Like gazing at the stars, the earth beneath our feet similarly provokes wonder in us: wonder at the precise and unexpected series of events leading to our existence; wonder at evidence of the patient preparation of the place we occupy; wonder at the gratuitous investment in materials and energy that fuel our productivity, form our buildings, power our devices, keep us warm, and adorn us with beauty.

Careful attention to the natural world reveals that we are surrounded by profound signs left behind by pre-historic events, even to the beginning of time itself.

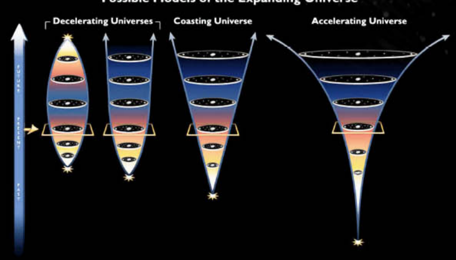
This Exhibit enters the fascinating story begging to be discovered in rocks, fossils, and many other earthly events.

NEW YORK ENCOUNTER

Signs Awaiting Discovery:

The Story Rocks Tell Us

In the Beginning...



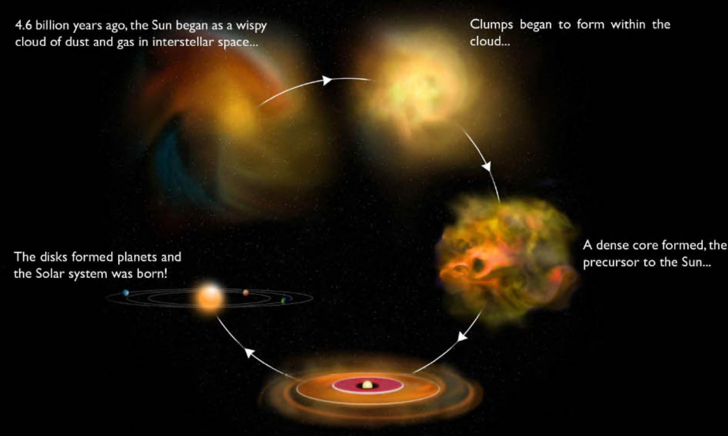
Expansion of the Universe at different possible rates. Only a narrow range of possible expansion rates would give rise to a Universe with long lived galaxies able to support life.

Fr. Georges Lemaitre's work on general relativity suggested a model for the origin of the Universe that has become popularly known as "The Big Bang." The prevailing view is that the Universe came into existence about 13.7 billion years ago.

Since the Big Bang, the Universe has expanded and cooled. Formation of simple atoms like hydrogen took roughly one million years of expansion and cooling. Much more time passed before those atoms came together to form clouds of such immense size and gravity to ignite a nuclear reaction and form a star. The fusion process in stars formed helium and heavier elements such as carbon, oxygen, nitrogen, and many others required for life as we know it. These stars would burn for millions to billions of years before exploding and sending their contents across the Universe.

The necessary elements to support life require a Universe just as old and large as our observed Universe, whether on one planet or many.

Southern Ring Nebula,
James Webb Space Telescope



Big Bang to Earth's Formation (13.7 – 4.6 billion years ago)

Inspiring Wonder:
Geology and the Discovery of Many Signs

Rocks contain the rich story of Earth's antiquity. Pre-historic events left many profound signs that tell this story and await our discovery.

What is the story of the events leading to our existence?

What is the story of the place we inhabit?

How was the Earth invested with the materials, energy, and beauty that enable human flourishing?

Geology pursues the answers to these questions. Rocks contain clues about events that pre-date history and reveal the story of those events with amazing detail. Geologists also help humankind possess wealth and resources and extract energy and materials needed to enhance productivity.

How Do the Rocks Tell a Story?

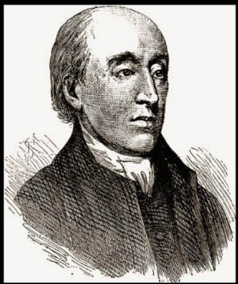
When something in nature strikes us with wonder, we often find that wonder multiplies itself as we pursue our curiosity and come to see how the original artifact is in fact connected with all things.

Nicolaus Steno (1638 – 1686)

Nicolaus is the father of modern stratigraphy, the study of the order and position of layers of rock. Steno's background in anatomy led to his realization that "tongue stones", a type of rock commonly found in Europe, were actually fossilized shark teeth covered by layers of Earth. He proposed the Principle of Superposition that states that strata, or layers of earth, occur sequentially with younger layers continually stacked above older layers. His observation tied time to sedimentary rocks and revised scientists' understanding of the age of the Earth and the importance of fossil placement.

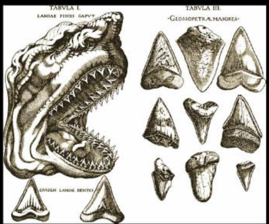
Folded rocks of Agios Pavlos, Greece

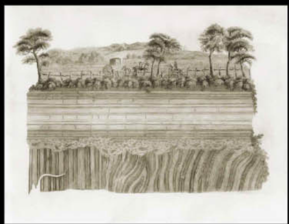
James Hutton (1726-1797)



Many geologists consider James Hutton to be the father of historical geology. Hutton observed such processes as wave action, erosion by running water, and sediment transport and concluded that, given enough time, these processes could account for the geologic features in his native Scotland. He thought that "the past history of our globe must be explained by what can be seen to be happening now."

Rocks have preserved a wealth of information about how our world came to be what it is today. Geosciences extract this information, ordering and assigning ages to past events by using various dating principles. For hundreds of years, scientists used relative dating methods, including the Principle of Superposition, to discover Earth's great antiquity. Only recently have scientists discovered ways to assign precise ages to events through absolute dating methods like radiometric dating.

