# Fire and Ice

## A Short Introduction to the Climate's History
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# The Theatre of Climate

Never – not before or since – have I been in such a desolate place. We were four guys doing field work in Agardh Bay, fifty kilometres from Longyearbyen on the arctic island of Svalbard. In the middle of this wilderness, we were surrounded by mountains with flat, truncated peaks, and foaming rivers that branched out into the blue-grey water of Storfjord, where little icebergs bobbed on the surface. A bleak splendour hung over the barren and treeless landscape. Earlier that day we had flown in from Longyearbyen by helicopter, and in the evening went out into the intense light of the midnight sun. We hiked along rugged cliffs and pebble beaches, climbed steep cliffs and waded through small, gurgling rivers.

For a geologist, there is always a tingle of anticipation before these kinds of trips: What will crop up this time? What will the rock layers tell us about the bygone landscapes, life and climate? The days in the field will often merge into one, it's early to rise and late to bed, and it can eventually feel like you're seeing stone while you're asleep. The most powerful memory I have from this trip, besides stumbling upon polar bear tracks, is of the huge, charred logs we found lying haphazardly in the layers of 180-million-year-old sandstone. The logs looked almost like they had been felled the night before, and testified to an entirely different climate on the archipelago.

I've been on many trips to Svalbard. As a student I spent two weeks there on a field course, looking closely at the rugged cliffs above Reindalen where the sandstone revealed the fossils of fifty-million-year-old ash, elm and beech trees. Thin layers of coal snaked across the mountainside, evidence that the area had once consisted of swamp and impenetrable scrub; the archipelago hadn't always been a treeless waste, it had been lush and warm. Now not a single tree broke the monotony of the vast tundra, but by interpreting the rock layers we could imagine the huge, deciduous forest that once covered the island.

The climate and landscape changes over time. It is the one thing we can be certain of. Nothing is constant. We are daily reminded about global warming, and yet we tend to be blind to change. It may have struck us that winters are gradually becoming shorter, the flowers are blooming earlier and the ski slopes are thawing in March, but we quickly get used to it. The new, changed, climate becomes a new normal. After all, we don't notice these changes from day to day. But it is different for those of us travelling in deep time: We see worlds vanish and appear. It is these great transitions that captivate us, emerging from the rock layers to show us how Svalbard's frozen, barren landscape was once covered by verdant forests.

I'm often asked questions like: When was the last time it was as hot as today? Has the temperature ever risen as quickly as it is doing now? Have $CO_2$ levels in past times been as high as they are today? To get an answer, we have to go back much further than thousands of years: Today's $CO_2$ emissions are breaking records that were set millions of years ago. Billions of tonnes of carbon, stored in the ground throughout millions of years, is now ending up in the atmosphere at a rapid pace.

Every day, we burn 95 million barrels of oil – so many that you could line them up around the equator. Every day, we also consume 2.5 million truckloads of coal – also enough to form a queue stretching around the equator. And every day, we burn up over ten billion cubic meters of gas.[1] This is all carbon that plants and algae once extracted from the atmosphere with the help of nature's most important invention: Photosynthesis. The plants and algae were eventually buried – removed from the carbon cycle – and today make up the planet's enormous carbon reserves. Nearly all the carbon on earth, 99.99 percent, or over 100 million gigatonnes, is stored as coal, gas and oil – as well as limestone. These reserves are what we are now unrestrainedly emptying; carbon which is being spewed out at record speed, from a geological perspective. And what this is doing to the atmosphere, to the life and climate on Earth, is one of the most important questions of our time.

Earth's history is long, and the present is built on it. Life, the landscape, and the climate as we know it today has been shaped over thousands upon thousands of years. We have to start thinking like mountains, writes the geologist Marcia Bjornerod in her book *Timefulness*, if we're to understand this ancient and complicated planet, which is eternally developing. We must appreciate the planet's long history – its deep time. It can help us take better care of it and point the way to the future. Earth's climate history is like a never-ending piece of music, constantly changing rhythm and tempo. Understanding the changes in climate can help us understand what is happening to today's and tomorrow's planet.

