, with 95% species loss. [9] A primary reason for this was the interdependency of ecosystems. Many forms of plankton, the base of the aquatic food chain, died out. [10] Most forms of coral were severely reduced too. Coral reefs shelter myriad species and slow down coastal erosion. After the extinction, sea floors were almost bare, with just a few sturdy shellfish remaining. Iconic sea creatures like armored fish and trilobites were gone forever.

On Pangaea, the landscape was also laid bare with decimation of the forests. It was a period of heavy continental weathering. Many large reptiles and amphibians were killed off, including gorgonopsians and fin-backed reptiles. This was the only mass extinction that even put a dent in insect populations. Global temperatures remained so high for so long that there was almost no life near the equator for millions of years. [11] Living things migrated toward the poles and adapted to the hot, low-oxygen environment.

The P-T extinction event defines the transition from the Paleozoic to the Mesozoic. With nine out of ten species wiped out worldwide, the planet became a desolate wasteland. It took tens of millions of years for life to fully recover. It was truly the end of an era.

C. Dinosaurs, Mammals, Birds, and Fruit

In the barren epochs of the early Triassic Period, ecosystems started over almost from scratch. One important fact remained: reptiles were still the dominant life form on land. The Mesozoic Era was truly the age of reptiles. Over the course of hundreds of millions of years, these successful survivors came to dominate all realms of the Earth. They begat lines of descent that went on to inherit their thrones.

An early reptilian breakthrough was conquest of the ocean. Turtles and sea serpents were already swimming before the extinction. Some of them, like *ichthyosaur* in the mid-Triassic, grew as large as great white sharks. Their bodies adapted to the marine environment to become streamlined with flippers. They assumed such a strongly fish-like appearance that it is easy to forget that they were reptiles. This is a good example of ***convergent evolution***. A common environment such as the shallow sea can shape entirely different creatures into similar physical forms.

Another case of convergent evolution is winged flight. After insects, the next animals to take to the air were flying reptiles, ***pterosaurs***, which evolved in the late Triassic Period. Pterosaurs were not ancestral to birds, but just happened to evolve flight earlier. Pterosaurs grew gradually larger over time. The first known specimens were a meter long. By the end of the Mesozoic, the monstrous *quetzalcoatlus* stood as tall as a giraffe and had a wingspan of 10 meters – a real-life dragon!

When we think of Mesozoic land reptiles, we are inclined to think of dinosaurs. Of course, not all reptiles at the time were dinosaurs. There were tortoises, lizards, snakes, crocodiles, and other varieties that don't exist anymore. The most important difference was that dinosaurs walked upright. Instead of sprawling crocodilian legs, dinosaurs had erect legs directly beneath their bodies. Like columns, upright legs are good at supporting weight. This is one of the main anatomical features that allowed many species of dinosaurs to grow so large. Upright legs also provided speed and agility. Many dinosaurs were ***bipedal***, walking on two legs, which freed up the front legs to be used as arms. Dinosaurs dominated the landscape with these major advantages.

The first known dinosaurs were modest, no larger than dogs or cats. They originated in the southern hemisphere in the middle Triassic Period, about 240 million years ago. [12] Their range eventually expanded across Pangaea; dinosaur fossils are now found on all continents. Dinosaurs flourished especially in the Jurassic and Cretaceous Periods, when the famously large species appeared. The largest land animal of all time, the *brachiosaurus*, was a Jurassic dinosaur. This four-legged herbivore weighed about 40 tons and could eat leaves from treetops ten meters high. "Jurassic Park" notwithstanding, the famous *Tyrannosaurus, Velociraptor,* and *Triceratops* came much later in the Cretaceous Period.

Some of the smallest bipedal dinosaurs went through significant transitions in the Jurassic Period. They evolved feathers, probably for body insulation at first. This suggests that they were becoming warm-blooded. [13] Their arms and hands evolved into wings, and wing feathers became specialized for flight. The skull features of embryonic and baby dinosaurs were extended into adulthood. [14] The result of these transformations was the bird, a whole new class of vertebrates. The Cretaceous Period saw an explosion of bird diversity and the refinement of body features for effective flight. By 30 MYA, most modern bird orders had appeared, from songbirds to ostriches.

Mammals evolved from a non-dinosaurian line of reptiles. This speciation occurred in the Triassic Period. The early appearance of mammals will be discussed further in the next section, in relation to human ancestors. Most mammals remained small through the Mesozoic Period, and were relegated to the role of nocturnal burrowing insectivores. They were largely unable to compete with dinosaurs or other large reptiles for dominance of the land. There were exceptions – some Cretaceous mammals were large enough to feed on small dinosaurs! [15] The great mammal radiation occurred shortly after the dinosaur extinction. Just ten million years into the Paleogene Period, mammals numbered 4,000 species, ranging from bats to whales. [16]

In the plant kingdom, the headline of the Cretaceous Period was the success of *angiosperms* – plants that produce fruit and flowers. These features serve valuable reproductive purposes. Fruit encloses seeds, providing them with nutrients and allowing dormancy for seasonal growth. Flowers and fruits serve to attract animals, which can carry seeds or pollen from one plant to another. It is no coincidence that birds and flowers evolved aggressively together during the same time period, as they enjoyed a mutually beneficial ***symbiotic*** relationship. The last major plant breakthrough was grasses, which appeared about 40 MYA. Grasses include not only the short green blades in your front yard but also bamboo and grains such as wheat and corn.

