In 2017, I read a non-fiction book named Who We Are and How We Got Here, Ancient DNA and the New Science of the Human Past, by David Reich. I also joined Ancestry.com. This is when I began genealogy research and began documenting everything that I had learned about my family and the ancient past. In 2019, I visited the National Museum of Natural History, in Washington DC, and took the guided tour of the David H. Koch Hall of Human Origins. This 15,000-square-foot gallery invites you to explore the scientific evidence of human origins over the past 6 million years and traces how we evolved the unique traits that distinguish our species.

In 2020, I had my DNA analyzed by National Geographic (NG) Geno 2.0, with DNA sequencing by Helix. My terminating Haplogroup was R-L21. In 2021, I joined the O'Mahony Society and learned that there were several additional haplogroups that I did not receive from NG. After I learned that this society was using Family Tree for Irish DNA analysis, I signed up for the Big Y-700 test. When I received my results, my DNA contained eight (8) additional haplogroups or mutations. In 2022, I began watching almost every episode of the NASA Open Volumes on Aerospace (NOVA) presentations on PBS, including the Universe Revealed: Big Bang and Milky Way. It was around this time that I realized that **our evolution actually began at the beginning of the Universe!**

In 2023, I read three more non-fiction books. The first is named Life on a Young Planet, The First Three Billion Years of Evolution on Earth, by Andrew H. Knoll. The second book is named Your Inner Fish, A Journey into the 3.5-Billion-Year History of the Human Body, by Neil Shubin. The third is named Cosmos, written by astronomer and Pulitzer Prize-winning author Carl Sagan. It was published in 1980 as a companion piece to the PBS mini-series Cosmos: A Personal Voyage, with which it was co-developed and intended to complement. Then I watched all 13 episodes of this mini-series.

Earlier this year, I organized all of my research into 17 chapters and titled my "text book" Evolution and Extinction. I did not actually write this book yet, but the material is organized for this endeavor. In parallel, I reorganized my document named My Paternal Heritage and Migration History. Family Tree provided a most impressive map in their GlobeTrekker feature of the journey that my paternal ancestors took to reach Ireland. Family Tree also updated the origin time estimate and location of my paternal haplogroups, which provided me with some very surprising information.

According to Family Tree, my haplogroup R-DF13, originated in Northwestern Britain (Cumbria)! R-DF13's paternal line was formed when it branched off from the ancestor haplogroup R-S552, around 2550 Before Common Era (BCE). **Haplogroup R-DF13 is characteristic of a majority of the living male inhabitants of Ireland, Scotland, Wales, and Brittany**. This means that the most recent common ancestor of almost every Irish male was born in or near Cumbria, around 2550 BCE! I will inform you how the Irish first settled in Cumbria later in this article.

In 1931, The Big Bang had been proposed, by Georges Lemaître, a Belgian physicist, who suggested that the evident expansion of the Universe in time required that the Universe, if contracted backwards in time, would continue to do so until it could contract no further. This would bring all the mass and energy of the Universe to a single point, a "primeval atom", **to a state before which time and space did not exist**. Fred Hoyle is credited with coining the term "Big Bang" during a 1949 BBC radio broadcast, saying that Lemaître's theory was "based on the hypothesis that **all the matter in the universe was created in one big bang at a particular time in the remote past**." Research published in 2015 estimated the earliest stages of the universe's existence as **taking place about 13.8 billion years ago** (Bya).[1]

In 1911, we now know that Ernest Rutherford discovered **the atomic nucleus,** a small, dense region at the center of an atom. After the discovery of the neutron in 1932, models for a nucleus were quickly developed by Dmitri Ivanenko and Werner Heisenberg. Now, we know that **an atom** is composed of a positively charged nucleus, composed of protons and neutrons, with a cloud of negatively charged electrons surrounding it, bound together by an electrostatic force.

Furthermore, **a chemical element** is a chemical substance that cannot be broken down into other substances. The basic particle that constitutes a chemical element is the atom, and chemical elements are distinguished from each other by the number of protons in the nuclei of their atoms. **When different elements undergo chemical reactions, atoms are rearranged into new compounds** held together by chemical bonds. For example, water (H_2O) is a chemical compound of hydrogen and oxygen atoms.

When ancient humans looked up at the sky at night, they could not have understood what they saw. What were the tiny lights dispersed across the dark sky? This ignorance existed until the invention of the telescope in the early 1600s Common Era (CE). We now know that **a star is a celestial object**, made mostly of the chemical elements hydrogen and helium, that produce light and heat from the churning nuclear forges inside their cores. A star's distance from the earth and its size are what determines its brightness. **A planet** on the other hand **is an object that orbits a star**, is big enough to have a gravitational force and spherical shape, and is big enough that its gravity has cleared away other objects near its orbit around the star.

Arthur Stanley Eddington first suggested in 1920, that **stars obtain their energy by** fusing hydrogen into helium (called **nuclear fusion**) and raised the possibility that the heavier chemical elements may also form in stars.[2] Fred Hoyle's original work on nucleosynthesis of heavier chemical elements in stars, occurred just after World War II. **Synthesize** means to make something, from simpler substances, through a chemical process. Hoyle's work explained the production of all of the heavier chemical elements, beyond hydrogen, and also explained how **the abundances of the chemical elements increased with time as the Universe aged**.

Nuclear fusion is a specific chemical reaction in which two or more atomic nuclei are combined to form one or more different atomic nuclei and subatomic particles (neutrons or protons). **Nuclear fusion is the process that powers active or main-sequence stars** and other high-magnitude stars, where large amounts of energy are released.[3] Main-sequence stars vary in surface temperature from approximately 2,000 to 50,000 Kelvin (K), whereas more-evolved stars can have temperatures above 100,000 °K or 99,727 °C or 179,540 °F. **This is why all of the chemical elements manufactured within stars are in their gas or plasma state**.

The state or phase of matter can change depending on pressure and temperature conditions, transitioning to other phases as these conditions change to favor their existence. For example, a solid will transition to a liquid with an increase in temperature. As heat is added to a solid it melts into a liquid at its melting point, boils into a gas at its boiling point, and if heated high enough would enter a plasma state in which the electrons are so energized that they leave their parent atoms. **Plasma (moldable substance) is the fourth fundamental state of matter after solid, liquid, and gas**.[4] It contains a significant portion of charged particles – ions and/or electrons. The presence of these charged particles is what primarily sets plasma apart from the other fundamental states of matter. **Plasma is the most abundant form of ordinary matter in the universe, being mostly associated with stars, including our Sun.**

A photon is an elementary particle that is a quantum (the minimum amount of any physical entity or physical property involved in an interaction) of the electromagnetic field, **including electromagnetic radiation such as light and radio waves**, and the force carrier for the electromagnetic force. Photons are massless, so they always move at the speed of light in a vacuum, about 186,282 miles per second. At around 47,000 years after the Big Bang, the universe cooled and its behavior began to be dominated by matter rather than radiation. **Until then, the universe's large-scale dynamics and behavior had been determined mainly by radiation**, meaning, those constituents that move relativistically, at or near the speed of light, **such as photons and neutrinos**.

The distances measured in the universe are unimaginable! **A light-year** is defined as a large unit of length used to express astronomical distances and **is equivalent to about 5.88 trillion miles**. As defined by the International Astronomical Union, a light-year is the distance that light travels in a vacuum in one Julian year (365.25 days). Earth's distance from the sun averages to about **93 million miles**, which scientists also call **one astronomical unit** (AU). It takes about 8.3 minutes for the light (photons) from the sun to reach our earth. Yes, the sun is really that far away from Earth!

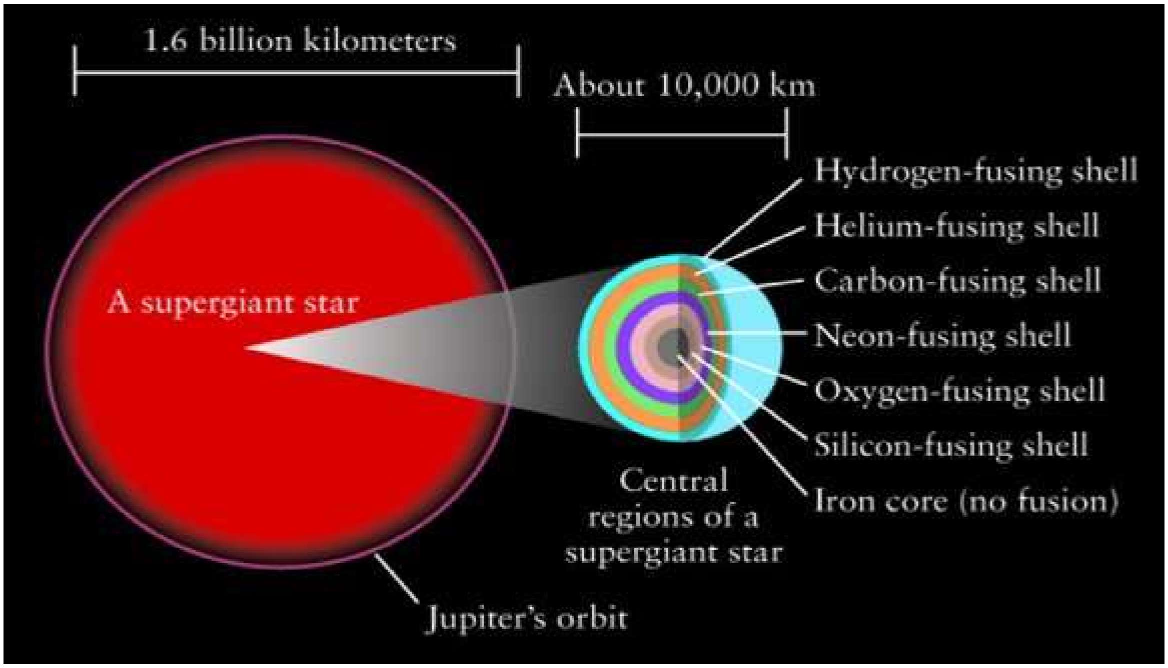
Since the universe is estimated to be 13.8 billion years old and since photons (light) have been traveling over 13 billion years, then a rough estimate of the size of the universe, in terms of the distance that light has traveled since the Big Bang, is 13.8 billion years times 5.88 trillion miles per year or 13,800,000,000 years times 5,880,000,000,000 miles per year or 81,144,000,000,000,000,000,000 miles!

At around 100,000 years after the Big Bang, the universe had cooled enough for helium hydride, the first molecule, to form. **A molecule is a group of two or more atoms held together by attractive forces known as chemical bonds**. The helium hydride ion has the chemical formula HeH^+. It consists of a helium atom bonded to a hydrogen atom, with one electron removed. **Much later, atomic hydrogen reacted with helium hydride to create** molecular hydrogen (H_2), **the fuel required for star formation**.

Stars form in large clouds of gas and dust called molecular clouds. Molecular clouds range from 1,000 to 10 million times the mass of the Sun and can span as much as hundreds of light-years! Molecular clouds are cold which causes gas to clump, creating high-density pockets. Some of these clumps can collide with each other, collecting more matter, strengthening their gravitational force as their mass grows. **Eventually, gravity causes some of these clumps to collapse**. When this happens, friction causes the material to heat up, which eventually leads to the development of a protostar, a baby star. **Proto means pre-formation**. Batches of stars that have recently formed from molecular clouds are often called stellar clusters, and molecular clouds full of stellar clusters are called stellar nurseries.

Stars are fueled by the nuclear fusion of hydrogen to form helium deep in their interiors. The surrounding molecular cloud is made up of dense dust and gas being drawn to the center, where the protostar resides. As the material falls in, it spirals around the center. **This creates a dense disk of material, known as an accretion disk**, which feeds material to the protostar. As the cloud collapses, a dense, hot core forms and begins gathering dust and gas. As it gains more mass and compresses further, the temperature and pressure of its core will rise, **eventually reaching the threshold for nuclear fusion to begin**.

The first generation of stars, known as Population III stars, formed within a few hundred million years after the Big Bang. Population III stars turn **the few light chemical elements that were formed in the Big Bang** (**hydrogen**, helium, and small amounts of lithium) into many heavier chemical elements. Hydrogen is the most important gas and one of the oldest and most ubiquitous chemical elements in the universe. **If hydrogen did not exist, stars would never have formed and life, as we know it, would not exist**.



All of the chemical elements in the universe heavier than hydrogen are forged by stars. In a star's core, the temperature and pressure are so high that hydrogen atoms fuse together to make helium. **Hydrogen fusion releases prodigious amounts of energy, the heat and light of the star**. That is the story for 90 percent of the life of a star, fusing hydrogen to make helium. Eventually, though, the star runs out of hydrogen and begins to fuse its stocks of helium, making yet heavier elements. Helium, taken three at a time makes carbon. Add one more helium to that carbon and make oxygen. **Since carbon, nitrogen, and oxygen, in their gas/plasma state or phase, are made in stars, we already have the principal chemical elements of life**.

Organic chemistry is the chemistry of carbon. In stars, carbon fuses after helium, and still heavier elements begin to form, including sulfur, argon, chlorine, potassium, calcium, and scandium, and the pace of nuclear fusion gets faster and faster. Back in the middle, silicon is starting to burn at stupendous temperatures, making titanium, vanadium, chromium, manganese, cobalt, nickel, and iron. Iron cannot fuel the stellar furnace. Iron, has the symbol Fe and atomic number 26, denoted (Fe,26), is really the end of the road. **When a star builds up too much iron, it dies**. The core collapses and bounces or rebounds. And it begins to move out, first slowly, and then faster and faster. This sends a very sharp wave back out through the star.

Most stars are between 1 billion and 10 billion years old. Some stars may even be close to 13.8 billion years old, the observed age of the universe. **The more massive the star, the shorter its lifespan**, primarily because massive stars have greater pressure on their cores, causing them to burn hydrogen more rapidly. The **most massive stars last an average of a few million years**, while stars of minimum mass (red dwarfs) burn their fuel very slowly and can last tens to hundreds of billions of years.

The whole thing is blowing up into a supernova.[5] A supernova explosion can be as bright as four billion stars like the sun. **Such outrageous energies overcome the iron barrier, cooking iron atoms into additional chemical elements on the periodic table**. In a few hundreds of thousands of years after the initial explosion, the supernova ejecta will eventually mix in with the general interstellar medium (the space between stars). The **interstellar medium** is composed primarily of hydrogen, followed by helium with trace amounts of carbon, oxygen, and nitrogen. The supernova has thus enriched the interstellar medium with heavy elements across a sphere distance of about one thousand light-years. **Over many billions of years, the interstellar medium is continuously enriched by thousands of supernovae**.

Now we know that stars manufacture and distribute heavy chemical elements and that their characteristics are intimately tied to the characteristics of the planetary systems that may coalesce about them. Consequently, the study of the birth, life, and death of stars is central to the field of astronomy. **You get carbon and nitrogen and oxygen made in stars. These chemical elements are the building blocks of life**. That means our universe is hospitable to life. There are billions and billions of galaxies everywhere, making stars that are right for solar systems. The habitat for life is everywhere. **The carbon in our bodies, the iron in our blood, the calcium in our bones, the oxygen in our water, every last atom, was formed in a star**. And the chemical elements in our Earth are the products of stars, supernovae, or merging neutron stars.

The Milky Way galaxy began to form at about 8.8 Bya.[6] The Milky Way galaxy contains billions of planets orbiting billions of stars. The Milky Way's complex structure has taken billions of years to evolve and contains the remnants of the first stars that formed in our part of the universe. The Milky Way galaxy is a spiral structure of hundreds of billions of stars, all orbiting around a supermassive black hole, right at the center of our galaxy. The Milky Way's elegant spirals are the signature of its dynamic history. The Milky Way galaxy takes its name from the dense band of stars that we see from Earth, when in fact, it is a structure that entirely surrounds us. **It was only a hundred years ago that people thought the Milky Way galaxy was the entire universe**.

The Hubble telescope told us that there are trillions of galaxies in the universe.[7] **Before the Milky Way galaxy formed, space was filled with a vast structure known as the "cosmic web."** Hydrogen and helium gas collect along the web's vast filaments, but the web itself is made from something more mysterious called "dark matter." Dark matter is something that has gravity but produces no light. It surrounds us, in fact, it dominates the mass in our own galaxy, and yet we do not know what it is. **Dark matter** creates these huge structures into which ordinary matter falls, and when that matter gets compressed, it can turn into stars. This is what really **seeds galaxy formation**.

The first stars are born where the filaments cross and dark matter is at its densest, drawing large amounts of gas together, until it collapses under its own gravity, causing stars to ignite. **The force that causes galaxies to form, merge and evolve is gravity**. It is the gravity of the stars within those galaxies and the underlying dark matter. The more we learn about the Milky Way and its dynamic history, the more incredible it seems that **we are orbiting just one star among billions**.

Our Solar System formed at about 4.6 Bya, with the earliest traces of life on Earth emerging by about 3.5 Bya.[8] The nebular hypothesis (or theory) says that the Solar System formed **from the gravitational collapse of a fragment of a giant molecular cloud**. The cloud was about 20 parsecs (or 65 light years) across, while the fragments were roughly 1 parsec across (3.25 light years). One of these collapsing cloud fragments, known as **the Presolar nebula, formed what became the Solar System**. **Most of the collapsing mass collected in the center, forming the Sun**, while the rest flattened into a **protoplanetary disk** out of which the planets, moons, asteroids, and other small Solar System bodies formed. The oldest inclusions found in meteorites, thought to trace the first solid material to form in the Presolar nebula, are 4.6 billion years old, which is one definition of the age of the Solar System.

Within 50 million years, the temperature and pressure at the core of the Sun became so great that its hydrogen began to fuse into helium, creating an internal source of energy that countered gravitational contraction (pressure) until hydrostatic equilibrium was achieved. This marked the Sun's entry into the prime phase of its life, known as the main sequence. **Main-sequence stars derive energy from the fusion of hydrogen into helium in their cores**. The Sun remains a main-sequence star today.

A chondrule is a round grain found in a chondrite.[9] Chondrites are formed when various types of dust and small grains in the early Solar System accreted to form primitive asteroids. **Chondrules form as molten, or partially molten, metal and rock droplets in space,** before being accreted to their parent asteroids. Because chondrites represent one of the oldest solid materials within the Solar System and are **believed to be the building blocks of the planetary system**, it follows that an understanding of the formation of chondrules is important to understand the initial development of the planetary system.

Planetesimals emerge from the giant, donut-shaped, protoplanetary disk of gas and dust that circles young stars.[10] Prominent components of stardust are silicon carbide, graphite (carbon), aluminium oxide, and other such solids that would condense at high temperature from a cooling gas. The metallic chemical elements, namely magnesium, silicon, and iron, which are the principal ingredients of rocky planets, condensed into solids at the highest temperatures of the planetary disk. Gravity and other forces cause material within the disk to collide. If the collision is gentle enough, the material fuses, growing like rolling snowballs. Over time, dust particles combine to form pebbles, which evolve into mile-sized rocks. As these planetesimals orbit their star, they clear material from their path, leaving tracks of space empty but for fine dust. At the same time, the star gobbles up nearby gas and pushes more distant material farther away. After billions of years, the disk will have totally transformed, much of it now in the form of new worlds. Watch this video to see this process unfold. https://youtu.be/sCkhEu3lYNc

Collisions and gravitational interactions between planetesimals combine to produce moon-size planetary embryos (protoplanets) and the planetary embryos collide to form planets. **Planets may take tens of millions of years to form after the birth of the star**. Once planets form around a star they are referred to as planetary or solar systems, which are defined as sets of gravitationally bound objects that orbit a star.

In the inner Solar System, chondrules appear to have been crucial for initiating accretion. **The particles that make up the terrestrial planets are made from liquid metal and liquid rock (think lava), that condensed in the inner Solar System, closest to the Sun**. The inner Solar System, the region of the Solar System inside 4 AU (13 light years), was too warm for volatile molecules like water and methane to condense, so the planetesimals that formed there could only form from compounds with high melting points, such as metals (like iron, nickel, and aluminum) and rocky silicates (silicon and oxygen). A terrestrial planet or rocky planet, is a planet that is composed primarily of silicate rocks or metals. **The terrestrial planets include Mercury, Venus, Earth, and Mars**.

Terrestrial planets are substantially different from the larger **gaseous planets, also called Jovian planets, including Jupiter, Saturn, Uranus, and Neptune, which are further away from the Sun**. Differentiation between these two classes of planets arise **due to the frost line** of the solar nebula. Jovian planets began as large, icy planetesimals, which captured hydrogen, helium, ammonia, and oxygen, in various physical states, from the solar nebula.

The Sun, along with its Jovian planets and the terrestrial planets is known as our Solar System. The Solar System travels through the Milky Way in a circular orbit approximately 30,000 light years from the Galactic Center. The period required for the Solar System to complete one revolution around the Galactic Center, the galactic year, is in the range of 220 to 250 million years. Since its formation, the Solar System has completed at least 20 such revolutions around the Galactic Center.

If we could rewind time 4.6 billion years, Earth was almost unrecognizable. Asteroids and comets repeatedly pelted Earth. **Earth was a ball of burning gas and hot lava-like liquids, spinning through space**. The **Hadean geologic Eon (4.5 to 4.0 Bya)** is characterized by Earth’s initial formation from the accretion of dust and gases, the frequent collisions of larger planetesimals, the development of its atmosphere and oceans, and the stabilization of its core and crust.[11] Throughout part of this eon impacts from extraterrestrial bodies released enormous amounts of heat that likely prevented much of the molten rock from solidifying at the surface. The name of the eon is a reference to Hades, a Greek translation of the Hebrew word for hell. **In the Hadean Eon, we have a heat source (our sun), and obtain a magnetic field, and the formation of our moon**. There are no fossil records because the temperature is too high to sustain life.

The Late Heavy Bombardment occurred approximately 4 Bya, between 500 to 600 million years after the formation of the Solar System.[12] This period of heavy bombardment lasted several hundred million years and is evident in the cratering still visible on geologically dead bodies of the inner Solar System such as the Moon and Mercury. **The oldest known evidence for life on Earth dates to 3.8 Bya, almost immediately after the end of the Late Heavy Bombardment**.

The giant impact hypothesis explains the formation of our moon. The Earth collided at least once with a very large protoplanet. One of these collisions is thought to have resulted in the formation of **Earth’s Moon**. This happened sometime at the start of the Hadean Eon. First, an object the size of Mars headed towards Earth. At tremendous speed, it delivered a glancing blow to Earth. **Earth’s gravity was able to pull the moon into its orbit** and the moon has remained orbiting Earth ever since.

After the moon-forming impact, Earth was a very different planet from the world we see today! Where the present-day Earth has oceans covering much of its surface, the early Earth was covered in a magma ocean, a layer of molten rock hundreds of miles deep, melted by the energy released during the collision. Any water present would only exist as water vapor in the atmosphere.

The origin of water on Earth is the subject of a body of research in the fields of planetary science, astronomy, and astrobiology. The inner Solar System's period of giant impacts probably played a role in the Earth acquiring its current water content from the early asteroid belt. Water is too volatile to have been present at Earth's formation and **must have been subsequently delivered from outer, colder parts of the Solar System**.[13] Earth is unique, among the rocky planets in the Solar System, in having oceans of liquid water on its surface. **Liquid water, which is necessary for life as we know it**, continues to exist on the surface of Earth, because **our planet is at a distance, known as the habitable zone**, far enough from the Sun that it does not lose its water, but not so far that low temperatures cause all water on the planet to freeze.

Multiple geochemical studies have concluded that **asteroids are most likely the primary source of Earth's water**. The giant Jovian planets scattered small icy planetesimals inwards. This process continued until the planetesimals interacted with Jupiter, whose immense gravity sent them into highly elliptical orbits or even ejected them outright from the Solar System. **The water on Earth was probably delivered by planetary embryos and small planetesimals thrown out of the asteroid belt by Jupiter**. A population of asteroid belt comets discovered in 2006 has also been suggested as a possible source for Earth's water. **One representative of this theory would be Enceladus**, the sixth-largest moon of Saturn, and about 310 miles in diameter. Enceladus is mostly covered by fresh, clean ice. In 2014, NASA reported that Cassini had found evidence for a large south polar subsurface ocean of liquid water with a thickness of around 6 miles.

There may have been a period when there were very few or no landmasses at all on Earth. Over the course of a few hundred million years, the planet began to cool and oceans of liquid water formed. Evidence found in the geologic record suggests that, **around 3.2 Bya, Earth was covered by a global ocean and had much less surface land than it does now**.