Not only have we humans explored remote continents, sent spacecraft to other planets and planted flags on the moon. We have also conquered the earth's long history. For the past two hundred years, we have explored the Earth's deep past, dividing it into eons, eras, periods and epochs from the Precambrian to the Quaternary ages. We have time traveled to these strange epochs, reconstructed landscapes, moved continents and populated them with life; from trilobites in the Cambrian, via the dinosaurs of the Triassic, to the mammalian conquest of the globe in the Paleocene Period. During this long history, the climate has constantly changed; it has lurched from icehouse to greenhouse, from tolerable heat to extremely cold. Despite our still fragmentary knowledge, our distant past is being brought to life thanks to an increasingly extensive climate archive drawn from the bottom of lakes and seas, from marshes, caves, glaciers and rock layers. This has helped us create a history of the climate, in which we have found a Medieval Climate Optimum, an ice age, and a warm age 50 million years ago.

We often have to reconstruct this history based on incomplete data, overcome the dizzying time gap, and deal with the fact that most of the "evidence" has long since disappeared – constantly having to rely on circumstantial evidence or "proxies." There are still many white spots on the maps of deep time, but we are expanding our archive and developing new analyses at a high tempo, which allows us to give this prehistory more and more colour. We are by no means at the end of the road, because our knowledge is – like the climate – constantly changing. Interestingly, sixty years ago the two most important theories for understanding Earth's climate over time – the theories of plate tectonics and the Milankovitch cycles – hadn't yet broken through. Using that as a backdrop, this book will also look at how our knowledge about the climate has evolved.

"The climate forms the theatre where human existence – the history of mankind – is played out, and it provides the framework for what can happen on earth," as the German geographer Wilhelm Lauer wrote.[2] The earth is habitable, it has produced life and sustained it for millions of years, precisely because of the climate. Had our planet been pushed just a bit further from the sun, it would have been ice cold, like Mars. Had it orbited a little closer, it could have been like Venus, hot and unliveable. It is a cosmic balancing act, that underpins both the history of our species and all the life breathing on earth: While trillions of other planets remain in a climatically uninhabitable darkness, a few are located in what the physicist Stephen Hawking called the Goldilocks zone – a thin belt around a star where the temperatures are "just right" for advanced life. Here there is a delicate balance between fire and ice, a lifeless darkness and a burning inferno. It is also where our blue planet floats.

Over millions of years, humans have evolved from the simplest organisms. We have created civilisations that have risen and perished. We have fought wars, built pyramids, cathedrals and skyscrapers. And we have lived our little everyday lives. The climate has simply been there, like a kind of invisible hand that provided a framework around the lives of our ancestors. Throughout all the ages, the climate, as the climatologist Hubert Lamb wrote, has been considered unreliable and changeable. Sometimes it "provided unexpected opportunities, while at other times it caused disasters like famines, floods, drought and disease." It generated a strong need for us to interpret and understand why it happened, something we find clear signs of in the world's religions. This same need is also one of the driving forces behind modern climate science. But the perspective can be broadened further: The climate has in many ways been decisive for evolution itself. Not just our societies, but our bodies – yes, even the mechanics of our consciousness – are the product of evolutionary adaptations to a changing climate.

This book is presented as a journey through the climate's history over the past 600 million years. During this time the climate has swung from one extreme to the other. The changes may have occurred slowly, over millions of years, and been governed by the slow dance of the continents, but they have sometimes occurred rapidly, triggered by huge volcanic eruptions, asteroid strikes, or ocean currents that have abruptly slowed down.

Svalbard's grey, rocky desert, allowed me to conjure up some of the contrasts in our murky prehistory. Fifty-five million years ago the area was abundant with forests. Back then, the globe was 14 degrees warmer than today. However, if I only go back 20,000 years, the situation was completely different. Back then, large parts of the northern hemisphere were covered in ice. Where I was currently standing, the ice had once been a thousand meters thick – and globally the temperatures were six degrees lower than today.

When I first visited the archipelago I didn't give this too much thought. I was instead fascinated by the details, by how the river channels had meandered across a large delta plain millions of years ago. Although we argued then that greenhouse gas emissions had to be curbed, it's still only quite recently that we realised humanity is changing the Earth's climate at such an insane tempo. Since then, we have simply raced ahead, towards an unknown climatic future.

