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ESR dating in Song Terus cave (East Java, Indonesia)

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Abstract

Electron spin resonance (ESR) dating on teeth has been used to determine the antiquity of the human presence in the area of Gunung Sewu (East Java, Indonesia). The Song Terus cave is one of the archaeological sites located in this area, which has yielded an important collection of fossil bones and prehistoric lithic industry. ESR dating shows that this cave belongs to a karstic system which has been in place since Middle Pleistocene. The results of coupled ESR/Uranium-series dating indicates closed system for uranium in tooth tissues yielding ages of between 216 and 392 ka for the oldest archaeological levels, confirming the possibility of finding Middle Pleistocene human occupations in such karstic sites in Java.

Keywords

ESR, U-series, Tooth, Middle Pleistocene, Indonesia

1. Introduction

The Gunung Sewu area, meaning Thousands of Hills, is close to the Indian Ocean on the south-eastern coast of Java (Fig. 1). This area has become known to prehistorians because the terraces of the Baksoka River yielded the archaic-looking artifacts named Patjitanian industry (von Koenigswald, 1936). Unfortunately, this industry has never been directly dated and was often assigned a late Pleistocene age (van Heekeren, 1972; Bartstra, 1976). Gunung Sewu is also the place of the discovery of the Punung Fauna (Badoux, 1959), which may correspond with the arrival of *Homo sapiens* in Java (de Vos, 1996). More recently, several Palaeolithic archaeological sites also located in this region have been dated from late Upper Pleistocene to Holocene (Simanjuntak, 2002). As this karstic area contains numerous caves (Waltham et al., 1983; Willis et al., 1984) with archaeological and palaeontological remains (Simanjuntak et al., 1998, Simanjuntak, 2002), it offers the possibility to discover a long chronological record.

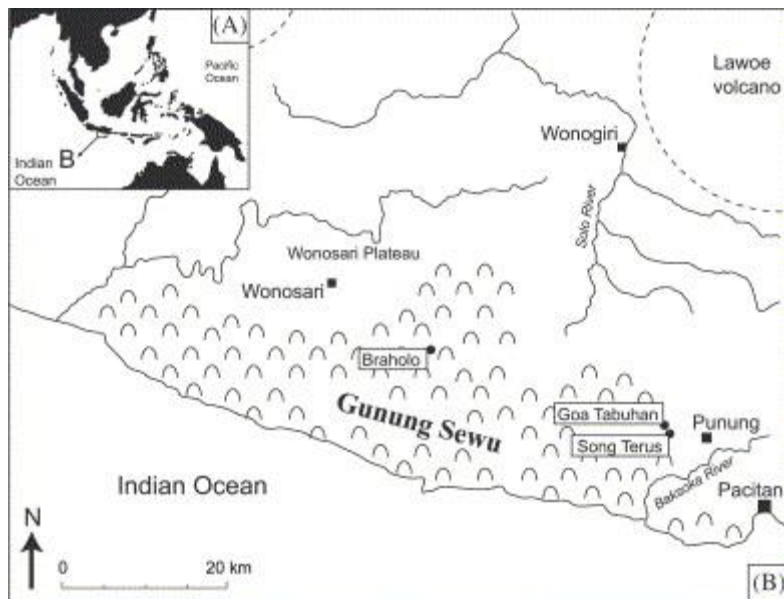


Fig. 1. Location of Song Terus cave in Gunung Sewu area, East Java, Indonesia.

In this area, near Punung village, Song Terus Cave has been excavated since 1994 by a French-Indonesian team. Excavations have yielded thousands of lithic artifacts (Sémah et al., 2004) associated with a fauna, which could be related to the Punung Fauna. This fauna first suggested a late Upper Pleistocene age for the human activity. The Song Terus sedimentary filling is over 15 m deep and consists of stratified deposits containing archaeological material and well-preserved fauna. It should represent a longer record within the Quaternary.

The aim of the present study was to date the oldest archaeological remains discovered in the Song Terus cave and to compare the results with those of the karstic fillings in other caves in this area. The ages of the archaeological levels in the Song Terus Cave and for the sedimentary fillings will provide an important new chronological framework and improve the understanding of the human prehistoric occupations in this area and the whole South East Asia.

