

# Reconstructing prehistoric environments in the Son and Belan valleys, north–central India: Retrospect and Prospect

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## ABSTRACT

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Pioneering archaeological surveys in the Son and Belan valleys of north–central India in the 1970s revealed that these valleys had been occupied at least intermittently during the Lower Palaeolithic, Middle Palaeolithic, Upper Palaeolithic and Neolithic. Later work in the early 1980s provided a reliable stratigraphic framework for the prehistoric sites and also resulted in the chance discovery of volcanic ash erupted from Toba volcano in Sumatra, Indonesia, 74,000 years ago. The discovery of the first Quaternary volcanic ash ever found in India prompted a search for the ash across the Indian sub–continent. By the early 1990s it was apparent that the entire sub–continent had been covered in a layer of ash 10–15 cm thick. Later work showed that some of this ash had been reworked by runoff and soil creep soon after deposition and accumulated in topographic depressions and valley bottoms where it remained in a relatively pure state. However, some of the ash has been reworked more than once since first deposited. Use of the ash as an isochronous marker depends upon establishing whether it is still in primary context and if not the degree to which it has been mixed with younger sediment. A key and as yet unresolved issue is whether or not the eruption had a major or minor regional and global environmental (including climatic) impact. High resolution records from speleothems, pollen spectra, varved lake deposits and ice cores will be needed to answer this question. The presence of similar stone artefact assemblages above and beneath the ash tells us nothing useful about the actual environmental impact of the eruption.

**Key–words**—Prehistory, Belan Valley, Son Valley, Toba volcano.

## INTRODUCTION

IT is still something of a mystery why fluvial sediments are more fully preserved in some river valleys than in others. One attempt to solve this problem is that of Nanson and Huang (2008) who used ideas derived from physics such as the principle of least action to help explain why certain types of alluvial channel are more stable than others and why alluvial sediments are better preserved in some sectors of a river than in others. It is therefore worth emphasising at the outset that any attempts to reconstruct prehistoric environments using alluvial sediments suffer from one huge disadvantage—the innately fragmentary nature of the fluvial record (Williams, 2012a). Any reconstructions of past environments deduced from discontinuous fluvial sedimentary records will inevitably be incomplete. However, even an incomplete environmental reconstruction is preferable to no reconstruction at all.

In his seminal volume *To Interpret the Earth: Ten ways to be wrong*, Schumm (1991) pointed to a further issue, namely, the innately complex nature of river systems. For example, many different causes can lead to the same end result, and a single initial cause can lead to a variety of quite different outcomes, whether it be a change from channel incision to channel aggradation or a change in channel pattern from straight to meandering or braided.

With these *caveats* in mind, we can now consider what we have learned from the river deposits preserved in the Son and Belan valleys, bearing in mind that what appear to be solid conclusions are simply a work in progress, liable to change in the future as more data become available and new analytical techniques are developed and applied.

The Son is one of the great rivers of north–central India (Fig. 1). It flows from west to east in a relatively deep and narrow valley. The valley is bounded by a steep sandstone

escarpment to the north. This escarpment marks the southern boundary of the deeply dissected uplands of the Kaimur Ranges which are part of the rugged Vindhyan Plateau (Fig. 2). To the south the land is lower in elevation and the Son Valley is flanked by a series of narrow strike ridges which run roughly parallel to one another. The location of the valley may well be controlled by a major fault system aligned parallel to the modern channel.

The Belan is a much smaller river than the Son. It rises immediately to the north of the Kaimur Ranges and flows west where it joins the Tons (Fig. 1). The Tons flows north and joins the Ganga about 20 km downstream of its confluence with the Yamuna. The historic city of Allahabad (renamed Prayagraj in 2018) is located at the junction of the Ganga and Yamuna and the mythical Sarasvati River, and is the site of the great annual Kumbh Mela pilgrimage.

