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News and Views

Still no archaeological evidence that Neanderthals created Iberian cave art

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1. Introduction

Based on uranium-thorium (U-Th) dating of calcite deposits overlying paintings in three Spanish caves, Hoffmann et al. (2018a) have proposed that a rectangular sign at La Pasiega (Cantabria), hand stencils at Maltravieso (Cáceres) and red traces on stalagmites at Ardales (Málaga) are at least 65,000 years old. Consequently, the authors claim Neanderthal authorship of the first parietal art in Europe. This proposition is alarming to many archaeologists (Aubert et al., 2018a; Pearce and Bonneau, 2018; Slimak et al., 2018; but see Hoffmann et al., 2018b, c), due to the multiple sources of error inherent in this dating method, notably the leaching of uranium resulting in an overestimation of sample ages (Borsato et al., 2003; Plagnes et al., 2003; Ortega et al., 2005; Scholz and Hoffmann, 2008; Pigeaud et al., 2010; Bajo et al., 2016; Valladas et al., 2017a). The possible overestimation of the U/Th dates is not discussed in Hoffmann et al. (2018a). Instead they considered that a correct stratigraphy is enough to prove a closed system because “it is highly unlikely that leaching of U or incorporation of Th would simultaneously affect all of its layers” (Hoffmann et al., 2016b:110).

The results presented by Hoffmann et al. (2018a) are especially troubling since they contradict more than one hundred years of research observations on the Neanderthal and modern human archaeological record. The authors seem to abandon that whole body of archaeological knowledge and reasoning, instead placing all their trust in physicochemical measurements. This approach is puzzling given that certain of the coauthors have previously railed against “the interpretative abuses derived from the uncritical application of ‘hard science’ analytical methods to the study of the Palaeolithic rock art phenomenon” (Alcolea-González and González-Sainz, 2015:1). While absolute dating methods have certainly modified some of our ideas about the chronology of rock art in Europe, the application of these methods (including U-Th dating) is not without problems.

The reasoning underlying this newly published research mirrors that of Pike et al. (2012), which provoked many doubts (Clottes, 2012; Bednarik, 2012; Pons-Branchu et al., 2014; Sauvet et al., 2017a; but see Pike et al., 2017). Of the 54 samples dated by Pike et al. (2012) fully two-thirds fall in the Holocene, not surprising given that calcite is deposited in humid periods, often long after the act of painting. Only one-third of the samples yield Upper Paleolithic dates, and only one (minimum age 40.8 ka for a red disk at Castillo) might possibly correspond to the late Mousterian, leading the authors to state that “it cannot be ruled out that the earliest paintings were symbolic expressions of the Neanderthals” (Pike et al., 2012:1412). From a large number of widely dispersed dates, only the oldest is selected to justify the claim for a pre-Upper Paleolithic origin for cave painting.

Hoffmann et al. (2018a) retained only the date of 64.86 ka for La Pasiega, chosen from among 20 much more recent dates (Table 1; Fig. 1). No consideration is given to the possibility that this outlier date could be due to uranium leaching resulting from local hydrological conditions.

Hoffmann's et al. (2018a) have very little discussion of the archaeological data that contradict their results. This led us to undertake a review of the totality of available data, focusing in particular on rectangular signs and hand stencils. To avoid distraction, we leave aside the question of Neanderthal symbolic and cognitive capacities in favor of a close examination of archaeological and geophysical facts and observations. It goes without saying that if the ca. 65 ka date is spurious, the claim for Neanderthal authorship dissolves, exclusive of whether Neanderthals were capable or not of such behavior.

2. Discussion

2.1. Cases of open system

Thin layers of calcite in wet environments can behave as an open system, either continuously or periodically, implying a loss of uranium and an overestimation of the calculated ages. An example was provided by Scholz and Hoffmann (2008) in the study of a flowstone in an Austrian cave (see Supplementary Online Material [SOM] S1 and Fig. S1) and a similar case was found for a fractured stalagmite in Maltravieso (MAL 24, Hoffmann et al., 2018a; see SOM S1 and Fig. S2). The uptake of detritic thorium or the transformation of aragonite in calcite (Lachniet et al., 2012; Bajo et al., 2016) may also be the reason for an overestimation effect (SOM S2).

In most cases, it is difficult to assert whether opening of the system occurred or not. Even the observation of a strict stratigraphic order of the ages of various subsamples does not prove that the ages are right. Indeed, if uranium loss occurs regularly with time, the outer layers have less time to lose uranium. They are less

Table 1
Calcite crusts dated by U/Th in La Pasiega Cave after Pike et al. (2012) and Hoffmann et al. (2016a, b, 2018a). Most of the dates are Holocene, a few are Upper Paleolithic and only one corresponds to the Middle Paleolithic (Neanderthal).

Sample	Gallery	Age (ka)	Underlying motif
O-101	C	0.73 ± 0.14	red bovid
PAS-35	C	1.12 ± 0.04	red acephalous deer (78 left)
O-103	B	1.706 ± 0.023	red megaloceros
PAS-38	C	2.16 ± 0.09	lines of points (superior 78)
O-109	B	2.258 ± 0.013	undetermined figure
O-106	B	2.523 ± 0.017	undetermined figure
PAS-33	C	3.07 ± 0.05	right side of rectangle (78)
O-107	B	3.307 ± 0.055	red bison
O-108	B	3.342 ± 0.029	red bison
O-105	B	3.967 ± 0.027	red horses
PAS-29	C	4.10 ± 0.06	yellow zoomorph (above PAS-31)
O-110	B	4.34 ± 0.044	red horse
PAS-07 (O-73)	C	4.585 ± 0.022	red triangle (idem PAS31)
O-102	C	5.323 ± 0.078	black ibex
PAS-37	C	5.39 ± 0.06	rectangle (76)
O-76	B	5.615 ± 0.116	red claviform
PAS-02 (O-98)	C	7.107 ± 0.044	red dot (idem PAS 32)
PAS-39	C	7.54 ± 0.05	rectangle (72)
O-74	C	8.732 ± 0.085	yellow double arch
O-100	C	8.924 ± 0.063	red deer
PAS-30	C	11.70 ± 0.1	red horse (75)
PAS-31	C	11.80 ± 0.2	red triangle (75 right)
O-97	C	11.89 ± 0.45	red deer
PAS-03 (O-99)	C	12.58 ± 0.14	line of points (lower 78)
PAS-32	C	13.2 ± 0.1	lines of points (75 left)
PAS-36	C	17.70 ± 0.34	red acephalous hind (82)
O-72	C	18.47 ± 0.1	red triangle (idem PAS-28)
PAS-28	C	22.90 ± 0.2	red triangle (75)
PAS-34	C	79.66 ± 14.9 (mini 64.8)	left side of rectangle (78)

affected by the aging and appear younger than the inner layers, which preserve the stratigraphy.

