ARTERRA/UNIVERSAL IMAGES GROUP VIA GETTY

Triassic rocks in the Italian Dolomites bear evidence of a surprisingly wet episode in Earth's history.

A MILLION YEARS OF TRIASSIC RAIN

An extended bout of warm, wet weather 232 million years ago might have triggered the rise of the dinosaurs and completely altered the history of life on Earth. **By Michael Marshall**

Alastair Ruffell could see there was something odd about the rocks near his childhood home in Somerset, UK. The deposits hail from the Triassic period, more than 200 million years ago, and most are a dull orange-red, signifying that they formed when the region was a parched landscape, baked by the sun. Nothing strange there. But outcrops on Somerset's Lipe Hill have a thin stripe of grey running through the heart of the red stone. That band signals a time when arid desert disappeared and the region transformed into a swampy wetland. For some reason, an incredibly dry climate had turned wet, and stayed that way for more than a million years.

The change intrigued Ruffell when he first found the outcrops in the mid-1980s, but the young geologist had a PhD project to finish. So he put the Triassic puzzle to one side, until a chance encounter in 1987 with another young scientist, palaeontologist Michael Simms. During his postdoctoral studies, Simms had discovered evidence of extinctions in the Late Triassic, during Ruffell's mysterious wet period. In the late 1980s, the pair pushed the idea that the two findings were connected, but for years, their results were dismissed.

Three decades later, there is a growing consensus that they were right, after all. Something strange happened in the Late Triassic — and not just in Somerset. About

232 million years ago, during a span known as the Carnian age, it rained almost everywhere. After millions of years of dry climates, Earth entered a wet period lasting one million to two million years. Nearly any place where geologists find rocks of that age, there are signs of wet weather. This so-called Carnian pluvial episode coincides with some massive evolutionary shifts.

Perhaps most dramatically, the Carnian pluvial might have overlapped with when a rare group of reptiles — early dinosaurs — evolved into a diverse group and came to dominate land ecosystems. The Carnian could have paved the way for the spectacular dinosaurs that evolved later, including *Stegosaurus* and *Tyrannosaurus*.

Other groups also left the Carnian in very different shape from how they had entered it: reef-building corals and marine plankton were all becoming more 'modern' — moving evolutionarily closer to the forms alive today. The period could even have seen the appearance of the first mammals. "It was almost like a turning point between some elements of a more ancient world and a modern world," says Simms.

After years in obscurity, the Carnian pluvial is becoming a major research focus. In May 2017, scientists gathered for the first conference dedicated to the period, held at the Institute for Advanced Study in Delmenhorst, Germany. Since then, the *Journal of the Geological Society* has dedicated two special issues to the topic. Over the past decade, many researchers have begun studying Carnian rocks intensively. They want to understand why the climate changed, and why that led to such dramatic evolutionary shifts. Evidence now points to massive volcanic eruptions.

This is a remarkable turnaround for an event discovered almost by accident in the 1980s.

A chance encounter

It began when Simms, now at National Museums Northern Ireland in Holywood, went to the University of Liverpool, UK, for a postdoctoral research fellowship. He studied crinoids: marine animals, related to starfish, that resemble flowers or feathers.

Simms focused on crinoids living in the Triassic period, which ran from 252 million years ago to 201 million years ago. The Triassic was bookended by two of the most troubled times in Earth's history: it started right after a mass extinction at the close of the Permian period, and ended with another mass extinction at the Triassic–Jurassic junction.

But Simms was in for a surprise. "By the tail end of 1987, it had become clear that there was a quite significant extinction among the Triassic crinoids," he says. But the die-off came tens of millions of years before the end of the period. This placed the extinction in the Carnian: the fifth of seven shorter ages in the Triassic.

Intrigued, Simms returned to the University of Birmingham, UK, where he had done his doctorate, for a visit. His old office was occupied by palaeontologist Paul Wignall and Ruffell, who is now at Queen's University Belfast, UK.