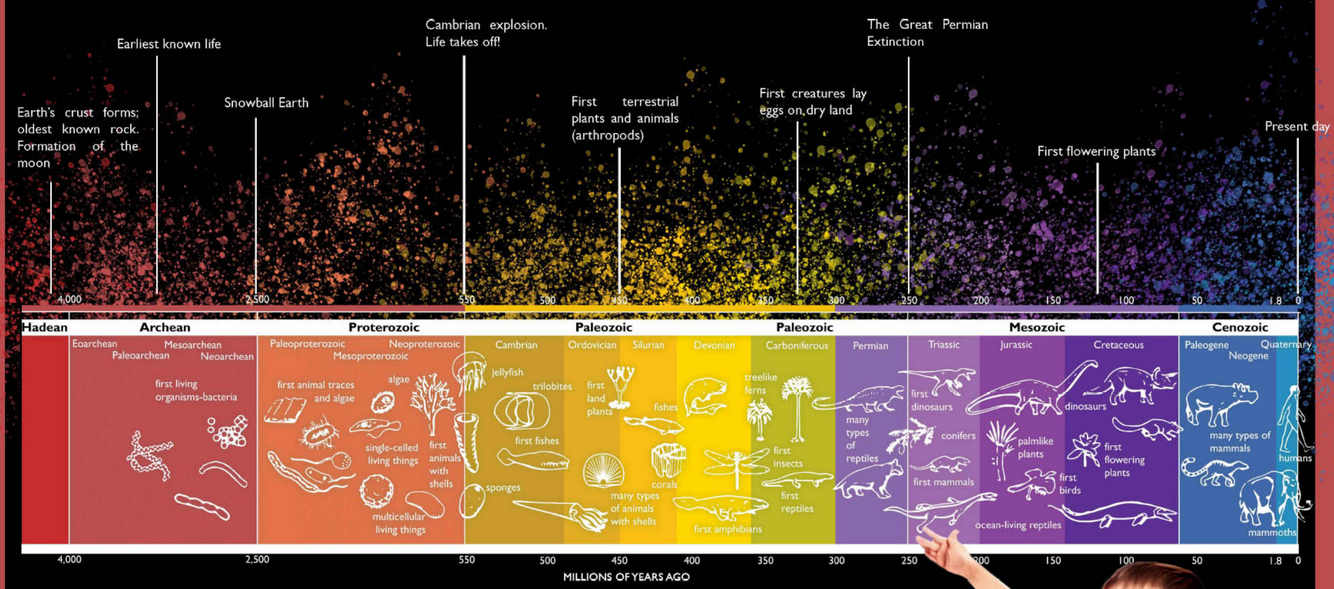




A drawing of shark teeth and "tongue stone" fossils by Nicolaus Steno (Left); Artwork of rock strata forming a structure known as an unconformity by James Hutton (Right)

Microscopic view of limestone similar to that used to build Egyptian pyramids. Contains foraminifera, ubiquitous single-celled marine organisms with carbonate shells

A Long Time in the Making



Acasta Gneiss – sample from an ancient rock outcrop on the surface today, over 4 billion years old

The geologic time scale is a representation of time based on signs preserved in Earth's rock record of the fascinating creatures, events and forces that shaped the planet.

The Earth is about 4.6 billion years old. The Earth's mass stabilized and its crust hardened in the Hadean Eon.

If the span of your outstretched arms represents all geologic time, and your fingertips on one hand represent the formation of Earth, the Cambrian Explosion would lie on the wrist of your opposite hand. The Permian Extinction is at the other end of the palm, the Cenozoic Era is a fingerprint, and a single stroke of a nail file would wipe out human history.

(John McPhee)

The planetary collision that formed the Moon

A MOVING TARGET

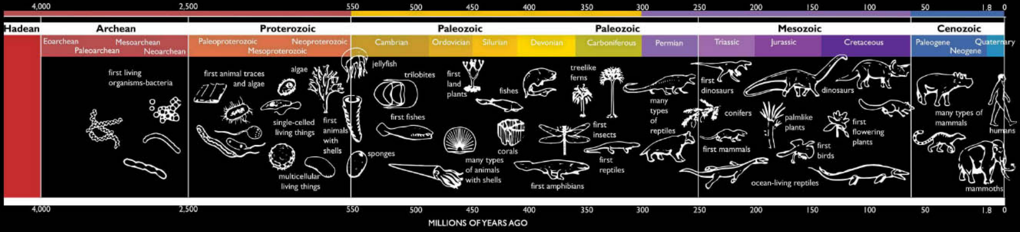
The Hadean Eon is named for the hellish conditions of the early Earth. At 1000°C, the Earth was still extremely hot as material collided during the formation process. Very early, around 4.5 billion years ago, the Moon was formed, likely through a collision with an ancient planet. Earth was inhospitable to life.

The Late Heavy Bombardment occurred between 4.1 and 3.8 billion years ago and is named for a series of smaller collisions. The moon's craters may have formed during this time. An estimated 22,000 meteors struck the Earth, each releasing a billion times more energy than an atomic bomb.

Zircon grains crystallized in magma during early formation of the Earth's crust. These are some of the oldest minerals that can be found today. The oldest known rock, a fragment of Earth's ancient crust, is exposed in the Acasta outcrop in a remote location north of Yellowknife, Canada.

Zircon crystal, approximately 1 mm

Hadean Eon (4600 – 4000 million years ago)



LET THERE BE LIFE

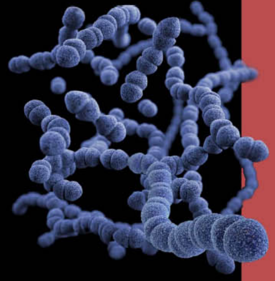
Stromatolite field

Fossilized stromatolite, 3.4 billion years old

The Earth continued to cool and formed the first permanent crust. Ocean temperatures also cooled giving rise to the earliest forms of life such as single-celled bacteria. These microbes interacted with sediment and formed "microbial mats" or stromatolites which still form today.

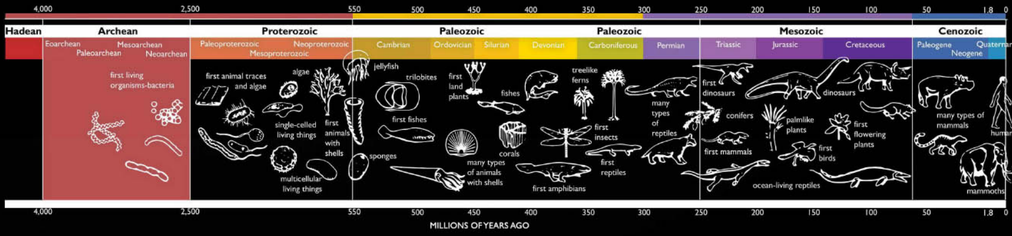
Simple life forms like photosynthetic cyanobacteria began to produce oxygen around 3.7 billion years ago, but much of it was quickly consumed in chemical reactions instead of accumulating in the atmosphere. These chemical reactions included the formation of iron oxides which deposited iron into the rock formations mined today for iron ore. Oxygen also reacted with methane in the atmosphere to produce CO_2 (a less potent greenhouse gas) and water, resulting in the Huronian ice age around 2.5 billion years ago. Oxygen reached significant levels in the atmosphere only after a billion years or more of photosynthesis.