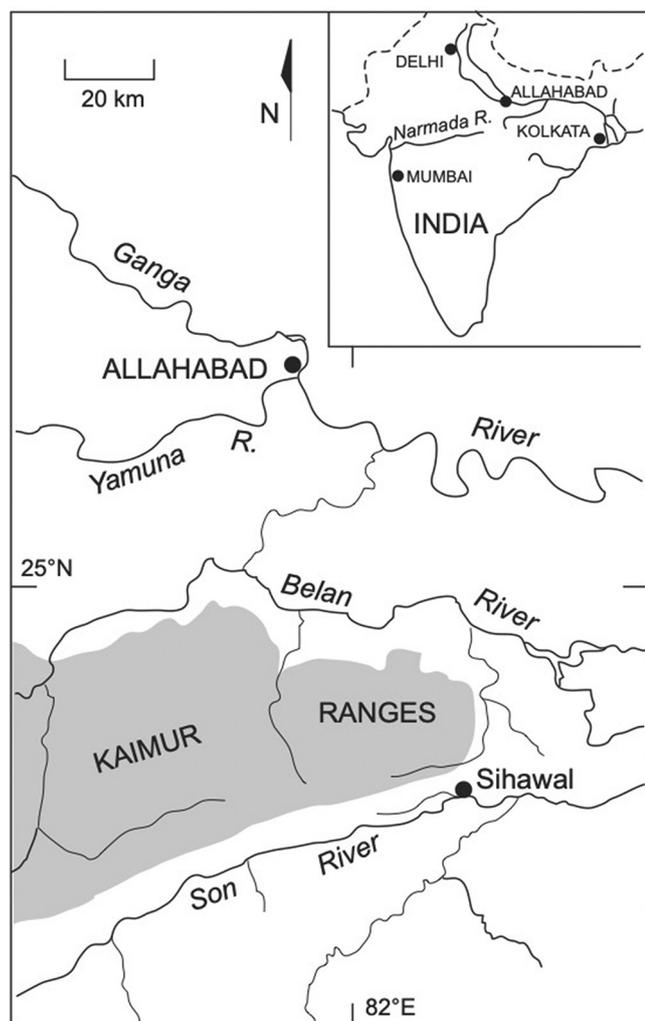


Fig. 1—Location map showing the Son and Belan valleys in north-central India. Note that Allahabad has recently been renamed Prayagraj (modified from Williams & Clarke, 1984, Fig. 1; Williams, 2011, Fig. 13.1).

The ancient city of Kaushambi is located in this region and was excavated under the direction of the late Prof. G.R. Sharma, who had earlier worked with Sir Mortimer Wheeler when he was conducting the early excavations at Harappa and Mohenjo Daro.

### EXPLORATORY PHASE

Prof. Sharma's interests were not simply confined to historic archaeology. He was eclectic in his approach to archaeology and catholic in his interests. With a team of energetic archaeologist colleagues and brilliant young postgraduates (including Umesh Chattopadhyaya and Jaganath Pal, who went on to distinguished academic careers), he surveyed, mapped and excavated a large number of prehistoric sites in the Son and Belan valleys during the 1970s. He and his team also identified a number of sandstone rock shelters in the Kaimur Ranges that contained Mesolithic artefacts and wall paintings of hunting scenes and of the contemporary fauna and excavated a series of Mesolithic and younger burials in the Ganga Valley (Sharma, 1973, 1975). Based on this work, Prof. Sharma proposed that seasonal migrations between alluvial plain and sandstone plateau in Mesolithic times eventually led to more intensive use of wild plants, culminating in the early domestication of plants and animals that ushered in the Neolithic cultural phase which had such a profound effect upon humans and their environment (Sharma *et al.*, 1980).

The prehistoric sites in the Son and Belan valleys ranged in age from Lower Palaeolithic through to Neolithic and younger. Most of the mapped sites were situated close to the present river channels. They were almost always most clearly exposed in recently eroded bank sections. The sediments exposed in these channel bank sections consisted of fluvial gravels, sands, silts and clays. In the middle Belan Valley three gravel units appeared to be very widespread and were identified as the lower, middle and upper gravel units, known, respectively, as Gravel One, Gravel Two and Gravel Three. Lower Palaeolithic artefacts were found within what was considered the lower gravel unit or Gravel One; Middle Palaeolithic artefacts within the postulated middle gravel unit or Gravel Two; and Upper Palaeolithic artefacts within the putative upper gravel unit or Gravel Three. However, reliance on river gravels to determine the age of any prehistoric cultural tradition has many pitfalls, which I discuss in the following section.

### STRATIGRAPHIC MAPPING

Prof. Sharma invited the distinguished British archaeologist Prof. J. Desmond Clark from the University of California at Berkeley to join his team. This he did for two seasons of work in 1980 and 1982, each three months in duration (Sharma & Clark, 1983). Desmond brought with

him a small team of graduate students. I had earlier worked as geomorphologist/Quaternary geologist/soil scientist with Desmond in the Sahara, Nile Valley and Ethiopia and so was also an invited member of the team. Our initial induction into the prehistoric archaeology of the Son and Belan involved a rapid tour of the main sites conducted by Prof. Sharma and his colleagues. It soon became clear both to me and to Desmond that the inferred correlation between gravels and prehistoric cultural phases was open to question, for several reasons.

First, any artefacts found within river gravels must, by definition, have been transported and so were not in primary context, however abundant. Any artefacts close to the river channel could be incorporated into the gravel traction load, irrespective of age, so that artefacts within a given bed of gravel could be of quite different ages. All that could be said is that the artefacts within a bed of gravel were either about the same age or, more often, older by an unknown amount. What also became clear to me during later stratigraphic mapping was that there were multiple gravel beds, not just three, and they were generally discontinuous.