Ruffell's studies focused on sediments from the later Cretaceous period, but for fun he was investigating Triassic rocks called the Mercia Mudstone Group, which mostly reflect dry climates. It was in the Carnian section of these rocks that he found a thin layer of grey sandstone, rich in fossils such as sharks' teeth. It was the remains of a river or delta. "Slap-bang in the middle of all this horrible arid stuff was this probably rather pleasant environment," says Ruffell.

I REMEMBER ONE OR TWO QUITE SENIOR ACADEMICS THOUGHT IT WAS A PREPOSTEROUS IDEA."

When the three were chatting, Simms mentioned the Carnian crinoid extinctions. According to Simms and Wignall, Ruffell replied: "It was raining then. Perhaps the crinoids didn't like the rain." It was a flippant remark, one Ruffell does not remember making, but it struck a chord with Simms. Changing climates can cause extinctions, so perhaps this was the case for the shifts in the Carnian.

Simms and Ruffell began investigating, and found that there was also evidence of a wet spell in the Carnian in rocks from Germany, the United States, the Himalayas and other places. What's more, it was not just the crinoids that faced extinctions: amphibians and land plants lost members, too. In 1989, the pair published evidence for an event they named the Carnian pluvial episode[1], using the geological term referring to rain.

The results didn't make much of a splash, except from some researchers who attacked the idea. "I remember one or two quite senior academics thought it was a preposterous idea," says Simms.

In 1994, a team led by Henk Visscher of Utrecht University in the Netherlands published a strongly worded rebuttal claiming that although some spots might have grown rainy during this time, many environments remained dry[2]. Visscher argued that, instead of an increase in rainfall, the evidence could be explained away by "high groundwater tables".

Rebuffed, Simms and Ruffell changed course. "We just moved on to all sorts of other things," says Simms. Whereas Simms pursued a career in geology and palaeontology, Ruffell became an expert in forensic geology.

Wet world

However, the Carnian pluvial episode did not go away. Geologists in Europe, especially Italy, continued amassing evidence for wet conditions around 232 million years ago. The coincidences piled up.

In the Late Triassic, the world looked nothing like today's (see 'Time for a change'). The landmasses were all connected, forming a 'supercontinent' called Pangaea, where the climate was hot and dry, especially in the interior. Land ecosystems were dominated by reptiles, including the first dinosaurs. There were no flowers, grasses or birds.

There were also no mammals, but the Carnian might have been when that changed. In 2005, P. M. Datta at the Geological Survey of India in Kolkata described a single mammal tooth from Carnian-aged rocks in India[3]. Another tooth, discovered in Carnian rocks in Germany, might also have belonged to a mammal[4].

The origin of mammals is a topic that triggers strong debate. Wignall, who is now at the University of Leeds, UK, says they could have appeared during the Carnian, but it's also possible that there are earlier ones we have not found yet. And many palaeontologists argue that true mammals did not emerge until the Jurassic, millions of years later. If so, the Carnian fossils are not from mammals, although they could be from their ancestors.

Whatever the case is with mammals, a string of discoveries in the past decade or so offers strong evidence for other evolutionary shifts. Researchers reported in 2013 that the Carnian saw the origin of marine organisms called calcareous nannoplankton[5]. These single-celled organisms surround themselves with hard shells of calcium carbonate. Today, they form huge blooms and are known as the 'grass of the sea'. They have a major role in cycling carbon between the air and the ocean.

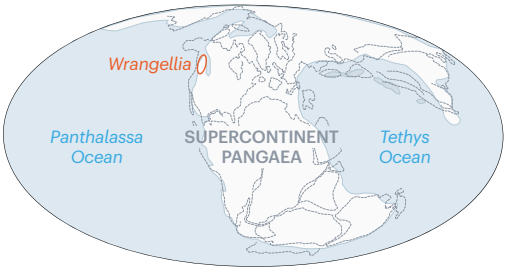
Another group that underwent major changes in the Carnian was the scleractinian corals, which build today's giant coral reefs. Scleractinians emerged earlier in the Triassic, but it was not until the Carnian or shortly afterwards that they began constructing big reefs. Isotopic evidence and other clues in fossil corals suggest this could be when they acquired their modern symbionts: photosynthetic algae that supply them with nutrients[6].

