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Acid damage to vegetation following the Laki fissure eruption in 1783 -- an historical review

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Abstract
Documentary evidence suggests that during the Laki fissure eruption, Iceland, in the summer of 1783, severe acid pollution of the atmosphere resulted in damage to crops and trees in eastern England and northern Germany; the acid pulses led to enhanced fish mortality in Scotland.
Keywords: Laki; Acid damage; Vegetation; Volcanic

1. Introduction

Recent research has focussed attention on the potential impact of the emissions of Icelandic volcanic eruptions on the British Isles. Dugmore (1989) and Pilcher and Hall (1992) have identified tephra from Icelandic volcanoes in peats in Ireland and Scotland.
Acid gases and halogens may be transported considerable distances (Fisher, 1981) and be deposited as dry particles (Fowler, 1984), as acid rain and snow (Davies et al., 1984; Koerner and Fisher, 1982) or as an acid fog, mist or dew (Wisniewski, 1982). The impact of acids and halogens from Icelandic volcanic eruptions are acknowledged to be capable of a serious impact on proximal plants and animals (Ogilvie, 1986; Th6rarinsson, 1969; 1979), but little serious consideration has been given to the possibility that these may have a serious impact on distant ecosystems. In an eruption cloud, soluble volatiles are intimately mixed with the suspended mass of tephra particles and may be scavenged or adsorbed onto the surface of the tephra grain (Rose, 1977; Oskarsson, 1980). Acids and halogens adsorbed onto the surface of tephra grains may therefore be transported over long distances. Tephra layers recovered from lakes and peats may therefore indicate the deposition of environmental pollutants and it is these which may have engendered change in the palaeoenvironmental record.
Icelandic eruption clouds are conventionally expected to be transported to the north, east and southeast of Iceland by the prevailing westerly winds (Th6rarinsson, 1980). Tephra fall has been reported in the Faroe Islands (Mitchell, 1757; Persson, 1971; Th6rarinsson, 1980) and Scandinavia (Nordenski61d, 1876; Th6rarinsson, 1967) and acid rain has been reported in Norway and Sweden (Th6rarinsson, 1981). Little evidence has been presented for the impact of volcanic emissions outside this area, beyond accounts of tephra fall and crop damage in Caithness, Scotland (Geikie, 1896; Lamb, 1970; 1982). Th6rarinsson's tephra isopach maps are now being reinterpreted and significant southerly tephra distributions have been identified in Iceland, along with over 30 tephra fall locations in Ireland and Scotland (Hunt, 1993).

2. The Laki fissure eruption, volatile emission and gas dispersal

The Laki fissure eruption began on June 8, 1783 and continued until early February 1784 (Th6rarinsson, 1969). During this period ~ 9.9 x 10 is g of acid were emitted of which 9.19 x 1013 g were sulphuric acid (Devine et al., 1984; Palais and Sigurdsson, 1989; Sigurdsson et al., 1985; Thordarson et al., 1992). The eruption cloud also contained hydrochloric and hydrofluoric acids (P6tursson et al., 1984). Thordarson et al. (1992) suggested that 60% of the total volume was discharged over the first 48 days, in five eruptive episodes, the first three of which occurred between June 8 and 14th. Estimates of the daily discharge of SO2 based on this work indicate a daily discharge of acid, in June and July, of 13.75 x 1011 g. Fissure eruptions rarely possess sufficient energy to penetrate the stratosphere (Tripoli and Thompson, 1988) and Thordarson et al. (1992) concluded that although Laki eruptions frequently possessed sufficient energy to reach altitudes of 5 km above sea level the majority of emitted material was confined to the troposphere. The dispersal of material ejected to high altitude depends on the speed and direction of high level rather than surface winds. While low level winds travel towards a low pressure centre, high altitude winds converge on high pressure areas. Anticyclonic weather dominated Europe's weather between June 21 and July 20 while a low-pressure area existed in the vicinity of Iceland (Kington, 1980; 1988). Volcanic material may therefore have been transported to Europe by high altitude convergent winds.

The removal of acid particles, < 1 /zm in diameter, from the atmosphere is by turbulent diffusion and depends on processes including windspeed, surface roughness and the temperature stratification of the atmosphere (Fowler, 1984). This process is inefficient and during calm, dry anticyclonic weather there will be an increase in particle concentration and a decrease in visibility (Whelpdale, 1978). Meteorological factors which limit atmospheric dispersal and produce ground level exposures may lead to pollution episodes (Scorer, 1968). Documentary material suggests that the conjunction of these conditions led to pollution episodes in June and July 1783.

2. Volcanic pollution, Britain 1783

The summer of 1783 in Europe was remarkable for the smokey haze which obscured the sun and reduced visibility:

'We never see the sun but shorn of his its beams, the trees are scarce discernible at a mile's distance' (Cowper, 1783, in King and Ryskamp, 1981).