There was therefore a need for careful “hand-over-hand” stratigraphic mapping along long continuous stretches of

exposed alluvial sections. The method adopted was to map the stratigraphy while following the river-bank sections on foot. Representative sections were then chosen and wherever possible they were exposed in more detail by excavating a step trench from the base to the top of the selected section. For each stratigraphic section examined, I recorded the thickness of each stratigraphic unit, the nature of its contact with adjacent units, its Munsell Chart colour (both wet and dry), soil structure, consistence and hardness, field texture (to within ~5% clay content, for sixteen soil textural classes), sand particle shape and degree of roundness (under 10 X magnification), sedimentary structures, carbonate concretions (shape, size and %), and presence of any shells, charcoal or other material. Where appropriate, samples were also collected for luminescence and/or radiocarbon analysis.

Depositional environments were inferred from the sediment texture (i.e., grain size), sedimentary structures and fossil content (e.g., aquatic snail shells). In 1980, working in partnership with Macquarie University Earth Sciences Honours student Keith Royce, I was able to identify and describe four major alluvial formations in the middle Son Valley (Fig. 3). From oldest to youngest these were informally



Fig. 2—The Kaimur Ranges immediately north of the middle Son Valley, north-central India. The lowland clay plain is located on the surface of the early Holocene Upper Member of the Baghor Formation (see Fig. 2 and text section 3). (Photo: Martin Williams).

termed the Sihawal, Patpara, Baghor and Khetaunhi formations respectively (Williams & Royce, 1982). During later work in the middle Son Valley in November–December 2005 with Prof. J.N. Pal (Fig. 4), we identified an additional Formation (the Khunteli Formation) intermediate in age between the Sihawal and the Patpara formations (Williams *et al.*, 2006). We were also able to relate these alluvial formations to concentrations of prehistoric artefacts, some of which were later excavated. Unfortunately, a full analysis of the artefacts collected during the 1982 season and stored in the Department of Archaeology at the University of Allahabad was never completed. However, they were examined by Dr Sacha Jones from the University of Cambridge during her later visits under the initial guidance of Dr J.N. Pal. This study provided a useful springboard for their subsequent joint archaeological work in the middle Son Valley (Jones & Pal, 2009).

The Middle Pleistocene Sihawal Formation consists of two stratigraphic units: a lower member comprised of local alluvial fan gravels interspersed with Lower Palaeolithic Acheulian artefacts and a grey silty clay upper member entirely devoid of artefacts. Williams and Royce (1982) interpreted this unit as wind-blown dust or loess on the basis of grain-size, sorting, lack of sedimentary structure and absence of artefacts, although it may have been in part re-worked by overland flow. Some of the artefacts in the lower member appeared relatively fresh with sharp edges, denoting that they were probably in primary context (Clark & Williams, 1986).

The Upper Pleistocene fluvial sands and gravels of the Khunteli Formation also contain Middle Palaeolithic artefacts (including a Levallois flake excavated by Prof. J.N.

Pal in November 2005) as well as deposits of relatively pure volcanic ash derived from the eruption of Toba volcano in Sumatra 74,000 years ago. The significance of this ash is discussed in sections 4 and 5. Widespread precipitation of calcium carbonate throughout the deposit is consistent with a relatively dry semi-arid climate during or soon after the formation was laid down.

The Upper Pleistocene Patpara Formation is a fining-upwards alluvial deposit of gravels, sand and clay with abundant agate, chalcedony and jasper pebbles in the lower gravel members, pointing to a source in the Deccan Traps near the headwaters of the Son River (Williams & Royce, 1982). The Middle Palaeolithic artefacts within this formation range from highly abraded and transported to retaining sharp edges indicative of a nearby source. Many of the artefacts show signs of heat treatment, which would have made them easier to work. All of the Patpara sediments had undergone extensive weathering and ranged in colour from red to reddish-brown, indicating precipitation of iron under oxidising conditions during a time of wetter than present regional climate.

