The year of darkness

In AD 536 the sun dimmed and global temperatures plunged, leading to famine, plague and the collapse of empires. At last clues are emerging about the cause of this event, as **Colin Barras** reports

ALAIN WILLAUME/TENDANCE FLOUE

THE year is AD 536, and Byzantine historian Procopius of Caesarea has just arrived in southern Italy. The balance of power in the Mediterranean is in flux: Vandals had sacked Rome in 455 and the Western Roman Empire had fallen in 476. Justinian I, the Byzantine (or Eastern Roman) Emperor, is determined to reclaim the lost territories. After a successful campaign against the North African Vandal Kingdom in the early 530s, Justinian dispatches his army to retake Italy.

Yet as Procopius records, something odd then happened. The sun dimmed, and the dimness lasted for more than a year. There were frosts and snows in the middle of summer – the winter never really ended. From Italy to Ireland, China to Central America, the year 536 was the beginning of a decade-long cold snap beset by turmoil. Religions lost believers, cities collapsed and one of the greatest plagues in history killed a quarter of the population in the Byzantine Empire. Justinian's armies did manage to retake Rome, but his weakened empire was overstretched, and soon lost the territory again.

In almost every region of the world, this period was marked with bad weather, social disorder – and death. This climatic downturn may well have profoundly altered the course of history. The trigger of this cooling has long been a mystery, but now we may finally be close to identifying the culprit – or culprits.

The first evidence of the AD 536 event came from a study in the 1980s by two NASA geologists, Richard Stothers and Michael Rampino. They trawled through early historical accounts looking for references to volcanic eruptions around the Mediterranean. They concluded that there had been at least seven major eruptions before AD 630, including the one in AD 79 that buried the town of Pompeii.

Yet while there were four accounts – including that of Procopius – of an 18-month-long period of unusually dim skies, beginning around AD 536, there were no direct references to a volcanic eruption at this time. Stothers and Rampino concluded that the cause must have been a massive volcanic eruption thousands of miles from Europe.

This was certainly plausible. The eruption of the Indonesian volcano of Tambora in 1815, after all, was followed by a "year without a summer" across the northern hemisphere (and may have given us *Frankenstein* and bicycles). The historical accounts suggested that 536 was much more severe than 1816, but could they be trusted?

"All of the ancient texts could be quibbled ›

"There was a sign in the sun the like of which had never been seen and reported before... The sun became dark and its darkness lasted for eighteen months. Each day it shone for about four hours, and still this light was only a feeble shadow. Everyone declared that the sun would never recover its full light. The fruits did not ripen and the wine tasted like sour grapes"

MICHAEL THE SYRIAN (Chronicle, 9.296)

with," says Michael Baillie at Queen's University Belfast, UK. But with his help, an impartial witness to the 6th century events broke its silence in the late 1980s. Baillie studies tree rings and, using oak preserved in Irish bogs, he and his colleagues put together a tree-ring record stretching back more than 7000 years. In 1988, they reported that during the first millennium AD, the narrowest tree rings – indicating poor growing conditions and cold temperatures – occurred within a few years of 536.

More tree-ring data followed from other groups, and a pattern emerged. "The narrow tree rings weren't just in European oak. They were in Scandinavian pines, and in trees from North and South America," says Baillie. "This pretty much had to be a global event."

But there was something missing. As volcanic ash and sulphur particles wash out of the atmosphere, they leave traces in the ice forming near the poles. During the 1980s, ice cores from Greenland were revealing evidence of many previously unknown eruptions, including a particularly massive one in 1257. There was, however, no volcanic signature in ice formed around 536.

The tree rings were also revealing something unexpected. Despite the emphasis that the historical accounts placed on 536, the tree-ring record suggested growing conditions were awful in the years following 540 as well. In fact, the tree rings showed that the cold snap continued for a decade. It is very unusual for an eruption to trigger a decade of cooling, says Baillie, because the ash and sulphur-rich particles thrown into the atmosphere by a volcano should wash out again within a few years. The findings got Baillie rethinking the source of the trouble. "Stothers and Rampino saw the event as evidence of a volcanic eruption, but perhaps there was another explanation," says Baillie.

