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Rapid Communication

Cryptotephra from the 74 ka BP Toba super-eruption in the Billa Surgam caves, southern India

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ABSTRACT

The ~74 ka BP Youngest Toba Tuff (YTT), from the largest known Quaternary volcanic eruption, has been found for the first time as a non-visible (*crypto-*) tephra layer within the Billa Surgam caves, southern India. The occurrence of the YTT layer in Charnel House Cave provides the first calendrical age estimate for this much debated Pleistocene faunal sequence and demonstrates the first successful application of cryptotephrochronology within a cave sequence. The YTT layer lies ~50 cm below a major sedimentological change, which is related to global cooling around the MIS 5 to MIS 4 transition. Using this isochronous event layer the Billa Surgam Cave record can be directly correlated with other archaeological sites in peninsular India and palaeoenvironmental archives across southern Asia.

1. Introduction

The Youngest Toba Tuff (YTT) was erupted from Sumatra, Indonesia, around 74 ka BP (Ninkovich et al., 1978). This volcanic eruption is the largest known in the Quaternary, erupting more than 2800 km^3 of magma (Rose and Chesner, 1987) and dispersing visible deposits of ash from sites as far west as the Arabian Sea and reaching east to the South China Sea (Buhring et al., 2000; Oppenheimer, 2002; Schulz et al., 2002). Although the YTT eruption is not believed to have contributed to glaciation (Robock et al., 2009; Timmreck et al., 2010), the eruption took place close to the onset of global cooling associated with the end of marine isotope stage (MIS) 5 and the start of glacial MIS 4, a time when human populations were expanding out of Africa and adapting to new environments. Despite much debate over the direct impact of this super-eruption on human populations and the changing global environments (e.g. Rampino and Self, 1992; Ambrose, 1998; Petraglia et al., 2007; Williams et al., 2009, 2010; Haslam and Petraglia, 2010), the YTT undoubtedly acts as a useful isochronous horizon for the climatic transition from MIS 5 to MIS 4, and facilitates correlation of widespread sites.

Cryptotephra investigations have been used widely across Europe as a means of locating widespread tephra isochrones in sites where they are not preserved as visible horizons (Dugmore et al., 1995; Lowe and Turney, 1997). These methods, which extract volcanic glass shards from their host sediment, have allowed known tephra fallout areas of volcanic eruptions to be greatly extended, facilitating chronostratigraphic correlations of widespread palaeoenvironmental records (e.g. Wastegård et al., 2000; Turney et al., 2004; Margari et al., 2007; Lane et al., in press). As well as tracing tephra deposits into ever more distal sites, cryptotephra investigations are also capable of locating tephra layers within sedimentary contexts where they are less concentrated and therefore do not form visible horizons. The method is therefore well suited to the study of Palaeolithic cave sediments within known tephra fallout areas, however, to date no such successful study has been published.

Here, we present the results of a cryptotephra investigation in one of the Billa Surgam caves, southern India (Fig. 1). This is the first example of a successful cryptotephra investigation within an archaeological cave record, and also within South Asia, and it demonstrates the potential extension of this dating method both across wider geographical areas and into non-open-air sedimentary deposits.

2. The Billa Surgam caves

The Billa Surgam caves (N 15° 26.126′; E 78° 11.131′) of Andhra Pradesh have been investigated by archaeologists and