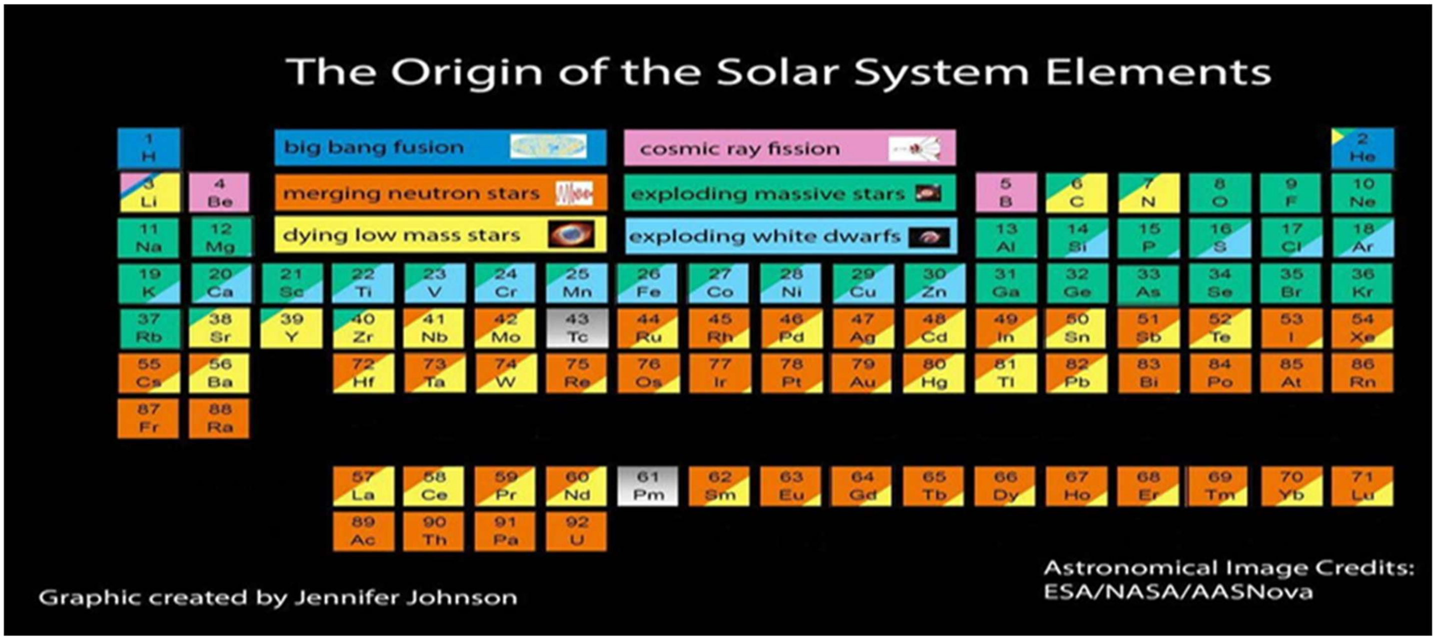
Over time, some of the magma ocean cooled enough to form a solid surface or crust. Heavier chemical elements, such as iron, descended to become the core, whereas lighter elements, such as silicon, rose and became incorporated into the growing crust. Convection currents in the mantle brought molten rock to the surface and caused cooling rock to descend into magmatic seas. As this occurred, Earth became differentiated into layers, with the outermost layer being a solid crust covering of relatively lighter material while the denser, molten material sunk to the center. Starting at the center, **Earth is composed of four distinct layers**. They are, from deepest to shallowest, the inner core, the outer core, the mantle, and the crust.

Earth's early atmosphere was replenished by volcanic eruptions, as well as water and other gasses delivered by comets and meteorites crashing into the surface. **Earth's early atmosphere was most likely composed of hydrogen and helium**. As the planet changed, and the crust began to form, volcanic eruptions occurred frequently. It is generally thought that ammonia, methane, and neon were present sometime after the crust cooled, and that volcanic outgassing added water vapor, nitrogen, carbon dioxide, and additional hydrogen to Earth's atmosphere.

The Earth, and most of the planets in the Solar System, all generate magnetic fields through the motion of electrically conducting fluids. **Earth's magnetic field** is the magnetic field that extends from Earth's interior out into space, where it interacts with the solar wind, a stream of charged particles emanating from the Sun. The magnetic field is generated by electric currents due to the motion of convection currents of a mixture of molten iron and nickel in Earth's outer core.

The solar wind exerts a pressure, and if it could reach Earth's atmosphere it would erode it. However, it is kept away by the pressure of the Earth's magnetic field. The **Earth's magnetic field** extends several miles into space and **protects Earth from the charged particles of the solar wind and cosmic rays** that would otherwise strip away the upper atmosphere, including the ozone layer that protects Earth from the harmful ultraviolet radiation.

Ozone is only a trace gas in the atmosphere, but it does a very important job. Even though we need some of the sun's radiation to live, too much of it can damage living things. **The ozone layer acts as a shield for life on Earth**. Ozone is good at trapping a type of radiation called ultraviolet radiation, or UV light, which can penetrate organisms' protective layers, like skin. This may damage DNA molecules in plants and animals. **The ozone layer, Earth's sunscreen, absorbs about 98 percent of this devastating UV light**.


The Origin of the Solar System Elements

Graphic created by Jennifer Johnson
Astronomical Image Credits: ESA/NASA/AASNova

The top 10 chemical elements in our Universe are the following: **hydrogen**, helium, **oxygen**, **carbon**, neon, **nitrogen**, magnesium, silicon, iron, and sulfur.[14] About 88% of the Earth's crust is made up of only four chemical elements, namely oxygen, silicon, aluminum, and iron. While iron, oxygen, silicon, and magnesium make up about 93% of the entire earth. There are over 100 chemical elements on the periodic table, and you might think that humans are made up of many of them. But that is not the case. The complex systems that make up our bodies have a surprisingly simple elemental makeup. **97% of our human body's weight is made of just four chemical elements, namely oxygen, carbon, hydrogen, and nitrogen**.

Everything found on planet Earth is composed of the same ingredients, i.e., chemical elements, a.k.a. atoms. Atoms can link up to form molecules, including organic molecules and biological processes, in interstellar space, as well as on planets. But this is only possible with heavy chemical elements, which are only created from stars.

The Archean Eon began about 4 Bya with the formation of Earth’s crust and extended to the start of the Proterozoic Eon 2.5 Bya.[15] Records of Earth’s primitive atmosphere and oceans emerge in the Archean Eon. **Fossil evidence of the earliest primitive life-forms, prokaryotic microbes, from the domains called Archaea and Bacteria, appears in rocks about 3.5 to 3.7 billion years old**.

How life on Earth began remains a scientific problem. **In biology, abiogenesis is the origin of life**, the natural process by which life has arisen from non-living matter, such as simple organic compounds.[16] The study of abiogenesis aims to determine how pre-life chemical reactions gave rise to life under conditions strikingly different from those on Earth today. It primarily uses tools from biology and chemistry, with more recent approaches attempting a synthesis of many sciences.

The prevailing scientific hypothesis for abiogenesis is that the transition from non-living to living entities was not a single event, but **an evolutionary process of increasing complexity, that involved the formation of a habitable planet**, the prebiotic synthesis of organic molecules, molecular self-replication, self-assembly, autocatalysis, and the emergence of cell membranes. Many proposals have been made for different stages of the process.

NASA defines life as "a self-sustaining chemical system capable of Darwinian evolution."[17] NASA’s definition of life begins with the chemical elements manufactured in the Big Bang and by millions of stars. All chemical elements except for hydrogen and helium derive from stellar nucleosynthesis. **The basic chemical ingredients of life**, the carbon-hydrogen molecule (CH), the carbon-hydrogen ion (CH+) and the carbon ion (C+), **were all produced from stars**. Carbon, in its gas state, is abundant in the stars and in the atmospheres of most planets.

An organic compound is a chemical whose molecules contain carbon. Complex molecules, including organic molecules, form naturally both in space and on planets. **An organic molecule is a molecule of the kind normally found in living domains**.[18] Organic molecules are usually composed of carbon atoms in rings or long chains, to which are attached other atoms or chemical elements, such as hydrogen, oxygen, and nitrogen. When combined with oxygen and hydrogen, **carbon can form many groups of important biological compounds** including sugars, lignans, chitins, alcohols, and fats. Carbon combined with nitrogen forms alkaloids, and with the addition of sulfur it forms antibiotics and amino acids. **Carbon combined with phosphorus and these other elements, forms DNA and RNA, the chemical-code carriers of life, and adenosine triphosphate (ATP), the most important energy-transfer molecule in all living cells**.

Life functions through the specialized chemistry of carbon and water, and **builds largely upon four key families of chemicals**: lipids for cell membranes, carbohydrates such as sugars, amino acids for protein metabolism, and nucleic acids such as DNA and RNA for the mechanisms of heredity. **Any successful theory of abiogenesis must explain the origins and interactions of these 4 classes of molecules**. Many approaches to abiogenesis investigate how self-replicating molecules, or their components, came into existence.

At some point in early evolution, life became cellular. Assuming that this step was required for the origin of life, there would necessarily be a pre-existing source of amphiphilic compounds capable of assembling into membranous compartments. If primitive metabolic pathways in early cellular life involved amino acids and phosphate, as seems likely, some form of membrane transport mechanism was required to provide access to external sources of nutrients.

Amino acids are organic compounds that contain both amino and carboxylic acid functional groups. Only 22 alpha amino acids appear in the genetic code of all life. **Amino acids are the basic building blocks of proteins**.[19] In the form of proteins, amino acid residues form the second-largest component (water being the largest) of human muscles and other tissues. Beyond their role as residues in proteins, amino acids participate in a number of processes such as biosynthesis. **It is thought that amino acids played a key role in enabling life on Earth and its emergence**.

Proteins are chains of amino acids that assemble via amide bonds known as peptide bonds. The uniqueness of different proteins is then determined by which amino acids it contains, how these amino acids are arranged in a chain, and further complex interactions the chain makes with itself and the environment. **These polymers of amino acids are capable of producing the diversity seen in life**. **Polymers are large molecules** made of smaller units called monomers that are linked together like beads on a string.

Iron is a very important chemical element required by living organisms to carry out numerous metabolic reactions, such as the formation of proteins involved in biochemical reactions. Examples of these proteins include iron–sulfur proteins, hemoglobin, and coordination complexes.

Enzymes are proteins that act as biological catalysts by accelerating chemical reactions. Almost all metabolic processes in a cell need enzyme catalysis in order to occur at rates fast enough to sustain life. A catalyst is a substance that increases the rate of a chemical reaction.

Biomolecules are the building blocks of life.[20] They are all made up of the following organic chemical elements, listed with their symbol, and in atomic number order: Hydrogen (H,1); Carbon (C,6); Nitrogen (N,7); Oxygen (O,8); Phosphorus (P,15); and Sulfur (S,16). They are all important because they make biomolecules that are necessary for life. Hydrogen is the most abundant element on Earth. However, carbon is the most abundant element in living things.

A carbohydrate is a biomolecule consisting of carbon (C), hydrogen (H) and oxygen (O) atoms. Carbohydrates are an important source of fuel for our muscles during exercise and are the only source of energy for our brain and red blood cells. Carbohydrate metabolism is the series of biochemical processes responsible for the formation, breakdown, and interconversion of carbohydrates in living organisms. **The most important carbohydrate is glucose, a simple sugar that is metabolized by nearly all known organisms**. Organisms typically cannot metabolize all types of carbohydrate to yield energy. **Glucose is a nearly universal and accessible source of energy**.

Nucleic acids are biocompounds, which are essential for living organisms.[21] Found in two forms, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), these polymer chains are composed of the same basic chemical elements and similar monomer nucleotides, yet with specific differences relating to form and function. **The five chemical elements necessary to construct a nucleic acid chain are carbon, hydrogen, oxygen, nitrogen, and phosphorus**.

Nucleotides are organic molecules composed of a nitrogenous base, a pentose sugar, and a phosphate. They serve as monomeric units of the nucleic acid polymers **DNA and RNA, both of which are essential biomolecules within all life-forms on Earth**. Nucleotides are obtained in the diet and are also synthesized from common nutrients by the liver. Nucleotides are composed of three subunit molecules: a nucleobase, a five-carbon sugar (ribose or deoxyribose), and a phosphate group consisting of one to three phosphates. Nucleotides also play a central role in metabolism at a fundamental, cellular level.

Nucleobases, or often simply bases, **are nitrogen-containing biological compounds,** and are components of nucleotides, constituting the basic building blocks of nucleic acids. The ability of nucleobases to form base pairs and to stack one-upon-another, leads directly to long-chain helical structures such as RNA and DNA. The five nucleobases - adenine (A), cytosine (C), guanine (G), thymine (T), and uracil (U), **function as the fundamental units of the genetic code**, with the bases A, G, C, and T being found in DNA, while A, G, C, and U are found in RNA.

Mitochondria produce adenosine triphosphate (ATP), the energy currency of the cell used to drive cellular processes such as chemical syntheses.[22] Also, **Adenosine diphosphate (ADP)** is an important organic compound in metabolism and is essential to the flow of energy in living cells. **The fuel for original cells was hydrogen, so it may be the spark that created life itself**. The decisive factors were having the right conditions and the right catalysts in place.

Ribozymes (ribonucleic acid enzymes) **are RNA molecules** that have the ability to catalyze specific biochemical reactions, including RNA splicing in gene expression, similar to the action of protein enzymes. The 1982 discovery of ribozymes demonstrated that RNA can be both genetic material (like DNA) and a biological catalyst (like protein enzymes), and contributed to the RNA world hypothesis, which suggests that **RNA may have been important in the evolution of prebiotic self-replicating systems**.

RNA replicase can function as both genetic code and a catalyst for further RNA replication, i.e., it **can be autocatalytic**. Jack Szostak has shown that certain catalytic RNAs can join smaller RNA sequences together, **creating the potential for self-replication**. A preliminary form of transfer RNA (tRNA) could have assembled into such a replicator molecule. Self-assembly of RNA may occur spontaneously in hydrothermal vents.

Catabolism is the set of metabolic pathways that **breaks down molecules into smaller units,** that are either oxidized to release energy or used in other anabolic reactions. Catabolism breaks down large molecules (such as lipids, nucleic acids, and proteins) into smaller units (such as fatty acids, nucleotides, and amino acids). **Anabolism** is the set of metabolic pathways that **construct molecules from smaller units** and require energy. **Anabolism is usually synonymous with biosynthesis**.

Metabolism is the set of life-sustaining chemical reactions in organisms. The three main purposes of metabolism are: the conversion of the energy in food to energy available to run cellular processes; the conversion of food to building blocks for proteins, lipids, nucleic acids, and some carbohydrates; and the elimination of metabolic wastes. **These enzyme-catalyzed reactions allow organisms to grow and reproduce, maintain their structures, and respond to their environments**. The word metabolism can also refer to the sum of all chemical reactions that occur in living organisms, including digestion and the transportation of substances into and between different cells. **The metabolic diversity found among the various species of Bacteria is enormous, encompassing all known major modes of nutrition and most known modes of metabolism**.

The **Three-Domain System** is a biological classification introduced by Carl Woese et al. in 1990, that **divides cellular life forms into the Bacteria (formerly Eubacteria), Archaea (formerly Archaebacteria), and Eukaryote domains**.[23] This classification system recognizes the fundamental divide between the two Prokaryotic groups, insofar as Archaea, bacteria-like organisms, genetically appear to be more closely related to Eukaryotes than they are to other Prokaryotes, even though they were more similar to prokaryotes in structure. This led to the conclusion that Archaea and Eukarya shared a common ancestor more recent than Eukarya and Bacteria.

Prokaryotes are a group of **unicellular (single cell) organisms, with no cell nucleus**, and with rudimentary internal organization that began to appear near the end of the Archean Eon. In biological evolution, **Prokaryotes are deemed to have arisen before Eukaryotes**. **Prokaryotes are organisms made up of cells that lack a cell nucleus or any membrane-encased organelles**. This means the genetic material (DNA) in prokaryotes is not bound within a nucleus. We now know that **prokaryotes were likely the first forms of cellular life on Earth**, and they existed for billions of years before plants and animals appeared. An organelle is any of the specialized structures within a cell that perform a specific function (e.g., mitochondria, ribosomes, endoplasmic reticulum.) **Organelles in unicellular organisms are the equivalent of organs in multicellular organisms**.

Bacteria evolved in a similar process to other organisms, through the process of **natural selection**, whereby beneficial adaptations are passed on to future generations until the trait becomes common within the entire population. **Cyanobacteria are a phylum of bacteria that obtain energy via oxygenic photosynthesis, which removes carbon dioxide from the atmosphere and releases oxygen**. They utilize sunlight in order to drive their metabolic processes.

Oxygenic photosynthesis evolved in Cyanobacteria, around 2.4 Bya, based on molecular clock estimates and geological data, **which ultimately led to the Great Oxidation Event, around 2.3 Bya**. Cyanobacteria are a highly diverse group of prokaryotes that have colonized a wide range of environments, from desert crusts to fresh and marine waters, and from the tropics to the poles. **They have played a crucial role in modifying the Earth's atmosphere,** through the process of oxygenic photosynthesis**, which enabled the evolution of life in more complex forms**. Cyanobacteria are the first organisms known to have produced oxygen.

The Archaea are prokaryotic, with no nuclear membrane, but with biochemistry and RNA markers that are distinct from bacteria. Archaea were discovered to be a unique life form, which are capable of living indefinitely in extreme environments, such as hydrothermal vents or arctic ice. Despite this morphological similarity to bacteria, archaea possess genes and several metabolic pathways **that are more closely related to those of eukaryotes**. The proteins that archaea, bacteria and eukaryotes share form a common core of cell function, relating mostly to DNA transcription and translation, and to nucleotide metabolism.

The relationships among the three domains are of central importance for understanding the origin of life on Earth. Molecular studies have provided insight into the evolution and interrelationships of the three domains of life. Most of the metabolic pathways, which are the object of the majority of an organism's genes, are common between Archaea and Bacteria, while most genes involved in genome expression are common between Archaea and Eukarya. **The division between prokaryotes and eukaryotes reflects the existence of two very different levels of cellular organization**. Organisms with nuclei are placed in the third domain, Eukaryota.

Eukaryotic cells are more complex than Prokaryote cells. Eukaryotic DNA is linear and found within a membrane-bound nucleus. The presence of a nucleus is one major difference between eukaryotes and prokaryotes. Eukaryotic cells boast their own personal "power plants," called mitochondria. **Only eukaryotic cells have an enveloped nucleus, that contains its chromosomal DNA, and other characteristic membrane-bound organelles, including mitochondria**.

So, how did the simple prokaryotic cell evolve into a more complex eukaryotic cell? **Evidence supports the idea that eukaryotic cells are actually the descendants of separate prokaryotic cells that joined together in a symbiotic union**. Symbiosis is an interaction between two different organisms living in close physical association, typically to the advantage of both. **Mitochondria** organelles within the eukaryotic cell not only produce chemical energy, but also **hold the key to understanding the evolution of the eukaryotic cell**.

Symbiogenesis (or endosymbiotic theory), is the leading evolutionary theory of the origin of eukaryotic cells from prokaryotic organisms.[24] The theory holds that mitochondria, plastids such as chloroplasts, and possibly other organelles of eukaryotic cells are descended from formerly free-living prokaryotes (more closely related to bacteria than to archaea) taken one inside the other in endosymbiosis. **The complex eukaryotic cell ushered in a whole new era for life on Earth, because these cells evolved into multicellular organisms, around 1.7 Bya.**

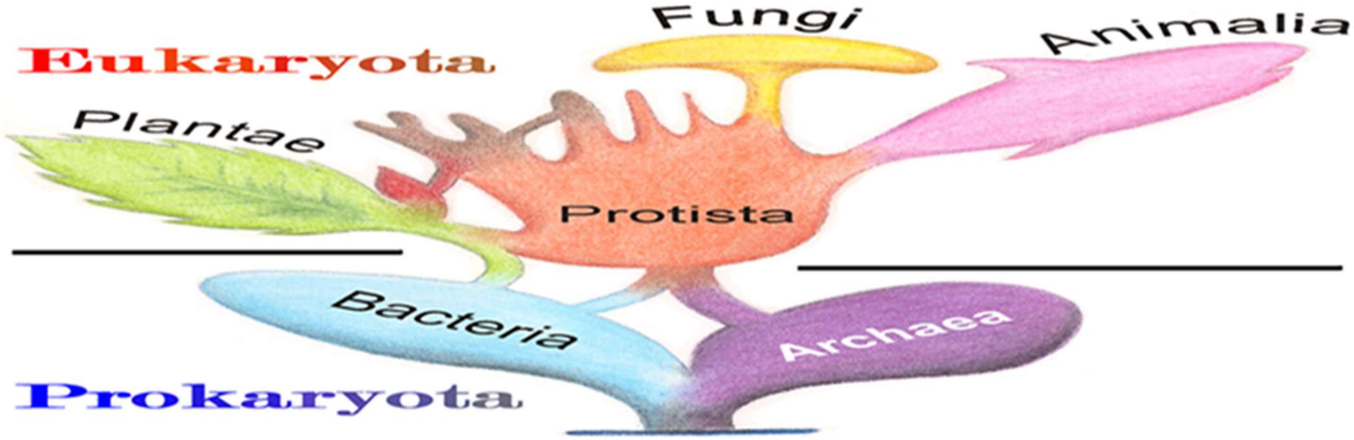
Eukaryotes emerged approximately 2.1 to 1.6 Bya, during the Proterozoic eon.[25] They include many large single-celled organisms and all known non-microscopic or multi-celled organisms. **The eukaryotes came to be composed of four kingdoms**: Protista, Fungi, Plantae, and Animalia.

A Protist is any member of a group of diverse eukaryotic, predominantly unicellular microscopic organisms, that is not an animal, plant, or fungus. While it is likely that protists share a common ancestor (the last eukaryotic common ancestor), the exclusion of other eukaryotes means that protists do not form a natural group, or clade. Therefore, some protists may be more closely related to animals, plants, or fungi than they are to other protists.

Fungi include both unicellular (yeast and molds) and multicellular (mushrooms) organisms. Unlike plants, fungi are not capable of photosynthesis. Fungi are important for the recycling of nutrients back into the environment. They decompose organic matter and acquire nutrients through absorption. While some fungal species contain toxins that are deadly to animals and humans, others have beneficial uses, such as for the production of penicillin and related antibiotics.

Plantae are multicellular eukaryotes and are extremely important to all life on earth as they provide oxygen, shelter, clothing, food, and medicine for other living organisms. This diverse group contains vascular, and nonvascular plants, flowering, and nonflowering plants, as well as seed-bearing, and non-seed-bearing plants. As is true of most photosynthetic organisms, plants are primary producers and support life for most food chains in the planet's major biomes.

Animalia are multicellular eukaryotes that depend on plants and other organisms for nutrition. Most animals live in aquatic environments and range in size from tiny tardigrades (near-microscopic animals) to the extremely large blue whale. Most animals reproduce by sexual reproduction, which involves fertilization (the union of male and female gametes). Animal cells are distinct from those of other eukaryotes, most notably plants, as they **lack cell walls** and chloroplasts.



A nutrient is a substance used by an organism to survive, grow, and reproduce. **The six essential nutrients are vitamins, minerals, protein, fats, water, and carbohydrates**. The requirement for dietary nutrient intake applies to animals, plants, fungi, and protists. Nutrients can be incorporated into cells for metabolic purposes or excreted by cells to create non-cellular structures, such as hair, scales, feathers, or exoskeletons. Some nutrients can be metabolically converted to smaller molecules in the process of releasing energy, such as for carbohydrates, lipids, and proteins, leading to end-products of water and carbon dioxide. All organisms require water. Essential nutrients for animals are the energy sources, some of the amino acids that are combined to create proteins, a subset of fatty acids, vitamins, and certain minerals. Plants require more diverse minerals absorbed through roots, plus carbon dioxide and oxygen absorbed through leaves. Fungi live on dead or living organic matter and meet nutrient needs from their host.

One quick tangent, as a point of reference. Mountains did not start forming widely until 2 Bya, half way through our planet's history.[26] A landmark 2021 study, led by scientists at the University of Aberdeen has revealed that an unprecedented abundance of oceanic life played a crucial role in the creation of Earth's mountains. While the formation of mountains is usually associated with the collision of tectonic plates causing huge slabs of rock to be thrust skywards, the study has shown that this was **triggered by an abundance of nutrients in the oceans 2 billion years ago** which **caused an explosion in planktonic life**.

When the plankton died, they fell to the ocean floor, **eventually forming graphite, which played a crucial role in lubricating the breakage of rocks into slabs**, enabling them to stack on top of each other to make mountains. Research has revealed that the amount of planktonic life was unusually high in this period, thus creating the necessary conditions that were crucial to the emergence of mountains over millions of years. Note: the explosion of planktonic life and the Eukaryotes emerged around the same time.

Now, from his book, Life on a Young Planet, Andrew Herbert Knoll wrote the following:

Shifts in climate, in geography, and even in the composition of the atmosphere and oceans have influenced the course of evolution, and biological innovations have, in turn, affected environmental history. Indeed, **the overall picture that emerges from our planet's long history is one of interaction between organisms and environments**. The evolutionary epic recorded by fossils reflects, as much as anything else, the continuing interplay between genetic possibility and ecological opportunity.

Despite an almost bewildering diversity of form and function, **all cells share a common core of molecular features**, including ATP (life's principal energy currency), DNA, RNA, a common (with a few minor exceptions) genetic code, molecular machinery for transcribing genetic information from DNA into RNA, and more machinery to translate RNA messages into proteins that provide structure and regulate cell function. The reciprocal observation is equally striking. **In spite of their fundamental unity of molecular structure, organisms display extraordinary variation in size, shape, physiology, and behavior**.