The Baghor Formation extends in time from at least 40,000 years ago until the early Holocene and also displays a fining-upwards depositional sequence. It consists of two main depositional units: a coarse-grained Lower Member and a fine-grained Upper Member. The Lower Member consists of cross-bedded and planar-bedded coarse sands (Fig. 5) and fine gravels and contains abundant transported and carbonate-cemented vertebrate fossils, which were studied by Umesh Chattopadhyaya (Department of Archaeology, University of Allahabad) for his doctoral degree at the University of Cambridge. The Lower Member spans the Last Glacial

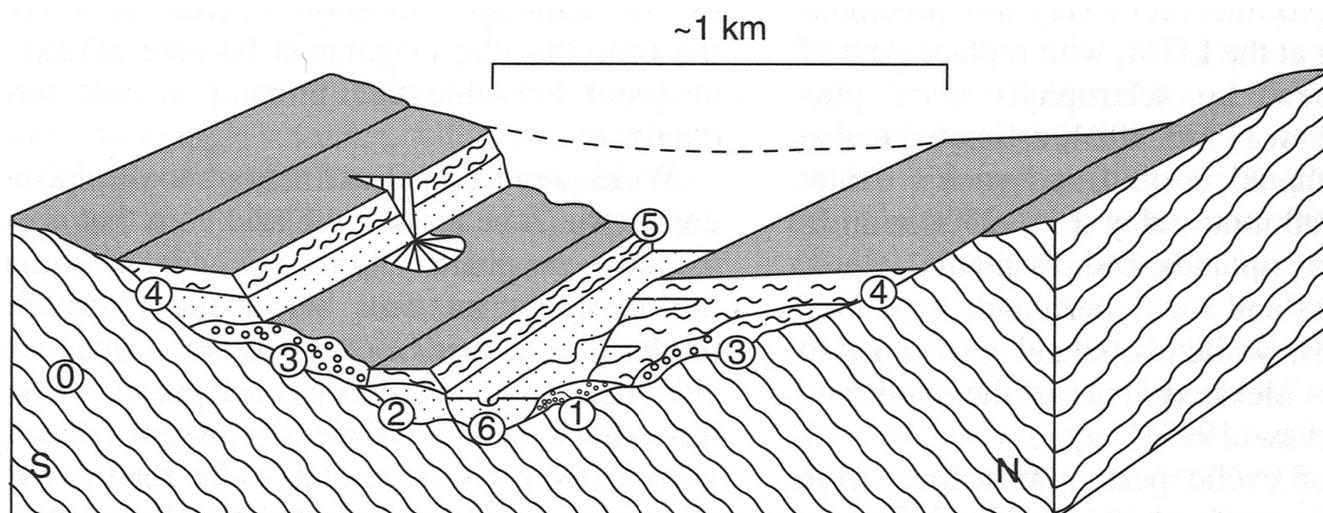


Fig. 3—Block diagram showing the five major alluvial formations investigated in the middle Son Valley. 0. Lower Proterozoic metasedimentary rocks. 1. Middle Pleistocene gravels and clays of the Sihawal Formation. 2. Upper Pleistocene sands and gravels of the Khunteli Formation. 3. Upper Pleistocene gravels, sands and clays of the Patpara Formation. 4. Terminal Pleistocene sands and clays of the Baghor Formation. 5. Late Holocene clays, silts and sands of the Khetaunhi Formation. 6. Present-day channel sands and point-bars of the River Son (modified from Williams *et al.*, 2006, Fig. 3; Williams, 2011, Fig. 30.2)

Maximum ( $21 \pm 2$  ka) (Mix *et al.*, 2001) which was a time of weaker summer monsoon and significantly colder and drier climate across peninsular India (Duplessy, 1982; Williams, 1985). Plant cover was sparse, hillslope erosion more rapid, and sedimentation more active in the Son and Belan valleys. The Upper Member consists of horizontally bedded alluvial clays that accumulated as flood plain deposits during the very late Pleistocene and early Holocene. Deposition of the Upper Member was followed by incision to a depth of about 30–35 m in the middle Son Valley. The river terraces exposed along the southern margin of the middle Son Valley indicate that this channel incision was intermittent, with phase of stability and local aggradation alternating with phases of vertical incision (Fig. 6). The Upper Member contains Mesolithic and early Neolithic artefacts, including the hoofprint of a Sambur deer (Fig. 7) while the Lower Member contains abraded and transported Upper Palaeolithic artefacts.

It is interesting to note that the Nile has a very similar late Quaternary depositional history to the Son and Belan rivers, for similar hydro-climatic reasons. During the cold dry

late Pleistocene, the Nile was transporting sands and gravels and aggrading. With a return to warmer, wetter conditions in its headwaters during the early Holocene, the Nile became a suspension load river, depositing silt and clay across its floodplain. During the last 7–8 ka the Nile has been engaged in incising its channel into its former floodplain (Williams, 2019).

The late Holocene clays, silts and sands of the Khetaunhi Formation represent a brief interval of fine-grained floodplain sedimentation during a short wetter climatic interval in the late Holocene followed by a return to a more seasonal climate and limited channel incision.

