Volcanoes

How did the summer go?

David M. Pyle

The summer of 1601 was, by all accounts, truly awful. Across England, "the month of June was very colde, frosts every morning"[1]. It was a similar story in northern Italy, where freezing weather extended into July, and the sky was 'overcast' for much of the year[2]. Iceland and Scandinavia also apparently experienced unseasonal weather. Just another poor northern European summer? It seems not.

Papers by Briffa *et al.*[3] and de Silva and Zielinski[4] (pages 450 and 455 of this issue) now reveal the true scale of this cold summer and the reasons for it. Patterns of tree growth across the Northern Hemisphere, analysed by Briffa *et al.*, confirm that the summer of 1601 was by far the coldest of the past 600 years, and about 0.8 °C cooler than the summer mean for the period 1881–1960. The cause is identified as a spectacular eruption of the volcano Huaynaputina in Peru in February 1600. Fieldwork[4,5] now shows that Huaynaputina (Fig. 1) was one of the largest eruptions of the past few centuries. In their paper, de Silva and Zielinski calculate that it threw out nearly 10 km^3 of molten rock, and left prominent records of sulphate pollution in polar ice-cores. For comparison, the damaging eruption of Mount Pinatubo, Philippines, in 1991, involved about 5 km^3 of magma, whereas that of El Chichón, Mexico, in 1982 involved about 1.3 km^3 of magma.

Eruptions of the scale of Huaynaputina occur only once or twice a century, and are often followed by a widespread, but short-lived, climate response caused by the volcanic pollution. Volcanic sulphur dioxide injected into the stratosphere oxidizes to form a sulphate aerosol layer that coarsens slowly, and drifts around the globe. This aerosol layer intercepts incoming solar radiation, disturbing Earth's surface temperatures. The mid-latitudes of the Northern Hemisphere seem to be particularly sensitive to the effects of large eruptions[6], experiencing slight winter warming and marked summer cooling as a result. Eventually, after transport to the poles, the sulphate aerosol may be preserved in accumulations of snow.

In detail, the time taken for sulphate to disperse from the tropics to higher latitudes depends on the phase of the stratospheric 'quasi-biennial oscillation'[7]. Under some conditions, aerosols can be stored within a tropical stratospheric reservoir for a year or two before being transported to higher latitudes. This introduces a time lag between large eruptions in the tropics and their effects at mid- to high latitudes. It also reduces the chance of identifying the source of any individual sulphate peak in polar ice-cores — which can only be done by matching the compositions of the accompanying fragments of volcanic glass with a known eruption[4,8]. If volcanic ash is held above the tropics for long enough, the ash particles will

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Figure 1 **Craters of Huaynaputina, in the Peruvian Andes. This was the site of one of the largest eruptions of the past few centuries, in February 1600. From their reconstruction of the extensive deposits of volcanic ash around the volcano, de Silva and Zielinski[4] calculate that this eruption threw out nearly 10 km^3 of molten rock. Briffa *et al.*[3] have studied patterns of tree growth, which show that the following summer of 1601 was the coldest of the past 600 years across the Northern Hemisphere. Sulphate pollution in polar ice-cores from the same time suggests that the eruption of Huaynaputina was directly responsible for this widespread cooling.**

NATURE

100 YEARS AGO

One of the elephants in Barnum and Bailey's Show, which has been visiting Liverpool during the past two weeks, having recently shown signs of insubordination, Mr. Bailey determined, in order to perfectly safeguard his visitors, to sacrifice the animal. He has had during his life occasion to destroy many elephants, which, as a rule, he has handed over to experienced veterinary and other surgeons, who have tried various methods, such as poisoning, shooting and bleeding. All have proved, however, unsatisfactory, because uncertain, tedious and not seldom dangerous to those engaged in conducting the operations. On this occasion it was determined, after consultation with several experts and with the Secretary of the Royal Society for the Prevention of Cruelty to Animals, to kill the elephant by strangulation, which had once before been adopted with success by Mr. Bailey. Accordingly it was arranged that on a recent Sunday morning – the day most suitable to the Show people and that freest from intrusion by the public – Don, as the doomed elephant, who was supposed to be about twenty-two years of age and nearly 4 1/2 tons in weight, was named, should be strangled.

From *Nature* 2 June 1898.

50 YEARS AGO

A valuable means of bringing about active co-operation between industry and the universities has recently been shown by the United Steel Companies, Ltd. At the invitation of the chairman, Sir Walter Benton Jones, fourteen mechanical and production engineering professors from British universities spent four days … in visiting the branches of the United Steel Companies at Sheffield, Scunthorpe and Stocksbridge, and in joint discussion both at the various works and at the Sheffield headquarters. … [T]he research staff of the United Steel Companies were grateful for suggestions thrown out by the professors, while the latter were appreciative of the new problems put to them and which, in some cases, could usefully be followed up by them and their research staffs. By arranging this tour the United Steel Companies have shown a way in which industry and scholarship can work together for their mutual help and the well-being of British economy.

From *Nature* 5 June 1948.

