

# YOUNGER TOBA TEPHRA 74 KYA: IMPACT ON REGIONAL CLIMATE, TERRESTRIAL ECOSYSTEM, AND PREHISTORIC HUMAN POPULATION

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**Abstrak.** Tephra Danau Toba yang Lebih Muda (74 Kya): Efeknya pada Iklim Regional, Ekosistem Darat, dan Populasi Manusia Prasejarah. Salah satu aktivitas vulkanik terbesar yang diperkirakan menjadi penyebab musim dingin vulkanik yang sangat dahsyat pada periode Kuartar adalah letusan Toba pada 74 ka, di Sumatra Utara, Indonesia. Berdasarkan pada teori bencana Toba, hal itu mengakibatkan musnahnya hampir seluruh populasi manusia, dan membentuk *bottleneck* yang terekam pada gen yang diturunkan di seluruh populasi manusia saat ini. Tulisan ini membicarakan tentang erupsi Toba serta pengaruhnya pada perubahan lingkungan flora, fauna, dan manusia berdasarkan pada hasil penelitian terdahulu.

**Kata kunci:** aktivitas vulkanik, perubahan iklim, populasi manusia

*Abstract.* One of the largest volcanic activity which predicted was caused terrible volcanic winter in Quaternary period is the Toba eruption in 74 ka, Northern Sumatra, Indonesia. According to the Toba catastrophe theory by some scholars, it had a global consequence of killing most humans who alive and creating of a population bottleneck that affected the genetic inheritance of all living humans today. This paper will discuss about Toba eruption and also its impact for vegetal, animal, and human environmental change based on previous research.

**Keywords:** volcanic activity, climatic change, human population

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## 1. Background

Tephra is fragmental material produced by a volcanic eruption, regardless its composition, fragment size, or emplacement mechanism. Tephra fragments are classified by size: Ash-particles smaller than 2 mm in diameter, Lapilli or volcanic cinders - between 2 and 64 mm in diameter, and volcanic bombs or volcanic blocks - larger than 64 mm in diameter. In geological terms, tephra is composed of (a) volcanic glass, (b) phenocrysts, and (c) small amounts of xenocrysts and xenoliths. Individual tephra events are characterized by their petrography and geochemistry including heavy minerals and trace element content (Herz and Garrison 1998).

The distribution of tephra following a volcanic eruption usually involves the largest

boulders falling to the ground quickest and therefore closest to the vent. While smaller fragments such as ash can often travel for thousands of miles, even around the earth, or it can stay in the stratosphere for days to years following an eruption. When large amounts of tephra accumulate in the atmosphere from massive volcanic eruptions, or from a multitude of smaller eruptions occurring simultaneously, they can reflect light and heat from the sun back through the atmosphere, in some cases causing the global temperature to drop, resulting in a climate change called as "volcanic winter" (Selley *et al.* 2005).

One site of the Earth's largest volcanic eruption which predicted has been causing terrible volcanic winter in Quaternary period is the Toba