It was **Charles Darwin (in 1859)**, however, who explicitly recognized the genealogical nature of this pattern. Biological differences have arisen through time, he wrote, because of “**descent, with modification**," that is, by evolutionary (genetic) divergence from common ancestors under the influence of natural selection.

Consider, in particular, nitrogen, an essential element required for the formation of proteins, nucleic acids, and other biological compounds. We live our lives bathed in nitrogen gas. Air is about 80 percent N_2 by volume. But this vast repository of nitrogen is not biologically available to us; like other animals, **we obtain the nitrogen we need by eating other organisms**.

The cycles of carbon, nitrogen, sulfur, and other elements are linked together into a complex system that controls the biological pulse of the planet. Because organisms need nitrogen for proteins and other molecules, there could be no carbon cycle without nitrogen fixation. Nitrogen metabolism itself depends on enzymes that contain iron; thus, without biologically available iron, there could be no nitrogen cycle... and, hence, no carbon cycle. Biology on another planet may or may not include organisms that are large or intelligent, but wherever it persists for long periods of time, **life will feature complementary metabolisms that cycle biologically important (chemical) elements through the biosphere**.

More than 50 percent of an Archaean’s genes are unknown in either eukaryotes or bacteria, confirming that **archaeans are distinctly different from organisms in the other two domains**. Archaeans do, however, **have some important characters in common with bacteria**, such as (most obviously) prokaryotic cell organization, the molecular structure of the ribosome, and the arrangement of genes on a single circular chromosome. Equally, on the other hand, **archaeans also share attributes** such as molecular details of DNA transcription and susceptibility to specific antibiotics **with eukaryotes**. And there are still other traits that bacteria and eukaryotes share to the exclusion of Archaea, prominent among these is the nature of the cell membrane.

The Tree of Life, thus, makes predictions about Earth history that can be tested against the geological record. The first essential point of the tree is that the organisms and environments of our common experience are relatively recent features; **the deep history of life is microbial**. The other main point is that life has not evolved on a static planetary surface. Rather, **life and environments have evolved together** throughout our planet's history, inexorably linked by the biogeochemical cycles in which both participate.

By 3.5 Bya, the metabolic diversification that ensured life's long-term perpetuation had almost certainly begun. Thus, by 2.7 Bya (or earlier), the Tree of Life had begun to branch, producing diverse bacteria as well as the first buds on our own, eukaryotic limb of the tree. **Around 2.4 to 2.2 Bya, it looks like the atmosphere changed**. It was early in the Proterozoic Eon that the oxygenation of air and water assumed global environmental and biological importance. **From this time onward, organisms that use or produce oxygen would dominate biology**. Indeed, **oxygen would eventually achieve concentrations able to support large, multicellular organisms**. By 1.5 Bya, then, the cyanobacterial revolution may have been complete, but a second revolution, the rise of eukaryotes to ecological prominence, was yet to come.

In 1967, Lynn Margulis (in her paper On the Origin of Mitosing Cells) reinvented the endosymbiotic hypothesis for eukaryotic cell origins. Lynn proposed not only that chloroplast had originated as endosymbiotic cyanobacteria, but also that mitochondria, the compartmentalized sites of respiration in eukaryotic cells, were descended from free-wheeling, respiring bacteria. As Lynn Margulis recognized, the story of mitochondria parallels that of chloroplasts. **Just as photosynthesis in eukaryotic cells is localized within chloroplasts, aerobic respiration, the metabolism that fuels our own bodies, is confined to mitochondria**.

From a 2016 article in Nature, **macroscopic multicellular life**, according to the discovery of well-preserved fossils from northern China, **existed as early as 1.56 Bya**. From comparisons with modern organisms, the authors suggest that the fossils were **probably photosynthetic eukaryotes similar to modern algae (plants)**.

By the time large animals appeared in the oceans, multicellularity was already well established among the algae. Around 590 to 600 million years ago (Mya), animal evolution may have begun, but the age of animals was still to come. Biology changed radically between 1.5 Bya, when the Siberian rocks were deposited, and 590 to 600 Mya, when Doushantuo sediments formed. Indeed, microfossils interpreted as spores of planktonic green algae suggest that **the "greening" of the oceans began at least one Bya**.

By 750 Mya, eukaryotes had begun to construct the complex food webs that today form a crown, intricate and unnecessary, atop ecosystems fundamentally maintained by prokaryotic metabolism. **As the long Proterozoic Eon moved into its final phase, Earth was becoming a eukaryotic planet**. Paleontology seems to be telling us that this "big bang" of eukaryotic evolution began at least one Bya. If the course of eukaryotic evolution was set so early in life's history, why should the domain (our domain!) have remained subservient to prokaryotes for a billion and a half years before spreading throughout the oceans?

Our prediction is that photosynthetic eukaryotes should have been most abundant and diverse along the ancient seacoast, where nitrate levels would have been highest and molybdenum (Mo) most readily available. That, it turns out, is just what we see. Indeed, it appears that, globally, **eukaryotic algae first took root in coastal waters and only later spread across continental shelves**. This ecological expansion is poorly documented, but in general **it appears to have commenced about 1.2 Bya** as nitrogen limitation in the "Canfield" ocean began to weaken. Oceans rich in oxygen from top to bottom may not have developed until the Proterozoic Eon was almost over. When they came, however, the culmination of Earth's environmental transformation paved the way for one last revolution in biology, **the rise of animals**.

The complex forms of modern animals emerged only during the Cambrian Period, taking shape over a time span of at least 10 to 30 million years. **Sponges form one great limb of the animal tree; all other animals fall on the other**. The earliest fishlike animals, may have formed as early as 520 Mya, still more than 20 million years after the Cambrian Period began. **Cambrian body plan evolution may have taken 50 million years, but those 50 million years reshaped more than 3 billion years of biological history**. The pageant of Cambrian evolution simply provides one last, and dramatic, confirmation that life did not evolve on a passive planetary platform. Rather, life and environment evolved together, each influencing the other in building the biosphere we inhabit today.

But we also need to think hard about environmental events that might have stimulated animal evolution, or more accurately, the evolution of large, preservable animals, 600 to 580 Mya. We need to look carefully at the momentous physical upheavals that shook the late Proterozoic world. The **Snowball Earth hypothesis** proposes that, during one or more of Earth's icehouse climates, the planet's surface became entirely or nearly entirely frozen. It is believed that this occurred **sometime before 650 Mya**. The icy veneer further prevented oxygen from diffusing into seawater from the atmosphere, **resulting in anoxic deep oceans**. But ice could not stop the main engine by which CO2 is added to the atmosphere, volcanism.

Late Proterozoic glaciation was extraordinary, and it must have left its mark on contemporary biology. If molecular clocks have any merit at all, even microscopic animals must have weathered some or all of these climatic storms. In fact, most major groups of present-day eukaryotes must have been present before the late Proterozoic ice ages began, **a lot of lineages survived climatic upheaval**.

On the Proterozoic Earth, **before animals evolved sophisticated circulatory systems, oxygen levels must have determined the effective sizes of animals**. The application to late Proterozoic biological history is obvious. Microscopic animals with scant oxygen requirements could have plied Proterozoic seas long before the Ediacaran period (635 to 539 Mya). **Only with a latest Proterozoic rise in oxygen, however, did macroscopic (and, hence, easily fossilizable) animals become possible**. Thus, geochemistry increasingly supports Nursall's hunch that animal evolution was stirred by oxygen. And with more oxygen, a new world began to emerge. Seaweeds and planktonic algae diversified across continental shelves. Among animals, **developmental mutations favoring large body size stopped being lethal and began to be advantageous**, introducing new functional possibilities.

Each of the 10 million or so species alive today is equally the product of Earth's 4-billion-year evolutionary history, myriad forms separated by evolutionary divergence, but united in ecological codependence. **Whatever the merits of viewing Earth as our world, we could not persist without the bacteria and algae, fungi, plants, and other animals**. We are evolutionary latecomers, among the latest threads in an ecological tapestry woven since our planet was young.

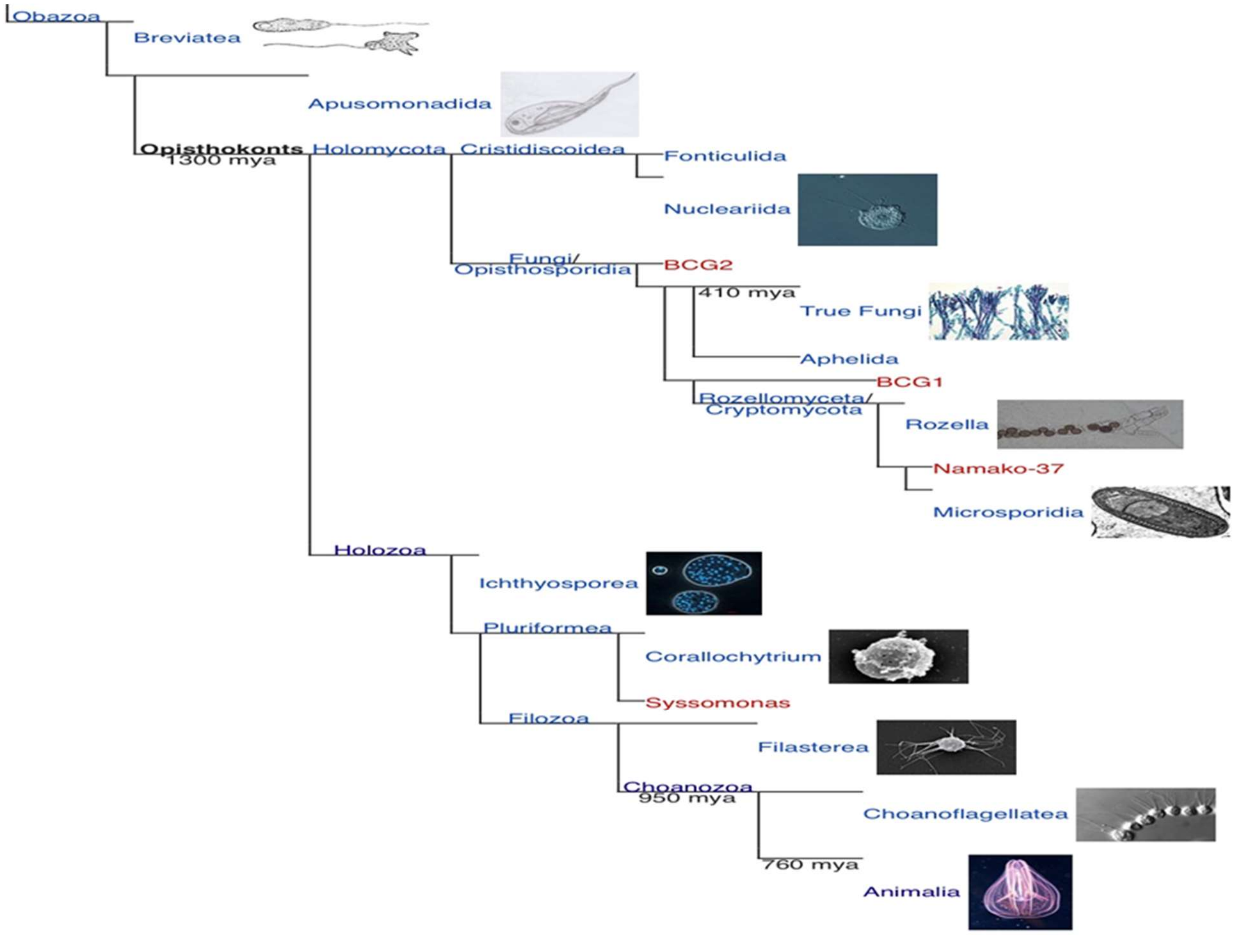
On this planet, at this moment in time, human beings reign. Regardless of who or what penned earlier chapters in the history of life, we will write the next one. Through our actions or inaction, we decide the world that our grandchildren and great grandchildren will know. **Let us have the grace and humility to choose well**.

Now, we leave Knoll's informative and pioneering book and move on to animal evolution.[27] A phylogenetic tree (also phylogeny or evolutionary tree) is a branching diagram or a tree showing the evolutionary relationships among various biological species based upon similarities and differences in their physical or genetic characteristics. **All life on Earth is part of a single phylogenetic tree, indicating common ancestry**. In cladistics, for a group of organisms, **monophyly** is the condition of being a clade, that is, a group of taxa composed only of a common ancestor (or more precisely an ancestral population) and all of its lineal descendants. **Animals are monophyletic, meaning they are derived from a common ancestor**.

Admittedly, the next section of this article is somewhat more difficult to read and possibly to follow. Please do not get stuck trying to pronounce some of the names used by biologists to identify these organisms. What is important, is to follow each of the direct descendants and the numerous rudimentary, anatomical human features, that develop is these very ancient creatures. Also, pay attention to the timeframes of these developments. **For examples, the first multicellular animals did not appear on Earth until about 600 Mya**. The earliest vertebrate fishlike animals, may have formed as early as 520 Mya, more than 20 million years after the Cambrian Period began. And lungfish evolved the first proto-lungs and proto-limbs, adapting to living outside a submerged water environment by the middle Devonian (397–385 Mya). **The bottom line is that evolution took billions of years to develop the anatomical human features that we all have today**.

A Diphoda or bikont ("two flagella") is any of the eukaryotic organisms classified in the group Bikonta. Many single-celled members of the group, and the presumed ancestor, have two flagella. Research suggests that Diphoda were the ancestors of Archaeplastida (Plants and relatives) and **the Opimoda** (originally unikonts), a eukaryotic cell with a single flagellum, **were the ancestors of Opisthokonts and Amoebozoa**. The Archaeplastida (or kingdom Plantae "in a broad sense") are a major group of eukaryotes, comprising the photoautotrophic red algae (Rhodophyta), green algae, and land plants.

Amorphea, are members of a taxonomic supergroup that includes the basal Amoebozoa and Obazoa. **The Obazoa contains the Opisthokonta**, which includes the Fungi and Animals, and the Choanoflagellates. **The Opisthokonts are a broad group of eukaryotes, including both the animal and fungus kingdoms**.



The close relationship between animals and fungi was suggested by Cavalier-Smith in 1987, who used the informal name Opisthokonta and was supported by later genetic studies. More recently, it has been determined that holozoa (animals) and holomycota (fungi) are much more closely related to each other than either is to plants. 6,331 groups of genes common to all living animals have been identified. **Genetic studies now indicate that the first single celled animal may have arisen from a single common ancestor that lived 650 Mya**.

Morphology is the branch of biology that deals with the form of living organisms and with relationships between their structures. A particularly striking and famous similarity between the single-celled choanoflagellates and multicellular animals is provided by the collar cells of sponges and the overall morphology of the choanoflagellate cell. Nicole King (born 1970) is an American biologist, in molecular and cell biology, and is a faculty member at the University of California, Berkeley. Work by King and colleagues showed that choanoflagellates possess several protein-coding genes that are highly related to protein-coding genes in animals at the base of the metazoan tree, such as sponges. The relationship has since been confirmed by multiple molecular analyses. More recent work by **King demonstrates that chemical molecules thought to underpin the transition to multicellularity also exist in choanoflagellates** and therefore were present in the single-celled and colonial ancestors of animals.

Animals (also called Metazoans) are mostly multicellular, eukaryotic organisms in the biological kingdom Animalia. Many modern animal phyla became clearly established in the fossil record as marine species during the Cambrian explosion, which began around 542 million years ago (Mya). Marine species, consist of the plants, animals, and other organisms, that live in the salt water of seas or oceans. **All early life forms, including animals, evolved initially in marine habitats**.

Animals have several characteristics that set them apart from other living things. Animals are eukaryotic and mostly multicellular. Unlike plants and algae, which produce their own nutrients, **animals are heterotrophic**, feeding on organic material and digesting it internally. With very few exceptions, **animals respire aerobically**. All animals **are motile** (able to spontaneously move their bodies) during at least part of their life cycle, but some animals, such as sponges, corals, mussels, and barnacles, later become sessile.

During development, the animal extracellular matrix forms, a relatively flexible framework upon which cells can move about and be reorganized, **making the formation of complex structures possible**. In contrast, the cells of other multicellular organisms (primarily algae, plants, and fungi) are held in place by cell walls, and so develop by progressive growth. **Due to the lack of a cell wall, animal cells can transform into a variety of shapes**.

With few exceptions, in particular, the sponges and placozoans, **animal bodies are differentiated into tissues**. These include **muscles**, which enable locomotion, **and nerve tissues**, which transmit signals and coordinate the body. Typically, there is also an internal digestive chamber with either one opening (in Ctenophora, Cnidaria, and flatworms) or two openings (in most bilaterians).

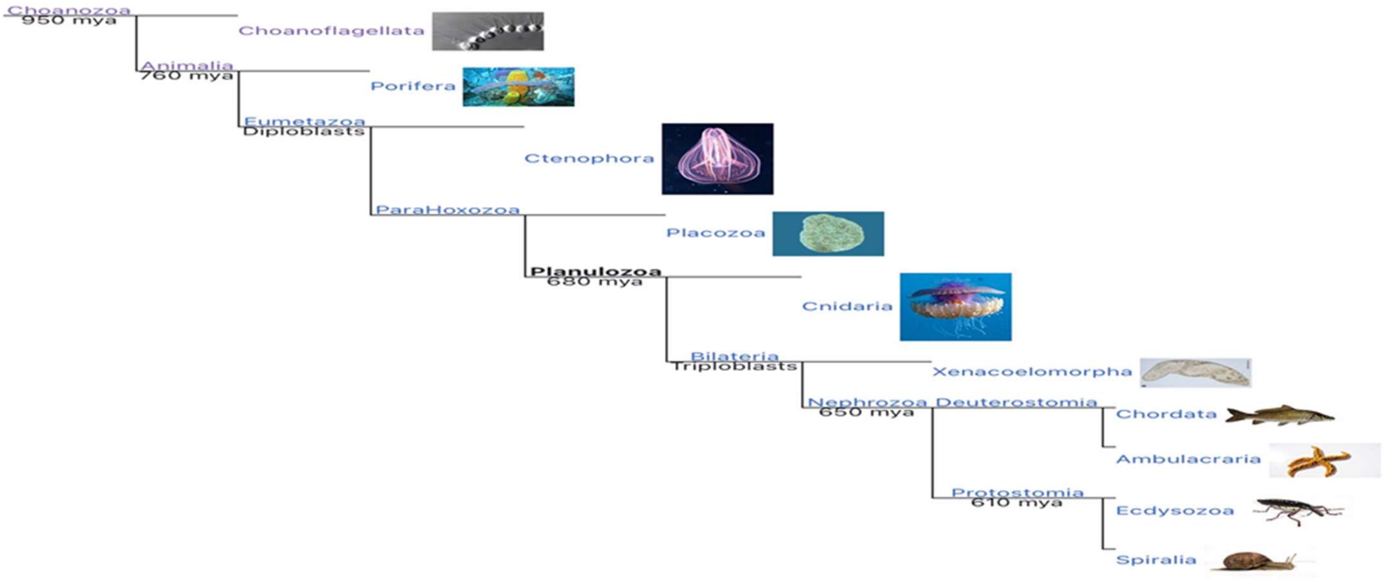
Basal animals, such as sponges, corals, and jellyfish, describe the four non-bilaterian phyla: Porifera (sponges), Cnidaria (sea anemones, corals, and jellyfish), Ctenophora (comb jellies), and the Placozoa. **Basal animals have body plans that lack bilateral symmetry**. Basal animals separated from other animal groups early in evolution. Placozoa are simple blob-like animals without any body part or organ, and are merely aggregates of cells. Both the Porifera and the Ctenophora lack hox genes, important in body plan development. These genes are found in the Placozoa and the higher animals, the Bilateria. Sponges do not have nervous, digestive, or circulatory systems. Instead, most rely on maintaining a constant water flow through their bodies to obtain food and oxygen and to remove wastes. **Sponges were first to branch off the evolutionary tree from the last common ancestor of all animals, making them the sister group of all other animals**.

The Bilateria or bilaterians are animals with bilateral symmetry as an embryo, i.e., having a left and a right side that are mirror images of each other. This also means they have a head and a tail (anterior-posterior axis) as well as a belly and a back (ventral-dorsal axis). **Having a front end means that this part of the body encounters stimuli, such as food, favoring cephalization, the development of a head with sense organs and a mouth**. The body stretches back from the head, and many bilaterians have a combination of circular muscles that constrict the body, making it longer, and an opposing set of longitudinal muscles, that shorten the body. Nearly all are bilaterally symmetrical as adults as well.

The first evidence of Bilateria, in the 555-million-years-old fossil record, comes from trace fossils in Ediacaran sediments, and the first bona fide bilaterian fossil is Kimberella. **The new forms of life, called Ediacara biota, were larger and more diverse than ever**. Though the taxonomy of most Ediacaran life forms is unclear, some were ancestors of groups of modern life. Important developments were the origin of muscular and neural cells. **None of the Ediacaran fossils had hard body parts like skeletons**.

One major difference that is apparent in the bilaterian, and absent in the jellyfish, **is the presence of a third germ layer called mesoderm, of which the heart and circulatory system is one of its greatest achievements**. As a jellyfish (Cnidaria) enters its reproductive stage, nerve cells and sensory cells can be found in a layer called entocodon, that separates away from the ectoderm.

Generally speaking, the ectoderm differentiates to form epithelial and neural tissues (spinal cord, peripheral nerves, and brain). This includes the skin, linings of the mouth, anus, nostrils, sweat glands, hair, nails, and tooth enamel. **The entocodon of the cnidarians is comparable to the mesodermal germ layer found in bilaterian animals**.



Myogenesis is the formation of skeletal muscular tissue, particularly during embryonic development. Specific genes have been isolated in the jellyfish (Cnidaria), which have been shown to play a role in myogenesis, leading to the conclusion that **these different genes may be the primordial beginnings of the heart and circulatory system that we see in later bilaterian species**.

Most living animal species are in Bilateria, a clade whose members have a bilaterally symmetric body plan. **The Bilateria include the protostomes**, containing invertebrates (such as nematodes, arthropods, and mollusks), and the **deuterostomes**. **Nephrozoa** is a major clade of bilaterians, divided into only the protostomes and the deuterostomes, containing almost all animal phyla and over a million extant species. **The coelom, the digestive tract and excretory organs, and nerve cords developed in the Nephrozoa**. The common ancestor of protostomes and deuterostomes was evidently **a worm-like aquatic animal** of the Ediacaran period (635 to 539 Mya). **The two clades diverged about 600 Mya**.

Deuterostomia ('second mouth') are animals typically characterized by their anus forming before their mouth during embryonic development. The group's sister clade is Protostomia. In deuterostomy, the developing embryo's first opening (the blastopore) becomes the anus, while the mouth is formed at a different site later on.

The three major clades of deuterostomes are **Chordata** (e.g., vertebrates), Echinodermata (e.g., starfish), and Hemichordata (e.g., acorn worms). A feature present in both the Hemichordata and Chordata is **pharyngotremy, the presence of spiracles or gill slits into the pharynx**, which is also found in some primitive fossil echinoderms. A hollow nerve cord is found in all chordates, including tunicates (in the larval stage). Some hemichordates also have a tubular nerve cord, which in the early embryonic stage, it looks like the hollow nerve cord of chordates.

The pharynx is the part of the throat immediately behind the mouth. **In fish, the pharyngeal slits are modified to form gills**, but in some other chordates they are part of a filter-feeding system that extracts particles of food from the water in which the animals live. In filter-feeding species it produces mucus to gather food particles, which helps in transporting food to the esophagus. It also stores iodine, and may be a precursor of the vertebrate thyroid gland.

Except for the echinoderms, both the hemichordates and **the chordates have a thickening of the aorta, homologous to the chordate heart, which contracts to pump blood**. This suggests a presence in the deuterostome ancestor of the three groups, with the echinoderms having secondarily lost it. The highly modified nervous system of echinoderms obscures much about their ancestry, but several facts suggest that **all present deuterostomes evolved from a common ancestor that had pharyngeal gill slits, a hollow nerve cord, circular and longitudinal muscles, and a segmented body**.

Chordates form a phylum of animals that are defined by having at some stage in their lives **all of the following anatomical features**: Chordates are bilaterally symmetric; have a coelom; possess a circulatory system; exhibit metameric segmentation; and have a notochord, a stiff rod of cartilage that extends along the inside of the body. Among the vertebrate sub-group of chordates, **the notochord develops into the spine**, and in wholly aquatic species this helps the animal to swim by flexing its tail. The vertebral column, also known as the backbone or spine, is the core part of the axial skeleton in vertebrate animals. Chordates also have a **dorsal neural tube**, which in fish and other vertebrates, **develops into the spinal cord, the main communications trunk of the nervous system**.