Another difficulty is the sampling procedure to be used. Aubert et al. (2014) in Indonesia cut a section through the calcite up to the bedrock and then dated in the laboratory very thin layers (<500 μm) successively excavated in the core sample. This is the best way to be sure to date the carbonate layer just overlying the paint. The technique used in La Pasiega cave (Hoffmann et al., 2018a), consisting of digging subsamples, without controlling for orientation and geometry, gives only mean values and does not prove that paint was present below the concretion. Importantly, Aubert et al. (2018a: Fig. 1D) reported cases in which calcite was already present when an artist painted over and weathering has since removed the paint. In this case, the age of the calcite might indeed be much older than the painting.

2.2. Current archaeological knowledge

We know from archaeostratigraphy and the many dates obtained by various techniques (^{14}C, thermoluminescence [TL], optically stimulated luminescence) that the ‘transition’ from Neanderthals to modern humans took place over a few millennia. In Western Europe, the latest Mousterian dates fall between 41 and 39 ka cal BP (Higham et al., 2014) and the oldest dates for the Aurignacian are between 43 and 41 ka cal BP at Geissenklösterle in the Swabian Jura (Higham et al., 2012). In the Southern Iberian Peninsula, the ‘transition’ is probably prior to 42 ka cal BP (Wood et al., 2010).

This chronological scheme, based on the most recent dating by ^{14}C, may well be refined and modified as radiocarbon techniques progress. Nonetheless, in the current state of knowledge, U-Th dates obtained in such fashion are far too sensitive to causes of error to cast doubt on the archaeological knowledge based on hundreds of stratified sites and absolute dates obtained over decades of research (Petrognani, 2013). Today, there exist more than 130 direct ^{14}C dates for paintings in decorated caves and shelters. None of them are older than 38 ka, even though ^{14}C dating is now able to reach back to 50 ka BP (Cottereau et al., 2007). Clearly, if such pre-40 ka BP radiocarbon ages were published, they would have to be taken as suggestive of Neanderthal authorship.

The symbolic practices of Neanderthals are exceedingly rare and often ambiguous. One may cite incised lines on bone (Lorblanchet, 1999; for a synthesis for Eastern Europe see Majkić, 2017), the engraving on limestone, possibly dating to the Mousterian, at Gorham's Cave (Rodríguez-Vidal et al., 2017), and digital flutings at La Roche-Cotard Cave (Marquet et al., 2014). Neanderthals occupied Bruniquel Cave (Tarn-et-Garonne, France) building complex structures of stalagmites, but leaving no trace of graphic activity (Jaubert et al., 2016).

No Mousterian site has revealed anything comparable to the figurative art that develops around 40 ka in the Swabian Jura (Floss, 2017), around 36 ka at Chauvet Cave (Quiles et al., 2016), and around 38 ka in the Vézère Valley of SW France (White et al., 2012, 2018; Bourrillon et al., 2018). There is broad consensus that “figurative art starts at the time that modern humans people the planet” (Lorblanchet, 1999:265). An ‘artistic explosion’ took place in Europe near 40 ka (White, 2000). Any remaining doubt concerns a very short period from roughly 42–40 ka, when the last Mousterians (Neanderthals) seem to have coexisted with the first Aurignacians, though there is no known interstratification (Bar-Yosef and Bordes, 2010).

2.3. The red-stained stalagmitic draperies of Ardales

In Ardales Cave (Málaga, Spain), red marks in the folds of a stalagmitic column were dated to between 65 and 40 ka by U-Th (Hoffmann et al., 2018a). According to the authors, these correspond to an initial prefigurative phase in prehistoric cave art such as they had already proposed for Castillo Cave (Pike et al., 2012). This would assume a limited symbolic capacity for Neanderthals.

At Ardales, the wide range of dates found by U-Th on the same stalagmitic column is seen by the authors as evidence of “distinct episodes over a period of more than 25 ka […] with a long tradition” (Hoffmann et al., 2018a:915). The hypothesis of erroneous dates seems to us far more likely.

In addition, it is not sure that these red stains are really paintings since they could be natural (Aubert et al., 2018b) or result from involuntary gestures (Medina-Alcaide et al., 2017). The case is different in Nerja (Málaga, Spain) where red-stained stalagmitic draperies are clearly associated with animals, such as a red deer doe and an ibex in the recess called Los Órganos. The floor of this narrow space is dated by ^{14}C to 24,140 ± 140 (28,182 ± 181 cal BP; Beta-277744; Sanchidrián Torti et al., 2013).

2.4. The place of La Pasiega in the archaeology of rectangular signs

More than 20 U-Th dates were obtained for La Pasiega. Most are Holocene, some corresponding to the Upper Paleolithic, only one is older (Table 1; Fig. 1). A minimum age of 65 ka was obtained for the left side of a large rectangular sign on panel 78 in La Pasiega C (PAS 34c), while the right side of the same rectangle yielded a date of less than 3.1 ka (Fig. 2). Moreover, the age of the outermost layer of sample PAS 34a is 50.5 ka, little different from that of the deepest layer (64.8 ka). Why would growth stop at 50 ka when most of the nearby concretions in the same panel started their growth after 12 ka? We know that “speleothem growth can be affected by several highly localized factors” (Aubert at al., 2018a:215), but this argument cannot be put forward in place of a geomorphological and hydrological study that could explain how a concretion that has