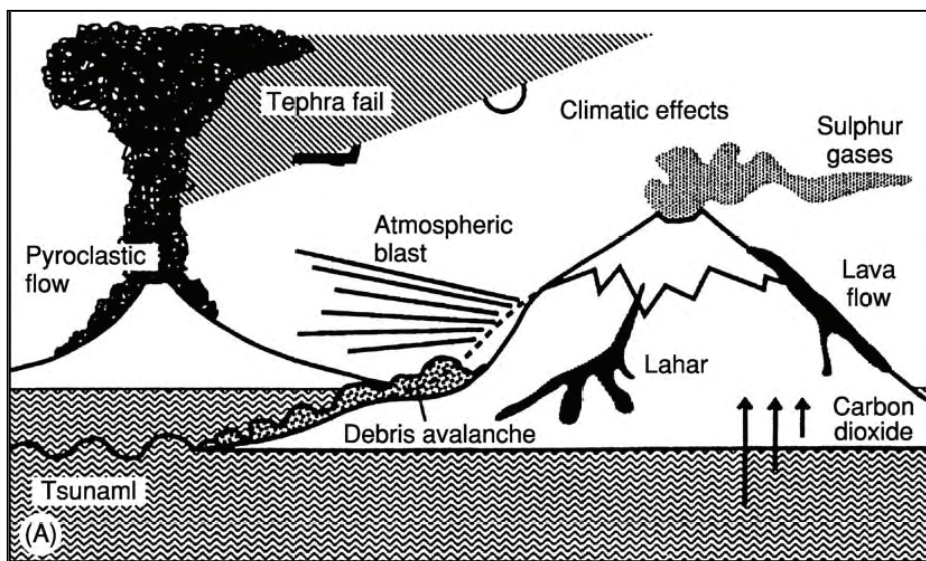


Figure 1. The destructive processes generated by volcanoes, showing those confined to the immediate vicinity (Selley *et al.* 2005)

Caldera in Northern Sumatra, Indonesia. This eruption dated at 74 ka, and produced the 2800 km<sup>3</sup> Youngest Toba Tuff (YTT) also ash-fall. Prior to the YTT eruption, another silica quartz-bearing tuffs known as the Middle Toba Tuff (MTT) and the Oldest Toba Tuff (OTT) were erupted from Toba at 0.501 Ma and 0.840 Ma respectively. Although the explosive contents of the Toba magmas are poorly constrained, aerosols generated by the YTT eruption are generally thought to have caused a global volcanic winter (Chesner and Luhr 2010).

The Toba Caldera Complex in northern Sumatra was the site of 4 caldera-forming eruptions in the past 1.2 Ma. Tuffs respectively known as the Haranggoal Dacite Tuff (HDT) erupted at 1.2 Ma, Oldest Toba Tuff (OTT) erupted at 0.840 Ma, Middle Toba Tuff (MTT) erupted at 0.501 Ma, and Youngest Toba Tuff (YTT) erupted at 0.074 Ma. Only welded tuffs are preserved from the three earlier eruptions and their estimated volumes are HDT = 35 km<sup>3</sup>, OTT = 500 km<sup>3</sup>, and MTT = 60 km<sup>3</sup>. The culminating event engulfed all previous calderas and was Earth's largest Quaternary volcanic eruption, producing 2800 km<sup>3</sup> of non-welded to densely welded ignimbrite (YTT) and co-ignimbrite ash-

fall. Volcanic deposits cover 20,000 – 30,000 km<sup>2</sup> in northern Sumatra and extend to the Indian Ocean and the Straits of Malacca. Ash deposits from the eruption have been found in Malaysia, India, the Indian Ocean, the Arabian Sea, and the South China Sea (van Bemmelen 1949; Song *et al.* 2000, Williams *et al.* 2009, Chesner *et al.* 2010).

## 2. Problematic

Lake Toba is the site of a super volcanic eruption that occurred about 74,000 years ago followed by a massive climate-changing event. The eruption is believed to have had a Volcanic Explosivity Index (VEI) of magnitude 8 described as a “mega-colossal”, and was the largest explosive eruption anywhere on the Earth in the last 2 million years. Major scholars have been accepted that the eruption of Toba followed by a volcanic winter with a worldwide decline in temperatures between 3°-5°C and until around 15°C in higher latitudes (Rampino *et al.* 1992). According to the Toba catastrophe theory by some anthropologists and archeologists, it had a global consequence of killing most humans who alive and creating of a population bottleneck in Central Eastern Africa and India, that will be affected the