The heart is the center of the circulatory system whose primary role is to pump blood through the pulmonary and systemic systems of the body network. The circulatory system is a body-wide network of vessels that transports nutrients, respiratory gases, metabolic waste, and hormones, distributes, and dissipates heat, and assists in defending the body against disease. **The first heart-like organ appeared in our biological history over 600 Mya** and has undergone many changes and adaptations during its evolution from a single-layered tube, with its own contractility supporting an open circulatory system, to a powerful four-chambered muscular pump devoted to loading and unloading a large amount of blood around a closed, valved circuit circulatory system.

The primitive blueprint for **the circulatory system emerged around 700 to 600 Mya** and exhibits diverse physiological adaptations across the radiations of vertebrates. **It has evolved from the early chordate circulatory system** with a single layered tube in the tunicate or an amphioxus, to a vertebrate circulatory system with a two-chambered heart made up of one atrium and one ventricle in gnathostome fish (Gnathostomata), to a system with a three-chambered heart made up of two atria which may be partially divided or completely separated in amphibian tetrapods. **Subsequent tetrapods, including reptiles (crocodiles, alligators, birds, etc.) and mammals, evolved a four-chambered heart**.

The rate of the evolution of life, as recorded by fossils, **accelerated in the Cambrian period (542 to 488 Mya), with the development of hard body parts such as shells, skeletons, or exoskeletons** in animals like mollusks, echinoderms, crinoids, and arthropods. This made the preservation and fossilization of such life forms easier than those of their Proterozoic ancestors. For this reason, much more is known about life in and after the Cambrian than about that of older periods. Chordate fossils have been found from as early as the Cambrian explosion, 541 Mya. **During the Cambrian, the first vertebrate animals, among them the first fishes, had appeared.**[28] A creature that could have been the ancestor of the fishes, or was probably closely related to it, was Pikaia. It had a primitive notochord, a structure that developed into a vertebral column later.

Chordates are divided into three subphyla: Vertebrata (fish, amphibians, reptiles, birds, and mammals); Tunicata or Urochordata (sea squirts); and Cephalochordata (lancelets). Cladistically and phylogenetically, **vertebrates are chordates with the notochord replaced by a vertebral column during development, and are considered to be a subgroup of the clade Craniata, which consists of chordates with a skull**.

Cephalochordata (lancelets), a class of fish-like marine chordates, **are the most distantly related ancestors that share the same olfactory receptors with humans**. **They diverged from our own ancestors approximately 550 Mya**, shortly before the development of the camera eyes and brain. Although they lack an identifiable olfactory organ, lancelets possess 40 olfactory receptor genes that are studded along their flanks to detect odor molecules from their surrounding marine environment.

Olfactores is a clade within the Chordata that represents the common ancestor of the Tunicata (Urochordata) **and the Vertebrata**. Olfactores developed a more advanced olfactory system than the lancelets. **In the immediate vertebrate generation, it caused the appearance of nostrils**. Vertebrate olfaction was first derived in an aquatic ecosystem, where water was the primary medium for odorants.

A rudimentary neural crest is present in Tunicates, implying its presence in the ancestor of Olfactores also, as vertebrates have a true neural crest. Early in the process of development, vertebrate embryos develop a fold on the neural plate where the neural and epidermal ectoderms meet, called the neural crest. **The neural crest produces neural crest cells, which become multiple, different cell types, and contribute to tissues and organs as an embryo develops**.

Vertebrates (Craniata) comprise all species of animals within the subphylum Vertebrata (chordates with backbones). Vertebrates represent the overwhelming majority of the phylum Chordata, with currently about 69,963 species described. **Vertebrates comprise such groups as the following**: jawless fish, which include hagfish and lampreys; **jawed vertebrates**, which include cartilaginous fish (sharks, rays, chimaeras, and ratfish); **bony vertebrates**, which include ray-fins (the majority of living bony fish); **lobe-fins**, which include coelacanths and lungfish; **and tetrapods** (limbed vertebrates).

The earliest vertebrates appeared in the form of fish, which live exclusively in water. Some of these evolved into amphibians, which spend portions of their lives in water and portions on land. One group of amphibians evolved into reptiles and mammals and a few subsets of each returned to the ocean as sea snakes, sea turtles, seals, manatees, and whales.

Jaw development in vertebrates is likely a product of the supporting gill arches. This development would help push water into the mouth by the movement of the jaw, so that it would pass over the gills for gas exchange. The repetitive use of the newly formed jaw bones would eventually lead to the ability to bite in some gnathostomes. **Placoderms were among the first jawed fish**; their jaws likely evolved from the first of their gill arches. **This includes a dentary bone**, which is found in humans and other tetrapods. **Placoderms were also the first fish to develop teeth and pelvic fins, the precursor to hindlimbs in tetrapods.**

Extraordinary evidence of internal fertilization, in a 380 Myo placoderm, was afforded by the discovery in the Gogo Formation, in Western Australia. A small female placoderm, about 25 cm. in length, **died in the process of giving birth** to a 6 cm. offspring and **was fossilized with the umbilical cord intact**. The fossil, named Materpiscis attenboroughi (after scientist David Attenborough), had eggs which were fertilized internally, the mother providing nourishment to the embryo and giving birth to live young. With this discovery, **the placoderm became the oldest vertebrate known to have given birth to live young (viviparous)**.

A study, published in 2012, concluded that placoderms likely possessed true teeth. The teeth had well defined pulp cavities and were made of both bone and dentine. **Fossil findings of juvenile placoderms, which had true teeth** that grew on the surface of the jawbone and had no roots, making them impossible to replace or regrow as they broke or wore down as they grew older, **proves the common ancestor of all gnathostomes had teeth, and place the origin of teeth along with, or soon after, the evolution of jaws**.

Gnathostomata is the group of vertebrates with jaws. The group is broken into three top-level groupings: Chondrichthyes, or the cartilaginous fish; Placodermi, an extinct clade of armored fish; and **Euteleostomi**, which includes the familiar classes of bony fish, amphibians, mammals, and reptiles. **It is now assumed that Gnathostomata evolved from ancestors that already possessed a pair of both pectoral and pelvic fins. Newer research suggests that a branch of Placoderms was most likely the ancestor of present-day gnathostomes**. In addition to opposing jaws, living gnathostomes have teeth, paired appendages, and a horizontal semicircular canal of the inner ear, along with myelin sheaths (protective membranes that wrap around part of certain nerve cells) of neurons.

Euteleostomi/Osteichthyes evolved from placoderms. Euteleostomes originally all had endochondral bone, fin rays, jaws lined by maxillary, premaxillary, and dentary bones composed of dermal bone, **and lungs**. Many of these characters have since been lost by descendant groups. In many ray-finned fish, lungs have evolved into swim bladders for regulating buoyancy, while in others they continue to be used as respiratory gas bladders.

Living teleostomes constitute the clade Euteleostomi, which includes all **Osteichthyes and Tetrapods**. Teleostomes have two major adaptations that relate to aquatic respiration. First, the early teleostomes probably had some type of operculum, which helps them breathe without having to swim. **The development of a single respiratory opening seems to have been an important step**. In the second adaptation, **the teleostomes developed a primitive lung** with the ability to use some atmospheric oxygen. This developed, in later species into the lung, and later into the swim bladder.

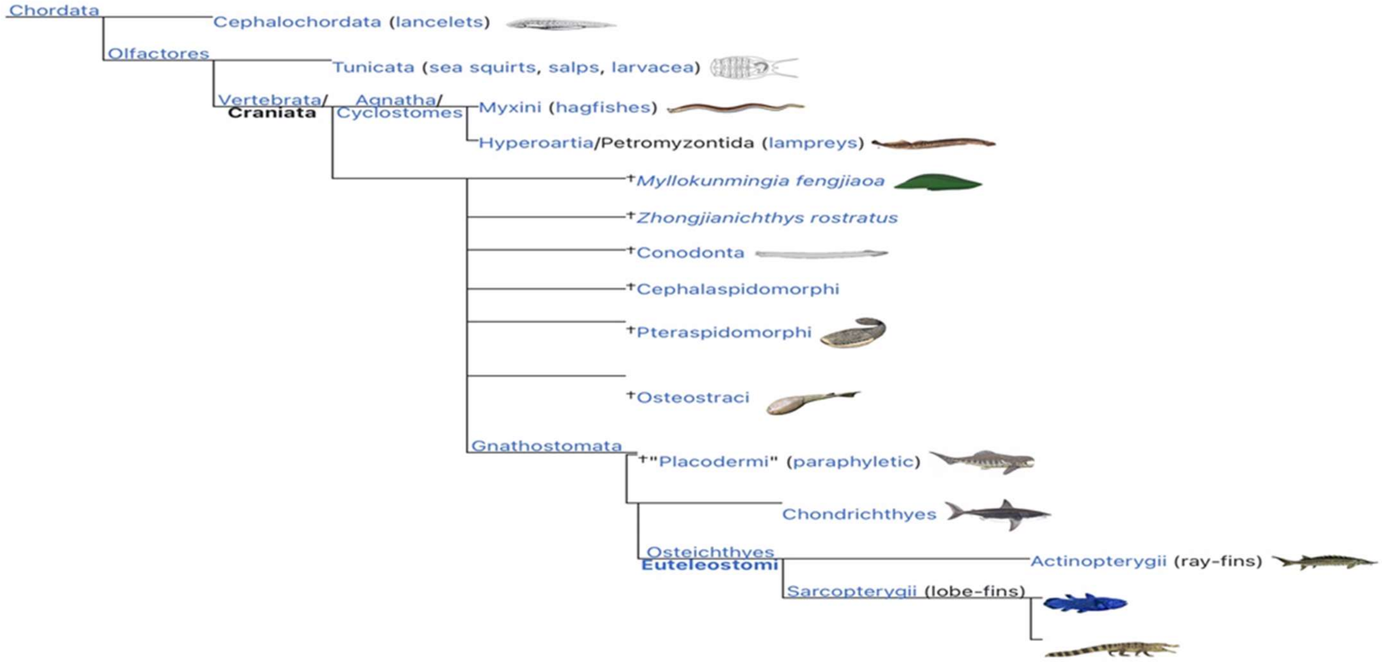
Osteichthyes, referred to as the bony fish, is a diverse taxonomic group of fish that **have skeletons primarily composed of bone tissue rather than cartilage**. The group Osteichthyes is divided into the ray-finned fish (Actinopterygii) and lobe-finned fish (Sarcopterygii). **The oldest known fossils of bony fish are about 420 million years old**, which are also transitional fossils, showing a tooth pattern that is in between the tooth rows of sharks and bony fishes.

Early bony fish had simple lungs (a pouch on either side of the esophagus) which helped them breathe in low-oxygen water. In many bony fish these have evolved into swim bladders, which help the body create buoyancy. **Lungs have been retained in dipnoi (lungfish), and many tetrapods (mammals, reptiles, and some amphibians)**.

Sarcopterygii, members of which are known as lobe-finned fish, is a group of the bony fishes.[29] Under modern cladistic classification schemes, Sarcopterygii is a clade of fish that includes the tetrapods. The living sarcopterygians are the coelacanths, lungfish, and the tetrapods**. Early lobe-finned fishes are bony fish with fleshy, lobed, paired fins, which are joined to the body by a single bone**. The fins of lobe-finned fishes differ from those of all other fish in that each is borne on a fleshy, lobe like, scaly stalk extending from the body. **All sarcopterygians possess teeth covered with true enamel**.

Choanae (singular choana), posterior nasal apertures or **internal nostrils**, are two openings found at the back of the nasal passage between the nasal cavity and the throat in tetrapods, including humans and other mammals. They **are considered one of the most important synapomorphies of sarcopterygians, that allowed the passage from water to land**. In animals with secondary palates, they allow breathing when the mouth is closed. In tetrapods, without secondary palates, their function relates primarily to olfaction, a sense of smell.

Sarcopterygians (lobe-finned fishes) and their relatives the Actinopterygians (ray-finned fishes) comprise the superclass of bony fishes characterized by their bony skeleton rather than cartilage. There are otherwise vast differences in fin, respiratory, and circulatory structures between the Sarcopterygii and the Actinopterygii. The earliest fossils of sarcopterygians were found in the uppermost Silurian, about 418 Mya. **In the early to middle Devonian (416–385 Mya), while the predatory placoderms dominated the seas, some sarcopterygians came into freshwater habitats**.



In the Early Devonian (416–397 Mya), the sarcopterygians split into two main lineages: the Actinistia (coelacanths) and the Rhipidistians. The **Rhipidistians**, whose ancestors probably lived in the oceans near the river mouths (estuaries), **left the ocean world and migrated into freshwater habitats**. The Rhipidistians speciated into two major groups: Dipnoi (lungfish) and the Tetrapodomorpha.

Dipnoi (lungfish) radiated into their greatest diversity during the Triassic Period; today fewer than a dozen genera remain. **Lungfish evolved the first proto-lungs and proto-limbs, adapting to living outside a submerged water environment by the middle Devonian (397–385 Mya)**.

The **Tetrapodomorpha** are a clade of vertebrates consisting of tetrapods (four-limbed vertebrates) and their closest sarcopterygian relatives that are more closely related to living tetrapods than to living lungfish. The morphology of tetrapodomorphs, **fish that are similar-looking to tetrapods, give indications of the transition from water to terrestrial life**. The fin-limbs of lobe-finned fishes, such as the coelacanths, show a strong similarity to the expected ancestral form of tetrapod limbs. Pectoral and pelvic fins have articulations resembling those of tetrapod limbs. **The first tetrapod land vertebrates, basal amphibian organisms, possessed legs derived from these fins**. The first tetrapodomorphs, which included the gigantic rhizodonts, **had the same general anatomy as the lungfish**, who were their closest kin, but they appear not to have left their water habitat until the Late Devonian period (~ 385 to 359 Mya), with the appearance of tetrapods. **Tetrapods are the only tetrapodomorphs which survived after the Devonian**.

Among the **characteristics defining tetrapodomorphs** are modifications to the fins, notably a humerus with convex head articulating with the glenoid fossa (the socket of the shoulder joint). Another key trait is **the internal nostril or choana**. Most fish have two pairs of nostrils, one on either side of the head for incoming water (incurrent nostrils) and another pair for outgoing water (excurrent nostrils). Early tetrapodomorphs, such as Kenichthys, had excurrent nostrils that had migrated to the edge of the mouth. **In later tetrapodomorphs, including tetrapods, the excurrent nostril is positioned inside the mouth, where it is known as the choana**. Tetrapodomorpha fossils are known from the early Devonian (416–397 Mya), onwards.

A rise in global oxygen content allowed for the evolution of large, predatory fish that were able to exploit the shallow tidal areas and swamplands as top predators. Several groups evolved to fill these niches, the most successful were the elpistostegalians. **Elpistostegalia** is an order of prehistoric lobe-finned fishes which lived during the Late Devonian period (~ 385 to 374 Mya).

Elpistostegalia represent the advanced tetrapodomorphs, the fishes more closely related to tetrapods than the Osteichthyes fishes. **Being shallow-water fishes, the elpistostegalians evolved many of the basic adaptions that later allowed the tetrapods to become terrestrial animals**. The most important ones were the shift of main propulsion apparatus from the tail fin to the pectoral and pelvic fins, and a shift to reliance on lungs rather than gills as the main means of obtaining oxygen. Both of these appear to be a direct result of moving to an inland freshwater mode of living.

The earliest elpistostegalians, combining fishlike and tetrapod-like characters, are sometimes called fishapods, a phrase coined for the advanced elpistostegalian Tiktaalik.[30] A notable feature of Tiktaalik is the absence of bones covering the gills. These bones would otherwise connect the shoulder girdle with the skull, making the shoulder girdle part of the skull. With the loss of the gill-covering bones, the shoulder girdle is separated from the skull, connected to the torso by muscle and other soft-tissue connections. **The result is the appearance of the neck**. **This feature appears only in Tiktaalik and tetrapods**, not other tetrapodomorphs.

Tiktaalik also had a pattern of bones in the skull roof (upper half of the skull) that is similar to the end-Devonian tetrapod Ichthyostega. The two also shared a semi-rigid ribcage of overlapping ribs, which may have substituted for a rigid spine. In conjunction with robust forelimbs and shoulder girdle, **both Tiktaalik and Ichthyostega may have had the ability to locomote on land in the manner of a seal**, with the forward portion of the torso elevated, the hind part dragging behind. Finally, Tiktaalik fin bones are somewhat similar to the limb bones of tetrapods.

Paleontologist and professor Per E. Ahlberg has identified the following traits as synapomorphic for Elpistostegalia (and thus Tetrapoda): the endocranium is hinged, the hinge forming the profundus nerve foramen; cranial kinesis is also visible in the skull roof, between the parietal bones and the post parietal bones; a rather small shoulder girdle is present; the anal and posterior dorsal fin are supported by a basal plate and three unjointed radials; **and the pectoral fin skeleton is composed of bones homologous to the tetrapod humerus, ulna, and radius**, followed by a host of smaller bones anchoring the fin rays; **the pelvic fin skeleton similarly has femur, tibia, and fibula**.

At the end of the Ordovician period, 443 Mya, additional extinction events occurred, perhaps due to a concurrent ice age. **The elpistostegalians gave rise to the tetrapods around 395 Mya**. While the early tetrapods flourished and diversified over the next 30 million years, the non-tetrapod elpistostegalians disappear from the fossil record fairly quickly in the early Frasnian, around 380 Mya, **leaving the tetrapods the sole survivors of their line**.

Neil Shubin is an American paleontologist, evolutionary biologist, and popular science writer. **The following excerpts were taken directly from his book titled "Your Inner Fish:"**

The shift from single-celled animals to animals with bodies reveals a whole new world. New creatures with whole new capabilities came about: they got big, they moved around, and they developed new organs that helped them sense, eat, and digest their world. Here is a humbling thought for all of us worms, fish, and humans: **most of life's history is the story of single-celled creatures**. **We, like all the animals and plants that have ever lived, are recent crashers at the party of life on earth.**

Then, roughly one Bya, the amount of oxygen increased dramatically and has stayed relatively high ever since. For billions of years, microbes developed new ways of interacting with their environment and with one another. A cause for the origin of bodies was also in place: by one Bya, microbes had learned to eat each other. **A microbe** or microorganism is an organism of microscopic size, which may exist in its single-celled form or as a colony of cells. There was a reason to build bodies, and the tools to do so were already there. Something was missing. **That something was enough oxygen on the earth to support bodies**. **When the earth's oxygen increased, bodies appeared everywhere. Life would never be the same**.

The vastness of this time scale becomes abundantly clear when we look at the rocks in the world. Rocks older than 600 million years are generally devoid of animals or plants. One message from this is very clear: **creatures with many cells began to populate the seas of the planet by 600 Mya**. These creatures had well-defined bodies and were not just colonies of cells. They have patterns of symmetry that, in some cases, resemble those of living forms. **This implies that the Precambrian organisms had a level of biological organization that at the time was utterly new on the planet**.

Our example will show us one of the great transitions in the history of life: the invasion of land by fish. For billions of years, all life lived only in water. Then, **as of about 365 Mya (Mya), creatures also inhabited land**. Life in these two environments is radically different. Breathing in water requires very different organs than breathing in air. The same is true for excretion, feeding, and moving about. **A whole new kind of body had to arise**. At first glance, the divide between the two environments appears almost unbridgeable. But everything changes when we look at the evidence; **what looks impossible actually happened**.

The order of fossils in the world's rocks is powerful evidence of our connections to the rest of life. My colleague Jenny Clack at Cambridge University and others have uncovered amphibians from rocks in Greenland that are about 365 million years old (Myo). Given this, it is probably no great surprise that we should focus on rocks about 375 Myo to find evidence of the transition between fish and land-living animals. The answer came from those rocks formed in ancient streams.

Consider the neck of Tiktaalik. All fish prior to Tiktaalik have a set of bones that attach the skull to the shoulder, so that every time the animal bent its body, it also bent its head. **Tiktaalik is different**. **The head is completely free of the shoulder**. This whole arrangement is shared with amphibians, reptiles, birds, and mammals, including us. The entire shift can be traced to the loss of a few small bones in a fish like Tiktaalik. Like a fish, it has scales on its back and fins with fin webbing. But, like early land-living animals, it has a flat head and a neck. And, when we look inside the fin, we see bones that correspond to the upper arm, the forearm, even parts of the wrist. **The joints are there, too: this is a fish with shoulder, elbow, and wrist joints**. All inside a fin with webbing.

This pattern underlies the architecture of all limbs. **There is a fundamental design in the skeleton of all animals**. Frogs, bats, humans, and lizards are all just variations on a theme. Shortly after Owen announced this observation in his classic monograph “On the Nature of Limbs,” Charles Darwin supplied an elegant explanation for it. **The reason the wing of a bat and the arm of a human share a common skeletal pattern is because they shared a common ancestor.**

Tiktaalik has a shoulder, elbow, and wrist composed of the same bones as an upper arm, forearm, and wrist in a human. We can trace many of the structures of our own limbs to the fins of these fish. Bend your wrist back and forth. Open and close your hand. When you do this, you are using joints that first appeared in the fins of fish like Tiktaalik. **Earlier, these joints did not exist. Later, we find them in (fish) limbs**.

The first true fingers and toes are seen in 365 Myo amphibians like Acanthostega. Finally, the full complement of wrist and ankle bones found in a human hand or foot is seen in reptiles more than 250 Myo. **The basic skeleton of our hands and feet emerged over hundreds of millions of years, first in fish and later in amphibians and reptiles**.

In fact, knowing something about the deep origins of humanity only adds to the remarkable fact of our existence: all of our extraordinary capabilities arose from basic components that evolved in ancient fish and other creatures. From common parts came a very unique construction. **We are not separate from the rest of the living world**; we are part of it **down to our bones** and, as we will see shortly, **even our genes**.

We begin with an apparent puzzle. Our body is made up of hundreds of different kinds of cells. This cellular diversity gives our tissues and organs their distinct shapes and functions. The cells that make our bones, nerves, guts, and so on look and behave entirely differently. Despite these differences, **there is a deep similarity among every cell inside our bodies: all of them contain exactly the same DNA**. If DNA contains the information to build our bodies, tissues, and organs, how is it that cells as different as those found in muscle, nerve, and bone contain the same DNA? **The answer lies in understanding what pieces of DNA (the genes) are actually turned on in every cell**.

Here is the important fact: these genetic switches help to assemble us. At conception, we start as a single cell that contains all the DNA needed to build our body. The plan for that entire body unfolds via the instructions contained in this single microscopic cell. To go from this generalized egg cell to a complete human, with trillions of specialized cells organized in just the right way, whole batteries of genes need to be turned on and off at just the right stages of development. Like a concerto composed of individual notes played by many instruments, **our bodies are a composition of individual genes turning on and off inside each cell during our development**.

We now know that the **Sonic Hedgehog is one of dozens of genes** that act to sculpt our limbs from shoulder to fingertip by turning on and off at the right time. Remarkably, work in chickens, frogs, and mice was telling us the same thing. **The DNA recipe to build upper arms, forearms, wrists, and digits is virtually identical in every creature that has limbs**. All appendages, whether they are fins or limbs, are built by similar kinds of genes. The Sonic Hedgehog (gene) signaling pathway transmits information to embryonic cells required for proper cell differentiation.

What does this mean for the problem we looked at in the first two chapters, the transition of fish fins into limbs? It means that **this great evolutionary transformation did not involve the origin of new DNA**: much of the shift likely involved using ancient genes, such as those involved in shark fin development, in new ways to make limbs with fingers and toes.

The little animals we found included frogs (some of the earliest), legless amphibians, lizards, and other reptiles, and, importantly, some of the earliest mammals. **The key point is that the early mammals were small**. Very small. Their teeth were not much more than 2 millimeters long. Each tooth had a characteristic pattern of wear at the face where upper and lower teeth fit together. I was seeing some of the first evidence of **our pattern of precise chewing**, only **in a tiny mammal 190 Myo**.

Once the process that makes teeth came into being, it was modified to make the diverse kinds of organs that lie within skin. Birds, reptiles, and humans are just as extreme in many ways. We would never have scales, feathers, or breasts if we did not have teeth in the first place. **The developmental tools that make teeth have been repurposed to make other important skin structures**. In a very real sense organs as different as teeth, feathers, and breasts are inextricably linked by history. Here, in teeth, mammary glands, and feathers, we find a similar theme. The biological processes that make these different organs are versions of the same thing. When you see these deep similarities among different organs and bodies, you begin to recognize that **the diverse inhabitants of our world are just variations on a theme**.

Buried in sediments over 500 Myo are small worms that lack heads, complex brains, or cranial nerves. They may not look like much, being small smudges in the rock, but the preservation of these fossils is incredible. When you look under a microscope, you find beautifully preserved impressions that display their soft anatomy in fine detail, occasionally even with impressions of skin. They show something else wonderful, too. **They are the earliest creatures with notochords and nerve cords**.

The essence of our head goes back to worms, organisms that do not even have a head. What does Amphioxus do with the gill arches? It pumps water through them to filter out little particles of food. From so humble a beginning comes the basic structures of our own head. **Just as teeth, genes, and limbs have been modified and their functions repurposed over the ages, so, too, has the basic structure of our head**. But there was more. The fish, amphibian, and chicken embryos were like nothing I had ever seen before in biology. They all looked generally alike. **All of them had a head with gill arches**. All of them had a little brain that began its development with three swellings. All of them had little limb buds.