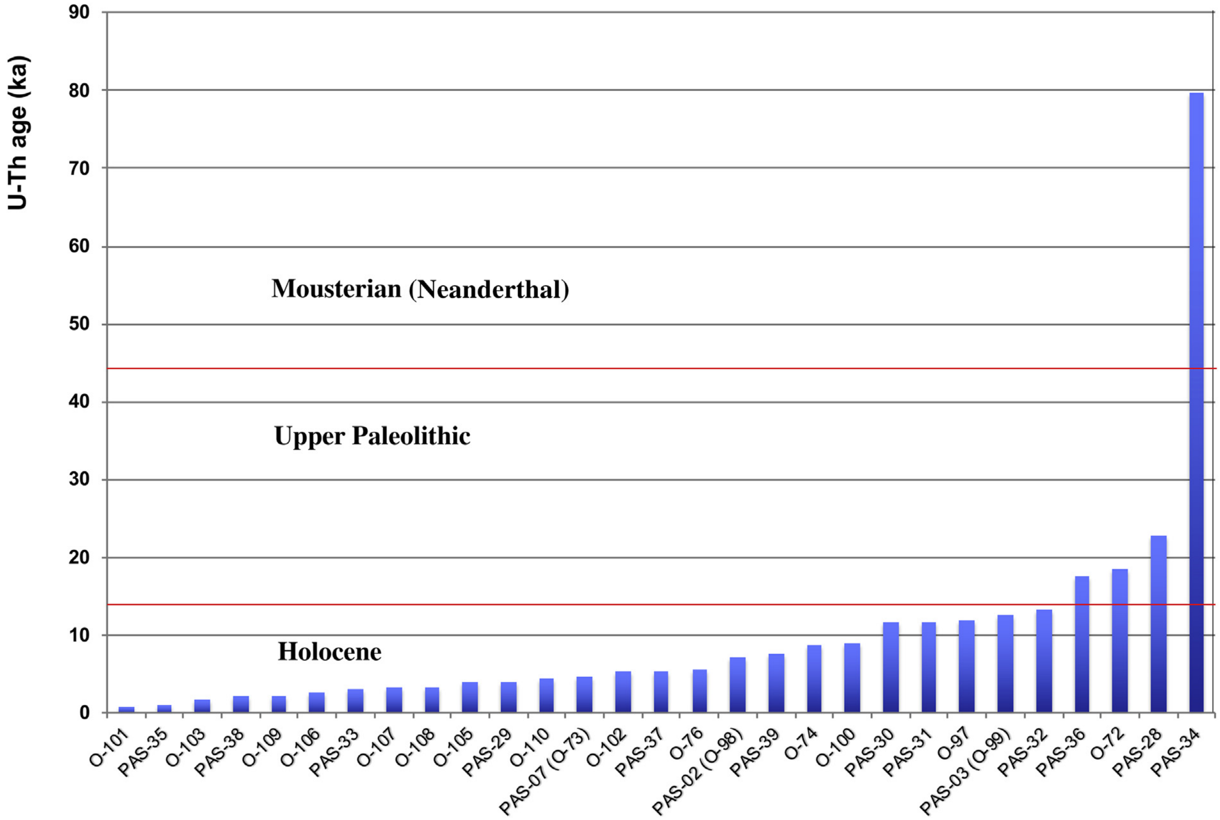

Figure 1. U-Th dates from La Pasiega Cave in chronological order. The graph shows the exceptional character of the date of 79.66 ± 14.9 ka (minimum age 64.8 ka) among other dates from the Holocene or Upper Paleolithic. The hypothesis of an open system is the most probable explanation.

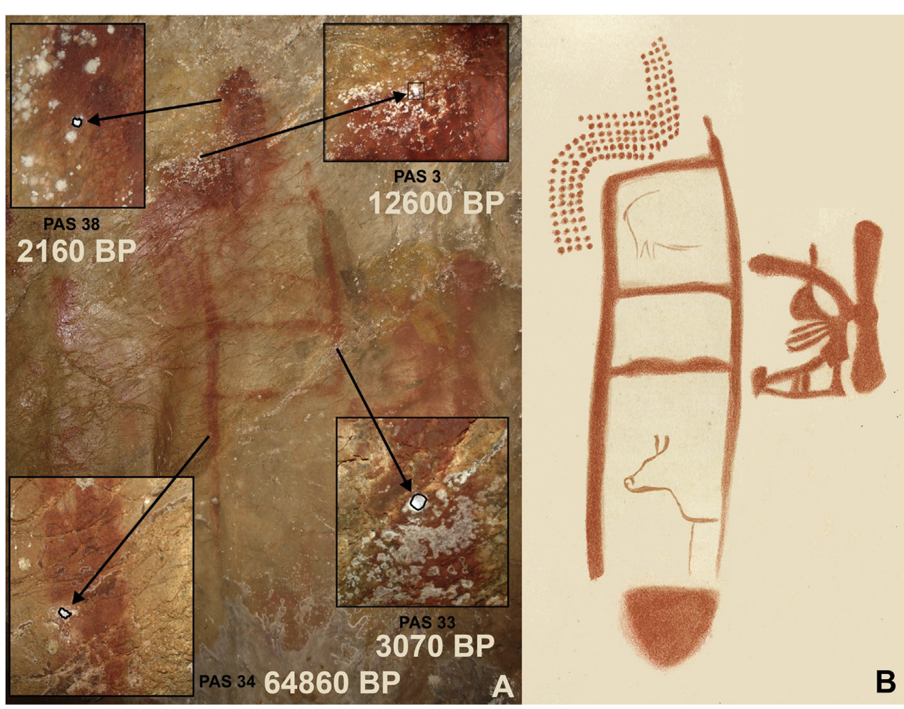

Figure 2. A) Panel 78 at La Pasiega C with four U-Th dates reported by Hoffmann et al. (2018a). Note the discrepancy between the left side and the right side of the same rectangle. B) Tracing by Breuil et al. (1913).

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exactly the same aspect as those surrounding it, could be so much older than the others.

Is the date of 65 ka reliable in the light of current archaeological knowledge? Rectangular signs constitute a highly diverse family of forms present in all of Franco-Iberia. Statistical analysis allowed Sauvet et al. (2017b) to distinguish a group characterized by a tripartite division of the sign. Available dates situate most of these tripartite signs in the Magdalenian. Those from Altamira have been directly dated by ^{14}C to 15,440 ± 200 (18,699 ± 219 cal BP; GifA-91185), and those from Las Chimeneas Cave in the same hillside as La Pasiega, to 13,940 ± 140 (16,899 ± 231 cal BP; GifA-95230) by dating of a line in the panel of quadrilaterals. Clearly, sign 78 from La Pasiega C belongs to this category of signs.

