TECHNICAL RESPONSE

PALEOANTHROPOLOGY

Response to Comment on "The earliest modern humans outside Africa"

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Our original claim, based on three independent numerical dating methods, of an age of ~185,000 years for the Misliya-1 modern human hemi-maxilla from Mount Carmel, Israel, is little affected by discounting uranium-series dating of adhering crusts. It confirms a much earlier out-of-Africa *Homo sapiens* expansion than previously suggested by the considerably younger (90,000 to 120,000 years) Skhul/Qafzeh hominins.

In reply to Sharp and Paces' comments on our recent paper (*1*), we here clarify some points that may have remained unappreciated in our initial work. Sharp and Paces (*2*) claim that Misliya-1 may not be as old [177 to 194 thousand years (ka)] as we argued (*1*). They propose an alternative interpretation for the U-series data we reported on calcitic crusts [table S1 of (*1*)], leading to the calculation of an apparent age of 60 to 70 ka. This age provides a minimum age for Misliya-1, as we also noted in the original paper (*1*). Although their reanalysis appears robust, Sharp and Paces give little credence to the importance of other dating evidence, such as the thermoluminescence (TL) dating of 23 samples from the associated Early Middle Paleolithic (EMP) lithic assemblage of the site (*3*). In this reply, we address (i) the uncertainties and limitations in the isochron U-series analysis of the calcitic crusts, (ii) the comprehensive evidence presented in the original paper for the specimen's antiquity, (iii) the unlikely possibility of later intrusion, (iv) the robust TL dating evidence, and (v) the inappropriate use of the Skhul and Qafzeh hominins to support their claim.

The Misliya-1 crusts were drilled in several locations from adhering lithified sediments above the molars (Fig. 1). The U-series isochron approach requires contemporaneous samples. However, there is layering within the crusts, which shows that they were formed during various wet phases over a longer period of time. Therefore, an isochron approach seems inappropriate. Additionally, although mentioned by Sharp and Paces (but later ignored), the scatter of the points around their regression line is quite large (13%), which may actually indicate a higher true age uncertainty than that reported in their comment.

Sharp and Paces ignore several lines of evidence, all pointing to a similar time range for Misliya-1:

1) All six EMP units in Misliya Cave contain only an Early Levantine Mousterian lithic industry (Tabun D-type). This industry is dated 276 to 140 ka (Fig. 2) on the basis of radiometric data obtained from Misliya (*3*), Hayonim (*4*), and Tabun (*5*).

2) The TL dating of nine burned flints from the upper part of the EMP archaeological layer from squares close to Misliya-1 (N-12, L-10) (Fig. 2) yielded a mean age of 179 ± 48 ka [all errors in this reply are 2σ; raw data from (*3*)]. The somewhat distant square (J-15) exhibited the same TL age range (Fig. 2). The combined mean age for these samples is 185 ± 50 ka (n = 15).

3) Direct dating of Misliya-1 provided a U-series age of 70.2 ± 1.6 ka and a combined U-series and electron spin resonance (US-ESR) age of 174 ± 20 ka. Because uranium uptake may be delayed after the death of the organism, and because it is difficult to accurately evaluate the radiation effects from previous computed tomography (CT) scanning, these two ages should be regarded as the minimum and maximum age brackets for the fossil, respectively. Misliya-1 was CT-scanned three times prior to the ESR dating analysis (*1*). The x-ray dose during CT scanning is highly variable (*6*–*8*). On the basis of our recent study (*7*), we could roughly estimate that the total x-ray dose was approximately 30 Gy, resulting in an effective equivalent dose (D_E) value of 98.3 ± 5.3 Gy. The corresponding US-ESR age would thus be 152 ± 24 ka (i.e., agreeing within error with the TL results). However, considering the significant uncertainty in the true

Fig. 1. The Misliya-1 specimen from a lateral view. The crust under the zygomatic arch was analyzed for U-Th dating. Note the different layers of the crust and the embedded foreign elements (bones and flints) suggesting different depositional episodes.