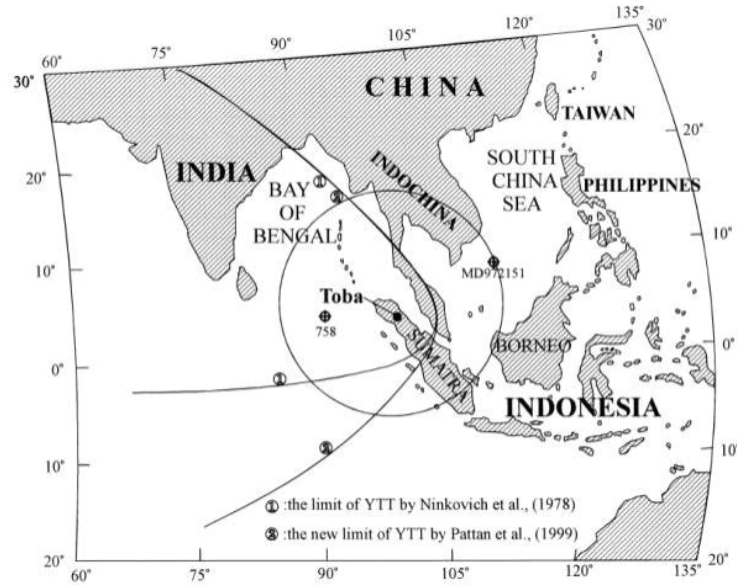


Figure 2. Map of the South China Sea, Indonesian arc and adjacent areas showing the location of the Toba eruption impact. The radius of the circle is 1500 km (Song *et al.* 2000)

genetic inheritance of all living humans today. This theory however, has been largely debated as there is lack evidence for any other animal decline or extinction, even in environmentally sensitive species. This paper will discuss about Toba eruption as a good chronological marker and also its impact for vegetal, animal, and human environmental change based on previous paleoenvironmental research.

### 3. Discussion

The eruption of Toba volcano in northern Sumatra some 74 ka was the largest explosive eruption of the past two million years with a VEI of magnitude 8, but its impact on climate has been controversial. The cooling effects of historic volcanic eruptions on world climate are well known but the impacts of even bigger prehistoric eruptions are still covered in mystery.

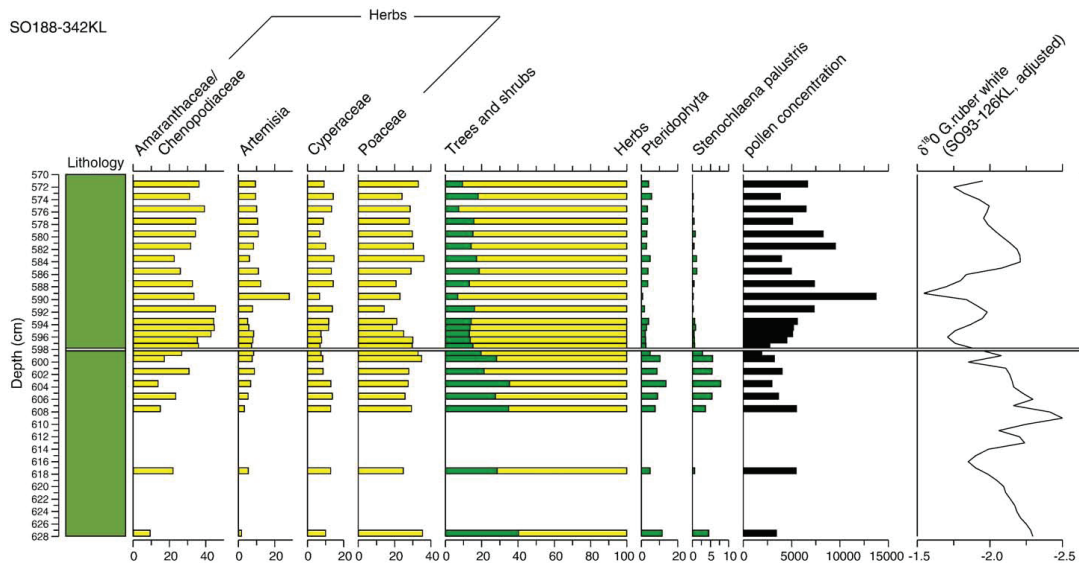


Figure 3. Pollen diagram and  $\delta^{18}\text{O}$  values for the planktonic foraminifera *Globigerinoides ruber* of part of marine core from the Bay of Bengal showing changes in pollen spectra after the Toba eruption (Williams *et al.* 2009)

In order to resolve this issue, Williams *et al.* (2009) have analyzed pollen from a marine core in the Bay of Bengal with stratified Toba ash, and the carbon isotopic composition of soil carbonates directly above and below the ash in three sites on a 400 km transect across central India. Their analysis result on the pollen evidence shows that the eruption was followed by cooling and long aridity, reflected on a decline of tree cover in India and surrounding region. Carbon isotopes show that forest was replaced by wood to open grassland in central India. Their analysis results demonstrate that the Toba eruption causes climatic cooling and prolonged deforestation in South Asia, and state a serious impact on tropical ecosystems and human populations (Williams *et al.* 2009).