A complete study of this panel (Fig. 2) is required before accepting that it was made by Neanderthals. A study of all the anthropogenic marks should be undertaken according to the current methods of rock art study (Fritz and Tosello, 2007) in order to determine the techniques and the sequence of lines. Such work must be accompanied by a hydrological and geomorphological study to reconstruct the whole history of the wall before and after the paintings. Accordingly, we could know whether the incomplete zoomorphs inside the quadrilateral were made prior to the frame around them as suggested by the first investigators (Breuil et al., 1913). Such knowledge is essential to testing the hypothesis of a Neanderthal work. Indeed, if Breuil et al. (1913) were right and if the Hoffmann et al. (2018a,b,c) date is accepted, Neanderthals would be the authors of the first figurative art, contrary to the claim that their art was "a restricted and nonfigurative set of subjects" (Hoffmann et al., 2018a:914). We emphasize, however, that Upper Paleolithic rectangular signs are frequently associated with animals (Fig. 3). In this same gallery of La Pasiega C, Magdalenian works are found: a bison and an ibex, both black, were dated respectively to 12,460 ± 160 (14,626 ± 308 cal BP; GifA-98165) and 13,730 ± 130 (16600 ± 211 cal BP; GifA-98166). If one supposes that the incomplete animals were drawn by *Homo sapiens* long after the rectangle, we would have to accept a time lag of 45–50 kyr between the tripartite quadrangular sign made by Neanderthals and the addition of the small animals by modern people. In sum, a single isolated date, detached from its archaeological context, leads to the most unlikely of interpretations.

2.5. *Negative handprints in the archaeology of Franco-Iberian caves*

The chronology of known negative handprints has been well established (Jaubert, 2008; Feruglio et al., 2011; Floss and Ostheider, 2013). Most of them can be assigned to the Gravettian period between 25 and 31.5 ka (SOM S3; SOM Table S1). Some of them have been directly dated by ^{14}C (Cosquer Cave, France) or by the dating of associated artifacts (Gargas Cave, Pech-Merle Cave). At La Fuente del Trucho (Spain), the calcite overlying negative handprints has been dated by U-Th and gave minimum ages ranging between 25.11 and 27.37 ka, compatible with the Gravettian (Hoffmann et al., 2016a:53). In this case, the results completely match the archaeological evidence, reinforcing their credibility.

A dozen hand stencils have also been found, from Northern France (the Grande Grotte d'Arcy) to Southern Spain (Ardales), within an archeological context that confirms a Gravettian origin for most of them (22.34–30.16 ka BP, i.e. 26.665 to 34.29 ka cal BP; SOM Table S2). This large and coherent sample of temporal data for negative handprints shows a relatively well defined chronological range.

At Maltravieso Cave, the U-Th dating of five samples of calcite obtained within a perimeter of 5 cm around a negative hand gave very dispersed minimum ages ranging from 14.7 to 55.2 ka and 66.7 ka for two of them (Hoffmann et al., 2018a). These dates are argued by these authors to support the attribution of the hand stencil to Neanderthals. It is noteworthy that some handprints in Maltravieso present foreshortened fingers, a particularity that is only known from the Gravettian caves of Gargas and Tibiran on the French side of the Pyrenees, and from La Fuente del Trucho and Cudón on the Spanish side.

It is noteworthy that hand stencils have also been found on Sulawesi Island and Borneo (Indonesia) and dated by U-Th to ca. 40 ka (Aubert et al., 2014, 2018b). The microstratigraphy of layers less than 500 μm thick in good stratigraphic order allows us to be confident that the calcite behaves as a closed system in this case. The Indonesian hand stencils are attributed to early *H. sapiens* (Curnoe et al., 2016).

2.6. *The need to confirm U-Th dates by other methods*

In order to control for postdepositional alteration of calcite veils, it is essential to apply independent dating methods to the same

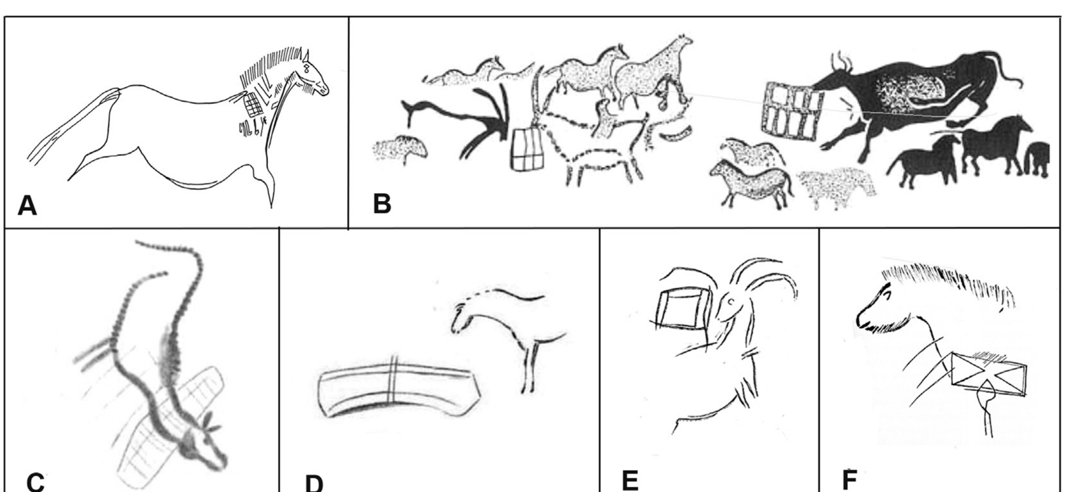

Figure 3. Examples of animals associated with rectangular signs. A) Lascaux (after A. Glory in Leroi-Gourhan and Allain, 1979); B) Lascaux (after Ruspoli, 1987); C–D) La Pasiega A (after Breuil et al., 1913); E) Gabillou (after Gaussen, 1964); F) Cosquer (after Clottes et al., 2005).

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samples (Pons-Branchu et al., 2014; Sauvet et al., 2017a). Experiments consisting in combining U-Th dating with ^{14}C dating of the same carbonate have recently been carried out by the Laboratory of Climatic and Environmental Sciences at Gif-sur-Yvette (France) in Nerja cave (Spain; Quiles et al., 2014; Sanchidrián et al., 2017; Valladas et al., 2017a). There, in the case of a thin layer of calcite overlying a red dot, the authors found a U-Th age between 60 and 56 ka (depending on the initial $^{230}Th/^{232}Th$ detrital value used) whereas the ^{14}C age varied from 33,769 to 27,491 cal BP, depending on the level of dead carbon used in the calculation (see SOM S4). Thus, the difference between the two methods is at least 22 kyr, which implies an important loss of uranium. Moreover, the U-Th date falls outside the Upper Paleolithic. If the authors had only used U-Th dating, they might have concluded that Neanderthals created the first drawings in Nerja.

