TECHNICAL COMMENT

PALEOANTHROPOLOGY

Comment on "U-Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art"

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Hoffmann *et al*. (Reports, 23 February 2018, p. 912) report the discovery of parietal art older than 64,800 years and attributed to Neanderthals, at least 25 millennia before the oldest parietal art ever found. Instead, critical evaluation of their geochronological data seems to provide stronger support for an age of 47,000 years, which is much more consistent with the archaeological background in hand.

Hoffmann *et al.* (*1*) announced the discovery of parietal art older than 64,800 years (64.8 ka). This would represent the first and only concrete evidence for such expressions in Neanderthal society. Previous U-Th dates propose to link parietal art and Neanderthal groups (*2*) from evidence of a red disc from El Castillo cave covered by calcite aged 40.8 ka. However, in that part of Cantabrian Spain, this date falls within the Aurignacian time scale and so could be associated with anatomically modern humans (AMH) (*3*, *4*). Applying U-Th dating from tiny efflorescences of calcites is a relatively recent development in archaeology (*2*); the method still has challenges and limitations.

Before the Hoffmann *et al.* paper, the world's oldest parietal art was placed around 36 to 40 ka. Proposing a minimal age of 64.8 ka indicates a very early origin for art. This is in itself not a problem, but the lack of parietal traces for more than 25 subsequent millennia raises questions, given the rich abundance (tens of thousands of recorded examples) of more recent Paleolithic parietal art. Why would parietal art simply become invisible for such a long time, with no plausible anthropological explanation?

The proposition of the discovery of a parietal art at such an age represents a bold claim and so requires careful confirmation of the reliability of the chronology. There is no doubt about the quality of the Hoffmann *et al.* U-Th analyses. The measured isotope ratio data are of state-of-the-art quality, and the corrections applied to the age calculation are within the typical range for these kinds of studies. A question remains, however: Are those corrections sufficient to produce robust ages, or do we find indications in the data that point toward biases in some of the calculated ages as the method reaches its limits?

The authors deserve credit for devising and applying the sequential sampling technique that tests for preservation of stratigraphic order in essentially every date published from the caves. We take a very conservative approach and cast doubt on a few of the oldest ages, not because there is evidence that they are inaccurate, but because there is not positive proof they are correct. Analyzing the U-Th data presented in that study, we do see strong support for an age of ~47 ka, but less for the ~65 ka age limit stated by the authors.

What is critical to obtain reliable ages for carbonates based on U-Th data?

1) Sample preservation/"closed system": The carbonate has not been altered in any way after its formation. Such alterations (e.g., diagenesis/recrystallization) have been found to promote a preferential loss of uranium (*5*, *6*), which would make a sample appear older.

2) Correction for nonradiogenic ^{230}Th: The second point addresses the common problem that not all the ^{230}Th measured originates from the ^{234}U decaying since the carbonate formed. This so-called "nonradiogenic" ^{230}Th is incorporated at the time of formation. If not corrected for, the sample again would appear to be older than it truly is. The two major sources of "nonradiogenic" ^{230}Th are the detrital fraction and ^{230}Th in the source water forming the carbonate. For the detrital fraction, the assumption of secular equilibrium of the ^{238}U decay chain nuclides involved (^{238}U, ^{234}U, and ^{230}Th) is typically made. The amount of detritus is estimated via ^{232}Th (not affected by the ^{238}U decay chain) and a correction factor representing the ^{238}U/^{232}Th ratio in the detrital fraction.

To evaluate the robustness of reported ages, we plot the corrected ages versus the activity ratio ^{232}Th/^{234}U (Fig. 1) of the samples overlying the respective pigment layers (minimum ages in table 1 of Hoffmann *et al.*). Although it is more common to use ^{232}Th/^{238}U, we consider ^{232}Th/^{234}U to be more appropriate in this case because of the differing initial ^{234}U/^{238}U ratios and the fact that for the anticipated age range, ^{234}U (i.e., the immediate parent nuclide of ^{230}Th) is the better representation. Because the corrections explained are based on ^{232}Th, the lower the amount of ^{232}Th found in a sample relative to the nuclides of the radiometric clock, the smaller the impact of any ^{232}Th-based correction on the age estimate. Conventionally, a value of ~0.005 (based on a ^{238}U/^{232}Th ratio of ~200) is considered to be the upper limit for highly reliable ages. Additionally, a high ^{238}U/^{232}Th ratio supports, but does not guarantee, the assumption of closed-system behavior, as it makes strong uranium loss appear less probable.