When he found obscure references to unusual partial eclipses in north-west Europe in 538 and 540, Baillie began to wonder whether the source of the trouble was not volcanic but extraterrestrial. In 1994, shortly before fragments of the comet Shoemaker-Levy 9 ploughed into Jupiter, he suggested that dust from a comet that had passed near Earth – or even collided with our planet – could explain both the unusually long climatic downturn and the lack of a volcanic signature.

In a 1999 book, Baillie went further, suggesting that several major climatic changes in the past 10,000 years were triggered by impacts. He speculated about links with a broad range of historical and even mythical events, including the death of King Arthur.

The plague of Justinian

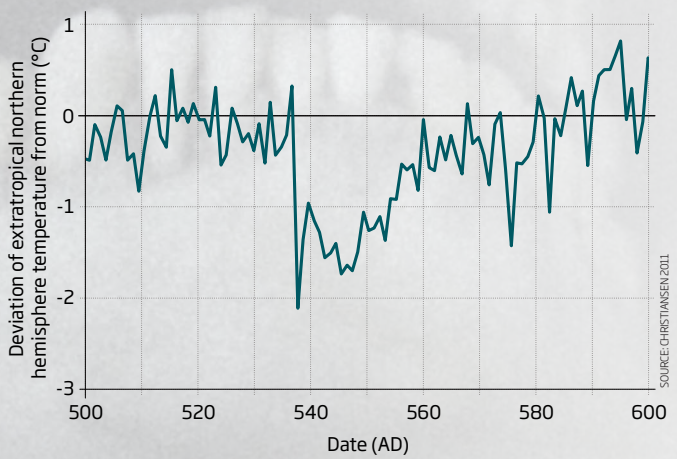
What is certain is that the years following 536 were eventful. In China, for instance, the Northern Wei dynasty collapsed around this time. "There's written evidence that about 75 per cent of people died because of cold, crop failure, starvation and droughts," says Payson Sheets, an archaeologist at the University of Colorado in Boulder. "There was political and religious turmoil."

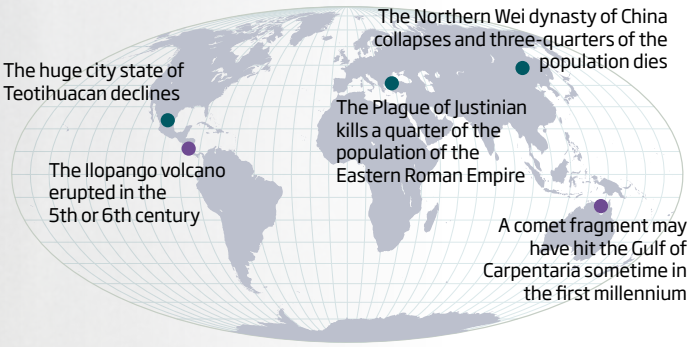
In Central America, the population of the huge city state of Teotihuacan also declined. "The exact dating is up for debate, but by around 550, the people there were deliberately burning the temples on the top of their step-pyramids," says Sheets. "They had lost faith in their rulers' abilities to act as intermediaries between people and their gods."

And just as Justinian was reconquering the Eastern Roman Empire, his subjects began dropping like flies. By 542, Procopius was lamenting what is now known as the Plague of Justinian – an early form of bubonic plague – which he said was claiming

Climate catastrophe

Tree rings and other records show the world suddenly cooled around AD 536, a period marked by famines, plagues and turmoil. But what caused it?





The Plague of Justinian was an early form of the bubonic plague that caused the Black Death

SCALA, FLORENCE - COURTESY OF THE MINISTERO BENI E ATT. CULTURALI

10,000 lives each day at its peak.

Were all these disparate events triggered by global cooling? Baillie thinks they might have been. For instance, the Plague of Justinian could have been an indirect result of food shortages throughout Eurasia, which led to the mass movement of people and disease-carrying rodents. "People were exposed to pathogens they were unfamiliar with," he says. "Plague broke out and spread – it's the classic Black Death scenario."