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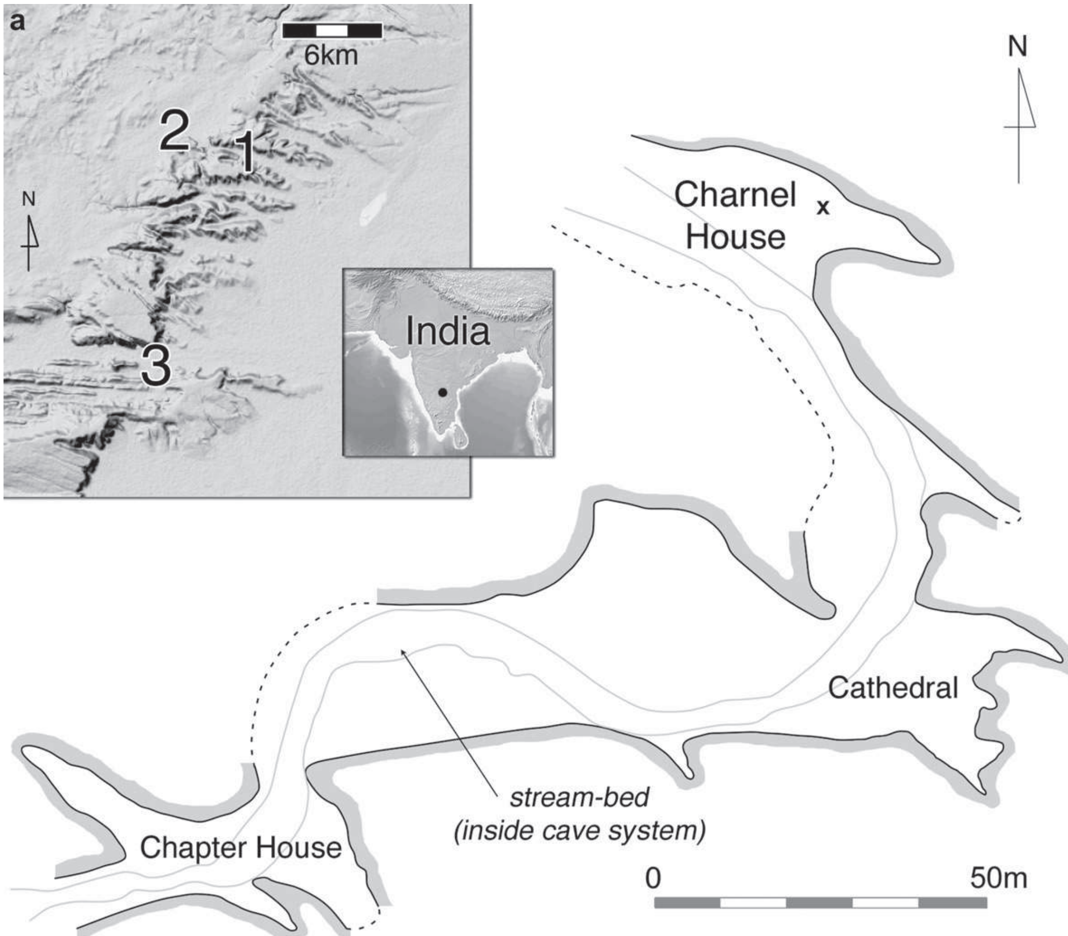