In Fig. 1, we find most of the Ardales samples meeting the criterion of low ^{232}Th/^{234}U clustering closely (highlighted by the green ellipse), indicating an upper limit of minimum carbonate formation age of ~47 ka. This age is additionally supported by the lower limit of maximum age

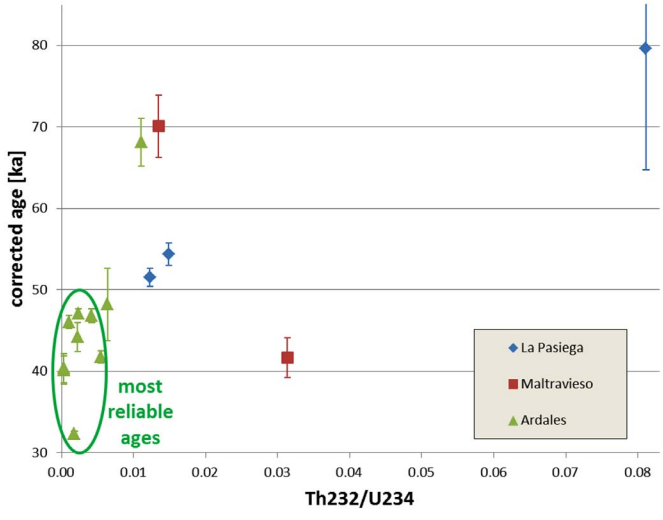

Fig. 1. Minimum U-Th age data from Hoffmann *et al*. (*1*) versus the activity ratio ^{232}Th/^{234}U, taken as age reliability indicator. Higher ^{232}Th/^{234}U ratios increase the impact of ^{232}Th-based corrections on the calculated age. All uncertainties are at 95% confidence level.

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estimated (47.6 ka) from carbonate underneath the pigment layer. The one older-appearing sample (68.1 ka) has a higher $^{232}Th/^{234}U$ ratio. It is accompanied by another sample from the exact same site dated at 47.1 ka, which by contrast meets the $^{232}Th/^{234}U$ reliability criterion. Thus, we consider a minimum age of ~47 ka very well constrained by dating of multiple samples. For now, any older limit for a minimum age solely depends on the robustness of the one sample dated 68.1 ka. Although it is entirely possible that the sample is providing a correct age estimate, we also need to consider that a single sample standing out from a larger group could indicate problems of this sample's preservation ("open system").

The three La Pasiega PAS34 subsamples have elevated $^{232}Th/^{234}U$ relative to the cluster of Ardales samples considered most reliable. Additionally, $^{230}Th/^{234}U$, the activity ratio carrying the chronological information, is correlated to $^{232}Th/^{234}U$; that is, the subsamples are becoming older with increasing $^{232}Th/^{234}U$, indicating possible varying contributions of nonradiogenic ^{230}Th. The authors test different correction factors in their supplementary materials. The age presented in the main text has been obtained using the lowest correction factor (0.8). When applying a slightly higher correction factor (2.0), the age estimate for sample PAS34c is shifted from 79.7 ± 14.9 ka toward 69.9 ± 25.2 ka.

Alternatively, we could consider the whole PAS34 calcite to have been formed in a relatively short period. The trend of $^{230}Th/^{234}U$ versus $^{232}Th/^{234}U$ could be interpreted as a mixing line between the radiogenic and nonradiogenic ^{230}Th phases. Extrapolating toward the radiogenic endmember ($^{232}Th/^{234}U = 0$) results in a combined age of <50 ka for all three subsamples of PAS34, with a nonradiogenic end-member $^{230}Th/^{232}Th$ between 2.2 (based on $^{238}U/^{232}Th$) and 2.8 (based on $^{234}U/^{232}Th$). This correction value is higher than the "bulk earth" value of 0.8 used by the authors, but is still lower than what has been used, e.g., for the Maltravieso samples (3.3 ± 0.2 based on measurements of local sediments). The low $^{238}U/^{232}Th$ ratio (3.6) and the strong impact of the applied correction both challenge the age estimated for sample PAS34c. The exact age calculated for PAS34 depends on the correction applied, allowing for a range of approximately 47 to 54 ka.

Like the La Pasiega PAS34 samples, those from Maltravieso also display elevated $^{232}Th/^{234}U$ ratios. The range of ages obtained for Maltravieso (supplementary materials of Hoffmann *et al.*), while sampled at close proximity to each other, challenges the reliability of the MAL13A age estimate of ~70 ka. It is a single sample standing out from a larger group of samples providing highly reliable ($^{232}Th/^{234}U < 0.005$) and younger ages. Again, we cannot prove that the sample MAL13A has been altered to appear older ("open system"), nor can we clearly rule out such a scenario.

It is noteworthy that Maltravieso and La Pasiega, which appear as the less reliable in terms of U-Th measures, represent the oldest and also archaeologically the only true parietal expressions of graphic categories that have direct comparisons with classic Upper Paleolithic parietal expressions, whereas Ardales concerns speleothems simply covered with red deposits, with no representation. Closer analyses of these red deposits will be needed to demonstrate their anthropogenic origin. If anthropogenic, these parietal deposits would then represent the strongest and oldest evidence for a parietal "art." At the Ardales chronology, ~47 ka ago, there is no anthropological evidence of AMH in the Iberian Peninsula and more largely in Europe. Only two transitional Paleolithic industries—the Bohunician from Bohunice in central Europe (*7*) and the Neronian from Mandrin in Mediterranean France, dated ~50 ka (*3*)—could possibly reveal an earlier AMH presence in Europe, but they have provided for the moment no hominin remains. In that context, Ardales might well indicate that in a more recent period than stated by Hoffmann *et al.*, some late Neanderthal societies may well have produced some parietal traces.

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