The reliability of the method is shown by a second experiment carried out in the same cave of Nerja. In this case, the two methods are in good agreement, showing that no uranium loss occurred. Indeed, ^{14}C cannot be used alone to determine a minimum age for the underlying painting because of the uncertainty on the dead carbon fraction, but it is a good way to detect open systems. In our opinion, U-Th results can be useful as long as they are validated by an independent method. In the absence of such confirmation, results remain unconvincing.

The use of a third element, protactinium (Pa), has been suggested to test whether the system had been partially open. More complicated to apply in the current state of the technique, the U-Th-Pa system could nonetheless offer, in the future, an effective means of evaluating uranium loss or gain over the history of the material being dated (Cheng et al., 1998; Dickin, 2018).

An additional possibility is to couple U-Th and TL dating. At La Garma (Cantabria, Spain) a strand of calcite overlying a red ibex was dated by these two methods (González Sainz, 2003). Three U-Th dates range between 26 and 28 ka, while TL gives an age of 34.2 ± 3.85 ka. As in the case of ^{14}C, the precision of TL is mediocre due to the difficult estimation of annual dose rates, so that the method cannot be used alone, but it could help to detect cases of open system.

3. Conclusions

Five conclusions can be drawn.

(a) As many studies have shown, U-Th results are sensitive to lixiviation of part of the uranium, leading to an overestimation of age. This possibility should be evaluated by all available means (hydrogeology, mineralogy) prior to sampling.
(b) Awareness of this important source of error imposes a protocol by which the U-Th values obtained, in order to be credible, must be cross-checked with other independent methods, and whenever possible with the results obtained on the same sample by other laboratories. In addition, to be sure that no uranium loss occurred, the stratigraphic order of the subsamples should be established by a sufficiently refined procedure (i.e., microstratigraphy of layers <500 μm).
(c) Under no circumstances should minimum ages as old as 65–70 ka be accepted for works of parietal art on the sole basis of U-Th dates on overlying calcite. Such dates are in contradiction with abundant archaeological data, now rigorously dated by ^{14}C.
(d) Archaeological context and reasoning need to be part of the process. A close reading of archaeological panels being dated should give pause to claims, such as that for La Pasiega, where two opposing sides of the same geometric form are accepted as giving minimum ages 60,000 years apart, in the absence of a geological explanation for this anomaly.
(e) In each case, geomorphological and paleoclimatic studies must accompany such U-Th based claims of great antiquity in order to account for the possible hiatus of calcite growth and the apparent discrepancy in the ages of closely located concretions.

Given the causes of error now demonstrated by numerous studies, and awaiting new results obtained by other methods, the claimed dates in the vicinity of 65 ka for prehistoric paintings in the Iberian caves, and consequently their attribution to Neanderthals, should be treated with extreme caution. Known sources of error can and often do result in dramatic overestimation of U-Th ages, making it both premature and scientifically unjustifiable to undertake a profound revision of the history of humanity and the evolution of symbolic graphic expressions based solely on such dates.

The paleoanthropological stakes are high. Art is intimately dependent on the sociocultural context in which it is produced. So far, we have no proof that Neanderthal society needed a long-lasting means of communication to consolidate its values and beliefs. A high degree of chronological certainty is required if that view is to be falsified. In short, there is still no convincing archaeological evidence that Neanderthals created Iberian cave art.

Supplementary Online Material

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Supplementary Online Material:

Still no archaeological evidence that Neandertals created Iberian cave Art

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SOM S1

Sampling issues, microstratigraphic discrepancies and the problem of open systems

In most cases, the samples used for U-Th dating are taken from the center of large stalagmites. Accordingly, the required assumptions (absence of ^{230}Th at initial time and a system remaining closed after calcite precipitation) are generally met. The dates appear stratigraphically coherent along the axis of growth (see for example Lauritzen and Lundberg, 1999). However, many cases have been reported for which calcite behaves as an open system, whether it be stalagmites, stalagmitic floors or small 'cauliflower' structures. Open systems result in uranium lixiviation due to the latter's water solubility and lead to overestimation of the calculated ages based on the $^{230}Th/U$ ratio.

The best way to show that the system remained closed is to observe a strict stratigraphic order of various subsamples. This can be achieved by sawing a core sample through the calcite and then to microexcavate it by successive layers less than 500 µm thick as done by Aubert et al. (2014) in Indonesia. To cut a section through the calcite up to the bedrock is the only way to be sure that the paint is underneath the calcite. However, the technique used in La Pasiega cave (Hoffmann et al., 2018), consisting in scraping several-millimeters-thick samples, without controlling for sample orientation and geometry, does not exclude the possibility that calcite was already present before the artist "painted over and weathering has since removed paint" (Aubert et al, 2018a). The apparent stratigraphic order found in La Pasiega cave for subsamples PAS 34 (79.66 ± 14.90 ka for the most inner sample and 51.56 ± 1.09 ka for the outer sample) might be indicative of such an effect. Moreover, sample PAS 34c is highly contaminated by detrital thorium as shown by the low $^{230}Th/^{232}Th$ value of 7.25, which requires a large correction of 14.9 ka of the age, so that the minimum age of 64.86 ka is questionable. From the published photograph (Hoffmann et al., 2018:Fig. S15), the cauliflower sample PAS 34 does not seem dense and compact. This alone could be seen as an argument in favor of an open system, as noted in the case of a drapery in Borneo where the external edge was porous and gives a U-Th age much older that the internal edge (Plagnes et al., 2003). It is noteworthy that the highly contaminated sample PAS 34c (which should have been dismissed) is the only sample in La Pasiega that allows an attribution of the art to Neandertals.

The phenomenon of uranium lixiviation may be continuous or limited in time, which makes it more difficult to identify. For example, Scholz and Hoffmann (2008) showed that a stalagmitic floor in an Austrian cave demonstrated a strong anomaly over only a few millimeters, leading to an essentially infinite age estimate ("out of range"; Scholz and Hoffmann, 2008:69) resulting from a briefly open system (SOM Fig. S1). On both sides of this anomaly, the dates are in chronological order (192 ka at 39 mm from the base and 134 ka at 42 mm from the base). If only these two samples had been taken, the authors could have mistakenly concluded a closed system. From these results, the authors rightly concluded that "this indicates U loss which is supported by lower U concentration in the white area" (Scholz and Hoffmann, 2008:69).