The Mesozoic Era formally ended 66 million years ago. Strong evidence links the end-Mesozoic extinction to at least one asteroid collision. [17] Scientists still debate whether this was the sole cause or the knockout punch after a period of climatic stress. [18] The second-worst mass extinction of all time, it spelled the end for dinosaurs, pterosaurs, and an entire sister order of birds. Sea serpents vanished along with *ammonites*, shelled squid-like animals that had been around for 300 million years.

D. Oil!

Petroleum is the liquid form of fossil fuel. It formed mostly from the remains of plankton and algae at the bottom of the sea. These organisms have been around for billions of years, and a modest amount of oil dates back to the Proterozoic Eon. Most of it, though, was deposited in the Mesozoic Era. [19]

Like coal, oil can only form in a low-oxygen environment where dead matter does not decompose completely. Since oxygen content decreases with water depth, the ocean floor is a good environment to preserve biofilm. In a properly anoxic region of seafloor, the topsoil gets enriched with organic sludge. Over millions of years, new sediments of sand and rock accumulate on top of it, and this layer of topsoil ends up meters or kilometers beneath the surface. Bacterial activity, heat, and pressure combine to eventually transform the sea sludge into oil. This process is a breakdown of organic macromolecules, mostly lipids, into smaller and simpler *hydrocarbon* chains. The bonds between the carbon and hydrogen atoms are high in potential energy, which is now released when people burn it.

The process is finicky. If conditions are not just right, oil will not accumulate and / or endure. First, dead matter must build up more quickly than it decomposes, which is relatively rare. After sedimentation, oil forms only within certain windows of temperature and depth. [20] If the wrong kind of bacteria finds the oil, it will be compromised. In fact, most of the world’s oil has been degraded to some extent. The overall process is pretty inefficient. It took 100 tons of dead sea life to form each gallon of gasoline in your car! [21] Because this process is so lengthy, fine-tuned, and wasteful, oil is non-renewable over any span of time less than millions of years. That is, once it is consumed, it cannot be replaced.

Since oil is liquid, its distribution depends on the geology of the bedrock. A reservoir of oil requires a layer of rock that is porous like a sponge, so the oil can flow and pool. It must be surrounded by non-porous rock so that it does not sink to lost depths or spill out onto the surface. Natural gas is often trapped in a reservoir above the liquid petroleum. Oil and gas can seep from one location to another when earthquakes or tectonic shifts dislocate the surrounding layers of rock.

Finding a large amount of useful oil in one place, then, is a rarity. In fact, there was only one spot in the world that met all of the ideal circumstances. In the Mesozoic Era, it was on the East Coast of Pangaea along the Tethys Sea, a large region of the Panthalassa Ocean ringed by islands. This tropical coastline was rich in plankton and minerals. Ocean currents deposited a large amount of dead matter onto the long continental shelf, producing a rich source rock. The oil sank into particularly porous and permeable reservoir rock and was then covered by a thick layer of solid cap rock. The oil reserve was never disturbed by earthquakes or harmful bacteria. Today, this region is located in Southwest Asia. [22] This streak of geological good luck is what makes the Arabian Peninsula the richest source of petroleum exports in the world today.

III. Mammals And Primates

A. Body

1. Warm-bloodedness

200 – 300 MYA, our ancestors were classified as “mammal-like reptiles”. The animals at the earlier end of this spectrum were closely related to reptiles, and those at the more recent end were nearly mammals, with a long continuous transition in between. We are all aware of the cosmetic differences between these vertebrate classes. Reptiles are covered in tough flat scales, while mammals have fur. Reptiles sprawl with legs jutting out to the side, unlike mammals with

erect legs directly beneath their bodies. Reptilian teeth are uniform and single-cusped, like points on a saw blade. Thankfully, mammals do not flash smiles of pointy triangles.

These traits don't just make us look better. They evolved together around one invisible but profound adaptation: warm-bloodedness. The term "warm-blooded" does not tell the whole story. Mammalian body temperature is not just high; it's also constant. A reptile is at the mercy of the environment. It is much more vulnerable to overheating or freezing to death if it does not hide in shelter. Except in the worst extremes, a mammal is safe and can stay active in all weather. This is the obvious advantage of warm-bloodedness.

Another benefit is chemical predictability. Cellular activity is temperature dependent. In a cold-blooded animal, a certain protein might be reactive one day and inert the next, abundant one day and then depleted. A well-regulated temperature helps sustain proteins, and therefore life functions, at a nice steady pace. This allows for much more efficient evolution of the genes regulating those proteins.