At the same time, climate history creates noise, and is constantly brought up by different factions in the climate debate. Some point to the fact that the earth has previously been warmer than it is today, and believe that the warming we are experiencing now is totally natural and unproblematic. Others claim – the exact opposite – that the planet's climate system was stable and like a paradise before we humans tipped it out of balance. What this book will show is that Earth's climate history is complex and multifaceted. There have been extreme heatwaves, droughts and devastating ice ages. The climate has also proven to be fragile; it can change suddenly and has dramatically affected life on the planet.

This is a story about how the earth's climate has varied throughout its long history. A core question is: What can the climate of a bygone age teach us about an oncoming, globally-heated world? It concerns a kind of “timefulness,” where deep time is used to peer into the years to come. The past, in a way, is key to understanding the future.

# Climate Mysteries at the South Pole

A professor once told me that you have to be both stupid and smart to get a PhD in geology. Stupid because you earn far less than those who go straight into the lucrative oil industry, and smart because writing a dissertation requires ingenuity. When I finished my master's degree, I took the chance anyway, and went for the PhD. I wanted to study the climate – and not the short-term changes that occurred during the last ice age or in the interglacial period, but the timespans that covered millions of years.

Core samples, meter after meter, raised from the bottom of the North Sea, were studied in detail. I was particularly interested in old, fossilised soil profiles, so-called *paleosols*, which are ancient testimony to a landscape that has long since vanished. Not only did these paleosols show that the North Sea was once dry land where rivers meandered across a vast flood plain and into the sea, they also revealed a number of secrets about climate development.

Three years of my life went on studying old soil profiles. And despite the huge effort – thousands of meters logged, and isotopes analysed – I only ended up using a fraction of the analyses. The ancient soil profiles indicated that the climate changed between the Triassic and Jurassic periods, approximately 200 million years ago.

In the Triassic, the soil was a desert-like, red-brown colour; and the climate in Scandinavia was like it is in parts of India today; dry and hot, but with periodic heavy rain. In the Jurassic the climate changed and became more humid. Black layers of coal indicate that the broad deltas and indented coasts were covered by forests and swamps. The landscape had gone from red tinged to green. Over tens of millions of years, the climate had slowly changed.

In these ancient, reddish-brown soil profiles, a white, tubular structure appeared too. It turned out to be a bone fragment from a plateosaurus, a type of dinosaur. Not only was this Norway's only dinosaur find, it was also reported in the media as the world's *deepest* dinosaur find since it was extracted from 2,256 meters below the seabed. The bone showed that although the climate had been at times inhospitable, there were animals living in the North Sea region.

It is these great upheavals that make climate's deep history so fascinating; that the cold and stormy North Sea was once a hot river-plain; that there are traces of different ice ages in the Sahara (445 million years old) and of tropical forests in the most northerly parts of Europe and North America (310 million years old). But when I point out these contrasts, people sometimes stare at me in disbelief and ask: What about today's climate change? Surely it’s just a ripple compared to the large waves of climate change that happened in our prehistory?

The climate changes over different time scales. It can happen quickly, just as today's global warming is doing, but it can also move slowly, over millions of years. So it really makes little sense talking about how during the Cretaceous period it was ten degrees warmer than it is today, or that the cold North Sea was dry and hot in the Triassic, in the same breath as today's climate change. Normally the processes driving the “slow” climate changes are fundamentally different from those that govern the “short-term” changes. But what actually caused the large, slow climate changes that occurred back in geological time?

## *The Forest in Antarctica*

“The Pole. Yes, but under very different circumstances from those expected ... Great God! this is an awful place,” wrote Robert F. Scott in his diary on 17 January 1912. The South Pole had lain virgin and undiscovered, and now the British had been beaten by Roald Amundsen's expedition in just five weeks. On the return journey, a myth about a martyr was created. We are all familiar with the tragic end of Scott and his men.