Banded iron formation



Photosynthetic bacteria

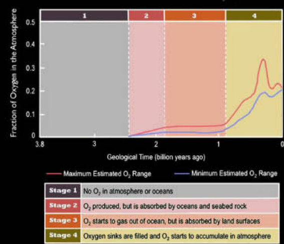
Archean Eon (4000 – 2500 million years ago)



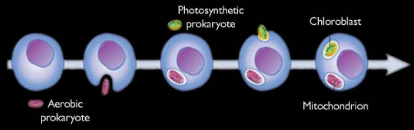
TERRAFORMING EARTH

Billions of years of photosynthesis precipitated iron from the oceans, removed methane from the atmosphere, and wiped out a multitude of life forms while giving rise to life as we know it.

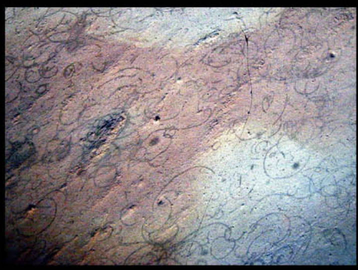
As oxygen accumulated in small amounts in the atmosphere, it nearly led to the extinction of life on Earth. Oxygen contributed to massive ice ages and was toxic to early life forms. This period is sometimes referred to as the Oxygen Crisis. Surviving organisms evolved methods of dealing with increased levels of oxygen, such as developing new biochemical pathways that used oxygen to exploit new stores of energy.



Eukaryotes are complex cells able to use these new pathways and first appeared in the fossil record during this time. Eukaryotes have complex organelles that allow cells to complete specialized functions enabling the formation of diverse multicellular organisms. At the end of the Eon, the impressive diversity of soft-bodied marine plants and animals foreshadowed the Cambrian Explosion

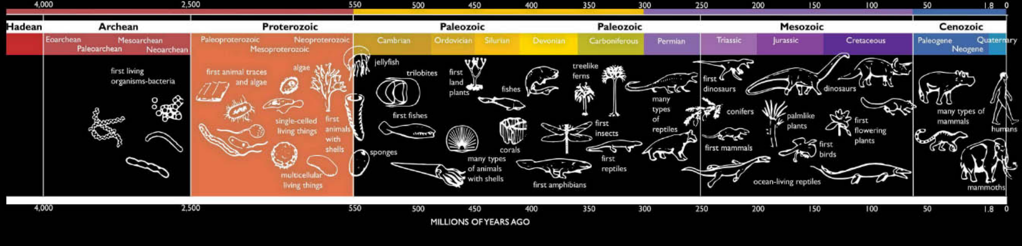


Evolution of eukaryotic cell



Glacial dropstone, typical evidence from glacial periods (Top); Grypania Spiralis fossil – eukaryotic fossil about 1.8 billion years old (Bottom)

Proterozoic Eon (2500 – 550 million years ago)



Forces that SHAPE the Earth

Convection & Plate Tectonics:

The cool, brittle outer layer of earth is broken into tectonic plates. These wide and thin slabs are driven around the surface by convection in the mantle. Convection is powered by heat escaping the mantle and core. The force of tectonic plates colliding causes them to crumple and form mountains.

Himalayas, Nepal; Appalachians, U.S.A

Earthquakes:

Convection in the mantle can send tectonic plates in opposing directions. When the brittle plates collide with each other they can catch and tension builds. When catching rocks break, all the pent-up energy is released as earthquakes. Large earthquakes can cause the land to heave like an ocean and reshape the surface in seconds.

Ridgecrest, California

Water Erosion:

Radiation from the sun heats the ocean and causes water to evaporate. Moist, hot air from the tropics rises and is spread around the planet. As the warm air rises in the atmosphere, it cools. Water vapor condenses and gravity pulls it back toward the surface. Falling water erodes soil and rock. It gathers into progressively larger streams carrying abrasive loads of sediment that wear away rocks and deposit them into basins.

Grand Canyon, Arizona

Glaciers:

When snow accumulates faster than it melts glaciers form. Under increasing weight, the snow compresses into ice. In mountains, the force of gravity drives the solid mass of ice toward lower elevations like a slow-motion river. Rocks and gravel picked up and lodged in the glaciers grind away at bedrock creating U-shaped valleys.

Johns Hopkins Glacier, Alaska

Impacts:

The solar system began as a swirling cloud of dust that coalesced into rocks and finally planets. Meteorites crashing into earth are a continuation of this process. Over time the pull of gravity incorporates more and more of the orbiting rocks and dust into planets. Large meteorite impacts have incredible power to reshape the surface.

Manicouagan Reservoir, Canada

Volcanoes:

Heat inside the Earth causes molten rock in its many forms to rise and surface, sometimes in oozing rivers of lava and sometimes in violent explosions of gas and rock. Volcanoes form huge mountain ranges, island chains, and isolated peaks.

Krakatoa Volcano, Indonesia

Wind Erosion:

Differential heating of earth's surface and atmosphere creates high-pressure (cold) and low-pressure (hot) zones. Wind is the movement of air in response to this pressure imbalance. Strong and sustained winds pick up silt and sand that wear away at protruding rocks.

Arbol de Piedra, Bolivian Salt Flats

Freeze Thaw:

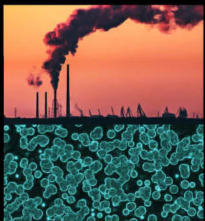
One of the amazing properties of water is that it expands in volume when frozen. Liquid water seeps into cracks in rocks and when the temperature drops it freezes and expands with enough force to split rocks in half. This process is a major contributor to the erosion of mountains.

Glyder Fawr, Snowdonia, Wales

Chemical Erosion:

Rocks are changed by chemical erosion. For example, when granite is exposed to water, feldspar in the granite reacts to form weaker clay minerals. Another example is when limestone, made of calcium carbonate ($CaCO_3$), dissolves in acidic rainwater. Dissolution of calcium carbonate creates fissures, sinkholes and caves in limestone dominated landscapes.

Bimmah Sinkhole, Oman



Life:

Photosynthetic organisms pumping oxygen into our atmosphere, corals secreting calcium carbonate to form coral reefs, the shells of tiny marine organisms accumulating to form limestone, and humans burning fossil fuels for energy are all examples of profound ways life has shaped our planet.

