both sense and anti-sense constructs[9]. Later, gene suppression of a foreign gene was achieved in stably transformed plant lines following a second transformation with the corresponding anti-sense gene[10]. A problem with transformed plants, however, is the large variation in expression of foreign genes from one transformed line to another (reviewed in ref. 11).

Van der Krol *et al.* in their paper in this issue[2] overcome this problem by targeting their anti-sense gene against an endogenous plant gene encoding a petal-specific chalcone synthase, an enzyme that allows the development of red petals in, among others, *Petunia hybrida*. Blocking expression of chalcone synthase produces white or variegated petals resulting from variations, within petal tissue, in chalcone synthase expression (see figure on page 867). An analysis of the transgenic plants, which have one or more copies of the anti-chalcone synthase gene, shows heritable but variable alterations of petal pigmentation correlating with alterations in both chalcone synthase enzyme and messenger RNA levels in petal tissue. The mechanism remains elusive, but evidence points to increased degradation of messenger RNA rather than inhibition of translation. This, along with other studies, should lead to a search both for the enzymes responsible for degradation of duplex RNA and for a natural role in higher organisms for gene regulation by anti-sense RNA. □

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Mass extinctions

Gradual volcanic catastrophes?

K. G. Cox

On pages 841 and 843 of this issue, Duncan and Pyle[1] and Courtillot *et al.*[2] present new $^{40}Ar/^{39}Ar$ dates for basaltic lavas from the Deccan trap continental flood basalt province of India, and together provide the most accurate information yet available for the age and duration of an immense volcanic episode. This is of exceptional interest as it confirms previous suggestions[3] that the province developed very rapidly and coincided closely with the Cretaceous/Tertiary boundary about 65 million years ago (Myr), at which important faunal and floral changes occurred. The new data must be woven into the continuing debate about whether faunal extinctions are triggered by volcanism or by meteorite impacts.

The Deccan traps province is far from unique. Since the late Palaeozoic (about 300 Myr) the Earth has been subjected to numerous similar volcanic episodes consisting of huge outpourings of basalt lavas onto continental surfaces. Among these, the Siberian traps (Permo/Triassic, 240 Myr), Paranà basalts (late Cretaceous, 130 Myr), and Karoo Province (early Jurassic, 180 Myr) all probably covered substantially larger areas than the Deccan[4], and in the Karoo, volcanic sequences are locally very much thicker than anything so far recorded from the Deccan[5]. So the contention of Courtillot *et al.*[2] that the Deccan "could have been the largest volcanic event in Mesozoic and Cenozoic times" is hard to sustain.

Given that numerous volcanic episodes have occurred, if we are to believe in a direct connection between mass extinctions and volcanism then a very significant correlation between the ages of the two phenomena must be demonstrated. There have been attempts[6], but I suspect that the accuracy of dating in several important provinces (Siberia, Paranà, Karoo, Antarctic) is not yet sufficient to produce convincing results, and this leaves aside the parallel question of how accurately mass extinctions can be quantified and dated. Obviously a great effort from geochronologists, volcanic stratigraphers, palaeomagneticians and palaeontologists will be required to resolve such questions.

But the new data in this issue[1,2] on the duration, as opposed to age, of the Deccan volcanism raise another interesting point. Although a large province seems to have been erupted remarkably quickly on a geological timescale, it actually consists of several individual eruptive events separated by repose periods. The environmental effects of each eruption would undoubtedly be dramatic[7], but the capacity of the biosphere to recover during repose periods would also be strong. Thus the creation of irreversible and permanent faunal or floral changes is likely to be highly dependent not just on the size of the province but also on the eruptive rate and the length of repose periods.

A crucial question then is how many eruptive events constitute a province? This is more difficult to answer than might at first appear. An eruptive event can be defined as a period of continuous magma emission, in the cases under study mainly from fissures from which floods of basaltic magma emerge and travel for perhaps hundreds of kilometres. But the advancing flow front can cool and act as a dam whose frozen crust must be breached by magma closer to the vent. Flow thus proceeds by leap-frogging, and the geologist examining sections through the volcanic pile could find it extremely difficult to decide which of the flow units observed really represent separate events. Often, only the presence of a weathering horizon, in many cases a laterite, or an intercalation of sediment, gives unequivocal evidence of genuine repose. Detailed field and geochemical work can potentially elucidate such problems, but there are very few parts of the world where reliable information is available.

From field studies in the Deccan, I estimate that the number of eruptive events is probably quite small, perhaps 100–500. If the whole episode lasted for 500,000 years, an average repose period would last about 1,000–5,000 years. On a human timescale this seems a long time: one small laterite horizon could be equivalent to the whole of human recorded history. Fortunately, there are no historic analogues of flood basalt volcanism, but as a result the capacity of the environment to recover from the effects of a single eruption during repose periods of this sort can only be guessed. The Laki fissure eruption in Iceland in 1783, following which starvation reduced the population by half, is the nearest comparison, but 200 years on the effects are no longer remarkable. Extrapolation from this eruption, which released 12 cubic kilometres of basalt, is difficult because a typical flood-basalt eruption in the past may have been two orders of magnitude larger.

One can conclude that if continental volcanism has anything to do with mass extinctions it is probably via a series of episodes of environmental stress. Unlike the meteorite-impact hypothesis in its simplest form, the volcanic model can be regarded as a stepwise catastrophe, and the geological evidence has been interpreted in this way[8]. Hybrid models[6], linking the volcanism itself to meteorite impact, introduce interesting complexities into the debate, as do models which postulate multiple impacts from a comet shower[9]. □

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