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News and Views

The super-eruption of Toba, did it cause a human bottleneck?

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Introduction

Lake Toba, Sumatra, Indonesia, is the site of the largest volcanic explosion in the late Pleistocene, which occurred about 73,500 (±2000) years ago (Chesner et al., 1991, Bühring & Sarnthein 2000). It has been asserted by Ambrose (1998) and others (Rampino & Self 1992, Rampino & Ambrose 2000, Rampino 2002) that the eruption gave rise to a "volcanic winter" of such a catastrophic scale that it caused a human population bottleneck. In this note we discuss the probable effect of the Toba eruption and the evidence that it caused the putative bottleneck.

The super-eruption of Toba produced 2500–3000 km^3 of magma (dense rock equivalent) and probably injected at least 10^{15} g of fine ash into the stratosphere (Rampino & Self 1993, Zielinski et al., 1996, Bühring & Sarnthein 2000). Pyroclastic flows covered about 10^5 km^2 (Rampino & Self 1993) with lava reaching both the Malacca straits and the Indian Ocean (Rose & Chesner 1987). Layers of tephra, identified as Toba tuff have been found in India, more than 3000 km away from Toba (Ninkovich et al., 1978, Ninkovich 1979, Rose & Chesner 1987, Chesner et al., 1991, Pattan et al., 1999), and in the South China Sea (Bühring & Sarnthein 2000).

Direct, explosive effects

The much smaller but very well known eruption of Krakatau in 1883 (Thornton 1996), can help us to elucidate the direct effects of the Toba eruption. It is probable that (as on Krakatau) all life in the immediate vicinity of the Toba crater was exterminated by the very hot tephra, lava and gasses. Further away, though the tephra would have cooled, the physical effects of heavy tephra falls would have knocked down trees and killed all mammals and birds (in a similar manner to what happened on the island of Sebesi-19 km from Krakatau-which had about 1 m tephra fall on it in the Krakatau eruption (Gathorne-Hardy et al., 2000)). It has been proposed that the direct effects of the eruption caused widespread human mortality in South Asia (Ambrose 1998).

Modern animal distribution data indicate that the maximum radius of direct destruction by heavy tephra was probably less than 350 km. The Mentawai islands (which lie about 350 km to the south east of Toba, 130 km from the Sumatran

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mainland) probably emerged from the sea at some point in the late Pliocene (Samuel et al., 1997), and they have been isolated from the mainland for about three million years (Chatterjee 2001). The presence of nine endemic species of non-volant rainforest-obligate mammals (four primates, four squirrels and one mouse species) on the islands (WWF report 1980) indicates that they have been continually covered by evergreen and everfruiting-rainforest since they separated from the mainland. Termite data also indicate that the islands have been ancient rainforest refugia (Gathorne-Hardy et al., 2002). Had the radius of direct destruction from the super-eruption of Toba been greater than 350 km, it is extremely unlikely that the faunal composition described above would be found on the Mentawai islands. It is possible that heavy tephra travelled further in other directions than south east, but the Mentawai data indicate that it is unlikely that its destructive effects reached as far as India or Indochina to the north, or Java to the south.

The “volcanic winter” and its effects

The super-eruption of Toba has been closely linked to a peak in SO_4^{2-} in the GISP2 ice core (Zielinski et al., 1996), and it has been proposed that the impact on the world’s climate caused by the eruption of Toba was considerable (Rampino 2002). Ice core data show that the weather was cooler for several centuries after the Toba eruption, possibly due to the large amount of stratospheric sulphur aerosol ejected by the volcano, and following that, increased albedo (Zielinski et al., 1996, Zielinski 2000, Rampino et al., 1988, Rampino & Self 1992, 1993, Ambrose 1998, Zielinski 2000). Rampino and Self (1992), Rampino and Self (1993) and Rampino (2002) estimated that worldwide temperatures were 3 to 5 °C cooler, and down to 15 °C cooler in high latitudes, for several years.