Another case of inversion of the stratigraphy of calcite layers is observed by Hoffmann et al. (2018) for a fractured stalagmite in Maltravieso (MAL 24). Six samples were dated and the third one from the core shows an age older than expected (SOM Fig. S2). This sample is highly contaminated and has a large standard deviation. The authors reduce the discrepancy and succeed in making it fall within the error estimation by changing the detrital activity from $^{238}U/^{232}Th$ = 0.8 to 3.3. However even taking the lower limit of 2σ error, the age remains equal to that of samples taken near the core. This would imply a very fast growth of the stalagmite. It is much more probable that the system was temporarily open. This result is similar to the Austrian flowstone studied by Scholz and Hoffmann (2008), which presents a short open behavior in a sequence of normal chronological order.

In other cases, a discrepancy between U/Th and ^{14}C are observed. For example, in the Mayenne-Sciences cave (Mayenne, France), U-Th dating of the most recent layer of calcite near a black painted bison produced a date of 54,800 ± 585 years, in total contradiction with the Gravettian age of other black paintings from the same cave dated by ^{14}C to 24,220 ± 850 BP (28,569 ± 859 cal BP; GifA-100647) and 24,900 ± 360 BP (29,007 ± 414 cal BP; GifA-100645; Pigeaud et al., 2010). The authors of this study considered that the excessively old U-Th date resulted from lixiviation of part of the uranium.

An open system can result from uranium lixiviation due to its water solubility or, alternatively, to recrystallization of aragonite in calcite (Lachniet et al., 2012). These phenomena entail a simultaneous lowering of the uranium concentration. This is particularly the case for the samples that gave the most ancient dates in the three Spanish caves. For instance, in La Pasiega, uranium concentration is 10 times lower in PAS 34c (79.66 ± 14.9 ka) than in PAS 33c on the right-hand side of the same rectangle which gives a much younger age (3.07 ± 0.05 ka). These various factors (low uranium concentration and high detritic contamination) point to a strong probability of an open system.

SOM S2

The Aragonite problem

The possibility that aragonite is present in some of the samples studied by Hoffmann et al. (2018) is not even considered. Yet it is known that recrystallization of aragonite into calcite may result in a loss of uranium in the neogenic calcite which leads to overestimation of the U-Th ages (Lachniet et al., 2012). The same phenomenon was identified in a stalagmite from Italy (Bajo et al. 2016). A series of more than 47 samples, 1 cm thick, were collected along the growth axis of the stalagmite and gives ages in perfect stratigraphic order, except one, which gives an age more than 12 kyr older than expected (16 ka instead of 3.9 ka). Again, a short period during which aragonite is formed, probably favored by a dry episode, was then followed by a significant recrystallization in calcite with loss of uranium. Interestingly, this phenomenon was 'cryptic' as petrographic observations fail to detect textural changes.

Aragonite is easy to identify by micromorphology or epifluorescence microscopy (Ortega et al., 2005) and was detected by Raman spectroscopy in three of the samples analyzed in the gallery of the red disks in El Castillo Cave, located in the same hillside as La Pasiega (D'Errico et al., 2016:Tables S6–S8). Owing to the very old age obtained for one sample in La Pasiega, it would be essential to falsify the hypothesis of calcitization of aragonite that could explain this exceptionally old age. More generally, a complete characterization of the coralloids (chemical and isotopic composition, porosity, etc.) and a better knowledge of their mechanism of formation would be essential (Hill and Forti, 1995; Bassel, 2017).

SOM S3

The dating of negative handprints

Negative handprints are one of the most emblematic subjects in all of Paleolithic parietal art. Often associated on the same panels with animal figures, their chronology, based on multiple data sources, has been very well established over the years (Jaubert, 2008; Feruglio et al., 2011; Floss and Ostheider, 2013). The main results may be found in SOM Table S1. In Cosquer cave (France), four black hands were dated directly by ^{14}C to between 24,840 and

27,740 BP (Clottes et al., 2005; Valladas et al., 2017b). Similarly, radiometric dates obtained for the immediate vicinity of negative handprints confirms a Gravettian origin for most of them. A spotted horse in Pech-Merle cave (France), surrounded by six hands was dated to 24,640 ± 390 BP (Lorblanchet et al., 1995). A black mammoth in Chauvet Cave, touching a red hand was dated to 26,340 ± 330 BP (Feruglio et al., 2011). A bone fragment stuck in the wall near a panel of black hands at Gargas was dated to 26,860 ± 460 BP (Clottes et al. 1992) in a Gravettian context linked to pigment manufacture (Foucher et al., 2011).

Some handprints have been indirectly dated by U/Th. At La Garma (Cantabria, Spain) a negative hand received a minimum age of 33 ka (Garate, 2006:410). At La Fuente del Trucho (Huesca, Spain), 8 negative handprints have been dated by U-Th, with minimum ages, compatible with the Gravettian, ranging between 25.11 and 27.37 ka (Hoffmann et al., 2016:53). In this case, the results completely match the archaeological evidence, reinforcing their credibility.

Other negative handprints from Gravettian archaeological contexts dated by ^{14}C between 27.5–34 ka cal BP can be cited (Jaubert, 2008; Valladas et al., 2013): the Grande Grotte of Arcy, Les Fieux, Vilhonneur, Le Moulin de Laguenay, La Fuente del Salín (SOM Table S2). A parietal block with a negative handprint was also found at the Abri Labattut (France) in a non-dated Gravettian archaeological context (Delluc and Delluc, 1991). Finally, other negative hands are also attributed to the Gravettian (and perhaps to the Aurignacian?) on the basis of stylistic comparaisons in the caves of Roucadour and Les Merveilles (Lot, France; Lorblanchet, 2010).

The weight of these data renders most unlikely the dates found by U-Th in the vicinity of a negative handprint at Maltravieso cave. Within a five centimeter perimeter, five samples gave very dispersed minimum ages ranging from 14.7 to 66.7 ka (Hoffmann et al., 2018). The oldest date is accepted to support the attribution of the nearby hand stencil to Neanderthals. In the context of the Gravettian chronology established for all the other handprints in Western Europe by multiple dating techniques (including U-Th at La Fuente del Trucho), the value of 66.7 ka appears most unlikely.

It is noteworthy that Maltravieso Cave contains handprints with foreshortened fingers, which have no equivalent in Western Europe, except in the Gravettian caves of Gargas and Tibiran (Hautes-Pyrénées) on the French side of the Pyrenees, and at La Fuente del Trucho and Cudón on the Spanish side.