### TOBA VOLCANIC ASH DISCOVERY

Perhaps the most important contribution of the 1980 fieldwork season was the chance discovery of volcanic ash close to the Son–Rehi confluence (Fig. 8). It is worth explaining in some detail how it happened, how the ash was identified as having come from the eruption of Toba volcano



Fig. 4—Crossing the Son, 26 November 2005. Third from the left is Prof. J.N. Pal; fourth from left, Prof. S.N. Ambrose; fifth from left, Dr Parth Chauhan. The remaining four passengers are from the Department of Archaeology, University of Allahabad. We were on our way to sample the Khunteli Formation (see Fig. 3 and text) on the right bank of the Son (Photo: Martin Williams).

in Sumatra, Indonesia, some 74,000 years ago, and its significance for Indian prehistoric archaeology. This ash was the first Quaternary volcanic ash ever identified in India. First, the discovery. Here I quote from Williams (2016, pp.105–6):

Our task was to define and map Quaternary sedimentary formations associated with prehistoric stone artefacts ranging in age from Lower Palaeolithic through Middle and Upper Palaeolithic to Mesolithic and Neolithic. In this we thought that we had been reasonably successful until we were confronted with an unusual deposit near the foot of a 35 m high bank section close to the junction of the Son and Rehi rivers. We had seen nothing like it before. I remarked casually to Keith [Royce] that if this had been Ethiopia, I would have called it a volcanic ash or, at least, a diatomaceous ash, but no Quaternary ash had ever been recorded anywhere in India. I decided to sample it at close intervals.

Discovery of the volcanic ash stimulated earth scientists across India to search for other exposures and it eventually became evident that all of peninsular India had been covered in a layer of ash 10–15 cm thick (Acharyya & Basu, 1993). Much of the ash was reworked soon after initial deposition by a combination of soil creep, raindrop impact and overland flow to accumulate lower in the landscape in depressions and valley

bottoms to form secondary deposits up to several metres thick.

Identifying where the ash came from proved an interesting exercise (see Williams & Clarke, 1995, pp. 287–8 for details). Microscopic analysis by Dr D.A. Adamson at Macquarie University in Sydney confirmed that the ‘fine aeolian sands’ that we had sampled were indeed composed of sherds of volcanic ash. Detailed particle size analysis by Dr Grant McTainsh at Griffith University, Australia, showed that all the grains were of similar size, with a modal range of 30–50  $\mu\text{m}$ . Strontium isotope analysis by Dr David Whitford (CSIRO Division of Mineralogy, Sydney) of the Son volcanic ash pointed to an origin from the Toba volcanic caldera in Sumatra (Whitford, 1975), later confirmed by Dr C.A. Chesner from Eastern Illinois University, who showed that the Son Valley ash came from the youngest of the three major Toba eruptions of the last million years, dated at that time to about 75,000 years ago (75 ka) (Rose & Chesner, 1987; Chesner *et al.*, 1991). Detailed geochemical analyses have subsequently confirmed that all the volcanic ash then sampled across India belonged to the youngest Toba eruption (Shane *et al.*, 1995, 1996; Westgate *et al.*, 1998; Pearce *et al.*, 2014), which has since been precisely dated to  $73.88 \pm 0.32$  ka (Storey *et al.*, 2012).



Fig. 5— Cross-bedded coarse sands of the Lower Member of the Upper Pleistocene Baghor Formation (see Fig. 2 and section 3), middle Son Valley, north-central India (Photo: Martin Williams).

### SIGNIFICANCE FOR PREHISTORIC ARCHAEOLOGY

The discovery of the 74 ka Toba ash in many parts of India has important implications for prehistoric archaeology. We noted in section 4 that this discovery prompted geologists across India to search for this ash, which is known as the Youngest Toba Tephra or YTT. It soon became clear that deposits chemically similar to the YTT were widespread across the sub-continent. The YTT ash occurs in three main forms in India. Most commonly, the ash has been reworked and re-deposited in depressions and valley bottoms on a number of occasions since initial deposition. Ages obtained on sediments above these redeposited beds of ash are invariably younger than 74 ka and so cannot be used to study the environmental (including climatic) impact of the initial eruption on India. The second most common occurrence of YTT ash consists of material that had been locally reworked quite soon after the eruption but that had been protected from subsequent erosion. This ash is relatively pure but much thicker than the initial airfall ash. The third and least common occurrence of the ash consists of a thin band no more than 10–15 cm thick of YTT ash in primary context. These deposits can be used most confidently to determine the possible impact upon prehistoric peoples and ecosystems of the YTT eruption. In addition, the ash that is in primary context can be used as an isochronous marker, enabling prehistoric environments and cultural remains evident before the eruption to be compared

with those evident after the eruption. Deposits of relatively pure ash that were transported and deposited soon after the initial airfall can also be used as isochronous stratigraphic marker beds provided due care is taken to establish that they were indeed displaced and buried very soon after the eruption of the YTT (Biswas *et al.*, 2013).

