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# Distinction between the Youngest Toba Tuff and Oldest Toba Tuff from northern Sumatra based on the area density of spontaneous fission tracks in their glass shards

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ABSTRACT

Determination of the area density of spontaneous fission tracks ($\rho_s$) in glass shards of Toba tephra is a reliable way to distinguish between the Youngest Toba Tuff (YTT) and the Oldest Toba Tuff (OTT). The $\rho_s$ values for YTT, uncorrected for partial track fading, range from 70 to 181 tracks/cm$^2$ with a weighted mean of 108 ± 5 tracks/cm$^2$, based on 15 samples. Corrected $\rho_s$ values for YTT are in the range of 77–140 tracks/cm$^2$ with a weighted mean of 113 ± 8 tracks/cm$^2$, within the range of uncorrected $\rho_s$ values. No significant difference in $\rho_s$ exists between YTT samples collected from marine and continental depositional settings. The uncorrected $\rho_s$ for OTT is 1567 ± 114 tracks/cm$^2$ so that confusion with YTT is unlikely.

The $\rho_s$ values of the Toba tephra at Bori, Morgaon, and Gandhigram in northwestern India indicate a YTT identity, in agreement with geochemical data on their glass shards, the presence of multiple glass populations, and a glass fission-track age determination. Therefore, the view of others that OTT is present at these sites – and thereby indicates an early Pleistocene age for the associated Acheulean artifacts – is incorrect.



## Introduction

Violent volcanic eruptions have characterized the Toba caldera complex of northern Sumatra during the Quaternary (Chesner, 2012) resulting in extensive tephra deposits across Sumatra, India, Indian Ocean, Arabian Sea, East Africa, Malaysia, and the South China Sea (Fig. 1). Three major and widespread tephra sequences have been identified: the Youngest Toba Tuff (YTT, 75 ka), the Middle Toba Tuff (MTT, ~500 ka), and the Oldest Toba Tuff (OTT, ~800 ka) (Diehl et al., 1987; Chesner et al., 1991; Dehn et al., 1991; Hall and Farrell, 1995; Lee et al., 2004; Mark et al., 2014). The multidisciplinary benefits offered by these tephra deposits have long been appreciated (Acharyya and Basu, 1993) and vividly demonstrated more recently in a volume on applications of the YTT to problems in the Quaternary sciences (Petraglia et al., 2012).

A prerequisite to the successful stratigraphic use of the Toba tuffs is an ability to recognize with confidence each of the three tuffs, YTT, MTT, and OTT. Acharyya and Basu (1993) argued that the numerous tephra occurrences across India are YTT based on the morphology of the glass shards and chemical composition of bulk tephra and glass separates. They noted a strong similarity to YTT deposits in sediments of the Indian Ocean (Layer A, ODP 758, Dehn et al., 1991), Bay of Bengal (Ninkovitch et al., 1978), the youngest welded tuff at Siguragura (Fig. 1A), and tephra in Malaysia at the Kota Tampan site in the Lenggong Valley (near site 6 on Fig. 1A). The major and trace element composition of glass shards from many Toba tephra occurrences, as determined by using an electron microprobe (EMP) and solution ICP-MS, respectively, led Westgate et al. (1998) to the same conclusion. This study showed that the major element composition of glass in YTT and MTT was very similar, but YTT had slightly higher average values for $K_2O$ and CaO, both units being readily distinguished on a CaO–$Na_2O$–$K_2O$ ternary plot. These authors correlated the OTT to Layer E of the ODP 758 sedimentary core in the Indian Ocean (Fig. 1), observing a clear difference in glass composition with YTT, but later work showed that Layer D was more likely correlative, in which case separation of YTT from OTT on the basis of major elements in their glass shards was not possible (Chen et al., 2004; Lee et al., 2004). Smith et al. (2011) examined all the glass compositional data on the Toba tuffs and concluded that it was not possible to recognize each of the three Toba tuff units in this way, although the caveat was added that some of the compositional variation may be due to varied calibration strategies on the different