### 3.1 Impact on Regional Climate

The Toba ash provides a good isochronous stratigraphic marker for correlation of terrestrial and marine environmental records. Williams *et al.* (2009) made a carbon isotope analysis from fossil soils found immediately beneath and above the Toba ash in central India. It is demonstrates a major isochronous change in vegetation from forest before to the open woodland or grassland after the eruption. The terrestrial pollen spectrum of a marine core collected from the Bay of Bengal support the terrestrial isotopic evidence indicating initial

cooler temperatures following the Toba eruption by decreased of tree cover and long dryness for at least a millennium. These terrestrial and marine climatic archives was change following the Toba super-eruption support for the hypothesis that severe environmental degradation could have been responsible for large mammal extinctions in Southeast Asia and genetic bottlenecks in humans population and other species that occurred in Africa and Southeast Asia at this time (Williams *et al.* 2009).

The basic concern of Haslam and Petraglia (2010) claims to Williams *et al.* (2009) reveals that the YTT eruption is used for a chronological marker of cooling at the end of Dansgaard–Oeschger interstadial 20, but there are no evidence provided the Toba eruption caused or prolonged this process. Furthermore, while the presented data adjoin with the South Asian palaeoenvironmental, the application of the results to questions of impact on human and other populations is overstated. Williams *et al.* (2009) have produced a useful addition to the study about the effects of thick YTT accumulations on local flora in north-central India, as well as the possible effects of D-O interstadial 20 and the subsequent glacial OIS 4 on South Asian environments. However, they failing to unequivocally associate the Late Pleistocene Toba super-eruption with any of the

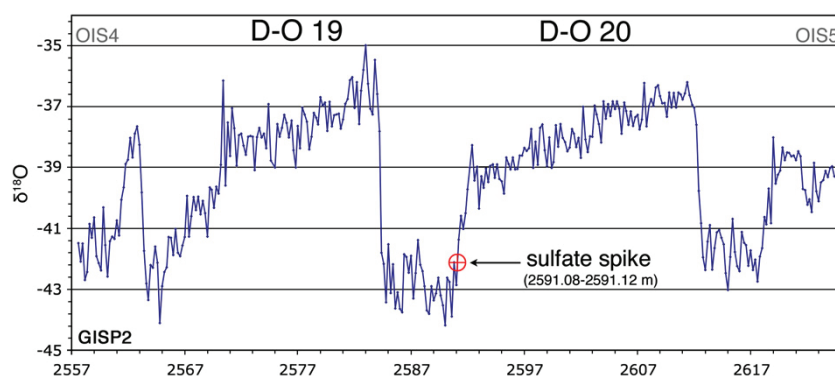


Figure 4. Oxygen isotope data for D-O 19 and D-O 20 at 20 cm resolution from the GISP2 ice core and target (arrowed) indicates the position of the Toba-attributed sulfate spike at a depth of 2591.08-2591.12 m in the GISP2 core (Haslam and Petraglia 2010)

environmental, genetic, or social changes discussed by them. Williams *et al.* (2009) notes this debate is destined to remain sterile until unambiguous evidence is available documenting the possible impact of Toba 74 ka upon terrestrial ecosystems. Haslam and Petraglia (2010) suggest it does demonstrate the critical

need for precisely dating and correlation of palaeoenvironmental and archaeological samples from all across South Asia sites.