A reptile's body heat literally goes with the flow. The mammalian body must resist temperature gradients with the outer environment. When it is hot outside, a warm-blooded animal must release heat. Venting is accomplished by exposure of vessel-rich skin to the air or by evaporation of small amounts of water from the body. A mammal must also retain heat in cold weather. That is the most important function of fur, an outer insulator. Sweat glands, body fat, and fur evolved along with warm-bloodedness. They are extremely efficient solutions, as they resist the temperature gradient without expending energy.

In fact, energy is the major cost associated with warm-bloodedness. Pound for pound, a mammal requires five to ten times as many calories as a reptile! [23] That is why warm-bloodedness did not evolve overnight. The body needed time to evolve the capability to catch and digest enough food.

This growing appetite explains certain skeletal trends among the mammal-like reptiles. A reptile does not chew its food. It uses its teeth only to catch and kill prey, which it then swallows whole. The digestive system slowly takes care of the rest. A mammal must chew its food to make digestion faster and easier. As our ancestors became less reptile-like and more mammal-like, they developed stronger jaws. Teeth became more robust, and they specialized into wedge-shaped incisors and flat-topped molars.

Meanwhile, our ancestors developed better legs to forage for food. Vertical limbs can take longer strides and navigate diverse terrain. With sprawling legs, reptiles need more muscular energy just to support their weight. Mammals can save this energy for running.

Soft anatomy, too, was overhauled for higher energy requirements. Muscles improved in strength and stamina. The heart evolved a fourth chamber to keep oxygen-rich blood separated from de-oxygenated blood. The diaphragm developed greatly to assist with breathing. The adaptation that directly caused warm-bloodedness was a simple increase in the number of mitochondria per cell.

Mammal-like reptiles are of particular interest because they were our "bottleneck" ancestors. They survived the P-T extinction while most tetrapods around them died. This may be testimony to their warm-bloodedness, or it may be simple luck. Whatever it was, nature selected these creatures to pass their traits along into the Mesozoic Era. After recovery, mammals became successful worldwide. Warm-bloodedness is organic climate control. It permitted our mammalian ancestors to thrive in all habitats.

2. The mammals who knew the dinosaurs

300 million years ago, there were no mammals or birds, only mammal-like reptiles and bird-like reptiles. These clades have had a roller-coaster relationship. In the Permian Period, proto-mammals ruled the land as the largest and most diverse animals, while smaller bird-like reptiles scurried around beneath their feet. After the P-T event, the roles were reversed. Most mammal-like reptiles went extinct. The survivors shrank and evolved into tiny mammals as proto-birds grew and evolved into dinosaurs.

The evolution of the earliest mammals, then, was guided by some crucial environmental factors. In their post-apocalyptic world, life was sparse, and the planet was hot. Dinosaurs were unbeatable in their roles as large creatures and carnivores. Rather than competing with dinosaurs for the top of the food chain, Mesozoic mammals specialized in lower niches. They were small burrowers and tree-climbers. Based on their teeth, it appears that they mostly ate insects and worms. In turn, they must have made perfect bite-sized snacks for large reptiles, so hiding was a top concern. They turned to a nocturnal lifestyle.

The earliest fossils that are classified unequivocally as mammals are from the late Triassic period, a little more than 200 MYA. Early mammals resembled rodents. They are identified as mammals primarily by features of the teeth and skull. Reptiles have a main jawbone with a number of secondary jawbones attached behind it. During the reptile-mammal transition, the main jawbone grew, and the secondary jaw bones shrank and became detached. The mammalian jaw formed a hinge at a different location, further forward in the skull. Two tiny secondary jaw bones found their way into the middle ear and became adapted for the purpose of hearing! Today, we call them the anvil and the stirrup. They give mammals the ability to hear a much broader range of frequencies than other animals. [24]

Good hearing is vital for nocturnal animals. So are smell and touch. Night life requires the ability to detect food, family, friends, and foe by any means possible. Fur and whiskers help animals feel their way around in the dark. Early mammals developed an advanced olfactory (smell) system. The nasal cavities were filled with convoluted structures that captured chemicals from the air. The parts of the brain responsible for processing smell, as well as tactile sensations from whiskers, grew significantly. [25]

The word "mammal" itself is borrowed from the mammary glands. Even the most basal mammals have them, so nursing probably evolved right around the time of the first true mammals. The production of milk may have first been useful for keeping eggs moist. [26] The first mammals laid eggs like their reptilian ancestors. Over time, eggs stayed longer inside the mother's body, with thinner shells, until eventually the young were born live. [27] Mammals that have a uterus and give live birth are called ***placentals***. Most modern mammals worldwide are placentals. Those that still lay eggs are found only in Australia. Almost all mammals that have a pouch for their young are also in Australia. This is the first sign of continental isolation. Pangaea was starting to disassemble as mammals diversified in the late Mesozoic.

3. Primates

Dinosaurs went extinct at the end of the Mesozoic Era. Mammals, with their competition gone, soon began to flourish and diversify, and went on to become masters of the Cenozoic Era. Birds carried on the dinosaur line. This was yet another role reversal of what had happened at the beginning of the Mesozoic, when dinosaurs had crowded out the mammal-like reptiles!