Benjamin Franklin speculated that the fog may have had its origins in an Icelandic volcanic eruption (Franklin, 1784) and a letter published in a Scottish newspaper confirms that the haze was not simply water vapour:

'A letter from Provence, July llth . . . . fog sometimes emits a strong odour and is so dry it does not tarnish a looking glass and instead of liquefying salts it dries them.' (The Aberdeen Journal, Monday August 18th).

Gilbert White observed:

'...the peculiar haze or smokey fog, that prevailed for many weeks in this island and in every part of Europe, and even beyond its limits, was a most extraordinary appearance, unlike anything known within the memory of man. By my journal I find I had noticed this strange occurrence from June 23 to July 20 inclusive...' (White, 1789).

These are not descriptions of a stratospheric aerosol layer nor are they descriptions of a fog composed of water vapour. A letter from Germany, published in the Ipswich Journal, suggests that the fog was composed of acid gases at sufficient concentrations to damage trees:

'Extract of a letter from Embden, July 12th. The thick dry fog that has so long prevailed seems to have spread over the whole surface of Europe; several mariners have also observed it at sea; in the day time it veils the sun and towards evening it has an infectious smell; in some places it withers the leaves, and almost all the trees on the borders of the Ems have been stripped of theirs in one night.' (The Ipswich Journal, Saturday August 9th, 1783).

Serious plant damage also occurred in eastern England:

'Throughout most of the eastern counties there was a most severe frost in the night between the 23rd and 24th of June. It turned most of the barley and oats yellow, to their very great damage; the walnut trees lost their leaves and the larch and firs in plantations suffered severely.' (The Sherbourne Mercury, July 14th 1783).

This event is described in greater detail in several accounts. The Reverend Sir John Cullum described the impact of an unseasonable frost on the 23rd of June 1783.

in bed about 3 o'clock in the morning, he looked out at his window, and to his great surprise saw the ground covered with a white frost; and I was afterwards assured, on indubitable authority, that two men at Barton, about 3 miles off, saw between 3 and 4 o'clock that morning, in some shallow tubs, ice of the thickness of a crown piece, and which was not melted before 6.

This unseasonable frost produced some remarkable effects. The aristae of the barley, which was coming into ear, became brown and weathered at their extremities, as did the leaves of the oats; the rye had the appearance of being mildewed; so that the farmers were alarmed for those crops. The wheat was not much affected. The Larch, Weymouth Pine, and hardy Scotch fir, had the tips of their leaves withered; the first was particularly damaged and made a shabby appearance the rest of the summer. The leaves of some ashes very much sheltered in my garden suffered greatly. A walnut-tree received a second shock (the first was from a severe frost on the 26th of May) which completed the ruin of its crop. Cherrytrees, a standard peach tree, filbert and haselnut-trees, shed their leaves plentifully, and littered the walks as in autumn. The barberrybush was extremely pinched, as well as the hypericum perforatum and the hirsutum: as the last two are solstitial and rather delicate plants, I wondered the less at their sensibility; but was much surprized to find that the vernal blackthorn and sweet violet, the leaves of which one would have thought must have acquired a perfect firmness and strength, were injured full as much. All these vegetables appeared exactly as if a fire had been lighted near them, that had shrivelled and discoloured their leaves. -- penetrabile