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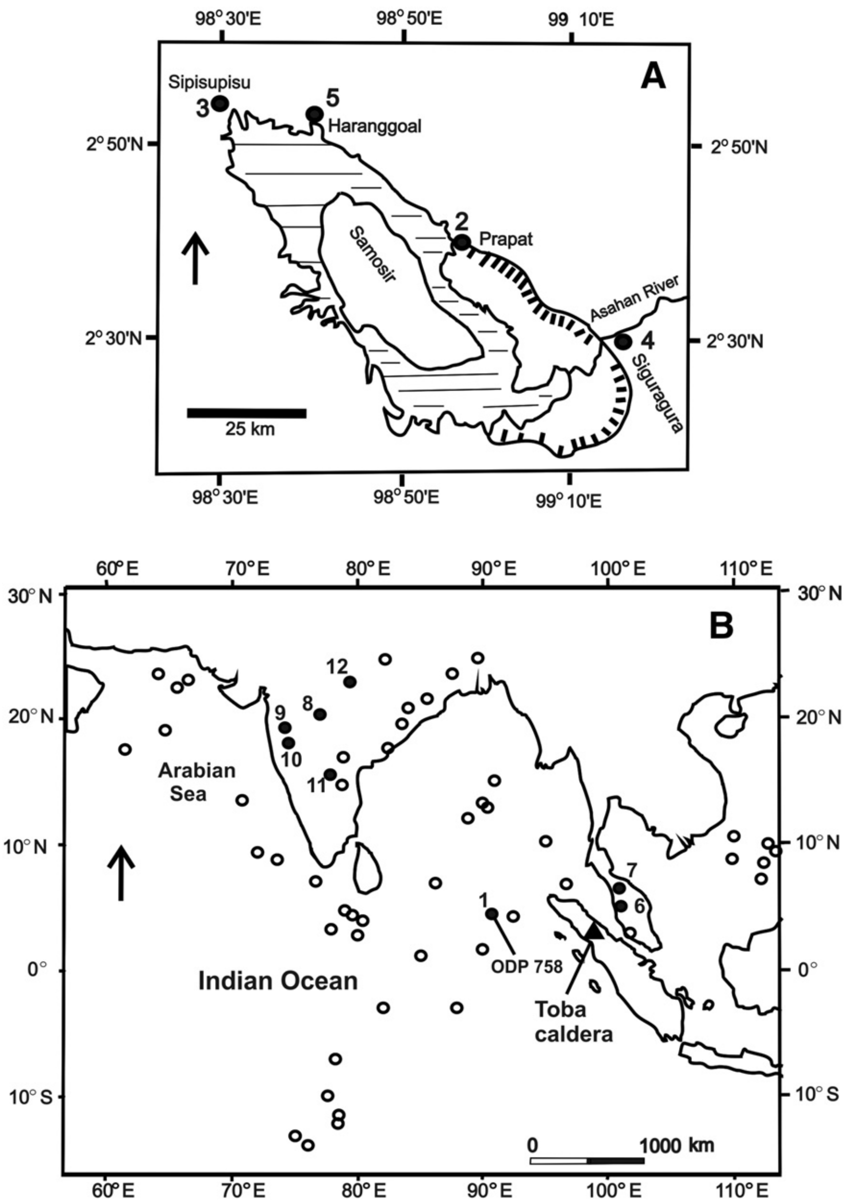


**Figure 1.** Location of the Youngest Toba Tuff (YTT) and Oldest Toba Tuff OTT) samples. (A) Toba caldera and sampled sites; hatched area is Lake Toba. (B) Distribution of YTT and OTT tephra-fall deposits; black dots indicate locations of samples used in this study whereas circles show other Toba tephra sites. Additional data are given in Table 1. Arrow indicates north. Modified after Westgate et al. (2013). The YTT occurrence in sediments of Lake Malawi, East Africa, is not shown on this map (Lane et al., 2013).

EMP instruments. Instead, these authors discovered that YTT can be separated from OTT and MTT by its biotite composition, which has lower values of $FeO_t/MgO$. In addition, OTT biotite crystals are relatively enriched in F, although there is overlap with YTT and MTT at lower concentrations. A comprehensive study on the composition of glass shards in the Toba tuffs was prompted by Smith et al.'s (2011) work (Westgate et al., 2013). The major and trace element compositions of glass shards in YTT, MTT, and OTT were determined, respectively, using an EMP and LA-ICP-MS system with the same shards being analyzed on both instruments to give a detailed compositional signature for each glass shard. All three Toba tuffs can be distinguished, based largely on the trace element composition of their glass shards. Four primary glass populations were found to be present in YTT, well defined by their Sr, Ba, and Y concentrations, whereas MTT and OTT have a single, distinctive glass population.

Despite this large body of data on the characterization of the three Toba tuffs, differences of opinion still exist on the identity of the Toba tuff at some sites across India — mainly at sites with artifact-bearing sediments (e.g. Mishra et al., 1995, 2009; Sangode et al., 2007; Gaillard et al., 2010). At least, this was true as of 2011, when Westaway et al. (2011) published their work. The essence of the controversy is the age of the artifacts as indicated by the associated Toba tephra bed. Is it YTT or OTT? These tephra beds differ in age by an order of magnitude, so recognition of the tephra is crucial to interpretation of the archeology. In an effort to resolve these conflicting views, we add a physical property of glass to the characterization/identification criteria, namely, the area density of spontaneous fission tracks.

Fission tracks in glass are revealed by etching in hydrofluoric acid. They are conical pits formed by the preferential solution of glass along a latent fission track, which, in turn, is formed by the spontaneous fission of $^{238}U$ or induced fission of $^{235}U$. Shapes, as seen under the optical microscope, vary from circular to elliptical, depending on the orientation of the cone axis with respect to the polished surface (Fig. 2).

It should be an easy task to separate YTT from OTT based on the area density of spontaneous fission tracks in their glass shards because of the large difference in age and the broadly similar U contents, which are in