A fiery time

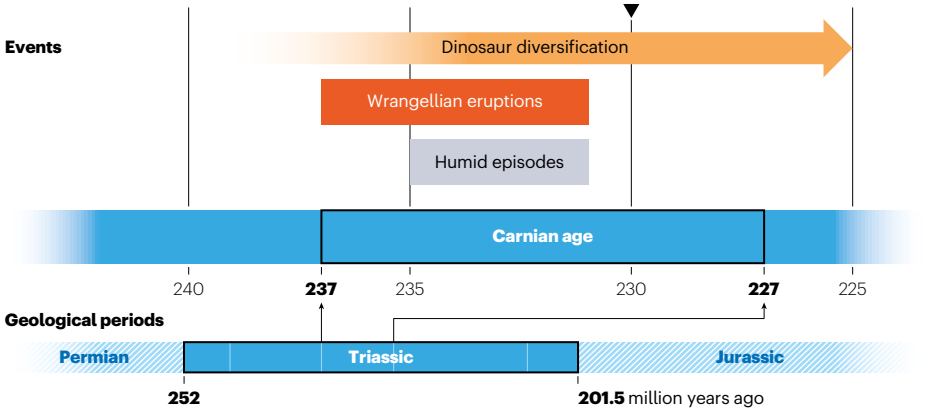
Not everyone is convinced that the world went through a warm, wet phase in the Carnian. "Still, I have my doubts," says Visscher. He accepts that the climate changed, but says rainfall could have become more seasonal, leading to annual blooms of vegetation. Similarly, Matthias Franz at the Georg-August

TIME FOR A CHANGE

After millions of years of generally dry climate, the planet went through several humid phases that together spanned more than a million years during the Carnian age of the Triassic period. The climate change coincided with massive eruptions — resulting in what are known as the Wrangellia flood basalts — in what is now northwestern North America. The upheaval might have spurred massive evolutionary changes, including the emergence of new dinosaur groups.



Earth during Carnian age of Triassic period, roughly 230 million years ago



University of Göttingen, Germany, has found evidence that the extra damp might have been caused by rising seas[7], at least in parts of Europe, although it is not clear that this can account for the changes elsewhere. Still, Franz emphasizes that the period is significant anyway. "There is obviously something happening at this time," he says. "The question is what."

Simms and Ruffell had previously suggested that volcanic eruptions were responsible for the climate change, and geologists knew there was a prime candidate: the cataclysm that created massive basalt formations — several kilometres thick in places — running from British Columbia in Canada to Alaska.

Dubbed the Wrangellia Terrane, after Alaska's Wrangell Mountains, these lavas are part of a Large Igneous Province formed by volcanoes spewing out huge volumes of lava over hundreds of thousands or millions of years, around 232 million years ago. The volcanoes were submarine, but emerged above the water as lava continued to pour out, says Andrea Marzoli at the University of Padua in Italy.

If these vast eruptions happened at the same time as the Carnian pluvial episode, they could have released enough carbon dioxide to warm the globe. And that could have increased rain, by enhancing evaporation from seas and rivers. Some scientists have come to regard the name Carnian pluvial as misleading, because the main change at the time would have been an episode of global warming.

"The natural thing to do was to understand if this increase in rainfall, that was seen everywhere, was triggered by injection of CO_2 in the atmosphere," says Jacopo Dal Corso, a geologist at the University of Leeds. His team analysed samples of carbon-rich Carnian material from the Italian Alps. In 2012, the researchers reported unusually low levels of carbon-13, a heavy isotope of carbon, during the Carnian pluvial[8]. This indicated that a huge volume of the lighter isotope, carbon-12, was injected into the atmosphere — and eruptions in Wrangellia could have been the prime source.