### TOBA ENVIRONMENTAL IMPACT

Marine sediment cores from the Bay of Bengal show that the YTT was about 10–15 cm thick (Ninkovich *et al.*, 1978a, b). We can therefore infer that continental India was also covered in 10–15 cm of Toba ash soon after Toba erupted 74,000 years ago. Isotopic analyses of pedogenic carbonate collected from fossil soils above and beneath the YTT along an east to west transect from the Son Valley to the Narmada show that in north-central India forest and woodland were widespread before the eruption and were replaced by grassland and open woodland after the eruption (Ambrose *et al.*, 2007; Williams *et al.*, 2009, 2010). Pollen from a marine sediment core collected from the Bay of Bengal shows drier conditions after the eruption (Williams *et al.*, 2009). Isotopic analysis of ice cores in Greenland show that temperatures fell sharply in Greenland immediately after the eruption and desert dust blown from Asia points to drier conditions in central Asia immediately following the eruption (Zielinski *et al.*, 1996). Isotopic evidence from a precisely dated speleothem from a cave in New Mexico shows prolonged dry conditions



Fig. 6—River terraces along the southern edge of the middle Son Valley, north central India (Photo: Martin Williams).

immediately after the Toba eruption (Polyak *et al.*, 2017). Cooling was already under way before the Toba eruption. Although it is likely that the eruption may have accentuated the global climatic cooling, it did not cause it.

At present, the debate is polarised between those (mainly archaeologists) who claim no impact and those (mainly earth scientists and climate modellers: e.g., Jones *et al.*, 2007; Robock *et al.*, 2009) who claim an impact ranging from moderate to severe and lasting from decades to centuries (see Williams, 2012b for details). Historic eruptions like Tambora (1815), Krakatau (1883), Agung (1963) and Pinatubo (1991) were all associated with a global fall in temperature of up to one degree C in the 12 months following the eruption. In the case of Tambora, the ‘year without a summer’, crops failed, and famine ensued in Europe and North America (Wood, 2014). The volume of equivalent rock erupted from Tambora amounted to 30–33 cubic km. The others were somewhat less. The volume of equivalent rock erupted from the 74 ka Toba eruption amounted to 2500–3000 cubic km, of which about 600 cubic km were ash. This is two orders of magnitude more than the historic eruptions. The lack of high-resolution dating of the putative environmental impacts has hindered progress (see Williams, 2012b). To progress, we need high resolution

dating of different environmental archives (speleothems, ice cores, lake sediments, marine sediment cores, pollen spectra) to establish prevailing conditions in different regions before and after the Toba eruption (Williams, 2012c).

There is still no consensus. I suspect that the key reason why current ideas about the impact of the Toba eruption remain so polarised is our lack of fine resolution chronology to define the nature of the environment immediately before and after the YTT eruption. A possible recent exception is Polyak *et al.* (2017), who have used fine resolution uranium series dating of a speleothem from New Mexico to show a rapid onset of regional drought synchronous with the onset of Greenland ice core stadial 20 as well as with the onset of the Toba eruption. The drought ended abruptly 1560 years later, at the end of stadial 20. They infer that the Toba eruption acted as a trigger or catalyst for more prolonged and widespread climatic change than the initial brief impact, which seems very credible.

Evidence used to reconstruct the possible impact of the 74 ka Toba eruption includes comparison with historic eruptions (Williams *et al.*, 2006); climate models (Williams *et al.*, 2009); molecular biology (Ambrose, 1998; Williams *et al.*, 2009); prehistoric archaeology (Petraglia *et al.*, 2007; Clarkson *et al.*,



Fig. 7—Early Holocene hoofprint of a Sambar deer exposed during excavation of the Upper Member of the Baghor Formation in 1982 (Photo by, and courtesy of, the late Prof. J. Desmond Clark).