Haslam and Petraglia (2010) raise three questions concerning Williams *et al.* (2009) studies about environmental impact of the 74 ka Toba super-eruption in South Asia. The first question is about relationship between the 74 ka Toba eruption and the cold stade between the Dansgaard–Oeschger interstades 20 and 19. The second is about regional impact of the eruption on vegetation. And the last question is about the possible effect of the eruption upon humans and mammals. To response the first and second questions, Williams *et al.* (2009) note that the 74 ka Toba eruption was followed by several centuries of intense cooling and wind-blown dust accession in the Greenland Ice Sheet Project 2 (GISP2) core. These phenomena made an environment change from forest to grassland or open woodland in central India suggested by carbon isotopic analysis, and in the wider region identified by pollen analysis of a marine sediment core in the Bay of Bengal. In regard to the last question, the genetic evidence is as yet too imprecisely dated to demonstrate causality as is the archaeological evidence cited by Haslam and Petraglia in favour of minimal impact of the eruption (Williams *et al.* 2010).

### 3.2 Impact on Terrestrial Ecosystem

Jones (2009) made a report the results of the analysis of sediments and stratigraphical sequences from sites in the Jurreru and Middle Son valleys in southern and north-central India. The aim of the study is to determine the extent of palaeoenvironmental change in both valleys as a result of the ash-fall. Inferences based on evidence from the Jurreru valley are more detailed, where pre and post Toba palaeoenvironmental changes are divided into seven phases. The results show that ash-fall deposits in both valleys underwent several phases of reworking that possibly occurred for several years, indicating that ash was

transportable in the landscape for a considerable period of time prior to burial. This could have enhanced and lengthened the detrimental effects of the ash on vegetation and water sources, and even on animal and human populations (Jones 2009).

These research by Jones (2009) represents the first study to investigate the environmental consequences of the Toba eruption in two river valleys in India, which separated by a distance of ~1100 km. Because of the types of sedimentological analyses employed, his interpretations presented focus predominantly on the geomorphological consequences of the ash-fall, such as changes in landscape and local hydrological systems. Substantial landscape remodeling appears to have occurred in both valleys after the Toba ash-fall, where a succession of separate phases of ash re deposition occurred, culminating in thick deposits of reworked ash. These processes probably resulted in a decline in vegetation coverage and cessation of pedogenesis. In addition, water sources and plants may have become toxic if leaching of heavy metals and fluorine contained within and adhering to the volcanic glass took place. This may have proved hazardous for grazing animals and human populations. But under normal conditions, the river valleys would have been attractive areas for both animals and human for food resources, water, and sources of lithic materials for artifact manufacture.

On a broader geographic scale, the Jurreru and Middle Son valleys are only two small areas which affected by the Toba ash-fall, and lower part of YTT covered a large area of peninsular India and those similar processes may have been repeated throughout on the subcontinent. In conjunction with topographic variability determining the rapidity with which ash was transported from the landscape and deposited, given the diverse range of habitats and micro-climates that exist throughout peninsular India. It is probably that the Toba eruption had

highly variable impacts throughout subcontinent. Geographical variability in post-Toba habitat disturbance and fragmentation caused by ash-fall and climate change, likely resulted in large spatial variability in human responses to the ash-fall. A heterogeneity on the degree of human populations survived after the Toba eruption is suggested, because some areas of peninsular India left worse-affected than others (Jones 2009).

### 3.3 Impact on Animal Population

Several scholars try to examine the effect of the Toba super-eruption at 74 Ka on the mammals of Southeast Asia. Although few Late Pleistocene sites from Southeast Asia have been described, an analysis of those which pre- and post-date Toba reveals relatively a small number of species became extinct following the eruption. It is suggested that species

survived in refuge immediately following the eruption, and that they repopulated vast areas of environmental devastation following a probable short period in decades to century. Study by Louys (2007) suggests that mammals are more robust at coping with catastrophic events than previously acknowledged, and perceives of human monopoly in overcoming ecological adversity.