Antarctica was *Terra Australis Incognita*, the unknown continent of the south. It wasn’t until 1820 that a Russian expedition, led by Fabian von Bellingshausen and Mikhail Lazarev, observed the continent; and not until 1853 that trappers and explorers set foot on mainland Antarctica.[1] At that time, just two hundred years ago, the Arctic was far better explored, while Antarctica was still an undiscovered icy waste. But that was to change in what would become known later as the “Heroic Age”: Antarctica went from being a white spot on the map to becoming an arena for the struggle for glory, fame and power – a continent that had to be explored and conquered to build the identity of nations and empires. One expedition after the next would set off for the ice desert in the south.

In 1911, Robert Scott and his *Terra Nova* Expedition anchored in McMurdo Sound. And among the 65 participants were many scientists. The goal wasn't just to reach the South Pole, they would also be exploring the continent. Because while Roald Amundsen, in his plan to conquer the South Pole, wrote that science could "fend for itself," it was an important motive for the British. During Scott's three-year-long expedition, one of the longest unbroken streaks of sample collecting was carried out. 2,109 animals, plants and fossils – of which 401 were new to science – were transported to England.[2] One of these discoveries was particularly noteworthy, a find that some claim was fateful for the Scott expedition.

On February 8, three weeks after Scott and his men had reached the Pole, they arrived at the Beardmore Glacier. After several cold and windy days, temperatures finally crept above zero. They were still only halfway through the return trip, and about 600 kilometers from their base on the coast. They were malnourished, tired, and ravaged by frostbite.

Worst hit was Edgar Evans, whose fingernails were all about to fall off. And yet they didn't hurry on to the next depot, but stayed longer at the glacier. Science had called: They had to "geologise," as Scott wrote in his diary. It was a stay that the author Roland Huntford, who is highly critical of Scott, called a "grotesque misjudgment."

Almost a day was spent taking geological samples. In the otherwise joyless diary of Dr. Edward Wilson it says: "Got some splendid things in the short time." Geologising was valuable work, but it was time consuming and slowed the men's progress – hence the harsh judgment from Huntford.

Among the 15 kilos of rock samples that Scott and co. collected, were two containing unique fossils. But Scott and his men never realised this. On the journey back, they succumbed to tragedy, one by one. Evans, who after injuring himself badly in a fall, collapsed, and died in his tent just over a week after the Beardmore glacier excursion. “A terrible day,” Scott noted laconically in his diary on the day Evans died.

Four weeks later, the frostbite had almost crippled Lawrence Oates as well. To avoid burdening the others, Oates wandered out of his tent on his 32nd birthday. His famous last words, “I am just going outside and may be some time,” will always follow him. His body was never found.

Despite all the toil and hardship the surviving men continued, bringing the stone samples with them by sled. But on March 21 they were struck by a blizzard and sought refuge in the tent, where they lay, trapped by the weather, until they died from the cold and exhaustion a week later. They had been a scant 18 kilometres from the next depot and only 280 kilometres from the expedition's base on the coast. For the British explorers, it was literally the end of the line.

In November 1912, the frozen corpses of Scott and his men were located; the polar explorers’ bodies lying surrounded by diaries and farewell letters. To his wife, Kathleen, Scott had written: “Make the boy interested in natural history if you can; it is better than games.” Some of his final words read: “It seems a pity but I don't think I can write more. These rough notes and our dead bodies must tell the tale. For God's sake look after our people.” Later, a cross was erected at McMurdo Sound to commemorate those who died: “To strive, to seek, to find and not to yield” is carved into the wood.[3]

A myth about British courage and heroism was created. Scott's expedition had lost the race to the South Pole, but in return the participants had sacrificed themselves for science. Lying on the sledge outside the tent was the bag containing the 15 kilos of rock samples that the British men had been dragging behind them throughout that last fatal month. So what special discoveries had they made? And how significant would they be?

Some of the things they had come across were plant fossils. Scott's findings would prove to be completely unique, although plant fossils had been discovered on the Antarctic mainland before. In December 1892, when the Norwegian whaler Carl Anton Larsen stepped ashore on the

Seymour Peninsula at the northern tip of Antarctica, he raised the Norwegian flag and found, to his astonishment, the 50 million-year-old fossils of conifers.[4]

After the rock samples had been shipped to England and analysed in detail, experts concluded that Scott's expedition had uncovered glossopteris fossils. This is an extinct tree genus, specifically a seed fern that lived over 280 million years ago, with tongue-shaped leaves, hence the name; glosso means tongue in Greek. These trees had a number of special characteristics: Roots and leaves that were adapted to a life cycle of rapid growth and photosynthesis in spring, and must also have been extremely resistant to frost damage in winter.