Here, in comparing how the skeleton developed in birds, salamanders, frogs, and turtles, I was finding that limbs as different as bird wings and frog legs looked very similar during their development. In seeing these embryos, **I was seeing a common architecture**. The species ended up looking different, but they started from a generally similar place. Looking at embryos, it almost seems that **the differences among mammals, birds, amphibians, and fish simply pale in comparison with their fundamental similarities**.

Hilde Mangold was a German embryologist who **discovered a small patch of tissue that was able to direct other cells to form an entire body plan**. The tiny, incredibly important patch of tissue containing all this information was to be known as **the Organizer**. What inside it tells cells how to build bodies? DNA, of course. **And it is in this DNA that we will find the inner recipe that we share with the rest of animal life**.

Mike Levine and Bill McGinnis, in Walter Gehring's lab in Switzerland, and Matt Scott, in Tom Kauffman's lab in Indiana, noticed that in the middle of each gene was a short DNA sequence that was virtually identical in each species they looked at. This little sequence is called a homeobox. **The eight genes that contain the homeobox are called Hox genes**.

When the scientists fished around for this gene sequence in other species, they found something so uniform that it came as a true surprise: **versions of the Hox genes appear in every animal with a body**. Hox genes also establish the proportions of our bodies, the sizes of the different regions of our head, chest, and lower back. They are involved in the development of individual organs, limbs, genitalia, and guts. Changes in them bring about changes in the ways our bodies are put together. **The discovery of Hox genes in the 1980s changed everything**.

Genes interact with other genes at all stages of development. One gene may inhibit the activity of another or promote it. Sometimes many genes interact to turn another gene on or off. **These off-on interactions underlie virtually all developmental processes**. All animals are the same but different. Like a cake recipe passed down from generation to generation, with enhancements to the cake in each, the recipe that builds our bodies has been passed down, and modified, for eons. **We may not look much like sea anemones and jellyfish, but the recipe that builds us is a more intricate version of the one that builds them**.

Fossils and the geological record remain a very powerful source of evidence about the past; nothing else reveals the actual environments and transitional structures that existed during the history of life. Our closest fish relatives have an arrangement somewhat like ours: the water enters a nostril and ultimately goes to a cavity linked with the mouth. Fish like lungfish or Tiktaalik have two kinds of nostrils: an external one and an internal one. In this, they are a lot like us. Sit with your mouth closed and breathe. Air enters an external nostril and travels through your nasal cavities to enter the back of your throat via internal passageways. **Our fish ancestors had internal and external nostrils, too, and to nobody's surprise these are the same fish that have arm bones and other features in common with us**.

We humans are part of a lineage that has traded smell for sight. We now rely on vision more than on smell, and this is reflected in our genome. In this trade-off, our sense of smell was deemphasized, and many of our olfactory genes became functionless. Our eyes have a history as organs, but so do eyes' constituent parts, the cells, and tissues, and so do the genes that make those parts. We use different **opsins** to see in black and white and in color. Just as an inkjet printer needs three or four inks to print in color, we need three light-gathering molecules to see in color. For black-and-white vision, we use only one. Despite the stunning variety of photoreceptor organs, **every animal uses the same kind of light-capturing molecule to do this job**. **Insects, humans, clams, and scallops all use opsins**.

Not only can we trace the history of eyes through differences in the structure of their opsins, but we have good evidence that we can thank bacteria for these molecules in the first place. **Essentially, an opsin is a kind of (chemical) molecule that conveys information from the outside of a cell to the inside**. It is identical to parts of certain molecules in bacteria. The very precise molecular similarities in this molecule suggest a very ancient property of all animals extending all the way to our shared history with bacteria. In a sense, **modified bits of ancient bacteria lie inside our retinas, helping us to see**. From studying the other primates that have color vision, we can estimate that **our kind of color vision arose about 55 Mya**.

Polychaetes are among the most primitive living worms known. They have a very simple segmented body plan, and they also have two kinds of light-sensing organs: an eye and, buried under their skin, a part of their nervous system that is specialized to pick up light. Detlev Arendt took these worms apart both physically and genetically. Knowledge of the gene sequence of our opsin genes and the structure of our light-gathering neurons gave Arendt the tools to study how Polychaetes are made. **He found that they had elements of both kinds of animal photoreceptors**. The normal "eye" was made up of neurons and opsins like the eye of any invertebrate. The tiny photoreceptors under the skin were another matter altogether. They had "vertebrate" opsins and cellular structure even with the little bristle-like projections, but in primitive form. **Arendt had found a living bridge, an animal with both kinds of eyes, one of which, our kind, existed in a very primitive form**. When we look to primitive invertebrates, we find that the different kinds of animal eyes share common parts.

Our middle ear contains a record of two of the great transformations in the history of life. The origin of our **stapes**, and its transformation, from a jaw support bone, to an ear bone, began when fish (amphibians) started to walk on land. The other big event took place during the origin of mammals, when bones at the back of a reptile jaw became our **malleus and incus**.

With every other animal on the planet, we share a body composed of many cells. **Call this group multicellular life**. We share the trait of multicellularity with everything from sponges to placozoans to jellyfish to chimpanzees. A subset of these multicellular animals **has a body plan** like ours, with a front and a back, a top and a bottom, and a left and a right. Taxonomists call this group **Bilateria** (meaning "bilaterally symmetrical animals"). It includes every animal from insects to humans.

A subset of multicellular animals that have a body plan like ours, with a front and a back, a top and a bottom, and a left and a right, also **have skulls and backbones**. **Call these creatures vertebrates**. A subset of the multicellular animals that have a body plan like ours, with a front and a back, a top and a bottom, and a left and a right, and that have skulls, **also have hands and feet**. Call these vertebrates **tetrapods (animals with four limbs)**.

A subset of the multicellular animals that have a body plan like ours, with a front and a back, a top and a bottom, and a left and a right, that have skulls, and that have hands and feet, **also have a three-boned middle ear**. **Call these tetrapods mammals**. A subset of the multicellular animals that have a body plan like ours with a front and a back, a top and a bottom, and a left and a | right, that have skulls and backbones, that have hands and feet, and that have a three-boned middle ear, **also have a bipedal gait and enormous brains**. **Call these mammal's people**.

In biology, **homology is similarity due to shared ancestry** between a pair of structures or genes in different taxa. A common example of homologous structures is the forelimbs of vertebrates, where the wings of bats and birds, the arms of primates, the front flippers of whales, and the forelegs of four-legged vertebrates like dogs and crocodiles, are all derived from the same ancestral tetrapod structure. Evolutionary biology explains homologous structures adapted to different purposes as the result of descent with modification from a common ancestor. **Once we identify these multiple layers of history in our organs, we understand that we are simply a mosaic of bits and pieces found in virtually everything else on the planet**.

Just as the space program changed the way we look at the moon, paleontology and genetics are changing the way we view ourselves. Couple these powerful new insights with the fact that **some of the most important discoveries** in paleontology, new fossils, and new tools to analyze them, **have come to light in the past twenty years**, and we are seeing the truths of our history with ever-increasing precision.

Now, let us leave this paradigm-shifting book and briefly discuss **the evolution of plants and fungi.**[31] From above, the Diphoda were the ancestors of Archaeplastida (Plants and relatives). The Archaeplastida (or kingdom Plantae "in a broad sense") are a major group of eukaryotes, comprising the photoautotrophic red algae (Rhodophyta), green algae, and land plants. Perhaps the most ancient remains of Archaeplastida are putative red algae found within stromatolites, in 1.6 Byo rocks, in India. **A molecular clock study has calculated that the green algae clade diverged about 1.5 Bya**.

Viridiplantae (literally "green plants") are a clade of eukaryotic organisms that comprise approximately 450,000 to 500,000 species and play important roles in both terrestrial and aquatic ecosystems. There have probably been several different territorialization events, in which originally aquatic organisms colonized the land, just within the lineage of the Viridiplantae.

According to molecular clock estimates the **Viridiplantae diverged 1.2 Bya to 725 Mya into two clades: chlorophytes and streptophytes**. Green algae are photosynthetic organisms that belong to the phylum Chlorophyta. The chlorophytes are considerably more diverse (with around 700 genera) and were originally marine, although some groups have since spread into fresh water. The streptophyte algae are less diverse (with around 122 genera) and adapted to fresh water very early in their evolutionary history.

While environmental factors are significantly responsible for evolutionary change, they act merely as agents for natural selection. **Change is inherently brought about via phenomena at the genetic level**: mutations, chromosomal rearrangements, and epigenetic (a stable change of cell function that happens without changes to the DNA sequence) changes. While the general types of mutations hold true across the living world, **in plants, some other mechanisms have been implicated as highly significant**.

A contributing factor in some plants leading to evolutionary change is due to coevolution with fungal parasites. Coevolution is an important phenomenon necessary for understanding the vital relationship between plants and their fungal parasites. In an environment with a fungal parasite, which is common in nature, plants must make adaptation in an attempt to evade the harmful effects of the parasite.

According to DNA analysis, Fungi diverged from other life around 1.5 Bya. The earliest terrestrial fungus fossils, or at least fungus-like fossils, have been found in South China from around 635 Mya, but terrestrial fossils only become uncontroversial and common during the Devonian, about 400 Mya.

Mycorrhizae are the species of specialized fungi that form symbiotic relationships between the roots of plants and the fungi. The term mycorrhiza refers to the role of the fungus in the plant's rhizosphere, its root system. In a mycorrhizal association, the fungus colonizes the host plant's root tissues, either intracellularly as in arbuscular mycorrhizal fungi, or extracellularly as in ectomycorrhizal fungi. **Mycorrhizae fungi play important roles in plant nutrition, soil biology, and soil chemistry**. Appearing as they did before these plants had evolved roots, mycorrhizal fungi would have assisted plants in the acquisition of water and mineral nutrients such as phosphorus, in exchange for organic compounds (sugars) which they could not synthesize themselves. Such fungi increase the productivity even of simple plants such as liverworts.

Whenever a parasitic fungus is siphoning limited resources away from a plant, there is selective pressure for a new plant to evolve that is better able to prevent parasitic attack from fungi. At the same time, fungi that are better equipped to evade the defenses of the plant will have greater fitness level. **The combination of these two factors leads to an endless cycle of evolutionary change in the host-pathogen system**.

Because each species in the relationship is influenced by a constantly changing symbiont, evolutionary change usually occurs at a faster pace than if the other species was not present. **This is true of most instances of coevolution**. This makes the ability of a population to quickly evolve vital to its survival. Also, if the pathogenic species is too successful and threatens the survival and reproductive success of the host plants, the pathogenic fungi risk losing their nutrient source for future generations. **These factors cause a dynamic that shapes the evolutionary changes in both species, generation after generation**.

An **arbuscular mycorrhiza (AM)** is a type of mycorrhiza in which the symbiont fungus penetrates the cortical cells of the roots of a vascular plant forming arbuscules. An arbuscular is a tuft of hairs or cilia. Arbuscules are one type of mycorrhizae among the seven types. AM fungi help plants to capture nutrients such as phosphorus, sulfur, nitrogen, and micronutrients from the soil. **It is believed that the development of the arbuscular mycorrhizal symbiosis played a crucial role in the initial colonization of land by plants** and in the evolution of the vascular plants. **AM fungi symbiosis** is a highly evolved mutualistic relationship found between fungi and plants, the most prevalent plant symbiosis known, and **is found in 80% of vascular plant families in existence today**.

The embryophytes evolved from the streptophytes. **The Embryophyta (land plants)**, are the most familiar group of green plants that comprise vegetation on Earth. **Embryophytes have a common ancestor with green algae**. **Between 630 to 510 Mya, land plants emerged within the green algae**. The embryophytes are informally called land plants because they live primarily in terrestrial habitats, while the related green algae are primarily aquatic. Living embryophytes include hornworts, liverworts, mosses, lycophytes, ferns, gymnosperms, and angiosperms (flowering plants). In the strictest sense, the name plant refers to those land plants that formed the clade Embryophyta, comprising the bryophytes and vascular plants. **Plants started to colonize land around 450 Mya.**

Bryophytes provide insights into the migration of plants from aquatic environments to land. Molecular phylogenetic studies conclude that bryophytes are the earliest diverging lineages of the extant land plants. A number of physical features link bryophytes to both land plants and aquatic plants. **Distinct adaptations observed in bryophytes have allowed plants to colonize Earth's terrestrial environments.**

The Silurian is a geologic period from 443.8 Mya to 419 Mya. **The first fossil records of vascular plants, that is, land plants with vascular tissues, appeared in the Silurian period**. The Devonian is a geologic period from 419 Mya to 359 Mya. By the Devonian period, the colonization of the land by plants was well underway.

Remember, the first tetrapod land vertebrates, basal amphibian organisms, did not appear to have left their water habitat until 385 to 359 Mya. And the earliest **amphibians evolved in the Devonian period from sarcopterygian fish with lungs and bony-limbed fins**, features that were helpful in adapting to dry land.

By the middle of the Devonian (~390 Mya), many of the features recognized in land plants today were present, including roots and leaves. Roots and root-like structures became increasingly common and deeper penetrating during the Devonian, with lycopod trees forming roots around 8 in. long. By the Late Devonian, forests of large, primitive plants existed: lycophytes, sphenophytes, ferns, and progymnosperms had evolved. Most of these plants have true roots and leaves, and many were quite tall.

In the Late Devonian (~370 Mya), the tree-like Archaeopteris, ancestral to the gymnosperms, and the giant cladoxylopsid trees had secondary vascular tissue that **produced true wood and had formed forests of tall trees**. These are the oldest known trees of the world's first forests.

The establishment of a land-based flora increased the rate of accumulation of oxygen in the atmosphere, as the land plants produced oxygen as a waste product. To photosynthesize, plants must absorb carbon dioxide (CO_2) from the atmosphere. However, making the tissues available for CO_2 to enter allows water to evaporate, so this comes at a price. Water is lost much faster than CO_2 is absorbed, so plants need to replace it. Early land plants transported water within the porous walls of their cells. **Later, they evolved anatomical features that provided the ability to control the inevitable water loss** that accompanied CO_2 acquisition.

By the end of the Devonian, the first seed-forming plants had appeared. This rapid appearance of so many plant groups and growth forms has been called the "Devonian Explosion". The 'greening' of the continents acted as a carbon dioxide sink, and atmospheric concentrations of this greenhouse gas may have dropped. This may have cooled the climate and led to a massive Late Devonian extinction event (~ 375 Mya).

Seeds offered further advantages to their bearers: they increased the success rate of fertilized gametophytes, and because a nutrient store could be "packaged" in with the embryo, the seeds could germinate rapidly in inhospitable environments, reaching a size where it could fend for itself more quickly. For example, without an endosperm, seedlings growing in arid environments would not have the reserves to grow roots deep enough to reach the water table before they expired from dehydration. Likewise, seeds germinating in a gloomy understory require an additional reserve of energy to quickly grow high enough to capture sufficient light for self-sustenance. **A combination of these advantages gave seed plants the ecological edge, thus increasing the biodiversity of early forests**.

Also in the Devonian, both vertebrates and arthropods (insects or bugs) were solidly established on the land. The primitive arthropods co-evolved with this diversified terrestrial vegetation structure. **The evolving co-dependence of insects and seed-plants that characterizes a recognizably modern world had its genesis in the Late Devonian**. The development of soils and plant root systems probably led to changes in the speed and pattern of erosion and sediment deposition.

The Carboniferous period (359 to 299 Mya) followed the Devonian period. The Permian Period (299 to 252 Mya) followed the Carboniferous Period. And the Triassic Period (252 to 201 Mya) followed the Permian Period. Beginning near the end of the Triassic Period, dinosaurs dominated terrestrial ecosystems for nearly 150 million years. **The first mammaliaforms (mammals) did not evolve from the probainognathian cynodonts** until the Late Triassic, **about 225 Mya**.[32]

It seems that on the level of the organ, **the leaf may be the ancestor of the flower, or at least some floral organs**. When some crucial genes involved in flower development are mutated, clusters of leaf-like structures arise in place of flowers. Thus, sometime in history, the developmental program leading to formation of a leaf must have been altered to generate a flower.

The Jurassic Period (201 to 145 Mya) immediately followed the Triassic Period. **Flowering plants, known as angiosperms**, originated, and diversified during the Early Cretaceous Period (145 to 66 Mya), although they did not become predominant until near the end of the period. **Possessed only by the angiosperms, flowers are relatively late to appear in the fossil record**. Flower-like structures first appear in the fossil records around 130 Mya. Around 40 Mya, the grasses were the latest major group of plants to evolve from among the angiosperms.

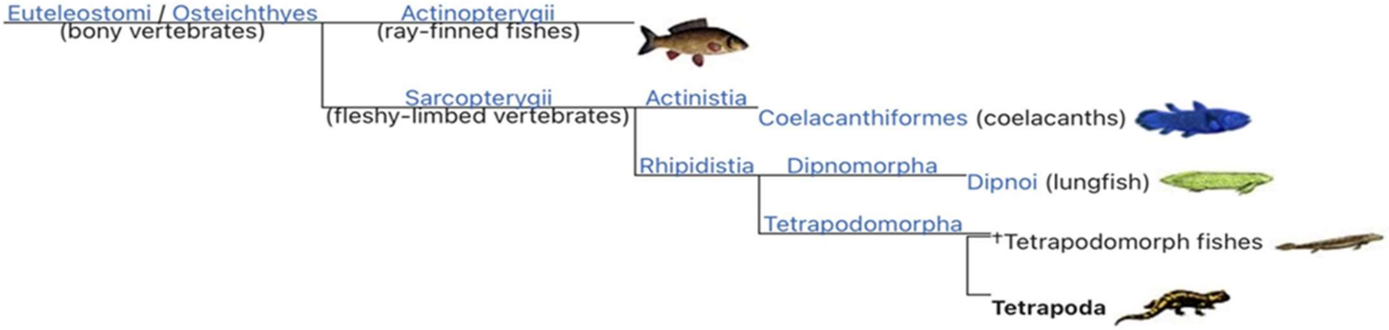
Below, you will find that **Primates did not arise until 85 to 55 Mya,** from small terrestrial mammals, which adapted to living in the trees of tropical forests. Above, we saw that **the human kind of color vision did not arise until about 55 Mya, again well after the origin of flowering plants.**

The main function of a flower is reproduction, which, before the evolution of the flower and angiosperms, was the job of microsporophylls and megasporophylls. **A flower can be considered a powerful evolutionary innovation, because its presence allowed the plant world to access new means and mechanisms for reproduction**. The earliest animal-pollinated flowers were shallow, cup-shaped blooms pollinated by insects such as beetles, so the syndrome of insect pollination was well established before the first appearance of bees.

The angiosperms evolution was aided by the appearance of bees. Bees evolved from ancient predatory wasps that lived 120 Mya. The novelty is that bees are specialized as pollination agents, with behavioral and physical modifications that specifically enhance pollination, and are the most efficient pollinating insects. **In a process of coevolution, flowers developed floral rewards such as nectar and longer tubes, and bees developed longer tongues to extract the nectar**. Bees also developed structures known as scopal hairs and pollen baskets to collect and carry pollen.

The evolution of plants has resulted in a wide range of complexity, from the earliest algal mats, through multicellular marine and freshwater green algae, terrestrial bryophytes, lycopods and ferns, to the complex gymnosperms and angiosperms of today. While many of the earliest groups continue to thrive, as exemplified by red and green algae in marine environments, **more recently derived groups have displaced previously ecologically dominant ones**; for example, the ascendance of angiosperms over gymnosperms in terrestrial environments.

Returning to the subject of animal evolution**, Stegocephalia** is a name used for four-limbed stem-tetrapods, and their amphibian-grade descendants, and in phylogenetic nomenclature for all tetrapods. Stegocephalia includes all vertebrate groups that have toes rather than fins, and a few that may have retained paired fins. As such, it **encompasses all presently living land vertebrates as well as their early amphibious ancestors**. Until finds of other early stegocephalians, and closely related fishes in the late 20th century, Ichthyostega stood alone as **a transitional fossil between fish and tetrapods, combining fish and tetrapod-like features**. Newer research has shown that it had an unusual anatomy, functioning more akin to a seal than a salamander, as previously assumed.

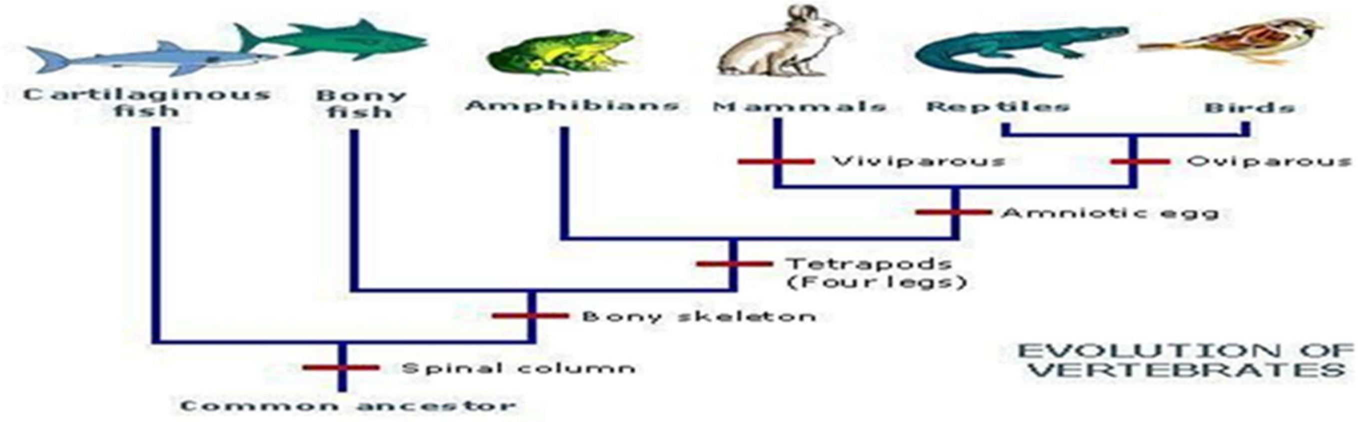


As discussed above, Tetrapodomorphs were transitional animals between lobe-finned fishes and the four-limbed tetrapods. Tetrapods are four-limbed animals constituting the superclass Tetrapoda. **Tetrapods evolved from Tetrapodomorphs, which, in turn, evolved from ancient sarcopterygian fish around 390 Mya** in the middle Devonian period. **Tetrapods can be defined** in cladistics **as the nearest common ancestor of all living amphibians and all living amniotes (reptiles, birds, and mammals)**, along with all of the descendants of that ancestor. **The first tetrapods appeared by the Late Devonian, around 368 Mya**.

The change from a body plan for breathing and navigating in water to a body plan enabling the animal to move on land is one of the most profound evolutionary changes known. Tetrapods have numerous anatomical and physiological features that are distinct from their aquatic ancestors. These include the structure of the jaw and teeth for feeding on land, limb girdles and extremities for land locomotion, lungs for respiration in air, a heart for circulation, and eyes and ears for seeing and hearing in air versus water.

Fins evolved to become limbs that the first tetrapods used to lift their heads out of the water to breathe air. This would let them live in oxygen-poor water or pursue small prey in shallow water. They may have later ventured on land for brief periods. Eventually, some tetrapods became so well adapted to terrestrial life that they spent their adult lives on land.

Amphibians are ectothermic, **anamniotes**, four-limbed vertebrate tetrapods that constitute the class Amphibia. The first major groups of amphibians **developed in the Devonian period, around 370 Mya**, from lobe-finned fish which were similar to the modern coelacanth and lungfish.[33] All extant (living) amphibians belong to the monophyletic subclass Lissamphibia, with three living orders: Anura (frogs), Urodela (salamanders), and Gymnophiona (caecilians). Evolved to be mostly semiaquatic, amphibians have adapted to inhabit a wide variety of habitats, with most species living in freshwater, wetland, or terrestrial ecosystems. **Modern amphibians are generally semiaquatic**; the first stage of their lives is as fish-like tadpoles, and later stages are partly terrestrial and partly aquatic. The word amphibian is derived from the Ancient Greek term (amphibious), which means **'both kinds of life'**. Amphibia is a paraphyletic group **encompassing all tetrapods, but excluding the amniotes** (tetrapods with an amniotic membrane, such as modern reptiles, birds, and mammals). About 365 Mya, another period of extinction occurred, perhaps as a result of global cooling.



Most tetrapod species today are amniotes, most of which are terrestrial tetrapod's whose branch evolved from earlier tetrapods about 340 Mya. **The key innovation in amniotes over amphibians is the amnion,** which enables the eggs to retain their aqueous contents on land, rather than needing to stay in water.

Fully terrestrial life was achieved with the development of the amniote egg, where a number of membranous sacks protect the embryo and facilitate gas exchange between the egg and the atmosphere. The first to evolve was probably the allantois, a sack that develops from the gut/yolk-sack. This sack contains the embryo's nitrogenous waste (urea) during development, stopping it from poisoning the embryo. A very small allantois is found in modern amphibians. **Later came the amnion surrounding the fetus proper**, and the chorion, encompassing the amnion, allantois, and yolk-sack. The chorion is the outermost fetal membrane around the embryo.