In the classic Linnaean scheme, humans belong to the class of mammals and the order of ***primates***. Our ancestors evolved into primates right around the Mesozoic-Cenozoic boundary. [28] The earliest primates lived in the northern continents, and it is likely that they originated in Asia. [29] Primitive examples of primates are lemurs and tarsiers, not much larger than the rodent-sized Cretaceous mammals from which they descended. They were omnivorous, eating small invertebrates as well as plant matter.

Early primates lived in trees. Their hands and feet had grasping fingers, which were effective for holding branches, catching insects, and picking fruit. Fruit was an extremely important part of the diet. Most tetrapods have a protein that allows them to produce their own Vitamin C. Our ancestors lost that protein early in primate evolution, so now we depend on fruit for most of that vitamin intake. [30]

This was also the phase when our ancestors acquired the “private parts” that resemble ours today. Primates have only two breasts. The penis is “pendulous”, meaning that it is not attached to or tucked into the abdominal wall as in other mammals. [31]

With dinosaurs out of the way, some primates, ***simians***, became active during the day. As daylight gave them much more visual information to process, simians began a trend toward better eyesight. Their eyes were close together in the front of the face. This arrangement narrowed their field of vision but provided good depth perception. Three-dimensional vision was useful for living in a treetop environment, where judging leaps could be a matter of life and death.

The first simians resembled miniature monkeys. [32] One Cenozoic trend was bodily growth. By about 35 MYA, our line the ***catarrhines*** emerged. [33] The range of catarrhines was restricted to Africa and Southern Asia. They preferred tropical forests and did not occupy Europe. The continents were far too spread apart by this time for them to make it to Australia or the Americas. The primitive catarrhines are thus known as Old World monkeys.

The word “catarrhine” describes Old World monkeys’ “downward nose”, to contrast them with New World monkeys, which had nostrils pointed to the sides. Instead of claws, catarrhines had flat nails on all fingers and toes. The catarrhine dentition has come down to us almost unchanged. In each quarter-jaw, there are two incisors, a canine, two bicuspids, and three molars. Early catarrhines retained the sharp, long canine teeth that get their name from dogs. Catarrhines reduced the prehensile tail, which had been almost like a fifth limb for older primates. Primates like lemurs and spider monkeys can use their tails to grasp branches. Catarrhines came up with an even better solution, the fully opposable thumb. As we know, this proved to be extremely valuable much later for the use of tools and text messaging.

Vision continued to advance. Other mammals see only greens and blues. Catarrhines were sensitive to red light as well. With three primary colors, they were able to perceive a much more vivid picture of the world. This *trichromatic* vision may have provided valuable advantages in the visually busy world of treetops. In a chaotic canopy of branches, vines, and flowers, it could be useful to discern ripe fruit and leaves from the background clutter. [34] The sense of sight proved so valuable for catarrhines that both the skull and the brain became much more dedicated to vision [35] at the expense of smell [36].

B. Brain and Behavior

Being mammal means so much more than just having hair and warm blood. The mammalian brain is more advanced than that of any other animal. Mammals, especially primates, are inherently social. The evolution of pregnancy and live birth created radically new social paradigms, like exaggerated gender roles and the mother-infant bond. All of these elements of mammalian nature are tied together with complex emotions. The lifestyle of even the lowliest placental mammal, the mouse, is far closer to human than the life of the lizard or fish.

1. The neocortex

When you visualize a brain, you probably think of the human brain with its wrinkly exterior. That outer layer is called the ***neocortex***, meaning “new covering”. Although it is only about a millimeter thick, it covers the brain’s entire outer surface. As its name suggests, the neocortex evolved more recently than the old *paleocortex*, which is shared by reptiles and, to a lesser extent, birds. [37] The neocortex must have originated 200 – 300 MYA in mammal-like reptiles. It is large and complex in primates, especially humans, and smaller and simpler in most mammals.

The neocortex serves at least three crucial functions. It is heavily involved in sensory processing. It may have evolved originally to handle the cognitive demands of the senses of smell and touch. [38] Second, the neocortex is proficient at motor control. The more complex the movement, the more brain surface is required. Primate hand-eye coordination and facial expressions are especially demanding.

The third major function of the neocortex is social intelligence and emotional processing. In primates, these forms of cognition are especially well developed at the front tip, the *prefrontal cortex*. Non-mammalian animals may have some emotions, but they don't seem to range far beyond survival directives. The half-joking summary of reptilian mentality is, "If it's smaller than me, I'll eat it. If it's the same size as me, I'll mate with it. If it's bigger than me, I'll run away." [39] A reptile's inner life is exceedingly simple. It does not torture itself over what it should have done yesterday or how to get along with its neighbors. On the other hand, it also does not enjoy the happiness of friendship or a life well lived.