2. Site presentation

The Song Terus cave about 20 m wide, 100 m long, and located a few km to the West of Punung Village (Fig. 1). The entrance of the cave is at 333 m asl. Two pits, named KI and KII, showed that the filling was thicker than 15 m (Fig. 2). The upper part is constituted of cave deposits which contain actual prehistoric occupations. In these levels, the sediments consist of brown sandy silt originating essentially from the cave's wall as well as an aeolian component coming from outside. These deposits were also studied in an excavated area (~40m²) where two archaeological levels could be distinguished.

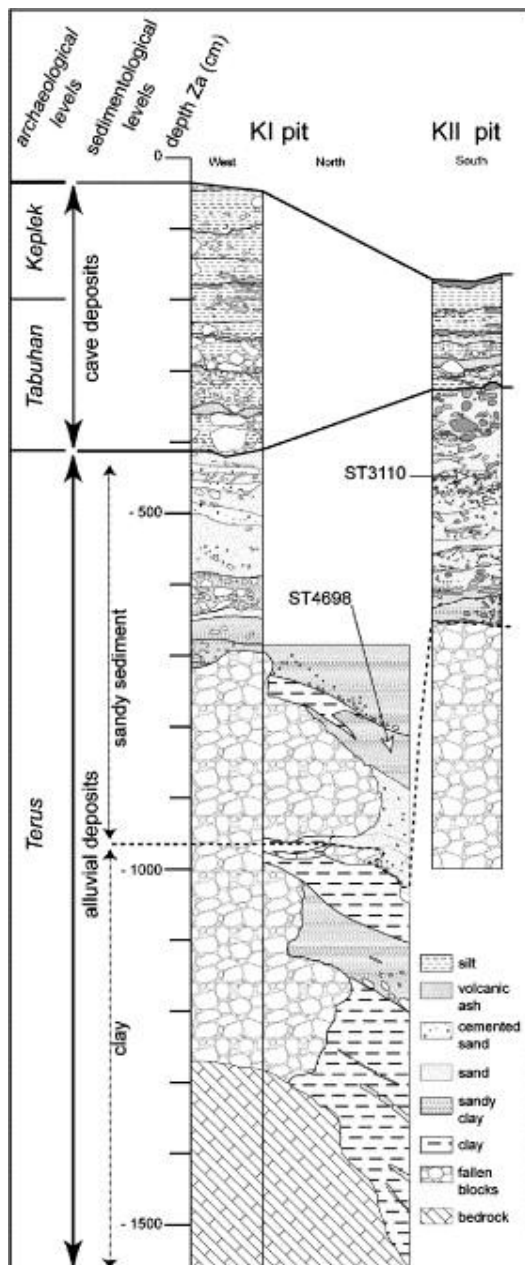


Fig. 2. Location of the teeth (ST3110, ST4698) sampled in the alluvial deposits of Song Terus cave (after Sémah et al. 2004).

The upper level (0–2 m), called Keplek, yielded thousands of lithic artifacts and faunal remains, and a *H. sapiens* burial at the top of the filling, close to the cave wall. It has been dated by the ^{14}C to between about 5700 and 9400 BP (Sémah et al., 2004). Between 2 and 4 m, in layers named Tabuhan, archaeological remains become less numerous, but human activity is attested by the presence of some lithic artifacts and of mammal remains. Many teeth of large mammals were found, providing a good material for ESR dating. However, these levels are strongly marked by volcanic ashes and ESR age determination requires precise palaeodosimetric measurements which are in progress.

The lower part of the filling (4–5 m) consists of alluvial sediments (thick layers of clay, sandy sediment) deposited when a river ran in the cave. A lithic assemblage, primarily constituted by flakes associated with some faunal remains, was discovered in these levels named Terus (Sémah et al. 2004). We presume that fossil remains and lithic artifacts come from close prehistoric settlements which were located at the river bank. The dating of this alluvial layer is the main purpose of this paper.

3. Samples

Two teeth were discovered in alluvial deposits of Song Terus cave and sampled for ESR dating (Fig. 3). The faunal remains discovered in this level are well preserved, indicating a short transport phase. These teeth did not have any transport marks and the enamel was not altered by oxidation, microfracturation or recrystallization. The first sample (ST3110) is a fragment of a rhinoceros tooth having a thick piece of enamel (1.5 mm) with dentine on one side, sampled in the pit KII at 448 cm depth. The second sample (ST4698) is a tooth of a *Tapirus*. It was located at 820 cm depth in the KI pit.