The amnion is a critical divergence within vertebrates that allows the embryos to survive out of the water. This enabled amniotes to reproduce on land and to move into drier environments, free of the need to return to water for reproduction as amphibians. The eggs could also "breathe" and cope with wastes, allowing the eggs and individuals to evolve into larger forms. **Features of amniotes evolved for survival on land, including** a sturdy but porous leathery or hard eggshell, and an allantois that facilitates respiration, while providing a reservoir for disposal of wastes. Their kidneys and large intestines are also well-suited to water retention.

The amniotic egg formed through a series of evolutionary steps. After internal fertilization and the habit of laying eggs in terrestrial environments became a reproduction strategy amongst the amniote ancestors, the next major breakthrough appears to have involved a gradual replacement of the gelatinous coating covering the amphibian egg with a fibrous shell membrane. **This allowed the egg to increase both its size and in the rate of gas exchange, permitting a larger, metabolically more active embryo, to reach full development before hatching**. Further developments, like extraembryonic membranes (amnion, chorion, and allantois) and a calcified shell, were not essential and probably evolved later. The only way for the eggs to increase in size would be to develop new internal structures specialized for respiration and for waste products. As this happened, it would also affect how much the juveniles could grow before they reached adulthood.

Amniotes are a clade of tetrapod vertebrates that comprise sauropsids (reptiles) **and synapsids** (mammals). They are distinguished by a membrane (amnion) protecting the embryo and a lack of a larval stage. Thanks to this, amniotes lay eggs on land or retain them within the mother, unlike anamniotes (fishes and amphibians), which typically lay eggs in water. Amniotes include the tetrapod's that further evolved for flight, such as birds from among the dinosaurs, and bats from among the mammals. **The divergence of the synapsids (mammals) from the sauropsids (reptiles) occurred around 310 Mya**. The reptiles, include lepidosaurs, dinosaurs (which includes birds), crocodilians, turtles, and extinct relatives.

Primitive synapsids are usually called pelycosaurs. **Therapsids evolved from "pelycosaurs" more than 272 Mya**. Therapsids replaced the "pelycosaurs" as the dominant large land animals in the Middle Permian through to the Early Triassic. In the aftermath of the Permian-Triassic extinction event, therapsids declined in relative importance to the rapidly diversifying reptiles during the Middle Triassic.

Therapsida is a major group of synapsids that includes mammals and their ancestors. Many of the traits today seen as unique to mammals had their origin within early therapsids, including limbs that were oriented more underneath the body, as opposed to the sprawling posture of many reptiles and salamanders. **Therapsids became the succeeding dominant land animals for the rest of the Permian, and in the latter part of the Triassic, they gave rise to the first true mammals**. All non-therapsid pelycosaurs, as well as many other life forms, became extinct at the end of Permian period.

The theriodonts are a major group of therapsids. **Theriodonts appeared about 270 Mya**, in the Middle Permian. Early theriodonts may have been warm-blooded. Early forms were carnivorous, but several later groups became herbivorous during the Triassic. **Theriodont jaws were more mammal-like** than was the case of other therapsids, because their dentary was larger, which gave them more efficient chewing ability. Furthermore, **several other bones that were on the lower jaw (found in reptiles), moved into the ears, allowing the theriodonts to hear better** and their mouths to open wider. This made the theriodonts the most successful group of synapsids.

Eutheriodontia refers to all theriodonts that included the therocephalians **and the cynodonts**. The eutheriodonts have larger skulls, accommodating larger brains and improved jaw muscles. **The cynodonts** are a clade of eutheriodont therapsids that first appeared in the Late Permian, **about 260 Mya**. Cynodonts had a wide variety of lifestyles, including carnivory and herbivory. Almost all Middle Triassic cynodonts are known from Gondwana, with only one genus having been found in the Northern Hemisphere. Gondwana, also called Gondwanaland, was an ancient supercontinent that incorporated present-day South America, Africa, Arabia, Madagascar, India, Australia, and Antarctica. See the following video to learn how super continents form and split up: https://www.bing.com/videos/riverview/relatedvideo?&q=Gondwana+vs+Pangea&&mid=3772E6A7697429316CDF3772E6A7697429316CDF&&FORM=VRDGAR

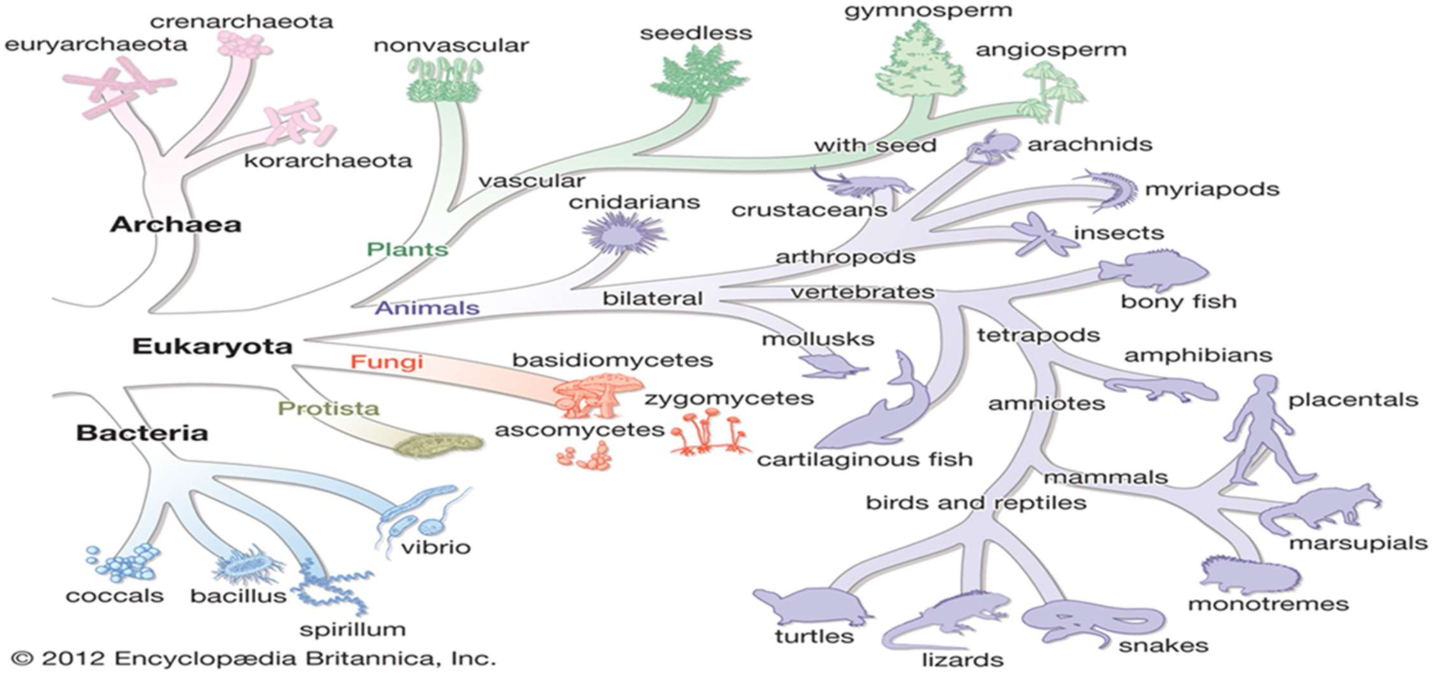
Approximately 252 Mya, the Permian-Triassic extinction event (**the Great Dying**) forms the boundary between the Permian and Triassic geologic periods.[34] **It is the Earth's most severe known extinction event**, with the extinction of 57% of biological families, 81% of marine species, and 70% of terrestrial vertebrate species. It is also the largest known mass extinction of insects. It is the largest of the "Big Five" mass extinctions of the Phanerozoic. This extinction did spare many of the dinosaurs, and they soon became dominant among the vertebrates. **Dinosaurs split off from their reptilian ancestors around 230 Mya**.

The Cynodonts were dominated by members of the advanced clade **Eucynodontia**, which has two main subdivisions, the predominantly herbivorous Cynognathia and the **Probainognathia**. During the Early and Middle Triassic, cynodont diversity was dominated by members of Cynognathia, and members of Probainognathia would not become prominent until the Late Triassic.

Probainognathia is one of the two major subgroups of the clade Eucynodontia. The earliest forms were carnivorous and insectivorous, though some groups eventually also evolved herbivorous diets. **Three groups survived the extinction at the end of Triassic**: Tritheledontidae and Tritylodontidae, which both survived until the Jurassic, the latter even into the Cretaceous, and **Mammaliaformes**.

Mammaliaformes originated from Probainognathian cynodonts during the Late Triassic, about 225 Mya. Mammaliaformes ("mammal-shaped") is a clade that **contains the crown group mammals** and their closest extinct relatives. During the evolutionary succession from early therapsid to cynodont to eucynodont to mammal, the main lower jaw bone, the dentary, replaced the adjacent bones. Thus, the lower jaw gradually became just one large bone, **with several of the smaller jaw bones migrating into the inner ear and allowing sophisticated hearing**. Early mammaliaforms were generally shrew-like in appearance and size, and most of their distinguishing characteristics were internal.

Mammals (from Latin mamma, 'breast') are a group of vertebrate animals constituting the class Mammalia, and **characterized by the presence of mammary glands** which in females produce milk for feeding (nursing) their young, **a neocortex** (involved in higher-order brain functions), fur or hair, **and three middle ear bones**. Most mammals are intelligent, with some possessing large brains, self-awareness, and tool use. **Most mammals do not lay eggs, but corresponding structures developed inside their placenta**. All modern mammals give birth to live young, except the five species of monotremes, which are egg-laying mammals. Instead of having many teeth that are frequently replaced, mammals have one set of baby teeth and later one set of adult teeth that fit together precisely. Most mammals use their four extremities for terrestrial locomotion, but in some, the extremities are adapted for life at sea, in the air, in trees, underground, or on two legs.



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The first mammals were very small, and were probably nocturnal to escape predation. Mammals range in size from the 1.2 to 1.6 in. bumblebee bat, to the 98 ft blue whale, possibly the largest animal to have ever lived. Maximum lifespan varies from two years for the shrew to 211 years for the bowhead whale. **The modern mammalian orders arose beginning in the Paleogene, after the extinction of non-avian dinosaurs**. The Paleocene is a geological epoch that lasted from about 66 to 56 Mya. By the early Paleocene, the earth recovered from the extinction, and mammalian diversity increased. **Mammals like the Ambulocetus took to the oceans to eventually evolve into whales, whereas some mammals, like primates, took to the trees**.

Therian mammals took over the medium-to-large-sized ecological niches, after the Cretaceous - Paleogene extinction event emptied ecological space once filled by non-avian dinosaurs and other groups of reptiles, and **underwent an exponential increase in body size**. **Then mammals diversified very quickly.** Therian mammals include the eutherians and the metatherians (including the marsupials). **Therian mammals gave birth to live young without a shelled egg**. This was possible thanks to key proteins called syncytins which allow exchanges between the mother and its offspring through a placenta, even rudimental ones such as in marsupials.

The marsupials and the eutherian mammals evolved from a common therian ancestor that gave live birth by suppressing the mother's immune system. While the marsupials continued to give birth to an underdeveloped fetus after a short pregnancy, the ancestors of placental mammals gradually evolved a prolonged pregnancy. **Pinnae (external ears) are also a distinctive trait that is a therian exclusivity**, though some therians, such as the earless seals, have lost them secondarily.

The Cenozoic is Earth's current geological era, representing the last 66 million years of Earth's history. It is characterized by the dominance of mammals, birds, and flowering plants, and the current configuration of continents. **The Cenozoic is also known as the Age of Mammals because the terrestrial animals that dominated both hemispheres were mammals**, the eutherians (placentals) in the northern hemisphere and the metatherians (marsupials, now mainly restricted to Australia) in the southern hemisphere. As they occupied new niches, mammals rapidly increased in body size, and began to take over the large herbivore and large carnivore niches that had been left open by the decimation of the dinosaurs. Mammals also exploited niches that the dinosaurs had never touched: for example, bats evolved flight and echolocation, allowing them to be highly effective nocturnal, aerial insectivores; and whales first occupied freshwater lakes and rivers and then moved into the oceans. The continents also moved into their current positions during this era.

Eutheria is the clade consisting of all therian mammals that are more closely related to placentals than to marsupials. Eutherians are distinguished from non-eutherians by various phenotypic traits of the feet, ankles, jaws, and teeth. All extant **eutherians lack epipubic bones**, which are present in all other living mammals (marsupials and monotremes). **This allows for expansion of the abdomen during pregnancy**.

Placental mammals arose from the Eutheria. Placentals are partly distinguished from other mammals in that the fetus is carried in the uterus of its mother to a relatively late stage of development. These early eutherians were small, nocturnal insect eaters, with adaptations for life in trees. **Placentals have a placenta, which enables the feeding of the fetus during gestation**. Genetic and morphological diversity rates suggest a Cretaceous (145 to 66 Mya) origin for placentals, and a Paleocene (66 to 56 Mya) origin for most modern clades.

Most mammals, including the six most species-rich orders, belong to the placental group. The three largest orders in numbers of species are Rodentia: mice, rats, porcupines, beavers, capybaras, and other gnawing mammals; Chiroptera: bats; and Soricomorpha: shrews, moles, and solenodons. The next three biggest orders, depending on the biological classification scheme used, are the **Boreoeutherian (Primates)**; the Cetartiodactyla: whales and even-toed ungulates; and the Carnivora which includes cats, dogs, weasels, bears, seals, and allies.

Boreoeutherian is a magnorder of placental mammals that groups together superorders **Euarchontoglires** and Laurasiatheria. With a few exceptions male animals in the clade have a scrotum, an ancestral feature of the clade. The sub-clade Scrotifera was named after this feature. **The common ancestor of Boreoeutheria lived between 107 and 90 Mya**. The boreoeutherian ancestor gave rise to species as diverse as giraffes, dogs, mice, bats, whales, and humans.

Euarchontoglires or Euarchonta are a proposed grand order of mammals containing four orders: the Scandentia (tree shrews), the Dermoptera (colugos), the extinct Plesiadapiformes, **and the Primates**. Recent molecular genetic research on primates, colugos, and tree shrews has shown that the two species of colugos are more closely related to primates than to tree shrews, even though tree shrews were at one time considered primates. **Euarchontoglires** arose in the Cretaceous period, about 88 Mya, and **diverged into** the groups of Scandentia (tree shrews) and **Primatomorpha, around 86 Mya**. The **Primatomorpha** are a mirorder of mammals containing two extant orders: the Dermoptera (colugos) and the **Primates** (Plesiadapiformes, Strepsirrhini, Haplorhini).

Plesiadapiformes is a group of Primates, a sister of the Dermoptera. While none of the groups normally directly assigned to this group survived, the group appears actually not to be literally extinct (in the sense of having no living descendants) as the remaining primates appear to be derived Plesiadapiformes. **Plesiadapiformes may have been the first mammals to have finger nails in place of claws**.

A Primate is a eutherian placental mammal constituting the taxonomic order Primates**. Primates arose 85 to 55 Mya, from Plesiadapiformes, small terrestrial mammals, which adapted to living in the trees of tropical forests**. Primates acquired specialized grasping hands and feet which allowed them to grasp branches, and large eyes with keener vision, which allowed them to forage in the dark. Many primate characteristics represent adaptations to life in this challenging environment.

At least five major features characterize modern primates: relatively large brains; **enhanced vision, and eyes that face forward**; a specialized ability to leap; nails instead of claws on at least the first toes; and specialized grasping dexterous hands and feet. Plesiadapiformes have some but not all of these traits. Primates also have air sacs attached to the larynx, which may function to lower the resonances or increase the volume of sound.

The primary evolutionary trend of primates has been the elaboration of the brain, in particular the neocortex (a part of the cerebral cortex), which is involved with sensory perception, generation of motor commands, spatial reasoning, conscious thought, increasingly complex social behavior and, in humans, language. Primates have large brains (relative to body size) compared to other mammals. **The cranium protects the large brain, a distinguishing characteristic of this group**. In intelligent mammals, such as primates, the cerebrum is larger relative to the rest of the brain.

The arboreal life of primates has led to a tactile, visually dominant sensory system, and a reduction in the olfactory region of the brain. Primates have an increased reliance on visual acuity **at the expense of the sense of smell**, which is the dominant sensory system in most mammals. **These features are more developed in monkeys and apes**, and noticeably less so in lorises and lemurs. Some primates are trichromats, with three independent channels for conveying color information. From studying the other primates that have color vision, **the human kind of color vision arose approximately 55 Mya**.

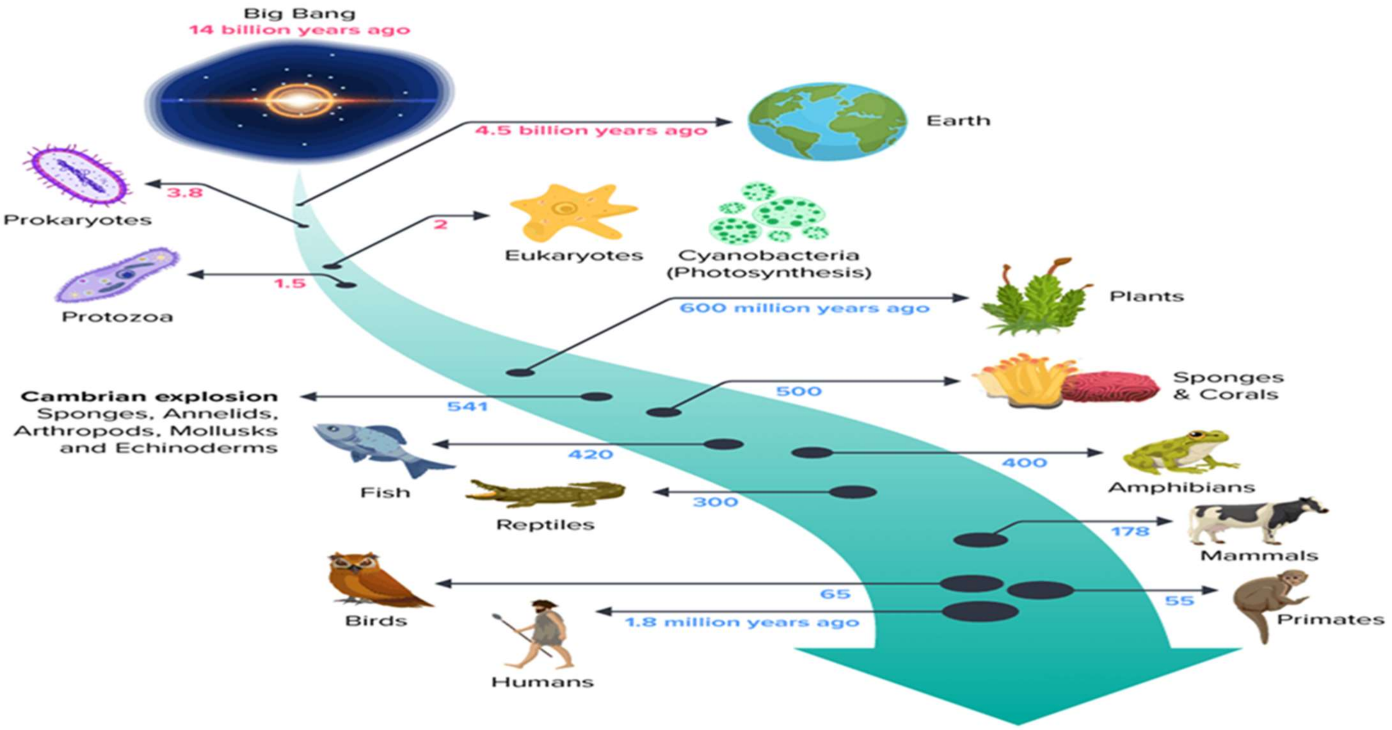
Some primates, including gorillas, humans, and baboons, are primarily terrestrial rather than arboreal, but all species have adaptations for climbing trees. Arboreal locomotion techniques used include leaping from tree to tree and swinging between branches of trees (brachiation); terrestrial locomotion techniques include walking on two limbs (bipedalism) and modified walking on four limbs (knuckle-walking). **Some mammals are bipeds, using only two limbs for locomotion, which can be seen in, for example, the great apes and humans**. Bipedal species have a larger field of vision than quadrupeds, conserve more energy, and have the ability to manipulate objects with their hands, which aids in foraging. Instead of walking, some bipeds hop, such as kangaroos.

Primates are classified as the strepsirrhines and the haplorrhines. Strepsirrhines include the lemurs, galagos, and lorisids, while **haplorrhines include** the tarsiers and **the simians (apes and monkeys)**. The primate skull has a large, domed cranium, which is particularly prominent in simians (anthropoids). Common species that are simians include the Old-World baboons, macaques, gibbons**, and great apes**; and the New World capuchins, howlers, and squirrel monkeys. **The simians, is divided into** two parvorders: Platyrrhine (the New World monkeys) **and Catarrhine (the Old-World monkeys and apes)**. The Platyrrhine split from catarrhines about 40 Mya and have African origin.

The Apes, in both traditional and phylogenic nomenclature, are exclusively catarrhine species. In traditional usage, ape describes any tailless, larger, and more typically ground-dwelling species of catarrhine. The **Apes diverged from Old World monkeys about 25 Mya**. Apes and Old-World monkeys spread from Africa, into Europe and Asia, starting about 23 to 5 Mya.

Hominoidea (Apes) are a branch of Old-World tailless simians native to Africa and Southeast Asia. They are the sister group of the Old-World monkeys, together forming the catarrhine clade. **They are distinguished from other primates** by a wider degree of freedom of motion at the shoulder joint as evolved by the influence of brachiation. Except for gorillas and humans, hominoids are agile climbers of trees. Apes eat a variety of plant and animal foods, with the majority of food being plant foods, which can include fruit, leaves, stalks, roots, nuts, and seeds.

There are two extant branches of the superfamily Hominoidea (Apes): The family **Hylobatidae, the Lesser Apes**, include four genera, and a total of sixteen species of **Gibbon**, including the lar gibbon and the siamang, all native to Asia. They are highly arboreal and bipedal on the ground. They have lighter bodies and smaller social groups than great apes. The family **Hominidae (hominids), the Great Apes**, are tailless primates, with teeth similar to those of the Old-World monkeys and gibbons, although they are especially large in gorillas.



New genetic studies indicated that **gibbons (the Lesser Apes)**, not humans, are the outgroup within the superfamily Hominoidea, meaning, the rest of the hominoids are more closely related to each other, than any of them are to the gibbons. With this splitting, the gibbons were isolated after moving the great apes into the same family as humans. **Those ancestors of the family Hominidae had already speciated, develop into a new and distinct species in the course of evolution, from the family Hylobatidae (the gibbons or Lesser Apes), between 18 to 12 Mya**.

The Hominidae, whose members are known as **Great Apes or hominids**, are a taxonomic family of primates that includes eight extant species in **four genera**: Pongo (the Bornean, Sumatran and Tapanuli orangutan); Gorilla (the eastern and western gorilla); Pan (the chimpanzee and the bonobo); **and Homo**, of which only modern humans remain.

By 1990, genetic investigations, comparing humans and the three other hominid genera, disclosed that the African apes (chimpanzees, gorillas, and humans) are more closely related to each other than any of them are to the Asian orangutans (Pongo). That is, the orangutans, not humans, are the outgroup within the family Hominidae. **The most recent common ancestor of all Homininae lived roughly 14 to 12 Mya**, when the ancestors of the Pongo (orangutans) speciated from the ancestral line of the other three genera.

Homininae, also called "African hominids" or "African apes", is a subfamily of Hominidae. **It includes two tribes**, with their extant as well as extinct species: 1) the tribe **Hominini** (with the genus Homo, including modern humans and numerous extinct species; the subtribe Australopithecina, comprising at least two extinct genera; and the subtribe Panina (Pan) and 2) the tribe Gorillini (gorillas).

DNA comparisons now provided evidence that gorillas, not humans, are the outgroup in the subfamily Homininae. **The Gorillini and Hominini (the "gorilla-human last common ancestor") separation is estimated to have occurred at about 10 to 8 Mya**, during the late Miocene. This resulted in the chimpanzees being grouped with humans in the tribe **Hominini**, but in separate subtribes.

The Hominini include the extant genera **Homo** (humans) **and Pan** (chimpanzees and bonobos). A small African great ape living around 7 Mya was the last animal whose descendants would include both modern humans and their closest relatives, the chimpanzees. Human DNA is approximately 98.4% identical to that of chimpanzees when comparing single nucleotide polymorphisms (SNPs). **The splitting date between human and chimpanzee lineages is placed 8 to 4 Mya**, during the late Miocene epoch. During this split, chromosome 2 was formed, from the joining of two other chromosomes, leaving humans with only 23 pairs of chromosomes, compared to 24 for the other apes.