As primate social groups grew, so did the neocortex. [40] It grew much faster than the skull, which is why it began folding and wrinkling to accommodate its increased surface area. The richness of primate emotion, then, comes from associating activity in the "reptilian" brain to its social context as understood by the intelligence of the neocortex. [*]

Interestingly, many of the most powerful mammalian emotions involve parts of the brain that already existed in reptiles and are regulated by brain chemicals that are also inherited from reptiles. For example, mammals feel a rush of euphoria when the ***neurotransmitter*** *dopamine* is released from one part of the brain's *limbic system* into another part. Reptiles also have dopamine and a limbic system, but they do not show any signs of emotional rushes. It seems that we must attribute most of our emotionality to the biological difference between the reptile and mammal brains: the neocortex.

Primate brains are unique in at least two other ways. Compared to other animals of the same size, primates have small neurons that pack together densely, especially in the neocortex. [41] Primates' neurons also have a thick version of the *myelin sheath*, a fatty coating that helps electrical signals travel more rapidly through the brain. [42] These micro-features give primates cognitive powers that cannot be matched by even the largest brains, those of elephants and whales.

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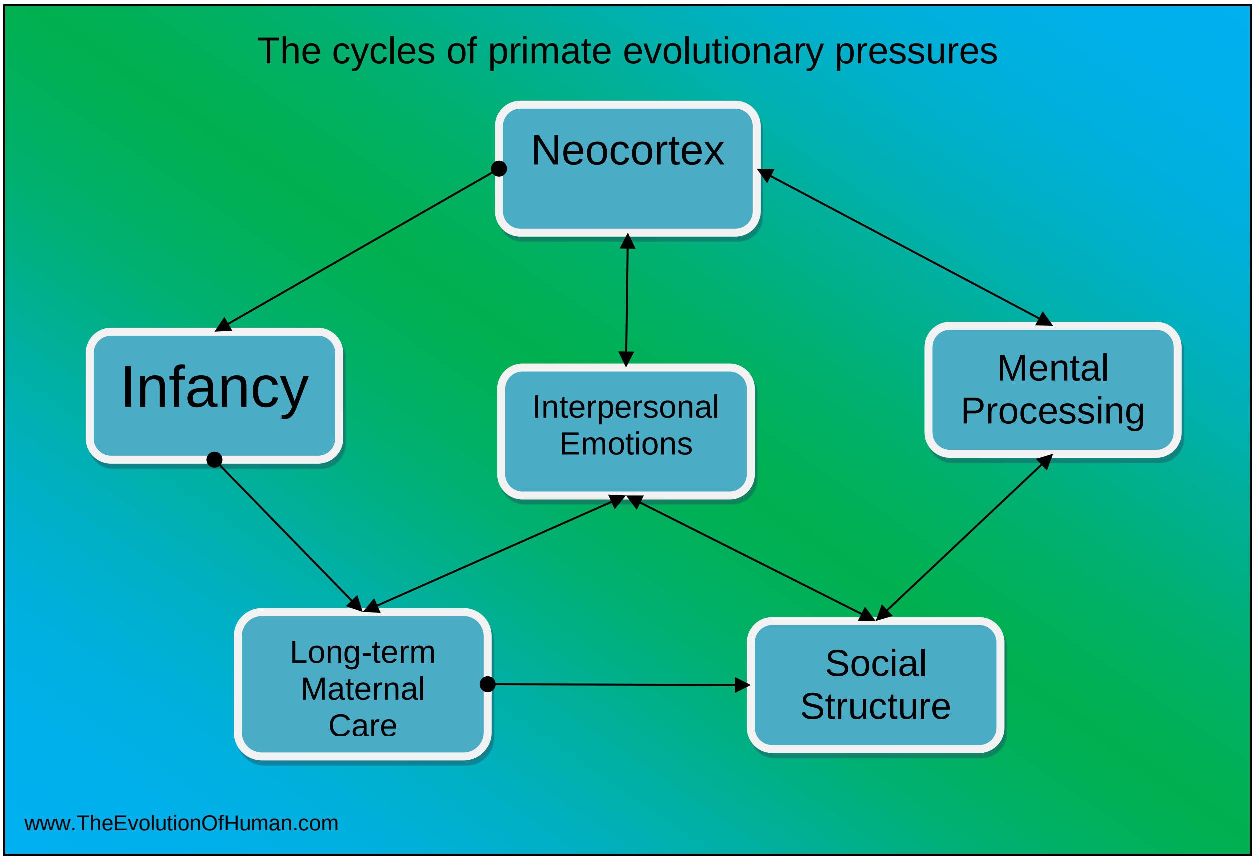
[*] The true "reptilian brain" is the entire brain beneath the neocortex. The term as it was coined by Paul MacLean last century referred only to the brainstem, which is actually shared by all vertebrates.

The relationships among the neocortex, mental processing, and interpersonal emotions are represented in this diagram. The chart shows that primate evolution involved still other social and biological factors, which will be elaborated below.



The arrows represent enabling factors or evolutionary pressures.