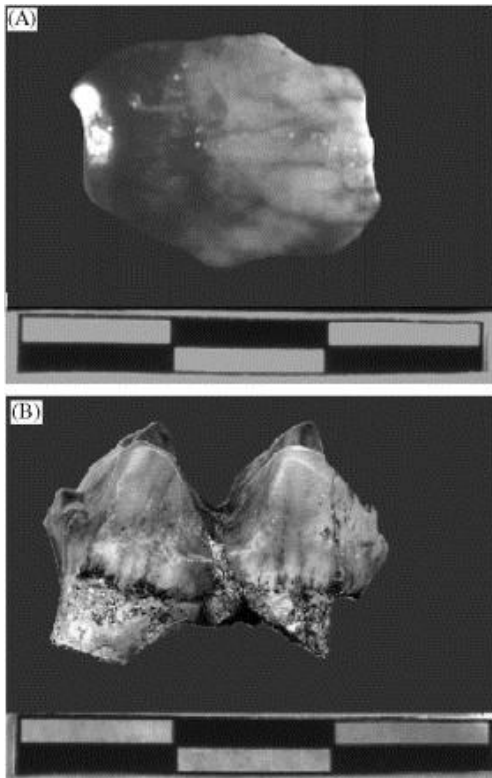


Fig. 3. Teeth from alluvial deposits in Song Terus cave. (A) fragment of *Rhinoceros* tooth (ST3110) and (B) tooth of *Tapirus* (ST4698).

4. Experimental procedures

The teeth were cleaned and dentine was separated from enamel to be analyzed separately. To remove the part of enamel affected by external α particles, $\sim 100\ \mu\text{m}$ from each side of the enamel pieces were removed with a drill. Enamel was then crushed and sieved in order to obtain 100–200 μm fraction for analysis. Finally, it was divided into 10 aliquots of approximately 80–100 mg and irradiated by a gamma source in increasing steps from 0 to 5000 Gy (Fig. 4). ESR ages were calculated by dividing the equivalent dose (D_E), determined with additive method, by the dose rate (d), which involves external dose (d_{ex}) and internal dose (d_{in}). To determine d_{in} , U-series analyses were made on the constituents of the teeth using alpha spectrometer (Table 1) followings the procedures of Bischoff and Fitzpatrick (1991). The U-series ages were calculated using the equation given by Ivanovich and Harmon (1992). To evaluate the sediment dose rate, samples surrounding teeth were collected and measured by γ spectrometry (Table 2). Varying the assumed water content did not substantially change the calculated ages. The cosmic dose was evaluated using the formula given by Yokoyama et al. (1982), taking into account altitude and latitude variations (Prescott et Stephan, 1982). The cosmic dose rate is very small ($<10\ \mu\text{Gy/a}$) due to the thickness of the cave roof which is more than 30 m.

ESR ages were calculated taking into account an alpha efficiency of 0.13 ± 0.02 (Grün and Katzenberger-Apel, 1994).