Proving that specific historical events were triggered by climate change is nigh on impossible, but painstaking studies by David Zhang of the University of Hong Kong have shown that there is a strong link between cooler periods and famine, plague, mass migrations, social turmoil and even wars (*New Scientist*, 4 August 2012, p 32). "I believe it is possible that the decadal-scale cooling in 530s and 540s could have caused epidemics," Zhang says. "Not only because of the migrations, but also because famine caused poor health among populations."

Although we will never know for sure what the historical consequences were, in 2002 Baillie set about looking for evidence of an extraterrestrial trigger – such as the solidified droplets of molten material generated by an impact – in a Greenland ice core. "We found that it was packed full of glassy and metallic spherules, and I thought we had our evidence."

But it wasn't to be. There was no trace of similar spherules in a second ice core. "The spherules in the first ice had to be contamination," says Baillie – perhaps from the equipment used to extract the core. By late 2002, then, the 536 event was more enigmatic than ever: there was growing direct and historical evidence of a sudden and severe cooling, but there was no sign of what had caused it. So Bo Vinther at the University of Copenhagen in Denmark and his colleagues decided to take another look at the ice cores – and in 2008 they reported that there was a subtle but substantial sulphur signal at 534, give or take a couple of years. The volcanic explanation was back on the table (*Geophysical Research Letters*, vol 35, L04708).

It is not actually surprising that earlier investigation of the ice core record revealed no volcanic signature at 536, says Vinther. Unless the eruption happens close to the ice sheet and blankets it in ash, the volcanic signature is likely to be small and subtle. "You need to be very careful with your measurements if you are going to detect it," he says.

And this eruption probably didn't happen anywhere near an ice sheet. Vinther's team found the sulphur traces in ice from both Greenland and Antarctica. "So the eruption had to have occurred in the tropics," he says. "Otherwise you wouldn't get a signal in the ice at both poles."

The hunt for the volcano was on – and a suspect soon emerged. Fortuitously, Steffen Kutterolf at Kiel University in Germany and his colleagues were reassessing the size of known volcanic eruptions in Central America by measuring ash deposits. Their work, published within months of Vinther's study, doubled the estimated size of an eruption from the Ilopango volcano in El Salvador. We now know this eruption generated 84 cubic kilometres of ash, says Kutterolf.

"That's huge – one recent estimate puts this eruption as the sixth largest on the planet during the last 10,000 years," says Robert Dull at the University of Texas at Austin, who has worked on Ilopango for years. There was just one problem: carbon dating of plant material found in the ash pointed to a date sometime around AD 430. That was 100 years too early, but the dating was only provisional.

Chinese records suggest Halley's comet shed more dust and debris than usual in AD 530

LEFT: MAT JACOB/TENDANCE FLOUE RIGHT: DETLEV VAN RAVENSWAAY/SCIENCE PHOTO LIBRARY

After reading these studies, Dull teamed up with Kutterolf. The idea was to pin down the date more precisely by carbon dating the growth rings in a tree trunk. That meant finding a tree in the ash. In 2010, the team announced finding a tree that had died sometime between 500 and 550, making a link with 536 a real possibility. In the past two years, work on other trees has confirmed that the eruption took place early in the 6th century and points to 535 as the most likely date, says Dull.

If Ilopango triggered devastating problems across the world, its effects on Central America must have been nothing short of apocalyptic. "Draw a circle with a radius of 200 kilometres around Ilopango, and you're potentially looking at the total wipeout of people, animals and trees," says Sheets, who has also teamed up with Dull. The Maya civilisation a few hundred kilometres further north may have escaped such total destruction, but it did mysteriously stop building elaborately carved monuments known as stelae, with dated hieroglyphic texts, in the 530s, says Dull.

Even if the Ilopango eruption did trigger the events of 536, it cannot easily explain why the cold snap continued for a decade, and why some of the coldest years came after 540. Was there more than one eruption? Within the last few months, an analysis of a Greenlandic ice core has revealed a sulphur signal at 540 – but the signal is only around 15 per cent the strength of the 534 signal. It is debatable whether an eruption of this size could have

ROBERT FRERCK/GETTY

Things got so bad in the city state of Teotihuacan that people burned down the temples on pyramids

had a significant climatic impact.