2. It takes a village to raise a child

Reptiles do not have an infancy life phase. They hatch as miniature adults ready to take on the world, and their mothers are nowhere to be seen. As mammals and primates became more biologically complex, it took longer for the young to reach maturity. Infants relied on their mothers' milk for sustenance, and their large brains needed time to develop. Parental care was absolutely essential for survival. Something had to compel mammalian mothers to undertake such a responsibility.

Although it is difficult for us to understand, it is not a given that an animal mother will care about her children. Many egg-laying animals abandon their nests, and some species are known to eat their own young! [43] To a fish, this might make sense. If a mother fish spawns 100 young and is feeling hungry, she can afford to weed out some of the slow weak ones and leave the hardier offspring to survive and carry on her genes.

Compared to egg-layers, a mammal mother has few offspring. Pregnancy is a big deal; it is highly demanding on the body. A female can only carry one or a small number of children at a time. At a minimum, the mother must carry each child to term through a full gestation period, not to mention nursing and other childcare, before her next pregnancy. Even the most fecund mammal like a rodent will have maybe 40 children in her lifetime. A typical monkey will bear about ten. In the wild, each individual child has low odds of success. For a primate mother, then, every baby matters.

Childbearing and prolonged infancy created the pressure for maternal love. Evolution will favor the mother who protects her children – and a female who loves her children will protect them. The emotions of love, trust, and bonding between a mother and child are associated with the neurotransmitter *oxytocin*, which is unique to mammals. It is released during pregnancy and childbirth into the bloodstream of both mother and child, and it assists with nursing. [44] It might strike us as hollow that love is chemical, but, in animal studies, motherly devotion can be turned on [45] and off [46] with the flip of an oxytocin switch.

In many mammal species, mother / child families are self-supporting social units. For most primates, these single-parent families form the core of larger communities. Our primate ancestors became increasingly social animals through the Paleogene Period. Simians are more social than prosimians, [47] and catarrhines all live in social groups. [48] The exact nature of the social unit varies by species. It depends on other factors in the environment such as availability of food and danger from predators. For instance, monkeys who eat fruit require larger groups than leaf-eaters in order to forage effectively. Most Old World monkeys live in social units with multiple adult females. [49] Extended female relatives help each other raise children and forage for food. Males can help expand the territory or defend it from other families and keep a look out for predators. [50]

Gender roles are exaggerated by the mammalian life cycle. Since a mother is limited to a relatively small number of children, the best strategy for her genes is to choose mates judiciously and supervise each child safely to adulthood. A competitive male can rely more on the law of large numbers – his genes will become predominant if he sires more children than other males. His options are determined by his social structure and his status within the community. Without the hormonal influences of pregnancy, mammal fathers do not get as emotionally attached to their offspring, and do not generally participate in the daily activities of raising their young.

Social life added a whole new dimension to the challenges of the environment. Primates now had to keep an eye out for scheming peers as well as scary predators. Cooperation, competition, and compromise were paramount to success. Since the neocortex is so heavily devoted to social skills, it is reasonable to assume that it evolved in response to these needs. Monkeys were able to recognize individuals by facial features instead of by smell. This was doubly important because facial expressions were sophisticated ways to communicate emotions. Monkeys began to understand concepts such as friendship [51] and fairness [52], guilt, cheating, and punishment. [53] A medium-term memory is essential for the social construct of *reciprocal altruism*. [54] If *A* does a favor for *B*, *B* should remember the favor and return it before too long. If *B* does not return the favor, then *A* knows that *B* is a cheater and will stop giving favors. Monkeys exhibit some innate sense for these rules of reciprocal altruism. [55] It's not chess, but it's certainly a step up from eating their own children.

Male social life is especially dynamic. Female hierarchies tend to be rigid. Males much more frequently compete and change status. Status can have clear survival benefits such as access to the best food, mates, and trees. A male monkey's status depends on aggressive competition as well as his social skills, conferring benefits for higher intelligence. [56]

Whatever the advantages, the primate brain clearly evolved to reward social success and to avoid social falling. [57] When an individual connects with his peers in a positive way, a burst of neurotransmitters surges through his brain to associate that moment with an emotional reward and to encourage him to do it again. We call it happiness.

IV. Summary

By 200 million years ago, our ancestors were mammals. They had survived the worst mass extinction of all time, and their bodies were highly adapted to life on land. Evolution was guided by the harsh climate of the post-extinction period, the consolidation of all continents into one grand Pangaea, and the towering presence of dinosaurs. The Mesozoic appearance of fruit trees also greatly shaped our past. In a less direct way, the geology of the Mesozoic Era impacted us with the accumulation of major oil reservoirs.

From the earliest mammals, we inherited our warm-bloodedness, our good sense of hearing, and, damn them, our body fat. Warm-bloodedness was an especially significant and complex trait. It involved the co-evolution of several supporting features, including teeth for chewing, legs for running, and efficient hearts and lungs.