There are some difficulties to examine the ecological aftermaths of super eruptions. Even when massive eruptions have occurred within recorded history, their effects on mammals have been little studied. Analyses are often the only means of exploring the ecological effects of super eruptions on fauna. While the data presented are not as constrained as could be hoped, the results are nevertheless suggestive of a far greater resilience of mammals coping with ecological adversity. Based on the current

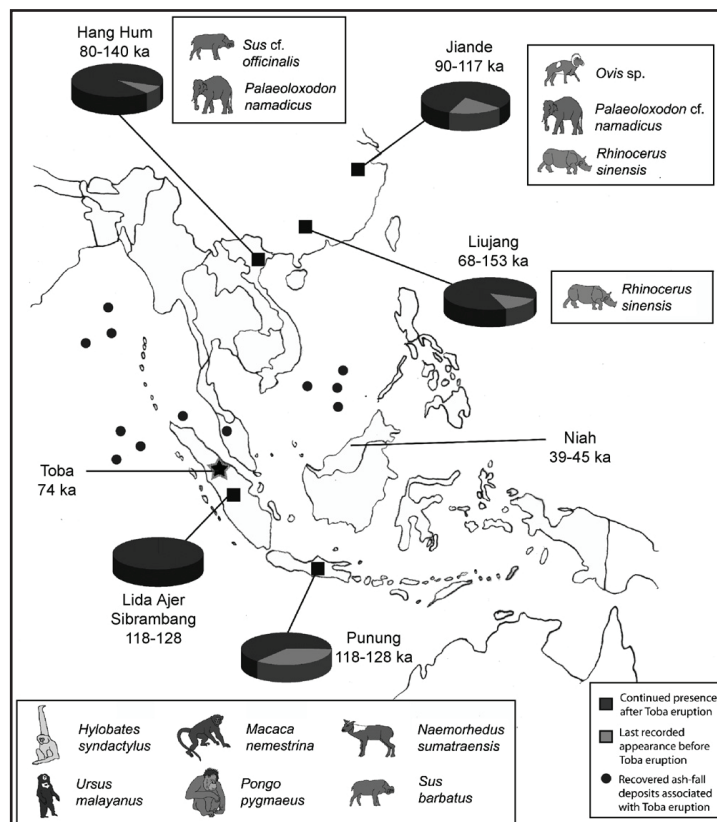


Figure 5. Map showing the approximate locations of fossil sites preserving an extinction signature for Toba. Pie graphs represent proportion of species not represented after the eruption for each respective site (Louys 2007)

palaeontological record, the total number of species recorded for the period of the super eruption of Toba is small. While a mass living extinction event for the region as a result of the eruption has been discounted by a number of scholars, such as Ambrose (2003).

A historical genetic study about orangutan (*Pongo*) from Sumatra and Borneo has done by Steiper (2009). Both populations show significant genetic differentiation from one another and their history does not differ significantly from an island model or population splitting without gene flow. Two different methods support a divergence of Bornean and Sumatran orangutans at 2.7 – 5 million years ago. This suggests that Pleistocene events, such as the cyclical exposure of the Sunda shelf and the Toba volcanic eruption, did not have a major impact on the divergence of Bornean and Sumatran orangutans. However, pair wise mismatch analyses suggest that Bornean orangutans have undergone a recent population expansion beginning around 39,000 – 64,000 years ago, while Sumatran orangutan populations were stable (Steiper 2009).

Small number of extinctions in Sumatra after Toba super eruption recorded is still surprising, particularly given the ferocity of the eruption event and its ecological effects proposed. Two different scenarios are explored by Louys (2007) based on whether these proposed ecological effects could be accepted. He suggests if the volcanic winter did proceed after the eruption of Toba, then his study suggests the ability of mammals to recover from catastrophic events. And then, super eruption has implications for other mass extinction events especially where large mammals feature dominant. If the volcanic winter were not as terrible as predicted, then it is unlikely that the human bottleneck observed was caused by the catastrophic events and the resultant climate change for the ecological effects of super eruptions was not causing mammalian extinctions.

