Most people know about Continental Drift and the breaking up of the supercontinent of Pangaea. But that all happened in the last 200 million years and few people think to ask what was happening in the previous four billion years of our planet’s existence.

My original reason for choosing this title was that I thought Pangaea was the fourth such supercontinent, so I could trace the kaleidoscopic motions of the tectonic plates during each phase of coalescence and dispersion. However, further research showed that the story is more complicated – or, at least, less certain – than that.

While I have learned an incredible amount from researching this report, I must stress that I am the merest amateur when it comes to paleogeology. Moreover, I have found that the experts are not in total agreement on what happened all those billions of years ago, so what I will be telling you today is only what I can discern are the hypotheses that the majority appear to support. So, please join me in this journey of exploration and feel free to come to your own conclusions.

For now, I’ll just enumerate the four eons that geophysicists use to divide the history of our planet from the time of its formation (BYA = billion years ago):

- Hadean Eon 4.6 – 4.0 BYA
- Archean Eon 4.0 – 2.5 BYA
- Proterozoic Eon 2.5 – 0.5 BYA
- Phanerozoic 0.5 BYA – present

However, the story properly begins with the formation of the Solar System, which probably took place in a vast nebula of gas and dust. The gas was primordial hydrogen and helium, while the dust was heavier elements produced in earlier generations of stars and dispersed when they exploded – those fusion products constituted a mere 2% of the nebula but they are the sole reason the Earth and ourselves are here today. The early Sun was most likely part of a cluster of stars that formed at about the same time, though they would have drifted apart within 500 million years.
The consolidation of the cloud formed a massive spherical centre and the increasing rotation formed an accretion disc around the protosun’s equator. It was here that clumps of solid matter formed and grew by collecting more dust, layer upon layer, until their masses were sufficient to retain halos of gas around them.

![Diagram of the solar system](image1.png)

When our Sun first achieved sufficient compression and internal temperature to initiate nuclear fusion, it first became a T Tauri variable star. This meant that, in its most active phases, the solar wind was much stronger than what we get now and much of the hydrogen and helium was blown out of the region where the rocky inner planets formed. The expelled hydrogen combined with carbon, nitrogen and oxygen to form the methane, ammonia and water that the outer gas giant planets are mostly composed of.

![Image of the solar system](image2.png)

The clumps of solid matter had by now grown to become planetesimals of at least 0.05 Earth masses, after which their continued growth was more due to collisions than to accretion. The kinetic energy of the collisions was converted to heat and yet more heat was generated by gravitational compaction. Our Earth became a molten mass surrounded by an atmosphere of carbon dioxide, methane and nitrogen.
Thus began the appropriately named Hadean Eon, during which the heavier elements – especially iron and nickel – sank toward the centre of the Earth while lighter elements were forced to the surface. Over time, our planet cooled enough for the crust to become solid – yet the oldest rocks ever found are zircons, which are hydrated crystals of zirconium oxide. Zircon has the highest melting point of any known mineral but there must have been liquid water for it to form! How? – it is thought that the Earth’s early atmosphere was much like that of Venus and its fantastic pressure enabled water to be a liquid at temperatures in excess of 500°C.

Our planet then took on its present structure, with a thin solid crust under which was a hot plastic mantle 3000 km thick. Under that was a core of liquid iron and nickel whose centre was compressed to a solid state. (It must be stressed that words like ‘liquid’ and ‘solid’ have different meanings when we are dealing with unimaginable pressures and temperatures.)
Little is known for certain about the next 500 million years, except that there must have been a great deal of vulcanism and the tectonic plates we have today had not yet formed. The heat flow from the centre was three times what it is today and it appears that the material in the Earth’s crust was largely recycled by some form of convection, even as magma and lava from the mantle penetrated into and flowed over the crust. Yet, there must also have been some heavy rains at that time, as some rocks from that eon are sedimentary in nature.

There was further disruption at that time from the Late Heavy Bombardment, a huge upsurge of asteroid strikes that battered all of the inner planets (and also our Moon). While erosion has obliterated the evidence on Earth, it is estimated that the bombardment left some 22,000 craters over 20 km in diameter and more than 40 impact basins with diameters between 1000 and 5000 km.
It was after that bombardment that the first protocontinents emerged in tectonic plates considerably smaller than what we have today. Known as cratons or continental shields, these ancient formations are now embedded in the present-day continents. They include the Laurentian Shield surrounding Hudson Bay (also Greenland), the Amazonian and Guiana Shields in South America, the Western Australian Shield, the Baltic Shield in Scandinavia, the Angara Craton in Siberia, the North China Shield, the Indian Craton, and the Niger, Congo and Kalahari Cratons in Africa. Some of these are mergers of smaller cratons and a few have been covered by younger rock; all are heavily eroded, as one would expect.

