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Research paper

A high-precision $^{40}Ar/^{39}Ar$ age for the Young Toba Tuff and dating of ultra-distal tephra: Forcing of Quaternary climate and implications for hominin occupation of India

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ABSTRACT

A new high-precision inverse isochron $^{40}Ar/^{39}Ar$ age for the youngest Toba super-eruption is presented: 75.0 ± 0.9 ka (1 sigma, full external precision, relative to the optimisation model of Renne et al., 2010, 2011). We present the most accurate and robust radio-isotopic age constraint for the Young Toba Tuff. $^{40}Ar/^{39}Ar$ ages for biotite shards harvested from ultra-distal Toba tephra deposits (>2500 km) preserved in archaeological sites in the Middle Son Valley and Jurreru Valley, India, establish provenance with the young Toba super-eruption. The air-fall tephra at these sites can be used as an isochronous horizon facilitating stratigraphic and temporal correlation throughout India. The high-precision $^{40}Ar/^{39}Ar$ age for the young Toba tephra can serve as a tie point for linking of the multiple Greenland ice cores beyond the *GICC05* timescale, and permits correlation to other absolutely dated palaeoclimate archives for the testing of synchronicity in the response of the global climate system.

1. Introduction

The Toba volcano located in northern Sumatra, Indonesia (Fig. 1), is the largest known Quaternary caldera. The caldera (as visible today) extends over 2270 km^2 and is the product of the young Toba super-eruption. The super-eruption produced approximately 2800 km^3 of pyroclastic ejecta (2400 km^3 of dense rock equivalent) (Chesner, 1998; Mason et al., 2004; Matthews et al., 2012), a volume of comparable size to the largest Yellowstone super-eruption (Huckleberry Ridge Tuff; Ellis et al., 2012), but dwarfing other Quaternary eruptions (Fig. 2), including the 1815 eruption of Tambora. Ash fall from the young Toba super-eruption covered approximately 40,000,000 km^2 of South and South-East Asia (Chesner et al., 1991) (Fig. 1). The young Toba tephra (or tuff) (YTT) can be found preserved in marine cores (e.g., ODP 758) throughout the Pacific Ocean, Bay of Bengal and Indian Ocean. Astronomical tuning suggests an age for the eruption of *c.* 73 to 74 ka (Ninkovich, 1979; Oppenheimer, 2002) supporting the radio-isotopic $^{40}Ar/^{39}Ar$ age of 73 ± 4 ka[1] (relative to Fish Canyon Tuff sanidine [FCs] at 27.84 Ma; Chesner et al., 1991).

Despite the large magnitude of the young Toba super-eruption, its impact on both the regional and global climate systems remains controversial with polarised interpretations. Geochemical evidence from ice core records support a hypothesis of substantial impact (Rampino and Self, 1992, 1993; Zielinski et al., 1996; Ambrose, 1998; Rampino and Ambrose, 2000; Williams, 2012b), whilst evidence from sea surface temperature estimates, mammal and termite survival, and archaeological artefacts support a hypothesis of

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[1] $^{40}Ar/^{39}Ar$ age ± analytical uncertainty here and throughout (unless otherwise stated) are reported at the 1σ (68%) confidence level.

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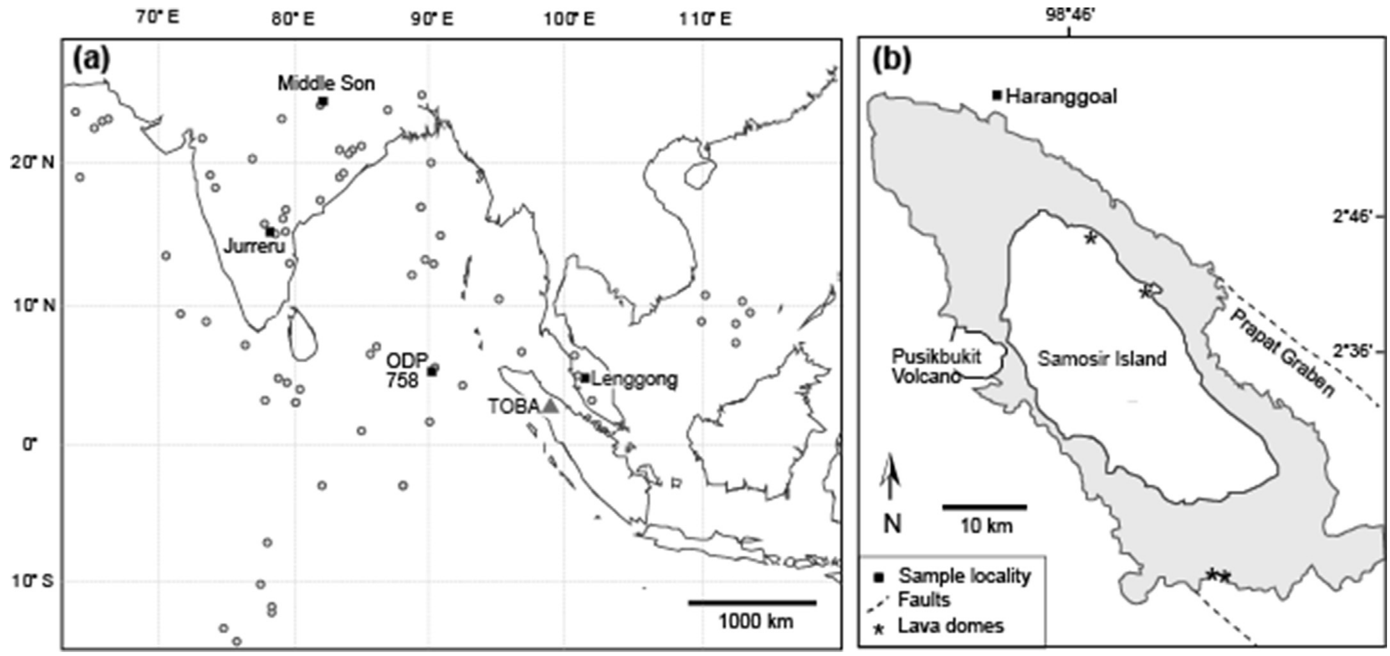