Enter Dallas Abbott, a geologist at Columbia University in Palisades, New York. Her team has also been studying ice cores from Greenland – and they, like Baillie, have found metallic spherules dating to around 536. But they have also found unusually high concentrations of nickel and tin. Nickel is abundant in extraterrestrial debris and is unlikely to reflect contamination, Abbott says, because it is not typically present in the equipment used to collect the ice. The tin, meanwhile, is suggestive of a comet.

So Abbott's findings have resurrected the comet hypothesis – and she even has a particular suspect in mind. "We know that Halley's comet came by Earth in 530," says Abbott. "And the Chinese record indicates it was unusually bright."

The brightness suggests that on this journey through the inner solar system, Halley's comet passed particularly close to the sun, she says. It would have lost more ice than usual, releasing more of the dust and debris frozen inside. "Halley might have been especially likely to lose material and make dust in 530," says Abbott.

Each year, Earth passes through two meteor showers produced by dusty fragments of Halley's comet. Throughout the 530s and into the 540s, these meteor showers may have been unusually heavy, and continued to top-up Earth's atmosphere with cooling dust – and perhaps more.

Impact site

There are other surprising clues in the ice. Cores from around the beginning of 536 contain the frozen remains of microorganisms normally found in shallow tropical seas, while samples from 538 also contain fossils of much more ancient marine microorganisms. Abbott thinks there is only one way these microorganisms could have ended up in Greenland ice.

Halley's comet might have shed a few especially large fragments during its journey through the inner solar system in 530. In the following years, perhaps including 536 and 538, these fragments slammed into Earth's oceans. When they did, dust and debris – containing living marine microbes in the water and fossils in the rocks that were struck – were thrown high into the atmosphere and global temperatures plummeted.

Abbot's team may have even found where one of these collisions occurred. Gravity anomalies and metallic spherules in a sediment layer suggest a large object struck Australia's Gulf of Carpentaria sometime in the first millennium AD, she says.

Abbott presented her team's findings at two conferences last year and will be publishing the details soon. However, she still has plenty of work to do to convince sceptics.

Don Brownlee at the University of Washington in Seattle worked on NASA's Stardust mission to collect dust from the Wild 2 comet in 2004. He says there is some evidence that cosmic impacts with Earth can have a major cooling effect: a brief episode of cooling about 12,800 years ago has been linked to major impacts at the time, for example. But he is sceptical that Halley played such a role in the 6th century, because the famous comet's history over the last few thousand years is reasonably clear. "Comets can brighten and even exceptionally fragment, but I don't know of any evidence for such behaviour of Halley in the past," he says.

Even if Halley was not involved, Abbott could still be right about Earth passing through dust and suffering two or more large impacts. Other groups are now taking another look at the ice cores. "With what Dallas is publishing now, I'm going to go back to our ice samples and see if we can find anything that replicates her results," says Baillie.

In the meantime, our neighbour Mars may soon let us see first-hand what happens when cometary debris hits a small planet. The Red Planet is due to plough through the dust and gas surrounding Comet C/2013 A1 in October.

In the past few years, then, we have gone from no evidence of either a volcanic eruption or any kind of impact around 536 to having preliminary evidence of both. So what caused the global cold snap? Dull will tell you it was a volcano, whereas Abbott is convinced it was a comet. But it could be that they are both right.

The unusually severe cooling and its persistence may be best explained by a double whammy. Vinther says the lack of any strong volcanic signature in ice from 540 certainly makes such a volcano-and-comet theory a possibility. It may seem unlikely that Earth experienced a massive volcanic eruption and a close brush with a comet within the same decade – but unlikely things do happen. ■

"And it came about during this year that a most dread portent took place. For the sun gave forth its light without brightness, like the moon, during this whole year, and it seemed exceedingly like the sun in eclipse, for the beams it shed were not clear nor such as it is accustomed to shed"

PROCOPIUS (Wars, 4.14.5)

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