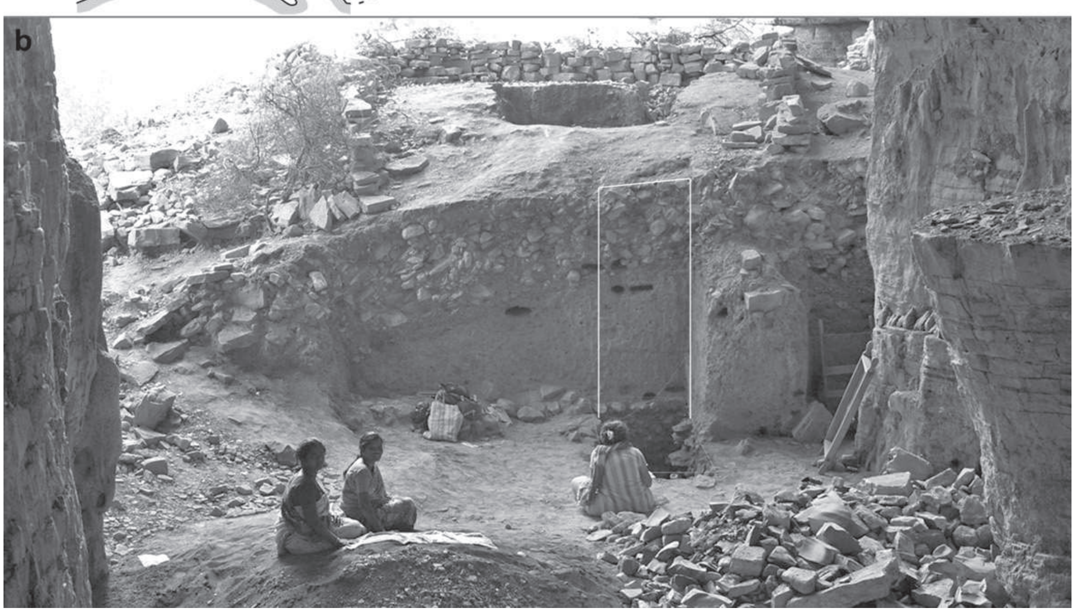

Fig. 1. (a) Map of the Billa Surgam Cave system showing the position of Charnel House Cave at its northern end; 'x' marks the spot from which the samples analysed in this study were collected. The inset shaded relief maps show the cave's location in southern India, with nearby towns marked: 1) Billa Surgam, 2) Betamcherla, 3) Jwalapuram. (b) View of the cave during excavation in 2009, facing west towards the entrance. The sampled section is outlined in white, and continues below the current cave floor level.

environmental scientists since the mid-nineteenth century (see Haslam et al., 2010b). Excavated extensively in the 1880s at the personal request of Thomas Henry Huxley (Duff, 1883a,b 1884), this series of deep sedimentary traps extending off a winding limestone dissolution channel has played a central role in debates over southern India's Palaeolithic and faunal sequences (Newbold, 1844; Foote, 1884a,b 1885; Cammiade, 1927; Murty, 1974; Murty and Reddy, 1975; Reddy, 1977; Prasad, 1996). However, at present no absolute dates for Pleistocene deposits have been reported for any of the Billa Surgam caves, though radiocarbon ages are available for Holocene deposits in the Chapter House North Cave (Petraglia et al., 2009).

Extensive deposits of tephra from the YTT super-eruption have been noted in the Jurreru Valley, 13 km south-southwest of Billa Surgam, as well as a number of other Indian localities (Jones, 2007; Petraglia et al., 2007; Haslam et al., 2010a). As the Billa Surgam caves preserve a Pleistocene sequence of several metres depth, including fauna such as *Rhinoceros* that are no longer present in the region (Lydekker, 1886), we anticipated that the cave stratigraphy might contain a YTT horizon. Cryptotephra analysis was attempted because a macroscopically visible tephra layer has not been identified in any cave in the Billa Surgam system during the past 160 years.

2.1. Charnel House Cave

The site chosen for cryptotephra investigation was Charnel House Cave (CHC). This cave was excavated to bedrock across most of its extent in the 1880s (Foote, 1884a), leaving only a block of original sediment standing at the entrance (Haslam et al., 2010b). The