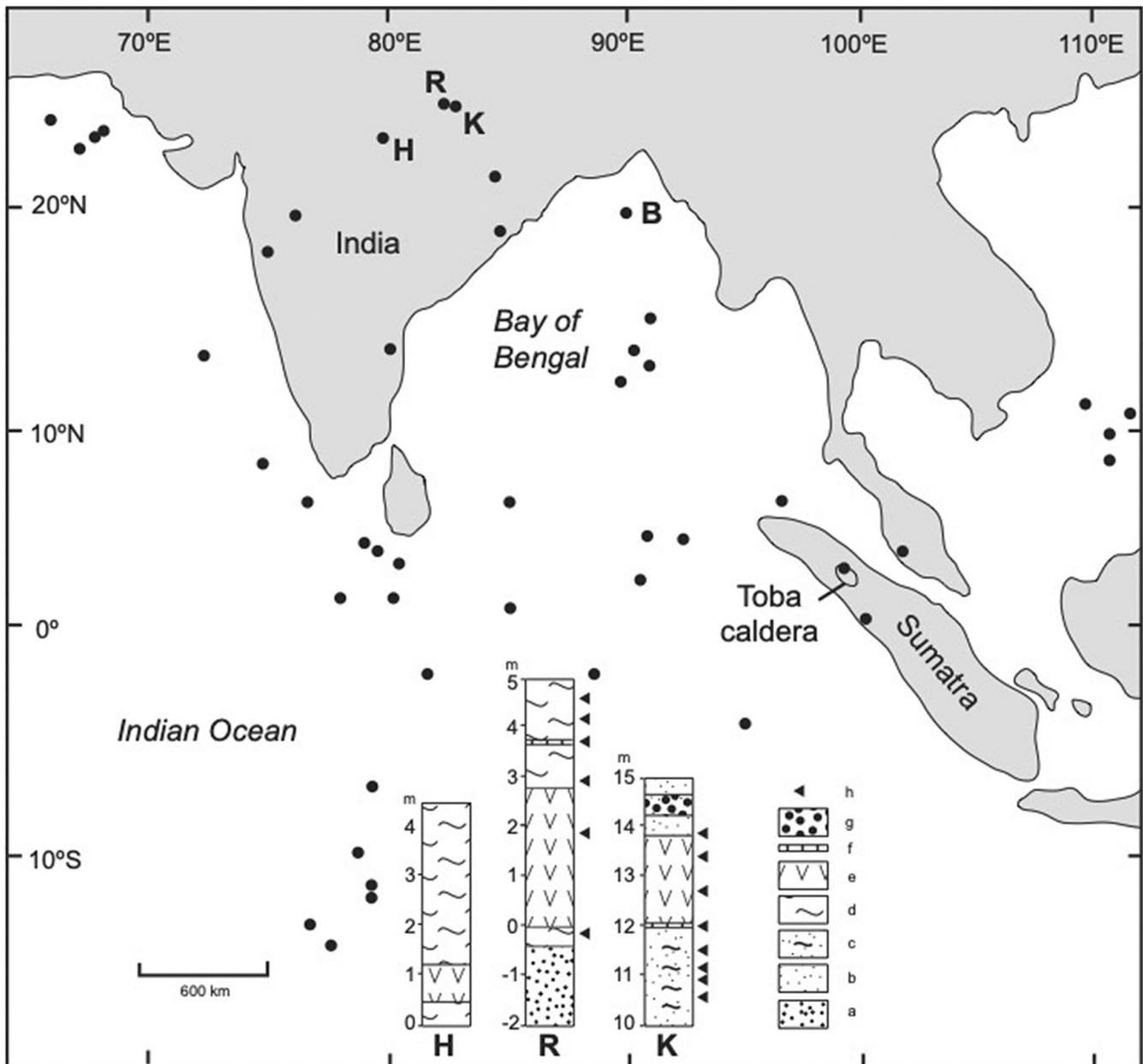


Fig. 8—Distribution of volcanic ash from the 74 ka Toba super-eruption showing location of marine sediment cores and sections sampled in India. The black dots represent Toba tephra occurrences on land and in marine sediment cores. R is the site of the first Toba ash discovery by Williams and Royce in February 1980 at the Son–Rehi confluence. B is marine core S0188–342KL in the Bay of Bengal; K is Khunteli; R is Rehi; H is Hirapur. Key to stratigraphic sections in India: a is coarse sand; b is medium/fine sand; c is silt loam/ sandy loam/interstratified sand and loam; d is clay; e is Toba volcanic ash; f is massive carbonate; g is gravel; h is sampled pedogenic carbonate horizon (after Williams *et al.*, 2009, Fig. 1; Williams, 2011, Fig. 30.3).

2020); ice cores (Zielinski *et al.*, 1996; Svensson *et al.*, 2013); stable isotope geochemistry (Ambrose *et al.*, 2007; Williams *et al.*, 2009); pollen analysis (Williams *et al.*, 2009; van der Kaars *et al.*, 2012); geology and geochemistry (Chesner *et al.*, 1991; Acharyya & Basu, 1993; Shane *et al.*, 1995, 1996; Westgate *et al.*, 1998); geomorphology (Williams & Royce, 1982; Williams & Clarke, 1995; Williams *et al.*, 2009); and

marine sediment cores (Ninkovich *et al.*, 1978a, b; Duplessy, 1982; Böhning & Sarnthein, 2000). The genetic evidence that is sometimes proposed in favour of a major impact is still too poorly dated to allow any sensible interpretation over the role of Toba in causing a genetic bottleneck (see Ambrose, 1998; Rampino & Ambrose, 2000 for discussion). Table 1 lists some of the actual and possible impacts of the Toba eruption.