Australopithecina or Hominina is a subtribe in the tribe Hominini. **The members of the subtribe are generally called Australopithecus**, and it typically includes the earlier Ardipithecus, Orrorin, Sahelanthropus, and Graecopithecus. All these related species are now sometimes collectively termed australopiths. **The australopiths** descended in the Late Miocene era, were bipedal and **dentally similar to humans**, but with a brain size not much larger than that of modern apes, with lesser encephalization than in the genus Homo. **Australopiths shared several traits with modern apes and humans**, and were widespread throughout Eastern and Northern Africa by 3.5 Mya. The earliest evidence of fundamentally bipedal hominins is a 3.6 Mya fossil trackway in Laetoli, Tanzania, which bears a remarkable similarity to those of modern humans. The footprints have generally been classified as australopith, as they are the only form of prehuman hominins known to have existed in that region at that time.

Australopithecus (A) is a genus of early hominins that **existed in Africa from about 4.0 Mya**.[35] The earliest known member of the genus, A. anamensis, existed in eastern Africa around 4.2 Mya. The scientific community took about 20 years to widely accept Australopithecus as a member of the human family tree. Major changes to the pelvis and feet had already taken place before the Australopithecus arose. Australopithecus possessed two (SRGAP2B and SRGAP2C) of three duplicated genes derived from SRGAP2 roughly 3.4 and 2.4 million years ago, **the second of which contributed to the increase in number and migration of neurons in the human brain**. In 1997, an almost complete Australopithecus skeleton with skull was found in the Sterkfontein caves of Gauteng, South Africa. It is now called "Little Foot" and it is around 3.7 Myo.

Note: **The Stone Age** was a broad prehistoric period during which stone was widely used to make stone tools with an edge, a point, or a percussion surface. The period **lasted for roughly 3.4 million years** and ended between 4,000 and 2,000 BCE, with the advent of metalworking. The Stone Age is the first period in the three-age system frequently **used in archaeology to divide the timeline of human technological prehistory into functional periods**, with the next two being the Bronze Age and the Iron Age, respectively.

Homo ('man') is the genus that **emerged, between 3 and 2 Mya, in the otherwise extinct genus Australopithecus.**[36] **Homo** encompasses the extant species Homo sapiens (modern humans), plus several extinct species classified as either ancestral to or closely related to modern humans, depending on the species, **most notably Homo erectus (ancestral) and Homo neanderthalensis (closely related)**. Genus (pl. genera) is a taxonomic rank used in the biological classification of living and fossil organisms as well as viruses. **In the hierarchy of biological classification, genus comes above species and below family**.

The Quaternary Period provides the climate conditions and geographic land boundaries for the evolution of the genera Homo. The Quaternary glaciation, also known as the Pleistocene glaciation, is an alternating series of glacial and interglacial periods during **the Quaternary Period that began 2.6 Mya**, and is ongoing. Since the planet Earth still has ice sheets, geologists consider the Quaternary glaciation to be ongoing, with the Earth now experiencing an interglacial period. Within the Quaternary Period, there were periodic fluctuations of the total volume of land ice, the sea level, and global temperatures. During the colder episodes (referred to as glacial periods, or simply glacials) large **ice sheets at least 13,000 feet thick at their maximum existed in Europe, North**

America, and Siberia. The shorter and warmer intervals between glacials, when continental glaciers retreated, are referred to as interglacials.

Homo (H) erectus (meaning "upright man"), a descendant of the Australopithecus, is an extinct species of archaic human from the Pleistocene, with its earliest occurrence about 2 Mya, and its specimens are among the first recognizable members of the genus Homo (H). **H. erectus was the first Homo to evolve a characteristically human body plan**. By about 1.8 Mya, H. erectus is present in both East Africa (H. ergaster) and in Western Asia (H. georgicus). Over the next 1.5 million years, H. erectus spread throughout Africa and Eurasia. H. erectus was the first human ancestor to spread throughout Eurasia, with a continental range extending from the Iberian Peninsula to Java, Indonesia. It was likely the first human species to live in a hunter-gatherer society and to control fire. An adaptive and successful species, **H. erectus persisted for more than a million years and gradually diverged into new species by around 500 thousand years ago (Kya).**

H. Heidelbergensis is regarded as a chronospecies and is thought to have descended from the African H. erectus (H. ergaster), during the first early expansions of hominins out of Africa, beginning roughly 2 Mya. **H. Heidelbergensis reached Europe by about 500 Kya**. In a wider sense, H. erectus had mostly been replaced by H. heidelbergensis by about 300 Kya. The following article contains a video named Origins of Man, which delineates when these ancient divergencies may have occurred: https://www.history.com/news/human-ancestors-bury-dead-graves

It is largely thought that H. heidelbergensis was the last common ancestor of Neanderthals, Denisovans, and modern humans (H. sapiens), before these populations became isolated in Europe, Asia, and Africa, respectively. According to genetic analysis, the last common ancestor of modern humans and Neanderthal split into a modern human line and a Neanderthal/Denisovan line, and the latter later split into Neanderthal and Denisovans. **Neanderthals and Denisovans are more closely related to each other than they are to modern humans**, meaning the Neanderthal/Denisovan split occurred after their split with modern humans. **The Denisovans and Neanderthals lineage split from modern humans about 804 Kya, and from each other about 640 Kya**.

All modern humans are classified into the species Homo sapiens, coined by Carl Linnaeus in his 18th-century work Systema Naturae. The name "Homo sapiens" means 'wise man' or 'knowledgeable man'. Human evolution is characterized by a number of morphological, developmental, physiological, and behavioral changes that have taken place since the split between the last common ancestor of humans and chimpanzees.

Homo sapiens are the most abundant and widespread species of primate, characterized by bipedalism and large complex brains. This has enabled the development of advanced tools, culture, and language. Humans have a large and highly developed prefrontal cortex, the region of the brain associated with higher cognition.

In the fields of molecular biology and genetics, **a genome is all the genetic information of an organism**. It consists of nucleotide sequences of DNA. **An allele** is a variant of the sequence of nucleotides at a particular location, or locus, on a DNA molecule. Alleles can differ at a single position through single **nucleotide polymorphisms (SNP)**, but they can also have insertions and deletions of up to several thousand nucleobase (base) pairs. **A haplotype** is a group of alleles in an organism that are inherited together from a single parent. More specifically, a haplotype is a combination of alleles at different chromosomal regions, that are closely linked, and that tend to be inherited together. **A SNP** is a genomic variant at a nucleobase, a single base position in DNA, that is, a DNA mutation marker, which genetically distinguishes one human population from another. A haplogroup is a group of similar haplotypes that share a common ancestor, with a single SNP mutation. **Haplogroups pertain to a specific lineage, a single line of descent**.

The Homo sapiens genome was first sequenced in 2001 and, by 2020, hundreds of thousands of genomes had been sequenced.[37] While no humans, not even monozygotic twins, are genetically identical, **two humans on average will have a genetic similarity of 99.5% to 99.9%**. This makes them more homogeneous than other great apes, including chimpanzees. This small variation in human DNA compared to other species suggests a population bottleneck during the Late Pleistocene (around 100 Kya), in which the human population was reduced to a small number of breeding pairs. Note: The last glacial period began about 110 Kya. **Now, with the advent of DNA genome sequencing, we know where and when ancient human populations lived**.

H. sapiens emerged around 300 Kya in Africa, evolving from H. heidelbergensis, and migrating out of Africa, gradually replacing local populations of archaic humans, including the Neanderthals and Denisovans. Soon after H. sapiens first emergence, they spread throughout Africa, to Europe, and to Western Asia in several waves, possibly as early as 250 Kya. **In July 2019, anthropologists reported the discovery of the 210,000-year-old remains of a H. sapiens,** in the Apidima Cave, in Peloponnese, **Greece**.

According to Family Tree, we now know, from human DNA genome sequencing, that the paternal lineage of **Haplogroup A-PR2921 (known as Y-Adam)** was formed when it branched off from the rest of mankind in Africa. The man who is the most recent common ancestor of this line is **estimated to have been born around 232,000 BCE**. He is the ancestor of at least 2 descendant lineages known as A-L1090 and A-L1087.

The paternal lineage of **Haplogroup A-L1090 (or A0-T)** was formed when it branched off from the ancestor haplogroup A-PR2921 and the rest of mankind around 200,000 BCE. The man who is the most recent common ancestor of this line **is estimated to have been born around 150,000 BCE**. He is the ancestor of at least 2 descendant lineages known as A-V148 and A-V168.

The paternal lineage of **Haplogroup A-V168 (or A1)** was formed when it branched off from the ancestor haplogroup A-L1090 and the rest of mankind around 150,000 BCE. The man who is the most recent common ancestor of this line is estimated to have been born around 125,000 BCE. He is the ancestor of at least 2 descendant lineages known as A-M31 and A-V221. **The man who first carried this mutation lived in Africa and is the ancestor to more than 99.9% of all paternal lineages today**.

We also know that **the maternal split of Neanderthal and modern human mtDNA is dated to about 498 to 295 Kya**. And, from the beginning of the modern human maternal lineage**, Haplogroup L (dubbed Mitochondrial Eve)** was formed when it branched off from the rest of modern womankind in Africa. The woman who is the most recent common ancestor of this line is **estimated to have been born between 230,000 and 150,000 BCE**. She is the ancestor of at least 2 descendant lineages known as **L0 and L1-6**.

The maternal lineage of **Haplogroup L0** was formed when it branched off Haplogroup L and from the rest of womankind in Africa, around 200,000 to 130,000 BCE. It is associated with the peopling of Southern Africa by populations ancestral to the Khoisan, after about 140,000 BCE. Its subclades L0d and L0k are almost exclusively restricted to the Khoisan of southern Africa, but L0d has also been detected among the Sandawe people of Tanzania, which suggests an ancient connection between the Khoisan and East African speakers of click languages.

The maternal lineage of **Haplogroup L1-6** was formed when it branched off Haplogroup L and from the rest of womankind in Eastern Africa, around 170,000 BCE, during the Penultimate Glacial Period. Haplogroup L1-6 diverged into haplogroups L1 (140 Kya), L5 (120 Kya), L2 (90 Kya), L6 (90 Kya), and L4 (70 Kya), none of which participated in the out-of-Africa migration.

The maternal lineage of **Haplogroup L3** was formed when it branched off L1-6 and the rest of womankind, in Africa, around 70,000 BCE, and participated in the Southern Dispersal event (Out-of-Africa migration), around 70,000 to 50,000 BCE. It **is inherited by all modern maternal non-African populations, as well as by some populations in Africa**.

The maternal lineage of **Haplogroup M** was formed when it branched off from haplogroup L3 and the rest of womankind in either Eastern Africa or Asia, between 65,000 to 50,000 BCE. An enormous haplogroup spanning all the continents, the macro-haplogroup M, like its sibling the macro-haplogroup N, is a descendant of the haplogroup L3. **All maternal mtDNA haplogroups, considered native outside of Africa, are descendants of either haplogroup M or its sibling haplogroup N**. However, haplogroup M and her offspring are found only among Asians and natives of the Americas.

The maternal lineage of **Haplogroup N** was formed when it branched off from haplogroup L3 and the rest of womankind in either East Africa or Asia, between 70,000 to 50,000 BCE. Haplogroup N is a macro-haplogroup and its descendant lineages are distributed across many continents. However, **descendants of maternal haplogroup N include almost all haplogroups found in Europeans, as well as most women from the Middle East, Southwest Asia, and the Caucasus**. Today, haplogroup N individuals who headed west are prevalent in Turkey and the eastern Mediterranean. Those who travelled east are found in parts of Central Asia and the Indus Valley of Pakistan and India. And members of this haplogroup who headed north out of the Levant and across the Caucasus Mountains have remained in southeastern Europe and the Balkans.

H. sapiens proceeded to colonize all the continents and larger islands, arriving in Eurasia 60 Kya, Australia around 65 Kya, the Americas around 15 Kya, and remote islands such as Hawaii, Easter Island, Madagascar, and New Zealand between the years 300 and 1280 CE. By 11 Kya, Homo sapiens had reached the southern tip of South America, the last of the uninhabited continents, except for Antarctica, which remained undiscovered until 1820 CE.

From here, I will detail the genetic evolution and geographical migration of my paternal ancestors, who originated in Africa, traveled into the Middle East, then across much of Asia and Europe, before migrating to the US in the late 1830s. For over 2,000 years, people all over the world have been researching, studying, and documenting archaeological remains, fossils, cultures, languages, and history. Up until the past 20 years though, most of this story could not have been told. **Now, because of the science of genetics, it can**.

The DNA haplogroups shown below belong to my paternal ancestor populations. Each haplogroup represents an ancient paternal population that survived and created descendent populations of men having the same haplogroups as their ancestors, unless a SNP mutation occurred. Over thousands of years, these populations, sequentially and directly, evolved several new SNP mutations.

We begin in Africa with the arrival of Homo sapiens around 300,000 BCE. **This species lived and evolved in Africa for over 200,000 years and ventured out of Africa in waves**. Following Family Tree's Globetrekker's maps, around 60,000 BCE, my paternal ancestors left Africa and ventured into the Arabian Peninsula. They spent a few millennia in the area of present-day Iran before venturing from there into South and Southeast Asia around 44,000 BCE. From Southeast China, they headed north into East Asia (Russia - Eastern Siberia). Then, **around 34,000 BCE, they began a long journey west from the Altai mountains, where China, Mongolia, Russia, and Kazakhstan meet**.

Note: The last glacial period was the most recent glacial period within the Quaternary glaciation, which began about 110 Kya and ended about 15 Kya. **The Last Glacial Maximum (LGM) was the most recent time that ice sheets were at their greatest extent**.[38] According to Clark et al., growth of ice sheets commenced 33 Kya and maximum coverage was between 26.5 and 19 Kya. According to the United States Geological Survey (USGS), permanent summer ice covered about 25% of the land area during the LGM.

During the Last Glacial Maximum, much of the world was cold, dry, and inhospitable, with frequent storms and a dust-laden atmosphere. Vast ice sheets covered much of North America, Northern Europe, and parts of Asia, and profoundly affected Earth's climate by causing drought, desertification, and a large drop in sea levels. The dustiness of the atmosphere is a prominent feature in ice cores; dust levels were as much as 20 to 25 times greater than now. This was probably due to a number of factors: reduced vegetation, stronger global winds, and less precipitation to clear dust from the atmosphere. **The massive sheets of ice locked away water, lowering the sea level, exposing continental shelves, joining land masses together, and creating extensive coastal plains**.

Since about 20 Kya, **deglaciation commenced** in the Northern Hemisphere, **causing an abrupt rise in sea level**. Decline of the West Antarctica ice sheet occurred between 15 and 14 Kya, consistent with evidence for another abrupt rise in the sea level about 14.5 Kya. **The warming trend following the LGM has resulted in a sea level rise by about 400 feet**.

By around 30,000 BCE my paternal ancestors were living in Eastern Asia (South Central Russia, north of Mongolia), around 26,000 BCE in Central Asia (Eastern Kazakhstan), around 20,000 BCE in the Western Asia area (Western Uzbekistan), and around 17,000 BCE, in the Western Asia area (Southwestern Kazakhstan). **The last glacial period may have been a reason for this migration from the Altai mountains to Eastern Europe**.

Try to keep in your mind as you read this, that within the various populations of men having these haplogroups, some SNP mutations would have originated in a geographical area further east, but as these families migrated to the west, younger family members, over numerous generations, would have inherited more recent paternal SNP mutations further west. Also, some of these families were migrating together for hundreds of miles per year.

My paternal haplogroup R-M269 originated around 12,000 BCE in Eastern Europe (Southwest Russia). The man who is the most recent common ancestor of this line is estimated to have been born around 4350 BCE. My haplogroup R-L23 was formed when it branched off from an ancestor having haplogroup R-M269 in the Caucasus Mountains / Pontic - Caspian steppe (Southwestern Russia). The man who is the most recent common ancestor of this line is estimated to have been born around 4250 BCE.

The haplogroup R-L23 subclade has been found to be prevalent in ancient male DNA associated with the Yamna (Yamnaya) culture and the Western Steppe Herders (WSHs).[39] **According to David Reich, from his book "Who We Are and How We Got Here"**, the Yamnaya people were the result of a genetic admixture between male Eastern European Hunter Gatherers (EHGs) and female Caucasian Hunter Gatherers (CHGs) from the Caucasus mountains. People with this ancestral component are known as WSHs. Also, the Yamnaya ancient DNA itself bore genetic affinity to ancient and present-day people of Armenia (females) and Iranian (males), in a one-to-one ratio of ancestry from these two countries.

The Yamnaya were a group of nomad pastoralists who lived on the Pontic - Caspian steppes, that stretch from Ukraine to Kazakhstan. Dr. Eske Willerslev, a geneticist at the University of Copenhagen, discovered that **the Yamnaya DNA contained the genetic signatures of a number of pathogens, including the one that caused plague, namely Yersinia pestis**.[40] The Yamnaya carried genetic mutations that most likely protected them from pathogens carried by their animals.

Today, people in northern Europe can trace most of their ancestry to the Yamnaya. From 4,000 to 3,000 BCE, **my Yamnaya and WSH ancestors** continued evolving and began spreading their herding culture across western Europe. By 3,000 BCE, according to my Family Tree GlobeTrekker map, my ancestors had headed south and further west through Ukraine and Hungary, near the Black Sea, and probably traveled along the Danube River through parts of what are now known as the Czech Republic, Austria, northern Italy, southern Germany, and Switzerland, and then into eastern France.

WSH ancestry was found to have been carried into the British Isles, by the Bell Beaker culture, in the 3rd millennium BCE. The Beaker Culture arose from around 2800 BCE. A genetic study published in Nature, in February 2018, examined the entry of

WSHs ancestry into the British Isles. The migrations of the Bell Beaker people were accompanied with a replacement of about 90% of Britain's gene pool within a few hundred years.[41] This could have been caused by a Yersinia pestis plague.

Olalde et al. (2017) trace the spread of haplogroup R1b-M269 in western Europe, particularly Britain, to the spread of the Beaker culture, **with a sudden appearance of many R1b-M269 subclans in Western Europe ca. 3000–2500 BCE**, during the early Bronze Age.[41] Note: Haplogroup R-L23, prevalent in the Yamnaya, is a subclan of R1b-M269.

My haplogroup R-Z290 originated around 2,800 BCE in Northwestern Europe (**Belgium**). R-Z290's paternal line was formed when it branched off from an ancestor having haplogroup R-P312 around 2800 BCE. The man who is the most recent common ancestor of this line is estimated to have been born around 2650 BCE.

My paternal haplogroup R-L21's paternal line was formed when it branched off from an ancestor having haplogroup R-Z290 around 2650 BCE in Western Europe (Northwest France). The man who is the most recent common ancestor of this line is estimated to have been born around 2600 BCE. **Haplogroup R-L21 likely belonged to the Celts**, who migrated to Western Europe during the Bronze Age (3300 to 1200 BCE), populating vast regions of what is now Ireland, Great Britain, Northern Spain, and northern France.

Today, **Haplogroup R-L21 is mostly found among the inhabitants of Ireland and Great Britain**, but is also found in Norway, Sweden, Brittany, northern France, modern Northern Portugal, Galicia, and Asturias in the northwest of Spain, and has some presence in Belgium and the Netherlands. **Members of this lineage reach their highest frequency in Ireland**.

The Celts (pronounced with a hard "c" or "k" sound), **originally came from the steppes of Central Europe,** began migrating West towards the Atlantic, consisting of various population groups, living in several parts of Europe, north of the Mediterranean region. With territory stretching from Spain to the Black Sea, the Celts were geographically the largest group of people to inhabit ancient Europe.[42] **The ancient Celts were never a single kingdom or an empire, but a collection of hundreds of tribal chiefdoms, with a shared culture and distinctive language**. The Celts spread, via migration, throughout western Europe, including Britain, Ireland, France, and Spain. Their legacy remains most prominent in Ireland, Great Britain, and Brittany, where their language and culture are still prominent today.

Beakers arrived in Britain around 2500 BCE, with migrations of Yamnaya-related people. The Beaker Culture lasted in Britain until as late as 1800 BCE, but in continental Europe only until 2300 BCE, when it was succeeded by the Unetice culture. **Beakers also arrived in Ireland around 2500 BCE** and fell out of use around 1700 BCE. The earliest British beakers were similar to those from the Rhine, but later styles are most similar to those from Ireland.

My haplogroup R-S552, originated around 2,600 BCE, in Western Europe (**Southeast Britain**). R-S552's paternal line was formed when it branched off from the **ancestor R-L21** around 2600 BCE. The man who is the most recent common ancestor of this line is estimated to have been born around 2550 BCE. He is the ancestor of at least 8 descendant lineages known as R-F4006, **R-DF13**, R-DF63, R-BY11894, R-BY24776, R-BY2994, R-FT21374, and R-BY65267.

Therefore, my paternal ancestors had reached Britain by around 2,600 BCE. This is much earlier than was thought in previous iterations of this material and was caused by Family Tree's new ability to identify the approximate origin date and location for more recently occurring haplogroups. This would place my ancestors in Britain around the same time that the people spreading the Bell Beaker culture, the Celtics, and the Yamnaya and WSH-related people, arrived in Britain.

A 2018 study, **focused on the genetics of England**, found that modern southern, central, and eastern English populations were of "a predominantly Anglo-Saxon-like ancestry", while **those from northern and southwestern England had a greater degree of indigenous (Celt and Briton) origin**.[43]

My haplogroup R-DF13 originated around 2550 BCE in Northwestern Britain (Cumbria). R-DF13's paternal line was formed when it branched off from an ancestor having haplogroup R-S552 around 2550 BCE. The man who is the most recent common ancestor of this line is estimated to have been born around 2450 BCE. He is the ancestor of at least 12 descendant lineages known as R-DF21, R-L513, R-FGC11134, R-FGC5494, R-ZZ10_1, R-Z39589, R-BY23434, R-BY39001, R-BY192942, R-BY145002, R-FTT9, and R-FTA36024. **Most, if not all, of the major Irish lineages branched off haplogroup R-DF13**.

One of the most important sites in Ireland during this period was Ross Island. Ross Island is a peninsula in what is now Killarney National Park, County Kerry. It was in the province of Munster. A series of copper mines from here are the earliest known in Ireland, **starting from around 2500 BCE**. A comparison of chemical traces and lead isotope analysis from these mines, with copper artefacts, strongly suggests that Ross Island was the sole source of copper in Ireland between the dates 2500–2200 BCE. In addition, two thirds of copper artefacts from Britain also display the same chemical and isotopic signature, strongly suggesting that **Irish copper was a major export to Britain at that time**.

My haplogroup R-BY70198 originated around 1550 BCE in Pembrokeshire County, **Wales**. R-BY70198's paternal line was formed when it branched off from an ancestor having haplogroup R-A12910 around 1550 BCE. The man who is the most recent common ancestor of this line is estimated to have been born around 300 BCE. Therefore, my paternal ancestors were still living in Britain around 300 BCE or for at least 2,300 years (2,600 BCE to 300 BCE). **As you will learn below, my paternal ancestors were initially Celtic Britons and possibly Cambro-Normans too!**

My haplogroup R-BY155978 was formed when it branched off from an ancestor having haplogroup R-BY70198, around 300 BCE, and eventually migrated to Southeastern Ireland (Waterford). The man who is the most recent common ancestor of this line is estimated to have been born around 1350 Common Era (CE). He is the ancestor of haplogroup R-BY143837.

My terminal haplogroup R-BY143837 originated around 1350 CE in Southeastern Ireland (Waterford), the same location as haplogroup R-BY155978, according to Family Tree. Haplogroup R-BY143837's paternal line was formed when it branched off from an ancestor having haplogroup R-BY155978. The man who is the most recent common ancestor of this line is estimated to have been born around 1400 CE. Therefore, my paternal ancestors migrated to Ireland, between 300 BCE and 1350 CE, and may have still been living in Waterford County, in 1400 CE.

Now, I will summarize the origin of the Britons and distinguish the Brittonic or Brythonic and Goidelic or Gaelic languages.[44] **The Britons, also known as Celtic Britons**, were the indigenous Celtic people who inhabited Britain from around 2600 BCE and into the Middle Ages (500 CE to 1500 CE), at which point they **diverged into the Welsh, Cornish, and Bretons**. In English, the terms "Briton" and "British" for many centuries originally denoted only the ancient Celtic Britons and their descendants, most particularly the Welsh, Cornish, and Bretons, **who were seen as heirs to the ancient British people**. They spoke the Common Brittonic, also known as the Common Brythonic language, the ancestor of the modern Brittonic languages.

Around 100 BCE the Romans knew the Celts living in present-day France as Gauls.[45] Gaul was a region of Western Europe first described by the Romans. During the 2nd and 1st centuries BCE, Gaul fell under Roman rule. The Celts fled from France to Britain following the Roman invasions. Although Caesar's invasion of Britain was unsuccessful, **the Romans eventually mounted a successful attack against the Britons in the first century CE.** This incursion effectively pushed the Britons on the British island, west to Wales and Cornwall, and north toward Scotland. Some of these Celtic Britons may have migrated to Ireland as well.