The first supercontinents were not at all ‘super’ – the name just means they were the only landmasses on the planet at the time, apart from volcanic islands. The first of these, supported only by paleomagnetic evidence, was a merger of the Kaapvaal Craton in South Africa and the Pilbara Craton in Australia. (It must be remembered that their present locations tell us nothing about where they were at earlier times.) Vaalbara, if it existed, stayed together from 3.6 to 2.8 BYA. There is more evidence for the supercontinent of Ur, which formed about 3 BYA and stayed together through all but the last cycle of mergers and break-ups. Parts of it are now in Madagascar, India, Australia and Antarctica.
The first serious supercontinent was Kenorland, formed 2.7 BYA from Laurentia, Baltica, Western Australia and Kalaharia. It likely straddled the Equator and lasted for 250 million years. By this time, two kinds of primitive life had evolved – the anaerobic bacteria that thrived in the early atmosphere of methane, carbon dioxide and nitrogen, and the cyanobacteria in the ocean which produced free oxygen through photosynthesis. It is thought that the coalescing cratons brought oceanic crust to the surface and the cyanobacteria injected so much oxygen into the atmosphere that most of the methane was converted to carbon dioxide and water. The resultant demise of the anaerobes was the first mass extinction in the Earth’s history.

The break-up of Kenorland is associated with another catastrophic event – the first ice age, known as the Huronian glaciation. Methane is a powerful greenhouse gas and its removal caused temperatures to plummet across the globe. The ‘Snowball Earth’ persisted for 300 million years, by which time the Earth was well into the Proterozoic Eon and a new supercontinent was about to form.
The early cratons grew in size as products of erosion formed sedimentary rocks on their coasts. When Kenorland broke up, the various parts took some uplifted seabed with them. But, when a continental mass moves, the seabed in front of the ‘leading edge’ is subducted under it and melts when it reaches the hot mantle. This results in lava plumes breaking through the continental plate, forming volcanos. The subduction also forms a trench called a geosyncline, in which sediments from the eroding continent can collect and then be squeezed up when the trench collapses. These processes are known collectively as orogenesis, which means ‘mountain formation’, and it can also happen when continents collide and join together.
The next supercontinent, Columbia, was formed in stages commencing 2.0 BYA and its break-up was complete by 1.3 BYA. This was the biggest merger yet, consisting of Laurentia, Baltica and the Ukrainian, Amazonian and Australian Shields. It may also have included North China, Kalaharia, India, East Antarctica and two cratons from each of what are now West Africa, Southern Africa and Siberia. The collisions produced massive amounts of orogeny that permanently welded some of those cratons together, so Columbia broke up into fewer pieces than it was originally produced from. By this time, plant life in the form of algae had evolved in the ocean and developed to the multicellular stage.

The geohistory of the last billion years is better understood, so a few more names may be of use. Laurentia and Baltica stayed together as Nena (Northern Europe-North America), while the amalgamation of South American and African cratons is called Atlantica. (Also, Ur became a separate entity again.) The next merger occurred between 1.1 BYA and 750 MYA and the resulting supercontinent of Rodinia is thought to have comprised virtually all of the continental masses on Earth. For the first time, orogenies from the continental collisions are still visible today — the Appalachian Range on the east coast of North America and the Ural Mountains between Europe and Asia. This massive amount of land area absorbed a lot of heat from the Sun at the expense of the ocean, increasing rainfall which, in turn, reduced the amount of carbon dioxide in the atmosphere. Again, this had an ‘anti-greenhouse effect’, causing two ice ages after Rodinia broke up — one lasted from 750 to 700 MYA and the second was from 645 to 635 MYA.
As before when major rifts occurred in supercontinents, magma flowed out through the ruptured crust. But, this time, a wholly new phenomenon occurred known as seafloor spreading, which has been the dynamic of Continental Drift ever since. Some of the magma formed an undersea mountain range while continuing flows produced new oceanic crust that filled the gap as the landmasses moved apart. This could have been when proper tectonic plates first formed.

There was still no life on land at this time and marine life was very primitive, though it is thought that nutrients from the magmatic extrusions may have changed that fairly quickly. By 600 MYA, the increasing amount of atmospheric oxygen from algae reached the upper atmosphere and formed the ozone layer, thereby giving life on land a better chance through its absorption of ultraviolet radiation.

The break-up of Rodinia first produced a massive continent called Proto-Laurasia, which then split into Laurentia, Baltica and Siberia. Atlantica and the Congo craton split off again, while Southern Africa, India, Australia and Antarctica became Proto-Gondwana. Some paleogeologists believe that they all merged again 600 MYA to form a short-lived supercontinent called Pannotia, which was near the South Pole and only had an unstable existence of 60 million years. Either way, we are now on the verge of the Phanerozoic Eon, the first primitive animals and land plants have evolved, and the ‘Cambrian explosion’ is about to commence.
For reasons that are not well understood, the rate of evolution of marine life greatly accelerated from 550 MYA and continued for 70–80 million years. Largely because so many of these new organisms had shells or exoskeletons, the fossil record from this era is quite extensive. All of the marine phyla are represented, including plankton, molluscs (sea snails and clams), echinoderms (sea urchins and starfish) and crustaceans. The continents, previously inhabited only by bacteria and possibly fungi, became home to an increasing variety of primitive plants, such as mosses and ferns. There was another ice age and mass extinction between 460 and 430 MYA but this did not set the evolutionary process back.