Fossil fuel power station; Cyanobacteria

EXPLOSION OF DIVERSITY

A trilobite, Anomalocaris (apex predator), and other marine life from the Cambrian period

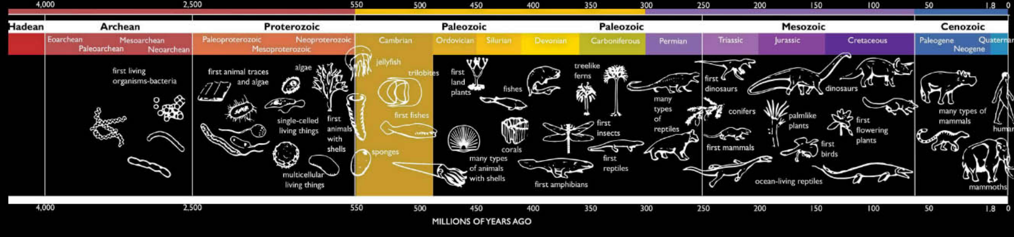
After a few billion years of gradual change, the Cambrian Period saw remarkably fast diversification of life. During this relatively brief period of geological time, sometimes called "The Cambrian Explosion", almost all existing modern animal phyla first appeared in the fossil record.

As multicellular life grew more complex, so did ecosystems, which developed predator/prey relationships. To survive, early arthropods developed hard shells and burrowed into the ocean floor. These defense strategies also aided the preservation of Cambrian fossils leaving us with many examples of life that thrived during that time. Trilobites, one of the most successful early animals, were especially well-represented in the fossil record because they shed an easily fossilized exoskeleton multiple times.

The Burgess Shale is a prime example of spectacular Cambrian fossil preservation. Shallow oceans and barren lands caused mudslides that quickly buried living organisms in underwater mudbanks. The sudden burial left well-preserved and detailed fossils of exoskeletons, limbs, and in some rare cases, evidence of gut contents and muscle.

Burgess Shale, Yoho National Park, British Columbia (Left)
Trilobite fossil (Right)

Cambrian Period (550 – 485 million years ago)



BEFORE TREES... MASSIVE FUNGI

Prototaxite fungi

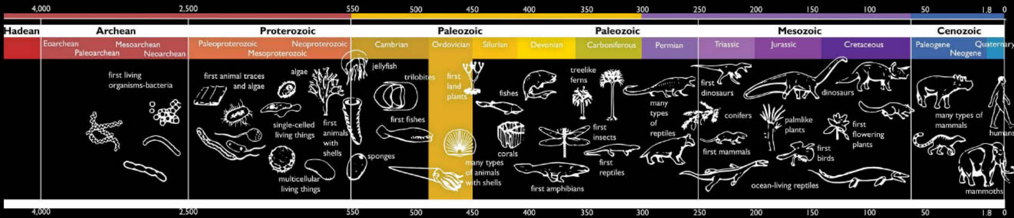
During the Ordovician period, many forces were shaping the Earth, including volcanic activity, uplifts forming new land masses, widespread glaciation, sea-level changes, and erratic climate change. The supercontinent Gondwana stretched from north of the equator to the South Pole whereas the northern hemisphere was home to a vast ocean and a flourishing marine ecosystem with arthropods, mollusks and coral. The period ended with a great ice age, which caused one of the first mass extinction events.

Fossils of a prototaxite (Left), Cephalopod (Top)

One of the first large terrestrial organisms, prototaxites, appeared during the Ordovician. Fossils of prototaxites, which had large trunk like structures up to 3 feet wide and 26 feet tall, initially mystified scientists who mistook them for large plants. Besides appearing too early in the fossil record to be plant-based, the abundance of certain carbon isotopes suggested that prototaxites were consumers like modern fungi. These giant organisms dominated the early terrestrial ecosystem where they fed on billions of years' worth of accumulated bacteria, protists and other microorganisms' debris.

Rock outcrop showing Late Ordovician Mass Extinction (Top) and fossil bed of Ordovician brachiopods (Bottom)

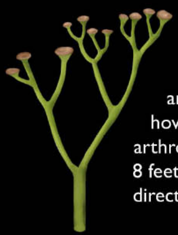
Ordovician Period (485 – 450 million years ago)



ESCAPE ONTO DRY LAND

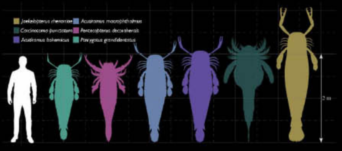
Fossil of a eurypterid, commonly called "sea scorpion" and a size chart for scale

Global climate during the Silurian was relatively stable and warm and life forms that survived the end-Ordovician ice age flourished and diversified. Land plants evolved vascular structures for transporting water and nutrients. This internal "plumbing" helped plants survive in non-ideal conditions and enabled them to grow to larger sizes. Meanwhile on land, millipedes became the first air-breathing life forms. Animals with the ability to breathe air could live out of and further away from water, which decreased competition and perhaps eluded predators.

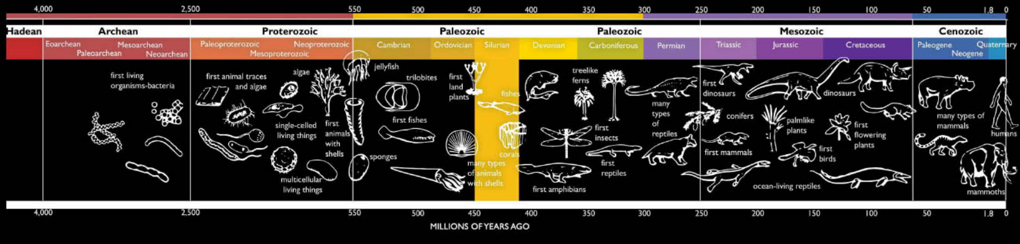


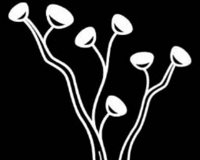
As marine life recovered, coral developed into reef-forming varieties and became fixtures of the aquatic ecosystems. Fish species advanced into diverse families including those with movable jaws, bony skeletons, and exoskeleton-like armor. Despite these advances by fish, however, the top underwater predators were giant arthropods, informally called sea scorpions, which grew over 8 feet in length and had pincer-like claws capable of grabbing and directing prey toward its mouth.

Fossil of Cooksonia, an early vascular plant (Top Left), and its representation (Top Right); Giant, fossilized reef, Guadalupe Mountains National Park (Bottom Right)



Silurian Period (450 – 420 million years ago)





AGE OF THE FISH

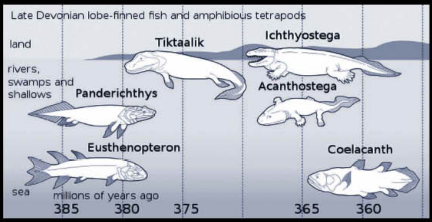
Placodermi (apex predator fish) and, underneath, the Acanthostega (an early tetrapod)

The Falls of the Ohio near Louisville, KY is home to many Devonian Period fossils. Walking through the fossil beds is like dry-scuba diving through a prehistoric sea

Global climate went from warm to hot, with average temperatures around 86°F. Glaciers and ice caps melted, which resulted in elevated sea levels and expansive warm and shallow marine habitats. The fossil record shows diverse fish populations, including the first sharks, and great coral reefs.