Subsequent studies have backed Dal Corso's claim that the carbon cycle was perturbed during the Carnian for about one million years[9], owing to the eruptions. But for some, the link remains tentative because uncertainty in the dating of rocks makes it hard to definitively say that the Wrangellia eruptions happened at the same time as the climatic and evolutionary changes in the Carnian. Wignall says this is because the Carnian has not yet been studied intensively; uncertainties can span one million years. Marzoli plans to sample Wrangellia next summer, partly to clarify its age. According to him, Wrangellia is the most likely explanation because there are no other candidates.

> "ONE OF THE FASCINATING THINGS ABOUT THIS INTERVAL IS HOW MANY MODERN GROUPS APPEAR."

Meanwhile, the list of evolutionary changes that happened in the Carnian pluvial continues to grow.

The most dramatic claim is that the Carnian was crucial for the dinosaurs' rapid evolutionary expansion. Evidence indicates that dinosaurs emerged before the Carnian, about 245 million years ago, but those earliest creatures are very rare and only a few species are known.

What's clear is that dinosaurs changed drastically. At the start of the Carnian, they were all small and bipedal. But by the end, the two major groups had emerged. These were the ornithischians, which later included *Stegosaurus* and *Triceratops*; and the saurischians, which gave rise to huge, long-necked species such as *Brachiosaurus*, and theropods such as *Tyrannosaurus rex* and birds. Mike Benton, a palaeontologist at the University of Bristol, UK, and his colleagues documented some of these changes by using well-dated samples from the Alps to create a high-resolution timescale of animal tracks in the Late Triassic[10]. The early Carnian was dominated by reptiles called crurotarsans. But by the end of the Carnian, the dinosaurs dominated. This shift took just 4 million years, and coincided with the pluvial episode. And after that rapid rise, dinosaurs ruled the world for more than 150 million years.

With all these changes happening, and the fuzzy dating of rocks from the Carnian, researchers are struggling to create a coherent picture of how the climate changed and how that affected ecosystems. But the Carnian has become a hot topic. "One of the fascinating things about this interval is how many modern groups appear, from vertebrates all the way down to plankton," says Wignall.

This was one of life's major transitions. The planet was still recovering from the end-Permian extinctions and the Carnian saw the rise of groups that have ruled the world ever since.

The two researchers who started this whole affair are surprised and delighted by what has happened. Simms is content to watch from the sidelines, but Ruffell has resumed studying Carnian geology. The irony, Ruffell says, is that his Carnian studies were only a hobby. This dramatic period that shook up evolutionary history was found, he says, by "a couple of guys who really shouldn't have been working on it in the first place".

SOURCE: A. RUFFELL, J. DAL CORSO & M. BENTON *GEOSCIENTIST* **28**, 10–15 (2018).

Michael Marshall is a science journalist in Devon, UK.

1. Simms, M. J. & Ruffell, A. H. *Geology* **17**, 265–268 (1989).
2. Visscher, H. *et al. Rev. Palaeobot. Palynol.* **83**, 217–226 (1994).
3. Datta, P. M. *J. Vert. Paleontol.* **25**, 200–207 (2005).
4. Lucas, S. G., Heckert, A. B., Harris, J. D., Seegis, D. & Wild, R. *J. Vert. Paleontol.* **21**, 397–399 (2010).
5. Preto, N., Willems, H., Guaiumi, C. & Westphal, H. *Facies* **59**, 891–914 (2013).
6. Stanley, G. D. Jr *Science* **312**, 857–858 (2006).
7. Franz, M. *et al. Glob. Planet. Change* **122**, 305–329 (2014).
8. Dal Corso, J. *et al. Geology* **40**, 79–82 (2012).
9. Dal Corso, J. *et al. Earth Sci. Rev.* **185**, 732–750 (2018).
10. Bernardi, M., Gianolla, P., Petti, F. M., Mietto, P. & Benton, M. J. *Nature Commun.* **9**, 1499 (2018).