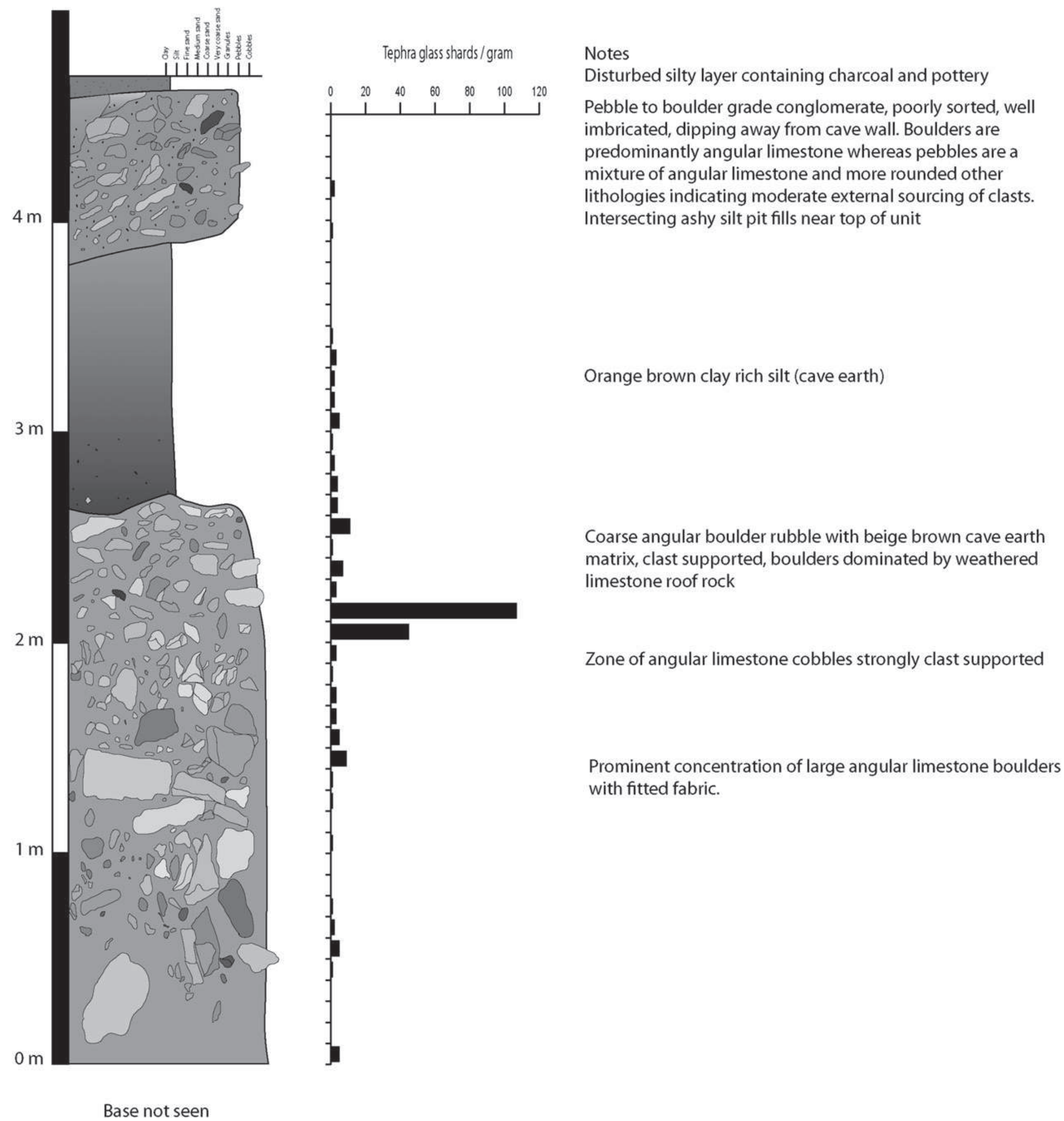

Fig. 2. Sedimentary log and lithological descriptions for the sampled Charnel House Cave sediments, with cryptotephra shard concentrations (s/g) plotted for each 10 cm depth sample.

remaining sedimentary sequence (Fig. 2) consists of over 4.5 m of clast-supported, weathered, angular to sub-rounded limestone cobble and boulder rubble in a yellowish-red to brown silty matrix, overlain by ~1.3 m of relatively undifferentiated yellowish-red silts, in turn overlain by 0.8–0.9 m of poorly sorted pebble-to-boulder grade conglomerate with likely mixed sediments at the very top. The interface between each of the cobble beds and the intervening silt layer is reasonably distinct and sharp, representing two dramatic changes in the sediment depositional regime. The limestone clasts are primarily derived from significant roof-fall events, and as the roof of the site is tens of metres high there are a number of naturally-fractured limestone pieces throughout the upper and lower rubble-beds. While this makes identification of cultural products difficult, there are presently no indisputably manufactured lithic items recovered from Charnel House Cave. A large number of microfaunal remains have been collected from the CHC sequence, along with a lesser number of macrofaunal skeletal elements, and these are currently being analysed for evidence of human processing.

3. Cryptotephra analysis methods

3.1. Sampling and laboratory processing

A total of 46 sediment samples collected at 10 cm intervals from the preserved CHC sediments (Fig. 2) were sub-sampled for cryptotephra investigations. These include 25 samples from the lower, weathered limestone rubble layer, 14 from within the silts, and 7 from the upper rubble layer. The samples were collected following cleaning of the exposed section, and sampling was conducted from the base of the sequence upwards to minimise any contamination. Cryptotephra extraction methods followed Blockley et al. (2005), with all sub-samples weighed to allow quantification of the number of shards per gram (s/g) of sediment.