Recently, hand stencils have been found on Sulawesi island and Borneo (Indonesia) and dated by U-Th to 39.67 and 40.70 ka (Aubert et al., 2014, 2018b). These dates are confirmed by the observed microstratigraphy of very thin layers of calcite (less than 500 µm thick), which shows that the system remained closed in this case. It is noteworthy that the Indonesian hand stencils are attributed to early *Homo sapiens* (Curnoe et al., 2016) and that some other hand stencils from Borneo have been dated by the same team to 15 to 14 ka (Aubert et al., 2018b), showing a very long duration of the motif.

SOM S4

Crossdating U-Th and ^{14}C

It is very difficult to prove that calcite was not affected by uranium loss. The best way consists of dating the same samples by two independent methods, namely by coupling U-Th dating with ^{14}C dating of the carbonate in the same sample of calcite. Bednarik (2012) reported that a thick deposit of calcite covering petroglyphs in a cave from South Australia gave an age of 28 ± 2 ka by U-Th, whereas the same sample had an age of 5,550 ± 55 by ^{14}C, but these results obtained in the 1980s were not explained. Similarly, Plagnes et al. (2003) found a large discrepancy in the age of a drapery covering a hand stencil in Borneo. Whereas the ^{14}C and U-Th ages are rather concordant at the inner edge (near the painting: 9.9 to 13 ka showing a closed system), the U-Th age was higher than 27 ka at the outer edge when the ^{14}C age remained ca. 9.9 ka, indicating uranium lixiviation.

A new series of experiments was systematically carried out to investigate the reason for this discrepancy by the Laboratory of Climatic and Environmental Sciences at Gif-sur-Yvette, France (Quiles et al., 2014; Sanchidrián et al., 2017; Valladas et al., 2017a). Their research in the cave of Nerja (Spain) has shown that cases where a thin calcite deposit behaves as an open system may be found in proximity to cases where calcite remains a closed system.

For instance, one of the analyzed samples (overlying a red dot) provided a U-Th age between 60.276 and 55.848 ka (depending on the initial $^{230}Th/^{232}Th$ detrital value used) whereas the ^{14}C age varied from 33.77 to 31.03 ka cal BP, depending on the level of dead carbon, between 0 and 20%, used in the calculation (Valladas et al., 2017a). Thus, even taking the extreme and less probable values (highest detrital values and lowest dead carbon fraction), the difference between the two methods is larger than 22 ka. Such a difference points to an open system. Moreover, the U-Th date falls outside the Upper Palaeolithic whereas the charcoals found in the cave show that the human occupancy in the cave is circumscribed to the period 40.7–25 ka cal BP (Valladas et al. 2017a).

In contrast, another sample from the same cave shows good correspondence between the two methods (25,374 to 22,716 ka cal BP for ^{14}C and 26,462 to 25,189 ka for U/Th), implying that, in this second case, the system remained closed. Thus, crossdating seems able to confirm the validity of the U/Th dating technique in certain circumstances. Indeed, ^{14}C cannot be used alone to precisely determine a minimum age for the underlying painting, but in most cases, it is a good way to discard erroneous results caused by open system. The argument put forward by Pike et al. (2017) against crossdating U-Th with ^{14}C is not enough to refute extreme cases such as those found in Nerja and those reported in Borneo (Plagnes et al., 2003). The example given of a mixture of two equal layers of 10 ka and 40 ka is not realistic (see Pike et al., 2017:Fig. 1). This is the reason why it is so important to analyze very thin microstratigraphic layers with controlled geometry and orientation.