frigus adurit.
'About 6 o'clock, that morning I observed the air very much condensed in my window chamber; and on getting up was informed by a tenant, who lives near, that finding himself cold At the time this havoc was made among some of our hardy natives, the exotic mulberry tree was little affected; a fig tree, against a northwest wall remained unhurt, as well as the vine on the other side, through just coming into blossom. I speak of my own garden which is high; for in the low ones about Bury, but a mile off, the fig trees in particular were very much cut.' (Cullum, 1783).
Similar accounts are found in several newspapers published in eastern England.
In Cambridge:
'...on Monday night last, (June 23rd) a very sudden and extraordinary alteration in the appearance of the grass and corn growing in this neighbourhood. The occasion of it is supposed to be owing to an unexpected change from excessive heat to its opposite extreme intense cold -- in so much that the grazing land, which only the day before was full of juice and had upon it the most delightful verdure, did, immediately after this uncommon event, look as if it had dried up by the sun, and was to walk on like hay. The beans were turned to a whitish colour, the leaf and blade appearing as if dead. The stag of the wheat did also undergo the like change: but the ear not being entirely shot forth the farmers hope the corn will not be impaired.' Our brackets (Cambridge Chronicle and Journal, Saturday July 5th, 1783) 1.
In Ipswich:
'On Wednesday June 25th it was first observed here, and in this neighbourhood, that all the different species of grain, viz, wheat, barley, and oats, were very yellow, and in general to have had all their leaves but their upper ones in particular, withered, within two or three inches at their ends; the forward barley and the oats most so. The former had not yet quitted their spatha or what is called by husbandmen at least their hose, but their awns appeared as far as they did appear, were withered also. Many of the oats were in their panicle, or had entirely quitted their hose, and all the ends of their calyces, or chaff husks were withered in like manner: but the grain within them did not appear to have suffered the least injury, being sufficiently protected by their coverings. The ears of wheat likewise, which were equally forward, were neither injured nor discoloured, except in the awns of what is generally called bearded wheat. About this time, and for 3 days both before and after, there was an uncommon gloom in the air, with a dead calm. The dews were very profuse. The sun was scarce visible, even at mid-day, and then entirely shorn of its beams so as to be viewed by the naked eye without pain.' (The Ipswich Journal, Saturday July 12th, 1783).
The damage described is too selective to have been the result of frost damage; it is difficult to imagine a midsummer frost which would blight a fir tree, but have little effect on a mulberry bush. The wheat crop was not damaged while the husks and leaves of Bearded wheat, barley, oats, rye and beans are all described as withered, spotted or discoloured while the grains protected by the husk were undamaged. Pasture and beans are reported to be dried. Some tree species are reported as shedding their leaves while the larch, Weymouth pine and Scotch fir had the tips of their leaves withered. Cullum described the damaged plants in his garden as appearing 'exactly as if a fire had been lighted near them'. These symptoms are typical of damage by acids and halogens (Lang et al., 1980).
Barrett and Benedict (1970) suggested that wheat was less susceptible to acid damage than barley and Craker and Bernstein (1984) found that wheat was able to efficiently buffer sulphuric acid. Fluoride may also have been present in the aerosol, but MacLean and Schneider (1981) found that wheat exposed to fluoride did not exhibit signs of foliar damage. The damage to the leaves of the trees and in particular the Scotch fir is typical of the damage caused by the absorption of sulphur dioxide (Caput et al., 1978). Leaf lesions may be observed at $pH < 3.5$ and serious leaf damage will occur at $pH < 2.8$ (Watt Committee on Energy, 1984). The shedding of leaves is a classic response to concentrations of fluorine, sulphur dioxide and hydrofluoric acid, and charring is typical of damage caused by a sulphuric acid aerosol (Wilcox 1959; Blong, 1984). The microclimate within a forest or plantation, can enhance the effect of acid deposition (Unsworth, 1984).
The mulberry is able to absorb and accumulate sulphur dioxide and hydrogen fluoride (Chia-hsi et al., 1982). All the symptoms described above suggest that volatiles were present in sufficient concentration to cause serious plant damage, the Laki fissure eruption is the most likely source for these. Kirchner et al. (1992) emphasized the role of micro and macro climate in determining the impact of acidification episodes. Certain themes common to these accounts, calm anti-cyclonic weather, heavy dews and frosts, suggest that the

phenomena described are the result of an extreme episode of acidification, classed by Wisniewski (1982) as a 'special event', these are associated with dews, frosts and fogs. The process of coalescence gathers water soluble material on the leaf into one spot, concentrating any contaminants present, with the result that necrosis follows (Jacobsen, 1984; Lang et al., 1980). The formation of a frost may also scavenge volatiles from the lower layer of the atmosphere, and cause a net flux of chemical compounds onto plant surfaces which are released when the frost melts (Giordiadis et al., 1993). Usually plants are able to replace leached cations, even when treated to a low pH rain but exceptional damage and leaching can occur when the cell membrane has been damaged, either by gaseous pollutants such as sulphur dioxide or by frost or both (Miller, 1984).

3. Fish kill in Scotland

If the accounts above detail the damage caused to plants by the volatile emissions of the Laki fissure, the following account of a fish kill observed in Scotland following a thunder storm appears typical of an acid pulse:

'On Wednesday night we had a great storm of thunder and lightning, accompanied by a very heavy fall of rain. No damage was done in this city; but we are sorry to have accounts from different parts of the country that they have not been equally fortunate. We hear, that next morning, after the storm of thunder and lightning here, there were found in the dam above the sawmills on the water of Leith, a number of different kinds floating on the surface of the water supposed to be killed by lightning.' (The Caledonian Mercury, Saturday July 5th, 1783).

Waters may be polluted by an acid pulse, acids which had been dry deposi~ted over a period of time are concentrated by one burst of rain and washed into a body of water; lowering the pH to levels which may be lethal to fish (Brown and Turnpenny, 1988; Gagen and Sharpe, 1987; Leivistad and Muniz, 1976). The concentration of volcanically generated fluoride, deposited over several days, in a short lived toxic pulse is illustrated by Oskarsson (1992).

Compensatory aspects are also suggested:

'The harvest is half over already all around us; and so pure that not a poppy or cornflower is to be seen.' (Walpole, in Cunningham, 1938).

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