Mammals were unlike any other class of animal. Not only did they give live birth and care for their young, but their brain had reached a new level of complexity with a neocortex. After the dinosaurs went extinct about 70 million years ago, the mammalian family tree radiated into a multitude of orders, including ours, the primates. In early primate evolution, again a host of traits co-evolved and reinforced each other. By this time, many of the defining traits were mental or behavioral: heightened senses and motor skills, prolonged infancy, emotional bonds, and social group life.

By the time of the catarrhine primates 35 million years ago, physical features included grasping fingers with opposable thumbs, full color 3D vision, and teeth that your dentist would recognize (well, okay, Count Dracula's dentist). Primate vision and manual dexterity taxed the brain and encouraged an especially advanced neocortex.

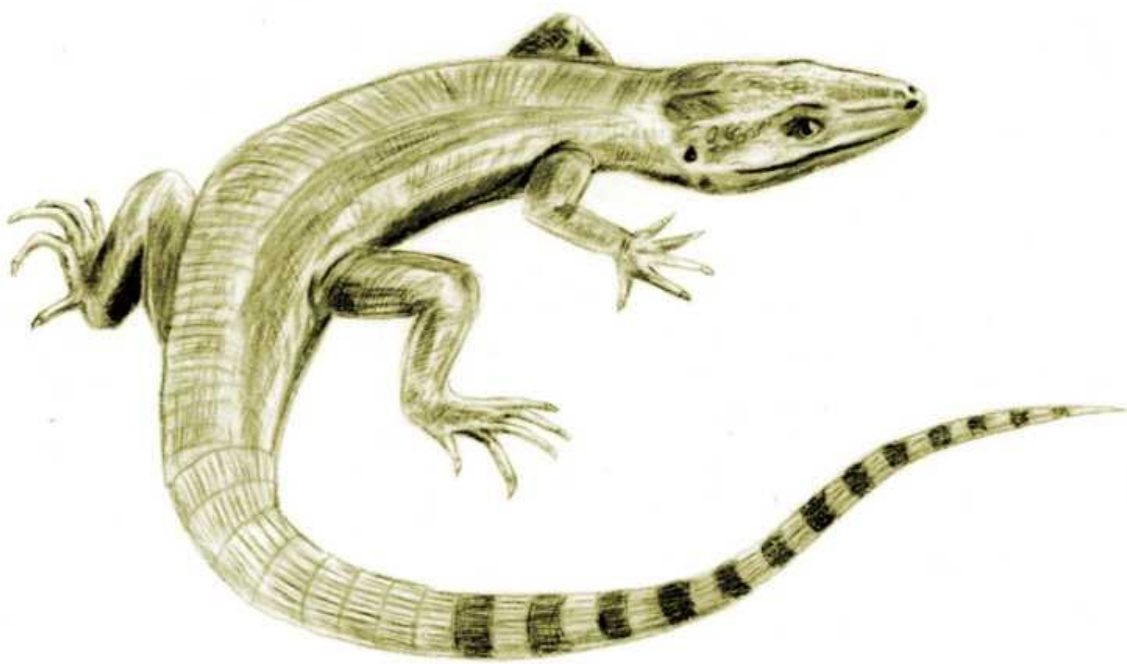
As young ones took longer to mature, they required more intensive parental care. Mothers stepped up to the plate. The life of a mother became deeply intertwined with the lives of her children, from pregnancy to nursing to supervision and education. The physical states of pregnancy and lactation actually promoted pharmaceutical bonds of love in the brains of mother and child. There were several models of mating behavior and gender roles, varying from species to species.

Living in cooperative groups forced the evolution of social intelligence. Monkeys learned to recognize each other's facial features and expressions. They developed social hierarchies and had to understand how they and their peers ranked within the group. Long before there was wealth or power, there was social status, and primates cared intensely about it. When we gossip with friends or watch reality TV shows, we see human social situations overflowing with drama – the ambition, the power plays, the cheating and the backstabbing! We might shake our heads and wonder what kind of society we live in today. The truth is, it's nothing new. Not by fifty million years.