Now begins the last and most interesting series of amalgamations that largely formed our familiar continents. The microcontinent of Avalonia broke away from Proto-Gondwana 480 MYA and moved toward Laurentia, followed by a piece of continental shelf that moved toward Baltica and would eventually become Southern Europe. By 440 MYA, Laurentia and Baltica had collided to form Euramerica, shortly joined by Avalonia in the middle. Proto-Gondwana lost the separate entities of North and South China to Siberia and moved near the South Pole, much of it becoming glaciated.

Siberia and its new acquisitions collided with Euramerica about 400 MYA, joined later by the united Chinese cratons and the Cimmerian Plate (Turkey, Iran, Afghanistan, Tibet and Southeast Asia), to form Laurasia. The resulting orogenies formed mountain ranges along the sutures that were once as high as the Himalayas. Gondwana came into its own when it acquired the remaining cratons that are now parts of Africa and South America. The global merger that we call Pangaea was complete by 200 MYA.
While all this was going on, plant and animal life was progressing in leaps and bounds. Fish, the first vertebrates, appeared 485 MYA and land-dwelling arthropods in the form of spiders and scorpions arose 420 MYA. By 360 MYA, sharks swam in the seas; insects (some very large) and amphibians crawled on the land; and vast forests of fern-trees covered most of the continents. The first reptiles evolved about 340 MYA, followed by egg-laying mammals 275 MYA. A mass extinction of unclear causation 250 MYA wiped out at least 90% of marine species with somewhat less effect on land organisms.

Shortly after that, the earliest dinosaurs made their appearance and also the first coniferous trees. These became the dominant animals and plants for 100 million years, even as their supercontinent was breaking up beneath them.
The fragmentation of Pangaea began 175 MYA, when Gondwana began to separate from Laurasia. The former broke up into South America, Africa-Arabia, India and Australia-Antarctica, starting 150 MYA with a rift between Atlantica and the eastern plates. Laurasia rotated toward an east-west orientation while Africa-Arabia and India moved north to connect with it. (Interestingly, Madagascar was connected to India until 100 MYA.)

Laurasia broke up only 60 MYA, splitting the former Avalonia down the middle. The western part became Nova Scotia, Newfoundland and Labrador, while the eastern remnant became Ireland, Great Britain and parts of Western Europe. The arrival of Africa-Arabia and India produced mountain ranges as various as the Atlas Mountains, the Pyrenees, the Alps, the Carpathians, the Caucasus, the Hindu Kush and the Himalayas; also the plateaus of Iran, Tibet and Burma.

The last fragmentation produced Antarctica, Australia and the little-known continent of Zealandia, which includes New Caledonia and some other island groups. The last dinosaurs perished in a mass extinction 66 MYA and were quickly replaced by giant flightless birds and mammals.
It is perhaps surprising how recent some of the most prominent features on our planet are. Continental Drift has produced some unusual effects, more than just creating new oceans and reducing older ones. An examination of the continental plates shows us the active plate boundaries where so many volcanos and earthquakes have occurred – we also see that eastern Siberia is actually part of the North American Plate, more than half of the Mediterranean Sea is on the African Plate, and Iceland was produced by outflows from a plate boundary that we know is still active.

The westward motion of North and South America has produced their only common feature – the Cordilleran Mountains formed by subduction of the Pacific Plate. It is thought that the formation of the Andes has actually reversed the direction of the Amazon River, which originally flowed westward from a source in what is now West Africa.
What does the future have in store? Will the Pacific Ocean disappear or will the continents reverse direction and come together again? The short-term projections are that Africa will continue to move northward, closing off the Mediterranean Sea and turning it into a new version of the Himalayas, even as it may split in halves along the Great Rift Valley. Australia and Antarctica are also moving north and will eventually join Asia. If the Americas do reverse direction, one scenario involves a new Pangaea 250 million years from now with what remains of the Indian Ocean completely surrounded by land.

This exploration confirms that the world as we know it has had a relatively short existence and has undergone some massive changes over the longer term – and we haven’t even looked at how periodic drops in sea level have changed the appearance of the present continents. Imagine all of these areas being dry land, as they have been as recently as the last Ice Age.

Conversely, imagine what the world will look like if the sea level rises by 30 metres (blue). We are in the process of doing this right now and it won’t take anything like a million years.