The Anglo-Saxon invasion and settlement of Britain, from the mid-5th to early 7th centuries CE, followed the end of Roman rule in Britain, around the year 410 CE.[46] It changed the language and culture of most of what became England, from Romano-British to Germanic. The Germanic-speakers in Britain, themselves of diverse origins, eventually developed a common cultural identity as **Anglo-Saxons**.

The Britons, also known as Celtic Britons or Ancient Britons, **were the indigenous Celtic people who inhabited Britain** from around 2600 BCE and into the Middle Ages (500 CE to 1500 CE), at which point **they diverged into the Welsh, Cornish, and Bretons**. In English, the terms "**Briton**" and "**British**" for many centuries originally **denoted only the ancient Celtic Britons and their descendants, most particularly the Welsh, Cornish, and Bretons**, who were seen as heirs to the ancient British people. **They spoke the Common Brittonic language, the ancestor of the modern Brittonic languages**. As one of the Brittonic languages, Breton is related closely to Cornish and more distantly to Welsh.

The Anglo-Saxon invasion and settlement of Britain changed the language and culture of most of what became England, from Romano-British to Germanic. The Germanic-speakers in Britain, themselves of diverse origins, eventually developed a common cultural identity as Anglo-Saxons. **This process principally occurred from the mid-fifth to early seventh centuries CE, following the end of Roman rule in Britain around the year 410 CE**.

Gauls and Bretons settled in the northwestern corner of present-day France, on the Armorican Peninsula, known today as Brittany. **Ethnically, along with the Cornish and Welsh, the Bretons are Celtic Britons**. **The Bretons are native to Brittany**. Celtic tradition survived in this region as it was geographically isolated from the rest of France, and many festivals and events can trace their origins to Celtic times. Many of the French Bretons wear traditional Celtic hats called coiffes, and roughly one-quarter of the region's residents speak Breton. The Bretons returned to Brittany, from southwestern Britain, particularly Cornwall and Devon, in waves, from the 3rd to the 9th century, most heavily from 450 to 600 CE, during the Anglo-Saxon invasion of Britain. **It is possible that some of my Briton paternal ancestors, that were living in southwestern Britain at this time, were part of this emigration to Brittany**.

The six territories, widely considered to be **Celtic nations,** are Brittany (Breizh), Cornwall (Kernow), Wales (Cymru), Scotland (Alba), Ireland (Éire) and the Isle of Man (Mannin or Ellan Vannin). In each of the six nations a Celtic language is spoken to some extent: Brittonic or Brythonic languages are spoken in Brittany, Cornwall, and Wales, while Goidelic or Gaelic languages are spoken in Scotland, Ireland, and the Isle of Man. **This could be a result of the divergence in paternal descent from haplogroup R-DF13,**

around 2550 BCE. Some descendants migrated north through western Scotland, west to the Island of Man, and into Ireland. Other descendants, including my paternal ancestors, migrated south into southwestern Britain, around Wales and Cornwall, and then on to either Ireland or Brittany, France.

Because my family does not directly descend genetically from the original O’Mahony tribe, I need to include the following **surname information**: The Norman invasion of Wales began shortly after the Norman conquest of England, under William the Conqueror, Duke of Normandy, France, from 1035 CE onward, who believed England to be his birthright.[25] Note, Brittany and Normandy are adjacent to each other. Initially, this invasion was fought between 1067 to 1081 CE. By 1094 CE, most of Wales was under the control of William's son and heir, the later King William II. **Cambro-Normans were Normans who settled in southern Wales after the Norman invasion of Wales**, allied with their counterpart families who settled in England following its conquest.

In 1150 CE **French born Henry II** was Duke of Normandy, France, **and was the King of England** from 1154 until his death in 1189 CE. In May 1169 the Anglo-Normans invaded Ireland.[47] South Wales was under Anglo-Norman control at this point in history, but **the Cambro-Normans, living in south Wales, owed their allegiance to Henry II**. Therefore, the Cambro-Normans are often confused with Anglo-Normans. Some Irish historians prefer to use Cambro-Normans, instead of Anglo-Normans, because many of the knights who invaded Ireland, such as the FitzGeralds, originated and settled in modern-day Wales, following the Norman conquest. The Cambro-Norman invasion was a watershed in Ireland's history, marking the beginning of more than 800 years of brutal, oppressive, and direct British conquest and colonialism in Ireland.

Richard de Clare, known as "Strongbow", was the leader of the invading Cambro-Norman Knights.[48] Strongbow died a very short time after invading Ireland **but the men he brought with him remained in Ireland**. His army took the Ostman towns of Wexford, Waterford, and Dublin, between 1169 and 1170.[49] So, my paternal ancestors could have been living in Waterford, Ireland around this time. The man who is the most recent common ancestor of haplogroup R-BY155978 is estimated to have been born around 1350 CE, in Southwestern Britian or Southeastern Ireland (Waterford). Most of these Normans came from Wales and thus the epithet 'Cambro-Normans' is used to describe them. They increasingly integrated with the local Celtic nobility through intermarriage and some accepted aspects of Celtic culture. The Norman conquest of Ireland (from 1169 to 1541 CE), saw Cambro-Normans settle vast swaths of Ireland, becoming the Irish-Normans. This is ironic since, ethnically, both populations were Celts!

The entire Province of Munster was under the control of the Ó Briain clan from 1072 to 1114. Their capital was located in Limerick. **In 1118 CE** the Treaty of Glanmire partitioned Munster, between the northern section of the province, the Kingdom of Thomond ("North Munster"), and the southern section became **the Kingdom of Desmond** ("South Munster").[50] Following the Cambro-Norman invasion of Ireland in the late 12th century, the eastern half of Desmond was conquered by the Cambro-Normans and became the Earldom of Desmond. But the western half of Desmond lived on as a semi-independent Gaelic kingdom. From the 12th to the 14th centuries the Cambro-Norman invasion, and their multiple attempts to take Thomond from the Gaels, was the main challenge to the realm.

The O’Mahony clan lived around Garranes Ringfort, in the Templemartin parish, near Bandon, County Cork. This may have been the location of the Rath Raithleann, the royal seat of the Éoganacht Raithleann, which became the O’Mahony clan around 1135 CE. **The Éoganacht Raithleann tribes lived in this area of Desmond for over 900 years, from about 340 CE to at least 1300 CE**.

Following the Norman invasion of Ireland in the late 12th century, **the eastern half of Desmond was conquered by the Cambro-Normans** and became the Earldom of Desmond. The king of Desmond, Diarmaid Mac Cárthaigh, submitted to Henry II of England, but **the western half of Desmond lived on as a semi-independent Gaelic kingdom**. **It was often at war with the Cambro-Normans**. **From the 12th to the 14th centuries**, the Norman invasion, and their multiple attempts to take Thomond from the Gaels, was the main challenge to the realm. The remainder of the Middle Ages was marked by conflict between Gaels and Cambro-Normans, the medieval ruling class in England.

From the late Canon John O'Mahony’s book, “A History of the O'Mahony Septs of Kinelmeky and Ivagha:” A considerable period elapsed after the death of Mahon (1038 CE, Annals Four Masters) before his name became the hereditary surname of his descendants. Mahon's son and successor was Brodchon, born around 1050 CE. If the entry in the Annals of Innisfallen (Dublin copy) for the year 1135 CE was an exact copy of an original written in that year, we should say that Cian (the second), great-grandson of Mahon, was the first designated by the surname: "Cian, son of Donogh Donn, son of Brodchon, O'Mahony, was killed at the battle of Cloneinagh." **Therefore, we should consider the year 1135 CE to be when the surname O'Mahony became the hereditary surname of Mahon’s descendants**.

Since my paternal ancestors probably lived in Southwest England (Wales) or Wexford County, Ireland, around 1350 CE, during the Anglo-Norman invasion of Ireland, between 1169 – 1541; and some Celtic men from Southwest England, namely the Cambro-Normans from Wales, owed their allegiance to the French born, Henry II, King of England; and Strongbow’s army took the Ostman towns of Wexford, Waterford, and Dublin, between 1169 and 1170; and the man who is the most recent common ancestor of haplogroup R-BY155978 is estimated to have been born around 1350 CE, in Southeastern Ireland (Waterford); and some of the Cambro-Norman men Strongbow brought with him remained in Ireland and increasingly integrated with the local Celtic nobility through intermarriage; and some Cambro-Normans settled vast swaths of Ireland becoming the Irish-Normans; and the O’Mahony families lived in Desmond during the Anglo-Norman invasion of Ireland; and the eastern half of Desmond was conquered by the Cambro-Normans; but the western half of Desmond lived on as a semi-independent Gaelic kingdom, and was often at war with the Cambro-Normans; it is possible to infer the following:

My paternal ancestors could have participated in the Cambro-Norman invasion of Ireland, settled first in Waterford and then in Desmond, married into the O’Mahony clan, or experienced a non-parental event, or just assumed the O’Mahony surname (more common in the tribes of those days). A non-paternity event (NPE) is a situation in which someone who is presumed to be an individual’s father is not in fact the biological father. This can happen due to various reasons such as undisclosed adoption, promiscuity, paternity fraud, adultery, or sexual assault.

Furthermore, **the most prominent Cambro-Norman family in Desmond was the FitzGerald or Geraldines**. The FitzGerald dynasty is a noble and aristocratic dynasty of Cambro-Norman origin. They have been peers of Ireland since at least the 13th century, and are described in the Annals of the Four Masters as having become "more Irish than the Irish themselves" or Gaels, due to assimilation with the native Gaelic aristocratic and popular culture. The dynasty has also been referred to as the Geraldines and Ireland's largest landowners. Gerald FitzMaurice FitzGerald (1335–1398), was the 3rd Earl of Desmond, under the first creation of that title, and a member of the Anglo-Norman dynasty of the FitzGerald or Geraldines. I wonder if this family had my haplogroup R-FGC11134, a descendent of haplogroup R-DF13, or even haplogroup R-BY155978. Also, **is Family Tree working on a DNA study for the Cambro-Normans?**

One major branch of the O’Mahony’s headed southwest to the Celtic Sea and settled near the eastern point of **Schull Harbor**, where they erected the Castle of Ardintennane (Ardintenant), ca.1310 CE, the principal seat of the Chieftain of Ivagha or the Fonn lartharach, "Western Land." **O’Mahony clan chiefs lived in either Ardintennane or Rossbrin Castle, from the early 1300s CE until the late 1500s CE**, that is, for almost 300 years.

My paternal ancestors were living in Bantry, Ireland around 1800 CE, and had already assumed the Mahony surname. The distance from Schull, where one major branch of O’Mahony families lived, to Bantry, where my ancestors lived in the early 1800s, is only about 16 miles. The Tithe War may have been the final reason why my family left Ireland, around 1838, for the US!

Here is a summary of my Paternal Ancestor Haplogroup Timeline

Step	Haplogroup	Age Estimate	Location	My Comments
1	R-BY143837	1,350 CE	Waterford, Ireland	Most recent common ancestor born around 1400 CE in Waterford, Ireland
2	R-BY155978	300 BCE	Waterford, Ireland	Most recent common ancestor born around 1350 CE in Waterford, Ireland
3	R-BY70198	1,550 BCE	Wales	In Pembrokeshire County, Wales. **Possibly associated to the Cambro-Normans**.
4	R-A12910	1,700 BCE	W. Central Britian	
5	R-A12897	2,450 BCE	W. Central Britian	
6	R-FGC5494	2450 BCE	Cumbria, Britian	FGC5494 is well dispersed in England, Scotland, Wales, Isle of Man, and Ireland
7	**R-DF13**	2,550 BCE	Cumbria, Britian	Characteristic of a majority of the living male inhabitants of Ireland, Scotland, Wales, and Brittany. **Most of the paternal genetic variations in Ireland branched from this SNP**.
8	R-S552	2550 BCE	SE Britian	**Possibly associated with the Britons** and both the Brittonic or Brythonic and Goidelic or Gaelic languages.
9	**R-L21**	2600 BCE	NW France	**R-L21 is likely a haplogroup belonging to the Insular Celts**
10	R-Z290	2,800 BCE	Belgium	
11	R-P312	3,000 BCE	Southern Germany	Most common clade of paternal lineages across much of Western Europe
12	R-L151	3,300 BCE	Eastern Germany	
13	R-P310	4,000 BCE	Austria/Slovakia	
14	R-L51	4,250 BCE	Ukraine	
15	**R-L23**	4,350 BCE	SW Russia	**Western Steppe Herder (WSH)** and **Yamnaya descent**. (Pontic–Caspian steppe)
16	R-M269	12,000 BCE	SW Russia	The most common European haplogroup
17	R-P297	15,000 BCE	Kazakhstan	Southwestern Kazakhstan
18	R-L389	15,000 BCE	Kazakhstan	Southwestern Kazakhstan
19	R-L761	16,000 BCE	Kazakhstan	Southwestern Kazakhstan
20	R-L754	17,000 BCE	Kazakhstan	Southwestern Kazakhstan
21	**R-M343 (R1b)**	20,000 BCE	Uzbekistan	**Highest proportion of R-M343 are the Kurds of southeastern Kazakhstan**
22	R-M173 (R1)	26,000 BCE	Kazakhstan	Very common throughout all of Eurasia, except East Asia and Southeast Asia
23	**R-M207**	30,000 BCE	Eastern Russia	**"Mal'ta boy" from the Altai region, in south-central Siberia, North of Mongolia**
24	P-P226	34,000 BCE	Mongolia	Descended into two of the most widespread male lineages in modern populations (Q & R)
25	P-P284	34,000 BCE	Eastern Russia	
26	P-M45	42,000 BCE	Eastern Russia	Basal P1* is now most common in Eastern Siberia and Central Asia
27	P-P295	42,000 BCE	China	
28	P-PF5850	42,000 BCE	Myanmar	Also known as P or K2b2
29	K-YSC0000186	43,000 BCE		Also known as K-K2b
30	K-M526	43,000 BCE	Bangladesh	Also known as K2. Found at the Tianyuan Cave near Beijing.
31	**K-M9**	44,000 BCE	Iran	**The ancestor of major haplogroups M, N, O, P, Q, R, S, L, and T**
32	IJK-L15	45,000 BCE	Iran	
33	HIJK-PF3494	46,000 BCE	Iran	
34	GHIJK-F1329	46,000 BCE	Iran	
35	**F-M89**	46,000 BCE	Oman	**This marker is found in 90 to 95 percent of all non-Africans.**
36	CF-P143	62,000 BCE	Ethiopia	This mutation is one of the oldest to have occurred outside of Africa
37	CT-M168	63,000 BCE	Ethiopia	His descendants became the only lineage to survive outside of Africa, making him the **common ancestor of every non-African man living today**.
38	BT-M42	85,000 BCE	Central Africa	This branch is shared by almost all men alive today, both in Africa and around the world
39	A-V221 (A1b)	120,000 BCE	Central Africa	
40	**A-V168 (A1)**	125,000 BCE	Western Africa	**Includes the vast majority of all living male modern human sapiens**.
41	A-L1090 (A0-T)	150,000 BCE	Western Africa	
42	A-PR2921	232,000 BCE	Western Africa	
43	A000-T	368,000 BCE	Western Africa	
44		640,000 BCE		Denisovans/Neanderthals split from each other
45	**A0000**	705,000 BCE	Western Africa	**First Homo Sapiens population**
46		804,000 BCE		Modern humans and Neanderthal/Denisovan split into two lines
47		~ 2 Mya		H. Heidelbergensis descended from African H. erectus (H. ergaster)

Carl Edward Sagan was an American astronomer and science communicator. **The following excerpts were taken directly from his book titled "Cosmos: A Personal Voyage:"**

For unknown ages **after the explosive outpouring of matter and energy of the Big Bang**, the Cosmos was without form. There were no galaxies, no planets, no life. Deep, impenetrable darkness was everywhere, **hydrogen atoms in the void**. Here and there denser accumulations of gas were imperceptibly growing, **globes of matter were condensing forming hydrogen raindrops more massive than suns**. Within these globes of gas was kindled the first nuclear fire latent in matter. A first generation of stars was born, flooding the Cosmos with light. There were in those times not yet any planets to receive the light, no living creatures to admire the radiance of the heavens. **Deep in the stellar furnaces the alchemy of nuclear fusion created heavy elements, the ashes of hydrogen burning, the atomic building materials of future planets and lifeforms**. Massive stars soon exhausted their stores of nuclear fuel.

Rocked by colossal explosions, these massive stars returned most of their substance back into the thin gas from which they had once condensed. **Here in the dark, lush clouds between the stars, new raindrops made of many elements were forming**, later generations of stars being born. Nearby, smaller raindrops grew, bodies far too little to ignite the nuclear fire, **droplets in the interstellar mist on their way to form the planets**. Among them was a small world of stone and iron, **the early Earth**.

After a time, the seas achieved the consistency of a warm, dilute soup. **Molecules were organized, and complex chemical reactions driven, on the surface of clays**. And one day a molecule arose that quite by accident was able to make crude copies of itself out of the other molecules in the broth. As time passed, more elaborate and more accurate self-replicating molecules arose. Those combinations best suited to further replication were favored by the sieve of natural selection. Those that copied better produced more copies. And the primitive oceanic broth gradually grew thin as it was consumed by and transformed into complex condensations of self-replicating organic molecules. **Gradually, imperceptibly, life had begun**.

Single-celled plants evolved, and life began to generate its own food. Photosynthesis transformed the atmosphere. Sex was invented. Once free-living forms banded together to make a complex cell with specialized functions. Chemical receptors evolved, and the Cosmos could taste and smell. **One-celled organisms evolved into multicellular colonies, elaborating their various parts into specialized organ systems**.

Eyes and ears evolved, and now the Cosmos could see and hear. Plants and animals discovered that the land could support life. Organisms buzzed, crawled, scuttled, lumbered, glided, flapped, shimmied, climbed, and soared. Colossal beasts thundered through the steaming jungles. **Small creatures emerged, born live instead of in hard-shelled containers, with a fluid like the early oceans coursing through their veins**. They survived by swiftness and cunning.

And then, only a moment ago, some small arboreal animals scampered down from the trees. They became upright and taught themselves the use of tools, domesticated other animals, plants and fire, and devised language. **The ash of stellar alchemy was now emerging into consciousness**. At an ever-accelerating pace, it invented writing, cities, art, and science, and sent spaceships to the planets and the stars. **These are some of the things that hydrogen atoms do, given fifteen billion years of cosmic evolution**.

Like all our organs, the brain has evolved, increasing in complexity and information content, over millions of years. Its structure reflects all the stages through which it has passed. The brain evolved from the inside out. Deep inside is the oldest part, **the brainstem, which conducts the basic biological functions, including the rhythms of life, heartbeat, and respiration**.

According to provocative insight by Paul MacLean, the higher functions of the brain evolved in three successive stages. **Capping the brainstem is the R-complex, the seat of aggression, ritual, territoriality, and social hierarchy, which evolved hundreds of millions of years ago in our reptilian ancestors**. Deep inside the skull of every one of us there is something like the brain of a crocodile.

Surrounding the R-complex is the limbic system or mammalian brain, which evolved tens of millions of years ago in ancestors who were mammals but not yet primates. It is a major source of our moods and emotions, of our concern and care for the young.

And finally, on the outside, living in uneasy truce with the more primitive brains beneath, is the cerebral cortex, which evolved millions of years ago in our primate ancestors. The cerebral cortex, where matter is transformed into consciousness, is the point of embarkation for all our cosmic voyages. Comprising more than two-thirds of the brain mass, it is the realm of both intuition and critical analysis. It is here that we have ideas and inspirations, here that we read and write, here that we do mathematics and compose music. The cortex regulates our conscious lives. **It is the distinction of our species, the seat of our humanity**. **Civilization is a product of the cerebral cortex**.

Books permit us to voyage through time, to tap the wisdom of our ancestors. The library connects us with the insights and knowledge, painfully extracted from Nature, of the greatest minds that ever were, with the best teachers, drawn from the entire planet and from all of our history, to instruct us without tiring, **and to inspire us to make our own contribution to the collective knowledge of the human species**. (Hopefully, this article will be my contribution to this collective knowledge! MPM)

Our intelligence has recently provided us with awesome powers. **It is not yet clear that we have the wisdom to avoid our own self-destruction**. But many of us are trying very hard. We hope that very soon in the perspective of cosmic time **we will have unified our planet peacefully into an organization cherishing the life of every living creature on it** and will be ready to take that next great step, to become part of a galactic society of communicating civilizations.

There are worlds (planets) on which life has never arisen. There are worlds that have been charred and ruined by cosmic catastrophes. We are fortunate: we are alive; we are powerful; **the welfare of our civilization and our species is in our hands. If we do not speak for Earth, who will? If we are not committed to our own survival, who will be? What account would we give of our stewardship of the planet Earth?** We have heard the rationales offered by the nuclear superpowers. We know who speaks for the nations. **But who speaks for the human species? Who speaks for Earth**?

If we are willing to contemplate nuclear war and the wholesale destruction of our emerging global society, **should we not also be willing to contemplate a wholesale restructuring of our societies?** From an extraterrestrial perspective, our global civilization is clearly on the edge of failure in the most important task it faces: **to preserve the lives and well-being of the citizens of the planet**. Should we not then be willing to explore vigorously, in every nation, major changes in the traditional ways of doing things, **a fundamental redesign of economic, political, social, and religious institutions? What is the alternative? Our loyalties are to the species and the planet. We speak for Earth**.

Let us now leave this fabulous book, by Carl Sagan, and discuss heredity. **Biology** is the scientific study of life. All living organisms are made up of cells that process hereditary information encoded in genes, which can be transmitted to future generations. Another major theme is **evolution**, which explains the unity and diversity of life. **Energy** processing is also important to life as it allows organisms to move, grow, and reproduce. So, what is heredity, and what does it mean?

Heredity, also called inheritance or **biological inheritance**, is the passing on of traits from parents to their offspring; either through asexual reproduction or sexual reproduction, the offspring cells or organisms acquire the genetic information of their parents. Through heredity, variations between individuals can accumulate and cause species **to evolve and mutate by natural selection**. The study of heredity in biology is **genetics**.

The Homo sapiens genome was first sequenced in 2001 and, by 2020, hundreds of thousands of genomes had been sequenced. **Now, with the advent of DNA genome sequencing, we know where and when ancient human populations lived**. We now know that the first known man was born around 232,000 BCE. He inherited haplogroup A-PR2921 from his father and branched off from the rest of mankind. We also know that the first woman was born between 230,000 and 150,000 BCE. She inherited haplogroup L from her mother and branched off from the rest of modern womankind. In July 2019, anthropologists reported the discovery of the 210,000-year-old remains of a Homo sapiens, in Greece.

We now know that Homo ('man') is the genus that emerged, between three and two Mya, in the otherwise extinct genus Australopithecus and that the Australopithecus is a genus of early hominins that existed in Africa from about four Mya. Going further back, the humans and chimpanzee lineages split around eight to four Mya. **This is our recent heredity**! From there, our heredity descends from the primates, the mammals, the amphibians, the fish, and the earliest animals, earliest Eukaryotes, and all the way back in time to the earliest Prokaryotes. **This is our ancient heredity**!

Animals are monophyletic, meaning they are derived from a common ancestor, 650 Mya. As Carl Sagan said, we know that **our human brain evolved from the inside out**, starting with the oldest part, the brainstem, which conducts the basic biological functions, including the rhythms of life, heartbeat, and respiration. Capping the brainstem is the R-complex, which evolved hundreds of millions of years ago **in our reptilian ancestors**. Surrounding the R-complex is the limbic system or mammalian brain, which evolved tens of millions of years ago in ancestors **who were mammals but not yet primates**. And finally, on the outside, living in uneasy truce with the more primitive brains beneath, is the cerebral cortex, which evolved millions of years ago **in our primate ancestors**. Civilization is a product of the cerebral cortex.

The more we learn about the Milky Way and its dynamic history, the more incredible it seems that we are orbiting just one star among billions. What if **liquid water (H_2O)**, which is necessary for life as we know it, did not exist on the surface of Earth? And what if our earth was not in the **habitable zone**, a distance far enough from the Sun that it does not lose its water, but not so far that low temperatures cause all water on the planet to freeze. And what if our Sun was not fueled by the **nuclear fusion of hydrogen** to form helium deep in its interior?

It is important to realize, astronomically, that **the seeds of life on Earth were sown when our solar system was formed**. It tells us that the story of life, of us, extends far beyond our Earth, our solar system, and our Milky Way galaxy. In 2022, I realized that our evolution actually began at the beginning of the Universe, with the introduction of hydrogen!

Only six chemical elements on the periodic table **account for 97 percent of your body's mass**: carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus. Not coincidentally, these elements exist in great abundance in our Milky Way galaxy and beyond. **If hydrogen** and helium were never created in the Big Bang of the Universe, and the other chemical elements were never produced by billions of stars, over billions of years, **you would not be reading this article**.

And in the words of Andrew Herbert Knoll, on this planet, at this moment in time, human beings reign. Regardless of who or what penned earlier chapters in the history of life, we will write the next one. Through our actions or inaction, we decide the world that our grandchildren and great grandchildren will know. **Let us have the grace and humility to choose well**.

Our differences are tiny! Hopefully, together, we can navigate a better destiny for all life on our little blue dot.

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