Not only did these plant fossils confirm that the earth's climate had been warmer back in geological time; they suggested that the frozen Antarctic had once been forested. But how this could happen was still unclear to scientists back then, and it would take quite some time before anyone gained more understanding of what controlled the earth's climate. Scott’s fossilised leaves then turned out to be another small piece supporting a grandiose hypothesis conceived by the German scientist Alfred Wegener who came to revolutionise not only our understanding of the climate, but of Earth itself.

## *The Climate Dance of the Continents*

Born in Berlin in 1880, Alfred Wegener obtained his doctorate in astronomy at the age of just 25, and later embarked on a career in meteorology. In 1911, while Scott and his men were fighting for their lives in the frozen wasteland, he had his big "eureka" moment. A colleague of his had received a world atlas for Christmas, the very first that showed the location of the continents and ocean depths. The two men studied the atlas for hours, and afterwards, in a letter to his lover Else Köppen, Wegener asserted that the coasts of Africa and South America fit together. Several others had pointed this out before Wegener, but what the German was particularly surprised by was how the sea depth also followed the same pattern on each side of the Atlantic. It could be no coincidence.[5] These continents *must* have once been connected. This was something he would explore further, he wrote.

In 1912, aged just 32, Wegener presented his theory at a geological congress in Frankfurt without making any great headlines. His work was then interrupted by the First World War, during which he fought in the trenches of Belgium. He was wounded twice, the second time by a bullet that grazed his neck, and it was during his convalescence in 1915 that he put the finishing touches to his particularly ambitious work *Die Entstehung der Kontinente und Ozeane* (The Origin of Continents and Oceans). Wegener compared his observations to piecing together a torn-up newspaper, then being able to establish that the sentences actually made sense – and similarly reassembled today's continents into a prehistoric supercontinent, Pangea, or “All the Earth.” He also, quite correctly, explained how this supercontinent had later been separated by a fault between South America and Africa, which had then widened to create the Atlantic Ocean.

One of the most important factors supporting Wegener’s theory was how the plant and animal fossils from the Carboniferous and Permian periods were almost identical on both continents.[6] In his work, Wegener pointed out how an enormous coal belt from the Carboniferous period stretched from North America to China and across to Europe. This coal originated from a huge strip of forest that formed around the equator in a land area that was later driven north. The discovery of glossopteris fossils lent even further weight to Wegener's theory. These fossils were discovered in both Africa and South America, which corresponded with the landmasses having once been joined as one supercontinent. They were also found in India, Australia and New Zealand, which strengthened the very recent and highly debated theory that the continental plates moved like giant ships upon the earth's glowing interior. The glossopteris fossils showed that an enormous forest had once spread across the original supercontinent,[7] and when Wegener learned that they had also turned up in Antarctica, it helped strengthen his theory further.[8] Antarctica had been part of Pangea as well.

Several other creative suggestions had been presented before explaining why certain plant species were found fossilised on several continents that are today separated by oceans: In 1861, the paleobotanist Franz Unger launched his theory of a sunken continent in the Atlantic Ocean – an Atlantis – which had served as a land bridge for plants and animals. Towards the end of the 1800s, Eduard Suess, an Austrian geologist, believed that South America, India and Africa had once been part of a large continent in the southern hemisphere. This was based specifically on the glossopteris finds. Suess believed that the continents had become separated due to rising sea levels. Wegener however rejected these theories: The continents had drifted apart.

In the light of Wegener's theory, it was no longer strange that forests had grown in Antarctica or that an arid desert had once spread across Europe. Wegener later summarised how all this was connected in the classic *Die Klimate der geologischen Vorzeit* (The Climates of the Geological Past), coauthored with his compatriot and father-in-law Wolfgang Köppen. In this chronicle of the earth's history and climate, Wegener and Köppen demystified these discoveries; it could all be explained by the fact that the continents had moved, and that the face of the earth had changed as a result.