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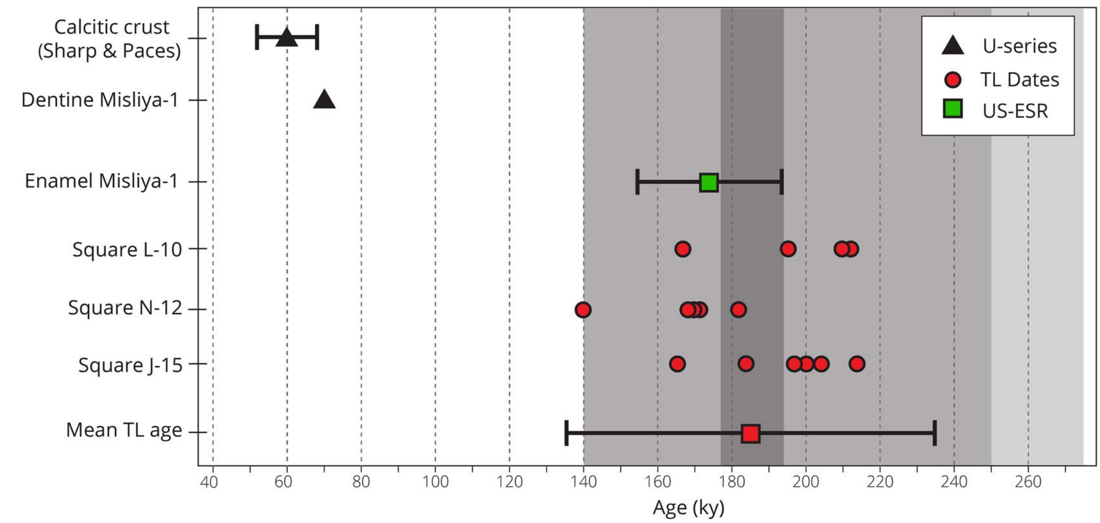

Fig. 2. Overview of the dating results. All errors are 2σ. For clarity, the individual errors on the TL ages (red dots) are not displayed. The combined US-ESR age (green square) should be regarded as a maximum age estimate for Misliya-1 (based on this method). The U-series age carried out on the dentine of the Misliya-1 lateral incisor should be considered as a minimum age estimate of the specimen. The TL ages from Misliya Cave (red dots) from the various relevant squares fall within the boundaries of the EMP period (entire gray-shaded area), as previously determined on the basis of TL data from Tabun Cave and Hayonim Cave (140 to 276 ka) [data from Mercier *et al*. (*4*) and Mercier and Valladas (*5*)]. Intermediate gray marks the EMP boundaries at Misliya Cave (140 to 250 ka) as published by Valladas *et al*. (*3*). The dark gray band marks the dating boundaries for Misliya-1 as published in Hershkovitz *et al*. (*1*) (177 to 194 ka).

x-ray dose absorbed by the tooth sample, regarding the cited date of 174 ± 20 ka as a maximum age is the most straightforward and reasonable interpretation of the combined US-ESR result.

4) The major criticism of Sharp and Paces relates to the U-series dates on the calcitic crusts, specifically to sample #6. The U-series dates were added at the request of one of the reviewers. We were aware of and mentioned the high detrital thorium in these samples and noted that corrections had a large impact on the apparent U-series ages [see table S1 of (*1*)]. The U-series results were therefore presented as additional support for the dates obtained by the other methods. It is worth noting that a crust deposited on a flint from a nearby square from a depth close to that of the maxilla yielded an apparent U-series date similar to sample #6 [table S1 of (*1*), sample #10, ~172 ka]. This sample also had a relatively high detrital thorium content. Even if the original U-series dates are discounted, there is no real impact on the dating of Misliya-1 (Fig. 2).