Fish unseated arthropods as the dominant life form in the seas. The Placodermi, armor-plated fish up to 30 feet long and weighing 4 tons, were the apex predator in nearly every aquatic environment and the largest living organism up to then. Animals that competed directly with Placodermi, such as the sea scorpions, went out of existence.

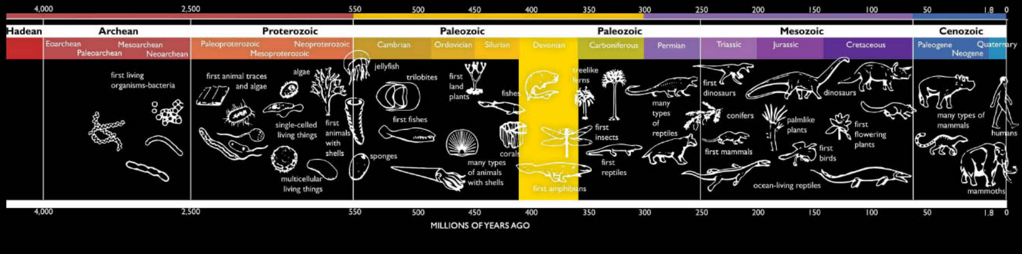
Some life forms avoided becoming a placoderm's lunch by escaping onto land. Early tetrapods descended from lobed-finned fish, which resembled something like a mudskipper, and many different species appear in the fossil record. Early tetrapods preyed upon arthropods already living on dry land, such as millipedes, centipedes, and early species of insects.

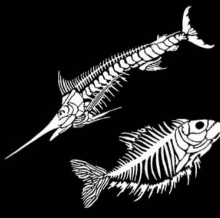


Snail fossil from Falls of the Ohio

Wasp Nest Coral fossil from Falls of the Ohio

Devonian Period (420 – 360 million years ago)





LIVING LARGE

Diplocaulus, a common amphibian of this period

The continents Gondwana and Euramerica collided along the equator, which raised the Appalachians and great mountain ranges, now largely eroded, across present-day Europe. The Carboniferous had steamy, tropical regions like rainforests today, but also glacial cycles, which caused sea levels to quickly rise and fall over vast stretches of swampy coastlands. Plant life thrived in the warm and wet conditions.

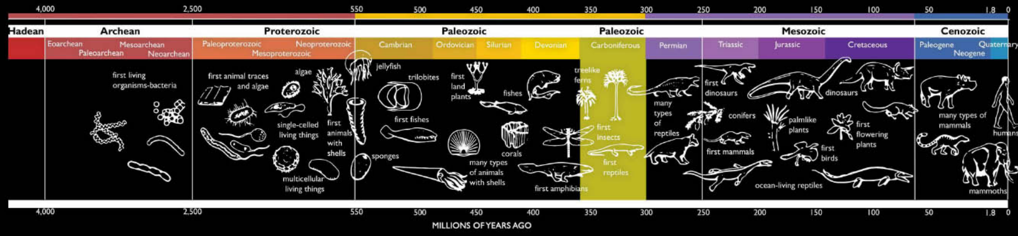
Fossilized remains of a fern (Top) and a griffinfly (Bottom) embedded in coal and a size comparison

Lycopsid fossil

The forests and swamps were not populated by trees, but by giant mosses and ferns. These plants had recently developed woody tissue and bark-like coverings, which protected against insects and retained moisture. These new developments also slowed plant decay and vast amounts of dead plant material accumulated and fossilized. Evidence of these prehistoric forests is found today in the large tracts of coal in the Eastern United States and Central Europe. The Carboniferous, meaning "coal-bearing," is named for this defining feature of the period.

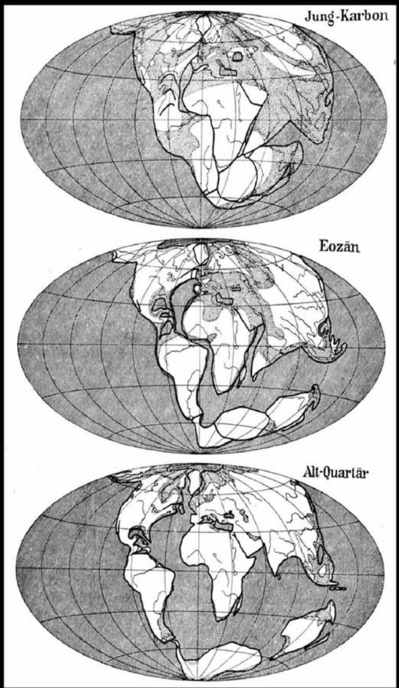
Abundant plant life caused oxygen levels to reach as high as 35%, nearly double the air we breathe today. Elevated oxygen levels allowed certain animals to grow much larger than their modern-day descendants. For example, the griffinfly, an ancestor of the dragonfly, had a two-foot wingspan. The wet conditions were prime for amphibians which became the top land predator in an ecological niche similar to crocodiles today and could grow several meters long.

Carboniferous Period (360 – 300 million years ago)

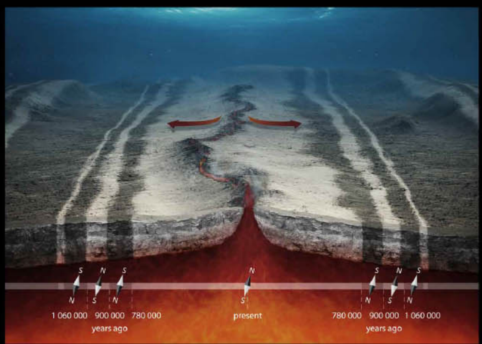


Attention to Signs: Pangea

Alfred Wegener was a German geologist and researcher who proposed the theory of Continental Drift in his 1915 work The Origin of Continents and Oceans. Wegener was also a pioneering polar researcher who made significant achievements in meteorology. He led arctic expeditions to study polar airflows before the jet stream was an accepted weather phenomenon.



Many scientists at the time were skeptical about his theory because scientists couldn't explain how tectonic plates moved. Within another 50 years numerous discoveries provided evidence to support Wegener's theory, and today's model of plate tectonics was born. One of the key supporting discoveries was paleomagnetism, the observation that the relatively frequent reversals of Earth's magnetic polarity that have occurred in the past are imprinted like mirrored barcodes around a spreading seafloor.