Like Scott, Wegener's life ended tragically in the frozen wastes. In 1930 he was doing some field work in Greenland, where three stations were set up to collect meteorological data and measure the thickness of the ice cap. After transporting provisions to one of the stations on the ice sheet, Wegener died on the way back. "Nobody has accomplished anything great in life who did not start out with the resolve: I will do it or die," he wrote in his diary.[9]

Wegener's theory of continental drift was ridiculed and called “an impossible hypothesis” and “a fairy tale.” It wasn’t until long after his death, towards the end of the 1960s, that his theory was accepted – albeit significantly modified – and called “plate tectonics,” a term derived from the Greek word *tekton*, meaning builder. Plate tectonics revolutionised our understanding of why the climate had changed over long periods of time. The continents’ passage through different climate zones was as if etched into the geological strata. This would explain why there were thick seams of coal left by tropical forests at the poles, and why there were traces of ice ages in the Sahara. Plate tectonics was also the basis for the climate change I described in my doctorate: The tectonic plate containing parts of Europe, the so-called Baltic shield, had slid from south of the equator to the far north over the course of a few hundred million years. As it did so, Scandinavia, during the Triassic period passed through dry regions at the same latitude as France is today, while during the Jurassic period it drifted further north into much wetter regions.[10]

Continental drift affects the climate in several ways. It is also the master of volcanism, which is in turn important for the amount of greenhouse gases there are in the air. Plate tectonics controls the position of continents, which in turn determines the circulation of the ocean and atmosphere. The colliding continents form mountains, just like the Himalayas when they rose onto the sky. This affects weathering, which keeps the atmosphere’s $CO_2$ levels in check. Plate tectonics is the most important driving force behind climate change on Earth – not over centuries, but over millions of years.

Roughly 600 million years ago, the slow dance of the continental plates began giving Earth a “roller-coaster” climate. And the roots of our understanding of this dramatic event can also, in a sense, be traced back to Antarctica.

# NOTES

*The Theatre of Climate*

1 The figures have been calculated from 8.5 billion tonnes of coal and 4,000 billion cubic meters of gas per year. Source: *BP Statistical Review*, 2020.

2 Cited according to Dybdahl (2016).

*Climate Mysteries at the South Pole*

1 The American seal hunter Mercator Cooper came ashore on the ice shelf in Victoria Land. Landfall had already been made on some of the islands, and there are some undocumented claims that people had already set foot on the continent in 1820.

2 Martin, C. (2012): “Scientist to the end”. *Nature*.

3 After a poem by Alfred Tennyson.

4 Carl Anton Larsen was on a two-year expedition from 1892 to 1894 aboard the schooner *Jason*. The discovery aroused considerable scientific interest; it was one of the first pieces of evidence that Antarctica had not always been covered by ice. Larsen's plant fossils were of a much younger age than Scott's glossopteris fossils.

5 Wegener was aware that the sea level could change significantly and that the alignment of coastlines might be coincidental, but the fact that the bathymetry also matched was a weighty piece of evidence. Much of the material on Wegener is taken from Greene (2015).

6 The Austrian geologist Eduard Suess studied glossopteris fossils in South America, Africa and India. He believed that the three land areas had once been connected, and called this prehistoric supercontinent Gondwana.

7 280 million years ago, Antarctica was located roughly where the continent is today, at the South Pole, which means that the global climate was far warmer than it is today. And considering the periods of polar darkness the area was subject to, among other things, the glossopteris forest must have endured enormous fluctuations in climate.

8 Köppen and Wegener (1924), p. 47: “Glossopteris found at 85 degrees south by Scott's expedition.”

9 “Nobody has accomplished anything great in life who did not start out with the resolve: I will do it or die." From Loewe (1970): *The scientific exploration of Greenland from Norsemen to the Present*. Institute of Polar Research, Report No. 5.

10 An extensive period of volcanic activity during the transition between the Triassic and the Jurassic periods, also called CAMP (Central Atlantic Magmatic Province), may have also affected the climate.