Table 1—Environmental impact of the 74 ka Toba eruption (modified from Williams, 2011, Table 30.4).

*Definite consequences*

- Eruption of ~3 000 km<sup>3</sup> of ejecta and sulphur particles.
- Formation of a volcanic ash veil across the globe that persisted for at least six years.
- Deposition of sulphates in Greenland ice during at least six consecutive years.
- Accumulation of central Asian wind-blown dust in Greenland ice for several centuries after the eruption.
- Destruction of forest in Sumatra as a result of the blast of the explosion and of fires triggered by very high temperatures from the erupted ash flow tuffs.
- Deposition of a layer of ash over adjacent lands and oceans.
- Deposition of a 10–15 cm thick ash mantle across peninsular India, leading to interference with respiration, transpiration and photo synthesis and associated widespread damage to the plant cover. Rivers and lakes choked with ash transported down slope by mass movement and surface runoff.
- Change from widespread forest across central India before the eruption to open woodland and grassland for many centuries after the eruption.
- Sharp drop in temperature recorded in Greenland ice cores.

*Probable consequences*

- Acid rain resulting from oxidation of the sulphur to sulphur dioxide and its conversion to sulphuric acid on reacting with water vapour.

*Possible consequences*

- Possible sharp drop in global temperature caused by the volcanic dust veil and sulphate aerosols.
- Pollution of rivers, lakes and other wetlands as a result of toxins leached from the ash.
- Possible abrupt decline in animal and prehistoric human populations linked to widespread ecosystem damage caused directly and indirectly by the eruption.

## CURRENT RESEARCH

Research in the Son and Belan valleys during the past few decades follows several, often overlapping, pathways. One involves a re-appraisal of the alluvial stratigraphy and depositional environments (Williams *et al.*, 2006; Giblin *et al.*, 2008). The second is a focus on improving the chronology of the alluvial sediments, prehistoric sites and YTT outcrops (Pal *et al.*, 2004; Williams *et al.*, 2006; Jones, 2010; Biswas *et al.*, 2013). The third is aimed at more detailed and more rigorous archaeological excavation and analysis (Clarkson *et al.*, 2020). The fourth and in many respects the most innovative is the use of novel geochemical and isotopic techniques to improve our understanding of past climate and prehistoric cultures in this region (Jha *et al.*, 2020). In an exemplary study, Deepak Jha and his colleagues have recently analysed charcoal remains from previously investigated prehistoric sites in the Belan Valley and were able to demonstrate deliberate human use of fire in this region in Middle Palaeolithic times (Jha *et al.*, 2021).

## FUTURE DIRECTIONS

For archaeologists seeking to study prehistoric artefact assemblages in deposits stratigraphically above and beneath

the YTT, it will be imperative to demonstrate beyond any reasonable doubt that the volcanic ash exposed within the excavated archaeological sections is either in primary context or at least has not been extensively reworked (Biswas *et al.*, 2013). This will require input from geochemists, field geologists/geomorphologists/soil scientists. Unless this can be done, it is unlikely that a simple comparison of archaeological assemblages recovered in primary context from sediments located stratigraphically above and beneath the putative YTT ash will be particularly informative.

A mere demonstration that the artefact assemblages above and beneath the YTT are essentially similar (Clarkson *et al.*, 2020) does not tell us much about any possible local or regional environmental changes associated with the 74 ka Toba eruption and YTT deposition across India. All it tells us is that the assemblages remained similar and humans were present at that particular site. They may or may not have experienced some impact.

Independent evidence from many different proxies, buttressed by a fine resolution chronology, is needed to determine whether or not there were changes in environment caused by the eruption. Only then will it be possible to throw further light upon human responses to possible environmental change and so contribute to the broader question of prehistoric human migrations in South Asia (O'Connell *et al.*, 2018).

## CONCLUSION

Archaeological surveys in the 1970s revealed evidence of human occupation in the Son and Belan valleys of north-central India extending back to Lower Palaeolithic times. Later field mapping of alluvial deposits in these valleys enabled a number of discrete fluvial formations to be identified and provided a stratigraphic context for the archaeological site excavations. A by-product of the field mapping (in February 1980) was the chance discovery of volcanic ash erupted 74,000 years ago from Toba volcano in Sumatra, Indonesia. Ash from Toba covered the Indian sub-continent to a depth of 10–15 cm. In north-central India forest that was dominant before the eruption was replaced by open woodland and grassland after the eruption. However, the precise regional environmental (including climatic) impacts of this eruption are yet to be determined and remain an exciting challenge for the current generation of younger Quaternary researchers across the Indian sub-continent.

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