3.2. Compositional analysis

Where tephra was located, glass shards were picked manually from the extracted sediment. These were then mounted in epoxy resin, ground and polished for compositional analysis. Electron probe microanalysis, using wavelength-dispersive spectroscopy (WDS-EPMA), was carried out on the JEOL JXA-8600 at the Research Laboratory for Archaeology and the History of Art, University of Oxford. Eleven major elements were analysed (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P and Cl) with an accelerating voltage of 15 kV, a 6 nA beam current and 10 μm defocused beam. Secondary standard glass StHs6/80-G from the MPI-DING fused volcanic glass sample set (Jochum et al., 2006) was used to check the instrument calibration and monitor for drift during the analysis session.

4. Results

4.1. Tephra glass shard concentrations

A distinct peak in tephra glass shard concentrations, of 140 s/g, was observed at 2.20 m (sample CHC_T2.20), ~0.40 m below the transition from the coarse rubble-beds to the fine-grained clay-silts (Fig. 2). As the samples were not contiguous, the exact first appearance of the tephra layer cannot be established, however the highest concentrations appear to occur above 2.10 m and below 2.30 m, and this <20 cm range is at a comparable resolution to the archaeological stratigraphy. The tephra in CHC_T2.20 appear colourless and are a mix of curvilinear plate-like shards and shards with elongate fluting. Shard sizes range from 50 to 150 μm (longest axis length). Tephra shard counts of <10 s/g, found in samples throughout the excavated section are not considered to represent other tephra fall events. These trace deposits are instead explained by a combination of biogenic and/or geologic reworking of small tephra particles within the dry and unconsolidated sediments (as observed in other terrestrial sedimentary contexts, c.f. Lowe, 2011) and limited aeolian input of YTT material transported from exposures in the surrounding landscape, which could have taken place over the past several millennia.

4.2. WDS-EPMA

Results of WDS-EPMA are presented in Table 1 alongside secondary standard glass analyses. Five analyses were achieved on CHC_T2.20 and these show a homogeneous rhyolitic composition. Fig. 3 compares the major element composition of CHC_T2.20 to a sample from the visible YTT deposits in the Jwalapuram Middle Palaeolithic site in the Jurreru river valley (Smith et al., in press) and to the composition of the proximal YTT, sampled in Sumatra, by Westgate et al. (1998). A good match is apparent to both reference datasets. There have been two other eruptions of the Toba caldera with similar glass compositions: the ~0.79 Ma Older Toba Tuff and the ~0.5 Ma Middle Toba Tuff (Smith et al., in press). However, tephra of such antiquity would not be expected in Late Pleistocene contexts and to date these have not been found on the Indian continent. The compositional match (Fig. 3) therefore confirms that CHC_T2.20 is a deposit of the ~74 ka YTT.

Table 1
Results of WDS-EPMA of tephra glass shards ($n = 5$) from sample CC_T2.20 from Charnel House Cave, along with summary data from associated StHs6/80-G secondary standard glass analyses (in grey shade). Summary data for the YTT from the Jwalapuram archaeological site (Smith et al., in press) is also included.

	SiO_2 wt%	TiO_2 wt%	Al_2O_3 wt%	FeO wt%	MnO wt%	MgO wt%	CaO wt%	Na_2O wt%	K_2O wt%	P_2O_5 wt%	Total
Charnel House Cave											
CHC_T2.20/1	73.95	0.05	12.09	0.96	0.10	0.06	0.74	3.17	5.09	0.00	96.2
CHC_T2.20/2	74.77	0.07	12.04	0.86	0.12	0.04	0.64	3.21	5.01	0.02	96.8
CHC_T2.20/3	74.97	0.04	12.02	0.86	0.12	0.06	0.80	3.00	4.85	0.04	96.8
CHC_T2.20/4	74.17	0.03	12.19	0.84	0.07	0.04	0.79	2.91	4.98	0.02	96.0
CHC_T2.20/5	74.72	0.05	12.04	0.78	0.05	0.06	0.65	3.24	4.82	0.03	96.4
StHs6/80-G secondary standard summary data											
Average ($n = 3$)	63.9	0.72	17.9	4.35	0.05	2.00	5.25	4.46	1.30	0.14	
2σ	0.10	0.12	0.28	0.34	0.09	0.08	0.11	0.07	0.09	0.01	
Jwalapuram YTT summary data											
Average ($n = 148$)	77.36	0.05	12.46	0.87	0.07	0.06	0.75	3.25	4.96	0.03	99.9
2σ	0.56	0.05	0.39	0.18	0.09	0.21	0.15	0.33	0.32	0.03	