Sharp and Paces hint at the possibility that Misliya-1 could be much younger than proposed, within the range of the Skhul/Qafzeh fossils (90 to 120 ka). Because the EMP context cannot be younger than 140 ka (see above), this would imply a later intrusion. This was discussed and dismissed (*1*) because there was no evidence for any culture later than the EMP at the site, which was apparently abandoned once the roof of the cave had collapsed.

Misliya-1 was derived from within a clear archaeological context, rich in lithics, animal bones, and well-defined in situ archaeological features (hearths). Detailed taphonomic and geoarchaeological studies (*9*, *10*) also indicate excellent preservation of original features (e.g., plant bedding) and no substantial postdepositional transport. This all suggests that the archaeological layers and the human fossil are coeval.

Sharp and Paces briefly mention the TL ages from Misliya but downplay their importance. The samples closest to Misliya-1 yielded a mean age of 179 ± 48 ka and, combined with other samples in the vicinity, a mean age of 185 ± 50 ka (see above). EMP lithic assemblages were found in two other caves. At Tabun (*5*), three samples from unit IX produced a mean age of 256 ± 52 ka, and two spatially isolated units yielded mean ages of 222 ± 54 ka (n = 4) and 196 ± 42 ka (n = 3). At Hayonim (*4*), layers F and Lower E produced 77 TL ages ranging from 140 ± 32 ka to 251 ± 40 ka. None of the three sites contains any EMP lithic industry younger than 140 ka. As there is no evidence to suggest that Misliya-1 is intrusive, we reasonably conclude that the mean TL age of 185 ± 50 ka provides a reliable indirect age estimate for this specimen.

Sharp and Paces present the ages of the Skhul and Qafzeh hominins (90 to 120 ka) as supportive evidence for a possible younger age for Misliya-1. The EMP of Misliya Cave, with its abundant blades and typical long Levallois and non-Levallois points (*11*), is distinctly different and stratigraphically older than the Middle Paleolithic found at Skhul and Qafzeh. The fact that there are other hominins dated to other time ranges in the area has little bearing on the age of Misliya-1.

The study of Sharp and Paces does not contradict our chronology for Misliya-1 (*1*). Although their reinterpretation of the apparent U-series ages on the calcitic crusts may be sound, the resulting minimum age of ~60 to 70 ka is neither new (it was already discussed in the original paper) nor incompatible with the other chronological data available (Fig. 2). Several lines of evidence, including direct dating of the specimen, the EMP lithic industry, and the TL dates, clearly support an early date for Misliya-1 of at least 140 ka, and most likely around 185 ka, consistent with our original conclusions.

REFERENCES AND NOTES

1. I. Hershkovitz *et al*., *Science* **359**, 456–459 (2018).
2. W. D. Sharp, J. B. Paces, *Science* **362**, eaat6598 (2018).
3. H. Valladas *et al*., *J. Hum. Evol.* **65**, 585–593 (2013).
4. N. Mercier *et al*., *J. Archaeol. Sci.* **34**, 1064–1077 (2007).
5. N. Mercier, H. Valladas, *J. Hum. Evol.* **45**, 401–409 (2003).
6. R. Grün, S. Athreya, R. Raj, R. Patnaik, *Archaeol. Anthropol. Sci.* **4**, 25–28 (2012).
7. M. Duval *et al*., *Quat. Geochronol.* **47**, 120–137 (2018).
8. M. Duval, L. Martín-Francés, *Am. J. Phys. Anthropol.* **163**, 205–212 (2017).
9. M. Weinstein-Evron *et al*., *Paleoanthropology* **2012**, 202–228 (2012).
10. R. Yeshurun, G. Bar-Oz, M. Weinstein-Evron, *J. Hum. Evol.* **53**, 656–677 (2007).
11. Y. Zaidner, M. Weinstein-Evron, *Before Farming* **2012**, 1–23 (2012).

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