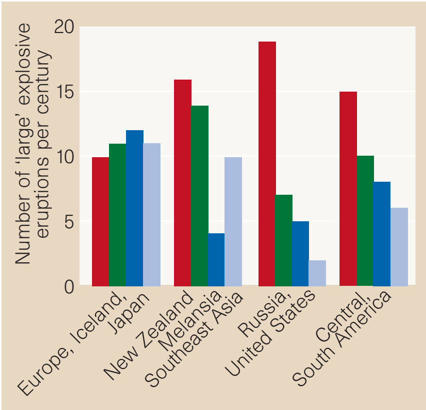

Figure 2 **A compilation of the numbers of reported[10] 'large' explosive volcanic eruptions — those with a volcanic explosivity index of 4 or more — during the past four centuries. (Red, twentieth; green, nineteenth; dark blue, eighteenth; light blue, seventeenth.) Whereas areas with long historical records (Europe, Iceland and Japan) experience eruptions at a constant rate, other areas apparently do not, showing that the record for these other regions is grossly incomplete. There were probably several tens of, as yet, unknown mid- to high-latitude eruptions in Kamchatka, the Kurile islands and Alaska between the seventeenth and nineteenth centuries. The seventeenth- and eighteenth-century records of tropical eruptions in Southeast Asia and Central and South America are also far from complete.**

settle out rather than being transported to the poles.

In contrast, the products of mid-latitude eruptions are dispersed rapidly towards the pole. The climate response in mid-latitudes is more immediate, and polar ice-cores are more likely to preserve sulphate and ash together. A final consequence is that the effects of any two eruptions of similar size can be quite different, depending on when and where they occurred. All of these features can be recognized in the Northern Hemisphere tree-ring record, as described by Briffa *et al.*[3].

The 'year without a summer' in 1816 and the subsequent cold summers of 1817 to 1819 all feature in the 'top 30' most extreme Northern Hemisphere summers of the past six centuries. These followed the eruption of Tambora, Indonesia, in April 1815. Similarly, the cool summer of 1884 followed the August 1883 eruption of Krakatau, Indonesia. In contrast, the June 1912 eruption of Novarupta, Alaska, had an immediate cooling effect, and shows up in the tree-ring records from 1912 as the most extreme summer of the twentieth century so far. An eruption of comparable scale[8,9], at Santa Maria, Guatemala, in October 1902, failed to register as a significant disturbance in the tree-ring record.

The record of the violent, but non-explosive, eruption of Laki, Iceland, in 1783 is also instructive. This eruption released more sulphur than Tambora, leading to a thick 'dry fog' that spread across northern Europe. However, because most of the pollution was restricted to the troposphere, cooling effects were locally severe but not hemisphere-wide, and the summer of 1783 ranks only twenty-sixth in the record of extreme low tree-ring density.

The association of the two most extreme summers, 1601 and 1816, with known eruptions suggests that some of the other cold summers might also have volcanic causes. Indeed, many of these, notably 1641–43, 1695 and 1698, match periods with increased levels of sulphate in polar ice-cores[8]. This is the 'smoking gun' that implicates volcanic eruptions as the cooling agent.

But which eruption? Tens of volcanoes erupt explosively every year. Most of them are too small to have any climatic effect, even though they might be locally devastating, and thereby spawn a rich historical written record. Unfortunately, the catalogue of known eruptions[10] rapidly becomes incomplete further back in time. A glance at the known 'large' eruptions of the past 400 years (Fig. 2) shows that, because eruptions in areas with long historical records occur at a more or less constant rate, there must be many tens of 'large', and potentially globally significant, eruptions that remain undiscovered from the remoter areas of the Pacific rim.

It took the combination of several different, highly time-resolved approaches (tree-ring and ice-core records) and field study to unravel the story of the summer of 1601. The largest volcanic eruptions need not be responsible for the largest sulphur releases[9], however, and none of the direct or indirect indicators of past volcanism is complete, so reading the record of past eruptions and their climatic effects poses a continuing challenge. □

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Neurobiology

A new image for fear and emotion

Steven E. Hyman

The study of emotion is enjoying a renaissance. Despite the importance of emotion in behaviour — indeed, in survival itself — it had largely been ignored as a field of study until recently. Then, several groups identified the anatomy, physiology and chemistry of the circuits that underlie fear in animals and humans, creating new possibilities for understanding emotions and human mental illness[1,2]. Not surprisingly, as for other brain–behaviour relationships, it has become clear that discrete emotions map onto specific neural circuits in the brain, and this view is now supported by papers[3,4] on pages 467 and 470 of this issue, along with two reports[5,6] in *Neuron*. These show that the amygdala, a complex structure within the temporal lobes of the brain, is involved in one form of emotional memory.

Survival depends on the ability of an organism to respond to threat or reward, and to predict the circumstances under which they are likely to occur. Thus, emotional circuits must appraise a situation and initiate adaptive physiological and behavioural responses. To link new predictive stimuli to these adaptive repertoires, emotional circuits must be intimately involved with the formation of memory.

The ability to activate fear circuits in the brain with a neutral stimulus such as a tone (see box, overleaf) has allowed the relevant pathways to be analysed using rats with carefully placed lesions in their brains. Such studies have shown that the amygdala is critical to fear responses and emotional memory[1,2]. In humans, examination of patients with lesions in the amygdala suggested that the amygdala is involved in fear. Moreover, studies using functional neuroimaging have shown[7] that the human amygdala is activated in response to visual processing of fearful faces, even when a subject does not consciously realize that he has seen a face. This can be done by presenting a brief fearful stimulus, immediately followed by a longer neutral masking stimulus[8].

Morris *et al.*[3], LaBar *et al.*[5] and Buchel *et al.*[6] and and have now used functional neuroimaging to investigate human emotional memory resulting from fear conditioning. They show that the amygdala is indeed involved in this form of emotional memory. Moreover, Adolphs *et al.*[4] report that three patients with complete bilateral damage to the amygdala cannot form accurate social judgements based on facial expression —