Fig. 1. (a) Map showing the location of the Toba caldera, the sample sites in India (Middle Son Valley and Jurreru Valley) and other locations where Toba tephra is found (circles) (modified from Oppenheimer, 2002; Jones, 2010). (b) The Toba caldera as visible today and the sampling location at Haranggoal (modified from Smith et al., 2011a).

minimal impact (Schulz et al., 2002; Petraglia et al., 2007; Louys, 2012). Some researchers have viewed the Toba super-eruption as one of the most significant events in the course of human evolution, leading to cataclysmic changes in terrestrial ecosystems and the near extinction of our species (Ambrose, 1998; Rampino and Ambrose, 2000; Williams et al., 2009). Genetic evidence has been used to suggest a sudden drop in the numbers of the ancestors of living human populations to a few thousand at *c.* 74 ka (Haigh and Maynard Smith, 1972; Harpending et al., 1993; Jorde et al., 1998), with survivors concentrated solely in African biotic refugia (Tishkoff et al., 2009). According to these catastrophic hypotheses, modern humans migrated to Asia and Europe following the young Toba super-eruption, eventually arriving in Australia by *c.* 50 ka (Bowler et al., 2003) and western Eurasia by *c.* 45 ka (Richter et al., 2008). However, the timing of expansion from Africa to Asia relative to the young Toba super-eruption, as well as its direct impact on human populations, has been strongly contested (Gathorne-Hardy and Harcourt-Smith, 2003; Scholz et al., 2007; Cohen et al., 2007).

The potential occurrence of YTT as an isochronous marker horizon across the peninsula of India has sparked debate about the severity of environmental change and the survivorship of foraging

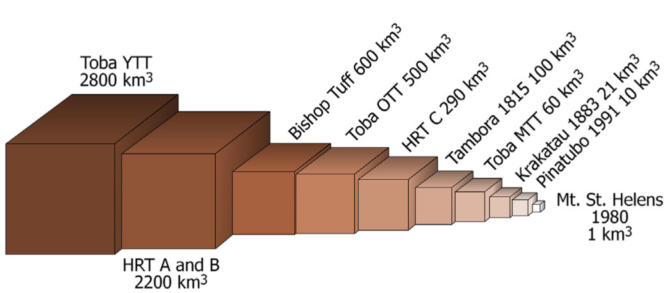

Fig. 2. Eruption volumes for selected Quaternary volcanoes (bulk rock estimates). Volumes are from Chesner and Rose (1991) for Toba (YTT, MTT and OTT), HRT is Huckleberry Ridge Tuff, Yellowstone (Ellis et al., 2012), Bishop Tuff from Hildreth and Wilson (2007), Tambora (Self et al., 2004), Krakatau (Carey et al., 1996), Pinatubo (Scott et al., 1996) and Mt. St. Helens (Sarna-Wojcicki et al., 1981).

populations (Haslam and Petraglia, 2010; Petraglia et al., 2012). The accurate identification and age of terrestrial deposits of ash is therefore critical for evaluating the climatic and environmental effects of the super-eruption and the dispersal and continuity of hominins in Eurasia.

Here we provide a new high-precision $^{40}Ar/^{39}Ar$ age constraint for the youngest Toba super-eruption. We also provide a methodology for $^{40}Ar/^{39}Ar$ dating of ultra-distal-tephra and investigate the ages of tephra located at archaeological sites across India with an aim to establish tephra provenance. The impacts of the young Toba super-eruption on both the local and global climate are discussed, and implications for the evolution of hominin populations are explored.

2. The Toba caldera and distal tephra in India

The Toba Caldera is the product of subduction of the Indian–Australian Plate beneath the Southeast-Asian Plate. Three main eruptive events define the history of one of the largest and most explosive volcanoes on Earth: the young Toba super-eruption (producing the YTT, *c.* 74 ka), Middle Toba eruption (producing the Middle Toba Tuff, MTT, *c.* 500 ka), and the old Toba super-eruption (producing the Old Toba Tuff, OTT, *c.* 790 ka) (Chesner and Rose, 1991; Chesner et al., 1991). At proximal locations on Sumatra each of these deposits are hundreds of metres thick, welded and crystal rich (up to 40%, containing mineral assemblages dominated by quartz, sanidine, plagioclase, biotite and amphibole) (Chesner, 1998). Below the deposits that record explosive volcanism on Sumatra is the Haranggoal Dacite Tuff (HDT, *c.* 1200 ka; Chesner and Rose, 1991) and a series of andesites (*c.* 1300 ka; Yokoyama and Hehanussa, 1981).

Distally, tephra from the Toba eruptions has been documented in Malaysia (Scrivenor, 1930), the Bay of Bengal (Ninkovich et al., 1978), the East China Sea (Lee et al., 2004), the Indian Ocean (Pattan et al., 2001), and sites across the peninsula of India (Westgate et al., 1998). The general NW distribution of Toba tephra (Fig. 1) is clearly a result of eruption magnitude and wind direction.