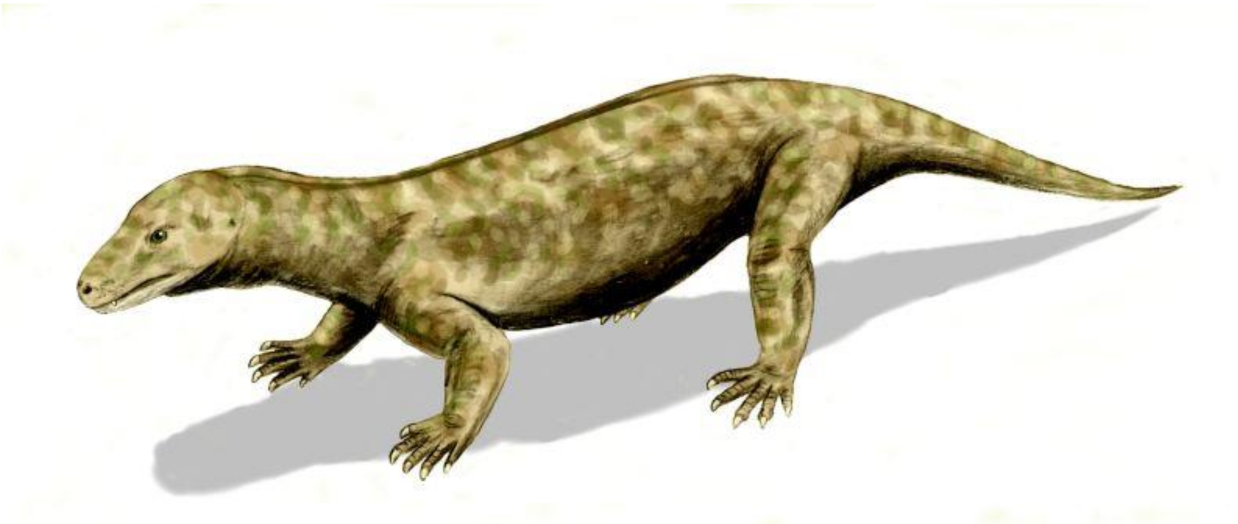
V. Human Ancestor Picture Gallery

These particular specimens are selected as basal embodiments of their clades, so they are known to be pretty closely related to our line of descent. Dates are grossly rounded.

300 MYA: ***Synapsids*** are the amniotes that are more closely related to today's mammals than to reptiles or birds. The marker that traces synapsid lineage is an internal feature, the pattern of holes in our skull. The first synapsids were still reptile-like. [58]



250 MYA: ***Cynodonts*** came about halfway through the reptile-mammal transition. The early cynodonts were the ancestors who lived through the worst of the P-T Extinction while almost all other tetrapods died around them. They had noticeably more erect legs than earlier synapsids, and their transition to warm-bloodedness was probably mostly complete. [59] [60]



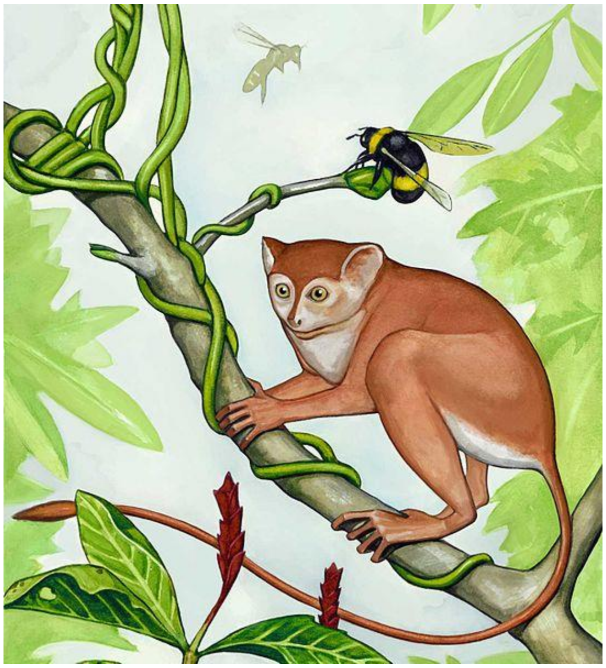
200 MYA: It is difficult to know for sure, but fur may have evolved in pre-mammalian cynodonts. [61]

200 MYA: Mammal skeletal features are recognizable in fossils dating back a little further than the 200-million-year mark. Mesozoic mammals were tiny, and they evolved slowly. [62]

150 MYA: *Eutheria* was a transitional form. The earliest eutheria still laid eggs, but their descendants all give live birth today. [63]

70 MYA: Placental mammals give live birth. The earliest placental species has been modeled in an amazing supercomputer project that analyzes fossils and reconstructs their common ancestors. [64] This hypothetical critter, the Eve of all wombs, has been named *Shrewdinger* by popular vote. Her "official" image is copyrighted, so I can't duplicate it here, but the story is too cool to pass up. Here's the link to that picture and a video describing the project. Shrewdinger basically looked like a shrew: [65]

70 MYA: Primates emerged as part of the early Cenozoic mammal radiation. We are defined mostly by our grasping hands and forward-looking eyes. [66]



50 MYA: Simians are active during the day. They have larger brains and more advanced social structures than earlier primates. Catarrhines in particular have opposable thumbs and human-like teeth, but for the long canines. The tail started to lose its function as a useful limb and gradually became weaker and shorter. [67]

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[65] Shrew image public domain, https://www.wpclipart.com/animals/S/shrew/Large_Tree_shrew__Tupaia_tana.png.html (accessed and saved 8/24/19).

[66] Primate image by Mat Severson (Own work), CC BY-SA 4.0 (http://creativecommons.org/licenses/by-sa/4.0), https://commons.wikimedia.org/wiki/File:Reconstruction_image_of_Archicebus.jpg (accessed and saved 8/24/19).

[67] Catarrhine image by Nobu Tamura (http://spinops.blogspot.com) (Own work), CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0), https://commons.wikimedia.org/wiki/File:Aegyptopithecus_NT.jpg (accessed and saved 8/24/19).