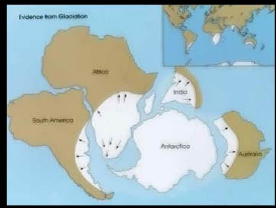


Alfred L. Wegener, 1880-1930 (Top)

Wegener's original maps showing Pangea and continental drift (Middle)

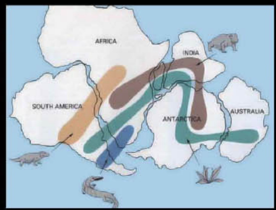
Seafloor spreading and the magnetism in rocks that was induced by the earth's magnetic field at the time of their formation (Bottom)

Alfred Wegener observed 5 signs that he provided as evidence that Earth's land masses were once connected and then drifted apart.



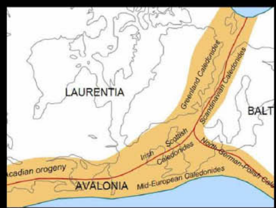
GLACIAL DEPOSITS

Glacial movement left scratches on bedrock that showed the direction flowed from a single central point.



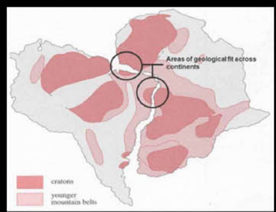
FOSSIL EVIDENCE

Plant and animal fossils from the same species are found across separate continents.



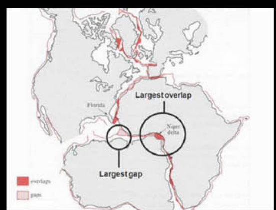
TECTONIC FIT

Evidence of an old mountain range is found spread throughout multiple distant continents today.



GEOLOGICAL FIT

Ancient rock outcrops are continuous across continents.

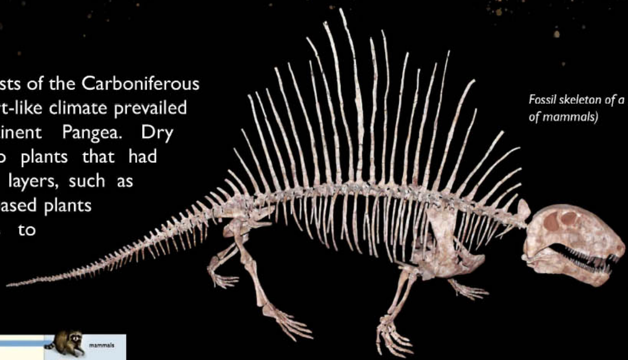


JIGSAW FIT

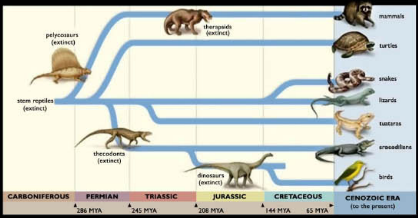
Continents, especially South America and Africa, noticeably fit despite changing sea and land levels.

THE GREAT DYING

The coal-forming swamps and forests of the Carboniferous mysteriously collapsed and a desert-like climate prevailed over the expansive supercontinent Pangea. Dry conditions gave an advantage to plants that had developed seeds with protective layers, such as early conifers, over earlier spore-based plants which rely on wet conditions to propagate.



Fossil skeleton of a Dimetrodon (synapsid ancestor of mammals)



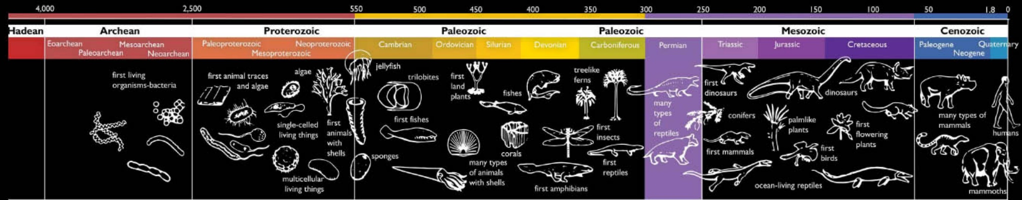
Arid climate also favored reptiles, which lay eggs with hard shells, over amphibians whose eggs must be laid in water. Reptile species rose during this period and diversified into two main lineages. One branch, called diapsids, considered "true" reptiles, were ancestors to dinosaurs, crocodiles, snakes, lizards and birds. The other branch called synapsids became more "mammal-like" species.

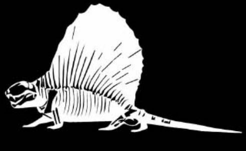
Diversification of ancestral reptiles (Top)
Reptile eggs hatching (Bottom)

The largest known extinction event ended the Permian. Some 95% of marine species and 70% of terrestrial organisms died out. The cause of the extinction is still uncertain, but the most likely event seems to be a 2-million-year period of volcanism that deposited about a million cubic miles of molten rock onto the surface. These flood basalts are known today as the Siberian Traps. The eruption released several trillion tons of CO_2, H_2S, and other gasses which caused dramatic, global climate changes. Trilobites died out forever.

Fossil of a conifer pine cone (Top)
Putorana Plateau, Siberian Traps (Bottom)

The Permian Period (300 – 250 million years ago)





RESURGENCE

A representation of a Lystrosaurus (Top Left) and a Metoposaurus (Top Right); A Lystrosaurus skeleton (Bottom)

Life slowly recovered from the greatest extinction event ever. Due to the severity of the climatic crisis, full ecosystem recovery took about 10-30 million years. Vacant ecological niches and selection pressures from the Permian-Triassic extinction event led to prosperity and diversification for the surviving species. Archosaurs, reptile ancestors of modern-day crocodiles and birds, were the apex predator and by the end of the Triassic, the first dinosaurs appeared.

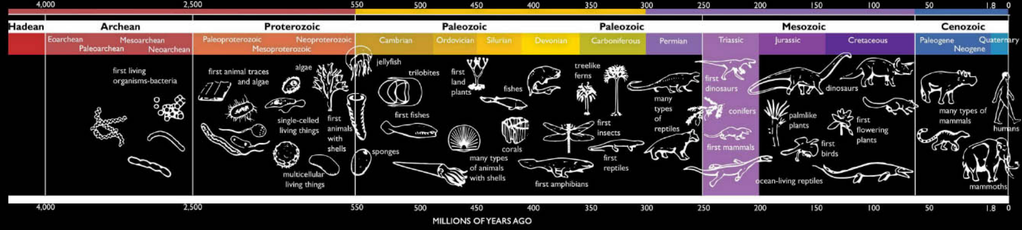
Marine ecosystems rebounded impressively and marine reptiles ruled the oceans for 200 million years. Ammonoids, pre-historic snails, and countless other species, including the predecessors of modern-day turtles and reptiles, survived the extinction event and thrived in hot (104°F!) and tropical oceans.