It appears that the cooling associated with Toba is not unusual in its extent however, as the cooling just before D/O event 20 was broadly similar in terms of temperature decrease (Oppenheimer 2002), as was that following D/O event 19 (δO^{18} values rise from -42 just before D/O 20 to -36.5 at D/O 20, drop to a low of -43 after the Toba eruption, rise again to -36.5 at D/O 19, and then drop to -42.5 (Zielinski et al., 1996, Lang et al., 1999, Zielinski 2000)).

Impact on humans and other biota

Following these estimates of global cooling it has been proposed that the Toba-induced “volcanic winter” lead to near-extinction of modern humans, and to a sudden, “hour-glass” shaped human population bottleneck (Rampino & Self 1992, Ambrose, 1998, Rampino & Ambrose 2000, Rampino 2002). However, we have found very little evidence to support the hypothesis that the Toba super-eruption had such a marked impact on modern humans and other biota.

If the putative Toba induced volcanic winter resulted in an environmental catastrophe strong enough to cause a bottleneck in a species as resourceful and adaptable as modern humans, one would expect that other, more environmentally sensitive taxa (with more specialised ecological requirements) would have suffered at least a similar population crash and that many would have become extinct. It appears that there has been no mammal extinction associated with Toba (A. Currant pers. com.), and Erwin and Vogel (1992) examined the hypothesis that super-eruptions (including that of Toba) have caused mass extinctions and found no evidence for this.

If the Toba eruption caused a bottleneck in modern human populations, it would be expected that this bottleneck would be hour-glass shaped, with human populations crashing at 73.5 Ka and then expanding again later. Recent work on the human genome, analysing nuclear sequences, the Y chromosome and mitochondrial DNA do support the existence of a bottleneck (Hammer et al., 1998; Harpending et al., 1998; Hawks et al., 2000). However, there is considerable debate surrounding the time period when the bottleneck was meant to have occurred. Some researchers have postulated that it may have been as long ago as 2 million years ago (e.g. Hawks et al., 2000). Other studies provide evidence suggesting that the bottleneck was effectively a long period of stasis, represented by a relatively small population of humans, followed by a population expansion between 100,000 and 50,000 years ago (Hammer et al., 1998; Harpending et al., 1998). Whether the timing of the population expansion was relatively early or late, both models are essentially a short bottle with a very long neck, and not the hourglass model that Ambrose (1998) and others (Rampino & Ambrose 2000; Rampino 2002) suggest was the result of the Toba event. Even if the bottleneck was hourglass-shaped, if the timing of the expansion has a minimum range of 50,000 years (Hammer et al., 1998, Harpending et al., 1998), there is not enough accuracy to pinpoint the possible effect of the Toba super-eruption.

A recent exhaustive review of Middle and Late Pleistocene human sites in Africa, based mainly on archaeological finds (McBrearty & Brooks 2000), shows that by 73.5 Ka, modern humans occupied a diverse range of habitats over the whole African continent, and were an extremely adaptable and resourceful species, with complex tool-kits, an ability to hunt and forage for a variety of different taxa, large geographic ranges, and a network of long distance exchange (McBrearty & Brooks, 2000). In light of this, it seems likely that by the time of the Toba event, modern humans had already developed a suite of risk-management strategies that would have made them able to cope with any sudden change in climate, such as a volcanic winter.

In summary, we have not been able to find any evidence to support the hypothesis that the Toba super-eruption of 73.5 Ka caused a bottleneck in the human population. The direct effects of the eruption were fairly localised, and at the time probably had a negligible effect on any human population in Asia, let alone Africa. Genetic evidence indicates that the Pleistocene human population bottleneck was not hour-glass shaped, but rather an up-side down bottle with a long neck. Modern humans at that time were adaptable, mobile, and technologically well-equipped, and it is likely that they could have dealt with the short-term environmental effects of the Toba event. Finally, we have found no evidence for associated animal decline or extinction, even in environmentally-sensitive species. We conclude that it is unlikely that the Toba super-eruption caused a human, animal or plant population bottleneck.

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