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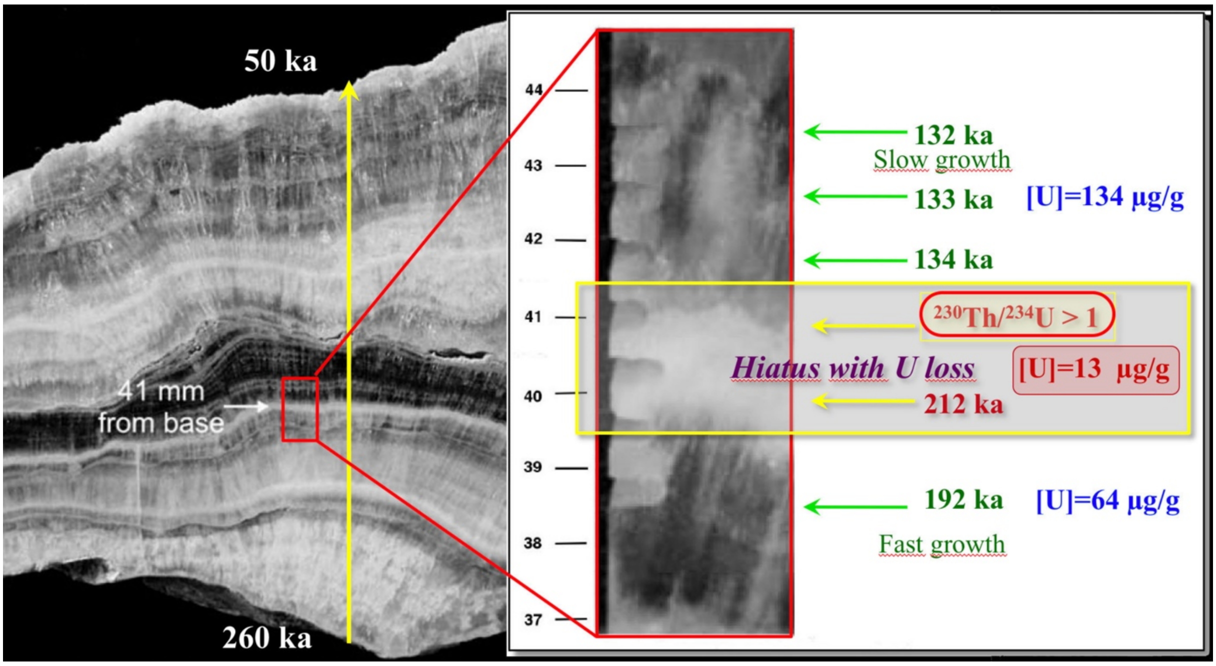
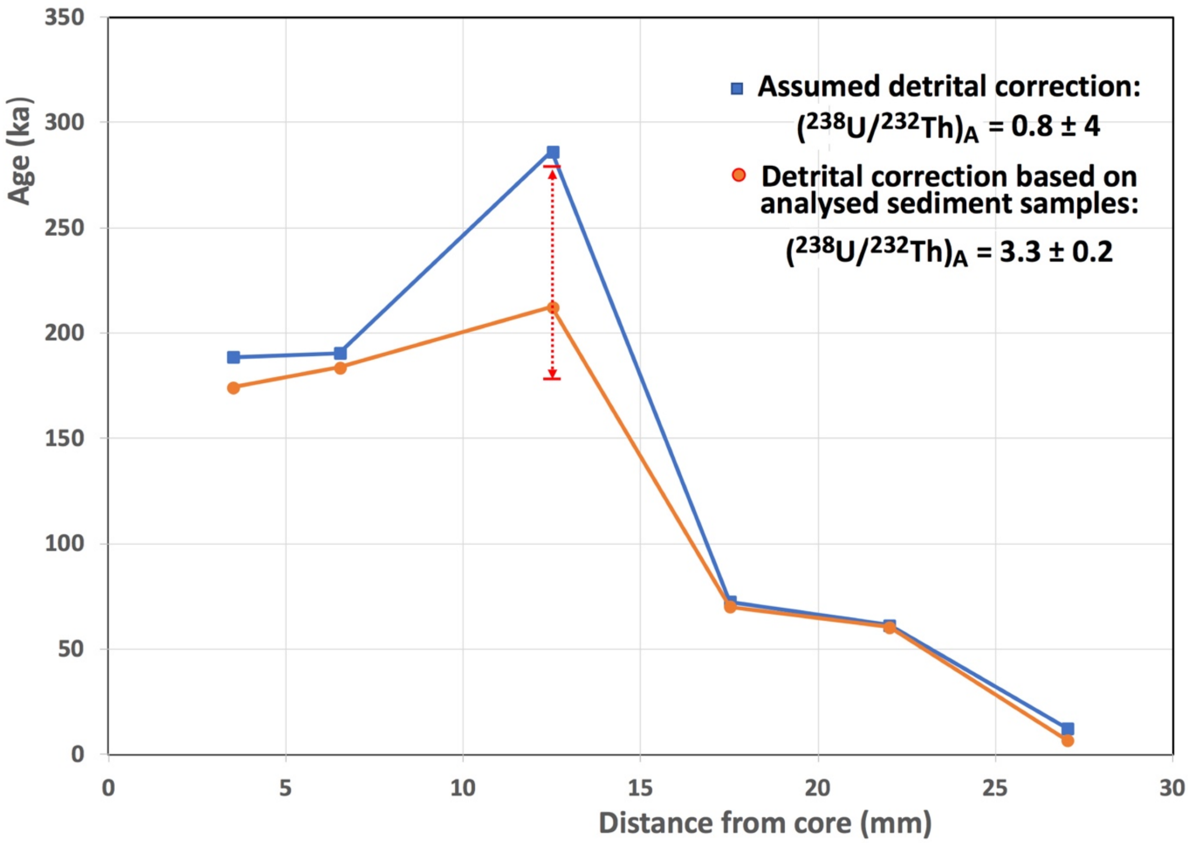


SOM Figure S1. Cross section of a flowstone from the Spannagel cave, in the Austrian Alps. The insert shows an enlargement of the layer near 41 mm from the base and the various measurements of the age. Note that a strong anomaly occurs between 40 and 41 mm and that this corresponds to a zone in which the U concentration is much weaker than below and above (modified from Scholz and Hoffmann, 2008).



SOM Figure S2. Ages of samples from a Maltravieso stalagmite (MAL 24) taken from the core to the outer surface. The age of the third sample was not in stratigraphic order. The deviation was partially reduced by using a much higher detrital correction for ^{232}Th, but even taking the lower limit of 2σ error, the value remains equal to samples taken 10 mm nearer the core (redrawn from Hoffmann et al., 2018:Fig. S41).

SOM Table S1

Dated hand stencils (directly or indirectly) by radiocarbon and by U/Th. Calibrated dates with Intcal13 (Reimer et al., 2013).

Site	Localization	Laboratory	Age ^{14}C (BP)	Age cal BP (2 σ)	Reference
Cosquer (France)	Hand n°19	GifA-96073	27,740 ± 410	31,770 ± 477	Clottes et al., 2005
	Hand MR7	GifA-92491	27,110 ± 400	31,162 ± 320	
	Hand MR7	GifA-92409	27,110 ± 430	31,178 ± 367	
	Hand n°12	GifA-95358	24,840 ± 340	28,933 ± 386	
Pech-Merle (France)	Horse surrounded by 6 hands	GifA-95357	24,640 ± 390	28,723 ± 433	Lorblanchet et al., 1995
Chauvet (France)	Hand touching the back of a mammoth	GifA-101468	26,340 ± 330	30,511 ± 343	Feruglio et al., 2011
Gargas (France)	Bone fragment near hands	Gif-A92369	26,860 ± 460	30,943 ± 400	Clottes et al., 1992
La Garma (Spain)	near a negative hand		U/Th	33,000 ± 2000	Garate, 2010
Fuente del Trucho (Spain)	Calcite overlaying red hand stencils		U/Th	25,330 ± 220	Hoffmann et al., 2016
			U/Th	26,210 ± 160	
			U/Th	25,350 ± 150	
			U/Th	25,850 ± 130	
			U/Th	26,520 ± 120	
			U/Th	26,850 ± 120	
			U/Th	26,370 ± 130	
			U/Th	27,500 ± 130	

SOM Table S2

Hand stencils found in a dated Gravettian archeological context in France and Spain. Calibrated dates with Intcal13 (Reimer et al., 2013).

Site	Laboratory	Age ^{14}C (BP)	Age cal BP (2 σ)	Reference
Grande Grotte of Arcy	GifA-93008	24,660 ± 330	28,726 ± 370	Valladas et al., 2013
	OxA-5003	26,250 ± 500	30,353 ± 483	
	GifA-93013	30,160 ± 640	34,288 ± 606	
Les Fieux	Gif-6304	23,900 ± 330	28,049 ± 297	Champagne and Jaubert, 1986
Vilhonneur	Beta-216141	27,110 ± 210	31,110 ± 132	Airvaux et al., 2006
Le Moulin de Laguenay	Ly	26,770 ± 380	30,876 ± 300	Pigeaud and Primault, 2007
Fuente del Salín	GrN-18574	22,340 ± 510	26,657 ± 482	Moure Romanillo and González Morales, 1992