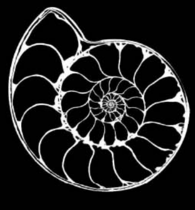
Archosaur

On land, an ancient ancestor of mammals called Lystrosaurus widely proliferated. A strong burrower, Lystrosaurus survived the extinction event and its fossils are found on multiple present-day continents supporting the theory that all land masses were once joined as Pangea. Proto-mammals like Lystrosaurus filled non-competing ecological niches to coexist with predatory reptiles. The adaptation led to mammalian characteristics like smaller size, nocturnal habits, acute senses, and thermal regulation.

Late Triassic marine reptile Plesiosaurus (Top) and an ammonoid fossil (Bottom)

Triassic Period (250 – 200 million years ago)





Dinosaur Dominance

Another one of the "Big Five" extinction events ended the Triassic when major tectonic movement began to break up Pangea, formed the Atlantic Ocean, and spurred extensive volcanic activity. The Central Atlantic Magmatic Province (CAMP) in Morocco is the massive lava flow associated with this event.

Gobi Desert, 1971 – a Velociraptor locked in combat with a Protoceratops (Left), an Allosaurus head (Center), Brachiosaurus (Right), and a Pterodactyl (Top)

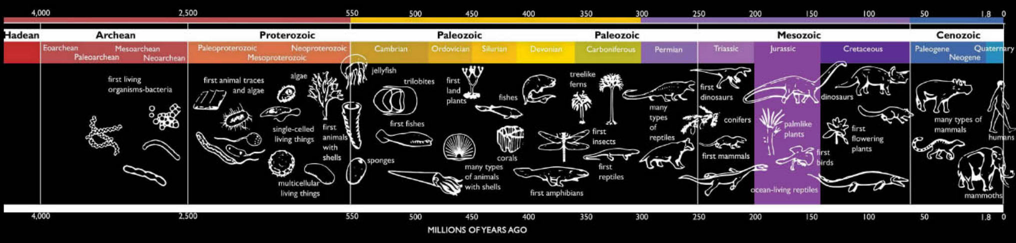
Dinosaurs were among the few species of Archosaurs (along with ancestors of crocodiles and birds) that survived and quickly became dominant. This was known as the "golden age of the dinosaurs." The fossil record contains many types of fossils from this period including skeletons, footprints, and even animal burrows (sometimes with their inhabitants inside).

Ancient lava flow, CAMP Igneous Province, Morocco

Jurassic period rocks were also the source of some of the largest oil reserves in the world. Accumulated organic matter like plants, algae, and plankton was converted into hydrocarbons through intense heat and pressure over long periods of time. These products seeped through rocks until they eventually settled in geologic traps and created oil fields. Ghawar Oil Field, Saudi Arabia, is the largest conventional oil reservoir in the world. About half of its roughly 140 billion barrels of oil have been produced since the field opened in 1951.

Ghawar oil field, Saudi Arabia

Jurassic Period (200 – 145 million years ago)



FLOWER POWER

The Cretaceous is the final period of the Mesozoic Era and the longest since the Cambrian Explosion. Warm climate and large, shallow seas provided the right conditions to produce many of the world's petroleum reserves. These conditions were also ideal for the preservation of fossils, such as the Hell Creek Formation in the Northern U.S. known for its rich supply of dinosaur and other fossils. Due to the marine environment and calcium-rich deposition during this time, the Cretaceous (from the Latin Creta meaning chalk) produced abundant chalk deposits like the famous Needles and nearby Cliffs of Dover in southern England.

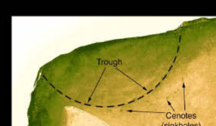
Triceratops and Chicxulub meteor (Top); a skeleton of Tyrannosaurus Rex (Left)

The Needles in Southern England

An important adaptation in plants was the appearance of flowering species (angiosperms) which brought innovative and successful reproductive strategies like seeds embedded in fruit. Compared to gymnosperms, which relied on wind for propagation, angiosperms relied on animals to eat the fruit or be pollinators. Flowering plants explosively diversified and today comprise most plant life on Earth.

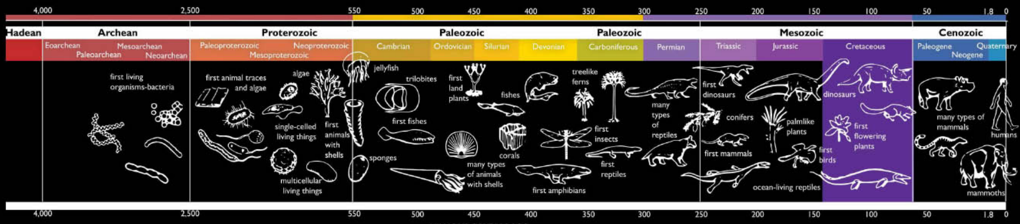
Archaefructus fossil of the earliest flowering plants (Left); fossil of Montsechia vidalii (Right)

The Cretaceous period dramatically ended with the impact of the meteor that formed the Chicxulub crater off the coast of Mexico. The impact of the meteor caused massive fires, devastating earthquakes and tsunamis. The widespread destruction ended the dinosaurs and opened the path for mammalian evolution.



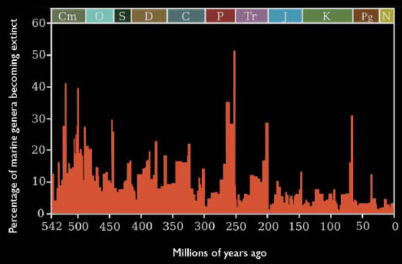
Chicxulub crater as it can be traced today (Left) and as it would have looked soon after impact (Right)

Cretaceous Period (145 – 66 million years ago)

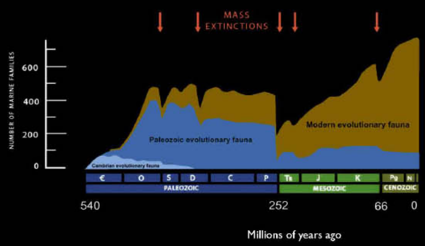


It Could Have Been Otherwise: Extinction Events

Extinction intensity through time



Diversity of animals through time



The rocks of some periods contain abundant fossils of many species that are simply absent in the rocks of the following period. The fossil record at times shows a "fossil gap" or lack of any kind of plant or animal that lasted for a time until biodiversity recovered. These mass extinctions led to openings in ecological niches that allowed surviving species to adapt and diversify. For example, the extinction of the dinosaurs led to the diversification and dominance of the mammals.