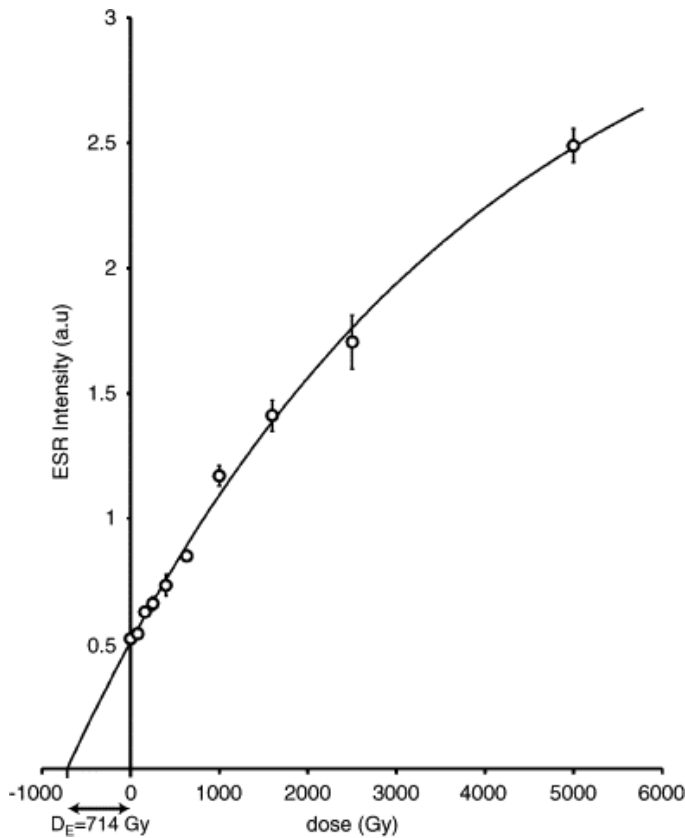


Fig. 4. Growth curve of ESR signal intensity vs irradiation doses (sample ST4698). 10 Aliquots of the sample were irradiated with a gamma source (^{60}Co) at Laboratoire National Henri Becquerel (LNHB), France, in increasing step from 0 to 5000 Gy. The D_E value results from the extrapolation to zero ESR intensity. The fitting is carried out using a single saturating function and weighted by the non-irradiated aliquot. ESR measurements were made at room temperature on a Bruker spectrometer (EMX). The microwave power was 10 mW and modulation amplitude 0.01 mT.

	Z (cm)		^{238}U (ppm)	$^{234}\text{U}/^{238}\text{U}$	$^{230}\text{Th}/^{232}\text{Th}$	$^{230}\text{Th}/^{234}\text{U}$	U-series ages (ka)
ST3110	-448	Dentine	38.61 ± 0.89	1.10 ± 0.02	>100	0.84 ± 0.03	$187 + 21 / - 18$
		Enamel	1.68 ± 0.11	1.12 ± 0.07	>100	0.91 ± 0.06	$235 + 108 / - 49$
ST4698	-820	Dentine	65.58 ± 1.06	1.26 ± 0.01	>100	0.91 ± 0.05	$215 + 41 / - 30$
		Enamel	4.17 ± 0.27	1.11 ± 0.07	>100	0.99 ± 0.03	$307 + 97 / - 50$

Table 1. U-series data for teeth from Song Terus

	D_E (Gy)	TET (μm)	RET (μm)	Sediment					EU model			LU model			Coupled ESR/U-series data		
				U (ppm)	Th (ppm)	K (wt%)	γ Sed D ($\mu\text{Gy/a}$)	β Sed D ($\mu\text{Gy/a}$)	En D ($\mu\text{Gy/a}$)	Den D ($\mu\text{Gy/a}$)	total D ($\mu\text{Gy/a}$)	En D ($\mu\text{Gy/a}$)	Den D ($\mu\text{Gy/a}$)	Total D ($\mu\text{Gy/a}$)	En D ($\mu\text{Gy/a}$)	Den D ($\mu\text{Gy/a}$)	Total D ($\mu\text{Gy/a}$)
ST3110	191 \pm 12	1500	100	1.81 \pm 0.12	0.99 \pm 0.08	0.29 \pm 0.01	187	42	381	192	802	185	95	509	365	159	753
ST4698	714 \pm 32	800	100	1.43 \pm 0.05	1.07 \pm 0.04	0.24 \pm 0.01	163	59	1487	563	2272	722	280	1224	1436	439	2097

Measurements were done on a quantity of about 100 g of sediment with an Ortec high purity germanium detector at the Département de Préhistoire du MNHN, France. The dose rates were calculated using the published tables (Adamic and Aitken, 1998). The water content of the soil has been measured (modern values range from 18% to 25%) and we considered an average water content of the soil equal to 20%.

D_E =equivalent dose; TET=total enamel thickness; RET=remove enamel thickness; Sed=sediment; En=enamel; Den=dentine; D =dose.

Table 2. ESR data for Song Terus samples

For each sample the early uptake (EU) and the linear uptake (LU) ages were determined (Ikeya, 1982). We also calculated coupled the ESR/U-series ages (US model, Grün et al. 1988). This model allows to calculate ages from ESR and U-series data and to determine a diffusion parameter (*p*-value), which indicates the uranium uptake history in each dental tissue.

5. Results and discussion

The U-series results are given in Table 1. The range of the U-content is different in the two teeth, 1.68 ± 0.11 and 4.17 ± 0.27 ppm in enamel and 38.61 ± 0.89 to 65.58 ± 1.06 ppm in dentine for ST3110 and ST4698, respectively. ^{230}Th age correction is not needed due to high $^{230}\text{Th}/^{232}\text{Th}$ ratios which demonstrate that the samples do not contain any detrital ^{232}Th . The uranium concentration in the surrounding sediment is quite the same for each tooth (Table 2). The higher uranium concentration in ST4698 is probably due to its fragmentary state.