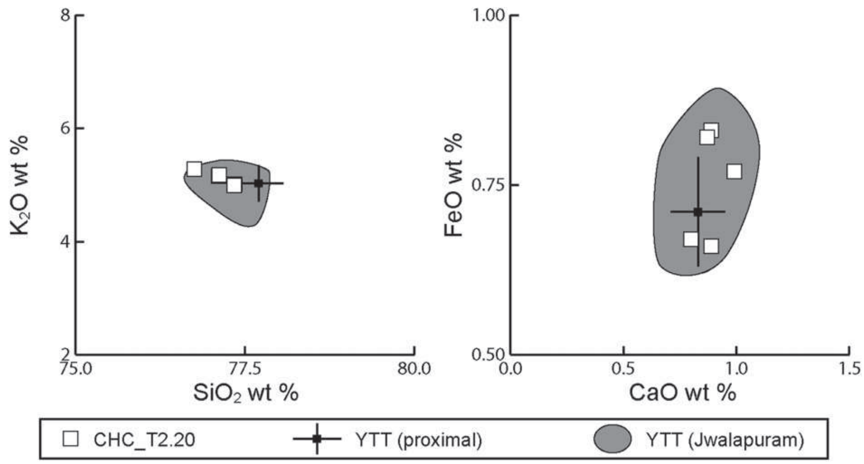

Fig. 3. Correlation of major element glass chemistry of CC_T2.20 with tephra glass from Jwalapuram archaeological site in the Jurreru Valley, India, and with the proximal YTT glass from Sumatra (error bars represent the two standard deviation uncertainty range around the published mean from Westgate et al., 1998).

5. Implications

5.1. YTT in Charnel House Cave

The discovery of the YTT as a cryptotephra layer in Charnel House Cave provides an isochronous marker horizon, which allows the faunal record of the site to be directly correlated to other archaeological sites in India that preserve the YTT as a visible layer. The age of the YTT is $\sim$74 ka BP and this can be imported into the Charnel House Cave sediment sequences, at around 2.20 m (Fig. 2). This is the first numerical age determination for the site. The position of the YTT indicates that the deposition of the lower rubble layers dates to MIS 5 and continued for a period after the YTT before the abrupt transition to deposition of fine silts occurred.

As noted above, there are no definitive Pleistocene archaeological artefacts recovered to date in the cave. However, initial analysis of faunal material has identified cut-marked non-human primate bones (cf. *Presbytis*) near the base of the exposed lower rubble layer (Miracle, 2010). This finding suggests hominin presence and subsistence behaviour in the Billa Surgam caves prior to the Toba eruption, likely during MIS 5, indicating that further archaeological exploration of the cave system is warranted.

5.2. Cryptotephra as a tool in archaeology

This study presents the first published occurrence of a cryptotephra layer detected within the sediments of a Palaeolithic cave. It is also the first application of cryptotephrochronology within South Asia. The successful location and identification of the YTT in the Billa Surgam caves highlights the potential to explore and date more sites in India that are likely to preserve late MIS 5 sediments but do not have macroscopic tephra layers. Such finds would build on the known network of terrestrial and marine sites connected by the presence of the YTT (Acharyya and Basu, 1993), allowing comparison of regional records on a common chronological timescale.

Furthermore, our results suggest that cryptotephra layers may be preserved as discrete event horizons within a more diverse range of sedimentary contexts than have been investigated to date. This includes sheltered sites, such as exogene caves or rockshelters, that may not be directly exposed to tephra fallout, but which frequently contain valuable Palaeolithic archaeological deposits.

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