A very bad day

The Chicxulub impact was caused by an asteroid about 6 miles wide traveling 12 miles/second. It left a crater about 110 miles wide. When it impacted it would have created 1,000 mph blast winds, tidal waves almost a mile high, and massive earthquakes. Bits of molten rock called tektites were thrown by the impact and showered the Earth starting fires everywhere. Darkness, toxicity, and rapid global cooling ensued.

2 million years of bad days

The volcanic activity that caused the Permian-Triassic extinction event formed the Siberian Traps over 2 million years with a flood of about 1 million cubic miles of lava, 4 million times greater than the Mt. St. Helens eruption. The Siberian Traps are the largest of several "igneous provinces" on Earth – geological structures formed of massive lava flows.

"The Big Five"

The five largest extinction events are well known in the geological record.

Ordovician-Silurian

Second most severe extinction with about 85% of marine species killed. There were two stages: intense glacial ice-age followed by glacial retreat and global warming with world-wide anoxia (lack of oxygen) lasting up to3 million years as evidenced by widespread black shale.

Late Devonian

Consisted of several events in the late Devonian. High ocean anoxia may have slowed decay and contributed to the high amount of oil found in porous Devonian rocks.

Permian-Triassic

"The Great Dying." The world's worst extinction event – up to 95% of all species died out. Thought to have been caused by about 2 million years of volcanism. Biodiversity recovered after about 30 million years.

Triassic-Jurassic

May have been caused by massive volcanic eruptions and catastrophic ocean acidification as Pangea was beginning to break apart.

Cretaceous-Tertiary

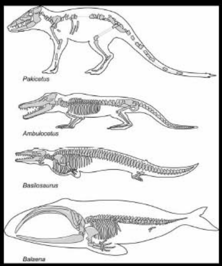
Ended the dinosaurs. This is the only extinction event definitively linked to an asteroid impact (Chicxulub crater). Volcanism also likely contributed.

SURVIVORS

A couple of small, primitive mammals called Alphadons (Bottom Left), a Hagerman horse (Top Left), and a Deinotherium, a large elephant-like proboscidean (Top Right)

Life slowly recovered from the extinction event that killed the dinosaurs. Survivors were organisms that could burrow underground like small birds and mammals or could shelter in water like reptiles. Mammals adapted and filled ecological niches that were previously occupied by large, top predators and that had been vacated by the extinction event. Initially, the most abundant mammals of this era were small rodent-like animals, followed by the rise in ungulates or hoofed mammals and eventually early primates. Finally, carnivorous mammals such as ancestral dogs and cats appeared.

A skull of a Hagerman horse (Top), and petrified trees, Yellowstone National Park (Bottom)



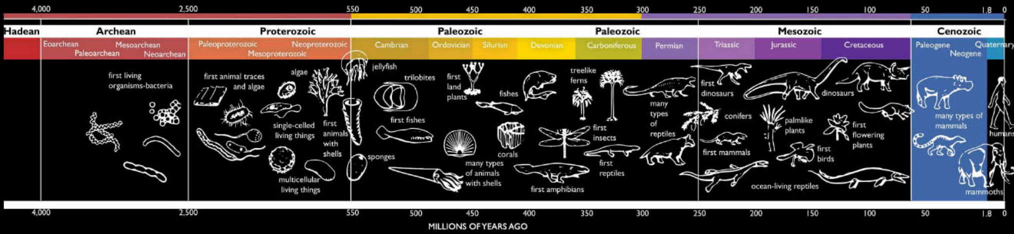
Evolution of whales

Whereas land animals once evolved from marine animals, an example of the reverse process happened during this time. One group of mammals, the hooved ungulates began to fill niches in the ocean by evolving body plans that helped them to swim. These are the ancestors of modern whales.

Ancestral whale fossil

By the end of the period, the climate in North America was temperate and mild, and life thrived. Rocks that formed during this time are visible on the surface in many parts of North America.

Tertiary Period (66 – 1.8 million years ago)



WE ARRIVE

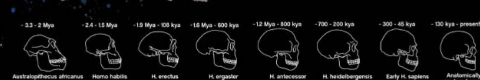
Humans occupy a tiny sliver of Earth's geological timeline. Our hominin ancestors diverged from our last common ancestor with chimpanzees 6 million years ago, to form a variety of hominin species. Genetic and fossil evidence suggests that several closely related species co-existed with Homo sapiens as recently as 30,000 years ago. Traits such as adaptability helped Homo sapiens survive where other hominin species did not. Modern Homo sapiens continue to adapt and evolve at an amazing pace; our technology has spanned from buffalo dung tablets to computer tablets in only a few thousand years.

Human creativity and ingenuity have enabled us to impact the Earth in a way unlike any other species past or present. Some have proposed to mark the official beginning of a new geological epoch called the Anthropocene (the age of humans) to indicate the global geological effects of human activity.

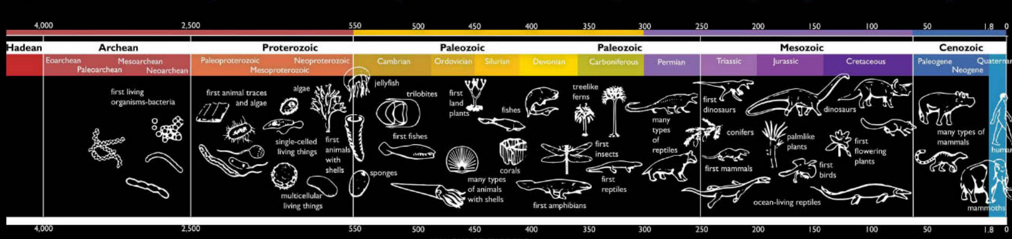
Bingham Canyon Mine, largest manmade removal of rock on Earth

Millions of years from now, what story will the rocks tell about us?

City lights seen from space (Top)
Lucy, Australopithecus (Left)
Evolution of the skulls of various hominids (Bottom)



Quaternary Period (1.8 million years ago-present)



What is all this for?

What is man that you are mindful of him,
And a son of man that you care for him?
Yet you have made him little less than a god,
Crowned him with glory and honor.
You have given him rule over the works of your hands,
Put all things at his feet.

-Psalm 8:5-7

Rocks contain signs that tell the story of our past and point to our future. Processes acting over millions or even billions of years stocked the Earth with the materials and energy necessary for our flourishing. Our land bestows our lives with breathtaking spectacles and wondrous marvels of beauty. Geology turns our attention to these signs and many others, but the most profound signs are the questions that emerge in us.

Curated by:
Brian Bohrer
Sarah Bohrer
Peter Putzier
Roland Rosario

Graphic design:
Filippo Mambelli

New York Encounter

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