The data used to calculate ESR and coupled ESR/U-series ages are given in Table 2. The external dose provided by the sediment is similar for the two samples. The sediment is sandy and quite homogeneous; U, Th and K concentrations are similar. The total internal teeth doses rates (enamel plus dentine) are 55% and 90% of the total, whatever the ESR model. The equivalent dose of ST4698 (714 ± 32 Gy) is much higher than the one of ST3110 (191 ± 12 Gy). This difference may be partly due to the age, as ST4698 was excavated deeper than ST3110 and partly due to the U-concentration in the teeth, which is higher in ST4698.

EU and LU ESR ages are presented in Table 3. The EU ages are 239 ± 28 and 315 ± 35 ka and LU ages 377 ± 45 and 584 ± 64 ka for ST3110 and ST4698, respectively. The EU age of ST3110 about 200 ka, can be considered as the minimal age and is significant concerning the geochronological scale of this sedimentary filling. In both cases, the U-series ages are lower than the ESR-EU ages. The coupled ESR/U-series ages (Table 3) are 254 ± 38 ka for ST3110 and 341 ± 51 ka for ST4698. These lie between the EU and LU ages, close to EU ages. In both teeth, the *p*-values are close to -1 in enamel and lower somewhat (-0.7) in dentine. This indicates early uranium uptake in both dentine and enamel. The difference in U content in the two teeth does not seem to have an influence on the ages, regardless when uranium entered the tooth, before or after the short transport. We can, therefore, consider that the coupled ESR/U-series ages as representing the “real” age of the samples. These ages are coherent and increase with depth. These results indicate that alluvial deposits containing Terus lithic artifacts and mammal fossils remains are dated, considering uncertainties, between 392 and 216 ka in the Song Terus cave.

	EU Age (ka)	LU Age (ka)	Coupled ESR/U-series data		
			<i>p</i> enamel	<i>p</i> dentine	Age (ka)
ST3110	239 ± 28	377 ± 45	-0.958	-0.804	254 ± 38
ST4698	315 ± 35	584 ± 64	-0.958	-0.742	341 ± 51

EU, LU and coupled ESR/U-series ages.

Table 3. ESR ages obtained on the teeth of Song Terus Cave

The ESR ages reported here are consistent with results obtained in other sites in the same area, already dated by U-series on stalagmitic flowstones. Goa Tabuhan, a cave located 200 m from the Song Terus, provided several stalagmitic flowstones discovered in a deep sedimentary filling. Two ages obtained by U-series using α spectrometry, were $189 \pm 30 / -23$ ka and $263 \pm 33 / -25$ ka (Hameau, 2004). The deepest flowstone, sampled at the bottom of the filling and analyzed by mass spectrometry (TIMS) gave an age of 326 ± 9 ka (Sémah et al., 2004). Braholo cave is another widely open cavity, located to

the West of Punung, containing a thick sedimentary filling and anthropic traces (Simanjuntak, 2002). An U-series age close to 250 ka was obtained on a stalagmitic flowstone located in the entrance of the cave (Falguères et al., 1998).

Those results give us an independent age control for the ESR ages and allow us to confirm that the karstic system in this area has been in place from the Middle Pleistocene.

6. Conclusion

The Gunung Sewu area contains thousands of caves, which may contain numerous archaeological prehistoric sites. It is very significant for the study of Indonesian and South-East-Asian prehistory. The Song Terus cave provided us with new chronological markers which lacked in other Eastern Java sites. Coupled ESR/U-series dating provided consistent ages of 254 ± 38 and 341 ± 51 ka for two teeth associated with lithic artifacts. These results confirm the Middle Pleistocene age for the Terus archaeological assemblage. These ages also confirm that the caves in this area were formed at least since 300 ka and may have preserved geological, paleoclimatological and archaeological records from the middle part of the Middle Pleistocene.

Finally, the ages obtained in this study show that the Song Terus sedimentary filling cover the controversial period in Indonesia between the end of *H. erectus* and the first *H. sapiens*, and highlight the interest of the Gunung Sewu karst in South-East-Asian prehistorical research.

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