### 3.4 Impact on Human Population

In the Greenland Ice Sheet Project 2 core, scientist has identified the largest sulphate anomaly as fallout from Toba's stratospheric aerosol veil. Correlation of the sulphate and oxygen isotope stratigraphy of the ice core suggests that the Toba eruption might have played a role in triggering a millennium of cool climate prior to Dansgaard-Oeschger event 19, although a comparable stadial preceded event 20. A possible 6 years duration "volcanic winter" and may have contributed to enhanced cooling for 200 years immediately following the eruption has also been proposed as the cause of a putative bottleneck in human population supporting the "Garden of Eden" model for the origin of modern humans. However, along with counter arguments regarding the exact timing of any demographic collapse, there remain major gaps in the understanding of the 74 ka BP Toba eruption that hinder attempts to reconstruct a model of its global atmospheric and climatic effect, also therefore human consequences (Oppenheimer 2002).

Gathorne-Hardy and Harcourt-Smith (2003), in their study suggest if we have not been able to find any evidence to support the hypothesis that the Toba super-eruption of 74 Ka caused a bottleneck in the human population. The direct effects of the eruption were fairly localized, 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, they have found no evidence for associated animal decline or extinction, even in environmentally-sensitive species. For the conclusion, that it is unlikely that the Toba super-eruption caused a human, animal

or plant population bottleneck.

Ambrose (2003) try to response Gathorne-Hardy and Harcourt-Smith (2003), for some questions about the accuracy of estimates of the magnitude of the climatic impact of the super eruption of Toba, whether it could have caused a human population bottleneck, the form, duration and timing of the human bottleneck, and cultural capacities for behavioral responses to climatic disasters. Arguments of Gathorne-Hardy and Harcourt-Smith against the significance of the Toba super eruption for rapid catastrophic climate change and population decline have provided the opportunity for a detailed reexamination and restatement of the main points of the hypothesis of Toba's relationship to the human population bottleneck, and to cultural developments (Ambrose 2003). Genetic study by Oppenheimer (2009) estimated dates for Eurasian mtDNA haplogroups M and R found in Mainland Southeast Asia, where less ash fell than in India, vary from 76 ka for M to 65 ka for R. These are older than eastern India and the Bay of Bengal, but younger than those inferred for Island of Southeast Asia or Sundaland, which received little or no Toba ash. This inversion of relative dates is again consistent with a pre-Toba exit and population recovery from a genetic bottleneck in the areas most severely affected by the ash fall (Oppenheimer 2009).

#### **4. Conclusion**

Tephra beds have been characterized geochemically and mineralogically, both to identify source and as stratigraphic markers. Chemical and chronological analysis shows that younger Toba tephra occurrences across peninsular India belong to the 74 ka. As a result, this tephra bed can be used as an effective tool in the correlation and dating of late Quaternary sediments, especially in India subcontinent. On one hand, YTT provides an explanation such as torch light to identified chronology problem in prehistory, but at another hand followed by some

implications which are difficult to answer the problem.

Geological evidence strongly suggests the eruption was significantly larger than previously estimated, and caused a long period of the coldest temperatures of the Upper Pleistocene. Numerous genetic studies suggest that the population bottleneck was real rather than presumed, and that it occurred during the first half of the last glacial period. Genetic study by Oppenheimer (2009) suggests there was an increasing human genetic mutation after Toba super eruption event. From anthropological point of view, capacities for modern human behavior were undoubtedly present during the last interglacial. But the stable environments of this period did not advance widespread adoption of the strategic cooperative skills necessary for survival in the last glacial era. Modern humans may have eventually developed such strategies during the last ice age, but they were crucial for survival when volcanic winter arrived. Actual human populations are the descendants of the few small groups of tropical Africans who united in the face of difficulty.

The potential impact of the 74 ka Toba super-eruption upon global and regional climate, terrestrial ecosystems and prehistoric human populations is not really gives clear explanation. Evidence from genetics, prehistoric archaeology, pollen analysis, stable isotope geochemistry, geomorphology, ice cores, and climate models has provided some useful working hypotheses. Further progress requires a substantial improvement in the accuracy, precision and resolution of the chronologies of each of the marine and terrestrial proxy records used to reconstruct the environmental impact of this extreme event (Williams 2011). Future work must be supported by higher resolution chronologies than are presently available to provide a less equivocal perspective of the environmental impact from the 74 ka Toba eruption.



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